CBCL LIMITED

Consulting Engineers

Flood Risk Study

Joint Flood Advisory Committee
County of Colchester, Town of Truro
and Millbrook First Nation

Final Report		Feb. 28, 2017	
Draft Report – For Review	VL	Mar. 16, 2015	ATW
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CBCL LIMITED
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Report: 141004.00

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February 28, 2017

Michelle Newell, P.Eng.
Director of Public Works
Municipality of the County of Colchester
1 Church Street
Truro, NS B2N 5E7

Dear Ms. Newell:

RE: Flood Risk Study

It is with great pleasure that I am submitting this abridged report for the Flood Risk Study in Truro. This report presents the main sections of the full report, where the more technical information has been omitted.

This report represents the result of a considerable amount of study and interpretation. This fascinating project should form the object of further research in the future, especially as technological tools become more advanced. In the meantime, it is hoped that this report will provide a significantly greater level of analysis and detail than previously available, so that it can resolve many of the issues faced over the years and overcome the previous barriers to implementing change.

Dealing with the challenges associated with flooding issues and embarking on a flood mitigation plan is no simple task and it is hoped that this report provides helpful advice in this objective.

I would like to thank you again for placing your trust with CBCL Limited and we hope that you find this report meets your expectations.

Yours very truly,

CBCL Limited

Alexander Wilson, M.Eng., P.Eng.
Water Resources Engineer
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Attachments: Final Flood Risk Study
Appendix A (under separate cover)

Project No: 141004.00

Introduction

General

The Mi'kmaq people were aware that the Salmon River floodplain is an unsafe area for permanent settlement and according to records, had originally located their settling areas on its fringe. Flooding risks have been of significant concern, however, for all subsequent settlers, starting with the Acadians in 1689, along the then called Wecobequitk River. Ever since and until now, regular flooding events and its aftermath affects the lives of floodplain residents. This highlights the need for a comprehensive approach to understand the overall flooding problem, followed by an implementation plan. Only through a holistic and realistic approach, based on sound science, can the breadth of the issues be understood, and a realistic plan be prepared to move forward.

> There will always be a risk of flooding within the floodplain and continued floods will likely occur in Truro's future. While future floods cannot be prevented, action can be taken to better ensure public safety and minimize flood damage.

The residents of Truro have endured repeated flooding damage at an alarming frequency. Indeed, floods have been documented almost every year since records began, with the earliest record dated in 1792 (in 1761, the region was mainly re-settled by Ulster-Scots). The year 1979 was an especially difficult year, with the area being flooded five times (four times between January and March). Perhaps related to climate change, flooding seems to have increased in frequency, often occurring more than once a year in the last few years. Schools, senior homes and residences are impacted almost every time, as well as access roads, commercial areas and industries. Lives are placed at risk, infrastructure is damaged, and the river quality is impacted with every flood.

The past history of Truro shows that following through on recommended changes in the time after major floods is always a challenge. In fact, it would seem that development within the floodplain has historically *increased* following large flooding events. Memories of the events fade, other priorities arise and budgets are focused on other more immediate needs.

The Joint Flood Advisory Committee (JFAC), uniting the Town of Truro, the County of Colchester, and the Millbrook First Nations, has undertaken the momentous step of leveraging available potential from the Flood Assessment Fund provided by the Nova Scotia Environment (NSE) Climate Change group, to commission the most comprehensive Flood Risk Study ever undertaken in the province. This financial support provided by NSE was part of the Flood Risk Infrastructure Investment Program, which provides up to 50% of eligible project costs. The rest of the necessary funding was split between the Town of Truro and the County of Colchester.

This report is the result of this study, and will guide the reader through the rigorous processes and complex analyses undertaken, emerging with recommendations for short term and long term solutions.

In this report, many new and old ideas for flood mitigation were investigated, and opportunities, as well as measures with little potential, were identified. Hard engineered structures, as well as softer modifications of the landscape, were analysed. Municipal planning tools were also considered and included in the overall flood

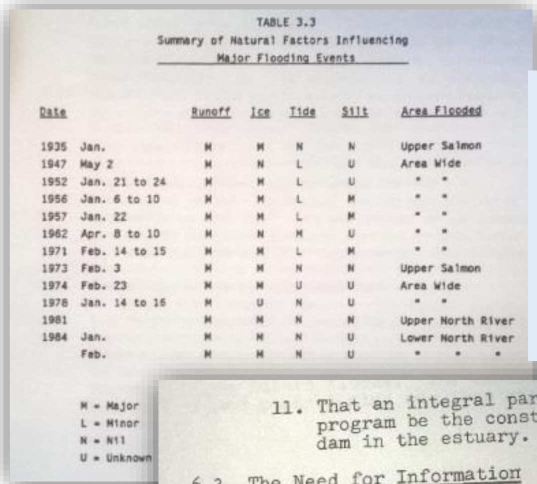
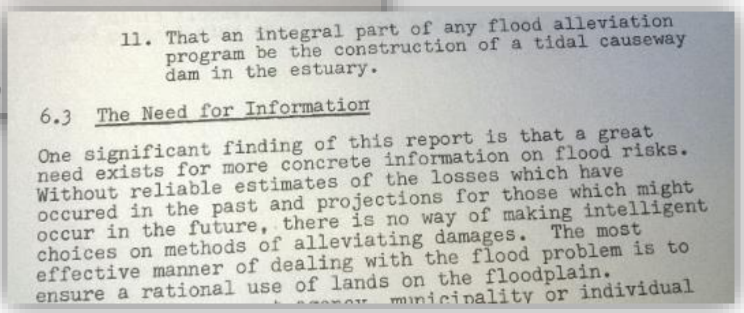


TABLE 3.3
Summary of Natural Factors Influencing
Major Flooding Events

Date		Runoff	Ice	Tide	Silt	Area Flooded
1935	Jan.	M	M	N	N	Upper Salmon
1947	May 2	M	N	L	U	Area Wide
1952	Jan. 21 to 24	M	M	L	U	" "
1956	Jan. 6 to 10	M	M	L	M	" "
1957	Jan. 22	M	M	L	M	" "
1962	Apr. 8 to 10	M	N	M	U	" "
1971	Feb. 14 to 15	M	M	L	M	" "
1973	Feb. 3	M	M	N	N	Upper Salmon
1974	Feb. 23	M	M	U	U	Area Wide
1978	Jan. 14 to 16	M	U	N	U	" "
1981		M	M	N	N	Upper North River
1984	Jan.	M	M	N	U	Lower North River
	Feb.	M	M	N	U	" " "

M = Major
L = Minor
N = Nil
U = Unknown



11. That an integral part of any flood alleviation program be the construction of a tidal causeway dam in the estuary.

6.3 The Need for Information

One significant finding of this report is that a great need exists for more concrete information on flood risks. Without reliable estimates of the losses which have occured in the past and projections for those which might occur in the future, there is no way of making intelligent choices on methods of alleviating damages. The most effective manner of dealing with the flood problem is to ensure a rational use of lands on the floodplain.
municipality or individual

Excerpts from the 1974 MRMS Floodplain Study and the 1988 Joint Nova Scotia Environment Canada Flood Damage Reduction Program - both aiming to understand and address flooding issues.

mitigation plan. Combinations of those options as well as other approaches, down to lot-scale improvements, were investigated, and social and environmental aspects, which play a key role in the sustainability of the recommended measures, influenced the selection of preferred options. Costs necessarily played a decisive role in evaluating the options, weighed against the potential for protecting the most vulnerable areas.

It was found, though the extensive analysis and modelling effort, that the scale of the flooding issues are such that the level of investment needed to curb the flooding risk needs to be scaled accordingly. Protecting a majority of the vulnerable areas in the short term would, unfortunately, require an unaffordable level of investment. The most effective short term flood protection system was identified as involving moving the dykes outwards to the fringe of the floodplain, with associated pumping stations to help drain upstream stormwater to the Salmon river. This involves constructing 12 km of dykes, constructing 7 very large pumping stations and 7 large aboiteaux structures, as well as raising Park Street. This option, even though a standard approach to flood protection, involves very high capital and maintenance costs, in the order of $140M, and only protects less than 40% of the vulnerable areas.

The conclusion of the analysis is that instead of constructing large flood protection infrastructure, a more realistic plan should focus on providing an immediate improvement in public safety, while gradually reducing flooding risks over time. This can be achieved by focusing on emergency management measures, including flood warning and forecasting systems, public education, coordination of the emergency management plan, as well as strategies to reduce runoff flows (infiltration of stormwater), and including the floodplains developed in this study in the current development restriction by-laws.

If funding becomes available, the infrastructure option can be implemented in part or in full, with incremental benefits. It is noted, nevertheless, that unless flood mitigation options are designed for the Probable Maximum Flood (most extreme event that climate can produce), there will always be a remaining risk, albeit smaller, that a flood of a greater magnitude will exceed the level of protection provided. Residences behind the flood protection system may not be aware of the risks and could be ill-prepared to face a flood from a failing dyke.

There will always be a risk of flooding within the floodplain and continued floods will likely occur in Truro's future. While future floods cannot be prevented, focusing on public safety and minimizing flood damage may be the most effective approach. In terms of reducing flooding risks by managing the flows, implementing rainfall infiltration measures wherever possible will have the potential to reduce flooding risks even further than the large infrastructure option. The only challenge is that such measures cannot realistically be implemented in the short term (this cost was estimated to reach almost $3bn), but if implemented wherever surfaces are renewed or replaced, the cost is then negligible.

Importance Given to Stakeholder Consultation and Prioritisation of the Issues

The first action taken by this project was to identify and consult with as many of the stakeholders as possible. Only through in-depth discussions during many meetings and workshops, could the full depth of concerns, goals, objectives and challenges be properly understood. This report has two primary goals: first, to understand the issues through those that experience them, and second, to look for solutions that consider their needs and priorities.

Approach Taken and Rationale

> The strength of this report lies in the comprehensive modelling undertaken to understand the complex processes that lie behind the mechanics of flooding.

The core strength of this study lies in the comprehensive computer modelling undertaken to understand the complex processes that lie behind the mechanics of flooding. Flooding is the result of extreme rainfall, tides, sediment levels and ice jams, in isolation or in combination, yielding extremely complex hydrodynamics. This state-of-the-art modelling provides a scientifically sound and defendable basis for various statements made about flooding, and most importantly, recommendations for flood mitigation measures. The Truro flooding concern has suffered from a combination of many reports and debates unsupported by modelling, as well as proposed flood mitigation options of an unaffordable magnitude. This report combines important historical information with the latest technologic methods to provide a clearer picture of the expected efficiency of various flood mitigation measures.

Main Areas of Investigation and Recommendations

Protecting residents is achieved by either keeping the water away from people, or moving people away from the water. Through the various analyses conducted in this study, some opportunities will be found. However, some difficult decisions will also have to be made where solutions are neither feasible nor affordable.

The multi-pronged approach to finding solutions adopted within this report includes the following various components:

1. Land Use Planning and By Laws (restricting development in the floodplain, and enforcing flow control measures for new developments).
2. Flow Control Measures (Reducing flows to reduce flooding).
3. Conveyance Capacity increase (Removing obstructions so water can drain away faster).
4. Flood Protection Measures (Protecting areas at risk from the water by building dykes and berms).
5. Relocation of residences and other vulnerable structures at risk (moving structures away from the water).
6. Accepting the risks and building resilience (includes implementing forecasting and warning systems, preparing for flooding, and preparing for recovery).

Beyond finding hard engineering solutions to a technical problem, the softer, larger picture aspects need to be considered and included in the evaluation. These aspects include the ability of the options considered to meet the various stakeholders' goals, the environmental effects of any proposed solution, the regulatory considerations, as well as the long term impacts on the health of the river. Considering the achievable nature of various options is also paramount, since recommending an option that is far beyond available budgets will not be of any help in solving, or reducing the scale of, the risks.

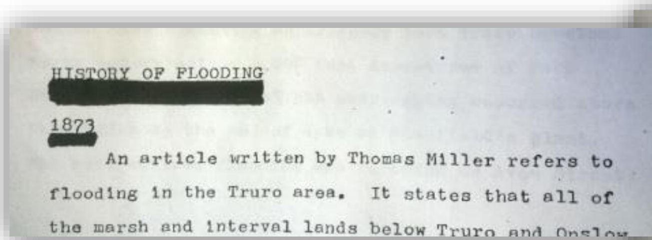
In the end, costing is of course all-important, and will be the factor that decides upon the viability of options that may otherwise be very efficient in reducing flooding risks.

Review of Previous Reports

Flooding and Marsh-Related Reports

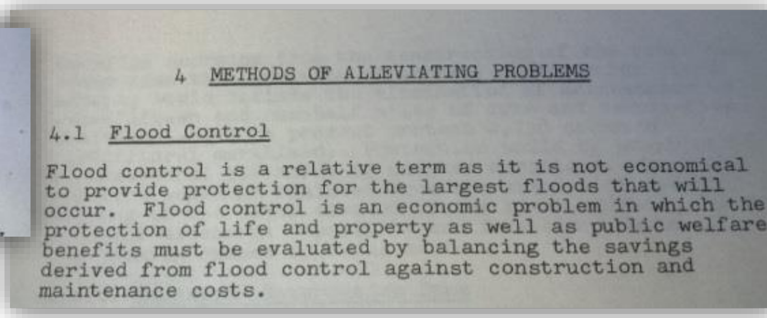
There has been a multitude of reports carried out which relate to flooding in the area or management of the marshland area. With this multitude or reports, has arisen a multitude of information and recommendations. A short synopsis of some of the recommendations found are listed below:

Recommendation Type	Ref #	Year	Description of Recommendation
Design Criteria	2	2012	"Use storm surge and sea level rise values provided by Richards and Daigle (2011)"
Structure	4	2006	The concept of dredging lower reaches of the Salmon River should be abandoned
Structure	4	2006	Possible straightening of channel which would increase water velocities to help remove sediment excess
Structure	4	2006	To reduce flood risk to urban development on Dykeland Park Marsh, Onslow Tracks 1 and 2 should be flooded after Onslow Track 3 reservoir
Structure	4	2006	A viaduct should be created through the Hwy 102 roadbed on the north side of the Salmon River
Structure	4	2006	Construct new dyke in Dykeland Park Marsh
Structure	4	2006	Construct bridge along Park St from CNR embankment to the existing Park St Bridge
Planning	5	1997	Review of Municipal Planning Strategies – Establishment of Inter-Municipal Joint Planning Strategy
Structure	6	1983	Construction of Storage Dams and Cobequid Causeway-Dam
Study	8	1988	Assessment of effectiveness of ice control berms
Study	8	1988	Study feasibility of floodproofing structures in this area
Study	8	1988	Study of feasibility for flood proofing and drainage improvements
Study	8	1988	Study feasibility of lowering dyke elevations to provide access for the ice to the marsh storage
Structure	8	1988	Straightening dykes between confluence of North and Salmon River and Hwy 102
Structure	8	1988	New dyke to protect existing residences along Salmon river road
Structure	8	1988	Improve drainage
Structure	8	1988	The existing dyke should be completed and connected to railway embankment
Structure	9	1971	Construction of tidal dam across Salmon River Estuary (design event 1 in 50 yr.). Construction from rock fill with multi-barrel concrete sluice. 4300 ft. long, 40 ft. high. Top width 20 ft.
Structure	9	1971	Raise height of approximately 14000 ft. of dyke on Truro Dykeland park and level approximately 5000 ft. of dyke in lower Truro marsh. (Locations to be confirmed)
Structure	9	1971	Construction of dykes from west end of Prince St westward to Hwy 102, high enough to contain flood waters.
Structure	10	1971	Construct large Dam to protect from high tides and contain flood waters
Structure	11	1971	Cobequid bay Causeway-Dam Jan 1971
Structure	12	1971	Report on Retention Dams in Upstream areas, concluding them not being cost-effective


HISTORY OF FLOODING
[redacted]

1873
[redacted]

An article written by Thomas Miller refers to flooding in the Truro area. It states that all of the marsh and interval lands below Truro and Onslow


4 METHODS OF ALLEVIATING PROBLEMS

4.1 Flood Control

Flood control is a relative term as it is not economical to provide protection for the largest floods that will occur. Flood control is an economic problem in which the protection of life and property as well as public welfare benefits must be evaluated by balancing the savings derived from flood control against construction and maintenance costs.

Main Findings – Historical Review of Previous Reports

In summary, the salient points emerging from the review of previous historical studies are the following:

- It is unclear whether flooding results mainly from the effects of rainfall, high tides, high sediment levels or ice jams, but it is accepted that each of those factors contribute to flooding;
- Other effects that have been credited for increasing flooding include development, clear cutting of forested areas, insufficiently strong planning regulations and implementation; and
- The main options discussed included more comprehensive planning strategies, the construction of upstream runoff storage dams, and the construction of a Causeway-Dam cordoning off the Cobequid Bay.

The most comprehensive document assembled was the joint Nova Scotia – Environment Canada Flood Damage Reduction Program, in which vulnerable areas were identified, and a subsidisation program was put in place. It was also made clear that any development past the report publication would not be eligible for flood relief funding. One important step achieved in the 1988 joint Nova Scotia – Environment Canada report was the delineation of a 1 in 20 year and 1 in 100 year floodline, which formed the basis for planning regulations.

Shortcomings

Through the many reports assembled over the decades, much discussion was provided, but very little actual analysis of the potential causes of flooding was conducted. River flows, rainfall patterns, extreme tidal events, variation in sediment levels, potential impacts of ice jams, were not analyzed to any significant level. Similarly, analyses of potential benefits of various structures were missing from the previous assessments and the McClure's Brook as well as Farnham Brook were rarely included in the previous documents. The result is that many ideas are brought forward, but none are compared or evaluated on a formalized basis. This has prevented the formulation of any plan to identify the main issues, and then address those issues using a methodical approach.

> The Report aims to fill the need to provide the scientific basis for the analysis of the causes of flooding as well as the formalised evaluation of a wide range of potential flood mitigation options.

The present report aims to fill this need and provide the scientific basis for the analysis of the causes of flooding, as well as the rigorous evaluation of a wide range of potential flood mitigation options. The provision of estimates of probable costs then allows an evaluation of cost-effectiveness of the various options investigated, as well as the formulation of an action plan resulting from this assessment.

Stakeholder Consultation and Identification of Priority Areas

This project places a central emphasis on stakeholder consultation, as it aims to identify and evaluate options to improve public safety in the Truro area. It was therefore conducted in partnership with the public, as well as the local stakeholders. There is a large number of stakeholders, and a substantial effort was made to consult with as many as possible. This process allows the project to be cognizant of the various concerns of the stakeholders, as various approaches to flood mitigation are first identified through stakeholder consultation, and then evaluated against the goals of the stakeholders.

Stakeholders involved:

- The Public;
- County of Colchester;
- Town of Truro;
- Millbrook First Nation;
- Nova Scotia Environment;
- Nova Scotia Department of Agriculture;
- Nova Scotia Transportation and Infrastructure Renewal;
- Nova Scotia Department of Natural Resources;
- Environment Canada;
- Canada National Railway; and
- Nova Scotia Power Inc.

Stakeholders were consulted with the objective of:

1. Gaining knowledge on sensitive infrastructure and services, history of changes, and general improvements they would like to see.
2. Obtaining their input on which areas, services or infrastructure need to be protected, and what level of priority should be assigned to each.

There are, however, inherent challenges and risks associated with prioritizing areas for protection, based on the wishes of a wide range of stakeholders, and difficult decisions have to be made to adopt a ranked list of priorities.

Public Consultation

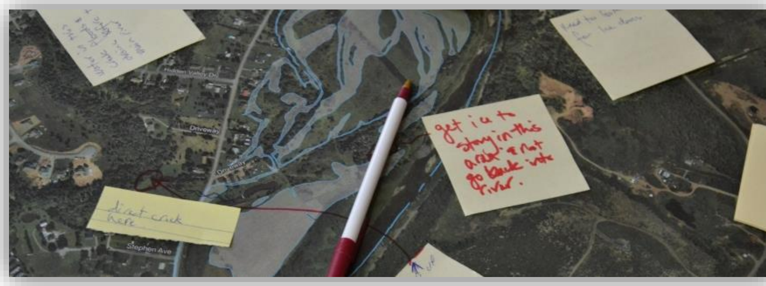
Prior Meeting with County of Colchester and Town of Truro Councillors

A meeting with the County of Colchester and Town of Truro Councillors was held prior to the public meeting. This meeting allowed the Councillors to be updated with the progress of the report, as well as explaining the objectives of the public meeting. In this public meeting, the project team was to gather information about individual issues experienced by the public as well as help the public think about the need to prioritize issues. There is a cost to protect infrastructure and services, and with limited funds, difficult choices will need to be made. It was felt that this message was very important and needed to be conveyed to the public as early as possible.

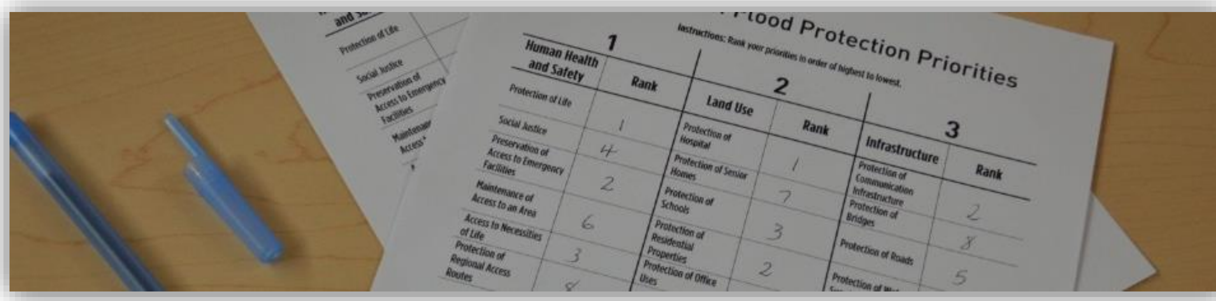
With this information, the Councillors had the tools to respond to questions from the public if needed, and help them through the workshop.

Public Open House

From the outset of the project, it was recognized that the importance of working with municipal council and staff, the public and other stakeholder groups. On May 21st, 2014 a drop-in public open house was held at the Salmon River Fire Hall to gather information from the community on flooding experiences, concerns, and priorities.



The open house session included three “stations” to capture public feedback. The first station provided general information about the study, detailing project objectives, tasks, and progress to date. At the second station, a large key map showed the study area. Community members were directed to large maps where they could speak with the consultation team about their flooding experiences and concerns, illustrating their issues with markers and pens on the maps provided. The final station provided an opportunity for community members to rate priorities for flood protection.



The open house interested 27 attendees, which included residents, elected officials, and other stakeholders.

Flood Protection Priorities

The success of the project relates to the ability for County and Town staff to use and implement the final document and related tools. At the third station, a rating sheet for flood protection priorities was distributed. The intention of the station was to collect information to form the basis of evaluating the priority of each flood mitigation option in the final Capital Works Planning Schedule.

The intention of the third station evaluate the priority of each flood mitigation option.

Open house attendees were asked to rank three categories of priorities (human health and safety, land use, and infrastructure) from highest to lowest. The information gathered was summarized to reflect a collective representation of flood protection priorities in the area.

Summary of Results from Public Consultation

Human Health and Safety	Rank	Land Use	Rank	Infrastructure Services	Rank
Protection of Life	1	Protection of Hospital	1	Protection of Water Supply / Treatment	1
Preservation of Access to Emergency Facilities	2	Protection of Residential Properties	2	Protection of Communication Infrastructure	2
Access to Necessities of Life	3	Protection of Senior Homes	3	Protection of Power Supply	2
Protection of Livelihood	3	Protection of Schools	4	Protection of Potable Water Infrastructure	3
Protection of Environment from Contamination	4	Protection of Industrial Lane Properties	5	Protection of Roads	4
Maintenance of Access to an Area	5	Protection of Agricultural Land	6	Protection of Wastewater Treatment Infrastructure	4
Social Justice	6	Protection of Retail Properties	7	Protection of Bridges	5
Protection of Regional Access Routes	7	Protection of Office Uses	8	Protection of Marsh Land Infrastructure (Dykes, Aboiteaux)	6
		Protection of Recreational Facilities	8		

The top two ranked human health and safety related priorities were protection of life and preservation of access to emergency services. Tied for third under human health and safety was access to necessities of life and protection of livelihood. The identified land use priorities were the hospital, residential properties, and seniors' homes. The highest ranked protection priority for infrastructure was the protection of water supply / treatment. Following this communication infrastructure, power supply, and potable water infrastructure received high ranks for flood protection.

The identified land use priorities were the hospital, residential properties, and seniors' homes. The highest ranked protection priority for infrastructure was the protection of water supply/treatment.

Many rating sheet respondents had difficulty selecting which items were of the highest priority. One open house attendee recognized the challenge of making decisions around which priorities are most important, commenting: *"It is almost impossible to rank these – many are of equal value but in different ways. Given this sheet tomorrow, the rankings would probably be very different, as all are valid good choices."*

Stakeholder Consultation

Joint Flood Advisory Committee

A stakeholder consultation meeting was held with the JFAC to engage in a targeted discussion to rank areas that need protection.

- The first part of the meeting included brainstorming to identify general areas that need protection. This included items such as protection of life, protection of vital services, of emergency response communications, access roads and inventory for example;
- The next step was to think of specific structures or buildings (i.e. schools, hospitals, senior homes…) and services (power grid, roads, potable water supply…) that needed protection; and
- The last step involved ranking the structures and services following the priorities established in the first step.

This led to the formulation of the JFAC grid of priority areas shown below.

PRIORITY MATRIX
Results from JFAC Meeting

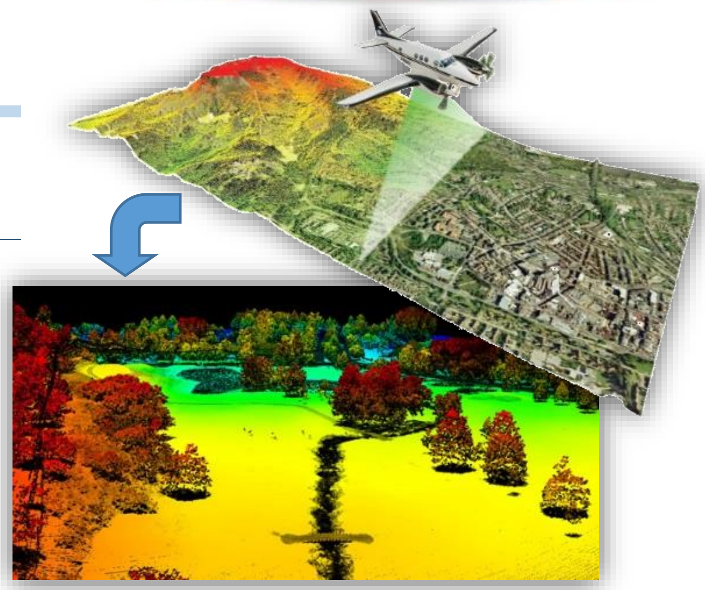
Decreasing Order of Priority

Protection of Life	Social Justice	Preservation of Access to Emergency Facilities	Maintenance of Access to an Area	Access to Necessities of Life	Protection of Regional Access Routes	Protection of Livelihood	Short & Long Term Impacts	Protection of Environment from Contamination
Protection of Hospital	Protection of Senior Homes	Protection of Schools	Protection of Residential Properties	Protection of Office Uses	Protection of Retail Properties	Protection of Industrial Lane Properties	Protection of Agricultural Land	Protection of Recreational Facilities
Protection of Communication Infrastructure	Protection of Bridges	Protection of Roads	Protection of Water Supply / Treatment	Protection of Power Supply	Protection of Potable Water Infrastructure	Protection of Wastewater Treatment Infrastructure	Protection of Marsh Lane Infrastructure (Dykes, Aboiteaux)	

Field Data Collection

Survey

Ground Topography



The data represents elevation data measured by billions of light beams across the entire watershed area. It is processed into producing average elevations for each square metre, both on the ground surface (Digital Elevation Model or DEM) and on the highest surface encountered – this can be trees, roads, bridge decks… (Digital Surface Model or DSM). This data is extremely useful to conduct detailed analyses with a high level of confidence in the topography.

Changes to the topography that occurred after the date of the Lidar data collection (2013) were surveyed on the ground (by AgriTech) and the topographic surface was updated.

River Bathymetry

AgriTech Mapping also carried out a spring pre-dredging survey of the river bed prior to river restoration work being carried out in 2013. This survey extended from the confluence of the North and Salmon Rivers, up both of the rivers, just past the CN Bridge on the Salmon River and up to the Highway 104 on the North River.

CBCL Limited extended this survey using a depth surveying system comprised of a professional single-beam echo sounder mounted on a boat, to collect high quality bathymetric data at a fast rate in areas that would be unsafe to access otherwise.

Culverts and Bridges

With the support of The Town of Truro staff, bridges, culverts and aboiteaux were measured in the field so that they could be included in the hydraulic model. This ensures any restrictions along the major river branches are accurately represented.

Number of Hydraulic Structures Included in the Model

	Salmon River	North River	Farnham Brook	McClures Brook	Minor FloodPlain Area Tributaries	TOTAL
Bridges	15	16	8	14	0	53
	0	0	4	12	9	25
Aboiteaux	0	0	1	1	10	12
	15	**16**	**13**	**27**	**19**	**90**

Rainfall

Tipping bucket rain gauges were installed in the spring of 2014 at the following three locations to monitor rainfall amounts at different locations within the watershed:

- Victoria Park Water Treatment Plant;
- Colchester Balefill Facility; and
- Millbrook Fisheries.

The purpose of the rainfall monitoring program was to better understand rainfall patterns and obtain calibration data for the hydraulic model if a large flood event happened to occur during the monitoring period. Locations for the rain gauges were selected such that the data collected would be as representative of the entire watershed as possible. The largest rainfall event recorded during the monitoring period was a storm event in September 2014, during which the rain gauges measured almost 100mm of rainfall.

Tide and River Water Levels

Water level gauges were installed within the Salmon River, North River and McClures Brook in the spring of 2014 at the following five locations to monitor river water levels in the Truro and Bible Hill areas:

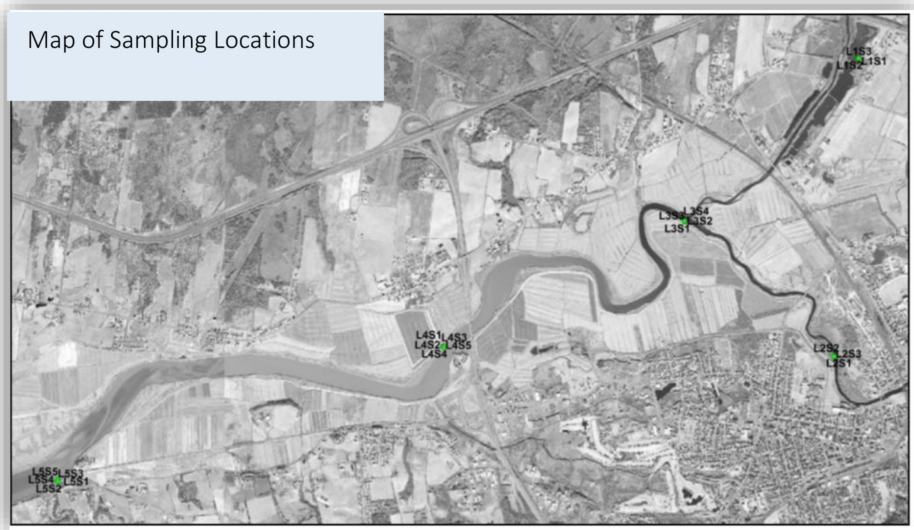
- Salmon River – Highway 102 Bridge;
- Salmon River – Park Street Bridge;
- Salmon River – CNR Bridge;
- North River – CNR Bridge; and
- McClures Brook – McClures Brook Aboiteau (upstream face).

Sediment Sampling

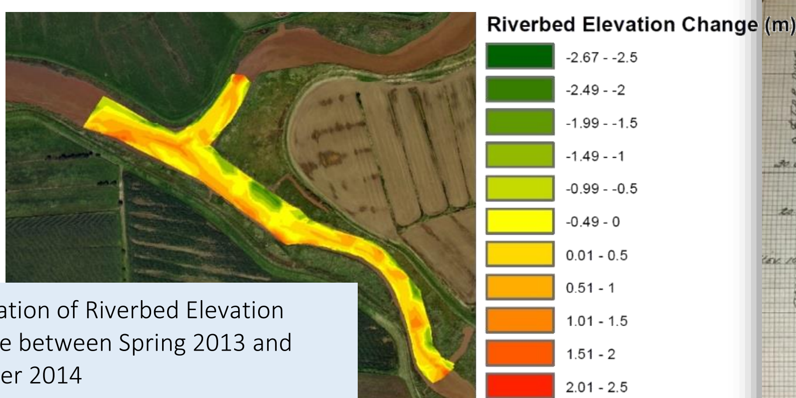
Sediment Samples

Five locations for collection of sediment cores were chosen based on discussion with modellers, accessibility, safety and need to ensure that the model domain reflected the anticipated differences in grain size between tidal versus fluvial dominated sections of the estuary. A minimum of three cores (10 cm) were collected along a transect from the thalweg to river bank at each site.

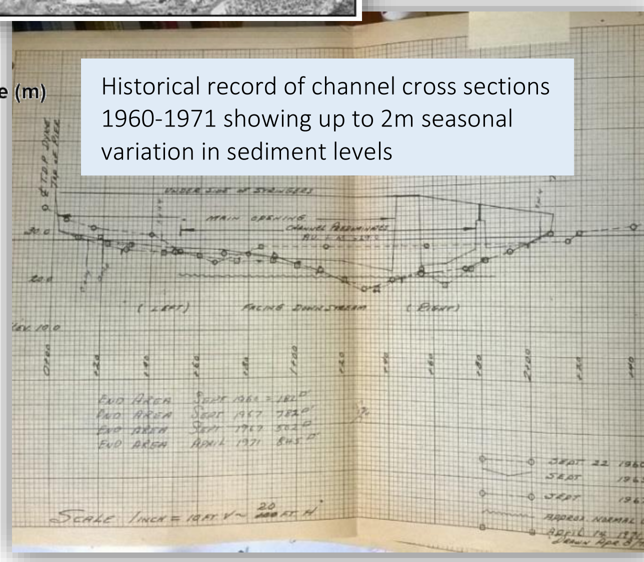
A total of 20 samples were collected on May 23rd, 2014 and 19 on September 19th, 2014.



Map of Sampling Locations



Calculation of Riverbed Elevation Change between Spring 2013 and Summer 2014



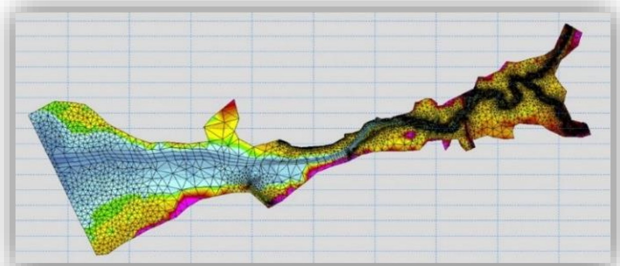
Historical record of channel cross sections 1960-1971 showing up to 2m seasonal variation in sediment levels

Overall Modelling Approach

There are several influences that lie behind the flooding that regularly occurs. These influences are complex to model and understand. As mentioned previously, they include the influence of extreme rainfall, tides, sediment levels and ice buildup, each playing a role, independently or in combination, which renders the picture extremely complex.

In order to address this complexity, the approach taken was to use the best available models for each purpose:

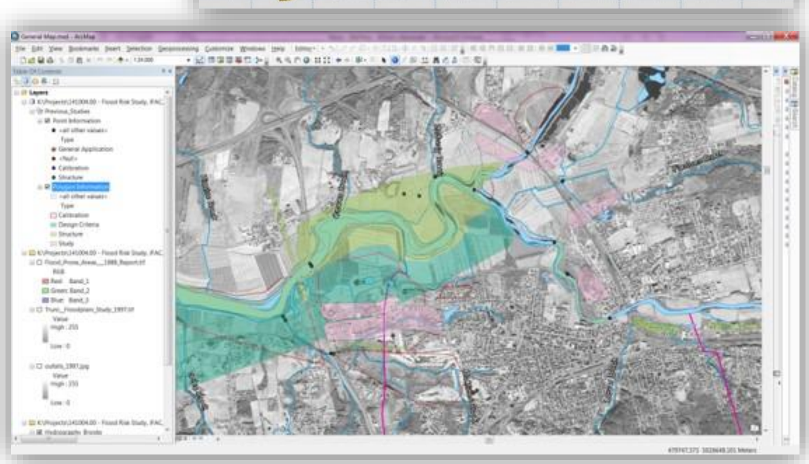
A hydrologic model (PCSWMM) to generate flows based on rainfall,



A hydraulic model (PCSWMM) to reproduce flows in the rivers and one-dimensional flow in the floodplain,

A two-dimensional hydraulic model (PCSWMM2D) to represent two-dimensional flow in the floodplain

An ice accumulation and jamming model (HEC-RAS) to better understand ice jam risks and mechanics.



A three-dimensional model (MIKE3) to study the tidal ingress and dampening as it progresses through the Cobequid Bay and into the Truro estuary

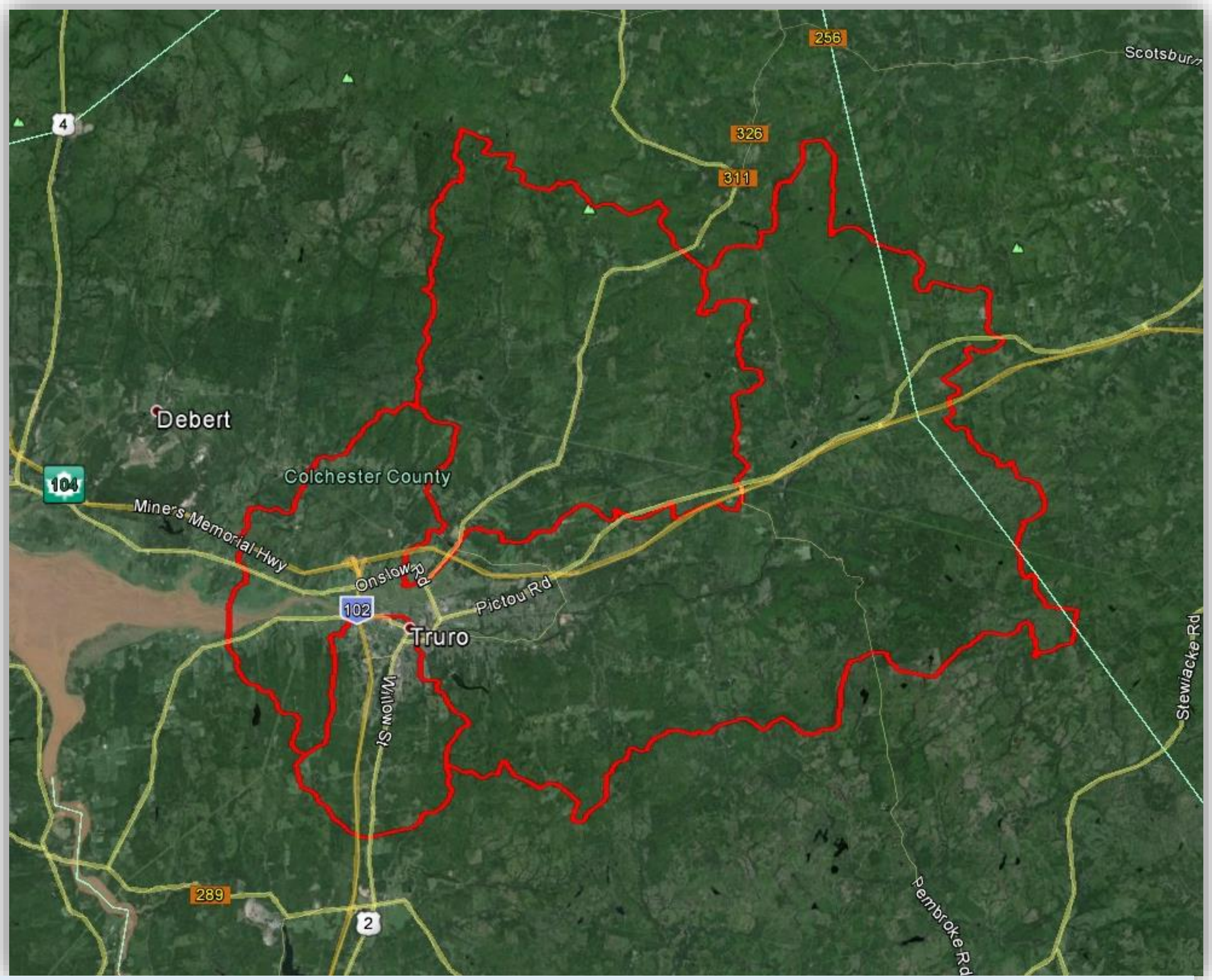
A three-dimensional model (MIKE3) to assess the sediment (mud) transport processes in the estuary, forced by the dynamic flux between saltwater and freshwater with each tidal ingress.

In addition to this state-of-the-art modelling, Geographic computer tools, some proprietary (ARCGIS), some included within the tools listed above (PCSWMM and MIKE3) and some developed in-house at CBCL Limited, were used to handle the extremely large sets of data. Data manipulation is not only complex, but the sheer scale of very detailed data (such as LiDAR and aerial photography) on such a large scale means that very heavy resources were needed to tackle this monumental amount of information.

It is noted that the general accuracy of those models is commonly accepted to be in the +- 30% range. This is due to two main factors:

1. The natural variation of hydrologic characteristics can have significant impacts of flows and water levels: for example, the January frozen ground with little vegetation will shed significantly more water than the August dry soil which is full of green vegetation. A model will typically use characteristics that tend to lean on the higher flow side, in order to be safer.
2. The model calibration, which is the adjustment of model parameters to make it representative of historic flood events, is an inherently imprecise process, since a given flood event may not be representative of average long term floods. Information on the floods may also be imprecise and sparse, which directly affects the quality of the model calibration.

Hydrologic Analysis



Map of Main Watersheds in the Hydrologic Study Area:

Aerial Photography was available from the County of Colchester in a 25-cm pixel resolution, which is extremely high, over the entire watershed area. This was invaluable to obtain a very clear view of the ground, not only in

Impact of Climate Change on Rainfall – Environment Canada

The impact of climate change on extreme rainfall amounts was analysed for this study to model future climate change conditions for the year 2100. According to a report by Lines et al. published by Environment Canada in 2008 entitled "Climate Change Scenarios for Atlantic Canada Utilizing a Statistical Downscaling Model Based on Two

Global Climate Models," the 24 hour duration 1 in 100 year rainfall amount at the Greenwood Airport climate station for the 2071 to 2099 horizon was predicted to increase by 29%. Extreme rainfall amounts in the Greenwood area were considered to be similar to those in the Truro true area, based on the "Rainfall Frequency Atlas for Canada" published by Environment Canada in 1985. Thus, a 29% increase in 1 in 100 year rainfall amounts for the year 2100 was estimated for this study.

Analysis of Recent Changes in Rainfall Data

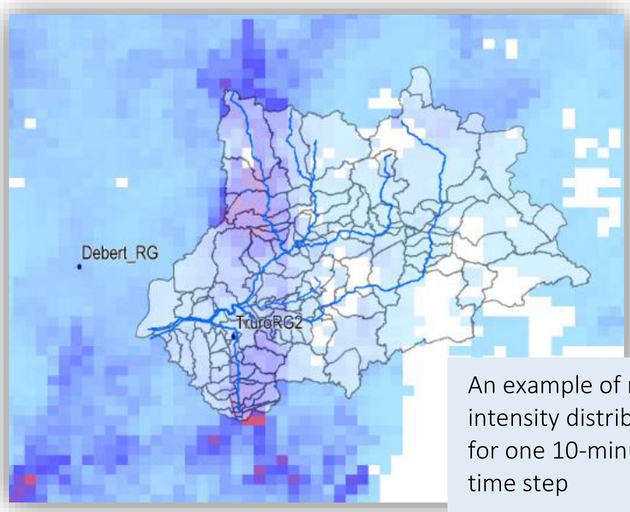
An analysis of recent versus long-term rainfall data was conducted to determine whether climate change effects could be identified. The existing Intensity-Duration-Frequency (IDF) curves published by Environment Canada for Truro are based on 21 years of available data collected between 1958 and 2001. In 2003, Environment Canada installed a new climate station at the Debert Airport and decided to shut down the Truro climate station. Maximum annual rainfall amounts for the Debert Airport climate station from 2004 to 2013 were therefore obtained from Environment Canada to update the existing Truro IDF curves for this study with rainfall data from Debert. Environment Canada was contacted to ensure that the statistical analysis procedure for estimating IDF curves carried out for this study followed the same method used by Environment Canada. It is noted that Environment Canada did not support carrying out this analysis, as the two rain gauges are too far apart to be considered to have similar rainfall patterns. The resulting calculation for the IDF curves for Truro are presented below. No increase in rainfall intensities was shown to have occurred by this analysis. In fact, the analysis shows a very slight reduction in rainfall intensities for the larger events. This may be a result of the distance between the stations rendering them inconsistent (as mentioned by Environment Canada), or it could be that no measurable trend in rainfall change is measurable at this time).

Radar Rainfall Analysis

Rainfall data is often one of the largest uncertainties during the calibration process. This uncertainty is amplified when the watershed is large and the rain gauges are very sparse. The rainfall intensity and total rainfall volume can vary significantly according to the location within the watershed. As the watershed size becomes larger, using a single point to estimate the rainfall across the entire watershed becomes less and less representative. The other uncertainty with using an isolated rainfall gauge is that the peak flow can be significantly affected by how the storm travels over the watershed.

This challenge was encountered when calibrating the model to the September 10th 2012 Flood Event. The total watershed area reporting to the downstream portion of the Salmon River is approximately 790 km^2 and only two known rainfall stations recorded the September 10th, 2012 rainfall event: the Environment Canada Debert Rain Station (just outside of study area) and the privately operated weather station commonly known as Davesweather.net station, however shown below as "TruroRG2".

Radar Data can be used to help reduce the uncertainty of using sparse rain gauge data by helping to determine the distribution of rainfall over a defined study area. Environment Canada radar data is provided in 1 km^2 grid format. Each 1 km^2 within the grid has a unique, 10-minute time step, rainfall intensity time series. Using radar data can help capture the spatial variation of a storm event and provide detailed rainfall data over the entire study area. The figure below shows an example of a snapshot of the radar data grid superimposed on the study area watersheds, which clearly demonstrates the spatial variation of the rainfall intensity distribution across the various watersheds in the study area.

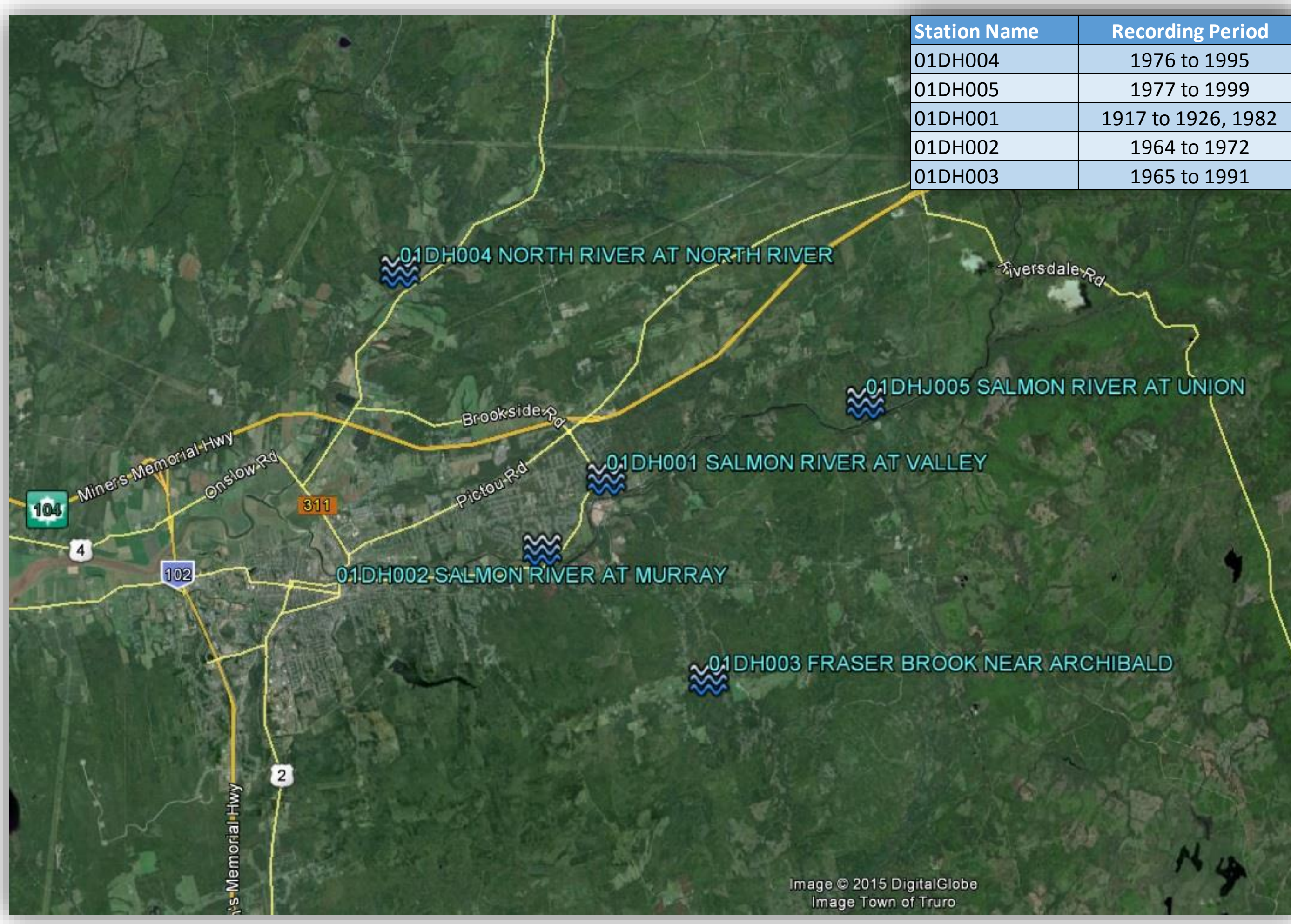


An example of rainfall intensity distribution for one 10-minute time step

Radar data must be calibrated before it is used for modelling. Areal measurements and ground measurements (from point rain gauges) are often different and can be in error of a factor of 2 or more. This error is due to the vertical and horizontal air motions, the measurement of radar reflectivity factor, evaporation and advection of the precipitation prior to reaching the ground and variations in drop-size distribution. One of the most common calibration methods is to use rain gauge data to "ground-truth" the radar data. Calibration results will improve based on the amount of rain gauges within the study area and the spatial distribution of the rain gauges. The calibration method chosen was the average method, which compares the average rainfall of each 1 km^2 radar grid element to the average rainfall measured by nearby rain gauges over a specified duration of time. Based on this comparison, a calibration factor for each 1 km^2 grid element is calculated and then applied to the radar measured rainfall. These calibrated rainfall intensities (for each 1 km^2 grid element) are then averaged across each watershed in the study area, providing each watershed with a unique and representative rainfall intensity distribution that could then be used for a more representative hydrologic model calibration.

River Flow Data

Historical flow and water level data for all five hydrometric stations along the Salmon and North River and their tributaries (see below) was obtained from the Environment Canada HYDAT database to be used as calibration data for the hydraulic model. The HYDAT database contains estimated flow data for all five hydrometric stations for the periods listed.



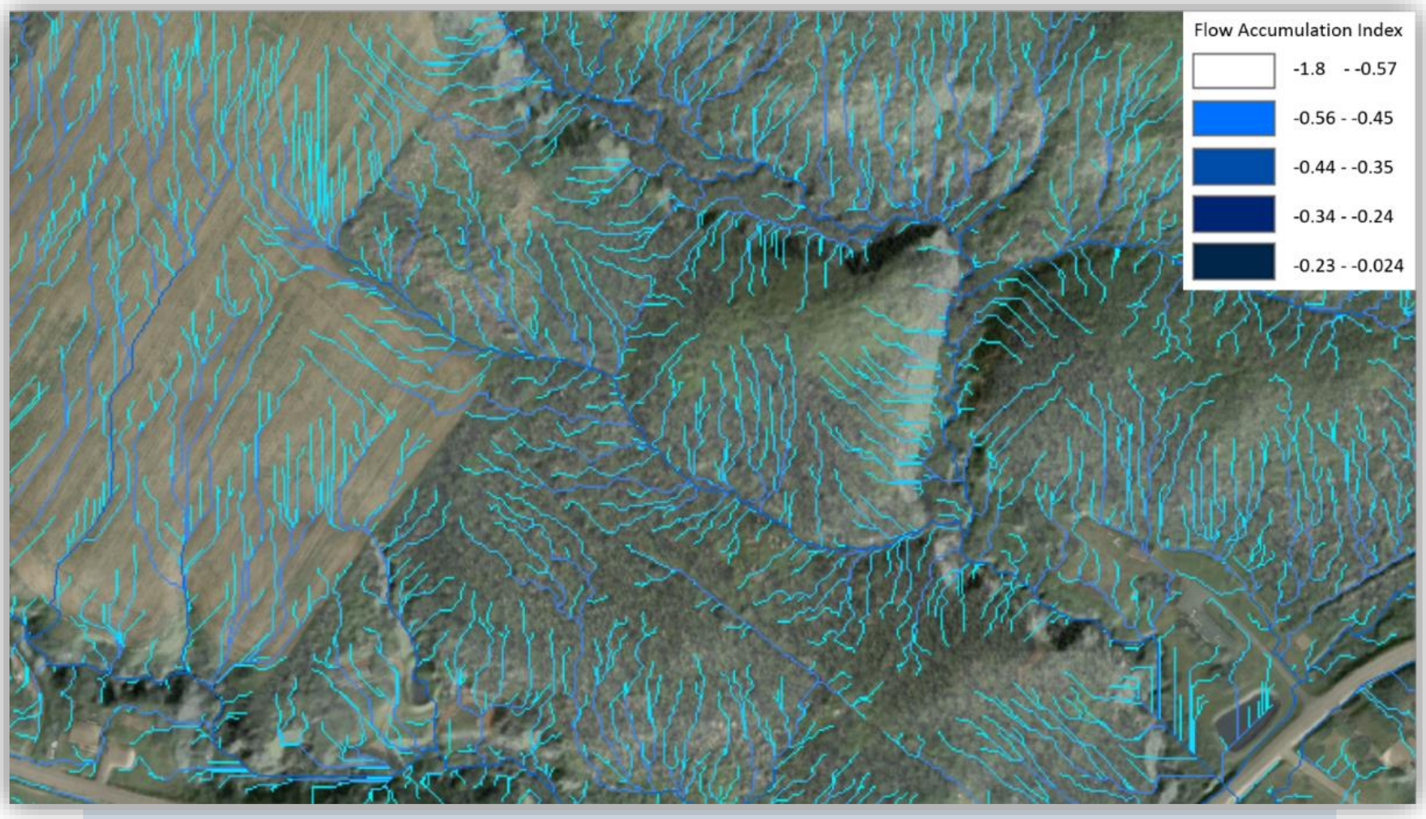
Station Name	Recording Period
01DH004	1976 to 1995
01DH005	1977 to 1999
01DH001	1917 to 1926, 1982
01DH002	1964 to 1972
01DH003	1965 to 1991

Hydrometric Stations and monitoring time periods

Hydrologic Parameters

A hydrologic analysis of the Salmon River, North River and McClures Brook watershed was carried out to delineate the watersheds and determine the watershed characteristics as inputs for the hydrologic model.

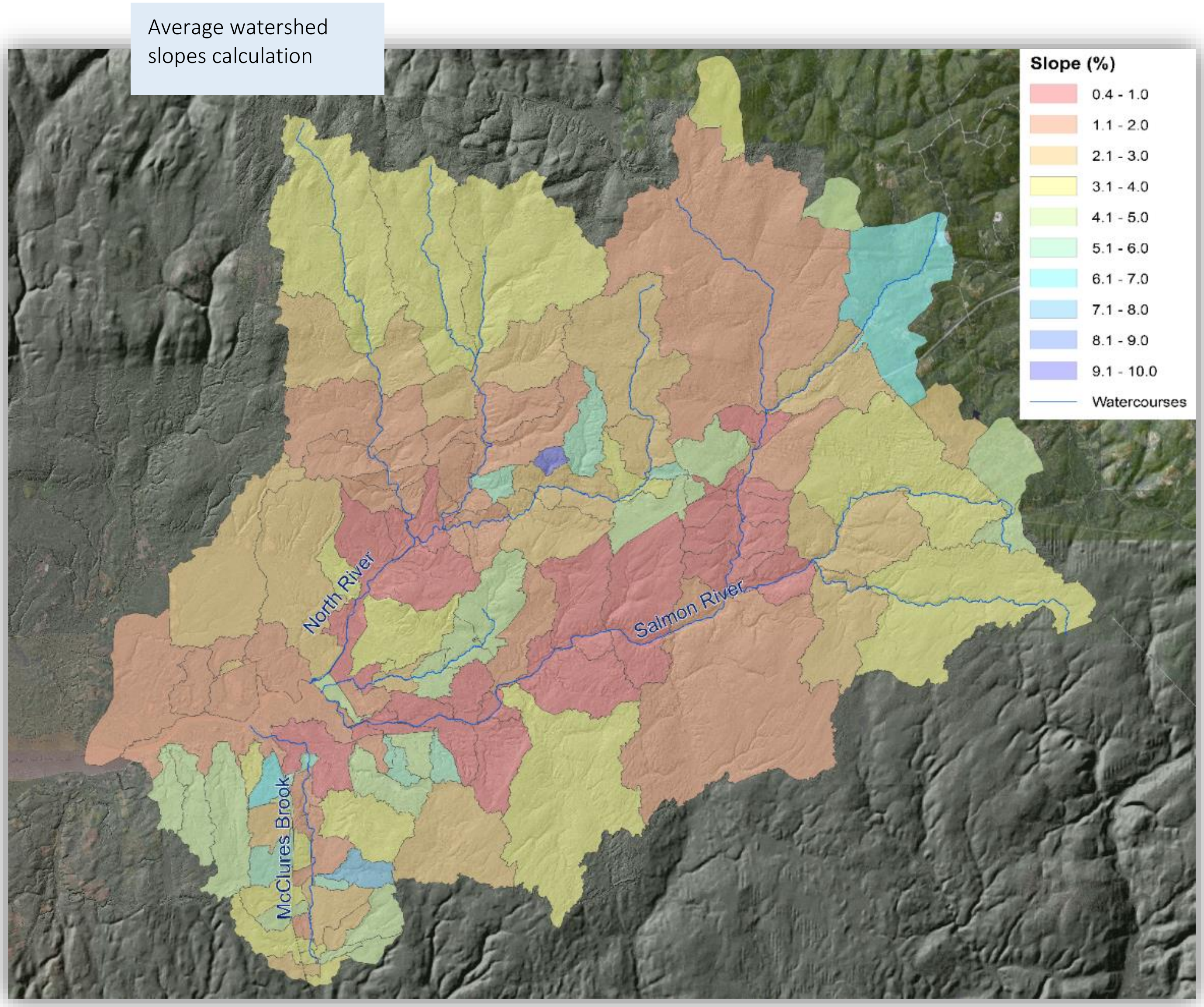
A hydrologic analysis of the Salmon River, North River and McClures Brook watershed was carried out to delineate the watersheds and determine the watershed characteristics as inputs for the hydrologic model. GIS software was used to delineate the watersheds from the Lidar data by first determining the cardinal direction in which surface runoff will flow for every square metre of land. The flow direction information was then used to calculate the amount of area that flows into each square metre of land, as presented in the flow accumulation mapping below. Finally, these areas were then automatically delineated to selected locations along the rivers to delineate 137 watersheds.



Example of Flow Accumulation analysis used for watershed delineation

The following watershed characteristics were extracted, for each of the 137 watersheds:

- Average Surface Slope;
- Maximum Overland Flow Length;
- Surface Roughness;
- % Land that is Impervious;
- Soil Characteristics: Hydraulic Conductivity, Soil Capillary Suction Head; and
- Watershed slope.



Calibration

After the hydrologic parameters described above are estimated and imported into the hydrologic model, the model must be calibrated. Although great care is taken to estimate the hydrologic parameters as accurately as possible, there are still many unknowns with regards to how the watersheds respond to a major storm event. In order to make sure the model is representative of actual flows during extreme events, it is necessary to use actual flow measurements and fine tune the model to reproduce them. Calibration is a fundamental part of modelling, since a model that is not representative of actual flows will not be able to estimate correctly potential extents of flooding, nor support the selection of appropriate flood protection measures.

Flow calibration was completed by ensuring that modeled flow results for a specific storm event are consistent with the recorded flow results for the same storm event at the same flow-gauging station. Two historical events and three total calibration sites were identified for calibration purposes based on location within the study area, historical significance and availability of both rainfall and river flow gauging data. The summary of the three calibration scenarios and the corresponding data available can be seen below.

Summary of Flow Calibration Events

Date	Available Data	
	Rainfall	Flow Gauging Station
	Environment Canada: • Truro Station.	Salmon River at Murray
		Fraser Brook near Archibald
	Environment Canada: • Truro Station.	North River at North River

In order to best replicate the recorded flow and volume results, watershed characteristics that are directly associated with how much and how fast rainfall will infiltrate into the ground, such as watershed conductivity, watershed width, and impervious area were adjusted within their range of uncertainty. Reproducing flow measurements is a critical step, prior to water level calibration, which ensures that the model will be satisfactory in terms of flow, volume, velocities and water level. Calibration results for Salmon River at Murray, Fraser Brook and North River are summarized in the table below.

Summary of Flow Calibration Results

Date	Flow Gauging Station	Recorded	Modeled	%
August 16 1971	Salmon River at Murray			
	Max Flow (m^3/s)	254	226.6	-10.8%
	Min Flow (m^3/s)	1.4	1.5	8.9%
	Mean Flow (m^3/s)	68.47	68.31	-0.2%
	Total Flow Volume (m^3)	34800000	33740000	-3.0%
	Fraser Brook near Archibald			
	Max Flow (m^3/s)	6.48	6.839	5.5%
	Min Flow (m^3/s)	0	0	0.0%
	Mean Flow (m^3/s)	1.3	1.9	43.6%
	Total Flow Volume (m^3)	816300	916800	12.3%
January 15 1978	North River at North River			
	Max Flow (m^3/s)	170	145.9	-14.2%
	Min Flow (m^3/s)	7.0	1.4	-80.1%
	Mean Flow (m^3/s)	137.1	144.4	5.3%
	Total Flow Volume (m^3)	24730000	26050000	5.3%

Tidal Analysis

Astronomical Tides

Similar to most rivers draining into the Bay of Fundy, the shape of the river bed, and the peak water levels in the downstream areas of the Salmon River are mostly influenced by the tide. The Bay of Fundy creates suitable conditions to allow water to oscillate at the right frequency to produce the highest tides in the world, which often results in flooding and damage in the area. Those extreme tides form a fundamental part of the mechanisms of flooding, and need to be carefully analysed.

Tidal levels in the Bay of Fundy are semi-diurnal, which means there are two high tides and two low tides in a day. The tidal level varies based on the lunar cycle (approximately monthly, based on the moon's orbit around the earth) and on the metonic cycle, (19-year cycle, based on relative position of the moon, earth and sun). In order to estimate reliably extreme tidal levels, an understanding of the complete 19-year cycle is therefore necessary. The following sections describe our approach, which involved using published information, research on extreme tide levels, site measurements, and a 3D tidal intrusion hydrodynamic model.

Definition of Tidal Surfaces

- Higher High Water Large Tide (HHWLT) = average of the highest high waters, one from each of the 19 years of astronomical tide data;
- Higher High Water Mean Tide (HHWMT) = average of all the higher high waters from 19 years of astronomical tide data;
- Mean Water Level (MWL) = average of all the hourly water levels over the available period of record;
- Lower Low Water Mean Tide (LLWMT) = average of all the lower low waters from 19 years of astronomical tide data; and
- Lower Low Water Large Tide (LLWLT) = average of the lowest low waters, one from each of 19 years of astronomical tide data.

Existing Information

Historical tide gauge observations in Cobequid Bay are sparse. The closest historical DFO tide gauge was at Burntcoat Head, 34 km West of the Salmon River mouth below. The station has approximately 1 months' worth of observations in 1960 and another 1.5 month in 1975. These observations cannot be reliably extrapolated to Truro for the following reasons:

The observations are referenced to the local Chart Datum. There is no conversion factor available for the area to relate the observations to the reference CGVD28 (Canadian Geodetic Vertical Datum of 1928). While the CGVD28 reference level is generally close to the Mean Water Level, the difference could be significant enough in the context of defining flood lines. The HHWLT level calculation was based on tide gauges that were surveyed into the CGVD28 datum using a reliable local monument. The prediction from DFO's Upper Fundy WebTide model (which doesn't cover the intertidal flats of the Salmon River estuary) at Burntcoat Head indicates that the maximum tidal elevations for mid-June 2014 correspond to the calculated HHWLT level over the 19-year cycle. While the predicted value itself (relative to MWL) cannot be converted to CGVD28 and extrapolated to Truro, the position of the tides relative to the tidal surfaces as defined over a 19-year cycle would be valid for the Salmon River estuary. The maximum surveyed high tide in the Salmon River in mid-June 2014 was 9.0 m CGVD28, which was therefore used as the HHWLT value for subsequent modelling.

Storm Surge and Sea Level Rise

Sea Level Rise (SLR) along eastern Canada's coast has been occurring since the end of the last ice age, approximately 10,000 years ago. The rate of global mean SLR is accelerating in the 21st century due to global warming impacts, notably the melting of polar ice caps. The Intergovernmental Panel on Climate Change (IPCC AR5, 2013) indicates that the current consensus is as follows:

- The likely range of global mean SLR for 2081-2100 relative to 1986-2005 was estimated from 0.26 m (lower bound value for low emission scenario) to 0.98 m (higher bound estimate for high emission scenario);
- There is currently insufficient evidence to evaluate the probability of specific levels above the assessed likely range; and
- There will be regional differences, with the northeastern coast of North America potentially experiencing a SLR rate higher than the global average.

Site-specific sea level rise allowances were recently developed by DFO based on emissions scenarios from the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) (Zhai et al 2014). For a high emissions scenario ('RCP 8.5'), the authors recommend a sea level rise allowance of 1.00 m for Saint John NB from year 2000 to year 2100. This is consistent with values from Richards and Daigle[1] (2011), which would translate into a recommended sea level rise allowance of 0.96 m (± 0.46 m) SLR for Truro from 2015 to 2100. Richards and Daigle also developed storm surge return period estimates for Truro, based on values extrapolated from the long-term tide gauge in Saint John NB. The Richards and Daigle components for storm surge and sea level rise were used to calculate local extreme water levels relative to CGVD28.

Average Storm Surge Estimates based on Tide, Storm Surge and Sea Level Rise

		Average Water Level Estimate (m)				
Storm surge Return Period	Average Storm Surge Residual (m)	Year 2015	Year 2025	Year 2055	Year 2085	Year 2100
2-year	0.67	9.7	9.7	10	10.4	10.6
10-year	0.89	9.9	10	10.2	10.6	10.9
25-year	1.01	10	10.1	10.3	10.7	11
50-year	1.1	10.1	10.2	10.4	10.8	11.1
100-year	1.2	10.2	10.3	10.5	10.9	11.2
Uncertainty	*0.2*					

Upper-Bound Storm Surge Estimates based on Tide, Storm Surge and Sea Level Rise

		Upper-Bound Water Level Estimate (m)				
Storm surge Return Period	Upper-bound Storm Surge Residual (m)*	Year 2015	Year 2025	Year 2055	Year 2085	Year 2100
2-year	0.87	9.9	9.9	10.3	10.9	11.3
10-year	1.09	10.1	10.2	10.6	11.2	11.5
25-year	1.21	10.2	10.3	10.7	11.3	11.6
50-year	1.3	10.3	10.4	10.8	11.4	11.7
100-year	1.4	10.4	10.5	10.9	11.5	11.8

*Upper-bound Storm Surge Residual = Average Storm Surge Residual + Uncertainty (0.2m)

It is noted that future water levels do not include tidal expansion in the Bay of Fundy, which is a topic of current research. In summary, sea level rise will increase the volume of water that flows back and forth in the Bay of Fundy with each tide. This increase in volume will slightly change how fast it flows back and forth, bringing that frequency closer to the natural resonance frequency of the Bay of Fundy. This will increase its amplitude by approximately 10% of the sea level rise (Greenberg 2001[1],[2]), i.e. a 0.1 m increase in peak high tide levels in the Bay of Fundy.

1 GREENBERG, D.A. 2001. Climate change, mean sea level and tides in the Bay of Fundy. Project report CCAF project S00-15-01, Dartmouth: Nova Scotia, Environment Canada.

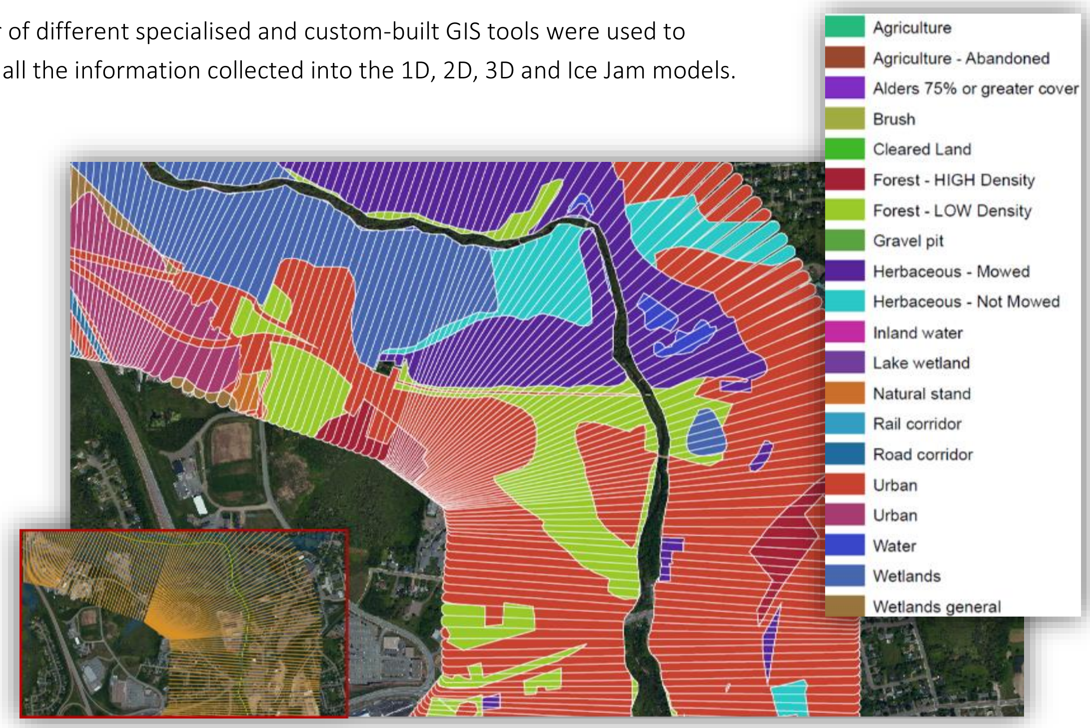
2 David A. Greenberg , Wade Blanchard , Bruce Smith & Elaine Barrow (2012) Climate Change, Mean Sea Level and High Tides in the Bay of Fundy, Atmosphere-Ocean, 50:3, 261-276, DOI: 10.1080/07055900.2012.668670

Hydraulic Analysis

Modelling Approach

Through the review of historical flood events and previous reports, it was determined that the dominant forces that lead to flooding include rainfall, tides, sedimentation and ice. In order to understand the influence of each of these forces, each one was studied separately and the results compared to understand where the dominant influences would arise.

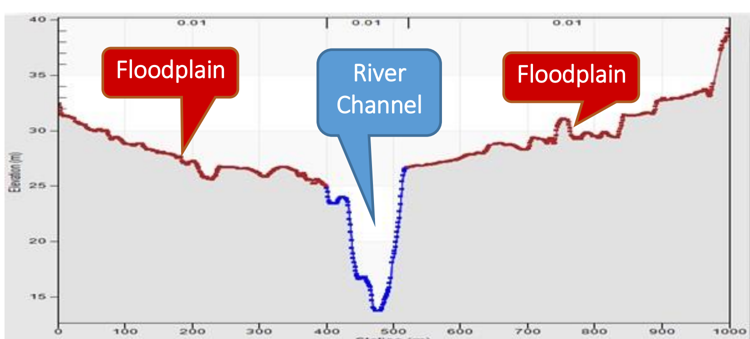
A number of different specialised and custom-built GIS tools were used to assemble all the information collected into the 1D, 2D, 3D and Ice Jam models.



McClures Brook – Example of GIS Surficial Analysis Tool used to Assign Surface Roughness to model of the floodplain – Data from the Lidar beam signals, aerial Photographs, and Satellite Imagery was used

Detailed representation of the riverbed and floodplain:

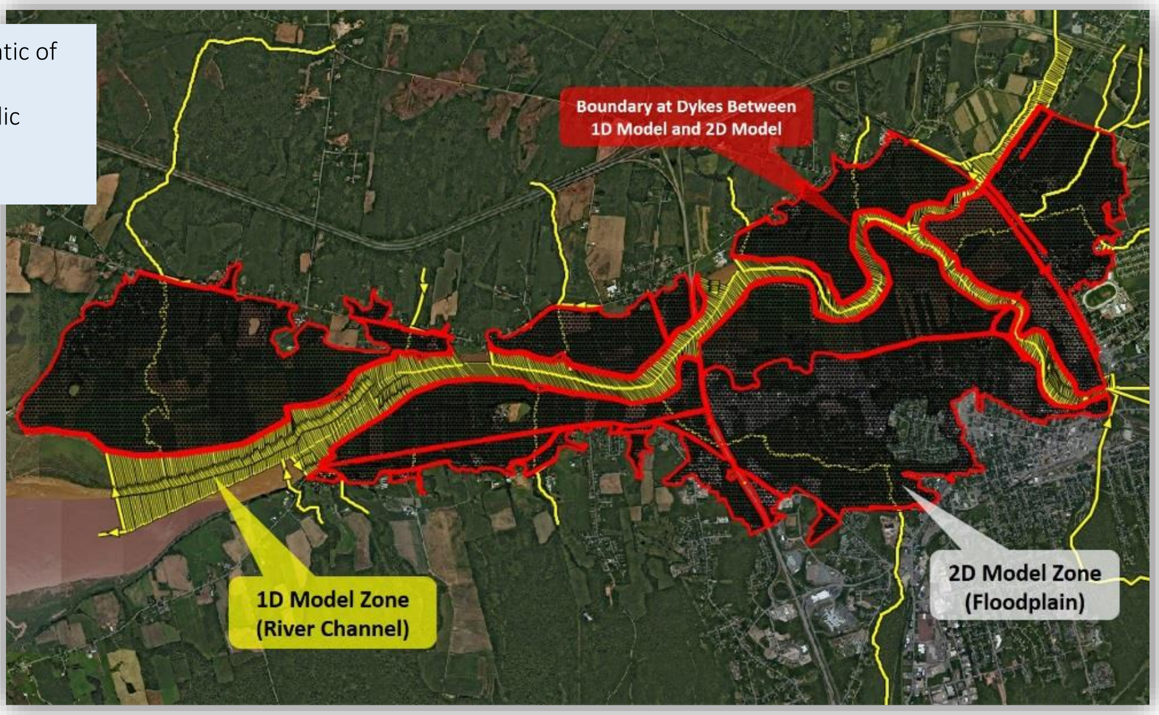
Over 3400 unique cross sections assigned to the channel at 20 - 50 m intervals. Points in the cross section are 1m apart, extracted from the



The models were customised to allow not only water to flow over the dykes in both directions, but also the potential failure of the dykes (in 20 metre segments along their entire lengths), should water raise more than 30cm above the dyke crest. This capability was included since there was some concern that dyke failure would lead to a dramatic increase in flooding risk.

The water level calibration process included multiple consultations with the JFAC. Floodlines were produced for the September 2012 event, presented to the JFAC and then feedback from the JFAC was recorded about where levels may be too high or too low. An example of the feedback received from one of our consultation sessions is shown below. This feedback was then used to help calibrate the model to ensure that it reached the known water levels.

Schematic of 1D-2D Hydraulic Model



Example of Information Used for Water Level Calibration.

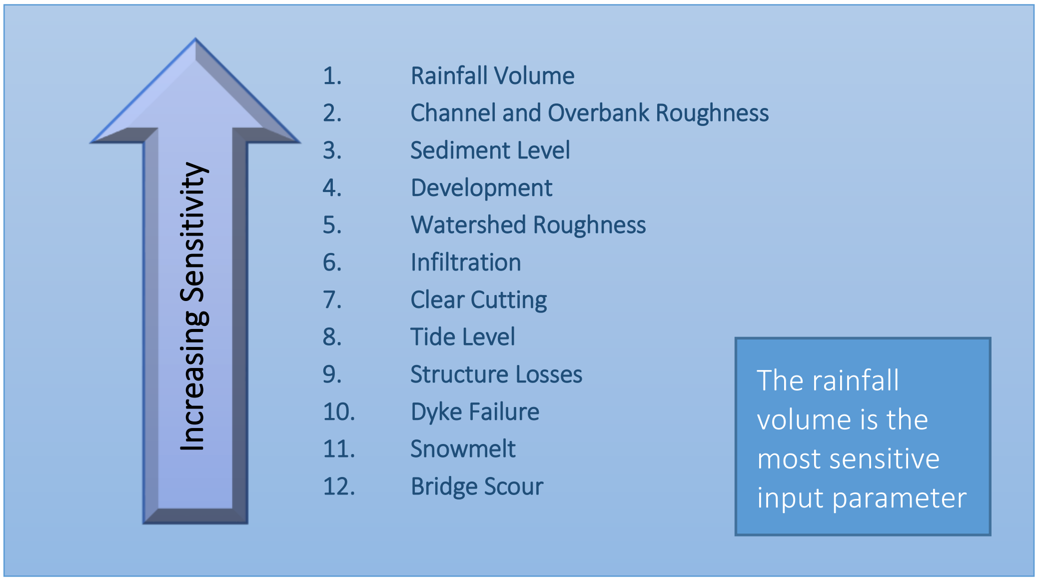
Sensitivity Analysis

Sensitivity Analysis helps understand which parameters have the greatest influence on flooding under a range of conditions, and is therefore an essential part of the flood study. It helps reduce the risk of underestimating the flood level and may also help focus attention on flood mitigation options that will be of most benefit under specific conditions.

During a sensitivity analysis, different input parameters that are uncertain or vary seasonally are adjusted within a reasonable range of uncertainty to see what effect each parameter has on the flood level. Some parameters (such as amount of bridge scour) will have a minor influence on flood levels (or low sensitivity) and other parameters (such as rainfall total volume) will have a greater influence on flood levels (or high sensitivity).

The Truro estuary and river structure is a unique system which is vulnerable to four major causes of flooding: heavy rainfall, high tides, severe sediment deposition within the tidal range and ice jams. In order to have a clear understanding of how each input parameter affects the water level, a baseline case was developed for each major cause of flooding (Rainfall, Tide, Sediment and Ice).

Several input parameters were adjusted in order to assess the sensitivity of the four baseline cases. Below presents the details of each sensitivity scenario and the associated results. Input Parameters were adjusted within a reasonable range of the natural upper and lower limit. Sensitivity results were found to follow the diagram presented below in order of most sensitive to least sensitive:



It is noted that ice is not included in the list because it was assessed with a different model. The results therefore cannot be directly compared. In general, flooding is quite sensitive to the volume of ice buildup. However, this is such an uncertain parameter that it is very difficult to estimate the risks that ice will build up to a certain thickness in a certain area, and therefore very difficult to rate. Further discussion on this is presented in the Ice Jam Model section.

Volume of Rainfall: Based on the sensitivity analysis results, the rainfall volume is the most sensitive input parameters. However, it is important to note that rainfall was modified by a 25% increase and 25% decrease. The resulting maximum increase and decrease in flooded area was 8.7% (Sediment Scenario) and -11.6 % (Tide Scenario), respectively. Additionally, when rainfall was modified and assessed for the rainfall baseline case, when flooding is at its peak, the decrease in total flooding area was only -2.6% when the total rainfall was decreased by 25%. This means that although the system is most sensitive to rainfall volume, the actual change in floodplain area is not that significant. This points to the fact that in order to notably reduce the flooded area, significant water management work will need to be undertaken.

Channel Surface Roughness: Another input parameter which showed to have high sensitivity was the channel and overbank roughness. This parameter describes how rough or smooth the channel and floodplain are. Smoother channels should theoretically allow water to move faster through the system and therefore lower water levels, while rougher channels will cause water to move slower, or back up and cause higher water levels. This analysis was consistent with this theory and showed an increase of 5.1 % and decrease of -7.7% for the rainfall scenario when the roughness coefficient was modified by +50% and -50%, respectively. Even though in practice it may be difficult to keep the channel and floodplain areas as smooth as possible, this analysis shows that seasonal variations in levels of vegetation will have a notable impact on flood levels.

Amount of Sedimentation in the River: Sediment Level primarily showed sensitivity in the tide scenario, decreasing the flooded area by -16.7%, when the sediment level was decreased by 50%. Apart from the tide scenario, the decrease in floodplain when decreasing the sediment level was -2.3% and -1.9 % for the Sediment Scenario and Rainfall Scenario, respectively. This shows that decreasing the sediment level (either by dredging or due to the natural seasonal variation) within the tidal zone may only be an effective flood mitigation measure to reduce the impact of extreme tides.

Development: The impact of development was also assessed by testing a ±50% change in development level. The model showed that increasing the development by 50% would increase the flooded area by 2.4%, whereas a reduction in 50% would decrease it by 5.2%. This means that although additional development may have limited impact on flooding, implementing stormwater Best Management Practices to re-infiltrate the rainfall into the ground (and restoring the natural pre-development balance) would have a notable beneficial effect.

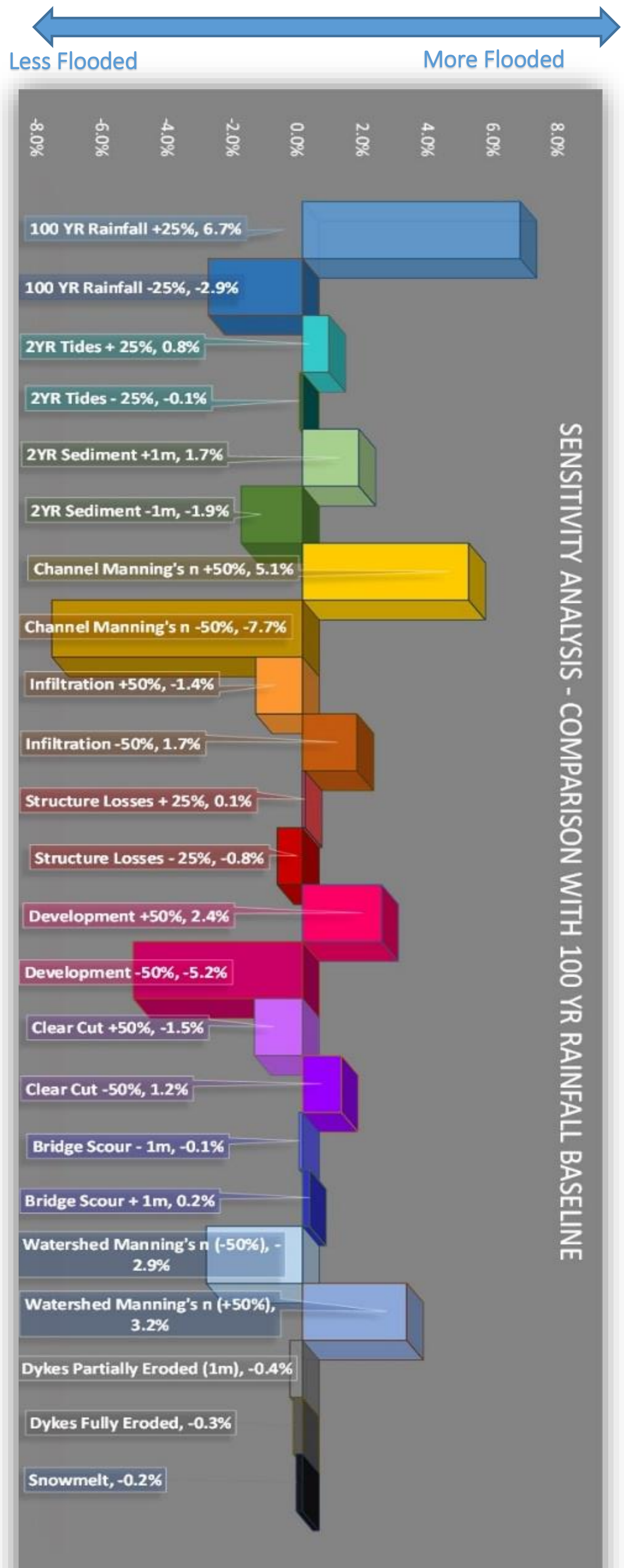
Watershed Surface Roughness: An interesting finding was the impact of changing the watershed roughness in the model. This would represent natural processes such as the changing of seasons, where the leaves densify and fall, or the ground is covered in brush and leaves at a certain point, and covered in ice at others. Changes in roughness may also represent man-made changes such as the farming process, where the ground cover changes from bare earth, to significant vegetation cover, to after harvesting conditions where much of the vegetation is removed. The model showed that such changes creates approximately ±3% change in surface of flooding, which is notable.

Infiltration: Infiltration was adjusted by ±50% for the rainfall baseline case, which could represent the range in watershed infiltration capacity from winter conditions to summer conditions. Increasing infiltration capacity by 50% only reduced the area flooded by 1.4% and decreasing infiltration capacity by 50% increased the flooding area by 1.7%. This shows that infiltration capacity may not be a very sensitive parameter during the rainfall baseline case and may be due to the fact that during a storm of this intensity, the ground would be close to fully saturated.

Clearcutting: Clearcutting ±50% of the total forested area was also tested with the model. Interestingly, even if half of the entire forested area was clear-cut, the impact on flooded area would be only in the 1% range. This is because the ground surface is still fairly rough, and that as shown above, most of the rainfall during extreme storm events remains on the ground surface and contributes to flooding. Since the ground quickly becomes saturated during extreme storm events, the overall proportion of infiltrated rainfall is very small. Changing this will have a very small effect on the overall flooding levels. It is very likely, however, that smaller rainfall events would produce higher flows than previously, as a large change in infiltration amount would then be expected.

Clearcutting ±50% of the total forested area was also tested with the model. Interestingly, even if half of the entire forested area was clear-cut, the impact on flooded area would be only in the 1% range.

Tidal Levels: Adjusting the tidal levels showed very little sensitivity, particularly in the Rainfall scenario. Decrease to the floodplain was negligible (-0.1%) when the 1 in 2 year tide level was decreased by 25%. This indicates that tidal levels are



Sensitivity scenarios and associated results not the primary cause of flooding and that developing flood mitigation options that control tidal levels will have overall little effect.

Dyke Failure: The model was set to allow the dykes to fail if more than 300mm of water was flowing over a given section of dyke. The dyke failure was tested given two different conditions. In the first scenario, it was assumed that if the dyke failed, it would only scour 1 m of depth in the dyke. In the second scenario, it was assumed that if the dyke failed, it would erode to its full depth. Both of these scenarios showed negligible effects. This may be due to the fact that if enough flow was overtopping the dyke to cause the dyke to fail then any additional flow allowed through the failed dyke itself would not affect the flood level significantly. It therefore shows that even if the dykes do fail during the storm event, they will still provide a similar level of protection. Failure of the dykes before the water level overtops them is not expected to be a risk, since the dykes all have vegetation and have slopes of 3:1 or flatter. Nevertheless, it is expected that flooding would increase slightly, more so if the tides are especially high. The main risk would likely be that the floodplain and farming areas would be flooded with salt water, which is what the dykes were originally built to protect against.

Even if the dykes do fail during the storm event, they will still provide a similar level of protection.

Structure Losses and Bridge Scour: The sensitivity of the system to the structures within it (bridges, culverts, etc.) was evaluated by adjusting structure losses and bridge scour. The system showed little sensitivity to both of these input parameters when evaluated in the rainfall scenario. This shows that although some structures may be restricting flow, the restrictions have very little effect on the floodplain during the 1 in 100 year storm.

Floodline Delineation for a Range of Extreme Events

One of the objectives of this study was to update the existing floodline delineation, which was made in 1988 in the joint Nova Scotia - Environment Canada Flood Damage Reduction Program, and reviewed in 1997 by EDM.

This updated delineation now includes the following aspects:

- Delineation and modelling based on highly detailed Lidar topographic data (1m grid resolution);
- Delineation and modelling of the full length of the Salmon River, the North River, McClure's Brook and Farnham Brook;
- State of the art two dimensional hydraulic modelling;
- Modelling of extreme flows in a dynamic setting;
- Modelling of extreme tides in a dynamic setting;
- Modelling of extreme sediment levels;
- Assessment of Climate Change impacts on extreme rainfall amounts;
- Assessment of Climate Change impacts on extreme tide levels;
- Delineation of the 1 in 2, 1 in 10, 1 in 20, 1 in 50 and 1 in 100 year events;
- Delineation of the 1 in 100 year event with the impact of Climate Change in the year 2100 horizon; and
- Assessment and delineation of the Probable Maximum Flood Event.

Three maps are presented in this report, in addition to the electronic files. They show the overall area (Map 9-1), the McClures Brook (Map 9-2) and the Truro urban area (Map 9-3). It is recommended that the 1 in 100 year floodline adopted for Land Use regulations include the effects of climate change. This is to better protect potential infrastructure and residences that can still be built within the major floodplain. It is noted that the models intended to compare the efficiency of various flood mitigation options used average values for variable coefficients such as impervious surface roughness, pervious surface roughness, soil hydraulic conductivity, suction head, whereas the models to produce floodlines that will be used to update the land zoning used the more conservative end of the parameters, in order to make sure the risks are not underestimated. Maps 9-4 to 9-9 show the floodline delineations for the various extreme events listed above, including the effects of climate change and the Probable Maximum Flood Event.

Flood Mitigation Options

The whole intent of assembling a hydraulic model is not only to understand better the processes that lead to flooding, but also to allow the testing of many options for flood mitigation. In this assessment, more than 40 options were tested, and each of those options were tested against extreme rainfall, tide and sedimentation levels using the various hydraulic models.

Such options fall under the “mitigation” type of approach as discussed in the first chapter. In essence, there are only a few main approaches to mitigating flood risks, which include:

- Reducing flows by infiltrating or storing water upstream of the floodplain;
- Protecting vulnerable areas with dykes or raising the ground level;
- Increasing the conveyance system capacity by widening bridges and rivers; and
- Protecting vulnerable areas locally using flood proofing methods at the lot scale.

Other more specific approaches include protection against extreme tides with aboiteaux, or reducing the risks of ice jams using ice berms.

Model Results

The hydraulic model tested each scenario against extreme rainfall, tidal and sediment levels (1 in 100 year events). Floodlines were calculated for each (more than 100), and are presented in Appendix B. It was found in general that the rainfall events were found to slightly dominate over the other flooding factors in generating the largest floodlines.

Sedimentation Analysis

Main Processes

Flooding may be the primary concern, but if the long term costs of removing sediments, or risks to the long term stability of some new infrastructure options are not acceptable, long term viability of those options will be compromised. The study of sedimentation and erosion therefore plays a critical role in this assessment. As change happens, the river will find a stable equilibrium that responds to this change. For example, if rainfall increases, the channel will tend to become wider, deeper and have fewer meanders. Similarly, if the tide levels increase, this will lead to an increase in average sediment levels.

Modifying the channel shape, without any permanent structure to protect it, will only provide temporary benefits. The river will revert to its original configuration, as the tidal and flow influences lead the river back into its natural equilibrium. It is noted that the notion of "equilibrium" does not imply a fixed channel shape and size. The equilibrated state of the river will change according to the seasons, and the varying climate of each year.

Modifying the channel shape, without any permanent structure to protect it, will only provide temporary benefits. The river will revert to its original configuration, as the tidal and flow influences lead the river back into its natural equilibrium.

As seen in the previous chapter, a large number of options have been investigated. Nonetheless, there are only a few types of approaches to flood mitigation that may influence, or be influenced by, the sedimentation processes.

These include:

- Removing sediments in the river;
- Changing its shape (widening, deepening, straightening);
- Widening the dykes; and
- Reducing flows to the river.

Sedimentation and sediment flushing is a naturally occurring process, but it is important to evaluate how a flood mitigation option will affect the sedimentation process. In order to compare the existing sedimentation conditions and the flood mitigation option conditions, the percentage of time when the bed shear stress is below the critical threshold for deposition was calculated with the model. The difference in this metric between existing conditions and the option is indicative of the tendency towards more (or less) sedimentation after implementation of the option.

Key Points

- Cohesive sediment transport is very complex to model;
- Erosion/deposition rates are non-linear and can change by an order-of-magnitude depending on sediment properties (water content, sediment size);
- Removing sediments / engineering interventions cause departures from natural, temporary balance between erosion and sedimentation; and

- Tidal river cross-section is generally related to its tidal prism (volume of water which flows past a given point during the tide):

Reduction in upstream tidal volume → Sedimentation, resulting in narrowing and rising of the river bed

Increase in upstream tidal volume → Erosion, resulting in widening and deepening of the river bed.

Waterlogged Silt / Aboiteau Outlet Requiring Periodic Maintenance Removal of Sediments

Ice Jam Model

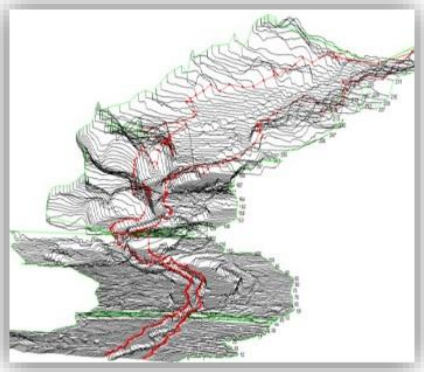
Ice jam formation can occur during the freeze-up period at the beginning of winter, or during the break-up period in spring. During the freeze-up period, ice forms on the river surface beginning at the banks. Ice crystals may also develop within the river as frazil ice, which is very common in rapids. The ice crystals tend to coalesce and accumulate, and may become attached to the underside of the ice cover or to the river bed as anchor ice.

Ice in the Salmon River in March 2014, with depths of ice exceeding 4m.

Frazil pans and floes are major components in the formation of a river's initial ice cover. In tranquil reaches, this cover is a mere surface layer of ice floes and pans, but elsewhere it can be several layers thick.

Ice jams during the freeze-up period usually form where floating ice slush or blocks encounter a stable ice cover. There are, however, certain features that, in conjunction with ice cover, enhance the probability of ice jam formation: bridge piers, islands, bends, shallows, slope reductions, and constrictions.

Salmon River March 2014 photo and model representation of the Salmon River, with tops of river banks represented in red.



During breakup in the spring, or during winter thaws, an ice jam results from the accumulation of ice from the breakup of the upstream ice cover. A rise in water levels may result from the spring snowmelt, or a sudden midwinter thaw, common in Atlantic Canada. Midwinter thaws are often accompanied by substantial rainfall, resulting in a rapid increase in water levels and severe ice jams.

The main types of options likely to impact ice jamming processes were tested with the model. These included a sensitivity test of raising or lowering the river bed by 1m. This seemed to have a negligible impact on ice jam related peak water levels (less than 1% difference in water level), as seen on Figures 11.2 and 11.3. The other options tested included raising the dykes by either 1m or as high as needed to contain the flood, and constructing an ice berm.

The model was able to show in Figures 11.4 and 11.5 that raising the dykes would increase peak flood water levels, by a marginal amount (~0.2m) if the dykes were raised by 1m, and by a significant amount (more than 2m) if the dykes were to contain all river flooding. This is an interesting finding, since the increased velocities do not seem to reduce the risk of ice jams in this case.

The ice berm was tested by adding to the model bridge-like structures that had piers every 2m, in order to restrict the size of blocks of ice that can be conveyed downstream, as well and increase the likelihood of ice jams forming at the safer locations of the structures. Unfortunately, the model was unable to show the increased potential of ice jam formation at those specific locations (see Figure 11.6).

This can be the result of many factors, but even though it is expected that such a structure would still provide an increased level of safety, it highlights the fact that ice jams could potentially be unaffected by such structures. Ice berms also need to be placed in locations where induced flooding results in minimal losses. As such, they need to be located upstream of urbanised areas, which leaves a significant amount of ice still available to form an ice jam anywhere downstream.

It is therefore expected that in certain circumstances, the ice berms may be able to reduce the risks of ice jams, but the exact reduction of risk is indeed very difficult to predict, and could unfortunately be quite low. In addition, the distance over which the risks of ice jams would be reduced may be quite low, as ice jams could start forming again after as little as a hundred metres downstream of an ice berm.

Ranking of Options

Approach

There are many aspects to take into account, which renders this task challenging, and by no means final.

In order to provide a clear and defendable recommendation for the plan of action to put forward, the options must be ranked following the objectives set at the outset of the project. There are many different factors to consider when trying to determine which option is the most suited for the Truro area and a well-defined ranking system can help this process. The approach to determining the best option will be based on factors such as protection of life, infrastructure to support protection of life, lifecycle cost, or cost-effectiveness. Because the ranking is based on a combination of factors, the most appropriate option, or combination of options, may not be the option that costs the least, nor that reduces the flooded area the most, nor the option that is the most cost-effective. There are many aspects to take into account, which renders this task challenging, and by no means final. Nevertheless, in an effort to be fair to each aspect, various ideas were considered, and an approach was reached through discussions with the JFAC working group. The main sources of information that have been taken into account include:

- The ranking of priority areas obtained through coordination with the public and other stakeholders;
- The protection level provided by each option during each type of event - extreme rainfall, tide, sediment or ice levels obtained through the modelling effort;
- Both the initial cost of each option, and more importantly the "life cycle cost" of each option, which is the total cost needed to construct, operate and maintain a system of protection over the expected lifetime of the system, in today's dollar value. This means for example that if sediment removal is considered, the cost of removing sediment every year over 60 years will be compared with the cost of other options over the same time period;
- The value of the land protected. A necessary question is: "does it make sense to spend more money to protect land than the land is worth?”
- Environmental and permitting requirements: some options may have significant negative impacts on the environment. If so, they may have unsurmountable permitting challenges that would render the option unfeasible; and
- A "common sense" test which consisted of discussions of the various options with the JFAC, trying to be fair to each stakeholder, and also looking at the hard realities such as level of funding potential.

The considerations not discussed previously are presented in the sections below.

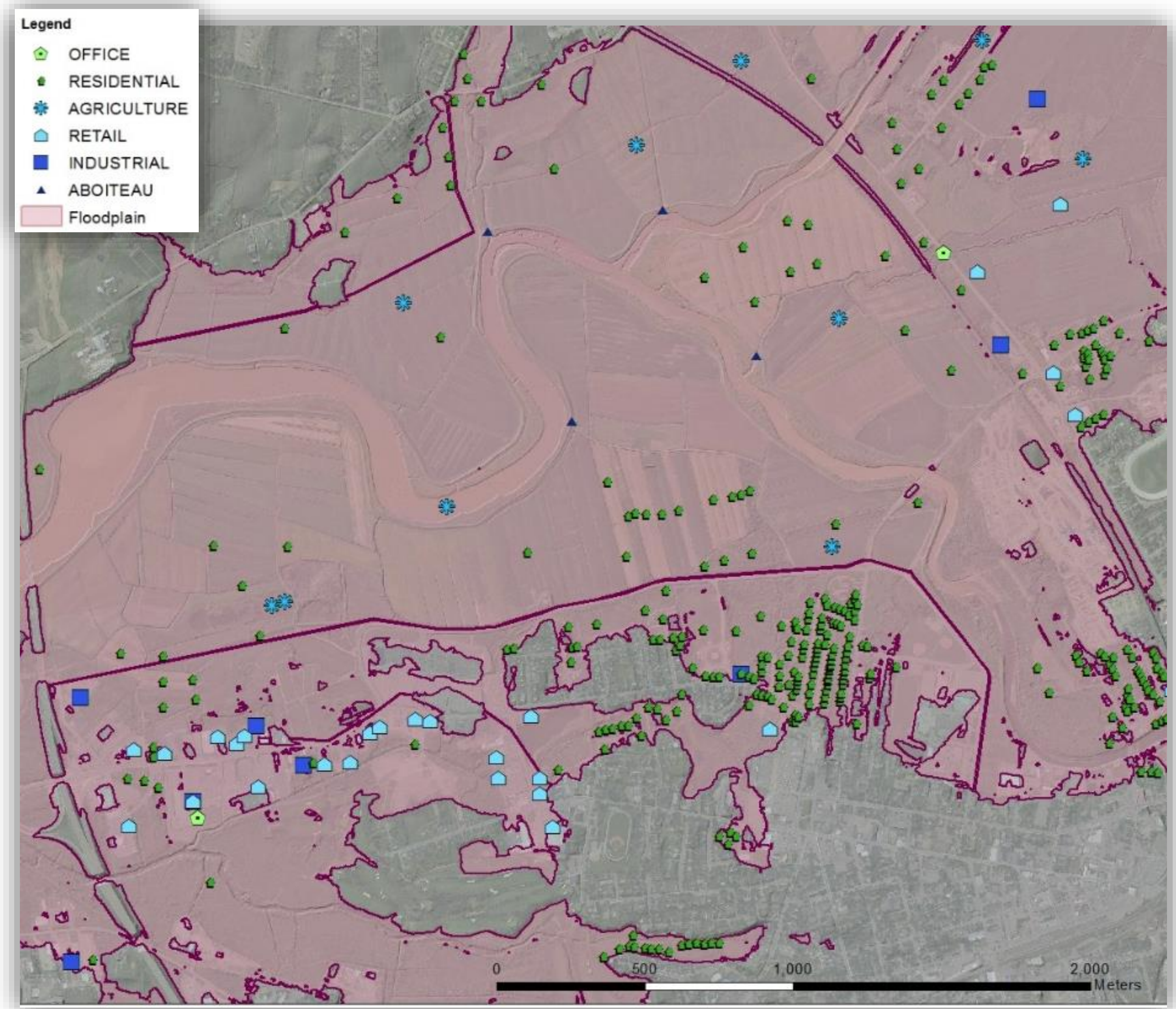
Environmental and Regulatory Considerations

The level of effort associated with obtaining regulatory approvals for flood protection options presented in this report varies depending on a multitude of factors. These factors include the presence of environmentally sensitive receptors, level of public interest, source of funding, land ownership and the nature of disturbance associated with the options.

For the purposes of this assessment, CBCL has provided a qualitative evaluation of the degree of regulatory approval requirements based on the nature of the disturbance for each adaptation option. The presence of environmentally sensitive receptors and public interest can greatly increase the regulatory permitting requirements as well as timelines, and should be further considered in selecting an option.

Protection of Vital Infrastructure

Based upon the various stakeholder consultations, a digital map of the vital infrastructure, ranked by the JFAC working group, was created using GIS. The vital infrastructure map includes points representing individual structures such as schools, hospitals, senior homes, etc. and areas of land used for agricultural, residential, industrial, commercial activities; etc. The maps also included lines representing roads, transmission lines, dykes and bridges. These features were intersected in GIS with each calculated floodline, with the objective of counting the number and types of flooded properties, and measuring the total length of roads, dykes, transmission lines and bridges that fell within each floodline. The graphic below shows an example of an intersection between various property types and one of the calculated floodlines. The difference in count of properties, structures and services that are flooded between existing conditions and a given flood mitigation measure shows which areas would no longer be flooded.



This provides a measure of the level of protection of various types of vital infrastructure, which can then be compared between each option.

Results

As mentioned above, it is critical to evaluate each flood mitigation option against a number of key criteria before making a selection. The major criteria considered are the following:

- The ranking of priority areas obtained through coordination with the public and other stakeholders;
- The protection level provided by each option during each type of event - extreme rainfall, tide, sediment or ice levels;
- Both the initial cost of each option, and more importantly the "life cycle cost" of each option, which is the total cost needed to construct, operate and maintain a system of protection over the expected lifetime of the system, in today's dollar value. This means for example that if sediment removal is considered, the cost of removing silt each year over 60 years will be compared with the cost of other options;
- The value of the land protected. A necessary question is: "does it make sense to spend more money to protect land than the land is worth?
- Environmental and permitting requirements: some options may have significant negative impacts on the environment. If so, they may have unsurmountable permitting challenges that would render the option unfeasible; and
- A "common sense" test which consisted of discussions of the various options with the JFAC, trying to be fair to each stakeholder, and also looking at the hard realities such as level of funding potential.

> There are more than 40 options included in this analysis, and each one has been tested against extreme rainfall, tide, sedimentation and ice events.

There are more than 40 options included in this analysis, and each has been tested against extreme rainfall, tide, sedimentation and ice events. In order to simplify the presentation of the results, they have been grouped into main types of flood mitigation techniques, including:

1. Constructing Aboiteaux to contain the extreme tides.
2. Raising the existing dykes to contain river floods.
3. Widening the dykes to restore some of the river floodplain to increase its capacity and reduce peak water levels upstream.
4. Removing sediments or improving the river section to increase its drainage capacity.
5. Widening and/or straightening the river to increase its drainage capacity.
6. Constructing a floodway bypass to double the drainage capacity of the river.
7. Reducing upstream flows through storage or infiltration.
8. Protecting specific areas at risk though measures such as localised dykes.
9. Protecting specific services at risk, such as raising roads.
10. Protecting specific areas at risk at the lot scale.

Each of those points is discussed in the following pages, with high level costing (Class “D”), and details of what the model results indicate. An assessment of the cost-effectiveness of each option is made, by comparing its ability to reduce flooding risks to the priority areas with its estimated cost. As previously described, the assessment of reduction in flooding risks is made using an average of the various 1 in 100 year events (from rainfall, tides, sediment and ice jams). Reducing flooding risks for smaller events (1 in 10 year events for example) would naturally require smaller measures, at a lower cost. There are, however, two issues that exist with designing flood protection measures for events that are smaller than the 1 in 100 year. First, the floodlines were found to be quite similar (perhaps 5% smaller for a 1 in 10 year event), meaning the cost savings would likely not be significant. Second, the residual risk of flooding would be quite high, which implies an increased risk to public safety, if the local population has an unfounded perception of increased safety during extreme events. It is therefore not recommended to carry out designs for events smaller than the 1 in 100 year event, unless they are progressive approaches, such as infiltration systems, as opposed to large structures, such as large berms.

Aside from those measures which involve engineering and infrastructure works, another approach would include the “do nothing” approach, where efforts are spent in recovery efforts, rather than preventative efforts. This is an important aspect to consider since as it stands, the County of Colchester, the Town of Truro and Millbrook First Nations do not endure costs for any flood damage that may occur within private properties. Incurred costs have only been related to emergency management support and have been low. It will therefore be important to consider the costs of potential flood mitigation measures with alternative approaches, in the wider context of long term budget planning.

Note on Potential for Power Generation

This idea has arisen several times, notably during the public meeting, and it has been investigated. Some of the elements that are favourable to generating power are certainly there, notably if water retention dams are constructed, or for aboiteaux for example, which regularly hold large amounts of water. There are, however, two main challenges: the first, with upstream storage dams, is that they are intended to only store water during extreme events, and as such, would only generate power at this time, which is an inconsequential amount of time.

The costs involved to generate power on a full time basis would involve a different type of structure, the costs of which could only be justified by the value of the power generated. As it stands, there is no opportune area within the watershed that would lend itself to a power generating project of sufficient returns.

The other main challenge would present itself if turbines are placed within aboiteau structures, within the tidal mudflats. This is an extremely harsh environment. Tidal power is currently being investigated in the Bay of Fundy, and even without the presence of constant fluid mud impacting the turbine mechanisms, the harshness of the environment is such that the necessary strengthening of the power generating equipment renders the potential returns very low.

If constant sediment accumulation and wear is introduced, the challenges would be even greater. As it stands, aboiteaux structures face the constant challenge of keeping tide gates operational, and this is a very simple mechanism.

Another approach that would not involve large capital works, but still provide a level of proactive effort to protect public safety, would be to focus on flood resilience. This approach would include elements such as education of the population at risk on floods, safety and recovery, it would include flood monitoring and forecasting, emergency planning, as well as support of recovery efforts.

1 - Constructing Aboiteaux to Contain the Extreme Tides and Storm Surges

This option is designed to protect the vulnerable areas from extreme tides and storm surges. The current network of dykes is designed to protect farmland from normal and spring tides, but not extreme storm surges. Constructing new aboiteaux and raising the associated dykes would hold back extreme tides and storm surges. There are, however, some remaining issues that are not resolved. The first one is associated with any aboiteau structure: If a tide gate is closed to hold back the tide, it also prevents freshwater from draining. Therefore, if it rains during a storm surge event (which is often the case), freshwater will build up behind the dyke and flooding will occur anyway.

If a tide gate is closed to hold back the tide, it also prevents freshwater from draining. Therefore, if it rains during a storm surge event, freshwater will build up behind the dyke and flooding will occur

The other issue is that it restricts the river flow: extreme rainfall events will now cause more flooding because of this restriction. It will also worsen the sediment buildup levels, meaning considerable sediment removal costs may be needed. With higher sediment levels, will also come a reduced drainage capacity of the river, which will therefore increase flooding risks. Finally, aboiteaux are prime locations for the formation of ice jams and therefore, flooding risks related to ice jams are also considerably increased. Permitting will also be very challenging and needless to say, the costs for any such structure will be considerable.

Three options have been investigated:

1. A causeway-dam-tide gate inside the Cobequid Bay (see *Aboiteau 1* in Appendix A)- *Est. $277M.*
2. An aboiteau at the Highway 102 location (see *Aboiteau 2* in Appendix A). – *Est. $53M.*
3. A "flushing aboiteau" at the confluence of the North and Salmon Rivers (see *Aboiteau 3* in Appendix A). – *Est. $25M.*

The first aboiteau was investigated because it was the preferred option noted in several reports in the 1970s. The model allowed us to investigate its potential merits, even though the drastic environmental impacts and permitting requirements would render this option unfeasible.

Unfortunately, even though it would indeed provide clear benefits in terms of a reduction in maintenance sediment removal, as well as lowering the river bed to increase its capacity, it did not help sufficiently in terms of reducing flooding risks from ice jams.

The second aboiteau (option 2) has the same function as the first one, except for the fact that the first one would allow more storage of stormwater before the upstream storage would fill up and cause flooding to occur. It was found that this additional storage only helped very marginally, with no notable difference. This is essentially due to the fact that rainfall-induced flooding occurs also when the tide is low, and is therefore not dependent on the downstream water level.

The "flushing aboiteau", or option 3, would reproduce what has been recently built in the Bay of the Mont-Saint-Michel in Normandy, France, to both offer protection from tidal flooding and lower downstream sediment levels. The system is designed with an automatic control that will keep the tide gate open to allow the tide to enter the river up to a certain level then close to hold back the water, and later open the gate at low tide to release the water and "flush" the sediment build up in front of the gate and downstream. The LaPlanche aboiteau, currently being constructed, allows a similar system to flush sediment build up, with the difference that the gate is manually operated, since power is not available at the site. The benefits of such a system can be very significant, since sediment removal conducted regularly to maintain drainage capacity in the Salmon River is very expensive (can reach $500,000 annually if both rivers have sediment removed). The flushing aboiteau would therefore be able to protect areas upstream of it from extreme tides and storm surges, and reduce flooding risks downstream by allowing the river channel to have additional capacity to drain peak flows.

This innovative idea was tested with the model as well. Unfortunately, even though it would indeed provide clear benefits in terms of a reduction in sediment removal costs, as well as lowering the river bed to increase its capacity, it did not help sufficiently in terms of reducing flooding risks from ice jams. Those would be clearly more frequent at this location, which would increase flooding risks in vulnerable areas. In addition, there is a safety concern associated with sudden high flows at unexpected times in areas that are accessible by the public.

For those various reasons, the aboiteaux options were not considered viable and not further investigated.

2 - Raising the Dykes to Contain Floods

Variations of this option have been investigated:

1. Raising all the dykes by 1m (see *Raise Dykes 1* in Appendix A). – *Est. $20.5M.*

2. Raising all the dykes as high as needed to contain the river's highest water levels (see *Raise Dykes 2* in Appendix A). – *Est. $94M.*
3. Raising all the dykes as high as needed, and pump the drainage accumulating behind the dykes (see *Raise Dykes 3* in Appendix A). – *Est. $300M.*
4. Construct new dykes upstream of the CN Bridge on the Salmon River (see *Raise Dykes 4* in Appendix A). – *Est. $60M.*

These options offer notable flood reduction potential that is roughly proportional to their cost. Indeed, *Raise Dykes 3* offers one of the highest levels of protection of the priority areas (30% during the 1 in 100 year event – *Raise Dykes 2* produces a 15% reduction) of all the options investigated, but it is also one of the most expensive ones. There are also other challenges associated with this option, including specialised engineering to design 6 m high dykes in some areas, raising bridges, and dealing with the risks of such infrastructure failing. Very large pumping stations will have to be operated and maintained at a high cost.

The other options (*Raise Dykes 1* and *Raise Dykes 4*) are more easily achievable, although they offer lower levels of protection (7% and 0.3%). When compared to other options, *Raise Dykes 4* is not very cost-effective, and even though *Raise Dykes 1* is very cost-effective, it only allows the protection of 7% of the priority areas. If this option is expanded to *Raise Dykes 2* or *Raise Dykes 3*, the costs will balloon and cost efficiency will drop sharply. This means that the general approach of raising the dykes is not a cost-effective long term solution.

3 - Widening the Dykes to Restore some of the River Floodplain

This option, not mentioned in previous reports, investigates the idea that the river needs its natural floodplain to carry extreme flows to the ocean. Although some of the river's floodplain is developed, most of it is used by farmland. This option would therefore involve purchasing farmland to move the dykes further out from the river.

A first set of options was investigated, consisting of widening the dykes by only 5m. This allows most of the land use to remain, and to test the theory that the river is constricted in specific areas, that widening those "choke points" would reduce overall flooding. As such, *Dyke Widening 2* (*Est. $4M*) involves widening the dykes on the North River upstream of the CN Bridge, and Salmon River upstream of Park Street by 5m, and *Dyke Widening 3* (*Est. $27M*) involves widening all the dykes by 5m. It was found that those options provided very little benefit to reducing the flood risks to the priority areas: *Dyke Widening 2* increased the flooding as it allowed flows to reach the priority areas faster, while *Dyke Widening 3* reduces the flood risks to the priority areas by 1%.

The second set of options investigated involved moving the dykes further out in the main floodplain areas, and reconstructing them in generally straight lines on the outside of the river meanders. *FloodPlain Restoration 4* (constructing new, wider dykes to supplement the existing ones - *Est. $22M*), *FloodPlain Restoration 1* (removing the existing dykes- *Est. $20M*), *FloodPlain Restoration 3* (adding pumps- *Est. $113M*) and *FloodPlain Restoration 2* (adding dykes and pumps in McClures Brook as well- *Est. $99M*) all follow gradual steps in reaching the highest flood protection potential for this approach. This approach is indeed generally simple, achievable, provides a high level of protection (2%, 5%, 21% and 29% for the four steps), but is still very expensive, as it involves reworking very large quantities of material, and constructing expensive pumping stations that require maintenance.

4 - Removing Sediment or Improving the River Section to Increase its Capacity

Dredging 1 – (Est. $10.5Bn) in Appendix A shows removing sediment along the whole river to reduce its bed level by 1m. As can be imagined, this option is extremely expensive, especially since this work would have to be carried out twice a year. If this cannot be allowed because of permitting restrictions, it would need to be carried out more extensively once a year, and this would allow increased risks of flooding in the Spring to exist. Discussions with County river restoration consultants showed that each tide can bring as much as 2 inches of sediment following sediment removal efforts. Indeed, even with 30% reduction

Discussions with County river restoration consultants showed that each tide can bring as much as 2 inches of sediment following sediment removal efforts.

in flooding of the priority areas (this option is effective), its cost amounts to several billion dollars over 60 years.

Dredging 2 – (Est. $3Bn) involves "river channel restoration", which is applying an "optimised" river section by moving material, and generally narrowing and deepening the river, roughly between the channel confluence and up 2km in the North and Salmon Rivers respectively. This option, even though less expensive on a one-time basis, is still in the billions of dollars over 60 years, even though it does carry some flood reduction merits (5% reduction of flooding of the priority areas).

5 - Widening and/or Straightening the River to Increase its Drainage Capacity

This type of option involves significant sediment removal and earthworks to create a new, much wider channel, in the hope that it may have flood reduction benefits. This option was tested by widening the river bed to 400m of width past its confluence with the North River, and 100 m of width upstream of this (*Dredging 3- Est. $210Bn*). It is noted that this option does not involve lowering the river bed, and as such, tested the viability of providing more capacity through widening the river rather than deepening it. Purely widening the river, and maintaining its original alignment (*Dredging 3*), would only provide a 1% reduction in flooding of the priority areas, which makes this option quite unattractive in light of its astronomical cost. However, widening and straightening the river (*Dredging 4 - Est. $175Bn*) would provide a 20% reduction in priority areas that are flooding. This is a very interesting finding, as it shows that slope has a lot more influence than width for the river drainage capacity. Nevertheless, the volumes of earthworks involved are so large that the costs are extreme. To make matters worse, the river will naturally revert to its original shape and width, by allowing the tides to bring back the sediment in the channel. This renders these two options the most expensive of all those investigated.

A much smaller version of this was tested just between the CN Bridge and Main Street on the Salmon River (*Dyke Widening 1- Est. $12M*). The river was widened by 10 m at the point where it is considered to cause the highest restriction. The model showed that this option generated an increase in flooding to the priority areas (by 5%). The reason for this is that it allows water to flow faster towards floodplain area, and therefore worsens its flooding risks.

6 - Constructing a Floodway bypass to Double the Drainage Capacity of the River

A floodway bypass channel was built in Winnipeg and effectively reduces flooding risks, albeit at a high cost (~$700M). A similar idea was brought forward to see what benefits it could bring. Unfortunately, the topography around the developed area does not allow floodways to bypass the developed area, but a floodway can exist beside the main branch of the Salmon River to increase its capacity during floods. A 100m wide floodway was therefore tested with the models, from the Stanfields' Plant to the McClures Aboiteau (*Floodway By-pass 1-Est. $25M*), then to just past the Wastewater

Red River Floodway, Winnipeg

Treatment Plant (*Floodway By-pass 2-Est. $32M*) and then to Lower Truro (*Floodway By-pass 3-Est. $39M*). The ability of these options to protect the priority areas is not very high, but is notable, at (9%, 13% and 15% respectively). These options are also among the highest ranked in terms of cost-efficiency.

Although the floodway would add more flow capacity to the river beyond Park Street, the floodway would eventually merge back into the main river channel downstream. At this confluence, there may be a significant restriction, particularly when there is a high tide, which cause the water levels in the main channel to be significantly higher than in the floodway. If the water in the floodway cannot flow back into the main channel, then it will back up and eventually breach the banks of the floodway, causing flooding. Based on this restriction, the *Floodway By-pass 1* was modified by extending the floodway by-pass further downstream. Although there was some improvement in the ability to protect the priority areas, the protection results are still quite limited.

One disadvantage of the floodway is that without flow control structures at the inlet and outlet of the floodway, the floodway would actually allow extreme tides to back-up the floodway and increase flooding as a result of extreme tide levels. These flow control devices or gates could be either manually opened or be automatic, based on when the water reaches a certain level. These control gates would require regular maintenance and replacement to ensure that they are fully functioning. They could also take the form of a narrow earthen berm, designed to fail when overtopped, which would not require any action from an operator during a storm event.

The advantage is that the cost of this is lower than many other options, and its cost-effectiveness is therefore quite high. Its cost is not as high as other options because the floodplain elevation is already very low, and a reasonable amount of excavation would be needed to bring it to the same general elevation as the river. Depending on the consistency and quality of the excavated material, it may be suitable for re-use to build new dykes and repair existing dykes.

7 - Reducing Upstream Flows through Storage or Infiltration

> If implemented as part of planning and building permit approval regulations, the incremental cost can be minimal, with significant improvements.

This is a different kind of approach, wherein floods are reduced by reducing flows. This is a common stormwater management approach, and can sometimes be very effective to control floods, typically in small watersheds. The topography of the watersheds was investigated to identify opportunities for storing water, and 10 locations were identified. Beyond this, storing water would become much less cost-effective. *Runoff Reduction 1 -Est. $14.5M* involves constructing 10 detention areas (dams), and reduces flooding of priority areas by only 2.4%. *Runoff Reduction 2-Est. $3.7M* involves detaining water only in Farnham Brook, and is 0.2% effective. The reason for this is that Farnham brook is very impacted by downstream flooding. Reducing flows in Farnham Brook will not reduce the water backup from the main floodplain. Other alternatives involve constructing storage along McClures Brook (*Runoff Reduction 3-Est. $5M*), or within the Millbrook watershed (*Runoff Reduction 4-Est. $0.8M*). Those options are more effective (1% of priority area flood reduction each), as they target smaller watersheds. In particular, since implementing storage in the Millbrook watershed is relatively inexpensive, this option carries the highest cost-benefit of all the options investigated, and is therefore clearly recommended for implementation.

In general, constructing dams is very expensive, and carries significantly adverse environmental impacts, not to mention residual risks, should those structures fail. More cost effective and efficient, are the smaller storage options. The most cost-effective option, which is clearly recommended for implementation, is the construction of storage areas within the Millbrook watershed.

An alternative approach to reducing flows is to infiltrate stormwater. This is a natural process, and one that has been tampered with through development of the watershed. Stormwater Best Management Practices can restore the natural (pre-development) hydrologic balance of infiltration vs rainfall, by constructing infiltration areas, permeable surfaces, perforated pipes, etc. The potential for retrofitting all the current development (*Runoff Reduction 5-Est. $2.7Bn*) was investigated, and was found to have a very high potential for flood reduction (38%

reduction in flooding risks of priority areas), in fact the highest of all options outside of purchasing, raising of moving all flooded properties. It is noted that this value would be higher for rainfall events with lower return periods (e.g. 1 in 2 years), as more rainfall volume will be able to infiltrate. Flooding resulting from extreme tides, or ice jams, would likely not change notably, however. Retrofitting applications would include for example replacing all stormwater pipes with perforated pipes, having all parking lanes surfaced with permeable pavers, and having each private lot fitted with a rain garden, or infiltration gallery that promotes infiltration of as much rainfall as possible. This can start very simply, by implementing a program of roof downspout disconnection, to be re-directed to a green space. Unfortunately, if implemented immediately, its cost would be prohibitive. However, if implemented as part of planning and building permit approval regulations, each time any modification is made, or a new construction is made, the incremental cost can be minimal, with significant improvements. This approach is therefore a first recommendation, to be implemented wherever possible, whenever the opportunity presents itself. In fact, since stormwater Best Management Practices can take many shapes and forms, it is recommended that a study be conducted to identify the best opportunities currently available, and optimise their implementation with planned capital works programs, for the County, the Town and the Millbrook community. A summary of suitable stormwater Best Management Practices is presented in the recommendations chapter.

8 - Protecting Specific Areas at Risk through Measures such as Localised Dykes

As mentioned above, there may be opportunities in protecting specific areas at a lower cost. This is true when upstream watersheds are small, and the area to protect is not affected by the main urban floodplain, such as in Millbrook for example. Other options to protect specific areas include increasing culvert capacities in Millbrook (*Additional Infrastructure 9 - Est. $2.5M*), although this option ends up increasing the flows to the main floodplain and increasing flooding of the priority areas by 2%, which is not acceptable.

Other options to protect specific areas include increasing culvert capacities in Millbrook (*Additional Infrastructure 9*), although this option ends up increasing the flows to the main floodplain and increasing flooding of the priority areas by 2%, which is not acceptable.

Upsizing the McClures Aboiteau (doubling its capacity) reduces flooding risks to priority areas by only 0.22% (*Additional Infrastructure 1-Est. $8M*), and also doubling the capacity of the highway 236 culvert (*Additional Infrastructure 2 - Est. $23M*) reduces flooding of the priority areas by only 0.23%. This points to the fact that the main restriction is the high water level on the other side of the aboiteau, which blocks completely any drainage from the brook when the aboiteau gate is closed. Upsizing the downstream culverts will improve drainage, but only marginally reduce the flooding in McClures Brook. If debris accumulation is an issue, however (this was not tested in the model), then upsizing the culverts will have clear improvements as it will lessen the risks of blockage of the structures.

Protecting the Elizabeth St area, and the residences along Riverside Ave and Avon St, including Stella-Jones Inc. (*Additional Infrastructure 8 - Est. $42M*), with berms will provide an efficient solution (9.8%), even if pumping the upstream drainage is somewhat expensive. *Additional Infrastructure 3 (Est. $2M)* involves burying the watermain that is protruding in the river bed by 0.75m by the Bible Hill Bridge, has a relatively low cost, and reduces flooding of the priority areas by 0.1% during the 1 in 100 year event.

Another measure that works effectively in New Orleans is to construct large pumping stations to push the river water out to the ocean. This was investigated with the model, with very large pumping stations (350 m^3/s) at Park St and at the river confluence (*Additional Infrastructure 5 - Est. $135M*), and also with one additional, even larger (600 m^3/s) pumping station at the Highway 102 (*Additional Infrastructure 6 - Est. $246M*), to push the water again further down. Interestingly, both those options only reduce flooding to the priority areas by 0.2%. Their cost is evidently prohibitive, not to mention the operational cost related to the extremely severe environment those pumps would be under.

An interesting option that has been discussed many times over the years is the construction of ice control berms (*Additional Infrastructure 7-Est. $9M*). These would take the form of a causeway over the floodplain, with large steel piles filled with concrete, with 2m of spacing between them, within the river. This would limit the size of blocks of ice that can move downstream, and greatly encourage the formation of ice jams at this location, reducing the risks of downstream ice jams. As mentioned previously, however, the potential for ice jams at other locations is still very high, and the reduction in overall risk is so low that it renders this option difficult to justify.

9 - Protecting Specific Services at Risk, such as Raising Roads

Raising Park Street above the peak water levels has been discussed many times, and may be the most preeminent subject of debate every time it floods. Raising a street that is placed in the middle of an active floodplain has evident consequences, however.

Example of road raised above the floodplain and dyke system – (Red River, Vietnam)

Park Street essentially cuts across the whole floodplain of the Salmon River. It is built just enough above ground level to drain the rain during small rainfall events, and the only raised part of Park Street is at the bridge over the Salmon River. It is kept purposely low in order to allow the floodplain to continue to drain the large floods away and avoid increasing flooding risks upstream. There has been much public pressure to raise the road so that it can remain open during flood and ice jam events. However, raising this road may not provide the benefits that are expected. A road that is raised simply using fill and no culverts will essentially act as a dam along the floodplain and will restrict flows, causing increased flooding in upstream areas. The increase in flooding risks is especially great on the south side of the bridge due to the very close proximity of the residential area and the CEC High school. On the North side of Park Street Bridge, the water flows in both directions (east and west) because the Farnham Brook Aboiteau allows water to accumulate and flow back along the dyke towards Park Street. Later on during large storm events, the flow in the Salmon River will keep increasing, and push the water back over Park Street towards the downstream side.

In order to reduce the upstream flooding risks caused by raising the road, the option of installing culverts that allow drainage of the total floodplain flows was investigated (*Additional Infrastructure 4 - Est. $20M*), but since the opening would be narrower than the current floodplain width, there would still be an increase in flooding of the priority areas (by 10.4%). This number is especially high because in addition to restricting the flow of water compared to the full floodplain, culverts would greatly increase the risks of ice jams at their location and consequently increase upstream flooding during winter storms. Having a high cost, and being the option that increases risks of flooding the most (out of all the options analysed) to the priority areas, it is strongly recommended to not implement this option.

In other areas around the world where the floodplain is a critical part of the flow capacity during extreme events, bridges can be constructed over the full span of the floodplain. This is the case in the example shown above along the Red River system in Vietnam. A bridge over the full 1.2 kilometers of Park Street would prevent Park St from being flooded and allow the floodplain to maintain its function, allowing the flow to pass unrestricted. The option of raising Park Street by converting the whole street between Marshland Drive and the CN rail to a bridge would also be one of the only solutions that would not increase flooding risks upstream (besides removing Park Street). Unfortunately, the cost of this is very high (~60 million) and would serve the purpose of protecting only one street, which means the cost effectiveness of this option is very low.

January 08, 2014 – Photo from the Truro Daily News

A driver who had recently moved from Ontario found himself stranded on Park Street during a winter storm. The option of raising Park Street and converting it to a bridge over the whole floodplain (1.2km) would be one of the only solutions to protect Park Street and not increase flooding risks upstream.

10 - Protecting Specific Areas at Risk at the Lot Scale

This approach involves selecting a number of the highest priority areas, and focusing protection measures specifically at their locations. Protecting the three highest priority areas would involve raising the school, senior homes and hospitals (as well as Park St in the residential areas for access), and include drainage culverts (*Priority*

Area Protection 1 – Est. $100M). As noted above, raising Park St and constructing culverts increases flooding to all the upstream areas. Even though the high priority areas would be protected, this option is therefore not encouraged.

Raising priority areas 1-4 (*Priority Area Protection 5– Est. $158M*) also includes residential areas, which has the benefit of protecting the residential areas that were at increased risk upstream of Park Street, and therefore provides a high level of protection of the priority areas on average (66% reduction in areas at risk). The various approaches investigated to protect the residential areas are listed below:

- *Priority Area Protection Option 5 (Est. $158M)* includes placing fill on residential properties and raising individual homes*;*
- *Priority Area Protection Option 6 (Est. $190M)* includes purchasing the individual homes at risk and removing them*; and*
- *Priority Area Protection Option 7 (Est. $190M)* includes physically moving homes at risk to safer areas.

If priority areas from 1 to 8 are protected, this will now involve the protection of the main road arteries and all offices, commercial and industrial areas at risk, with the various approaches to protecting residential properties as listed below:

- *Priority Area Protection Option 2 (Est. $182M)* includes placing fill on residential properties and raising individual homes*;*
- *Priority Area Protection Option 3 (Est. $220M)* includes purchasing the individual homes at risk and removing them*; and*
- *Priority Area Protection Option 4 (Est. $220M)* includes physically moving homes at risk to safer areas.

With Priority Area Protection Options 2, 3 and 4, the protection level increases to 79%. In general, these approaches are the most cost-effective, mostly since they can offer protection in areas where no other option is available or feasible. Even though options 2 and 5 are the most cost-effective (besides implementing stormwater infiltration measures over time) they are still extremely expensive. The other issue with those options is that they involve infilling in the floodplain. This causes a disturbance to the natural system, and restricts the natural river floodplain. Erosion risks will constantly remain, and will constantly threaten the areas that are raised. In addition, if a storm of greater magnitude (1 in 200 year event for example, which has a 0.5% change of occurring in any given year) occurs, the areas that have been raised will be again at risk of flooding. For those reasons, it is recommended that if priority areas are to be specifically protected, residents should be moved out of the floodplain. Businesses are less concerning, since they are workplace areas and people do not sleep in those areas. Furthermore, recovery of business areas following a flood is much quicker than recovery of homes, since there is typically less structural damage, basements are not involved, and financial resilience is much greater.

Preferred Options

An initial ranking was produced that takes into account the average protection of the priority areas by each option, divided by its cost, which represents a "cost effectiveness in protecting the areas that need to be protected".

Through the review of the various options considered above, it was found that in general, there is no clear winner, and significant challenges exist with any of the options available. Any measure that protects more than 20% of the priority areas costs more than $100M, and involves infrastructure that needs maintenance in order to stay effective.

This explains why it has been very difficult for the local governments to identify and implement flood protection measures, even after centuries of flooding history.

In addition, with flood protection infrastructure, the risk of failure always remains, through an event that is greater than the design event, an unexpected flaw, or lack of knowledge/experience with such infrastructure.

The only options that do not involve this residual risk are implementing stormwater Best Management Practices that infiltrate rainfall into the ground, or moving residents away from the floodplain.

Otherwise, options that involve berms and earthworks that allow an increase in channel capacity tend to be cost effective in protecting the priority areas. The testing of many options has showed that one of the principal causes of flooding is the inability of the water to drain fast enough away from the floodplain. The vast watershed brings a tremendous quantity of water to the floodplain during extreme rainfall events. Furthermore, since it takes more than a day for the water to drain, the tides inevitably interact with the flood, and slow the drainage process even more. As a result of the water's inability to drain, it accumulates and rises, causing extensive flooding.

However, the priority areas that encroach on the river floodplain mostly lie on its outer boundary, and therefore berms that provide local protection to those areas would not reduce the floodplain by a significant amount (this type of option can provide up to 28% of flood reduction to the priority areas).

Similarly, a floodway bypass that would increase the capacity of the river for a lower cost than other options also involves earthworks and berms, although the maximum level of protection provided to priority areas only reaches 15%. Such measures are typically the most common types of flood protection measures in a floodplain.

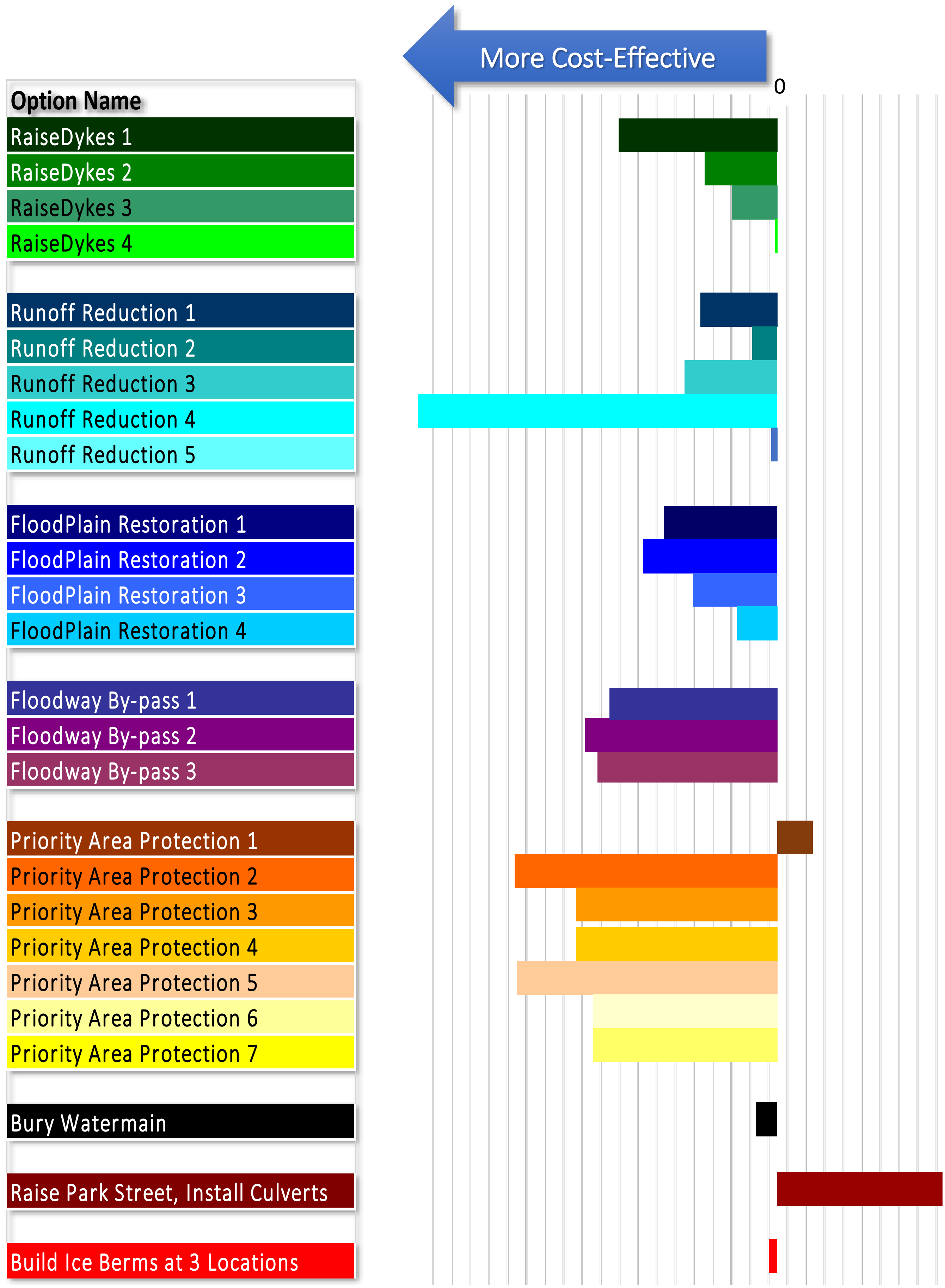
Raising the existing dykes will increase flood protection at first, and can provide 7% of reduction in flood risks to the priority areas with a 1m increase in dyke height, for a similar cost-effectiveness. Raising the dykes further, and adding pumps behind the dykes (which is a common approach) will significantly reduce the cost- effectiveness of this measure, which will reach an estimated $300M to protect only 30% of the priority areas.

An initial ranking was produced that takes into account the average protection of the priority areas by each option, divided by its cost, which represents a "cost effectiveness in protecting the vulnerable areas that are most important to the stakeholders". The most effective options are presented below.

Option Name	Option Description	Cost Effectiveness	% Protection of Priority Areas	Net Cost	Recommend?
RaiseDykes 1	Raise all Dykes by 1 m	0.34%	7.0%	$M 20.5	
RaiseDykes 2	Raise all Dykes (Varied Height) to Contain all River Flood	0.16%	14.6%	$M 93.4	
RaiseDykes 3	Raise all Dykes (Varied Height) to Contain all River Flood & Pump Drainage from Behind Dykes	0.10%	29.6%	$M 300.0	
RaiseDykes 4	Build Dykes Upstream of CN Bridge to Protect Elizabeth St	0.01%	0.3%	$M 60.0	
Runoff Reduction 1	Upstream Dams: North River, Salmon River, Farnham Brook and McClures Brook	0.17%	2.4%	$M 14.5	
Runoff Reduction 2	Upstream Flow Control Dams on Farnham Brook	0.05%	0.2%	$M 3.7	
Runoff Reduction 3	Construct Six Dams in McClures Brook to Reduce Flooding in McClures Brook	0.20%	1.0%	$M 5.0	
Runoff Reduction 4	Construct 1 Dam in Millbrook Area Upstream of Willow St Culvert	1.20%	1.0%	$M 0.8	Recommended
Runoff Reduction 5	Implement BMPs to Reduce Runoff to Pre-Development Conditons	0.01%	38.4%	$Bn 2.7	Recommended, but through policies and by-laws
FloodPlain Restoration 1	Widen Dykes to Larger Floodplain	0.24%	4.9%	$M 20.3	
FloodPlain Restoration 2	Widen Dykes to Larger Floodplain, Add Dykes to Reduce Flooding in McClures Brook & Pump	0.29%	28.6%	$M 99.0	Recommended
FloodPlain Restoration 3	Add Wider Secondary Dyke System to Existing Dyke System (to Maintain Protection of Farmland)	0.18%	20.5%	$M 113.0	
FloodPlain Restoration 4	Widen Dykes to Larger Floodplain & Pump Drainage from Behind Dykes	0.09%	1.9%	$M 22.0	
Floodway By-pass 1	Floodway Bypass Channel - 100m Wide to McClures Brook (4.3km)	0.36%	9.0%	$M 25.0	Recommended
Floodway By-pass 2	Floodway Bypass Channel - 100m Wide - Extended to the WWTP (6km)	0.41%	13.2%	$M 32.0	
Floodway By-pass 3	Floodway Bypass - Extended to Lower Truro (7.75km)	0.39%	15.2%	$M 39.0	
Priority Area Protection 1	Raise Priority Areas 1 -3 to Elevation 13m	-0.08%	-7.7%	$M 102.0	Recommended where other measures cannot help
Priority Area Protection 2	Raise Priority Areas 1-8 to Elevation 13m	0.56%	79.0%	$M 182.0	
Priority Area Protection 3	Raise Priority Areas 1-8 (excluding Residential) & Purchase and Remove Residential Properties	0.43%	79.0%	$M 220.0	
Priority Area Protection 4	Raise Priority Areas 1-8 (excluding Residential) & Physically Move Residential Buildings	0.43%	79.0%	$M 220.0	
Priority Area Protection 5	Raise Priority Areas 1-4 to Elevation 13m	0.56%	66.0%	$M 158.0	
Priority Area Protection 6	Raise Priority Areas 1-4 (excluding Residential) & Purchase and Remove Residential Properties	0.40%	66.0%	$M 190.0	
Priority Area Protection 7	Raise Priority Areas 1-4 (excluding Residential) & Physically Move Residential Buildings	0.40%	66.0%	$M 190.0	
Additional Infrastructure 3	Bury Watermain Just Upstream of Bible Hill Bridge	0.05%	0.1%	$M 2.1	Recommended
Additional Infrastructure 4	Raise Park Street, Install Culverts	-0.53%	-10.4%	$M 19.5	
Additional Infrastructure 7	Build Ice Berms at 3 Locations	0.02%	0.2%	$M 9.1	

OR

Summary table of the most effective options



Cost-effectiveness of the most effective options

The cost effectiveness of the options is a good initial measure of comparison. The most cost-effective of all the options is to implement storage in the Millbrook area to control flows and address local flood issues. This is therefore recommended for implementation. The other solution that has a very low cost and high benefit is implementing infiltration systems as a continuous effort at any time when surfaces (roads, sidewalks, parking lots) are repaired or renovated, as well as disconnecting all roof downspouts from foundation drains (even if they are connected to the sanitary sewer, an overflow will occur somewhere and flows to the river are increased). This is recommended for implementation through planning, storm water regulations and building permit approval regulations, and is discussed further in the recommendations section. From here, it is still necessary to look at the bigger picture. There is a fundamental issue with the decision to spend many millions of dollars on an option that would protect less than half of the areas identified as priorities, and that is not able to extend any further to offer more protection. As demonstrated in the graph above, the cost of the vast majority of options far exceeds the value of the land protected.

The only alternative that can protect more of the priority areas (up to 66%), as well as being cost effective (its cost is estimated at approximately $167M) would be to purchase the residences at risk at fair market value, or move them physically (estimated to have a similar cost). This would also involve raising the land around the CEC school (CEC, Legion, Food Bank, Children's aid Society and Family Services, and Institute for Human Services Education), and raising Park Street with culverts. The main advantages of this approach are that it will offer permanent protection with no residual risk to residences, and that it does not affect the floodplain area. Essentially, residential development is taken out of the floodplain, while the essential services (access roads) are maintained. The main challenge, however, is that it involves moving people out of their current homes. This is likely to be a very difficult issue to resolve, since those living in the area have been aware of flooding risks since they moved in, and have been willing to continue to live in the floodplain since. Perhaps the financial incentive will make a significant difference, but it is expected that some homeowners will not be willing to move out. Moving out should therefore be proposed to be on a voluntary basis. The problem will then be that some homeowners will still be at risk, even if they are fully aware of the risks they are taking. This will not be very different to the current situation, where those at risk are aware of those risks, and have made the decision to stay. If the goal is to protect public safety during flood events, this option will not be as effective in some areas as protection provided by a berm or dyke.

As such, the preferred infrastructure option for flood protection is the combination of *FloodPlain Restoration 2* and *Additional Infrastructure 8*: Widen dykes to restore most of the natural floodplain, add dykes to reduce flooding in McClures Brook & pump, as well as protecting the Elizabeth Street subdivision and the residences along Riverside Avenue and Avon Street, including Stella-Jones Inc. through berms and pumping stations. Maps 12-1 to 12-4 show the benefits of this option during the 1 in 2 year and 1 in 100 year event, as well as the floodway bypass option for comparison. Residences that are not protected by this option could then be purchased or moved as part of a subsequent plan.

Even though this would be the most effective overall infrastructure approach, it is noted again than the cost of those measures is immense compared to the currently available resources, and such an approach may simply be unrealistic. Flood preparation and flood resilience may be more appropriate tools in this instance. This would involve methods such as education, emergency preparedness, flood forecasting, flood-proofing, and flood recovery efforts.

Discussion of the Results

This analysis has involved the following main steps:

- Detailed review of past reports and analyses;
- Thorough stakeholder consultations;
- The preparation of a list of vulnerable areas ranked by priority to the stakeholders;
- Detailed modelling assessments of each of the main causes of flooding;
- Conceptual design and modelling of more than 40 flood mitigation options;
- Evaluating the ability of each of those options to protect the ranked priority areas;
- Estimating costs for each of those options, and establishing the cost-effectiveness of protection for each option;

- Identifying the options that are the most cost-effective, protect the most vulnerable areas, are achievable with current technologies and realistically constructible, and leave as little residual risk as possible; and
- Preparing pre-design level drawings of the preferred infrastructure option.

A responsible approach to this situation is to start acting immediately on aspects that are achievable today.

Through this vast review, consultation, analysis and design effort, has emerged a preferred infrastructure flood mitigation option, albeit at an extreme cost. Even being far beyond any amount of funding that the JFAC might be able to provide without federal resources, it only provides protection to approximately 38% of the areas that need protecting the most. Whether the funding becomes available in the next few years, or decades, or not, is a real question that needs to be weighed carefully. In the meantime, Truro will flood once or twice per year, placing lives and livelihoods at risk each time.

A responsible approach to this situation is to start acting immediately on aspects that are achievable in the near future. Immediate needs are perhaps not best met with a plan for a large capital works project, to be finalised sometime in the distant future. Residents need to feel safer by seeing a plan that is implemented in the short term, and need to feel supported in their struggle to recover each time they flood. There are aspects of a community's emergency management plan and emergency recovery plan that can be implemented with resources that are currently available. Even though these actions may not provide any extensive flood protection value to infrastructure, they can be implemented immediately and certain measures can make a large difference and help improve the safety of the residents. The follow sections in the report will provide details on the following emergency management measures:

- Education of the residents on the current situation with regards to options that alleviate flooding risks – this can be done with the help of this report and with the help of the sources recommended in this report;
- Awareness of the flooding risks – this can be done by publicising the flood map extents from the 1 in 2 year event to the Probably Maximum Flood event;
- Reviewing and updating the Emergency Preparedness Plans;
- Studying and Implementing a flood warning system – even though only hours are available between extreme rainfall, tides or ice jams and extreme water levels, a web-based system, in conjunction with radio-broadcasted warning, should be developed to warn people of imminent floods;
- Installing a network of rainfall gauges and water level systems to support the flood warning system and allow better understanding of floods in future efforts;
- Information on flood-proofing measures at the lot scale. Homeowners should have easy access to information helping them to protect their safety and valuable assets; and
- A flood resiliency program whereby a portion of flood-proofing costs are eligible for subsidy.

It is therefore recommended that such measures be implemented, as they are a fraction of the cost of the structural flood mitigation measures, and will make a measurable impact in helping the local population face, accept, prepare for and become more resilient to flooding risks. Further details on those measures is provided below.

Recommendations for Stormwater Best Management Practices

One the most efficient ways to deal with flooding risks is to manage the issue of high runoff at its source. Flooding is only amplified when runoff is allowed to increase, and infiltration of water into the ground is decreased. Most often, development allows this to happen and therefore increases flooding risks. The more water is encouraged to infiltrate in the ground, the more the high water levels are controlled, and the more the overall river health is protected. Stormwater Management has the following benefits for the river, the riverine residents, the overall watershed community and the Town and County:

- Decreases flooding risks and entailed risks to infrastructure, land value, liability and public safety;
- Decreases peak flows, resulting in smaller infrastructure costs;
- Aquifer recharge, reducing the strain on water supply sources;
- Reduces pollution to drinking water supplies, recreational waters and wetlands, saving future expenditures for restoration of valuable water resources;
- Protects water quality and increases low flows in the river, enhancing fish habitat in this uniquely valuable river system;
- Reduces energy costs by constructing new green roofs or retrofitting existing roofs; and
- Through the above results, improves the quality of life and increases property value.

A more concentrated (cluster) subdivision design, with less impervious area and smaller infrastructure (stormwater drainage and other utilities), also means significant cost savings to developers (who will therefore show less resistance in implementing this type of design) and reduces maintenance costs to the Town and County.

These aspects show that even if the original target for stormwater management is the reduction of flooding risks, there are a host of other associated benefits to the overall community, which all contribute to more sustainable development. This makes stormwater management through Low Impact Development (LID) and Best Management Practices (BMPs) an important recommendation for implementation at the planning and by-law levels in the Town and County.

Stormwater management is no longer an innovative or rare approach. It is now very well understood and implemented in a majority of communities across North America. There is a multitude of very-well researched documents describing comprehensively how-to approaches to Low Impact Development (LID) from the planning level to the lot development stage, including retrofitting existing developments. This section of the report gives a summary of typical approaches in various settings from areas with proven records of successfully implementing LID and BMPs.

Emergency Management

It is recommended that the current emergency management plan be reviewed and updated to reflect the latest available information. The adjacent graphic shows a flow chart cycle for emergency management. One of the major components of the emergency management cycle is mitigation. As explained above, it may be more realistic to focus efforts on lot-scale mitigation efforts, rather than constructing large flood protection infrastructure. Mitigation efforts would therefore consist of the following types of measures:

- Basement flood-proofing;
- Adding sump pumps;

- Locally raising the ground by the foundation walls to help water drain away;
- Removing any items, surfaces, flooring, that may be damaged by water; and
- Leaving the basement unfinished, or using no more than coated concrete (with a polyurethane).

The following sections will discuss the various components of the emergency management cycle. These components can be implemented with low resources and can significantly improve the safety of the residents at risk. Examples of measures that could be applied directly in Truro are presented below, and include flood warning systems, emergency preparedness and flood proofing approaches at the lot level.

Flood Forecasting and Preparedness

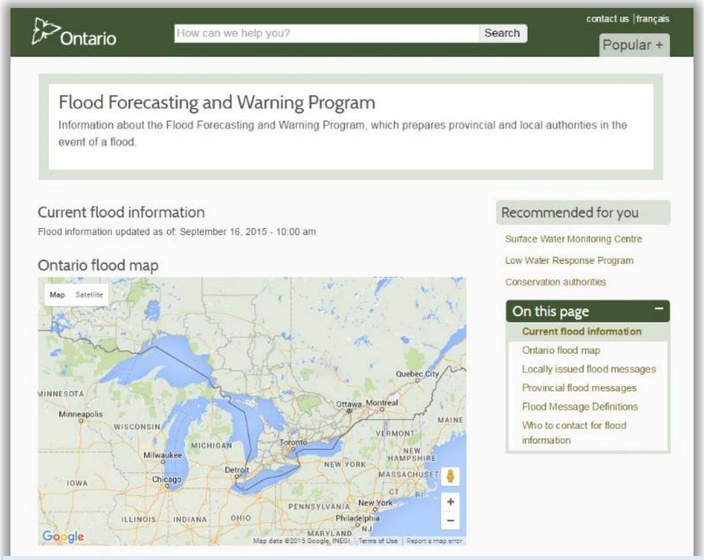
Flood forecasting is an essential tool in helping emergency response teams, as well as residents, prepare for a flooding event. It is therefore recommended to implement a flood forecasting and warning system in the area.

In terms of flood warning systems, it is recommended that three weather stations be installed in the central area of the three main watersheds, and connected to the county SCADA system, as well as published online (*Est. $90,000*)

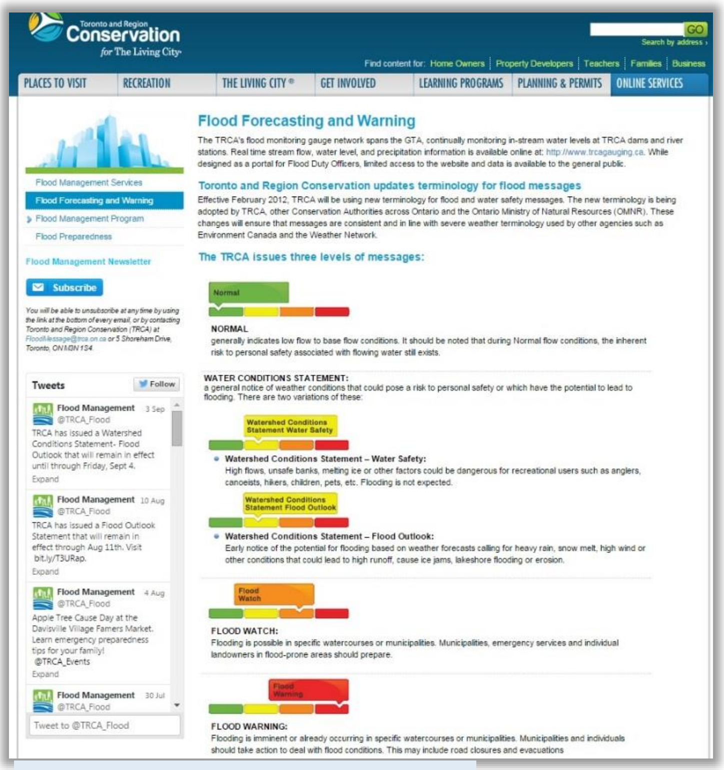
Similarly, it is recommended that flow monitoring stations be installed in each one of the three main watercourses, as well as a water level monitoring station at the highway 102 bridge. The flow and water level monitoring stations would best be installed, operated and maintained by Environment Canada, since they would be able to provide a proven system at the best cost (through their current standing offer) and allow the system to be operated and maintained by the most experienced staff in the country. In addition, the information would be published via satellite both to a real-time graph of flow data available on a website, as well as on the Water Survey of Canada Hydrometric Database. (*Est. $120,000 for purchase and installation, plus $55,000 each year for maintenance and operation*).

Preparing as a Community

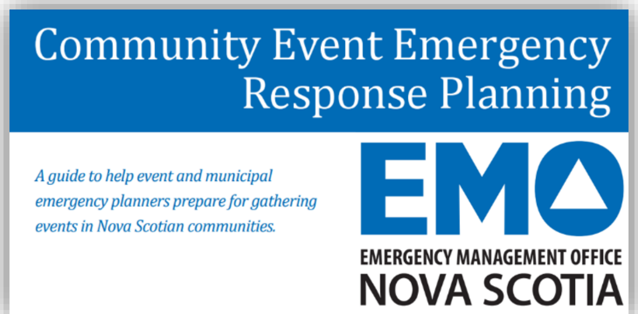
In January 2014, the Nova Scotia EMO issued a Community Event Emergency Response Planning Guide which provides support and information to municipal emergency planners on how to best prepare communities for emergencies. Although the guide is not directly related to flooding events, it provides detailed information to develop a response plan before and during an emergency and much of the information is relevant to a flooding event.



Ontario Environment and Energy Flood Forecasting Website

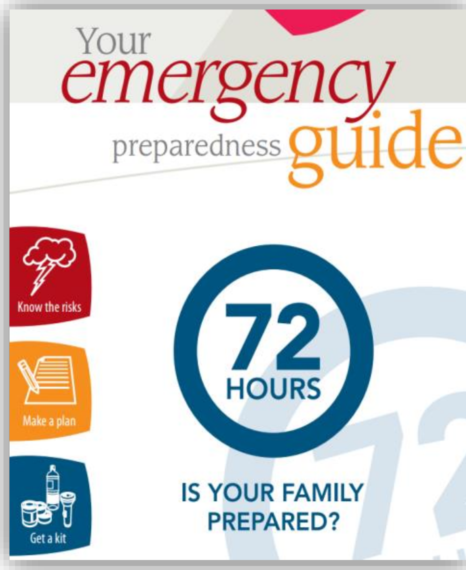


TRCA Flood Forecasting Website

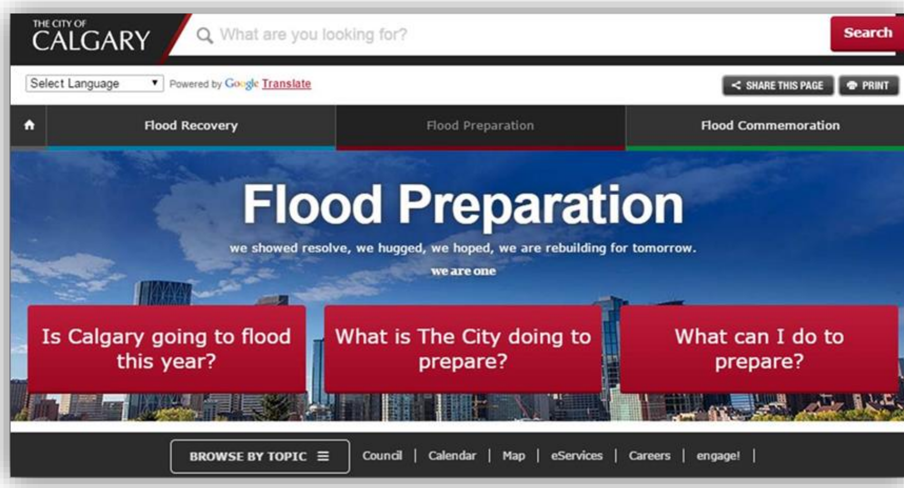


Preparing as a Resident

Community residents will also need to plan and prepare for a flooding event on an individual and family basis. There are many measures that individuals can take to better prepare their homes and residences on a lot level. The City of Calgary has a good resource for this type of preparation. It is also very important for residents to prepare their households for the emergency itself. Possible situations to prepare for include loss of power, injury, evacuation, or possible isolation, where emergency workers may not be able to reach you for a period of time. Communication and collaboration between neighbours and community members may be extremely helpful to residents when preparing their own homes and properties. Holding a community meeting to educate residents on flood response preparation is often recommended so that flood risks, response guidelines, and communication lines are clear.



Public Safety Canada's Emergency Guide



City of Calgary's Flood Forecasting and Preparedness Website, including notification apps.

Public Safety Canada issued an Emergency Guide summarizing steps that individuals can make in order to prepare themselves and their families for an emergency. This guide was prepared in collaboration with the provinces and therefore many of the provinces base their own recommendations on this guide. The guide can be distributed to residents and the residents can fill in their emergency response plan information and keep it in their house for future reference.

Flood Response and Resiliency

Flood Resiliency is the ability to cope with flooding and to recover from flooding.

There is no shortage of information on flood resilience throughout the world, with main publications originating from Europe (England has suffered from many recurring floods in recent years) and the US Environmental Protection Agency. These sources will provide generic and valuable information for anybody who would like to gather information on the topic. In order to present locally realistic and pertinent information on flood resiliency that can be implemented and can make a difference for the residents of the Town of Truro. Nova Scotia provides some general recommendations on how individual residents and households can react during different phases of a flooding event that will help prepare them during the event. This Flood Response Recommendation summary is presented below.

Although not presented in detail in this section, other valuable sources of information for flood preparation and resiliency were found in the City of Manitoba, the Province of Alberta and the Province of Ontario.

When a Flood Warning is Issued:

- Fill your bathtub(s) with water for flushing, washing and cleaning;
- Be sure to tune in to local broadcast networks for updates from authorities;
- Set aside a supply of drinking water, in case your supply becomes contaminated;
- Disconnect eaves troughs that drain into sewer;
- Remove all chemicals from basement;
- Move furniture and personal belongings to a higher floor;
- If your property is close to water consider piling sandbags; and
- Put away lawn furniture, planters, picnic tables, small boats or anything that could be swept away in a flood.

If your Home is Flooded:

- Turn basement furnace off and shut off outside gas valves.
- Turn off electrical power. If your main power box is not in a dry, safe location, do not attempt to turn it off. Contact Nova Scotia Power at 428-6004 or 1-877-428-6004.
- Do not stand or wade in water where contact has been made with electrical equipment.
- If drinking water is contaminated, purify by boiling, using purification tablets or chlorinate with a bleaching compound.
- Do not use well water for drinking, cooking or bathing until the water has been tested and determined to be safe.
- If you have questions about your water, you should contact your local environment office by calling 1-877-9ENVIRO.

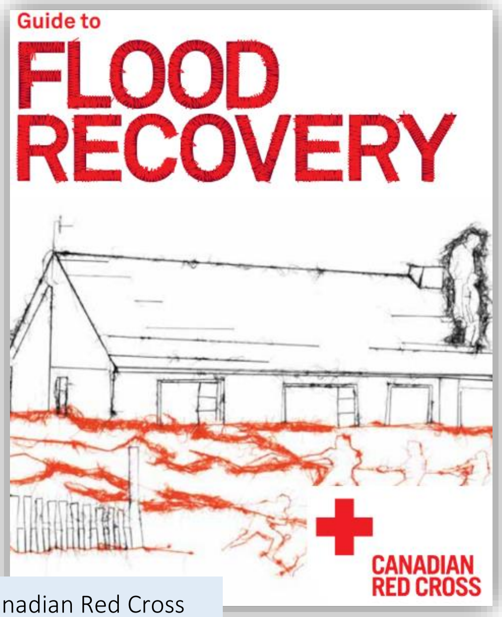
Re-entering your Home:

- Do not return home until authorities have advised that it is safe to do so;
- If the main power switch was not turned off prior to flooding, do not re-enter your home until a qualified electrician has determined it is safe to do so;
- Appliances that may have been flooded pose a risk of shock or fire when turned on. Do not use any appliances, heating, pressure, or sewage system until electrical components have been thoroughly cleaned, dried, and inspected by a qualified electrician; and
- The main electrical panel must also be cleaned, dried, and tested by a qualified electrician to ensure that it is safe.

Flood Recovery

Although the flooding event is over, this stage of the emergency management cycle can be difficult for residents. Families may be moving back into damaged houses, be recovering from injuries or in the worst case, be recovering from a fatality of a friend or family. Community and government support will be relied on heavily during this stage, so it is important that Residents and Emergency Planners also be educated about planning for the Recovery Stage.

The Red Cross of Canada provides a very good guide on Flood Recovery and such information should be distributed to residents before a flooding event occurs so that they can plan accordingly. The clean-up and repair may take some time. Of utmost importance during this stage will be ensuring that the flooded environment is safe for re-entry. Even if residents and the community conducted efficient preparation efforts, there may still be hazardous materials, loose powerlines, gas leaks or other exposed dangers that will need to be dealt with by qualified personnel before community residents are allowed to return to their homes.



Canadian Red Cross Guide to Flood Recovery

Summary and Recommendations

This report has placed significant emphasis on the following aspects:

- Stakeholder consultation and prioritization of vulnerable areas;
- In-depth State-of-the-Art modelling;
- Assessment of many different options to identify the most cost effective and achievable solutions; and
- Conducting the overall assessment in a holistic approach to make sure that recommendations make sense for Truro and are sustainable in the long term.

The depth and thoroughness of this assessment was necessary to lend as much credibility as possible to the results attained. This report is the first one to involve calibrated computer models of rainfall, flows, tides, sediment and ice, directly used to assess more than 40 flood mitigation options.

In summary, it was found that the only flood mitigation capital infrastructure projects that provided an effective reduction in flood risks were those involving the re-establishment of the natural, wider river floodplain and salt marshes. This can be achieved through the removal of the existing dykes, and the construction of new dykes further out to protect the areas at risk. Further efficiency can be gained by constructing pumping stations that will extract the water backed up behind the dykes. This project is simple in nature, uses proven methods already in place in the area, requires minimal maintenance, and can be implemented in many smaller phases as funding becomes available.

Such a project carries very high costs, however, and without access to large funding programs, implementing a project of this magnitude with the available resources would likely take many decades. It is therefore recommended that more immediate measures be implemented first, that will make a recognizable and visible difference for the community in the short term.

Immediate measures that are recommended include:

1. Implementing the updated floodlines developed in this study in the Municipal and Town planning documents. It is recommended that the floodlines that include climate change be used, such that planning for future development can take into account future risks.

2. Development within the 1 in 100 year floodplain should be discouraged to the extent possible, as it will only increase the population at risk, and the vulnerability of the new development. It is encouraged that if any development is allowed within the 1 in 100 year floodplain, it be kept outside of the 1 in 20 year floodplain, consist of uses that are not vulnerable to flooding, and do not increase upstream flooding risks. Development such as recreational areas and sports fields would be suitable for example. This has been a recommendation in most of the previous flood studies in the area.

3. To the extent possible, the long term goal should be to restore the floodplain to its natural configuration, with removal of the current dyke system along the channel banks and restoration of the natural salt marshes, while keeping development safe from flooding risks.

4. Any development that is approved by the Municipality of Colchester or the Town of Truro within the 1 in 100 year floodplain should be flood proofed and flood resilient to ensure that any population using the approved development can be kept safe from the flood water. Safe and reliable access to emergency services should be ensured, as well as safe and reliable access to drinking water, electricity and food supplies for the duration of flood events, which can last several days. This can be achieved by raising the level of the land and access to it above the 1 in 100 year flood level.

Example of permeable pavers for a parking lane in Yarmouth

5. Any development that is considered for approval by the Municipality of Colchester or the Town of Truro within the 1 in 100 year floodplain should be subjected to an analysis to demonstrate that it will not increase upstream flooding risks and therefore not increase vulnerability to upstream population, services and land uses. Measures such as placing fill within the floodplain can be offset by using other flood mitigation measures (such as stormwater infiltration) to ensure that no increase in flooding risk is created.

6. Incorporate planning regulations to enforce Low Impact Development approaches and infiltration systems for all new development. Runoff volumes and peak flows shall by reduced to 25% below pre-development runoff volumes and peak flows. Approaches to achieving this are presented in the Recommendations for Stormwater Best Management Practices section.

7. Implementing peak flow control measures such as storage and infiltration systems in the Millbrook area to address local flooding issues.

8. Implementing regulations to enforce the replacement of high runoff surfaces with stormwater infiltration systems, throughout the three study area watersheds, wherever a high runoff surface surface is renewed, replaced or maintained.

9. The County and Town have carried out major channel improvements in key areas of the North and Salmon Rivers which involved the removal of sediment and gravel buildup. Sediment buildup is a rapid tidal process with seasonal variations in the range of 2 metres, whereas gravel buildup is strictly a river erosion process and therefore much slower, with a time to accumulate in the order of several years. Removal of some of the underlying gravel has increased the capacity of the channel and reduced flooding risks. The present analysis has, however, shown that sediment and gravel removal efforts, even though effective in reducing flooding risks, are not the most cost-effective option in the long term. It is therefore recommended that future flood mitigation efforts be more focused on some of the more cost-effective flood mitigation options in the long term. This includes for example implementing infiltration systems in areas where work is already scheduled to take place, such as replacement of pipes, roadway or sidewalk surfaces;

10. Implementation of a weather, flow and tidal monitoring system. This is critical to the implementation of a flood forecasting and warning system. Furthermore, as more information is collected on the weather and the flood response, better data will be available to improve the quality of the models in the future;

11. Development and implementation of a flood forecasting and warning system. This will provide valuable input to emergency management staff to prepare and manage emergencies during floods and better respond to risks to public safety;

12. Update of emergency management plan; and

13. Development of educational and reference material (websites, brochures) on flood preparedness, resilience and recovery.

It is recommended that the involvement of as many stakeholders as possible be promoted in each of those steps to facilitate buy-in, but also to provide education on the reality of the issues. Large scale options for flood control in the Truro floodplain are very costly, and therefore more suitable to long-term protection. In the short term, it is more cost effective to focus on small scale measures such as infiltration and focusing on flood preparedness. It would also be beneficial to include stakeholders at large, such as the Dalhousie Faculty of Agriculture, the NRC, Environment Canada, and local associations such as the Cobequid Salmon Association, and members of the Marsh Bodies.

It is hoped that this report is a valuable document to inform the stakeholders of the wide range of issues that play a role in explaining the current flood risks, as well as mitigating them.

It is recommended that the involvement of as many stakeholders as possible be promoted in each of those steps to facilitate buy-in, but also education on the reality of the issues. It would also be beneficial to include stakeholders at large, such as the Dalhousie Faculty of Agriculture, the NRC, Environment Canada, and local associations such as the Cobequid Salmon Association, and members of the Marsh Bodies.

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CBCL LIMITED

Consulting Engineers

Flood Risk Study

Joint Flood Advisory Committee
County of Colchester, Town of Truro
and Millbrook First Nation

Appendices

APPENDIX A

Flood Mitigation Options Sketches

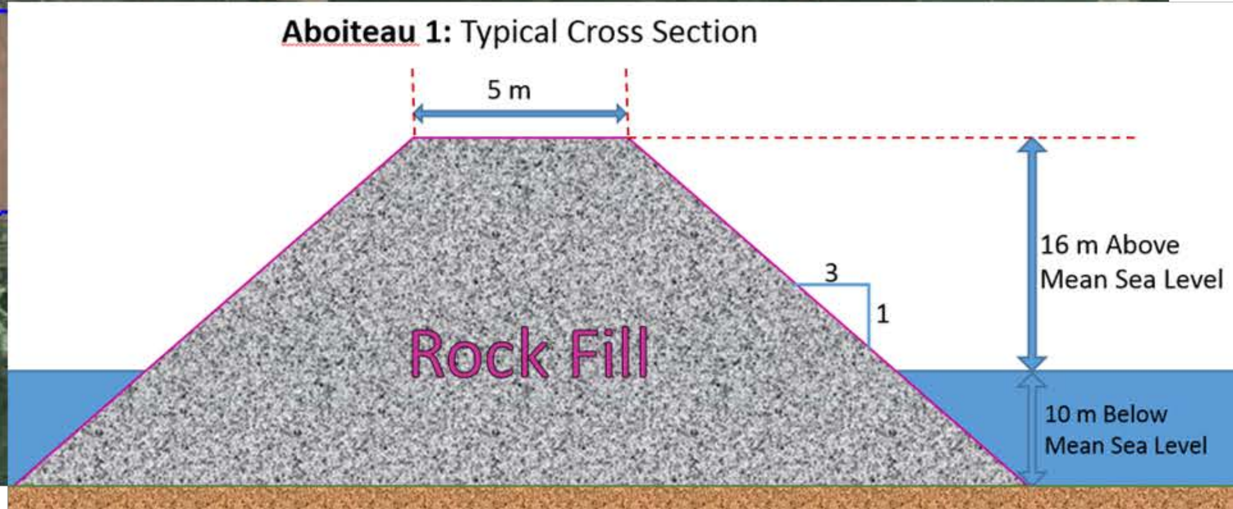
Aboiteau 1:

Construct Aboiteau in Cobequid Bay to Control Tides from Salmon and Shubenacadie Rivers

Cobequid Bay Aboiteau

- Length = 4.2 km

Area	2158	m^2
Volume of Fill	9,063,600	m^3
Bottom Area	676,000	m^2
Piles Every 5 m^2	135,240	Piles
20 m Long Piles	2,705,000	m Total Length of Pile

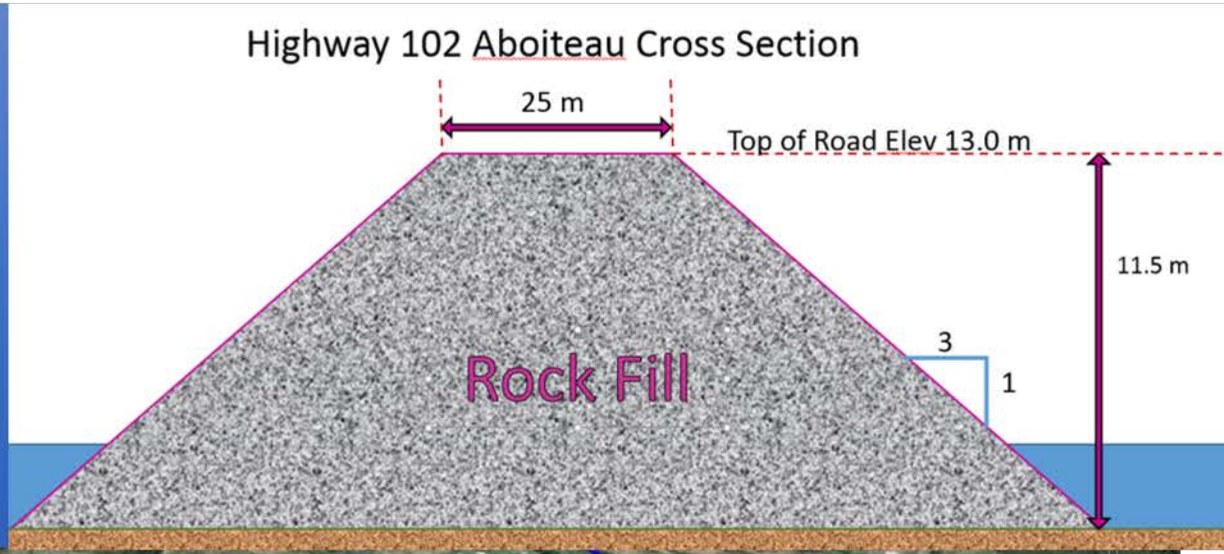


Aboiteau 2:

Construct Aboiteau at HWY 102

Highway 102 Aboiteau

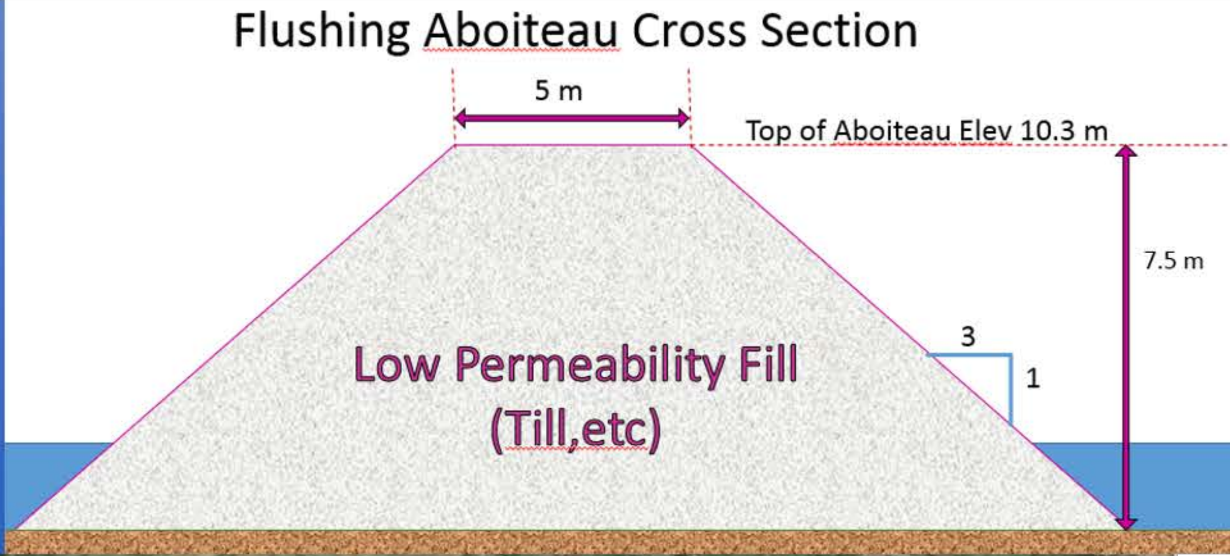
Length	125	m
Area	684	m2
Volume	85,531	m3
Bottom Area	11,750	m2
Piles Every 5m2	2,350	Piles
20 m Long Piles	47,000	m Total Length of Pile
100 m Length of Flow Control Structures		



Aboiteau 3:

Construct Flushing Aboiteau (with actively controlled gates with computer logic) Downstream of River Confluence to Control Tides and Sedimentation

Length	125	m
Area	684	m2
Volume	85,531	m3
Bottom Area	11,750	m2
Piles Every 5m2	2,350	Piles
20 m Long Piles	47,000	m Total Length of Pile
Structure	30 (w) x 10 (h) m	Concrete Control Structure

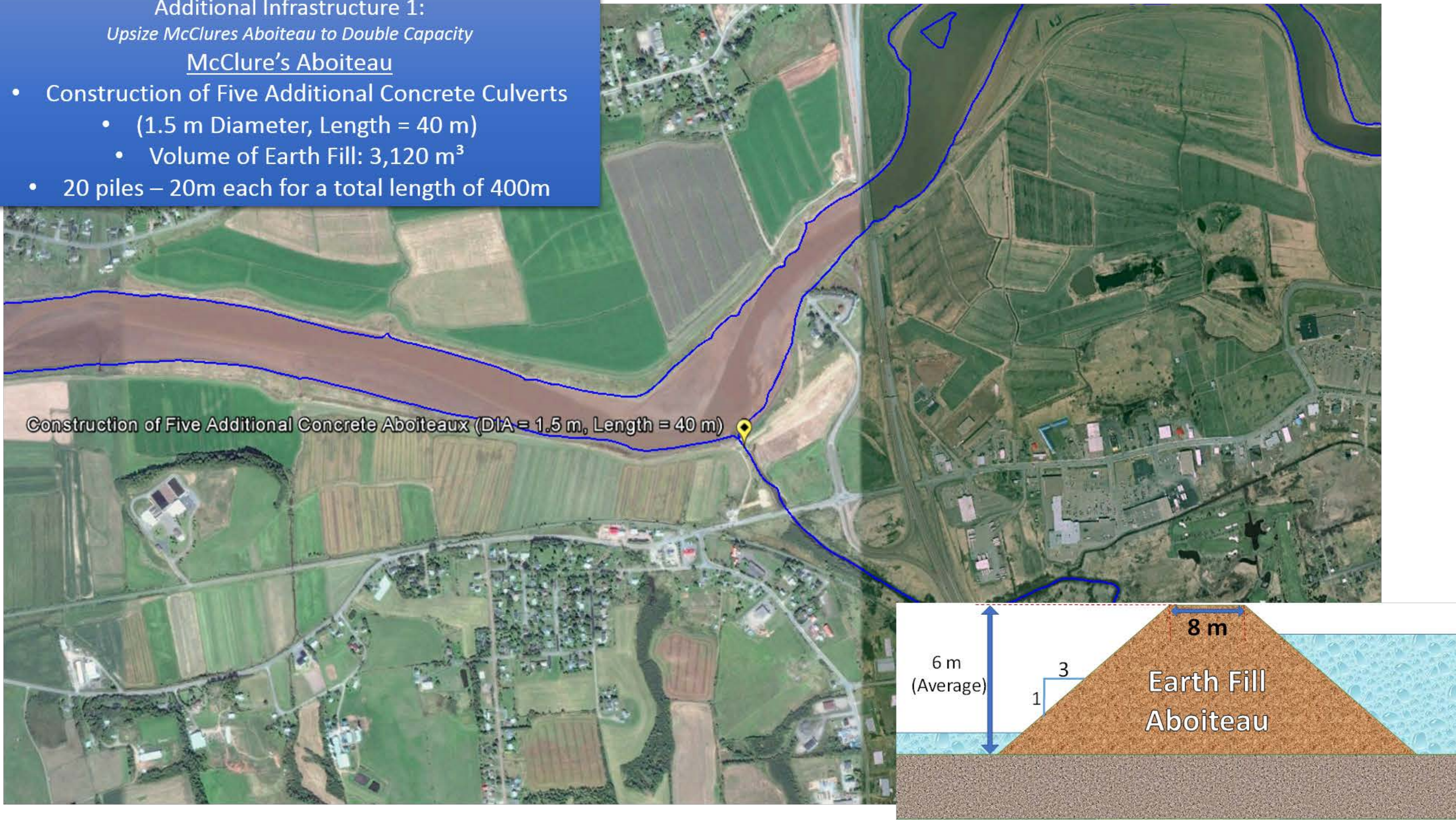


Additional Infrastructure 1:

Upsize McClures Aboiteau to Double Capacity

McClure's Aboiteau

- Construction of Five Additional Concrete Culverts
  - (1.5 m Diameter, Length = 40 m)
  - Volume of Earth Fill: 3,120 m^3
- 20 piles – 20m each for a total length of 400m



Additional Infrastructure 2:

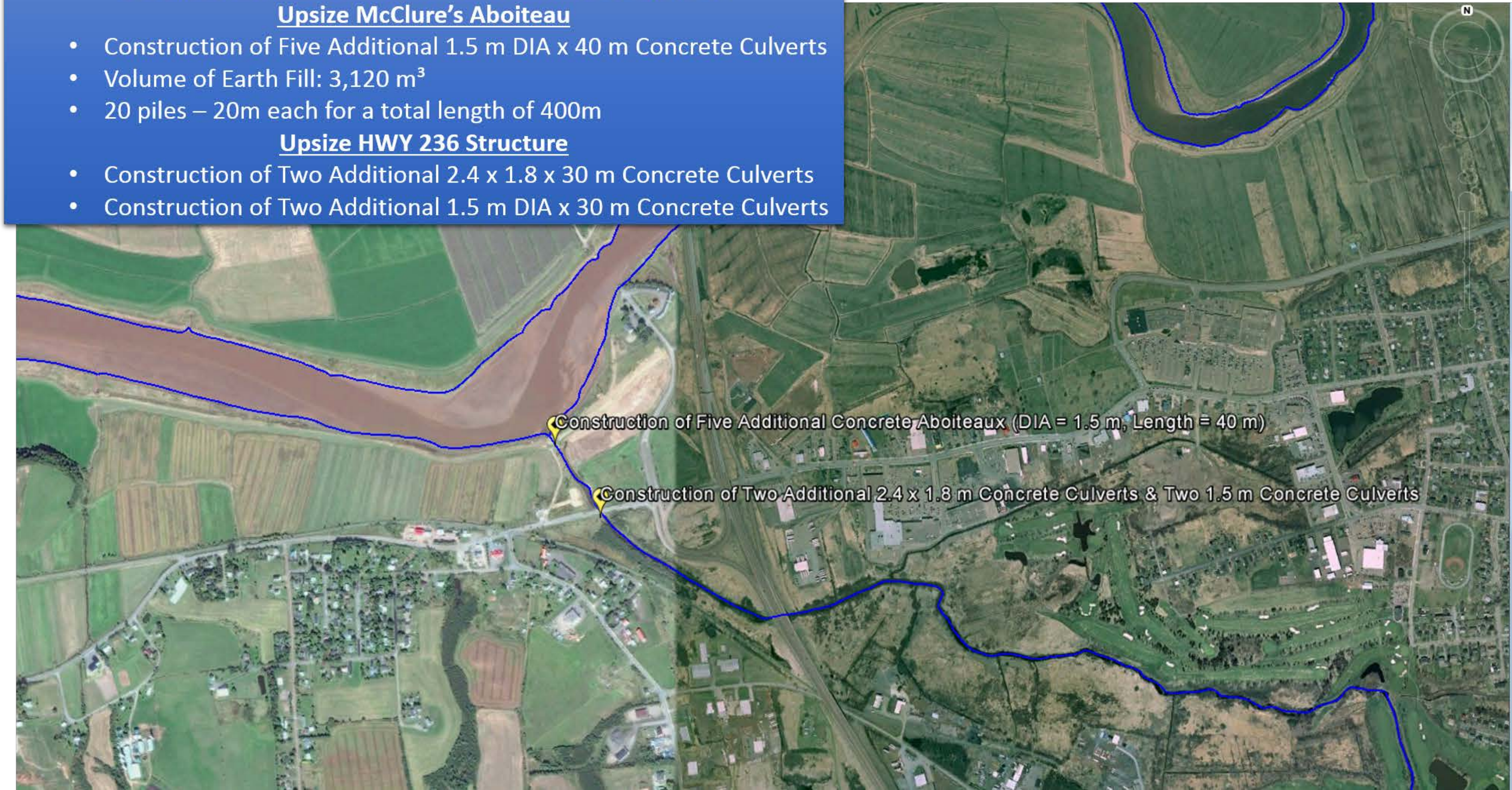
Upsize McClures Aboiteau and HWY 2 Culverts to Double Capacity of Both

Upsize McClure's Aboiteau

- Construction of Five Additional 1.5 m DIA x 40 m Concrete Culverts
- Volume of Earth Fill: 3,120 m^3
- 20 piles – 20m each for a total length of 400m

Upsize HWY 236 Structure

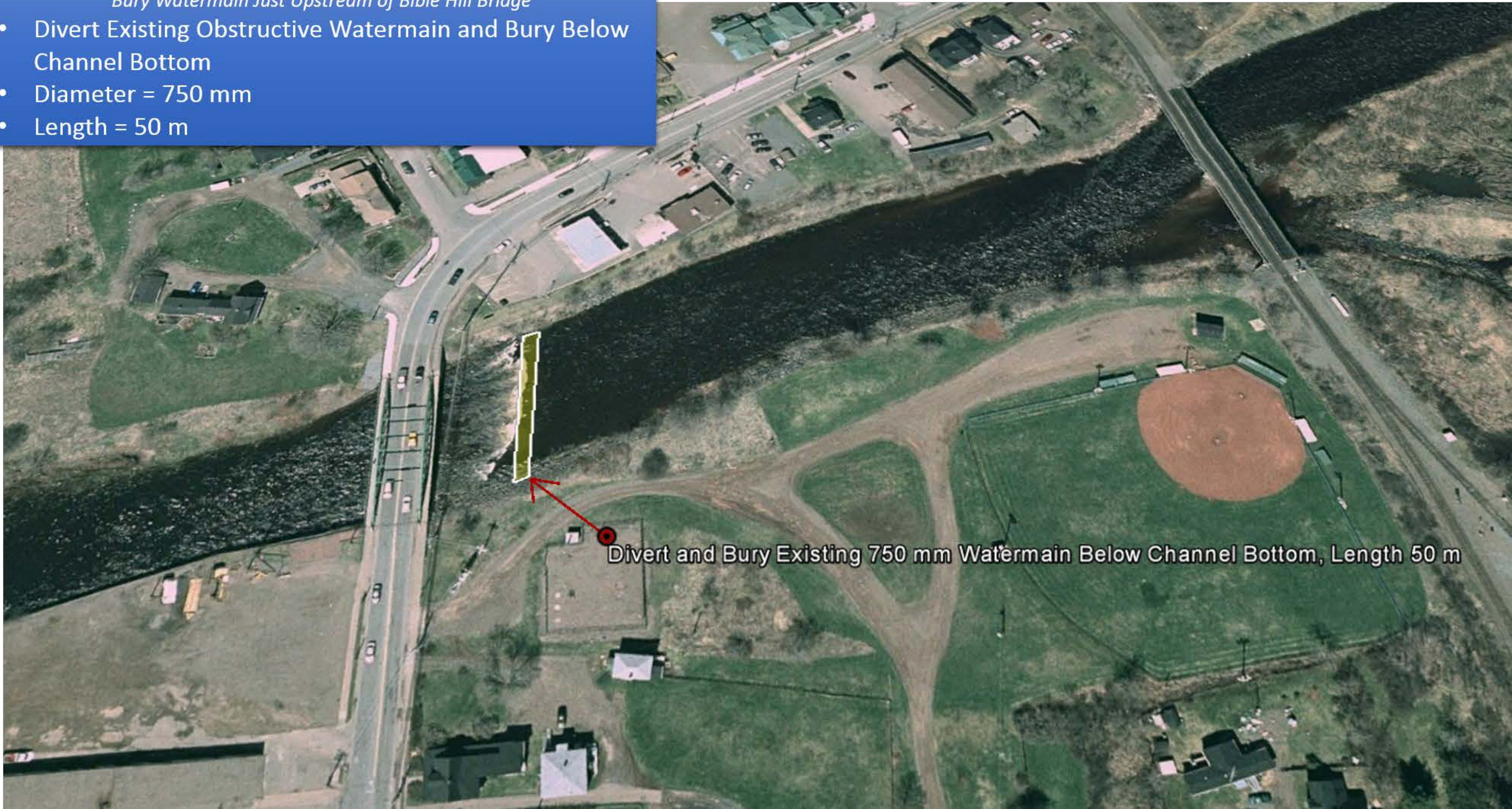
- Construction of Two Additional 2.4 x 1.8 x 30 m Concrete Culverts
- Construction of Two Additional 1.5 m DIA x 30 m Concrete Culverts



Additional Infrastructure 3:

Bury Watermain Just Upstream of Bible Hill Bridge

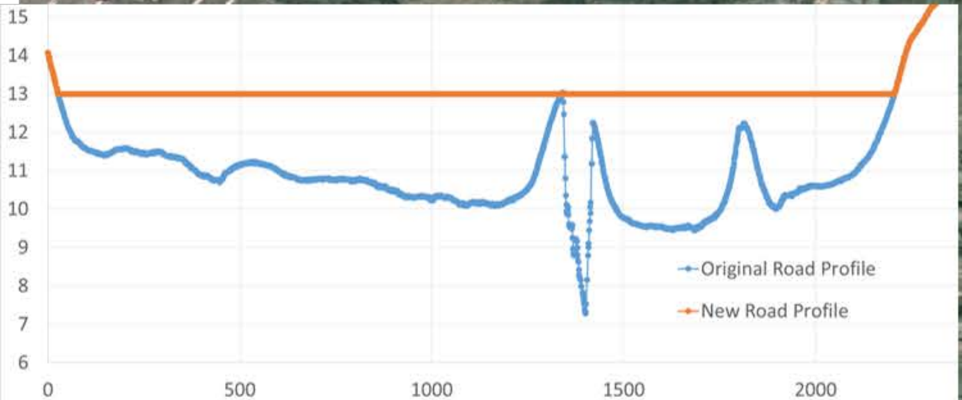
- Divert Existing Obstructive Watermain and Bury Below Channel Bottom
- Diameter = 750 mm
- Length = 50 m



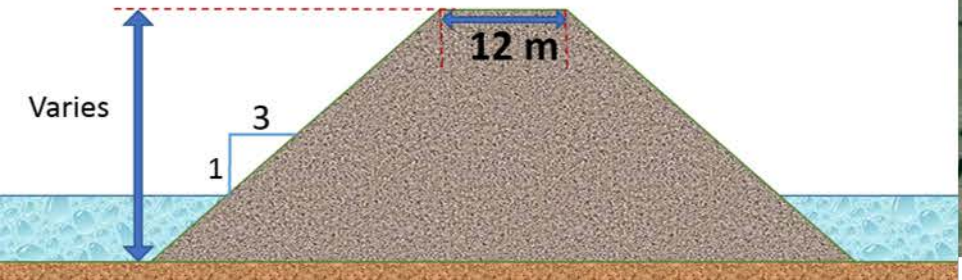
Additional Infrastructure 4:

Raise Park Street and Add Floodway Culverts

- Raise Park Street and Approaches to Elevation of 13 m
- Total Fill Volume for Road 121, 000 m^3
- Add 6 Total Concrete Culverts 2 x 3 m
- Length = 42 m

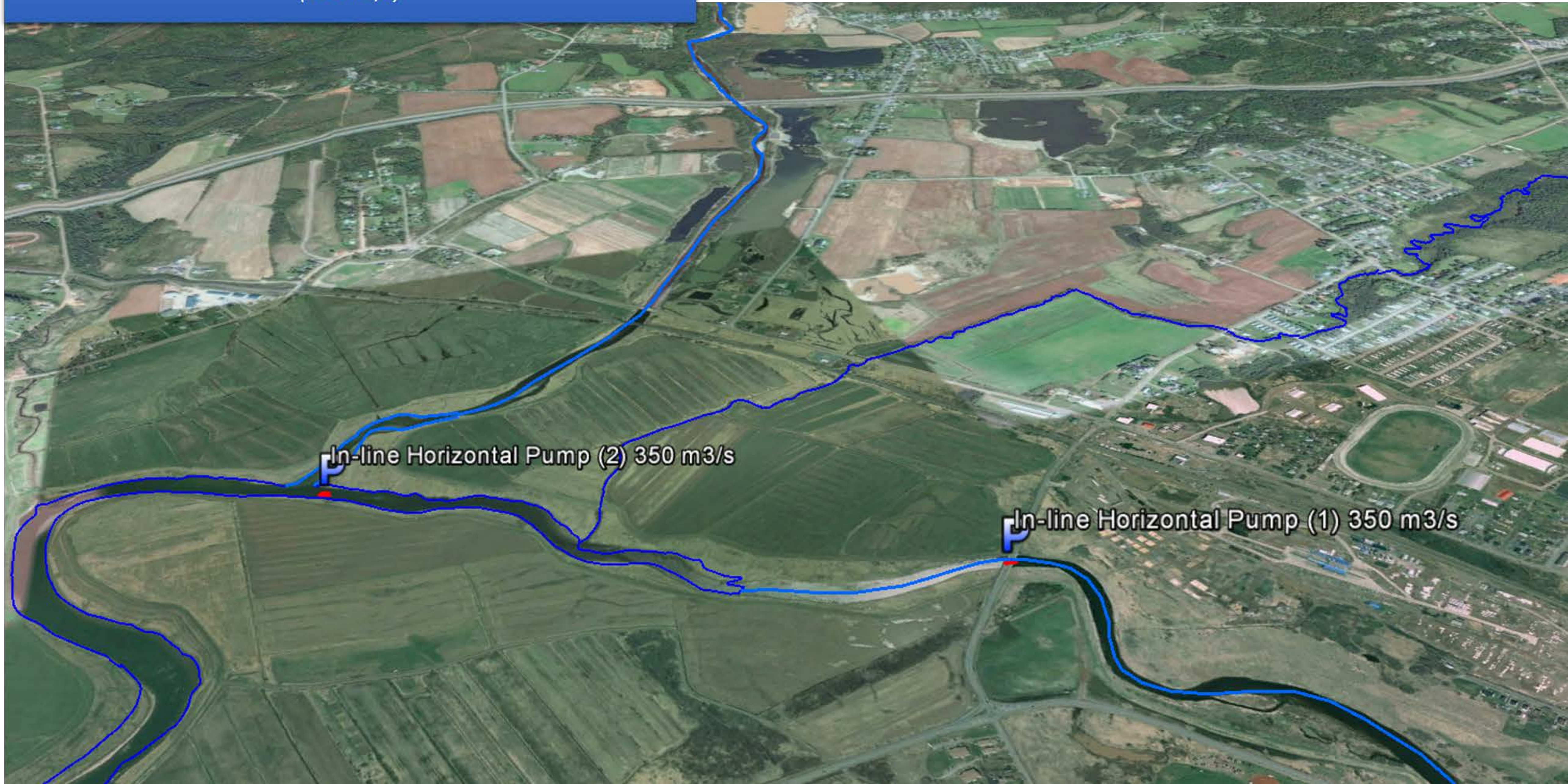


Additional Infrastructure 4: Typical Road Cross Section



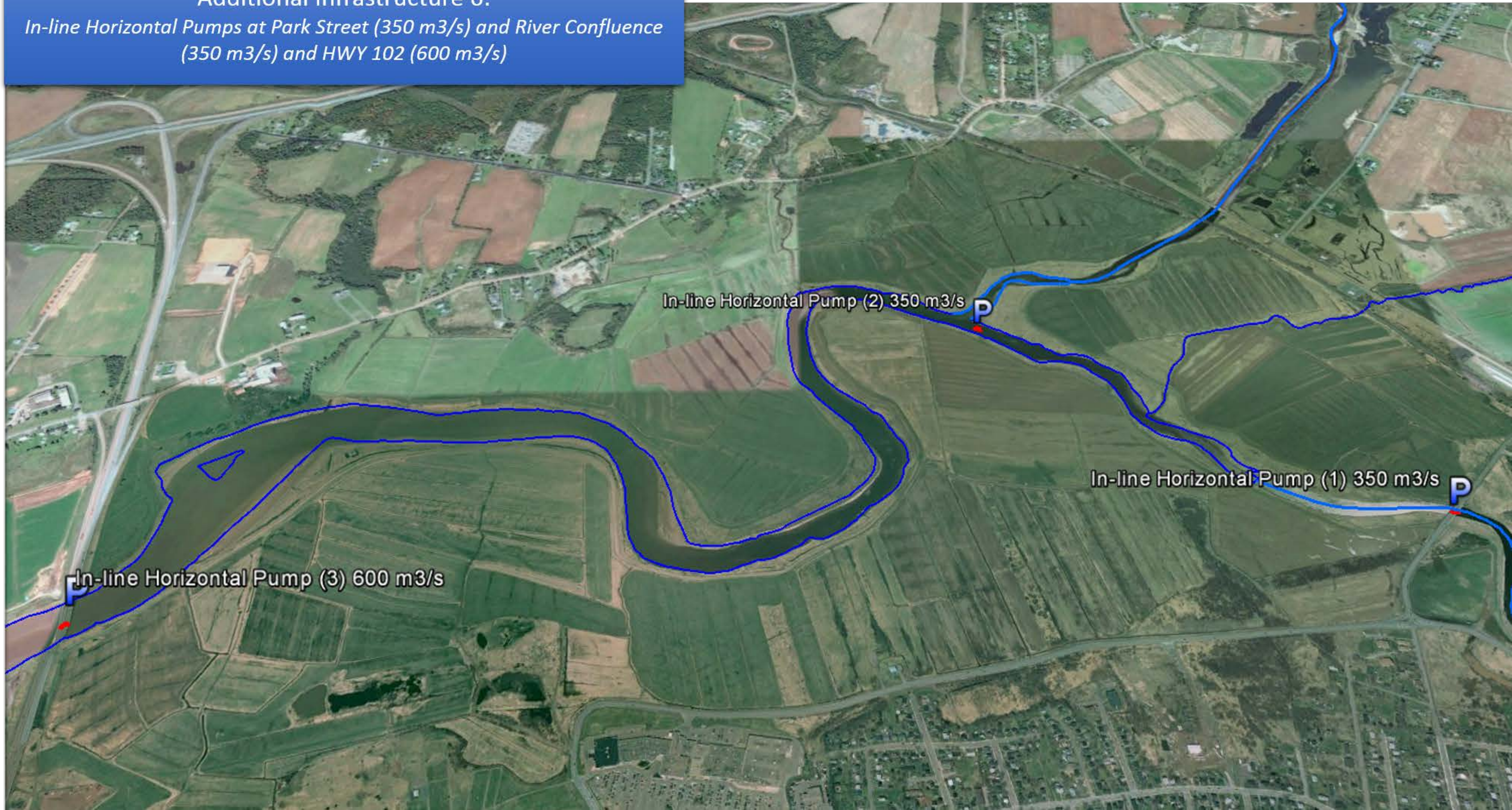
Additional Infrastructure 5:

In-line Horizontal Pumps at Park Street (350 m3/s) and River Confluence (350 m3/s)



Additional Infrastructure 6:

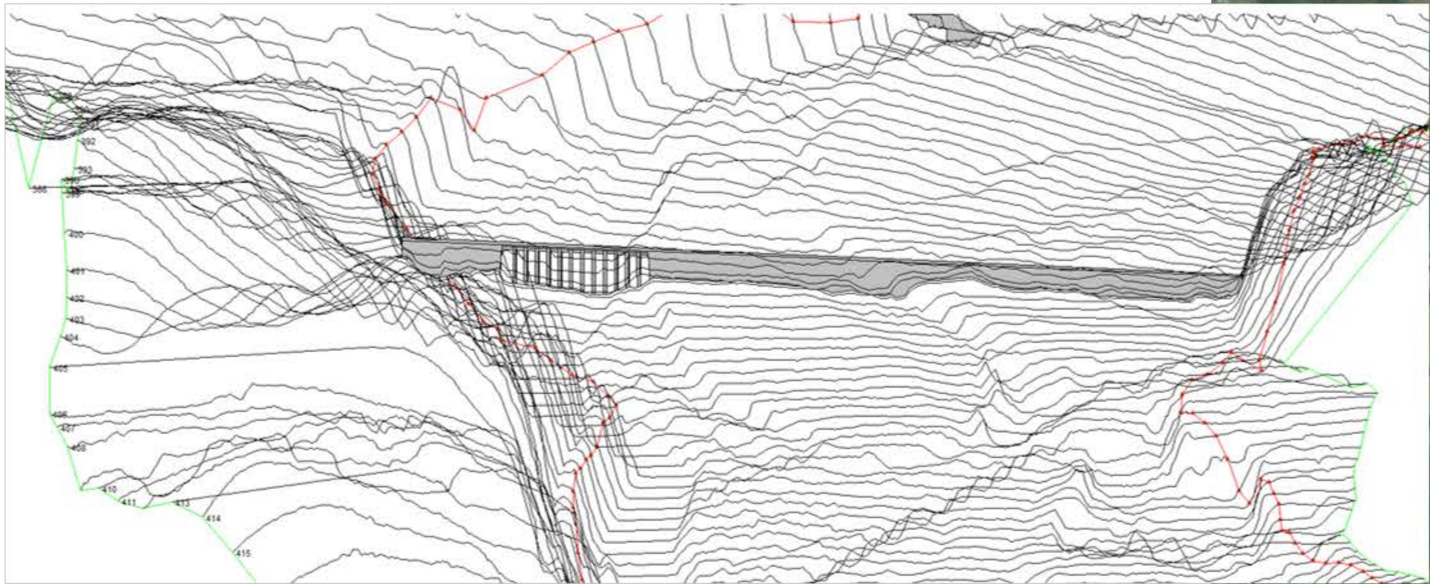
In-line Horizontal Pumps at Park Street (350 m3/s) and River Confluence (350 m3/s) and HWY 102 (600 m3/s)

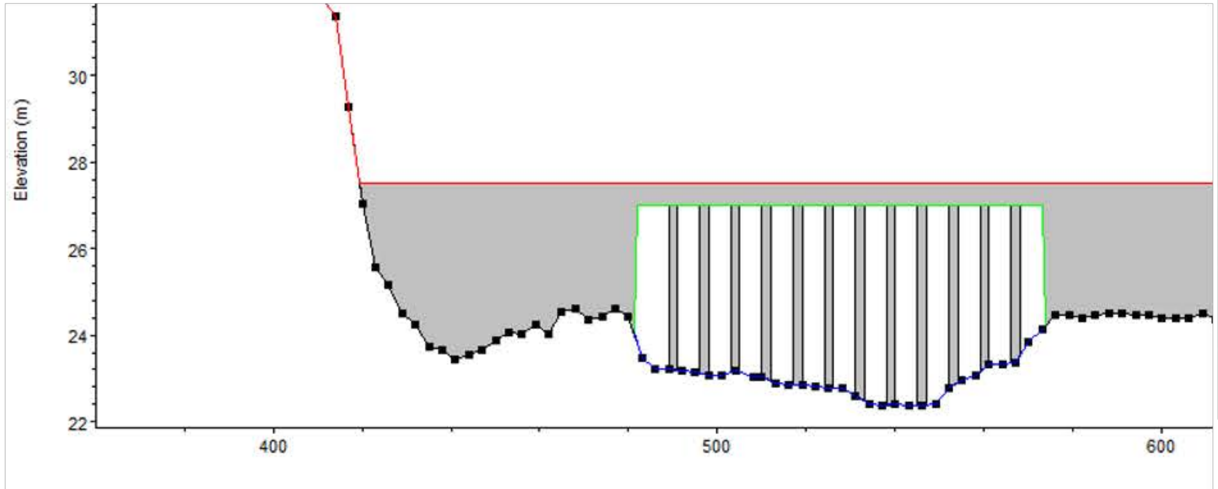


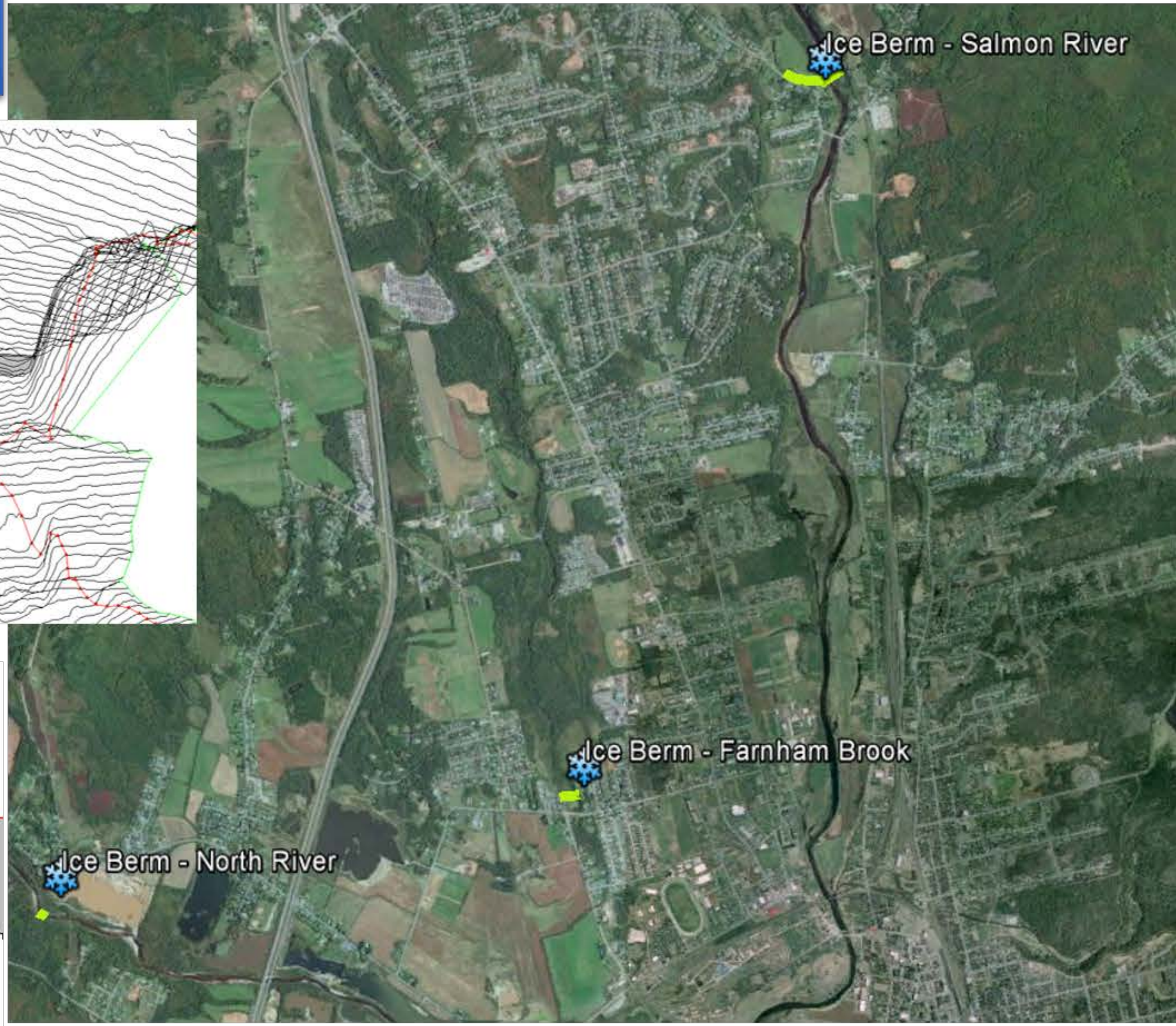
Additional Infrastructure 7:

Ice Control and Holding Berms

- Installation Ice Berms at 3 Locations
- 60 Total Battered Piles
- Earth Berm Extending to Floodplain Banks
- Total Fill = 12, 800 m^3



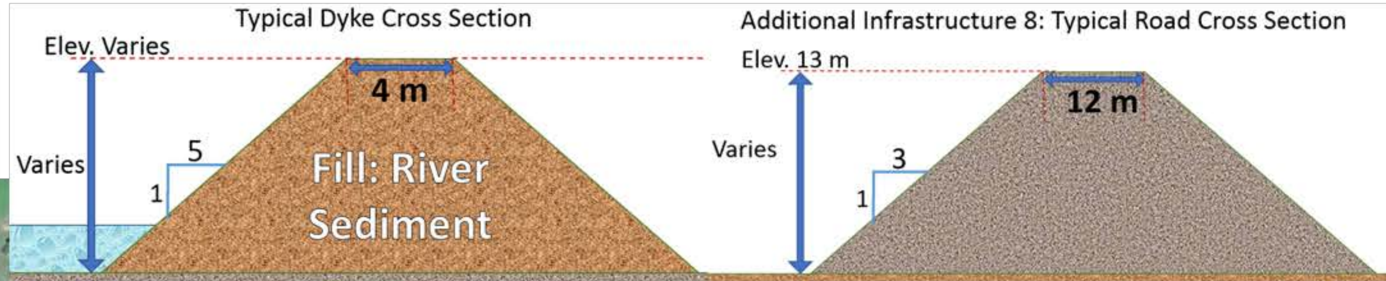


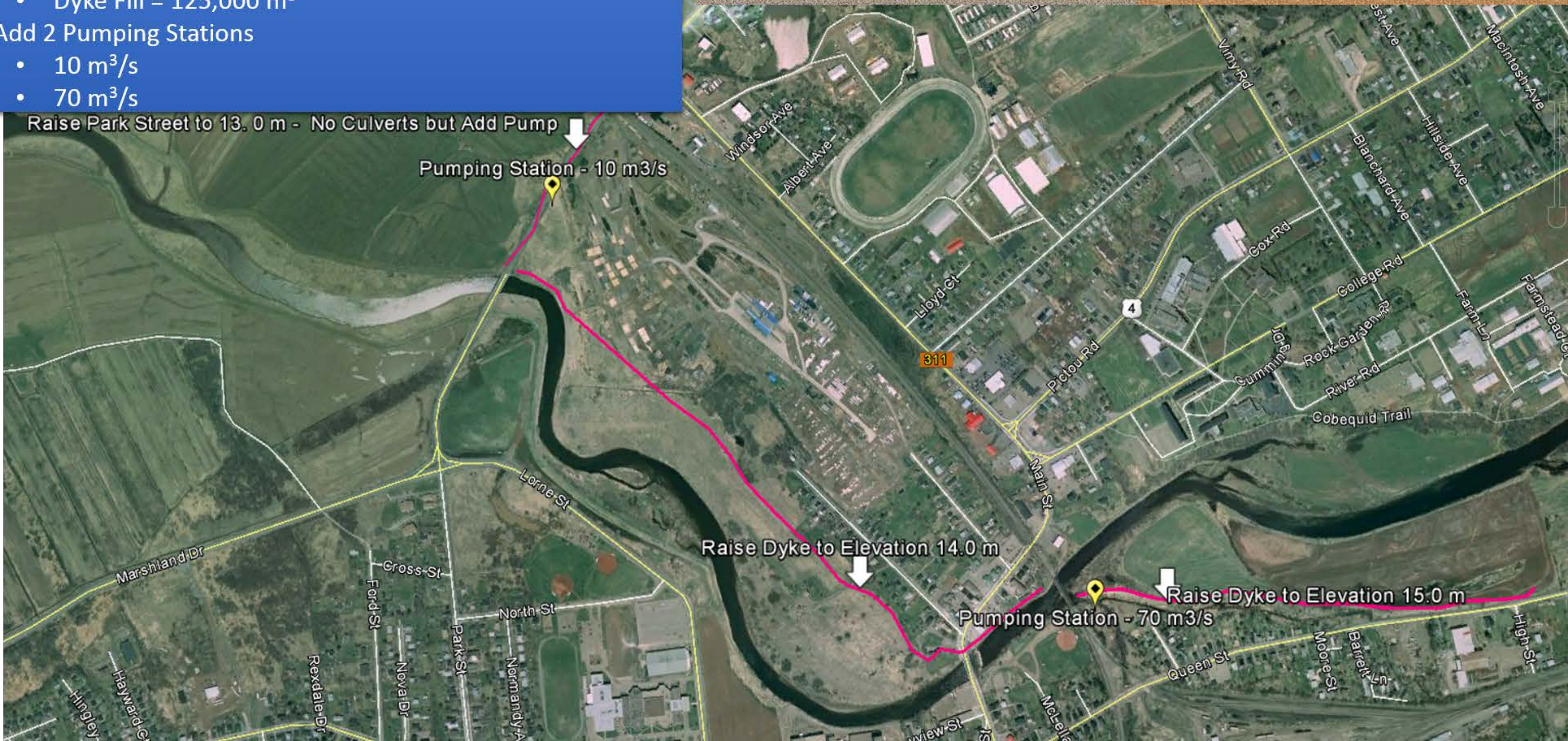


Additional Infrastructure 8:

Construct Localised Dykes to Protect Specific Residential Areas

- Raise Park Street Section Elev. = 13.0 m
  - Road Fill = 24,500 m^3
- Raise Dykes
  - Dyke Fill = 125,000 m^3
- Add 2 Pumping Stations
  - 10 m^3/s
  - 70 m^3/s

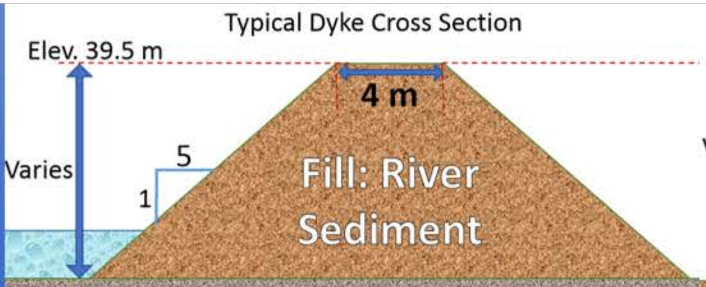


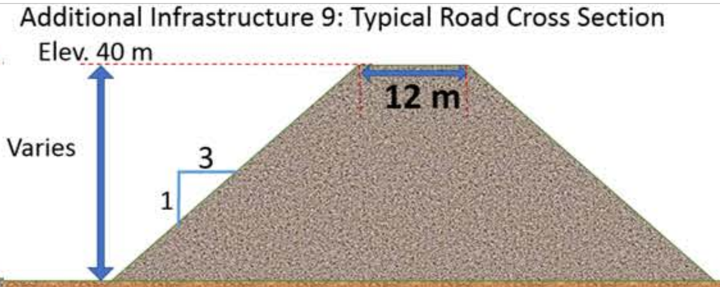


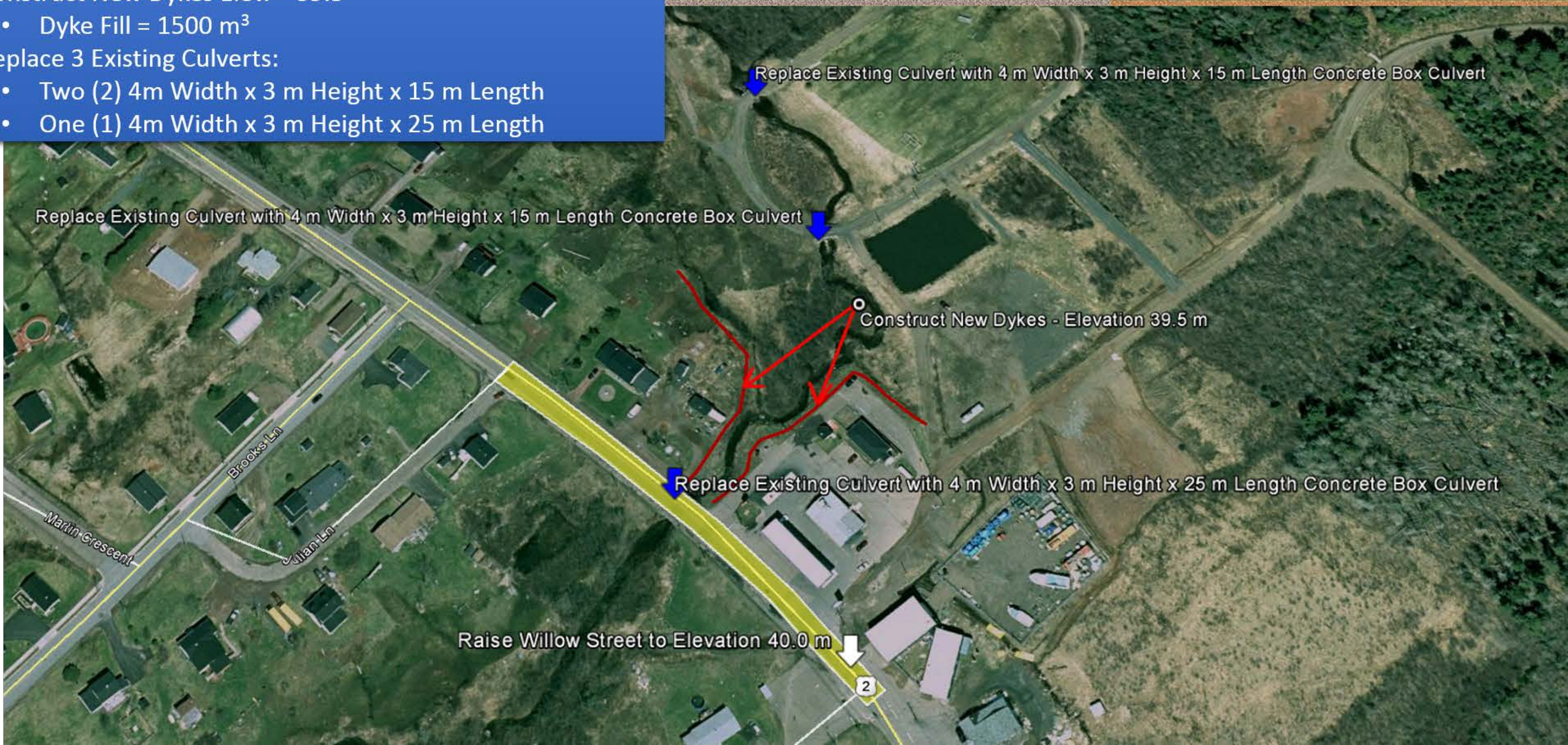
Additional Infrastructure 9:

Millbrook Flood Mitigation - Replace Willow Street and Upstream Culverts and Construct Dykes

- Raise Willow Street Section Elev. = 40.0 m
  - Road Fill = 3600 m^3
- Construct New Dykes Elev. = 39.5
  - Dyke Fill = 1500 m^3
- Replace 3 Existing Culverts:
  - Two (2) 4m Width x 3 m Height x 15 m Length
  - One (1) 4m Width x 3 m Height x 25 m Length



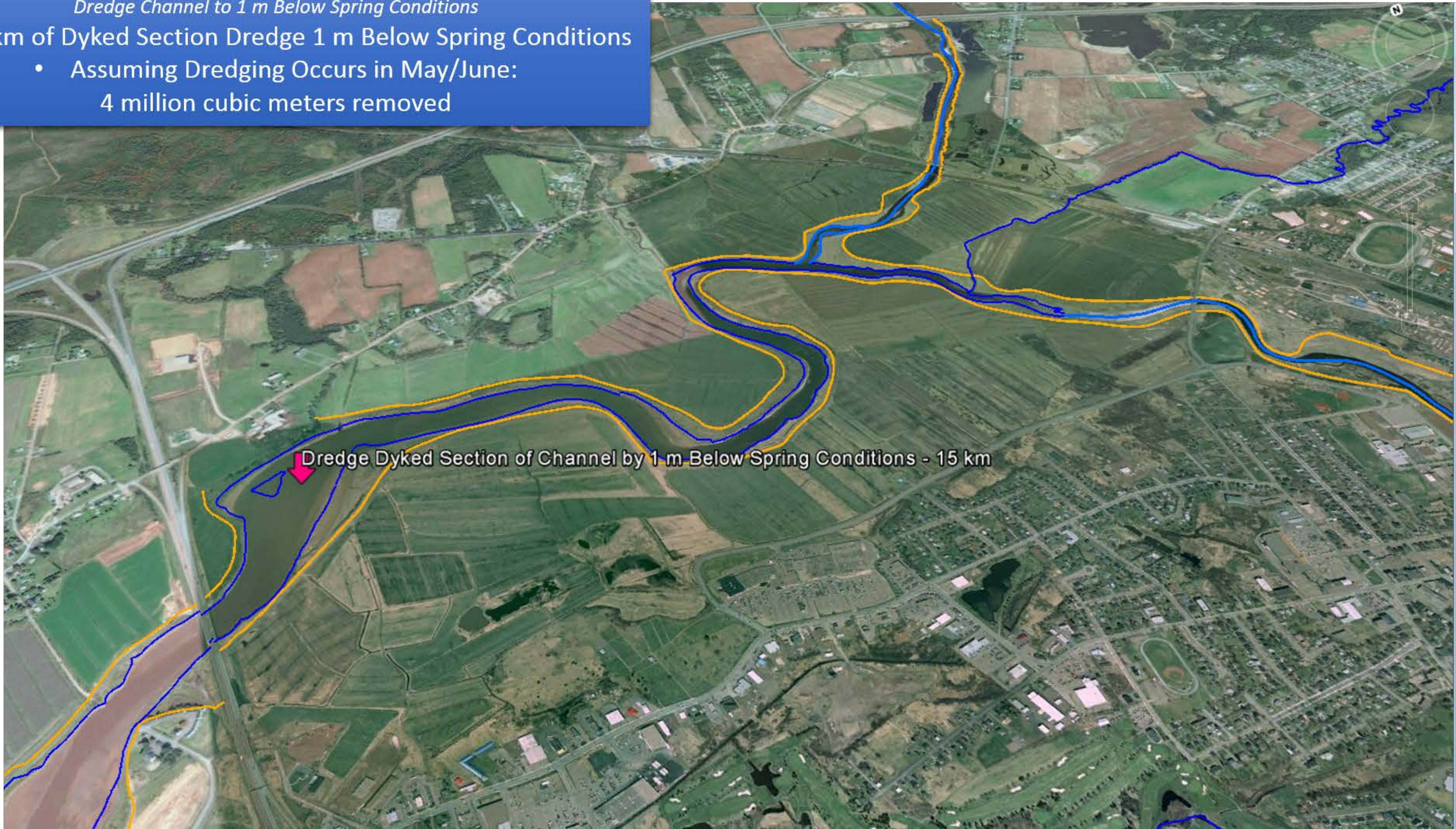




Dredging 1:

Dredge Channel to 1 m Below Spring Conditions

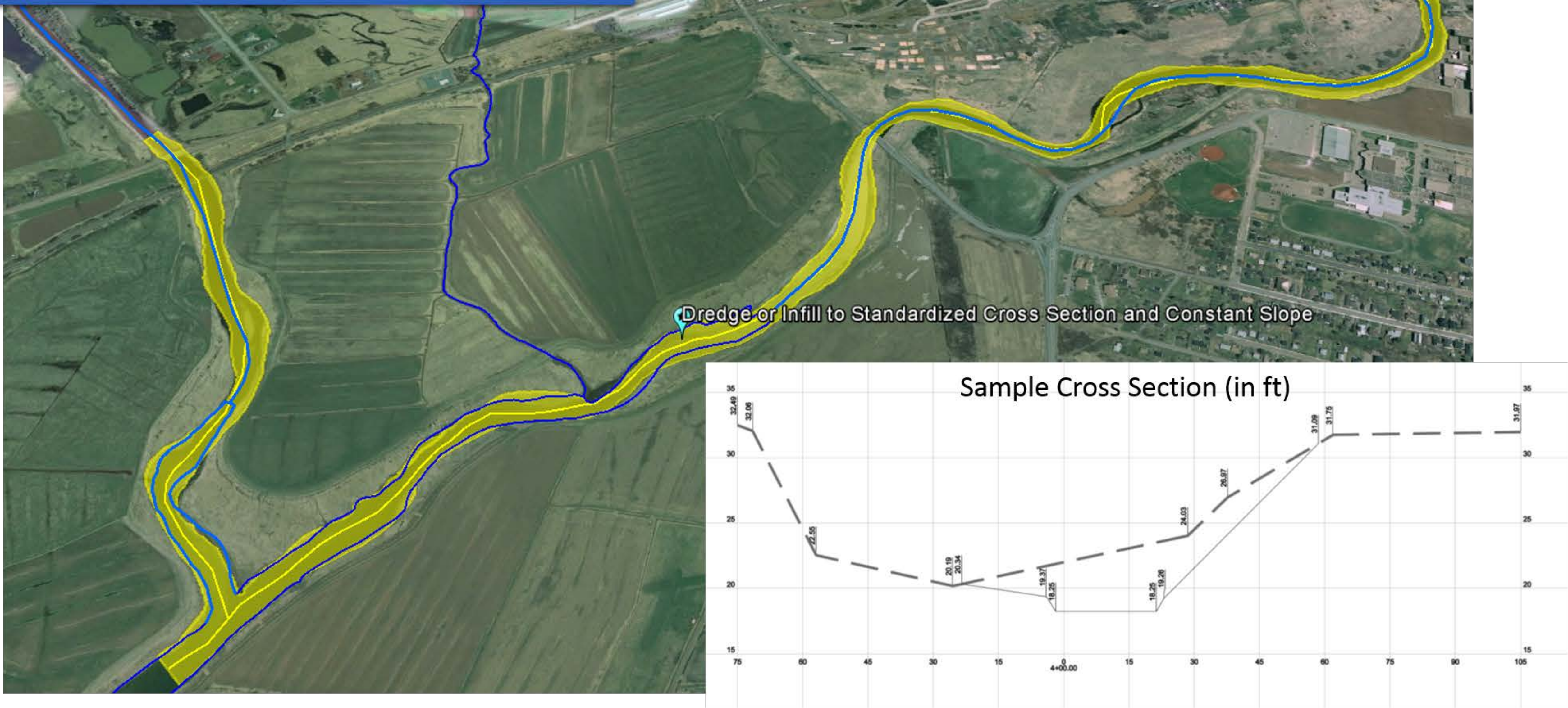
- 15 km of Dyked Section Dredge 1 m Below Spring Conditions
  - Assuming Dredging Occurs in May/June:
  4 million cubic meters removed



Dredging 2:

Dredge to Standardized Cross Section Construction (Primarily Dredging) of Standardized Cross Section

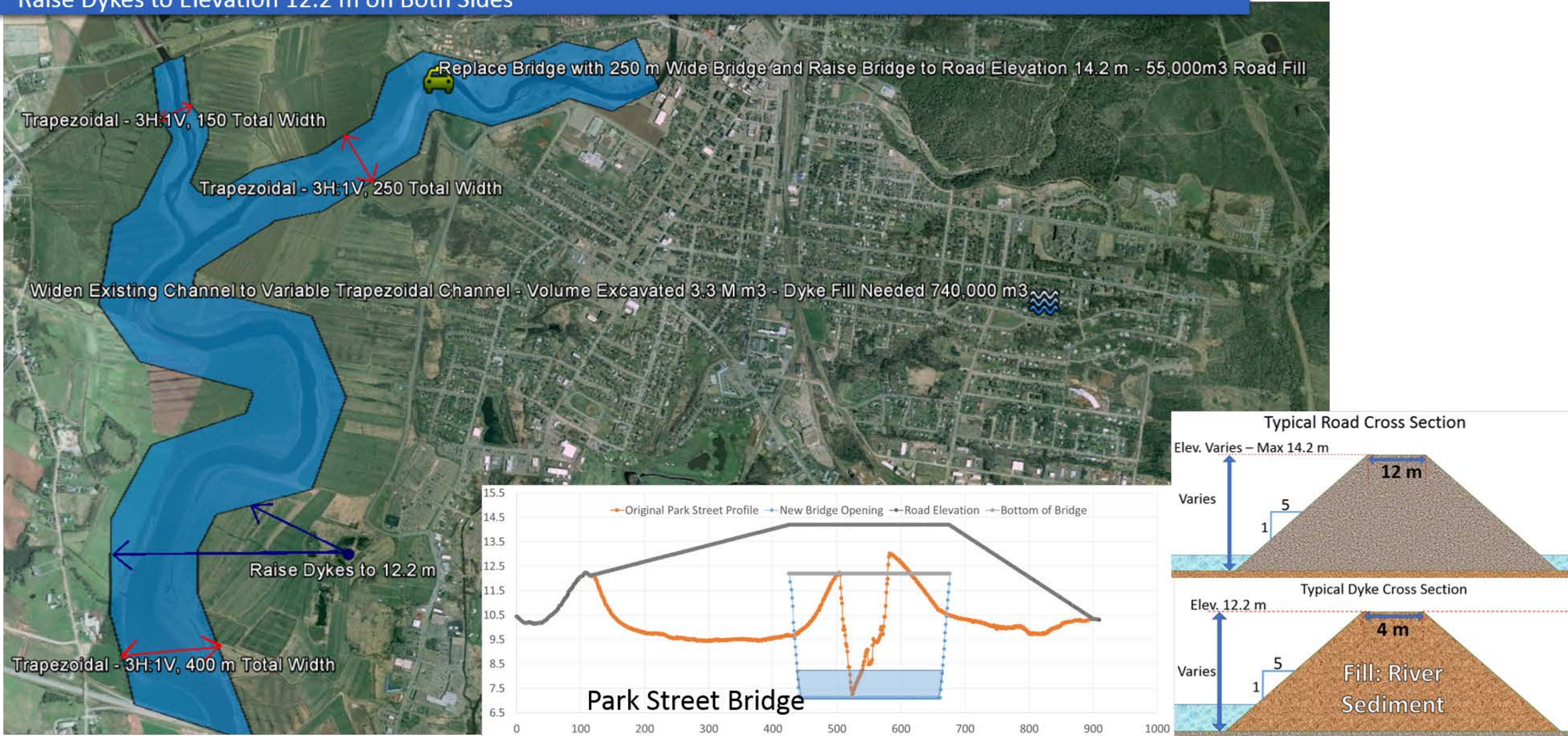
- Total Length = 4220 m
- Total Volume Dredged = 1,105,000 m^3
- (Assume Dredging to Occur in Late Spring)



Dredging 3:

Widen River to 400 m Wide Trapezoid From CN on North River and Main Street on Salmon River to HWY 102:

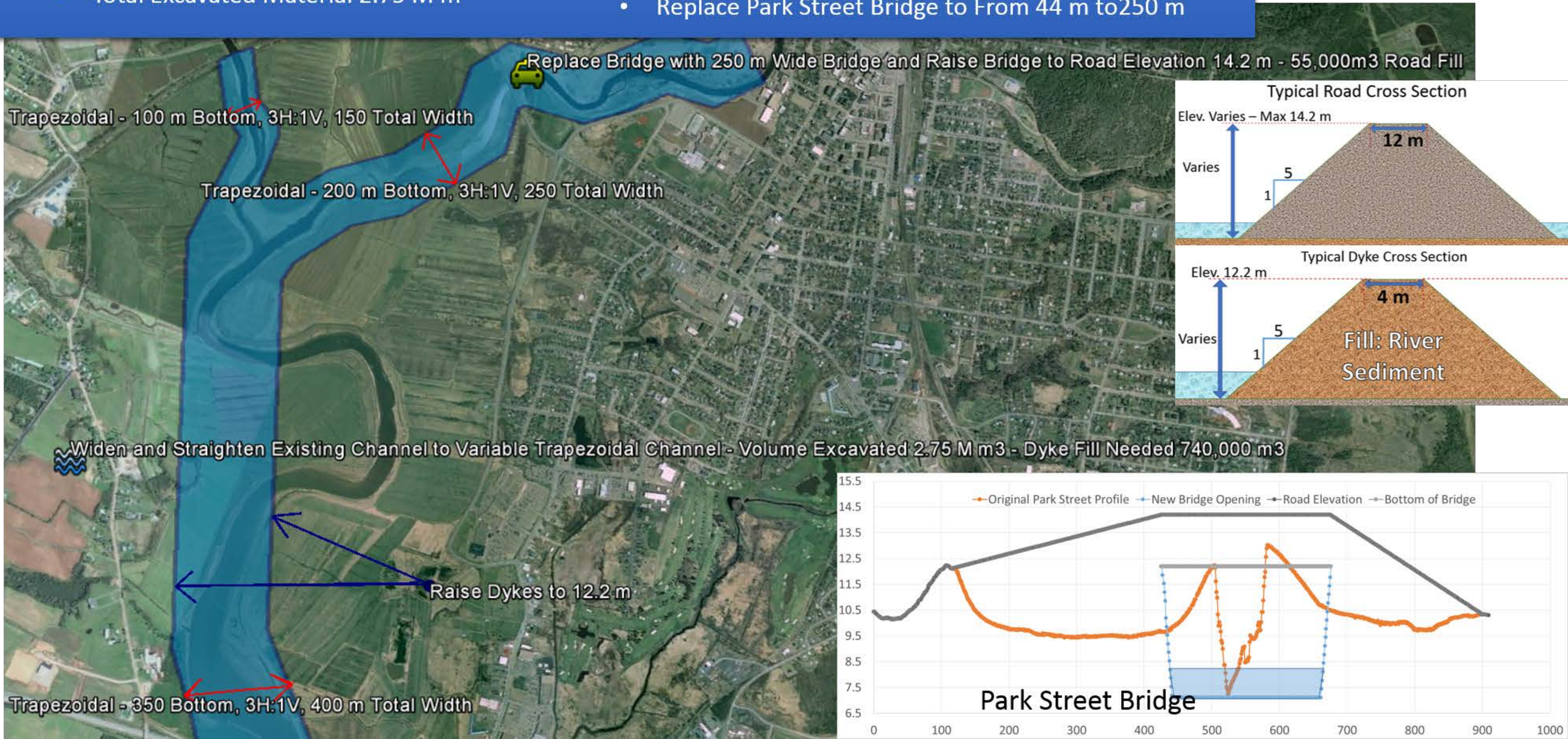
- Widen Channel to Trapezoidal Channel
  - Total Excavated Material 3.3 M m^3
- Raise Dykes to Elevation 12.2 m on Both Sides
  - Total Fill: 740,000 m^3
- Raise Park Street Bridge El 14.2
  - Total Road Fill = 55,000 m^3
- Replace Park Street Bridge From 44 m to 250 m width



Dredging 4:

Widen and Straighten River to 400 m Trapezoid From CN on North R. and Main St. on Salmon R. to HWY 102

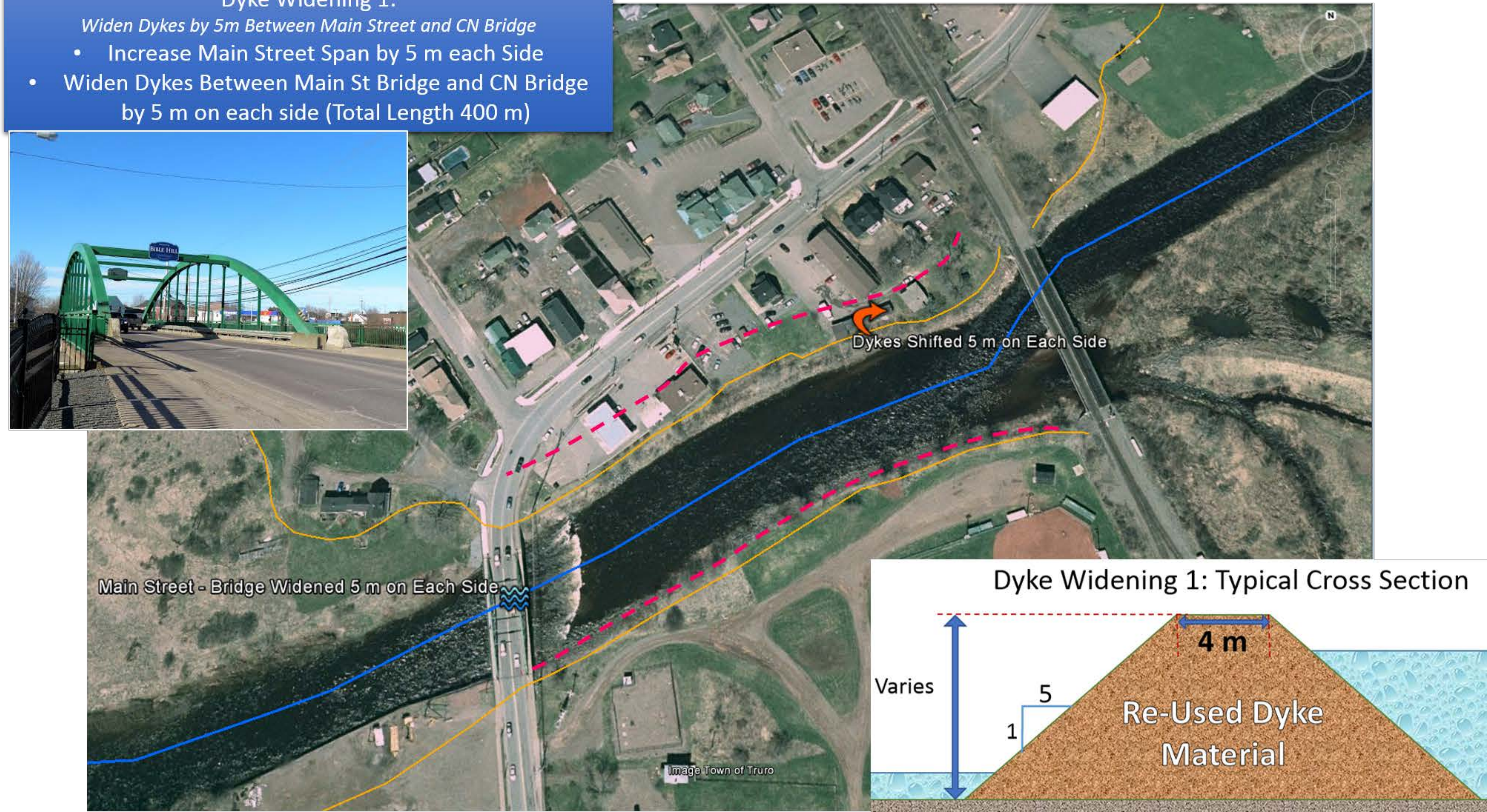
- Widen Channel to Trapezoidal Channel
  - Total Excavated Material 2.75 M m^3
- Raise Dykes to Elevation 12.2 m on Both Sides
  - Total Fill: 740,000 m^3
- Raise Park Street Bridge El 14.2
  - Total Road Fill = 55,000 m^3
- Replace Park Street Bridge to From 44 m to250 m



Dyke Widening 1:

Widen Dykes by 5m Between Main Street and CN Bridge

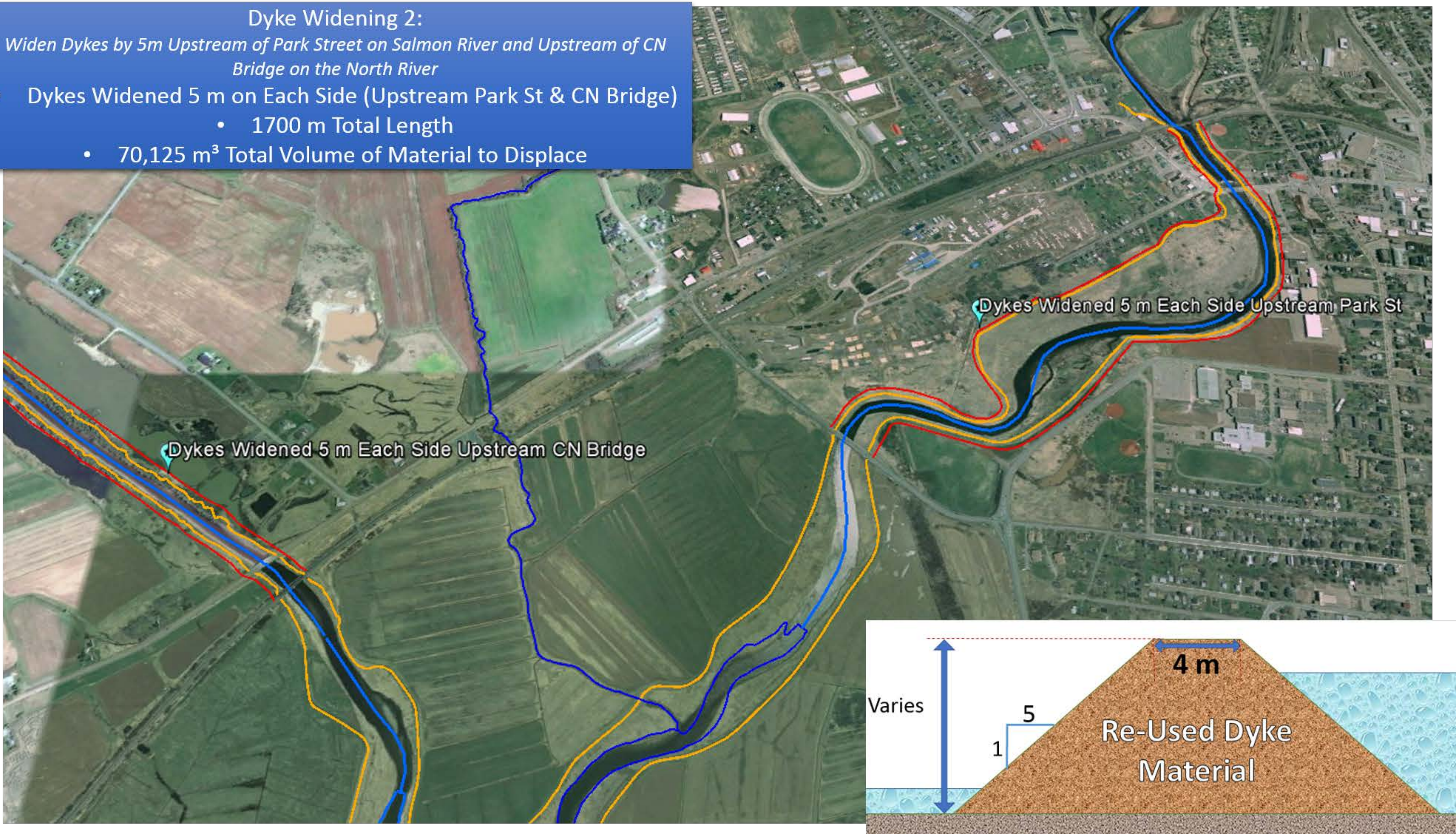
- Increase Main Street Span by 5 m each Side
- Widen Dykes Between Main St Bridge and CN Bridge by 5 m on each side (Total Length 400 m)



Dyke Widening 2:

Widen Dykes by 5m Upstream of Park Street on Salmon River and Upstream of CN Bridge on the North River

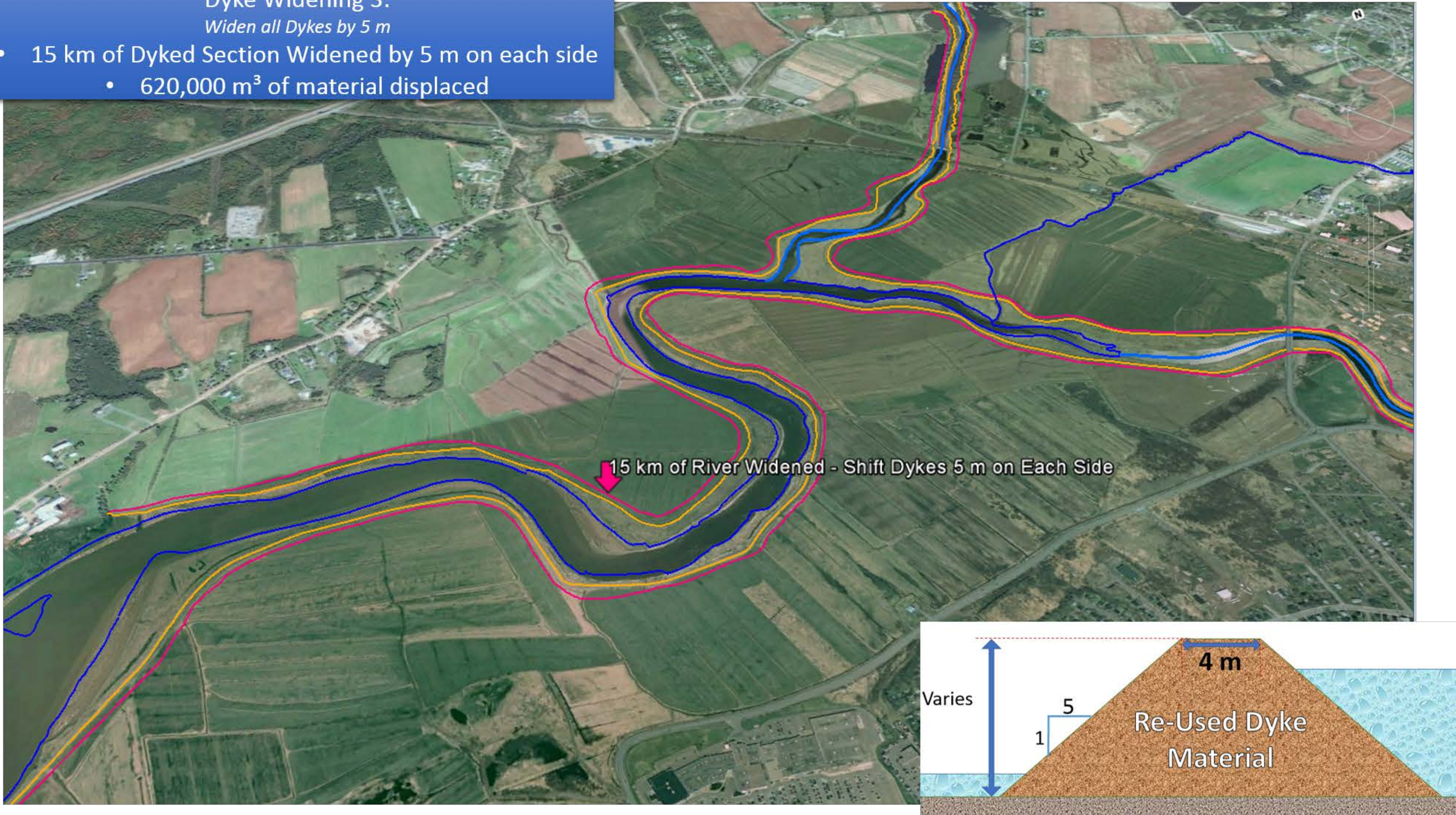
- Dykes Widened 5 m on Each Side (Upstream Park St & CN Bridge)
- 1700 m Total Length
- 70,125 m^3 Total Volume of Material to Displace



Dyke Widening 3:

Widen all Dykes by 5 m

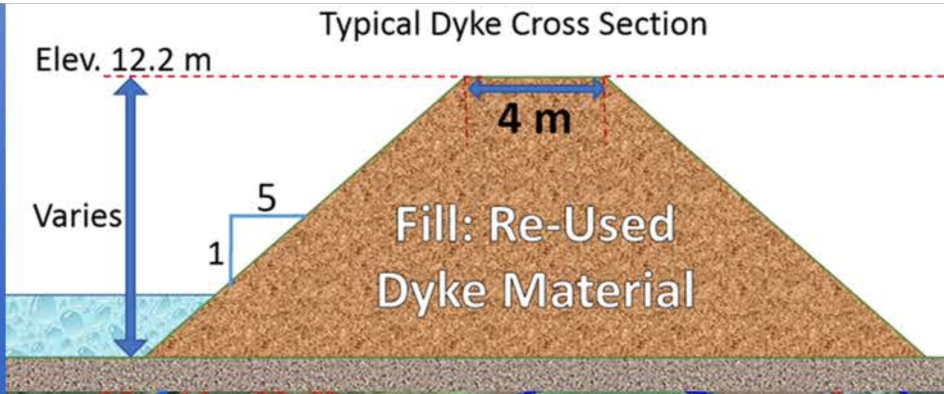
- 15 km of Dyked Section Widened by 5 m on each side
  - 620,000 m^3 of material displaced

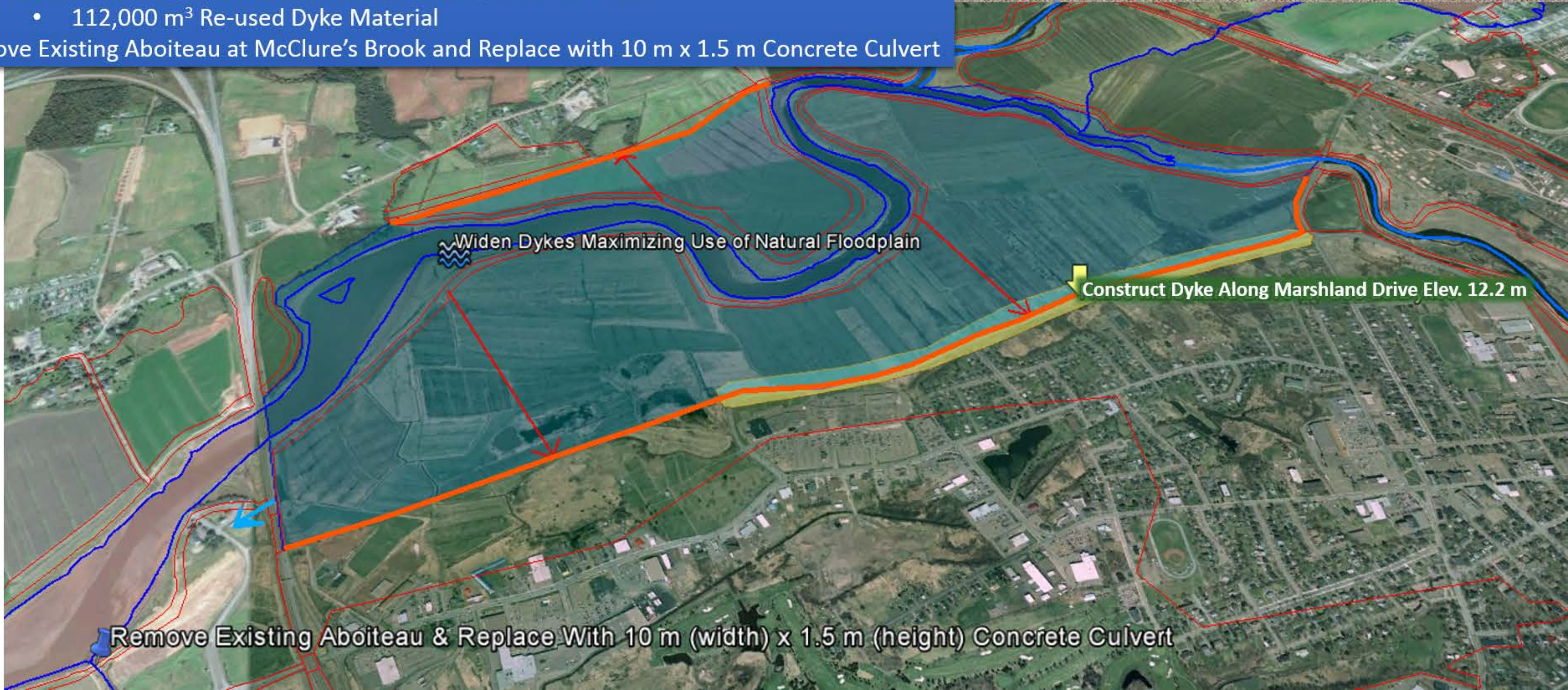


FloodPlain Restoration 1:

Widen Dykes to Larger Floodplain

- Construction of Secondary Dyke System
  - Construct Dyke Along North Side of Marshland Drive - Elevation 12.2 m
    - 97,000 m^3 Re-Used Dyke Material
  - Remove Existing Dykes and Construct New Dykes from Marshland Dr to HWY 102
    - 80,000 m^3 Re-used Dyke Material
  - Remove Existing Dykes and Construct New Dykes on RH-Side
    - 112,000 m^3 Re-used Dyke Material
- Remove Existing Aboiteau at McClure's Brook and Replace with 10 m x 1.5 m Concrete Culvert





FloodPlain Restoration 2:

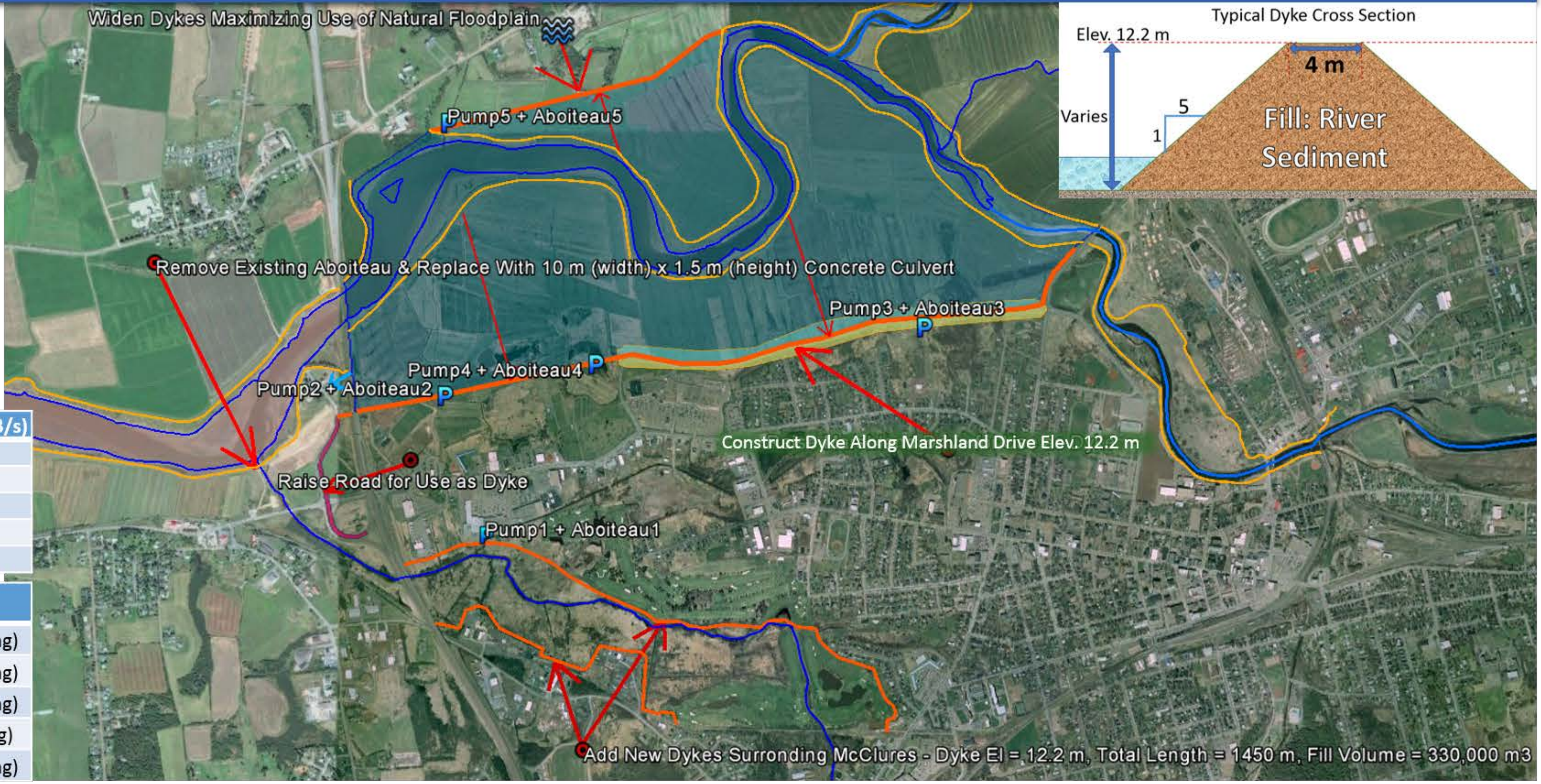
Widen Dykes to Larger Floodplain, Add Dykes to Reduce Flooding in McClures Brook & Pump Widen Dykes and Pump Behind Dykes

- Remove Existing Dykes and Construct New Dykes on RH-Side
  - 112,000 m^3 Re-used Dyke Material
- Remove Existing Aboiteau at McClure's Brook and Replace with 10 m x 1.5 m Concrete Culvert
- Add 5 Pumping Stations

- Construct Dyke Along North Side of Marshland Drive Elevation 12.2 m
  - 97,000 m^3 Re-Used Dyke Material
- Remove Existing Dykes and Construct New Dykes from Marshland Dr to HWY 102
  - 80,000 m^3 Re-used Dyke Material

Raise Tidal Bore Road
- Total Fill Volume 45,000 m^3

Construction of Dykes for McClures Brook
- Length = 790 m, Average Height = 3.1 m (Elevation 12.2 m)
- Total Fill Volume = 330,000 m^3
- Add 5 New Aboiteaux



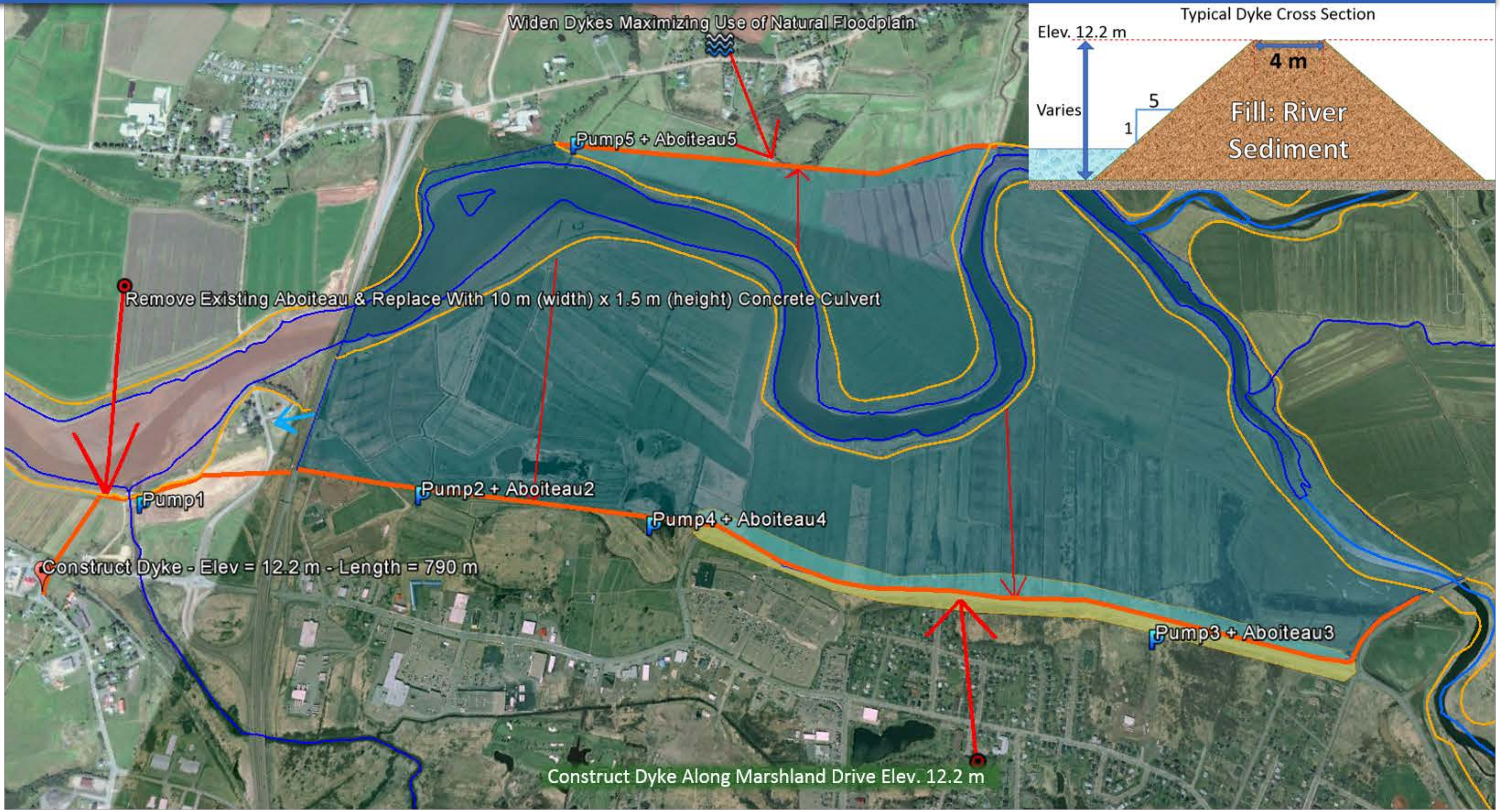
Pump#	Pumping Capacity (m3/s)
Pump1	20
Pump2	15
Pump3	25
Pump4	5
Pump5	15

Aboiteau#	Size
Aboiteau1	1800 mm (65 m Long)
Aboiteau2	1200 mm (24 m Long)
Aboiteau3	1200 mm (24 m Long)
Aboiteau4	900 mm (24 m Long)
Aboiteau5	1800 mm (24 m Long)

FloodPlain Restoration 3:

Widen Dykes to Larger Floodplain & Pump Drainage from Behind Dykes

- Construct Dyke Along North Side of Marshland Drive to Elevation 12.2 m
  - 97,000 m^3 Re-Used Dyke Material
- Remove Existing Dykes and Construct New Dykes from Marshland Dr to HWY 102
  - 80,000 m^3 Re-used Dyke Material
- Remove Existing Dykes and Construct New Dykes on RH-Side
  - 112,000 m^3 Re-used Dyke Material
- Add Dyke From HWY 102 to Truro Heights Rd (790 m)
  - 50,000 River Sediment
- Remove Existing Aboiteau at McClure's Brook and Replace with 10 m x 1.5 m Concrete Culvert
- Add 5 Pumps
- Add 5 New Aboiteaux



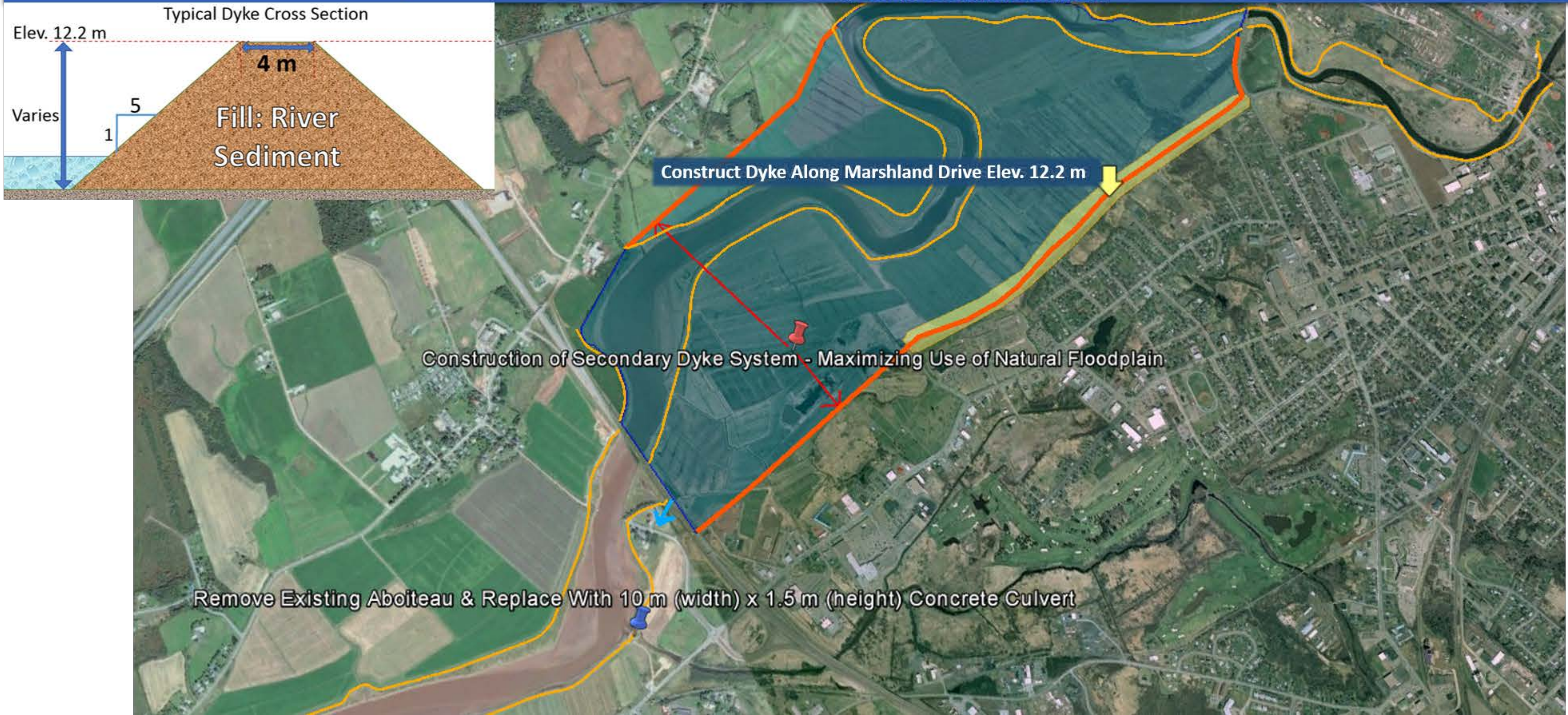
Pump#	Pumping Capacity (m3/s)
Pump1	50
Pump2	40
Pump3	25
Pump4	5
Pump5	30

Aboiteau#	Size
Aboiteau1	10 m x 1.5 m Concrete
Aboiteau2	1200 mm (24 m Long)
Aboiteau3	1200 mm (24 m Long)
Aboiteau4	900 mm (24 m Long)
Aboiteau5	1800 mm (24 m Long)

FloodPlain Restoration 4:

Add Wider Secondary Dyke System to Existing Dyke System (to Maintain Protection of Farmland)

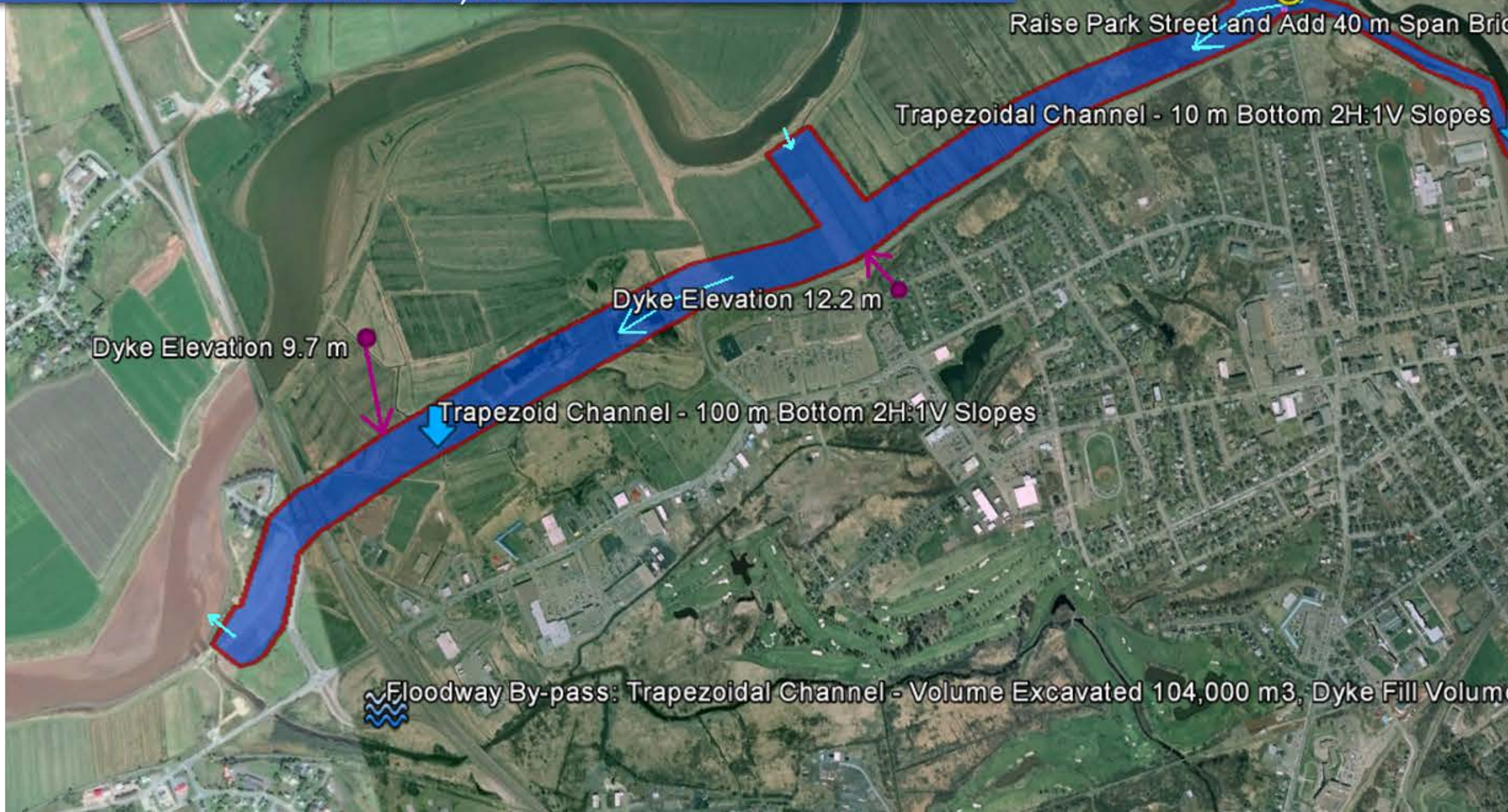
- Construction of Secondary Dyke System
  - Construct Dyke Along North Side of Marshland Drive
    - 97,000 m^3 Re-Used Dyke Material
- Construction of New Dyke from Marshland Dr to HWY 102
  - 80,000 m^3 River Sediment
- Construction of New Dyke on RH-Side
  - 112,000 m^3 River Sediment
- Remove Existing Aboiteau at McClure's Brook and Replace with 10 m x 1.5 m Concrete Culvert

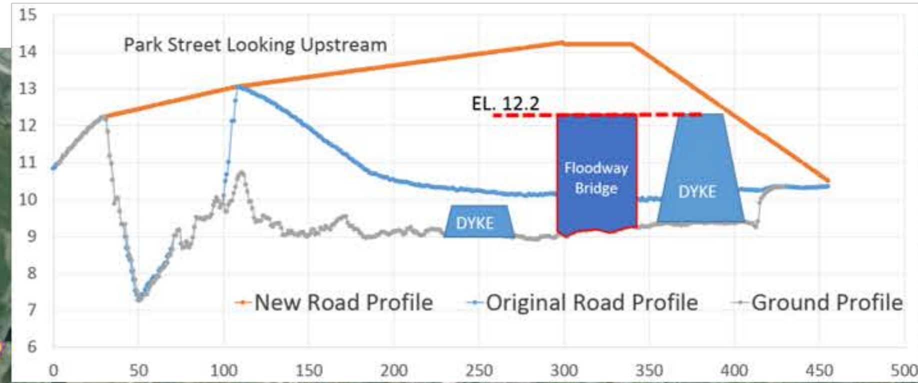


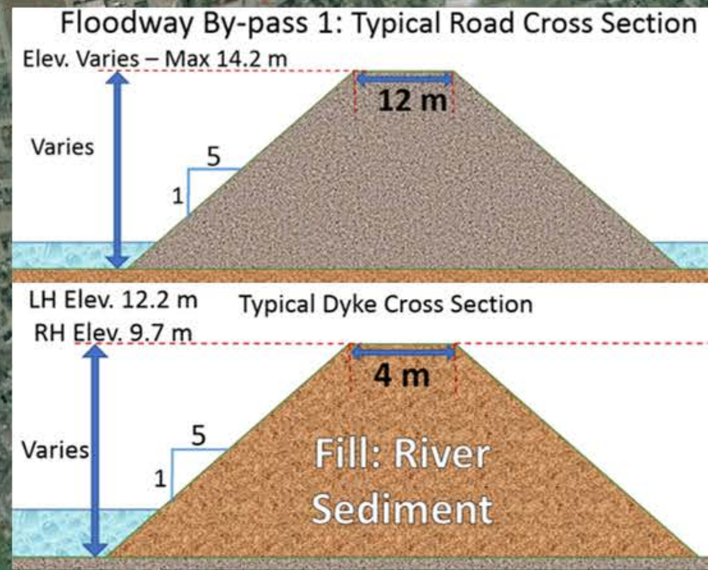
Floodway By-pass 1:

Floodway Bypass Channel - 100m Wide to McClures Brook (4.3km)

- Construction of 4.3 km Floodway Bypass
    - Channel 1 – 10 m Bottom, 3H:1V Side Slopes
    - Channel 2 – 100 m Bottom, 3H:1V Side Slopes
        - Total Volume Excavated 104,000 m^3, Total Volume for New Dykes 400,000 m^3
    - Raise 350 m Park St (Max El 14.2 m) and Construct 40 m Span Concrete Bridge
        - Road Fill Volume 45,000 m^3



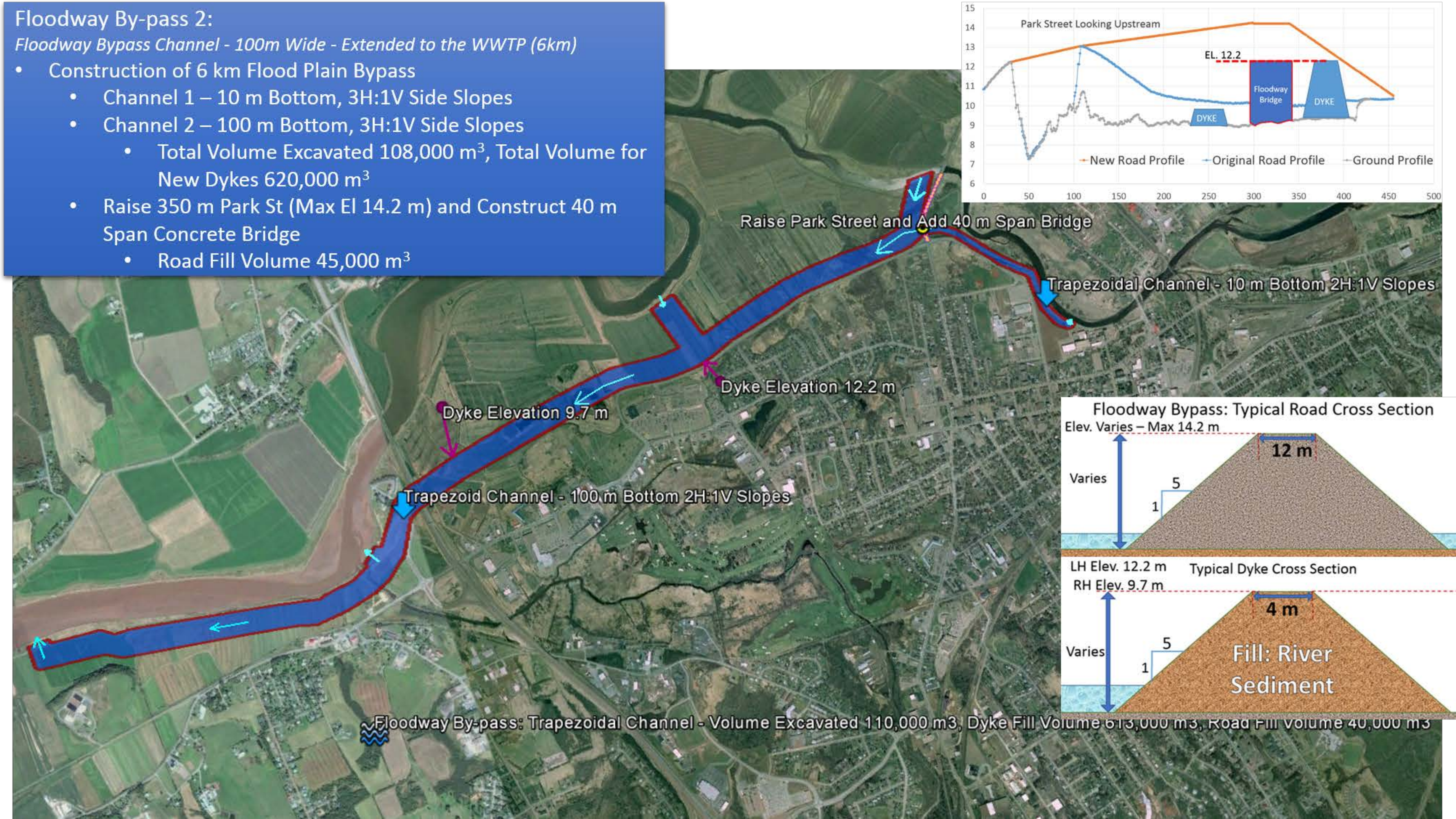




Floodway By-pass 2:

Floodway Bypass Channel - 100m Wide - Extended to the WWTP (6km)

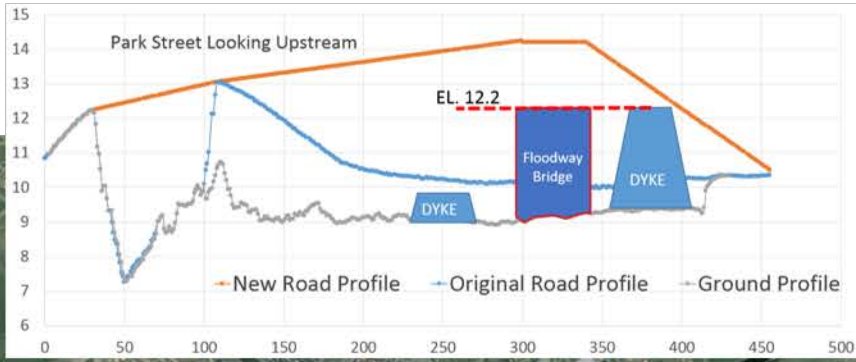
- Construction of 6 km Flood Plain Bypass
  - Channel 1 – 10 m Bottom, 3H:1V Side Slopes
  - Channel 2 – 100 m Bottom, 3H:1V Side Slopes
    - Total Volume Excavated 108,000 m^3, Total Volume for New Dykes 620,000 m^3
  - Raise 350 m Park St (Max El 14.2 m) and Construct 40 m Span Concrete Bridge
    - Road Fill Volume 45,000 m^3

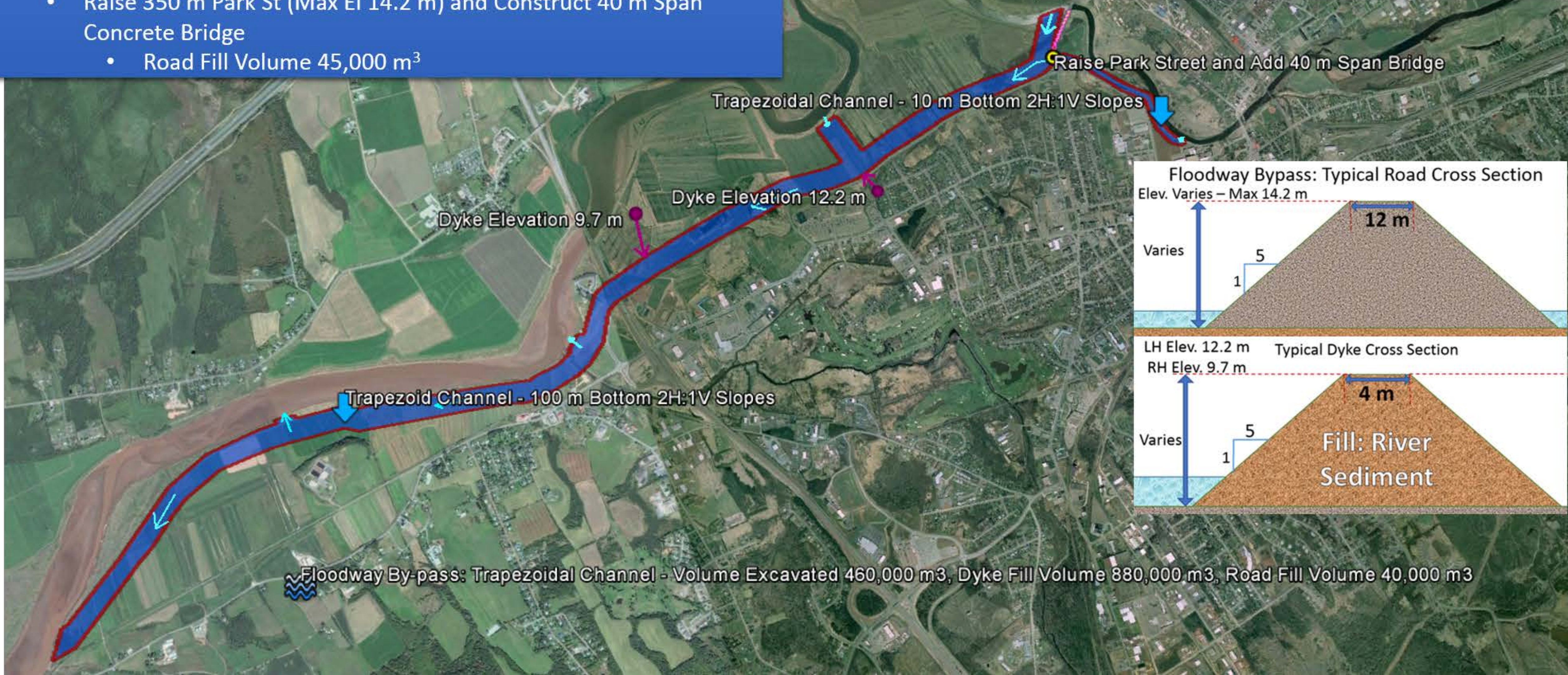


Floodway By-pass 3:

Floodway Bypass - Extended to Lower Truro (7.75km)

- Construction of 7.75 km Flood Plain Bypass
  - Channel 1 – 10 m Bottom, 3H:1V Side Slopes
  - Channel 2 – 100 m Bottom, 3H:1V Side Slopes
    - Total Volume Excavated 460,000 m^3, Total Volume for New Dykes 880,000 m^3
  - Raise 350 m Park St (Max El 14.2 m) and Construct 40 m Span Concrete Bridge
    - Road Fill Volume 45,000 m^3





Priority Area Protection 1:

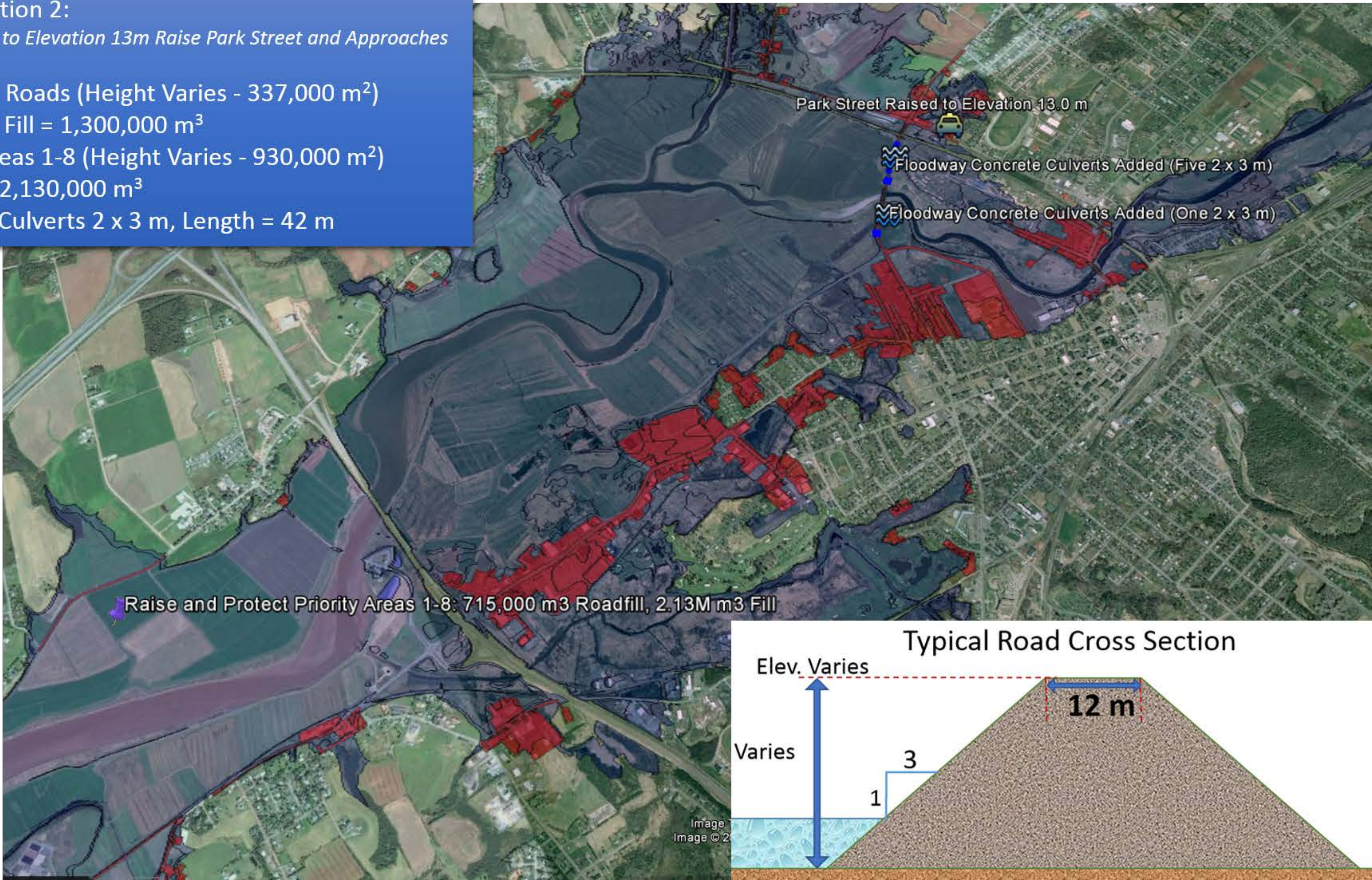
Raise Priority Areas 1 -3 to Elevation 13m Raise Park Street and Approaches to Elevation of 13 m

- Raise Main Street 2 m
  - Total Road Fill = 282,000 m^3
- Raise CEC High School and Surrounding Area
  - Total Fill = 163,000 m^3
- Add 6 Concrete Culverts 2 x 3 m, Length = 42 m

Priority Area Protection 2:

Raise Priority Areas 1 -8 to Elevation 13m Raise Park Street and Approaches to Elevation of 13 m

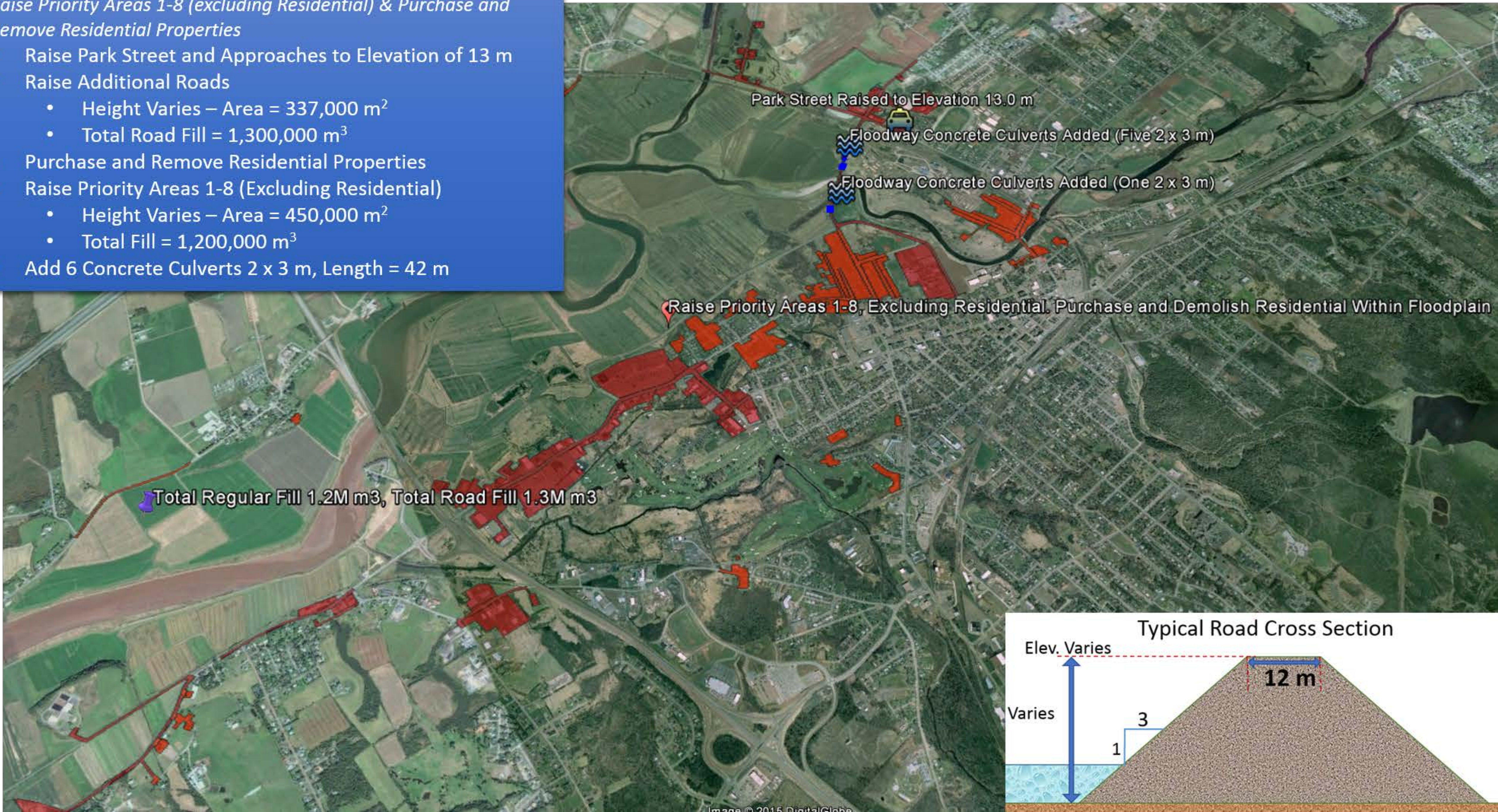
- Raise Additional Roads (Height Varies - 337,000 m^2)
  - Total Road Fill = 1,300,000 m^3
- Raise Priority Areas 1-8 (Height Varies - 930,000 m^2)
  - Total Fill = 2,130,000 m^3
- Add 6 Concrete Culverts 2 x 3 m, Length = 42 m



Priority Area Protection 3:

Raise Priority Areas 1-8 (excluding Residential) & Purchase and Remove Residential Properties

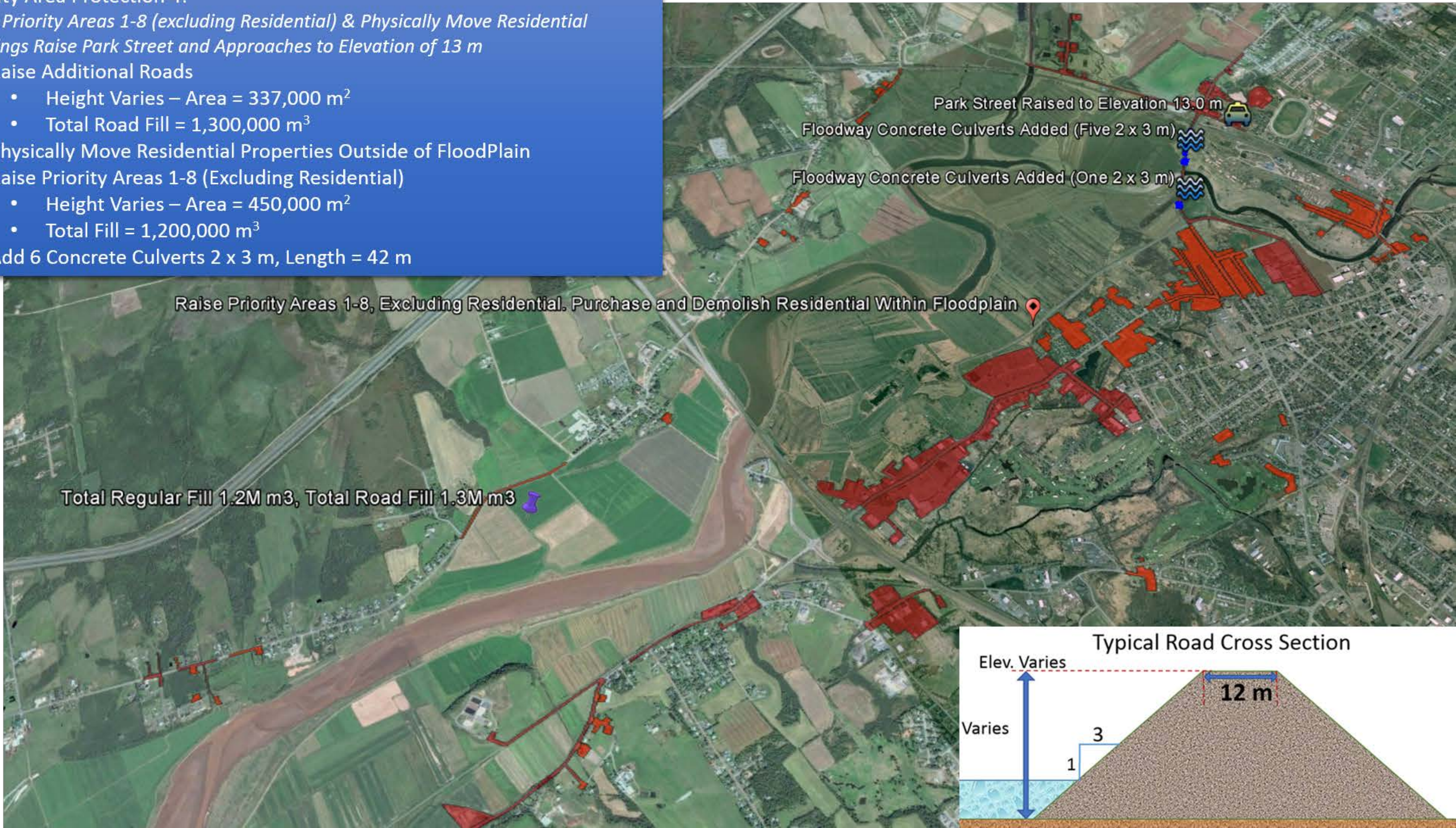
- Raise Park Street and Approaches to Elevation of 13 m
- Raise Additional Roads
  - Height Varies – Area = 337,000 m^2
  - Total Road Fill = 1,300,000 m^3
- Purchase and Remove Residential Properties
- Raise Priority Areas 1-8 (Excluding Residential)
  - Height Varies – Area = 450,000 m^2
  - Total Fill = 1,200,000 m^3
- Add 6 Concrete Culverts 2 x 3 m, Length = 42 m



Priority Area Protection 4:

Raise Priority Areas 1-8 (excluding Residential) & Physically Move Residential Buildings Raise Park Street and Approaches to Elevation of 13 m

- Raise Additional Roads
    - Height Varies – Area = 337,000 m^2
    - Total Road Fill = 1,300,000 m^3
- Physically Move Residential Properties Outside of FloodPlain
- Raise Priority Areas 1-8 (Excluding Residential)
    - Height Varies – Area = 450,000 m^2
    - Total Fill = 1,200,000 m^3
- Add 6 Concrete Culverts 2 x 3 m, Length = 42 m



Priority Area Protection 5:

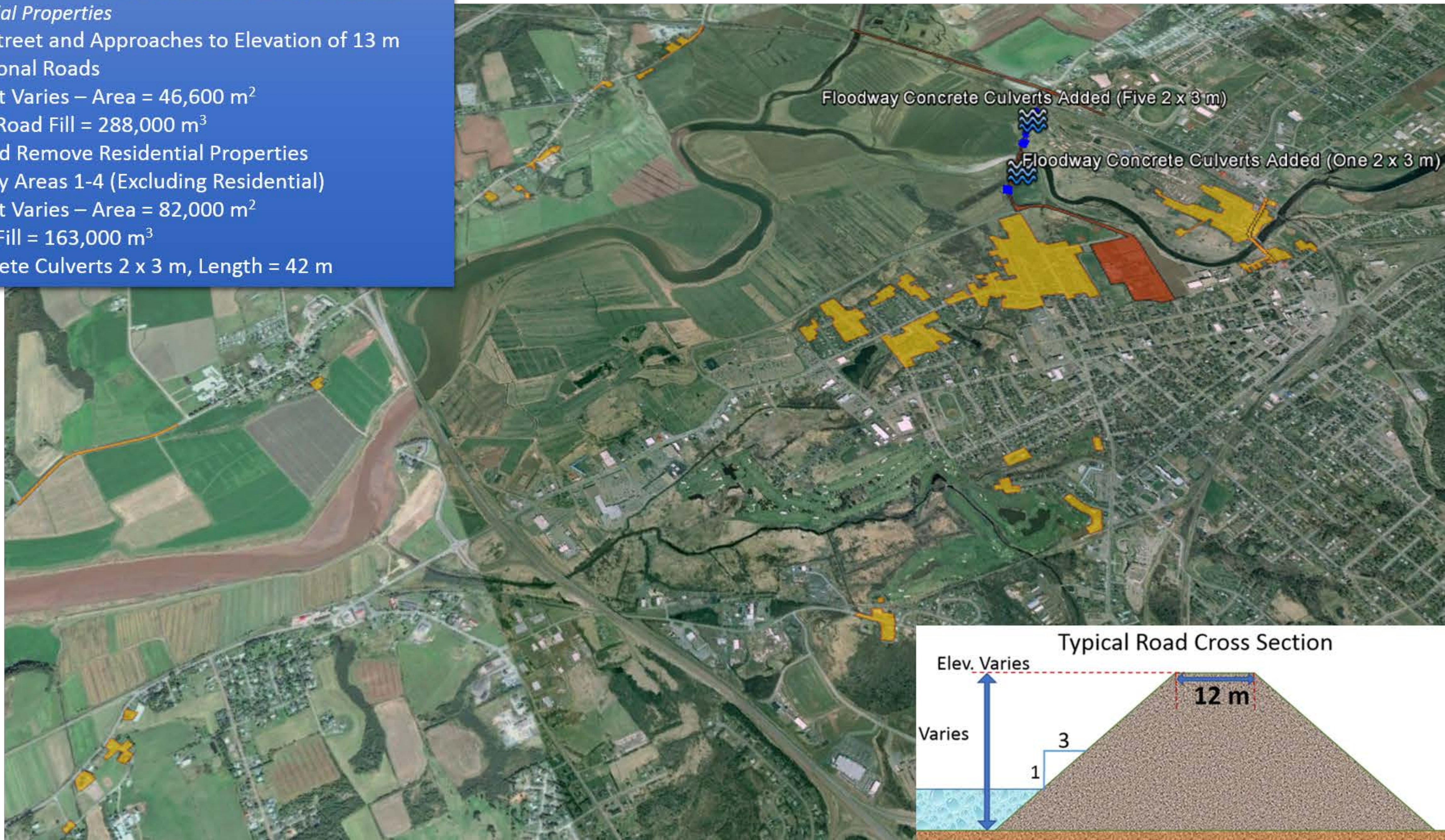
Raise Priority Areas 1 -4 to Elevation 13m

- Raise Park Street and Approaches to Elevation of 13 m
- Raise Additional Roads (Height Varies – 298,000 m^2)
  - Total Road Fill = 1,148,000 m^3
- Raise Priority Areas 1-4 (Height Varies - 561,000 m^2)
  - Total Fill = 1,140,000 m^3
- Add 6 Concrete Culverts 2 x 3 m, Length = 42 m

Priority Area Protection 6:

Raise Priority Areas 1-4 (excluding Residential) & Purchase and Remove Residential Properties

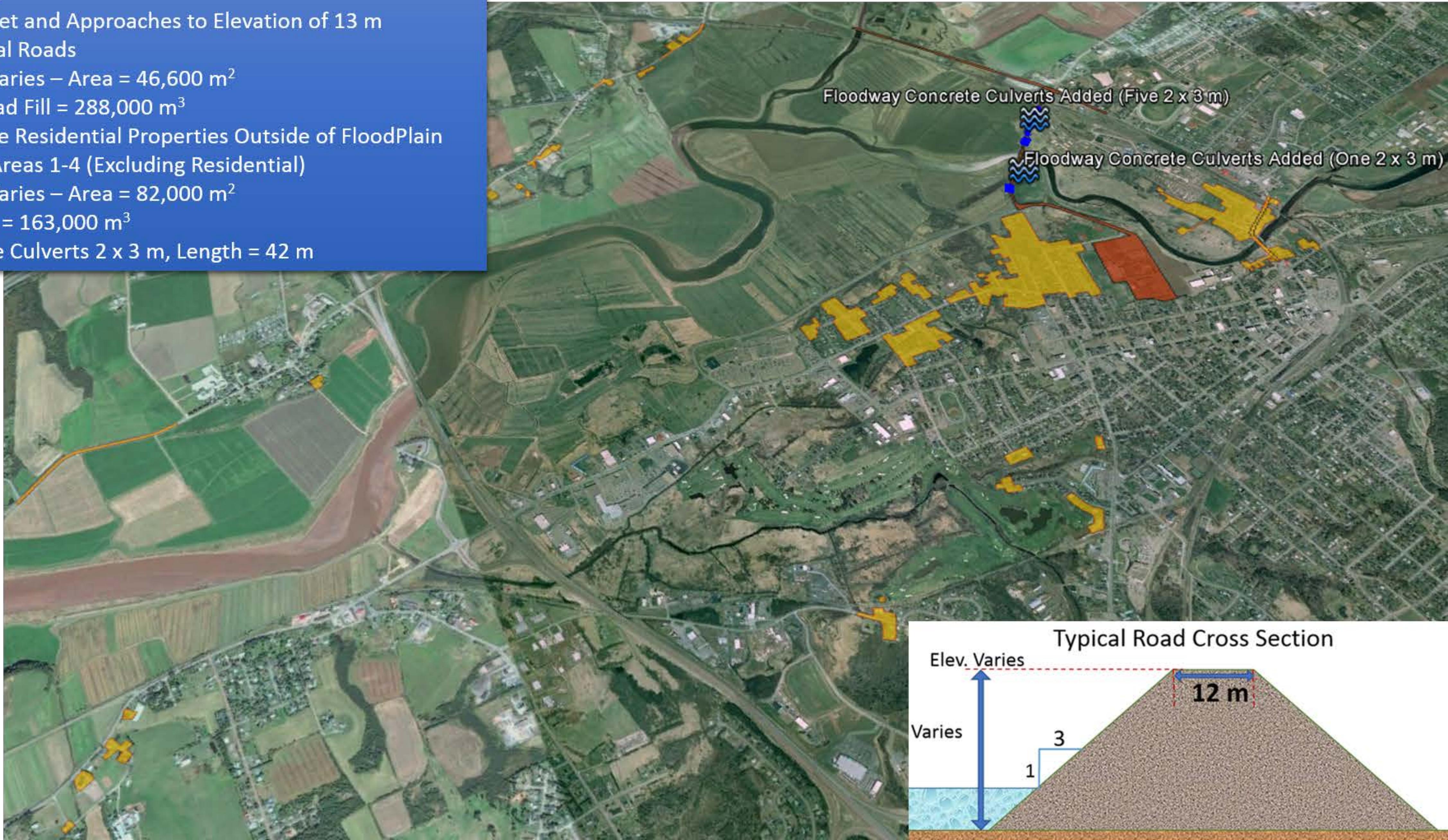
- Raise Park Street and Approaches to Elevation of 13 m
- Raise Additional Roads
    - Height Varies – Area = 46,600 m^2
    - Total Road Fill = 288,000 m^3
- Purchase and Remove Residential Properties
- Raise Priority Areas 1-4 (Excluding Residential)
    - Height Varies – Area = 82,000 m^2
    - Total Fill = 163,000 m^3
- Add 6 Concrete Culverts 2 x 3 m, Length = 42 m



Priority Area Protection 7:

Raise Priority Areas 1-4 (excluding Residential) & Physically Move Residential Buildings

- Raise Park Street and Approaches to Elevation of 13 m
- Raise Additional Roads
    - Height Varies – Area = 46,600 m^2
    - Total Road Fill = 288,000 m^3
- Physically Move Residential Properties Outside of FloodPlain
- Raise Priority Areas 1-4 (Excluding Residential)
    - Height Varies – Area = 82,000 m^2
    - Total Fill = 163,000 m^3
- Add 6 Concrete Culverts 2 x 3 m, Length = 42 m



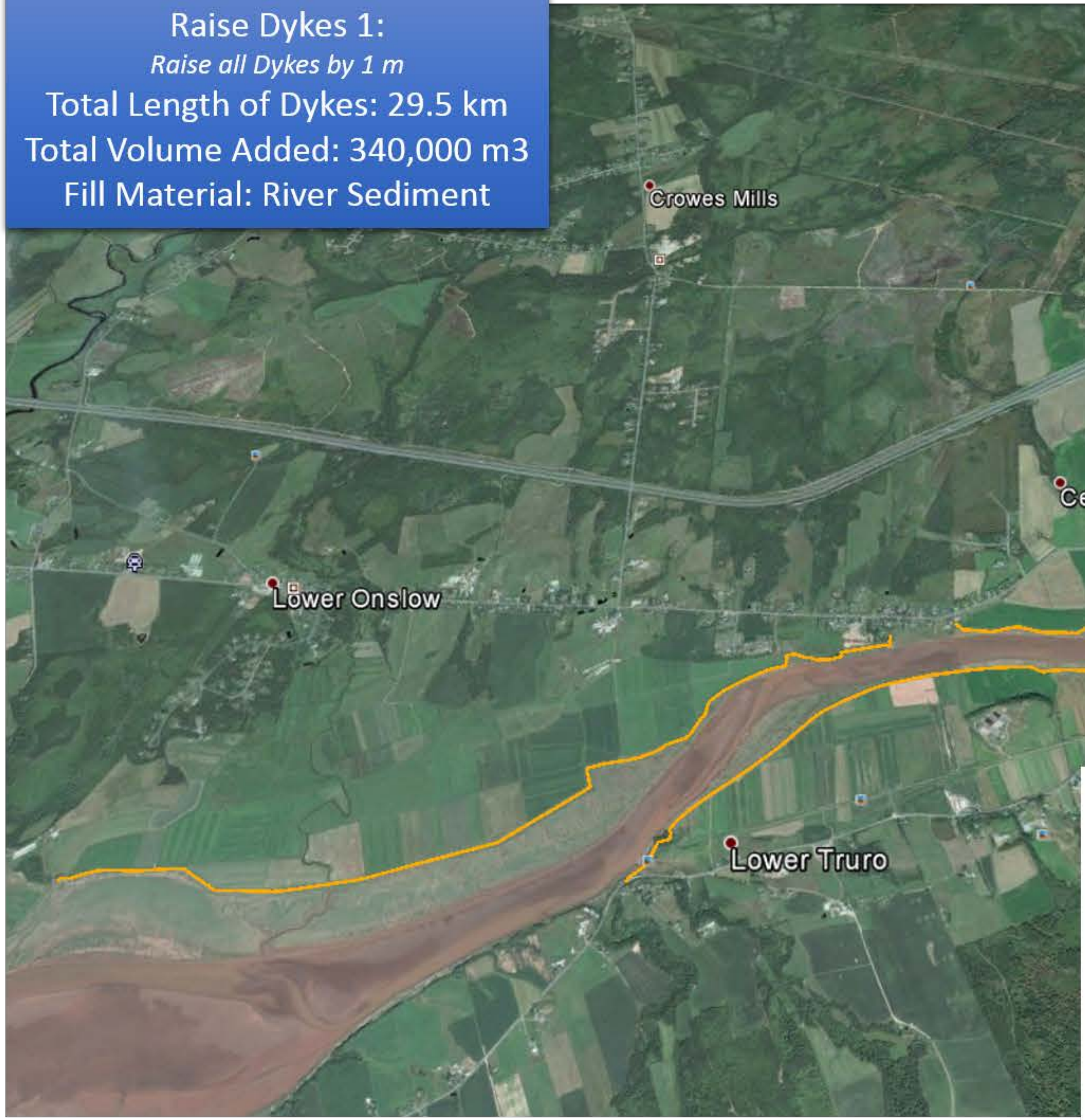
Raise Dykes 1:

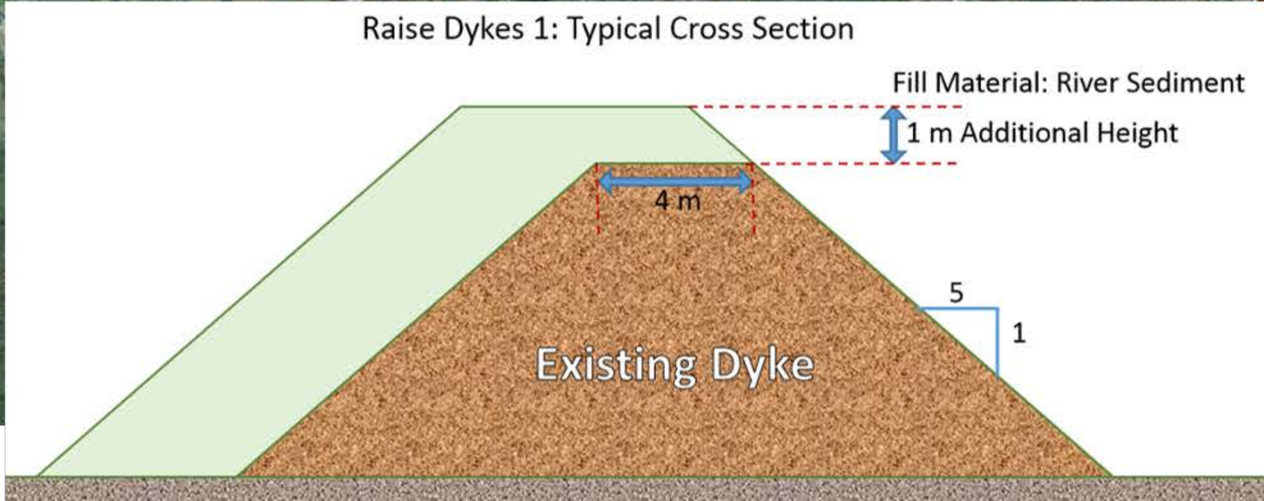
Raise all Dykes by 1 m

Total Length of Dykes: 29.5 km

Total Volume Added: 340,000 m3

Fill Material: River Sediment





Raise Dykes 2:

Raise all Dykes (Varied Height) to Contain all River Flood

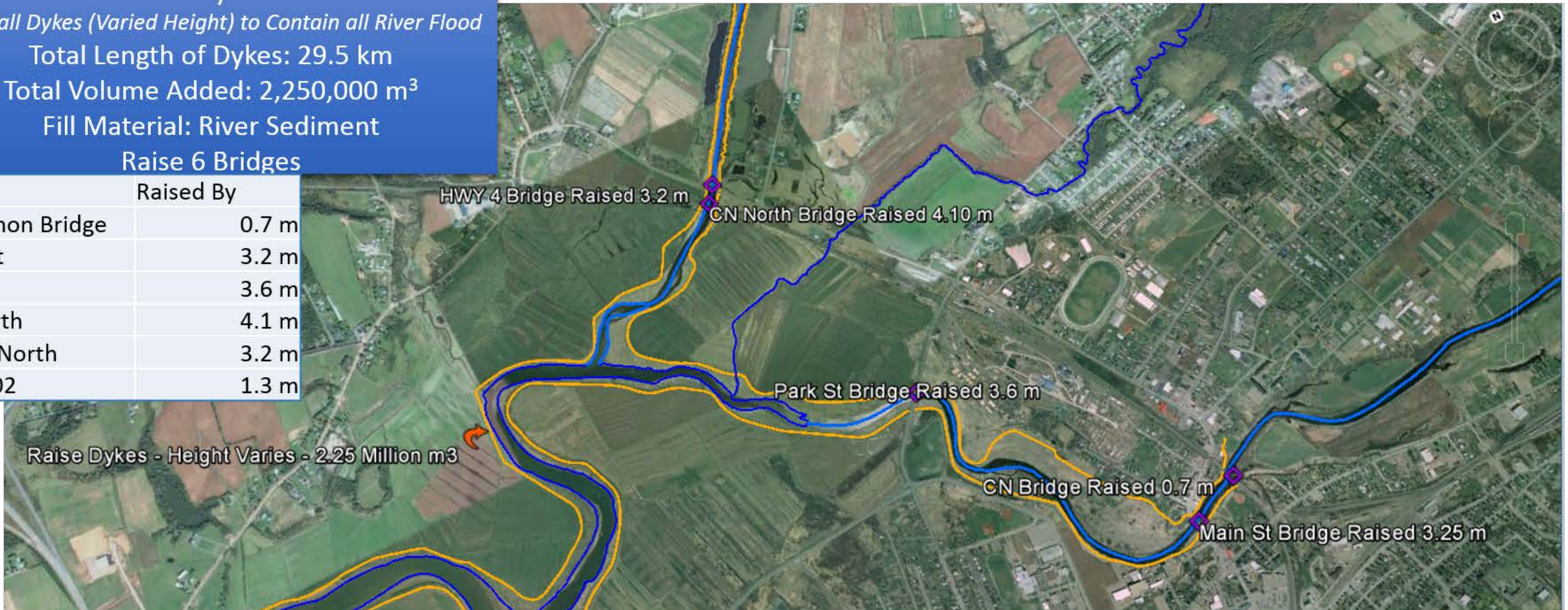
Total Length of Dykes: 29.5 km

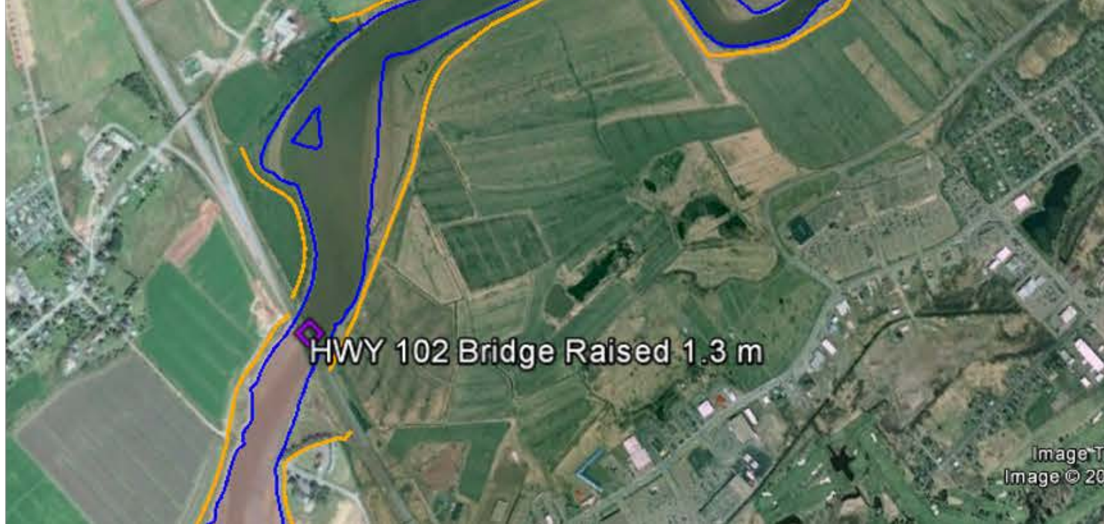
Total Volume Added: 2,250,000 m^3

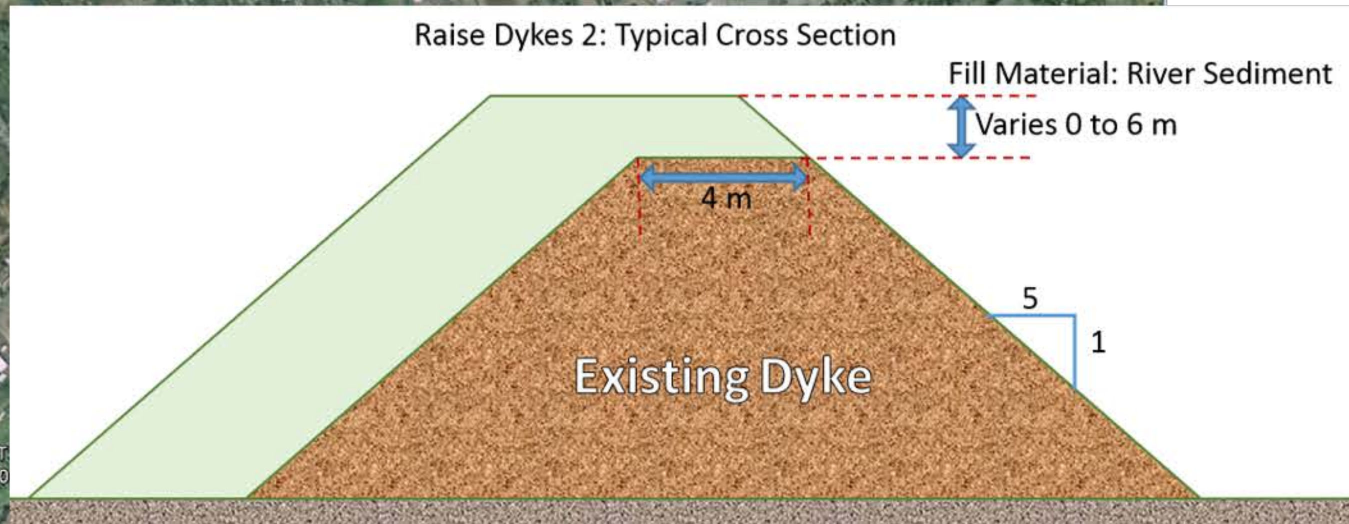
Fill Material: River Sediment

Raise 6 Bridges

Bridge	Raised By
CNSalmon Bridge	0.7 m
Main st	3.2 m
Park St	3.6 m
CN North	4.1 m
HWY4 North	3.2 m
HWY102	1.3 m







Raise Dykes 3:

Raise all Dykes (Varied Height) to Contain all River Flood & Pump Drainage from Behind Dykes

Total Length of Dykes: 29.5 km

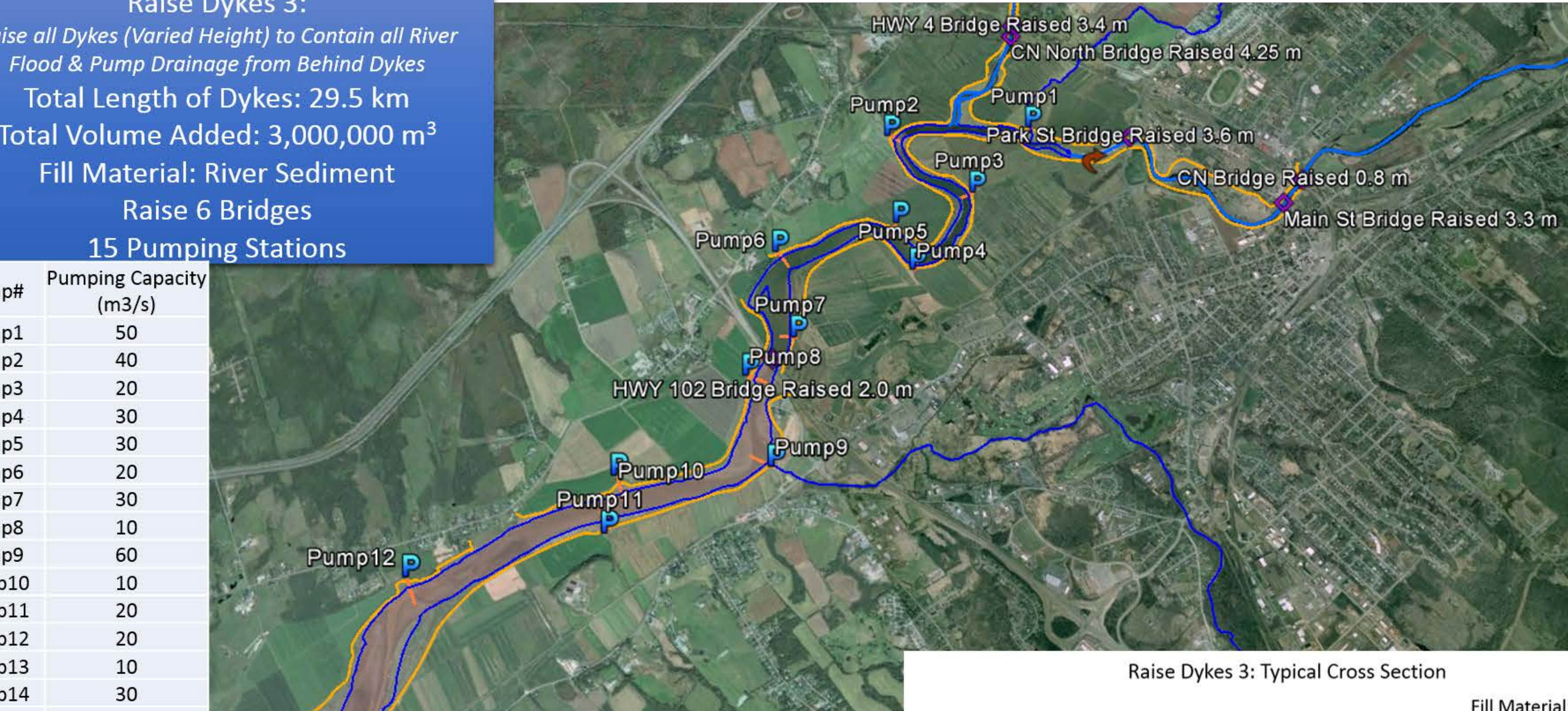
Total Volume Added: 3,000,000 m^3

Fill Material: River Sediment

Raise 6 Bridges

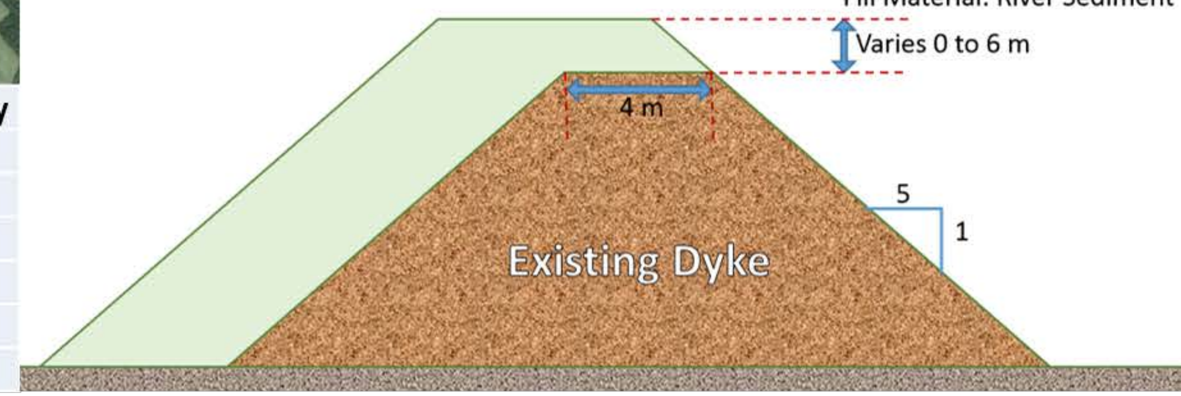
15 Pumping Stations

Pump#	Pumping Capacity (m3/s)
Pump1	50
Pump2	40
Pump3	20
Pump4	30
Pump5	30
Pump6	20
Pump7	30
Pump8	10
Pump9	60
Pump10	10
Pump11	20
Pump12	20
Pump13	10
Pump14	30
Pump15	110



Bridge	Raised By
CNSalmon Bridge	0.76
Main st	3.29
Park St	3.76
CN North	4.23
HWY4 North	3.37
HWY102	2

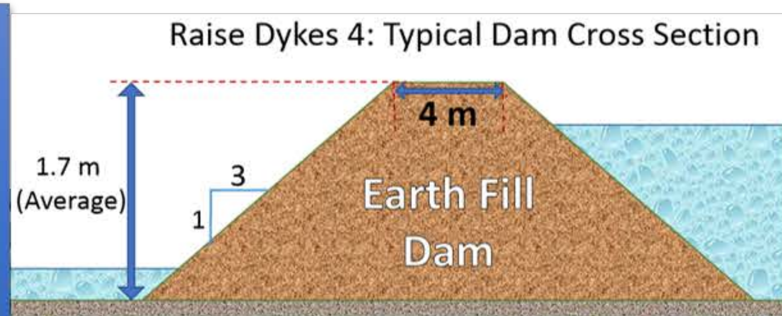
Raise Dykes 3: Typical Cross Section

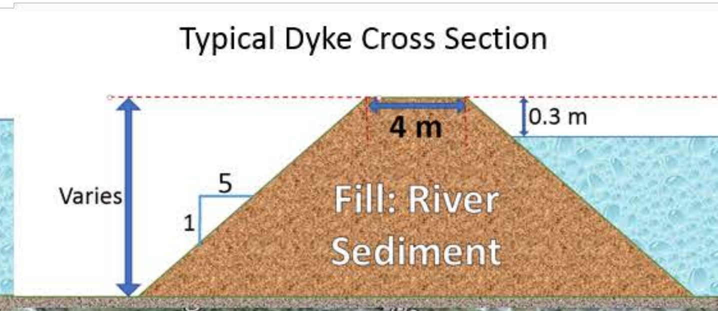


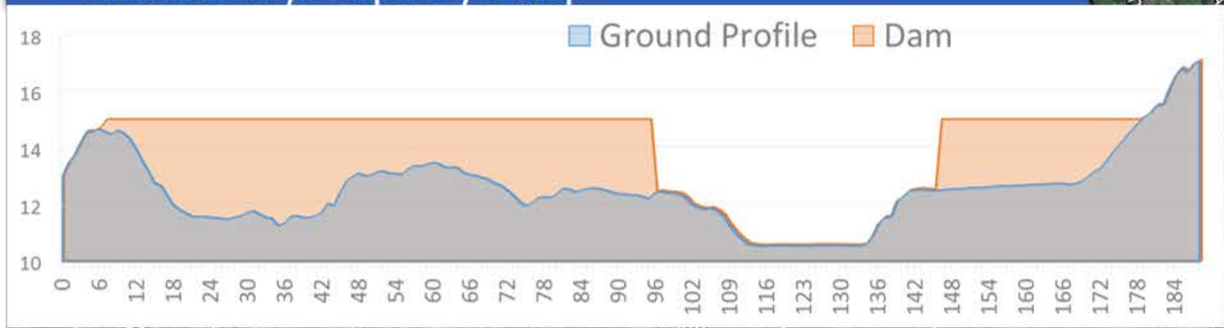
Raise Dykes 4:

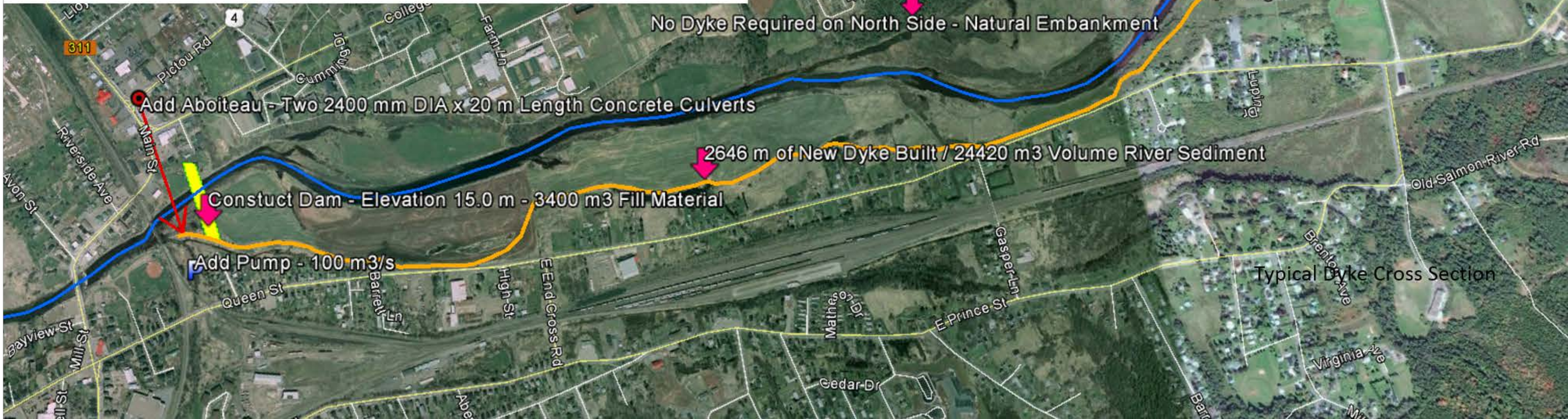
Reduce flow to CN Bridge on Salmon River and Build Dykes Upstream

- Construct Dam Upstream CN Bridge
  - 3400 m^3 Fill
- Construction of 2646 m of New Dykes
  - 24420 m^3 Fill
- Add Aboiteau
  - Two 2400 mm x 20 m Concrete Culverts
- Add 100 m^3/s Capacity Pump









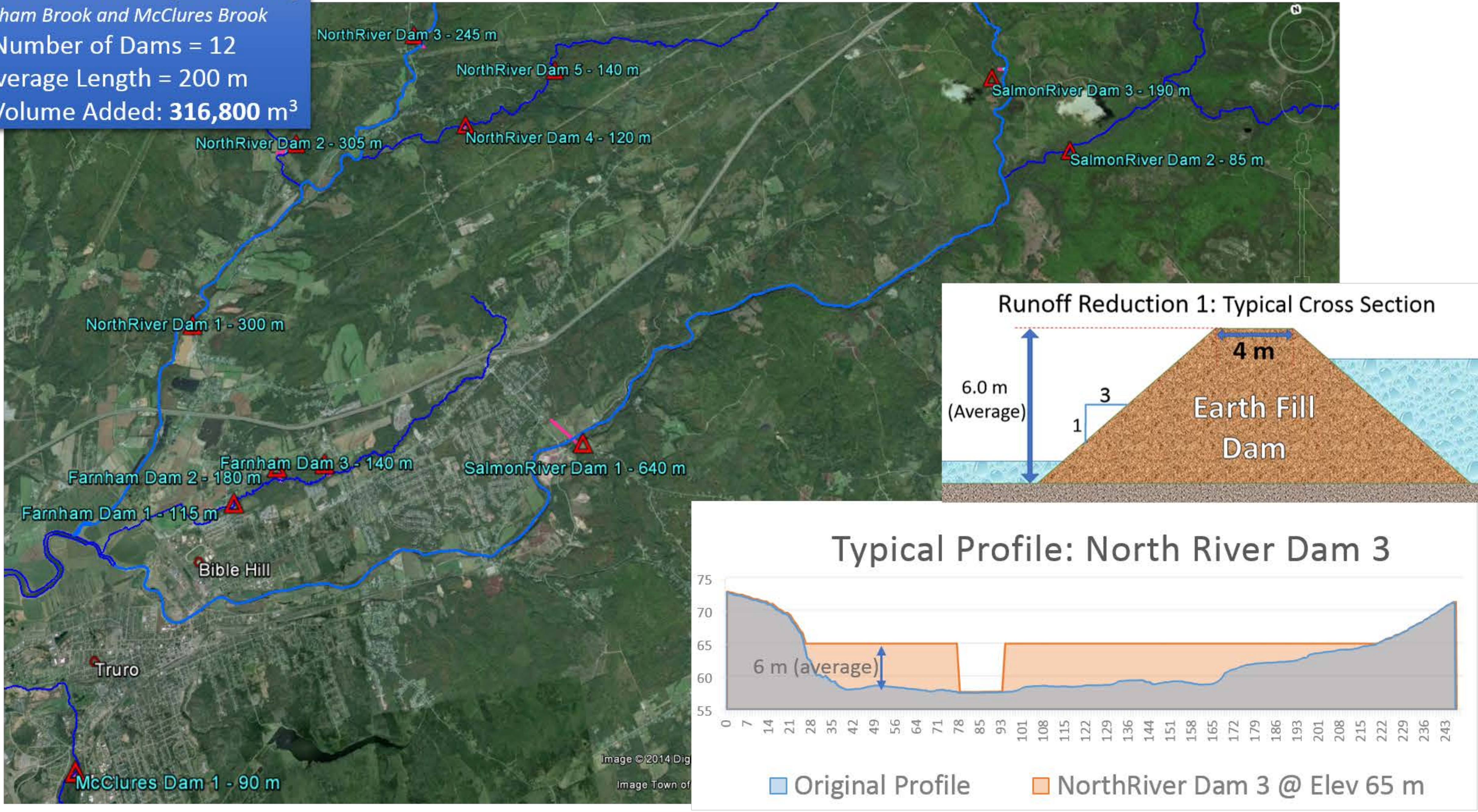
Runoff Reduction 1:

Upstream Dams: North River, Salmon River, Farnham Brook and McClures Brook

Number of Dams = 12

Average Length = 200 m

Total Volume Added: **316,800** m^3



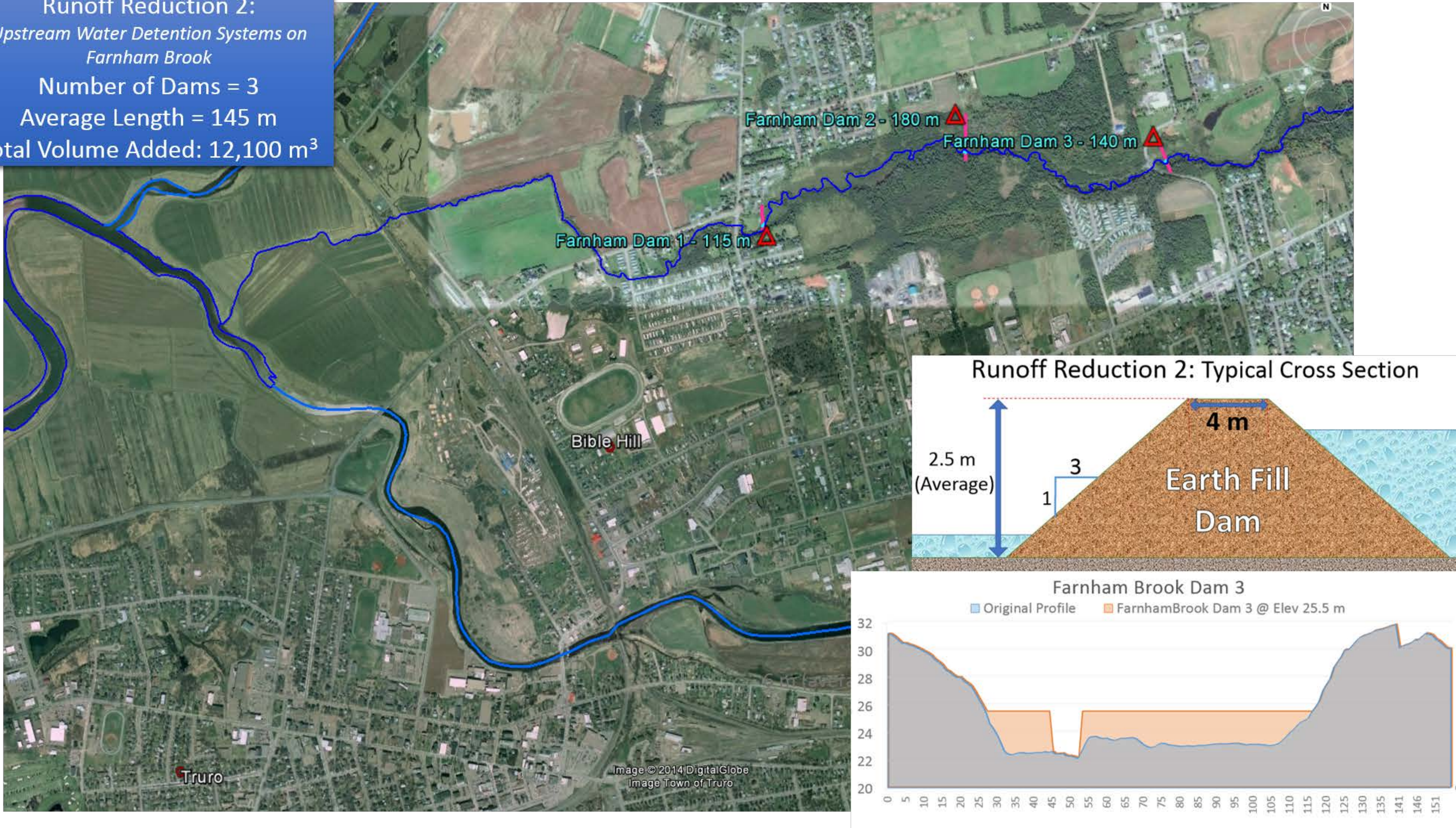
Runoff Reduction 2:

Upstream Water Detention Systems on Farnham Brook

Number of Dams = 3

Average Length = 145 m

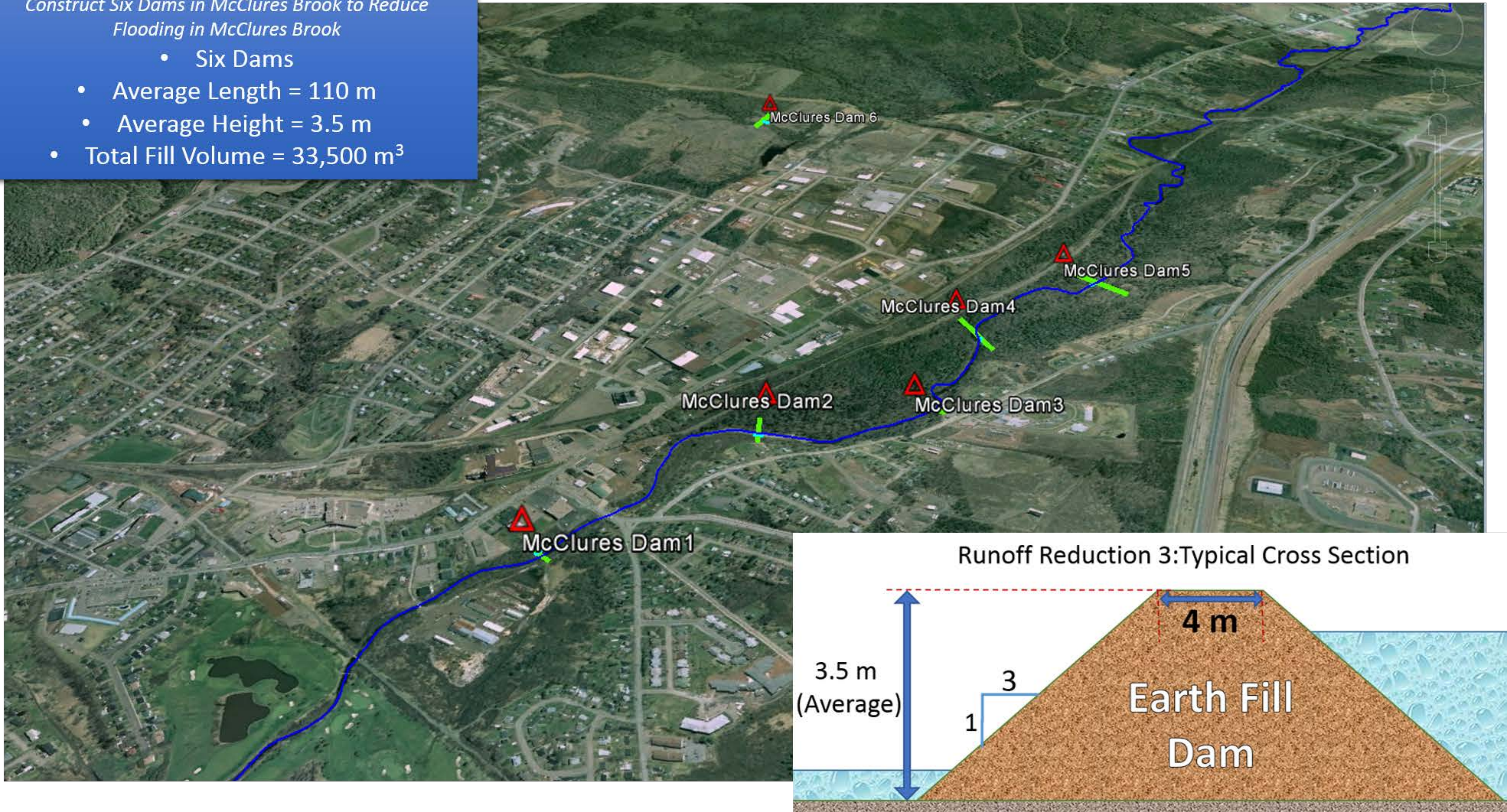
Total Volume Added: 12,100 m^3



Runoff Reduction 3:

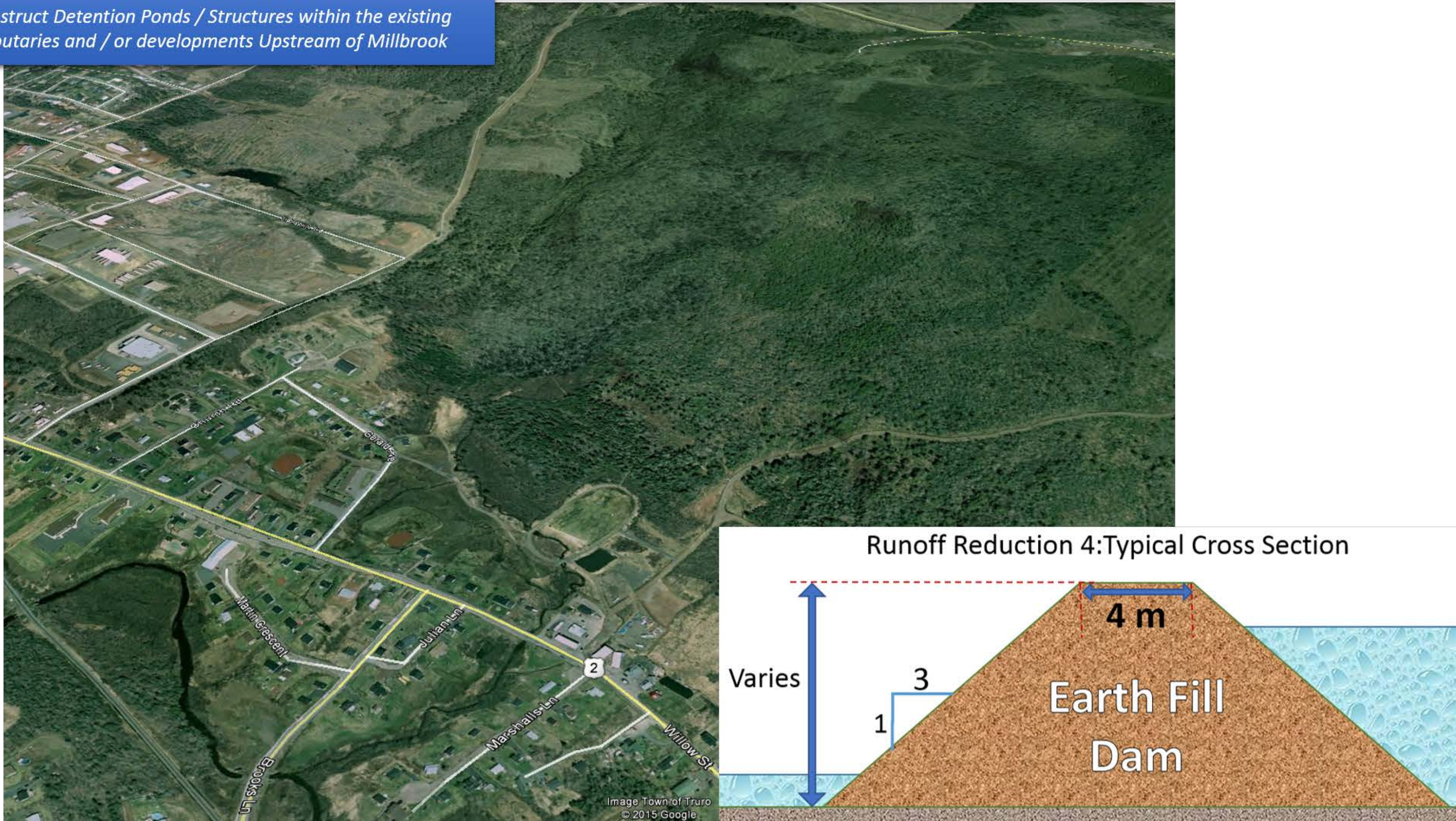
Construct Six Dams in McClures Brook to Reduce Flooding in McClures Brook

- Six Dams
- Average Length = 110 m
- Average Height = 3.5 m
- Total Fill Volume = 33,500 m^3



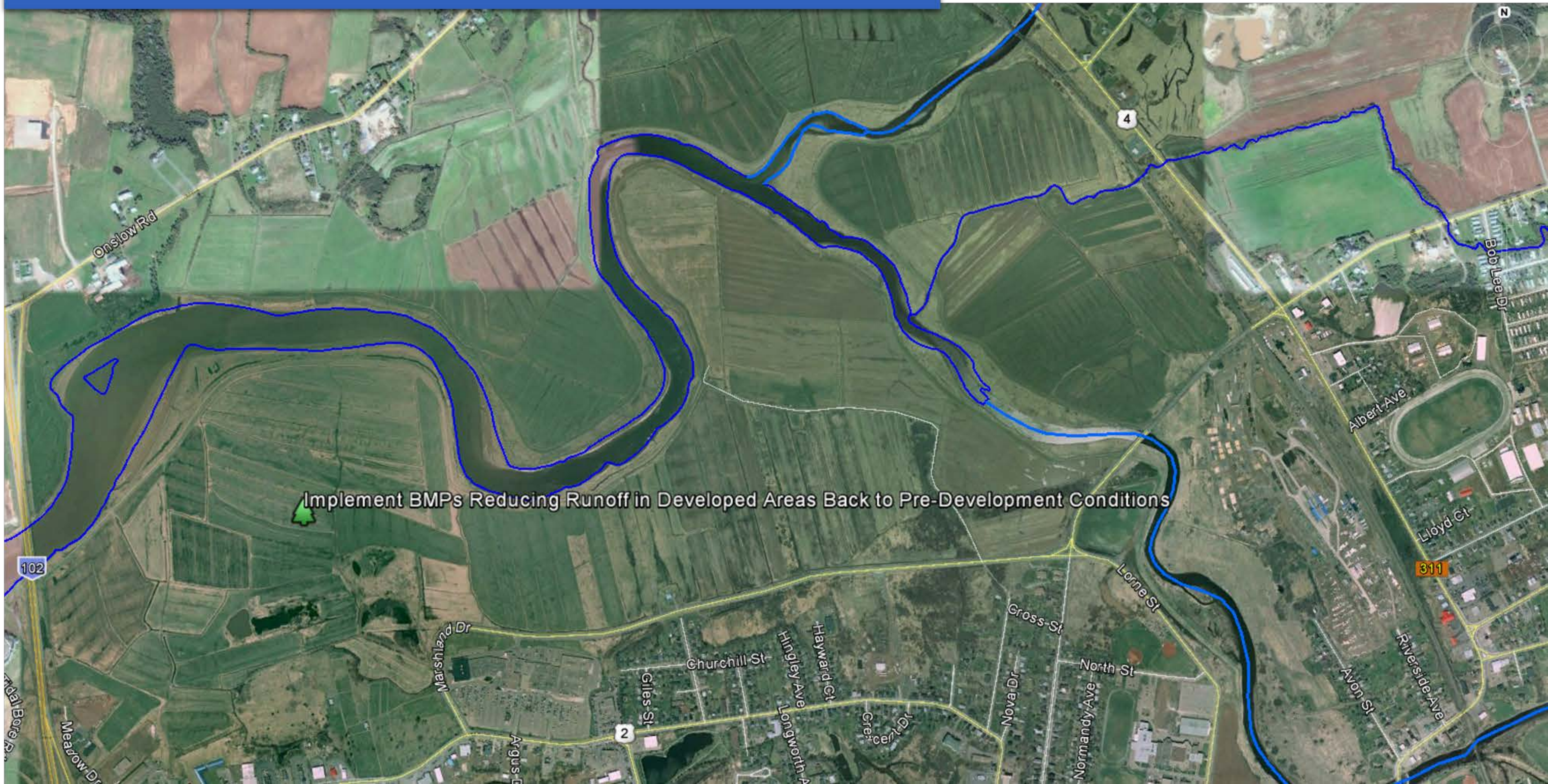
Runoff Reduction 4:

Construct Detention Ponds / Structures within the existing tributaries and / or developments Upstream of Millbrook



Runoff Reduction 5:

Implement Best Management Practices (BMPs) to Reduce Runoff to Pre-Development Conditions



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