GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

FLOOD RISK MAPPING PROJECT
CORNER BROOK STREAM and PETRIE'S BROOK

Submitted to:

Water Resources Management Division
Department of Environment and Conservation
Government of Newfoundland and Labrador

Submitted by:
AMEC Environment & Infrastructure,
a Division of AMEC Americas Limited
133 Crosbie Road, PO Box 13216
St. John's, Newfoundland & Labrador
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February 2013
TA1112735

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February 27, 2013

AMEC Project # TA1112735

To: Department of Environment and Conservation
Government of Newfoundland and Labrador
4th Floor, Confederation Building, West Block
PO Box 8700, St. John's, NL, Canada A1B 4J6

Attn: Mr. Amir Ali Khan, Ph.D, P.Eng, Manager
Hydrologic Modelling Section
Water Resources Management Division

Dear Sir:

Re: Flood Risk Mapping Project for
Corner Brook Stream and Petrie's Brook
Final Project Report

AMEC Environment & Infrastructure, a Division of AMEC Americas Limited, is pleased to provide the attached report for the above noted project. This report embodies revisions stemming from your review of the initial draft document. The report also includes updates resulting from a second internal review by senior staff. We submit this report to facilitate your confirmation that all of the issues raised by your office have been addressed to your satisfaction.

When we have received your acceptance of the report we will finalize all deliverables associated with this component of the overall project.

Yours truly,

AMEC Environment & Infrastructure,
a Division of AMEC Americas Limited

J. Chris Innes, B.A.
Information Management Group Lead
Ottawa, Ontario

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LIMITATIONS

1. This report was prepared exclusively for the Government of Newfoundland and Labrador, Department of Environment and Conservation, Water Resources Management Division (WRMD) by AMEC Environment & Infrastructure, a Division of AMEC Americas Limited (AMEC).
2. The work performed in this report was carried out in accordance with the Standard Terms of Conditions made part of our contract. The conclusions presented herein are based solely upon the scope of services and time and budgetary limitations described in our contract.
3. The report was prepared in accordance with generally accepted environmental study and/or engineering practices for the exclusive use of WRMD. No other warranties, either expressed or implied, are made as to the professional services provided under the terms of our contract and included in this report.
4. Third party information reviewed and used to develop the opinions and conclusions contained in this report is assumed to be complete and correct. This information was used in good faith and AMEC does not accept any responsibility for deficiencies, misinterpretation or incompleteness of the information contained in documents prepared by third parties.
5. The services performed and outlined in this report were based, in part, upon visual observations of the site and attendant structures. Our opinion cannot be extended to portions of the site which were unavailable for direct observation, reasonably beyond our control.
6. The objective of this report was to assess environmental conditions at the sites, within the context of our contract and existing environmental regulations within the applicable jurisdiction. Evaluating compliance of past or future owners with applicable local, provincial and federal government laws and regulations was not included in our contract for services.
7. The contents of this report are based on the information collected during a review of available background information, interviews, site inspection and investigation activities, our understanding of the actual site conditions, and our professional opinion according to the information available at the time of preparation of this report. This report gives a professional opinion and, by consequence, no guarantee is attached to the conclusions or expert advice depicted in this report. This report does not provide a legal opinion in regards to Regulations and applicable Laws.
8. Any use of this report by a third party and any decision made based on the information contained in this report by the third party is the sole responsibility of the third party. AMEC will not accept any responsibility for damages resulting from a decision or an action made by a third party based on the information contained in this report.

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APPROVALS

Feb 27, 2013

Prepared by: Peter Nimmrichter, M.Eng., P.Eng. — Date

Feb 27, 2013

Reviewed by: Ron Scheckenberger, P.Eng., Senior Review — Date

Feb 27, 2013

Approved by: Chris Innes, B.A., Project Manager — Date

Rev.	Description	Prepared By	Reviewed By	Approved By	Date
001	Draft Report	PN	KD	CI	October 5, 2012
002	Revised Draft Report incorporating client comment dispositioning	PN	RS	CI	Dec 4, 2012
003	Draft incorporating updated dam information	PN	RS	CI	Feb 27, 2013

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PREFACE

AMEC Environment & Infrastructure, a division of AMEC Americas Limited was retained by the Province of Newfoundland and Labrador, Department of Environment and Conservation, Water Resources Management Division in October 2011 to develop flood risk mapping for the areas of Corner Brook and Goulds and Petty Harbour focusing on three watercourses, namely;

- Petrie's Brook in the Corner Brook Area
- Corner Brook Stream in the Corner Brook Area
- Petty Harbour River in the Goulds and Petty Harbour Area

Two reports have been generated for this project each detailing the development of the flood risk mapping specific to the focus areas of the Province.

This report summarizes the development of flood risk mapping along Corner Brook Stream and Petrie's Brook in the Corner Brook Area.

EXECUTIVE SUMMARY

Infrastructure, whether built, human or natural, is critically important to people and economies. The purpose of infrastructure is to protect the life, health, property and social welfare of all of its beneficiaries from the weather elements, to host economic activities and to sustain aesthetic and cultural values. When infrastructure fails under extreme weather conditions and can no longer provide services to communities, the result is often a disaster. As the climate changes, it is likely that risks for infrastructure failure will increase as weather patterns shift and extreme weather conditions become more variable and regionally more intense. Since infrastructure underpins so many economic activities of societies, these impacts will be significant and will require adaptation measures. Adaptation planning enables government and industry to understand the impacts, risks and opportunities posed by a changing climate and provides a basis for preparation of strategic roadmaps towards long-term resiliency.

As global climate changes, and increases in human population, development and green energy demand continue in the coming decades, understanding and sustainable management of water resources will be critical. One potential result of the interplay of these global changes is an increase in flooding. To assist with planning in and around potential flood zones and to minimize damages associated with flooding, information on the projected spatial extent and expected frequency of floods is critical. The factors that affect flooding must also be evaluated periodically, particularly when those factors are subject to on-going change. Changes in climate and development can have significant impacts on flood risk and both have been changing at an increasing rate. The nature of these changes and their associated impacts on flood risk need to be evaluated on a periodic basis.

AMEC Environment & Infrastructure, a division of AMEC Americas Limited (AMEC) was retained by the Water Resources Management Division (WRMD) of the Province of Newfoundland and Labrador in October 2011 to develop flood risk maps for the areas of Petrie's Brook and Corner Brook Stream. The flood risk mapping project was completed using acceptable industry best techniques and currently available data. The technical guidelines developed under the Canada-Newfoundland Flood Damage Reduction Program (Hydrologic and Hydraulic Procedures for Flood Plain Delineation, Environment Canada, 1976) provided the basis for the guiding principles and approaches for all components of the study. This basis was then supplemented with additional guiding principles, by WRMD, which are reflective of current technological and data methods. These guiding principles included the following:

- Use established engineering methods, tools and software,
- Use Geographic Information Systems (GIS) tools and software,
- Incorporate land cover analysis based on optical satellite imagery,
- Incorporate LiDAR digital elevation data and orthophotography,
- Use the most up-to-date climate data, and
- Use climate change projections up to year 2100 to model potential flood risk.

This report summarizes the development of flood plain mapping defining the 1:20 and 1:100

annual exceedance probability (AEP) flood risk for existing land use and climate conditions (2012) and three future time frames, namely, 2020, 2050 and 2080 for study reaches along Corner Brook Stream and Petrie's Brook in the Corner Brook area.

Thirty-nine (39) flood events have been documented (AMEC, 2012) in the Corner Brook area since 1950. Of these, only one (1) is defined in the Petrie's Brook area. One flood event is documented where ice jamming was deemed the primary cause, however, it was determined that this event was erroneously associated with the City of Corner Brook as the reference was taken from the Flood Mapping Study for the Codroy Valley (Fenco, 1990). As such, there is no documented evidence of ice jamming as a primary cause of flooding in the Corner Brook area. The City of Corner Brook was provided with the opportunity to review the documented flood events compiled for the present study. The City of Corner Brook provided no additional information regarding flood events in the community.

No previous flood mapping studies have been completed for the Corner Brook Stream and Petrie's Brook watersheds. However, a dam safety assessment was completed for the dams on Corner Brook Stream for Corner Brook Pulp and Paper in 2001 (AMEC, 2001).

The 1:20 year and 1:100 year AEP streamflows were estimated for the subject watersheds, namely: Corner Brook Stream and Petrie's Brook, using both statistical and deterministic methodologies. A comparative assessment of the flow estimates over the range of methodologies concluded that the deterministic model results, based on hydrologic modelling package HEC-HMS (available from the US Army Corp of Engineers) program, provided a good and supportable estimate of streamflow for these watersheds.

It is understood that the hydrologic model is sensitive to a variety of input parameters including rainfall and Soil Conservation Service Curve Number. These parameters were developed based upon the best available soils information from Agriculture Canada and land cover data as provided by WRMD; the latter reflecting current conditions in late 2011. Further, limited statistical streamflow data is available for these watersheds. As such, it is recommended that the deterministic analysis results, based on the hydrologic modeling software HEC-HMS from the US Army Corp of Engineers, be carried forward for use in the hydraulic model for base case conditions.

Hydraulic models based on the United States Army Corp of Engineers program HEC-RAS were developed for reaches of Corner Brook Stream and Petrie's Brook covering linear distances of approximately 8.3km (with 352 cross-sections) and 3.3km (with 85 cross-sections), respectively. The models were developed based on field surveyed bathymetric data and LiDAR survey conducted in November and December of 2011. It should be noted that the open water flood assessment is based on summertime 1:20 year AEP and 1:100 year AEP floods.

The hydraulic model developed for this study was also used to evaluate the potential flood conditions (i.e., resultant water levels) associated with ice jamming events. Petrie's Brook was not deemed to have the potential for ice jam formation. The evaluation for Corner Brook Stream confirmed that along limited reaches of the watercourse, computed water levels associated with ice jams have the potential to generate water levels exceeding 1:100 year AEP open water event levels. It should be noted that the ice jamming assessment is similarly based on 1:20 year AEP and 1:100 year AEP floods, except that these floods are based on winter conditions only.

Since all hydraulic model input parameters were selected based on reliable background information, it is expected that the uncertainty associated with model output is minimal. As such, it is recommended that the hydraulic model be used as the basis by which to simulate the base case (i.e. existing land use and hydraulic conditions) and climate change flood scenarios.

An evaluation of the potential impacts of climate change on flood risk was completed. Estimates of flood plains for the periods 2020, 2050 and 2080 were computed and delineated. Two sources of rainfall estimates for these future periods were determined. Dr. Joel Finnis, an Associate Professor in the Department of Geography at Memorial University provided one set of estimates (12 hour and 24 hour durations) for Stephenville. AMEC, as a component of the current project, developed projected Intensity-Duration-Frequency (IDF) relationships for the Environment Canada Deer Lake station. It was concluded from this assessment that climate change has the potential to increase flood risk in the Corner Brook Area.

It should be noted that there is a great deal of uncertainty with all climate models, statistical downscaling and projection of rainfall to point locations. The quantification of rainfall and, subsequently, flood plain estimates should not be interpreted as an accurate portrayal of possible future events. These estimates provide a good indication of upward and downward trends and general sense of the magnitude of the potential change but should not be considered absolute.

Key recommendations stemming from the assessments completed for this study are outlined as follows:

1. It is recommended that the City of Corner Brook adopt the flood lines developed by the current study for its municipal plan and development regulations.
2. It is recommended that the City of Corner Brook and its partners make use of the up-to-date LiDAR topographic data and orthophotography which was collected for this study for relevant municipal initiatives.
3. The Deer Lake and Stephenville Environment Canada stations, relative to the Corner Brook Watersheds, lie about 49 km and 65 km, respectively from the approximate centroids of the watersheds. It is recommended that a rainfall station, local to the Corner Brook Area be installed to support assessment of IDF relationships, watershed analysis and give insight into local meteorological conditions specific to the area.
4. It is recommended that the City of Corner Brook engage in a program to measure water levels at designated watercourse crossing structures during flood events. This will provide a database of information which could be used to support both hydrologic and hydraulic modelling in the future.
5. It is recommended that a streamflow continuous monitoring station be installed at the outlet of the two study watersheds and Bell's Brook watershed. The information gathered will provide for the development of a database which could be used to support both hydrologic

and hydraulic modelling in the future.

6. It is recommended that that HEC-GeoHMS, HEC-HMS, HEC-GeoRAS and HEC-RAS be used in future watershed and flood studies as their use both simplifies the development of deterministic models, as well as provides for the generation of a significant warehouse of information that can be used for other ancillary purposes beyond hydrologic assessments.
7. It is recommended that special consideration be given to higher water levels (than those based on the 1:100 year AEP flow) associated with ice jam conditions in the reach above Glynmill Pond Dam. The ice jamming assessment concluded that water levels associated with ice jamming can exceed those generated by a summertime open water flood event (for both the 1:20 year and 1:100 year AEP conditions). However, there is no evidence of ice jamming as a primary flood causing factor in the Corner Brook area. As such, the community can opt to designate the "ice jam" flood inundated area as a special policy area which will allow the City of Corner Brook to enact specific policies/guidelines regarding development while recognizing the low expectation (base on historical occurrence) of ice jamming.
8. It is recommended that the City of Corner Brook consider stream and/or structure rehabilitation in the areas where water levels exceed the river banks during the 1:100 year AEP flood and spill over land. This will confine extreme flood flows to the river channel and avoid the risk of overland flooding.
9. It is recommended that meteorological conditions in the Corner Brook Area be monitored towards determination of increasing trends in rainfall and generally extreme weather.
10. It is recommended that climate change be integrated into municipal planning in those areas where increasing flood risk is relevant such as infrastructure and emergency planning.
11. It is recommended that this study should be revisited in approximately ten years, after which time additional detail may be available from rainfall and streamflow gauges in the basin.
12. It is recommended that flood studies be initiated in early spring. Starting these projects in early spring will provide the time necessary to better plan field programs that can be conducted over the summer months. This allows surveying to be conducted during low flow conditions and allows for easier and safer access during summer months. Another benefit is that it potentially allows for the collection of more model calibration data. Flow metering (when required) and water surface profiles can be conducted in the spring when river levels are typically high, and also in the late summer when river levels are low. This would help to provide a good range of model calibration and validation data.
13. It is recommended that LiDAR topographic survey and orthophoto databases continue to be used for future flood risk mapping studies as they provide an accurate means of collecting high quality topography information over large areas.
14. It is recommended, although fundamental principles remain the same, that the "1976 Hydrologic and Hydraulic Procedures for Flood Plain Delineation" be updated to reflect current technological and engineering practices in regards to flood plain delineation and development of flood plain mapping.

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1.0 INTRODUCTION

As global climate changes and increases in human population, development and green energy demand continue in the coming decades, sustainable management of water resources will be critical. One potential result of the interplay of these global influences is an increase in flooding. Floods have the potential to cause significant personal injury, damages to property and loss of life. To assist with planning in and around potential flood zones and to minimize damages associated with flooding, information on the projected spatial extent and expected frequency of floods is critical. The factors that affect flooding must also be evaluated periodically, particularly when those factors are subject to on-going change. Changes in climate and development can have significant impacts on flood risk and both have been changing at an increasing rate. The nature of these changes and their associated impacts on flood risk need to be evaluated on a periodic basis.

Over the past several decades, the City of Corner Brook has experienced problems with flooding. Development initiatives, in combination with anticipated climate change impacts, have the potential to significantly affect flood risk in the City of Corner Brook. These developments as well as anticipated climate change impacts highlight the need for a comprehensive flood risk study and associated new flood risk mapping.

Under the Canadian constitution, flood plain management is subject to the jurisdiction of the provinces, as they are primarily responsible for water resources and land use matters. The objective of the Federal government by way of its program, is to reduce major disruptions to regional economies and to reduce disaster assistance payments. Traditionally, this had been achieved by building structural measures to control flooding. In the 1950s, 1960s, 1970s, and to a lesser extent in the 1980s, the Federal government allocated millions of dollars, in conjunction with the provinces, to build dams and dykes. Extensive flood damages across Canada in the early 1970s clearly demonstrated that a new approach to reducing flood damages was needed. These flood events were the catalyst for the Federal government to initiate the national Flood Damage Reduction Program (FDRP) in 1975 under the Canada Water Act. The FDRP has been carried out under cost shared Federal-Provincial agreements.

The Federal minimum criterion for defining a flood risk area is the 100 year flood, i.e., a flood that has one chance in one hundred of being equalled or exceeded in any given year. However, the Federal government adopts provincial criteria if they are more stringent. For example, in British Columbia the 200-year flood is used, in Saskatchewan the 500-year flood is used, and in parts of Ontario a "Regional Storm" (based on Hurricane Hazel or the Timmins Storm) or highest observed flood is used.

Newfoundland and Labrador joined the Flood Damage Reduction Program (FDRP) in 1981 signing General and Mapping Agreements and two years later a Studies Agreement. Since signing this agreement, the Province has delineated over thirty (30) areas and flood risk information maps have been produced for the benefit of Federal, Provincial and Municipal governments, private companies and the general public. These maps illustrate the area flooded under the 1:20 and 1:100 annual exceedence probability (AEP) floods. The 20-year flood was used to designate the floodway and the 100-year flood to designate the flood fringe. The FDRP ended in 1999.

The Department of Environment and Conservation's Water Resources Management Division (WRMD) first incorporated climate change projections into flood risk mapping in 2008/2009, when the flood risk maps for Stephenville and Cold Brook were updated. The Stephenville/Cold Brook study was the first in Canada to delineate climate change-based Regulatory flood risk mapping but only included the worst case climate change scenario.

AMEC Environment & Infrastructure, a Division of AMEC Americas Limited (AMEC) was retained by the Water Resources Management Division (WRMD) in October 2011 to develop flood risk maps for the areas of Petrie's Brook and Corner Brook Stream. The flood risk mapping project was completed using acceptable industry standard techniques and data currently available. The technical guidelines developed under the Canada-Newfoundland Flood Damage Reduction Program (Hydrologic and Hydraulic Procedures for Flood Plain Delineation, Environment Canada, 1976) provided the basis for the guiding principles for all components of the study. This basis was then supplemented with additional guiding principles and approaches, by WRMD, which are reflective of current technological and data methods,. These guiding principles included the following:

- Use established engineering methods, tools and software,
- Use Geographic Information Systems (GIS) tools and software,
- Incorporate land cover analysis based on optical satellite imagery,
- Incorporate Light Detection and Ranging (LiDAR) digital elevation data and orthophotography,
- Use the most up-to-date climate data, and
- Use climate change projections up to year 2100 to model potential flood risk.

This report summarizes the development of flood plain mapping defining the 1:20 year and 1:100 year AEP flood risk for existing conditions (2012) and three future time frames, namely, 2020, 2050 and 2080 for study reaches along Corner Brook Stream and Petrie's Brook.

1.1 Study Areas

The City of Corner Brook study area, the focus of this report, includes Corner Brook Stream (including the tributary Bell's Brook) and Petrie's Brook. The total watershed areas are 158.4 square kilometres and 6.2 square kilometres respectively. Both Corner Brook Stream and Petrie's Brook discharge into the Humber Arm. WRMD has not previously undertaken a flood risk study for the City of Corner Brook.

Figure 1-1 provides regional perspective of the study areas. Figure 1-2 and Figure 1-3 illustrate a local perspective of the individual study watersheds.

1.2 Work Scope

The primary study tasks can be summarized as follows:

1. Conduct a thorough review of existing information for the purpose of understanding the nature of flooding for the individual watercourses and the circumstances contributing to past flood events. This aspect of the study is detailed in Section 2 of this report.
2. Co-ordinate a field program to collect data required to support preparation of the LiDAR / GIS mapping database, to establish historical flood levels and to calibrate/verify the selected mathematical models. This aspect of the study is detailed in Section 3 of this report.
3. Acquire LiDAR data and orthophotography. This aspect of the study is detailed in Section 3 of this report.
4. Carry out a land use / land cover classification using remote sensing technology. This aspect of the study is detailed in Section 4 of this report.
5. Provide climate change projections for input into hydrological models. This aspect of the study is detailed in Section 7 of this report.
6. Conduct a hydrologic investigation of the study watershed areas to determine the flows associated with the 1:20 year and 1:100 year AEP floods by comparing streamflow record analysis with flows obtained by modeling the physiographic features of the watersheds using specified precipitation/snowmelt input. This aspect of the study is detailed in Section 4 of this report. Sensitivity analysis associated with the hydrologic model is detailed in Section 6 of this report.
7. Using flows obtained from the hydrological analyses, perform a hydraulic analysis to determine water surface profiles associated with the 1:20 year and 1:100 year AEP floods. This aspect of the study is detailed in Section 5 of this report. Sensitivity analysis associated with the hydraulic model is detailed in Section 6 of this report.
8. Develop flood plain maps illustrating the flood inundation zones for the 1:20 year and 1:100 year AEP floods. This aspect of the study is detailed in Section 8 of this report.

Section 9 of this report provides conclusions and recommendations that stem from this study.

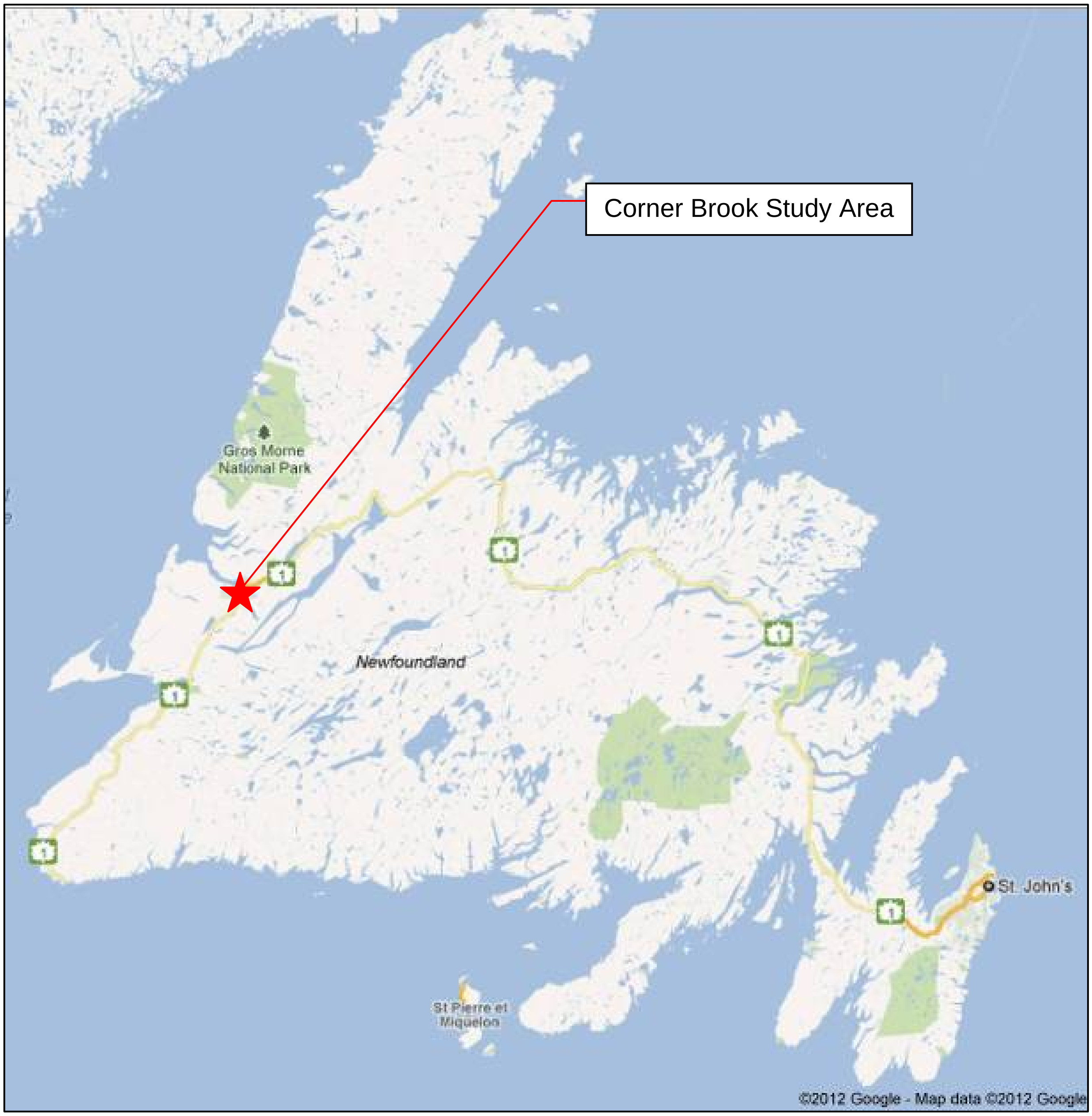

Figure 1-1 : Study Area - Regional Context

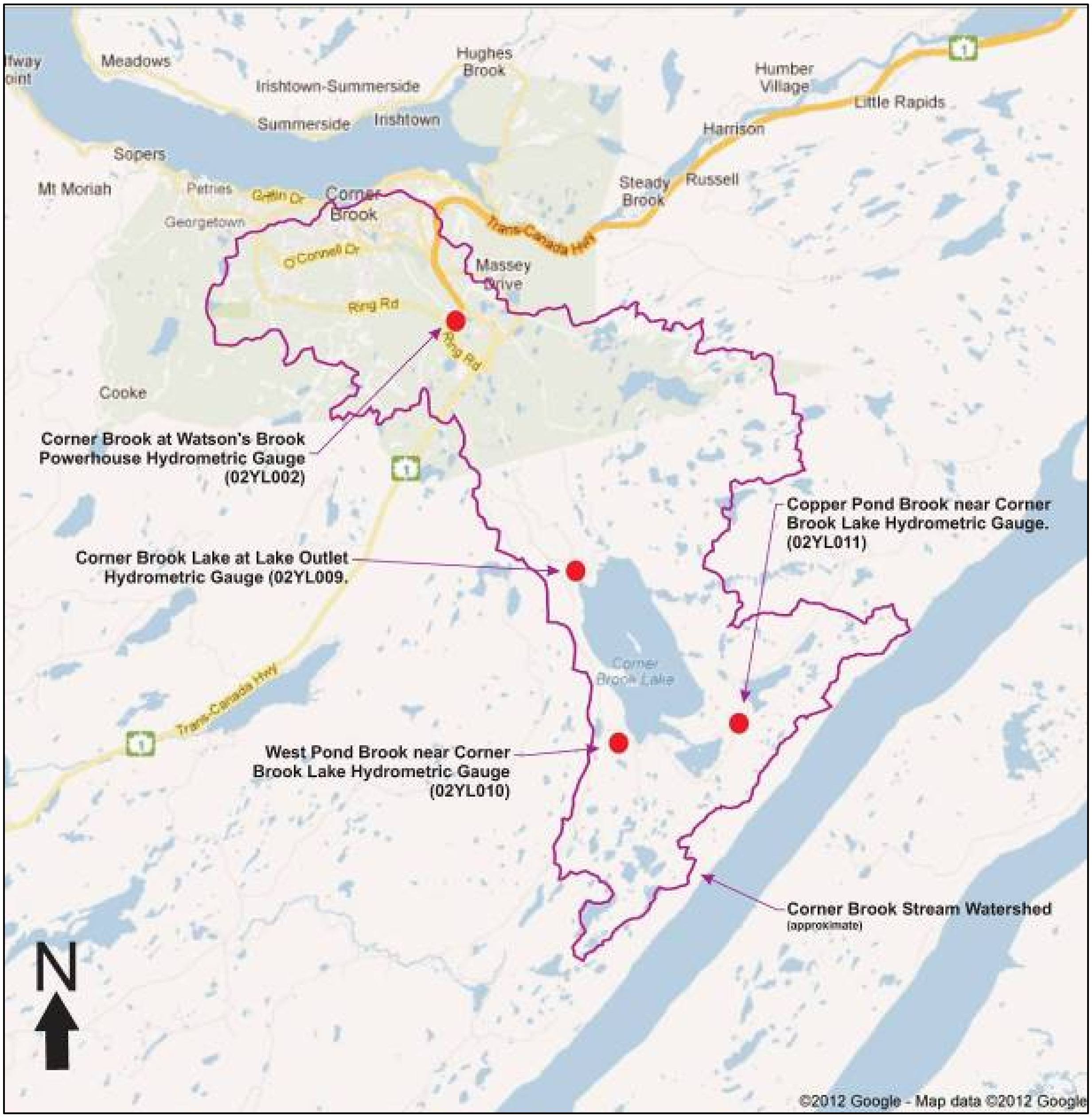

Figure 1-2 : Corner Brook Stream Study Area - Local Context

Figure 1-3 : Petrie's Brook Study Area - Local Context

2.0 BACKGROUND INFORMATION

A thorough review of existing information was completed to obtain an understanding of the historical flooding problem in the study areas and the factors responsible for past floods. A summary of the information sources that were reviewed is outlined in the following sections.

2.1 Historical Flooding / High Flows

The Flood Events Inventory for the period of 1950-2012 (AMEC, 2012) formed the basis for definition of historical flooding for the Corner Brook area. Additional information was also requested from the City of Corner Brook Engineering Department.

The Flood Events Inventory documents thirty-nine (39) flood events in the Corner Brook area including one (1) in the Petrie's Brook area. Floods events have occurred in all seasons of the year (13 in the period Jan/Feb/Mar; 4 in the period Apr/May/Jun; 9 in the period Jul/Aug/Sep; and 13 in the period Oct/Nov/Dec).

Only one flood is documented to have occurred along the Petrie's Brook in December 2008[1]. The inventory documents the following description of this flood event:

> "*Heavy snow and rains caused a flash flood in Corner Brook area. Petrie's Brook overflowed. A culvert was engulfed and the bank collapsed, sending water, rocks and trees rushing past nearby homes*."[1]

Figure 2-1 : Petrie's Brook Flooding - December 2008[1]

[1] Source : http://www.thewesternstar.com/Living/Motoring/2008-12-12/photo-1476805/Torrential-downpour-creates-havoc-in-flooded-area-of-Curling/1

One flood event is documented where ice jamming was deemed the primary cause, however, it was determined that this event was erroneously associated with the City of Corner Brook as the reference was taken from the Flood Mapping Study for the Codroy Valley (Fenco, 1990). As such, there is no documented evidence of ice jamming as a primary cause of flooding in the Corner Brook area.

Appendix A includes a table summarizing some of the details of the flood events and associated damages with the study areas.

2.2 Previous Studies

No previous flood or hydrotechnical studies have been completed by WRMD for the Corner Brook study area.

A dam safety assessment was completed for the dams on Corner Brook Stream for Corner Brook Pulp and Paper in 2001 (AMEC, 2001).

2.3 Additional Background Information

The information described below was made available to AMEC from WRMD, or with the assistance of WRMD, from a third party.

2.3.1 Information from WRMD

At the onset of the study, WRMD provided AMEC with the following information:

- SPOT satellite images covering the study areas.

  SPOT satellite imagery was provided to AMEC by WRMD with assistance from Iunctus Geomatics Corp. The SPOT images were delivered as previously ortho-rectified datasets and with a combination of clipped and/or full scenes that included 2.5-meter panchromatic, 2.5-meter fused natural color (3-band), and 10-meter resolution multispectral (4-band). Four image acquisition dates were included; one in 2009, one in 2010, and two in 2011 (refer to Appendix C for additional details).

- Topographic Mapping

  - 1:50,000 National Topographic Series Mapping (digital)

  - Community scale (1:2,500) digital topographical mapping supplied by the Surveys and Mapping Division, Department of Government Services and Lands, dated to 1984.

    This topographic map data was provided to AMEC as a series of one thousand nine hundred and seventy-one (1,971) ESRI SHP files as a combination of structured (Corner Brook area) and un-structured (Goulds and Petty Harbour area) datasets. Structured datasets are vector based and have been organized into layers and are GIS useable.

Unstructured data represents digital conversion (scans) of hardcopy maps that have been vectorized but not organized into layers. The usefulness of the unstructured maps is limited to use as a backdrop image in a GIS application.

- o In anticipation of the production of flood plain maps, a deliverable of this project (a street names layer) was created specific to the study reaches designated for floodplain map development. Street names were sourced from Google Earth^{TM}.

- Rainfall estimates

<u>Historic Rainfall</u>

A weather station with published Intensity-Duration-Frequency (IDF) data was not available specifically for the Corner Brook study area. IDF data is available, however, for weather stations at Stephenville Airport (#8403800 with a period of record from 1966 - 2007) to the south west of this study area and Deer Lake (#8401501 with a period of record from 1966 - 2002) to the north east. The current IDF reports/data available for these two stations is dated April 13, 2010.

A general review of the applicability of the data from these stations to support the hydrologic modeling effort for this project was completed. The following comments stem from this review.

- o The Deer Lake and Stephenville stations relative to the Corner Brook Watershed lie about 49 km and 65 km respectively from the approximate centroid of the watershed. Additionally, the centroid of the Petrie's Brook Watershed also lies closer to the Deer Lake station.
- o Figure 2-2 illustrates the Public Forecast Warning Areas used by Environment Canada. The Public Forecast Warning Area boundaries were developed by Environment Canada several decades ago based on rigorous climate studies and considerable public consultation. The Corner Brook Stream and Petrie's Brook Watersheds lie almost entirely within the Deer Lake - Humber Valley Warning Area.
- o Based on the information above, it was recommended to use the Deer Lake IDF data as the representative IDF relationship for the drainage basin feeding Corner Brook Stream and Petrie's Brook.

<u>Future Rainfall</u>

Rainfall estimates for the future periods 2020, 2050 and 2080 were provided to AMEC by WRMD. Two sources of projected rainfall data were provided, namely;

- o *Climate Change Scenarios for Atlantic Canada Utilizing a Statistical Downscaling Model Based on Two Global Climate Models*, Gary Lines, Michael Pancura, Chris Lander and Lee Titus, Meteorological Service of Canada, Atlantic Region, Science Report Series 2009-01, July 2008.

- o Dr. Joel Finnis, an associate professor of Synoptic Climatology in the Department of Geography at Memorial University in St. John's, Newfoundland. The projected rainfall estimates for St. John's and Stephenville for 2050 were provided at the request of WRMD and were based on the revised St. John's IDF relationship described above.

A third approach was utilized by AMEC to develop projected IDF relationships for the required future periods which uses a statistical model that derives the sensitivity of extreme precipitation to climate conditions from the historical climate information for a site. This approach, which is referred to as the delta approach, is used to reduce some of the inevitable bias inherent in projections of future climate. A detailed description of the methodology and results is provided in Section 7 of this report.

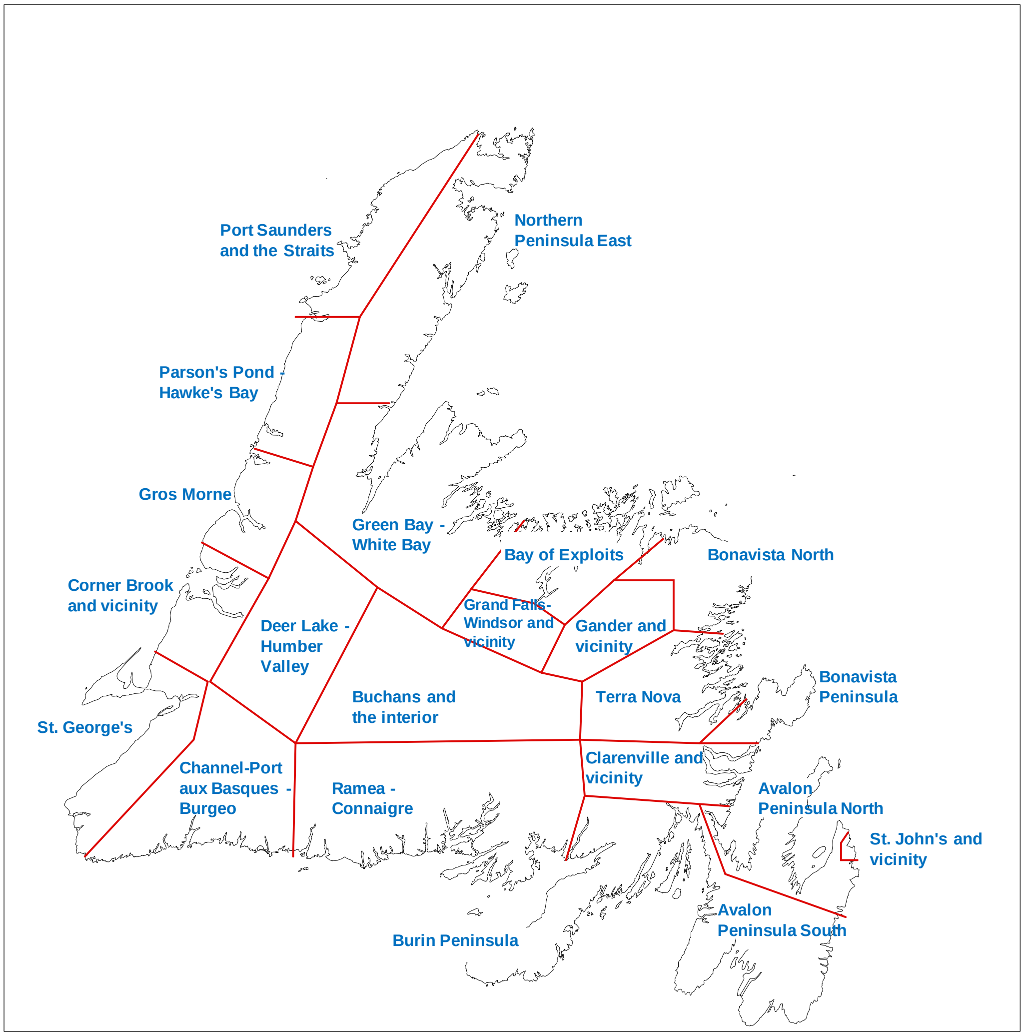

Figure 2-2 : Public Weather Warning Regions for Newfoundland

(Based on http://www.weatheroffice.gc.ca/warnings/nl_e.html)

2.3.2 Dams

There are four (4) dams in the Corner Brook Stream Watershed (see Figure 2-3) for which data was required to facilitate either hydrologic or hydraulic modeling, namely:

- Glynmill Pond Dam (Corner Brook Pulp and Paper[2])
- Margaret Bowater Park Dam (City of Corner Brook)
- Three Mile Dam (Deer Lake Power[2])
- Corner Brook Lake Dam [also known as Twelve Mile Dam] (Deer Lake Power[2])

No dams are located in the Petrie's Brook Watershed.

Information regarding these dams was sourced from the dam owners and other available reporting as could be located through Internet searches. The information obtained included:

- drawings of the dams (where available)
- historic water level data
- rule curves
- dam safety and other reports

Photos of the dams are presented at the end of this section.

It was anticipated that stage-storage-discharge relationships would be available as a component of the dam safety study (AMEC, 2001), however, these relationships were not provided with the reporting. As such, the stage-storage-discharge relationships for the four (4) dams were developed independently for this study. The stage-storage-discharge relationships as well as other dam information are provided in Appendix M.

The following descriptions of the dams were, in part, abstracted from a number of documents, namely:

- *Corner Brook Stream Management Study*, The Corner Brook Stream Development Committee, prepared by John Chisholm, Mike Caroll, Nancy Griffiths, Joanne Morehouse with Peter Klynstra, Environmental Planning Department, Nova Scotia College, December 1992.
- Corner Brook Pulp and Paper Limited, Dam Safety Inspection – Twelve Mile Dam, Three Mile Dam and Glynmill Pond Dam, Hatch Mott MacDonald, June 29, 2009.
- Dam Safety Study: Dams on Corner Brook Stream, AMEC E&C Services Limited, July 10, 2001.
- Dam and Reservoir Inventory Update Form, Margaret Bowater Park Dam.

[2] A business of Kruger Inc.

Corner Brook Lake Dam[3]

Corner Brook Lake Dam is the main reservoir for storage and regulation of water for power generation at Watson's Brook Hydroelectric Plant and finally for the paper mill water supply at Corner Brook. Corner Brook Lake Dam is a zoned earth and rock filled embankment dam about 250m long and about 8.5 m high at its highest point. This dam was re-constructed to its present design in 1974. The reservoir surface area is about 8.3 km^2 and has a volume of approximately 39.5 million cubic metres at full supply. It contains two outlet sluiceway openings for flow regulation and spilling of flood waters past the dam. Each of the two sluiceway openings has a ductile iron gate (each 1.83m x 1.83m) complete with screw stem for manual operation which is assisted for faster operation by a gasoline generator and mounted hand held drill. Operator attendance frequency at the dam varies from daily to weekly depending upon the time of year and flow conditions. The dam does not have an emergency overflow spillway.

The general physical characteristics of the dam are outlined in Table 2-1.

Table 2-1: Corner Brook Lake Dam - Key Elevations

Characteristic	Elevation (m)
Full Supply Level	326.00
Flood Surcharge Level	327.07
Maximum Flood Level	327.83
Dam Crest	329.35
Gate/Sluiceway Invert	320.51

The rule curve for the dam indicates the target water levels for the months of the year as outlined in Table 2-2.

Table 2-2: Corner Brook Lake Operating Water Levels

Month	Depth Range[4] (ft)	Depth Range (m)	Elevation Range (m)
January	17.4 - 15.9	5.3 - 4.8	325.8 - 325.4
February	15.9 - 14.1	4.8 - 4.3	325.4 - 324.8
March	14.1 - 11.6	4.3 - 3.5	324.8 - 324.0
April	11.6 - 8.9	3.5 - 2.7	324.0 - 323.2
May	8.9 - 18	2.7 - 5.5	323.2 - 326.0
June	18	5.5	326.0
July	18 - 16.8	5.5 - 5.1	326.0 - 325.6
August	16.8 - 13.7	5.1 - 4.2	325.6 - 324.7
September	13.7 - 11.8	4.2 - 3.6	324.7 - 324.1
October	11.8 - 16.5	3.6 - 5.0	324.1 - 325.5
November	16.5 - 17.0	5.0 - 5.2	325.5 - 325.7
December	17.0 - 17.4	5.2 - 5.3	325.7 - 325.8

[3] Corner Brook Lake Dam is also known or referred to as the 12 Mile Dam
[4] Depth of water above Gate/Sluiceway Invert

Dam operation when impending storms or other extreme weather is forecasted is described as follows:

> *"In the event of a storm the operator would close the gates if the reservoir level is below the target water level and open them if they are above the target water level."*

Definition of the '*target water level*' noted above was not provided by Corner Brook Pulp and Paper. For the purposes of modelling it has been assumed to mean the '*Maximum Flood Level*' as defined in Table 2-1.

Three Mile Dam

Three Mile Dam is operated by Deer Lake Power[5] and generates the head pond for the 9.3 MW Watsons Brook hydro-electric plant. The dam, constructed in the 1930's, is a gravity concrete structure. The dam structure includes two overflow spillway sections topped with steel bulkheads which are raised to release spill flows. The bulkheads are about 6.8m (22.25ft) long and 1.2m (4ft) high. The dam is about 15.5m long and about 7.6m high at the central spillway location. The forebay area is noted as having an area of about 22 hectares and a volume of 561,000 cubic metres. Potential flood storage available, between the full supply level and the top of the dam, is estimated to be about 27,000 cubic metres.

The topographic mapping compiled for this project was used to confirm above normal water level storage capacity for the reservoirs associated with the dams. Through this process, it was determined that the documented surface area of 22 hectares (0.22 km^2) for the Three Mile Dam reservoir was questionable. Measurement of surface area from the available digital mapping indicated a surface area of 2.2 hectares (0.022 km^2).

Also, a comparison of the head pond water level obtained from the LiDAR data in comparison to the documented normal operating water level indicated a difference of about -30m. This correction was applied to the other documented elevations associated with Three Mile Dam as noted below.

The general physical characteristics of the dam are outlined in Table 2-3.

A rule curve for Three Mile Dam was not made available to this project.

Although, it was noted in the available documentation that the dam includes two overflow spillway sections topped with steel bulkheads which are raised to release spill flows, no specific information was provided to this project to define water levels which trigger operation of the bulkheads or general operation of the dam during extreme weather.

[5] owned by Kruger Inc

Table 2-3: Three Mile Dam - Key Elevations

Characteristic	Elevation (m)	
	From available documents	Corrected based on LiDAR
Spillway Crest	240.85	210.85
Normal Operating Level	241.95	211.95
Top of Stop Logs / Full Supply Level	242.01	212.01
Maximum Operating Level	242.32	212.32
Top of Dam	242.93	212.93
Gate/Sluiceway Invert	236.56	206.56
Dam Invert	235.61	204.39

Margaret Bowater Park Dam

Margaret Bowater Park Dam was constructed in 1994 and is owned and operated by the City of Corner Brook. The dam serves the function to create a swimming area which is a feature of the park. The dam has a maximum height of 5.6m and a crest length of about 28.3m and features three primary spillways, two electrically operated gates and a fishway. The gates have dimension 2.134m x 2.134m.

The City of Corner Brook provided the following information regarding the operation of this dam:

- The City does not have any documented operating procedures for the dam with the exception that the gates are fully open over the winter months and fully closed over the summer months with closing taking effect on or soon after Canada Day and opening taking effect sometime after Labour Day depending on weather and park usage.
- The City does not know of any requirement for downstream low flow maintenance/ augmentation.
- There is no specific target or full supply level identified for the head pond, although a Normal Water Level of 27.2m is indicated on the available drawings.
- The reservoir is generally allowed to self regulate water levels with the water level dependent on stage-discharge relationship provided by the primary and secondary spillways incorporated in to the dam (again the gates are closed for the summer operating season).
- The City does not have a full time operator on site but City staff visit the facility on a daily basis.
- Gate operation is by manual winch.

A comparison between the drawing based information for this dam and the field survey conducted as a component of this project indicated a discrepancy of about +3m. The source of the discrepancy could not be clearly identified. As such, for the purposes of modelling and consistency with the topographic mapping used for flood plain delineation purposes, the drawing based information for this dam was adjusted by +3m as indicated in Table 2-4.

The general physical characteristics of the dam are outlined in Table 2-4.

Table 2-4: Margaret Bowater Park Dam - Key Elevations

Characteristic	Elevation (m) From drawings	Elevation (m) Adjusted based on field survey
Dam Invert	22.732	25.732
Gate/Sluiceway Invert	23.182	26.182
Fishway Invert	26.95	29.95
Primary Spillway Crest	27.00	30.00
Normal Water Level	27.20	30.20
Secondary Spillway Crest	28.00	31.00
Top of Dam	28.322	31.322

Glynmill Pond Dam

The Glynmill Pond Dam, constructed in 1989, impounds water primarily to keep a fairly constant water level and to allow the water to be piped from an intake to the paper mill. The dam is a reinforced concrete gravity dam with wing walls and earth embankment abutments at either end. Its overall length is about 55m and its height about 10m at maximum. The dam consists of three undershot steel gates (1.83m x 1.83m). The gates are controlled remotely and automatically to maintain the water level in the forebay. There is also an overflow spillway about 8m long and a fishway. The documented surface area of Glynmill Pond is about 3.9 hectares with its volume at the normal operating water level is about 70,000 cubic metres. Potential flood storage available, between the full supply level and the top of the dam, is estimated to be about 80,000 cubic metres.

The general physical characteristics of the dam are outlined in Table 2-5.

Table 2-5: Glynmill Pond Dam - Key Elevations

Characteristic	Elevation (m)
Dam Invert	10.00
Normal Water Level	15.20
Emergency Spillway Crest	15.35
Maximum Flood Level	16.50
Top of Abutment	17.00
Top of Dam	17.50

A rule curve and details on operations during extreme weather for Glynmill Pond Dam were not made available to this project.

Figure 2-3 : Dam Locations in Corner Brook Stream Watershed

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Photos Illustrating the Nature of the Subject Watercourses

Corner Brook Stream Dams

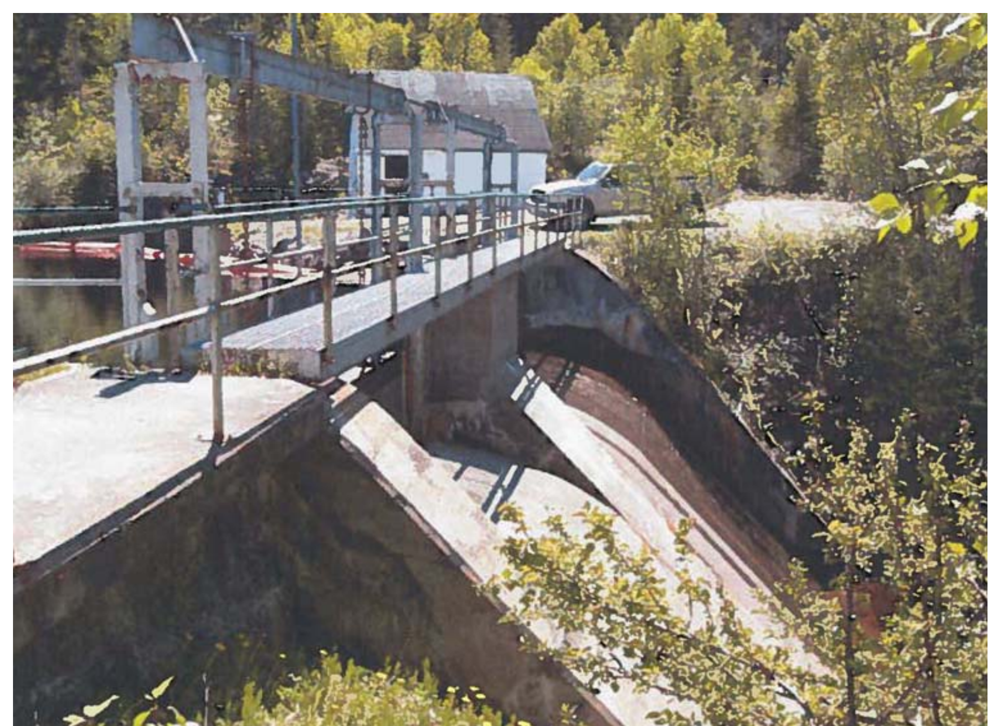
Glynmill Pond Dam
(AMEC, 2011)

Margaret Bowater Park Dam
(AMEC, 2011)

Photos Illustrating the Nature of the Subject Watercourses

Corner Brook Stream Dams


Corner Brook Lake Dam
(Hatch Mott MacDonald, 2009)

Three Mile Dam
(Hatch Mott MacDonald, 2009)

3.0 FIELD PROGRAM

The field data collection program focused on collection of the following data, completed in November and December 2011.

- Historical flood levels (subject to identification in the field using high water marks)
- Survey of hydraulic structures including upstream and downstream natural watercourses sections
- Survey of natural watercourse sections associated with streamflow monitoring locations
- Photographic survey of hydraulic and other relevant watercourse features
- High resolution Light Detection and Ranging (LiDAR) topographic data along with ortho-imagery of the floodplain.

The field program was planned through a desktop exercise using available mapping which identified watercourse crossings and cross-sections for below waterline survey. The overall field program, including a windshield survey, and in-stream survey of hydraulic structures and channel sections, was completed by geomatics staff from AMEC's St. John's.

3.1 Windshield Survey

A windshield survey was completed in teams of two staff in consideration of safety issues associated with the remoteness and dangerous access conditions that some locations presented. In sheltered locations, a danger due to slips and falls was possible due to frost and ice forming overnight. Safety for the field staff was a primary concern in the successful completion of this component of the project work.

The main objectives of the windshield survey were:

- Assessment of existing watercourse and floodplain conditions
- Identification of deviations from available mapping
- Identification of potential flood damage zones
- Initial data collection and photography of watercourse crossings
- Estimation of channel and overbank roughness coefficients
- Creation of a photo database of the subject areas designated for flood plain preparation – these photos were attached to relevant sections in the HEC-RAS model.

3.2 Cross Sections and Structure Survey

3.2.1 Cross Sections

Sections not associated with watercourse crossings were proposed to be defined using LiDAR data only. With small watercourses, such as those that are the focus of this study, the below waterline capacity is limited and is not expected to contribute significantly to conveyance for the 1:20 year and 1:100 year AEP floods. However, WRMD requested below waterline survey at a number of locations within the study areas to determine applicability of this proposed approach. The information gathered through this aspect of the field collection program was integrated into the hydraulic models of the three watercourses by adding a single cross-section X,Y point located at the centerline of the section with a depth interpolated between the nearest surveyed cross-sections when compared with the LiDAR abstracted section elevation at that point.

Figures 3-2 to 3-5 depict the extent of field survey programs for Corner Brook Stream and Petrie's Brook. Details related to these field efforts are described below. Sample photos illustrating the nature of the subject watercourses are provided in the following pages.

<u>Corner Brook Stream</u>

Four (4) open water sections (see Figure 3-1) along Bell's Brook were surveyed in the field for below waterline data. The results indicated that low flow water depths along the study reach (specific to hydraulic modeling) are in the range of about 0.4m to 0.5m downstream of the first tributary and 0.1m to 0.2m upstream of the first tributary. Plots of these sections are provided in Appendix L.

Along the main channel of Corner Brook Stream water depths in the vicinity of bridges/culverts that were surveyed ranges to about 0.7m with the shallower depths surveyed in the upper reaches of the study zone.

<u>Petrie's Brook</u>

Four (4) open water sections (see Figure 3-2) were surveyed in the field for below waterline data. The results indicated that low flow water depths along the study reach (specific to hydraulic modeling) are in the range of 0.1m to 0.3m. Plots of these sections are provided in Appendix L.

<u>Data from Previous Hydrotechnical Studies</u>

As noted previously, no previous flood or hydro-technical studies have been completed by WRMD for Corner Brook Stream or Petrie's Brook. However, information regarding the dams in the Corner Brook Stream Watershed was abstracted from available previous dam safety and other relevant reporting as noted in Section 2.3.2.

3.2.2 Structures

The field program related to structures is also depicted in Figures 3-2 to 3-5. As illustrated in the figures each structure has been assigned a number and the associated structure summary sheets are provided in Appendix B. Structure locations identified for survey were originally identified from the 1:50,000 NTS topographic maps.

The overall field survey for Corner Brook Stream encompassed thirty-one (31) structures and for Petrie's Brook encompassed eight (8) structures. The structures identified for survey are listed in Table 3-1. Watercourse crossing summary sheets are available in Appendix B.

Data from Previous Hydrotechnical Studies

As noted previously, no previous flood or hydro-technical studies have been completed for Corner Brook Stream or Petrie's Brook.

3.2.3 Dams

As noted in Section 2.0 of this report, information related to dams that are located within the study area was obtained from the dam owners or abstracted from available literature and topographic mapping.

Some limited survey of Glynmill Pond Dam and Margaret Bowater Park Dam, relevant for hydraulic modeling, was included in the field data collection program.

Table 3-1: Structure Survey Locations

Corner Brook Stream	
Structure#	Location/Description
2101	Corner Brook Pulp & Paper Foot Bridge/Pipe Rack
2102	Corner Brook Pulp & Paper Overhead Conveyor System
2103	Corner Brook Pulp & Paper Abandoned Bridge
2103-B	Corner Brook Pulp & Paper In-stream drop structure
2104	Corner Brook Pulp & Paper Bridge
2105-B	Lewin Parkway
2106	Main Street
2107	Pedestrian Trail Bridge
2108	Glynmill Pond Dam
2109	Pedestrian Trail Bridge
2110-A	Pedestrian Trail Bridge
2110-C	O'Connell Drive
2111	Margaret Bowater Dam
2112	Unnamed Road
2113	Unnamed Road
2114	Pedestrian Bridge
2115	Valley Mall Culvert (downstream)
2116	Valley Mall Culvert (upstream)
2117	*No structure found at this location*
2118	Blackwood's Hill
2119	Wellington Street
2120	Bliss Street
2121-B	Walbournes Road
2122	Boones Road
2123	Driveway / Accessway
2124	County Road (downstream end of 2125)
2125	O'Connell Drive (upstream end of 2124)
2126	Reids Road
2127	Carberry's Road
2128	Forest Trail
2129	Ring Road
2130	O'Connell Drive / Mount Batten Road

Petrie's Brook	
Structure#	Location/Description
1101	Barletts Avenue
1101-1	Unnamed road allowance immediately upstream of Bartlett's Road
1102	Petries Street
1103	*Rail Trail*
1104	O'Conner Drive
1105	Candow Drive
1106	Georgetown Road
1107	Access Road
1108	Access Road
1109	*Two Ponds Road/Martins Lane*

The italicized locations were not field surveyed as no structure was found to exist at the noted location. As noted previously, the field survey program for watercourse crossings was developed as a desktop exercise. It was found that the 1:50,000 scale mapping available at the outset of the project was not of sufficient resolution to clearly identify structures. As such, a number of locations where it was identified on a map that a structure existed, it was determined in the field that no structure was at that location.

The late start to the project was key issue in this regard. Typically, the field survey program is developed as a component of the windshield survey effort. During the windshield survey the subject watercourse is walked and structures and notable other issues along the watercourse, that should be included in the field topographic survey effort, are identified. The late start to the project required that the windshield survey and field topographic survey were completed in parallel.

Photos Illustrating the Nature of the Subject Watercourses

Corner Brook Stream

Downstream Reach – near section CornerB-M001 352.89

Middle Reach - near section CornerB-M002 1065.81

Upper Reach - near section CornerB-M003 2163.63

Downstream reach near confluence with Corner Brook Stream

Downstream Reach – near section BellsB-M001 1705.77

Downstream Reach – near section BellsB-M002 2991.47

Photos Illustrating the Nature of the Subject Watercourses

Petrie's Brook


Downstream Reach - near section PetriesB-M001 164.90


Upper Reach - near section PetriesB-M001 2733.55


Middle Reach - near section PetriesB-M001 811.85

Figure 3-1 : Corner Brook Stream Field Survey Program

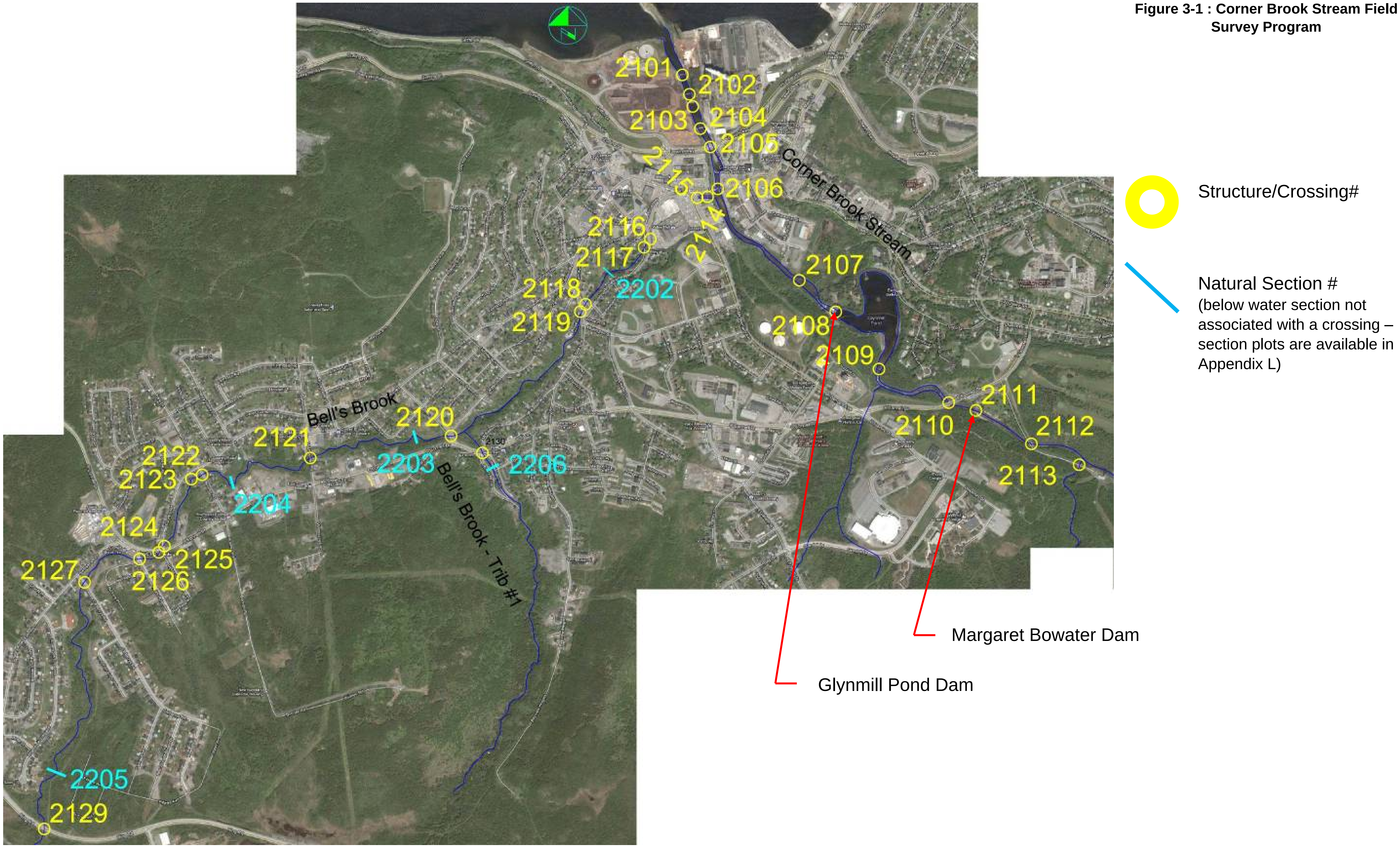


Figure 3-2 : Petrie's Brook Field Survey Program

Structure/Crossing #

Natural Section #
(below water section not associated with a crossing – section plots are available in Appendix L)

3.3 Water Surface Profiles

At study start-up, it was anticipated that streamflow monitoring would be undertaken by the Water Survey of Canada. Due to the late time of year start to this project and scheduling issues at Water Survey of Canada, this aspect of the project could not be completed in advance of freeze up of watercourses in the project study areas. As such, this task of the project was not completed.

3.4 LiDAR Survey and Map Preparation

LiDAR data was collected by Leading Edge Geomatics Limited (LEGEO - Lincoln, New Brunswick) providing full coverage for the two subject watersheds. LEGEO used a Riegl LMS-680ii Airborne Scanner. This system makes use of a powerful laser source with multiple-time-around (MTA) processing and digital full waveform analysis. This combination allows for the operation at varying flight altitudes and is ideally suited for aerial survey of complex terrain. The LIDAR system was stabilized with the Applanix Position and Orientation system model 410.

The data deliverables from this effort were:

- Bare Earth DEM in both DWG and ESRI Grid format
  - Absolute Elevation precision : +/-15cm RMSEz
  - Horizontal accuracy 50cm RMSExy
  - Data collection density - 1 point per square meter
- Accuracy Report (provided in Appendix L)
- Tile Index
- Orthophotography was collected at a resolution of 15cm for the developed urban areas where floodplain mapping was to be produced.

Data collection in the Corner Brook study area was completed during the week of November 7, 2011.

The figures on the following pages illustrate the extent of the LiDAR and orthophoto data coverage across the subject watersheds.

3.5 Data Gap Filling Related to Field Program

Data gaps were identified in the following areas:

- No as-built data was made available from municipalities for watercourse crossings. This gap did not pose any impact to the project as it was mitigated by in-field structure survey as required to support hydraulic modeling.

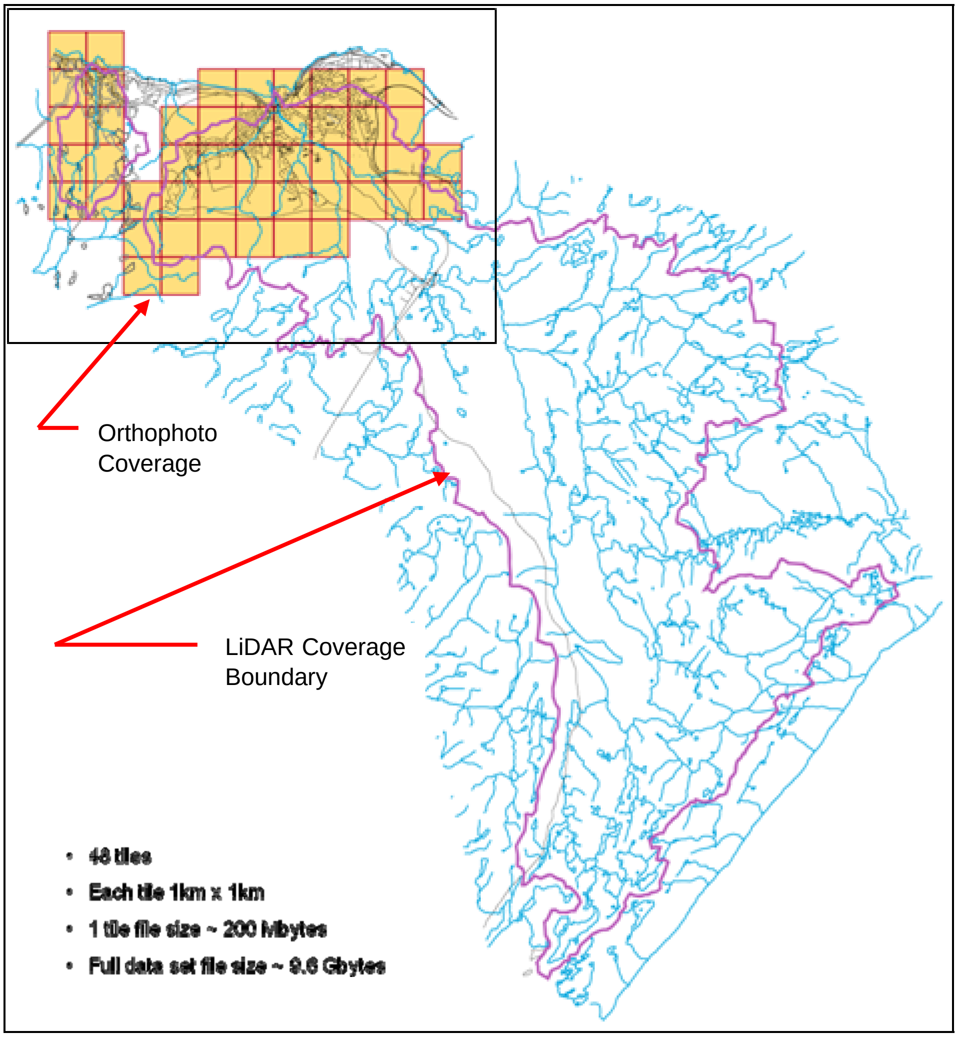


Figure 3-3 : LiDAR and Orthophoto Coverage in the Corner Brook Area

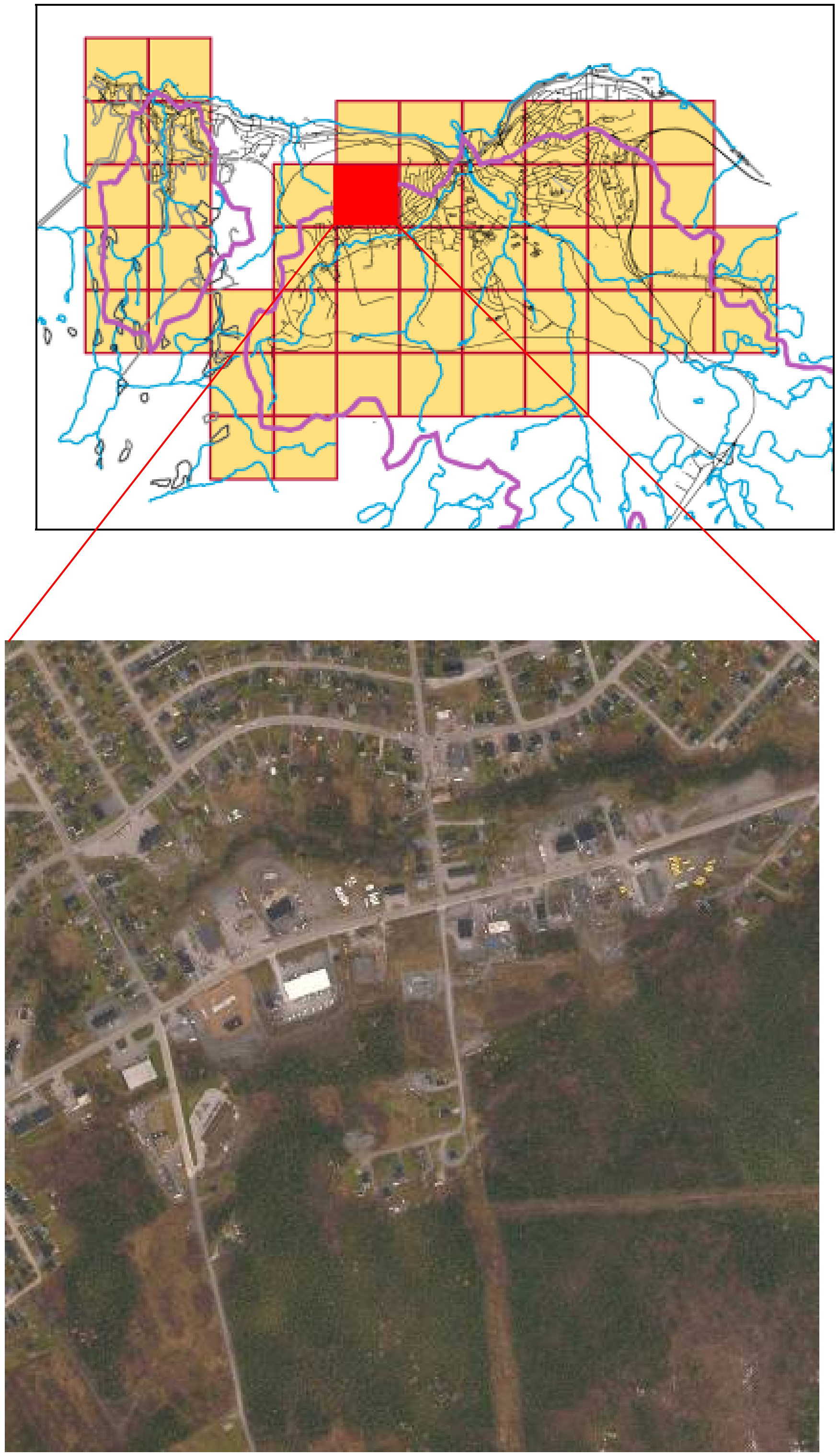


Figure 3-4 : Sample Orthophoto from the Corner Brook Area

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4.0 HYDROLOGIC ANALYSIS

The purpose of the hydrologic analysis was to determine 1:20 and 1:100 annual exceedence probability (AEP) flow estimates for the Corner Brook Stream and Petrie's Brook Watersheds. These flows were subsequently simulated in the hydraulic model to estimate flood levels across the study area.

Estimates of the 1:20 year and 1:100 year AEP flows were computed using both statistical methods and deterministic modelling. Given the uncertainty inherent in flood estimation, comparing results from alternative techniques enables an estimate to be adopted with greater confidence in its reliability and accuracy. In the case of this study, statistical estimates of flows were made by utilizing historical flow records from local hydrometric gauges. These statistical estimates were then used as the basis by which the deterministic hydrologic model HEC-HMS was calibrated. The following sections of this report detail this approach.

4.1 Statistical Analysis

4.1.1 Review of Data

The Corner Brook Stream and Petrie's Brook Watersheds are located in tertiary drainage 02YL[6] as illustrated in Figure 4-1. Environment Canada hydrometric gauges, located within the tertiary drainage area, were evaluated for potential use in the streamflow estimation effort. Three of the gauges are located within the Corner Brook Stream Watershed (noted in *italics* in Table 4-1), however, none of these are located within the study reaches where flood plain mapping was developed. Of those stations located within the Corner Brook Stream Watershed, only stations 02YL010 and 02YL011 record natural flows (i.e. not modified by the influence of dams).

Stations 02YL002 and 02YL009 are located downstream of dams and record regulated flows and water levels, respectively, only. The flows downstream of dams are influenced by the gate settings at the dams, starting water levels in the upstream reservoirs, changing reservoir volumes (due to sedimentation), etc. These influences vary between individual storm events and, as such, the inflow to the dam/reservoir is influenced differently over time depending on specific circumstances. For this reason the stream flow record downstream of a dam is generally not used for single site frequency analysis as a means of calibrating or validating a hydrologic model of the watershed draining to the dam.

Station 02YL009, located downstream of Corner Brook Lake Dam, records water levels only. No rating curve was available to this project which would facilitate conversion of the recorded water levels to streamflows. As such, data from this gauge could not be integrated into this project.

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[6] The primary watershed (02) is the St. Lawrence River, the secondary watershed (02Y) is named 'Northern Newfoundland', the tertiary watershed (02YL) is named 'Humber-Lower" (source: http://stds.statcan.gc.ca/sdac-ctad/sdacmenu-ctadmenu2-eng.asp?criteria=02Y)

Table 4-1: Environment Canada Hydrometric Gauges in Tertiary Drainage Area 02YL

Station Name	Station ID	Latitude Longitude	Data Type	Available Data Record	Drainage Area (km^2)
Corner Brook at Watson's Brook Powerhouse	02YL002	48°55'26'' N 57°54'11'' W	Flow	1959 – 2010 (51 years)	127.0
South Brook at Pasadena	02YL004	49°0'44'' N 57°36'41'' W	Flow	1983 – 2010 (28 years)	58.5
Rattler Brook Near McIvers	02YL005	49°3'29'' N 58°6'18'' W	Flow	1985 – 2010 (26 years)	17.0
Corner Brook Lake at Lake Outlet	02YL009	48°50'55'' N 57°51'7'' W	Level	1990 – 2010 (20 years)	65.3[1]
West Pond Brook Near Corner Brook Lake	02YL010	48°48'31" N 57°50'21" W	Flow	1995-1997 (2 years)	31.1
Copper Pond Brook Near Corner Brook Lake	02YL011	48°48'23'' N 57°47'1'' W	Flow	1995 – 2010 (16 years)	12.9

NOTES:

1. Drainage area not available from Water Survey of Canada, estimated from available mapping.
2. Italicized Station Names identify streamflow gauging stations located within the Corner Brook Stream watershed.

Station 02YL002, located downstream of Three Mile Dam, records daily average maximum flows. Statistical estimation of return period streamflows is based on maximum instantaneous recorded streamflows, as such, the recorded time series at this station cannot be used directly. An estimation of maximum instantaneous for this station was completed to facilitate use of the data set for statistical estimation of streamflows as described in Section 4.1.2.1.

Station 02YL010 has only two years of data. This was not considered sufficient for estimation of return period flows.

It is understood that the confidence in statistical estimates of streamflow increases with the length of the available streamflow historical record upon which to base the estimate. However, there is varied opinion as to the required length of record to support a 1:100 year AEP estimation with suggestions ranging from 18 years (WRMD, 1999), to 20 years (Alberta Transport, 2004), to 30-40 years (Watt et al, 1989; EC, 1976). The Institute of Hydrology (1999) suggests that a viable estimate of the 100 year AEP flow would require a 200 year streamflow record. The foregoing suggests a diversity of opinion on the minimum amount of data required. It can be concluded from the available references that extrapolating the data records at the gauges 02YL004 (28 years) and 02YL005 (26 years) to a 1:100 year AEP event can be done with a reasonable level of confidence, albeit uncertainty remains. The limited data record at gauge 02YL011 (only 16 years) reduces the confidence associated with the estimation of the 1:100 year AEP flow (and not the 1:20 year AEP flow); however, these estimates are for the study watershed and, hence, still bear consideration in this assessment.

Figure 4-1 : Location of Environment Canada Hydrometric Gauges in Tertiary Drainage Area 02YL

The hydrologic data should satisfy certain assumptions as follows for the results of a statistical frequency analysis to be theoretically valid, namely;

- Randomness – variations in the flows should arise from natural causes.
- Independence – there should be no serial dependence between successive flows.
- Lack of trend – the series should display no long term trends over time, such as might be caused by changes in land use or climate.
- Homogeneity – All events should originate from a single population (i.e., represent similar hydrological phenomena, be caused by a compatible flood-generating mechanism).

The streamflow data series was tested prior to the frequency analysis to ensure the data can be considered random and show no statistically significant serial dependence, trend or non-homogeneity. The Consolidated Frequency Analysis Package Version 3.1 (CFA_3) developed by Environment Canada was used to conduct the following screening tests;

- General Randomness Test,
- Spearman (independence) Test,
- Spearman (trend) Test, and the;
- Mann-Whitney split sample homogeneity test.

The following comments are relevant to the recorded streamflow data series screening assessment:

Stn ID	**Screening Assessment Commentary**
02YL004	The recorded data series (spanning 1983 to 2011) was missing instantaneous maximum flow values for the years 1994 and 1996. The average daily maximum record was complete over the period of record. Estimates of instantaneous maximum flow for the missing years were computed using the average peaking factor over the available data series. The revised data series (including the estimated values) failed the homogeneity test. One high outlier was detected and removed (January 1983 flood) and the screening tests were all passed.
02YL005	The recorded data series (spanning 1985 to 2011) was missing instantaneous maximum flow values for the years 1985, 1986, 1994, 1996 and 2003. The average daily maximum record was complete over the period of record. Estimates of instantaneous maximum flow for the missing years were computed using the average peaking factor over the available data series. The revised data series (including the estimated values) failed the General Randomness and the Spearman Independence tests. The estimated instantaneous maximum flow for 1985 (which was also the maximum flow in the series) was removed from the data series and the screening tests were all passed.
02YL011	The recorded data series (spanning 1995 to 2011) was not missing any instantaneous maximum flow values. All screening tests were passed without alteration of the available data series.

Additional details on the statistical screening analysis are provided in Appendix I.

4.1.2 Distribution Fitting and Quantile Analysis

The theoretical probability distributions generally considered for single site frequency analysis are the log-normal (LN) and three parameter log-normal (3PLN) distributions; and the Gumbel (EV-1) and Generalized Extreme Value (GEV). While all of these distributions have been historically recognized as possible flood frequency distributions in Newfoundland, streamflow estimates produced using these distributions typically lie within a narrow band. Further, other studies have concluded the 3PLN distribution to give the best overall fit to flood time series (WRMD, 1999; EC, 1985). Therefore, the 3PLN distribution was selected as the appropriate statistical distribution for estimation of streamflow from the historical record for this project.

The CFA_3 software package was used to estimate the 1:20 year and 1:100 year AEP flows from the streamflow record. Details from this analysis are provided in Appendix I. Unfortunately, the CFA_3 software does not provide confidence limits for the AEP estimates. Therefore, an estimate of the confidence limits associated with both the 1:20 year and 1:100 year AEP streamflow estimates was computed using the methodology defined in Bulletin B17 (USDI, 1982). The estimates of the 95% upper confidence limit associated with the 1:20 year and 1:100 year AEP single site frequency estimates are also provided in Table 4-2. As expected, given the limited period of record for the stations, the 95% upper confidence limit indicates a large range for the 100 year AEP estimate but a more constrained range for the 1:20 year AEP estimate. This result is consistent across the three stations assessed.

Unitary (flow per unit of area) and gauge specific streamflow results for 1:20 year and 1:100 year AEP flood events from the single site frequency analyses are presented in Table 4-2 for the three streamflow gauging stations recording unregulated flows.

Table 4-2: Single Site Frequency Analysis Results

Station[1]		Type of Flow	Statistical Estimates[2] (m^3/sec)		Unitary Flows ($m^3/sec/km^2$)	
			20 yr	100 yr	20 yr	100 yr
South Brook at Pasadena	02YL004	Instantaneous Max	77.8	118.0	1.33	2.02
Rattler Brook Near McIvers	02YL005		25.0	40.2	1.47	2.36
Copper Pond Brook Near Corner Brook Lake	02YL011		16.6	31.8	1.29	2.47

Station		95% Upper Confidence Limit Estimates[3] (m^3/sec)	
		20 yr	100 yr
South Brook at Pasadena	02YL004	110.2	194.8
Rattler Brook Near McIvers	02YL005	37.9	73.1
Copper Pond Brook Near Corner Brook Lake	02YL011	26.1	64.0

NOTES:

1. Stations noted in *italics* are located in the study watershed
2. Based on application of the 3 Parameter Log Normal Distribution
3. Based on the USDI (1982) B.17 methodology

The unitary flows outlined in Table 4-2 were then multiplied by the relevant watershed area associated with Petrie's Brook and Corner Brook Stream to obtain statistical estimates of the 1:20 year and 1:100 year AEP flood flows as outlined in Table 4-3. One location selected for Corner Brook Stream lies at the outlet from the most upper subcatchment in the HMS model, essentially at the outlet from Corner Brook Lake. This location is taken to lie above the dam and, as such, does not incorporate routing influences of the dam. The drainage area to this location is 65.1 km^2. The second location selected is located at the 02YL011 streamflow gauge which has a drainage area of 12.9 km^2.

Table 4-3: Statistical Estimates of Streamflow for the Subject Watersheds

Watercourse	Statistical Estimates based on Specific Gauges (m^3/sec)					
	02YL004		02YL005		02YL011	
	20 yr	100 yr	20 yr	100 yr	20 yr	100 yr
Petrie's Brook (6.2 km^2)	8.2	12.5	9.1	14.6	8.0	15.3
Corner Brook Stream (12.9 km^2 – unregulated watershed area)	17.2	26.1	19.0	30.4	16.6	31.8
Corner Brook Stream (65.1 km^2 – unregulated watershed area)	86.6	131.5	95.7	153.6	84.0	160.8

4.1.2.1 Statistical Assessment of Streamflows at Station 02YL002

Water Survey of Canada streamflow gauging station 02YL002 (Corner Brook at Watson's Brook Powerhouse) is located at Three Mile Dam (even though the name suggests it is located at the powerhouse about 2.9 kilometres downstream). Conversion of the latitude/longitude coordinates (from Water Survey of Canada) to MTM coordinates (using the coordinate conversion online tool GSRUG[7]) confirmed the location as just downstream from the dam. Data is available for this gauging station over the period 1959-2010. Table 4-4 provides a basic summary of the range of flows measured at this station.

Table 4-4: Streamflow Summary (02YL002)

Statistic	Daily Maximum Streamflow (m^3/s)
Average	26.1
Max	51.5
Min	6.0

In the context of single site frequency analysis, data for this station is available as daily maximum values only, not maximum instantaneous peak flows and the measured flows are regulated by the operation of the dam. Notwithstanding, a review of the streamflow information was completed to determine its value in the context of a qualitative comparison to the HEC-HMS computed streamflows.

The drainage area determined using the LiDAR topographic database is 126.4 square kilometres, which compares well with the listed drainage area for streamflow station 02YL002.

[7] available at http://www.geod.nrcan.gc.ca/tools-outils/tools_info_e.php?apps=gsrug

Two elements are missing from the documented streamflow record for station 02YL002 to allow direct comparison of the 1:20 year and 1:100 year HEC-HMS computed flows, namely maximum instantaneous streamflow over the period of record and flow diversion (which occurs at Three Mile Dam – upstream of the streamflow station) for power generation.

Estimation of Maximum Instantaneous Streamflow

Estimation of the maximum instantaneous flow record can be approximated by using a peaking factor from streamflow gauges in the same watershed or in nearby adjacent watersheds. Four stations are available for this purpose as outlined in Table 4-5.

Table 4-5: Peaking Factors

Station Name	Station ID	Peaking Factor	
		Range	Average
South Brook at Pasadena	02YL004	1.2 - 2.9	1.9
Rattler Brook Near McIvers	02YL005	1.1 – 2.5	1.6
West Pond Brook Near Corner Brook Lake	02YL010	1.3 - 1.8	1.5
Copper Pond Brook Near Corner Brook Lake	02YL011	1.1 – 1.8	1.3

The seasonal review of the peaking factors, for each of the gauges listed in Table 4-5, does not suggest any trend regarding high peaking factors in the summer or low peaking factors in the spring, for example. Further, average peaking factors in the winter months (December through April) versus the rest of the year (May through November) are nearly equal.

In the absence of a detailed review of the comparative topographic makeup between the various drainage areas to the drainage area to station 02YL002, selection of peaking factor from the list above is somewhat arbitrary. However, a visual inspection of topographic mapping does suggest a higher lake area to total drainage area ratio for the area above Corner Brook Lake than below Corner Brook Lake (through to Three Mile Dam). Further, the previous analysis reviewing the potential influence of Corner Brook Lake on flood management suggests that peak flows downstream of Corner Brook Lake are more influenced by local drainage characteristics (i.e., peak flows are generated by the drainage area below Corner Brook Lake). From this it can be postulated that higher peaking factors may be relevant below Corner Brook Lake. As such, a peaking factor of 1.8 was evaluated, which aligns with the maximum peaking factor for the streamflow gauges located in the Corner Brook Stream watershed. Further, a peaking factor of 2.5 was also evaluated as an assumed upper limit for the Corner Brook Stream watershed.

Estimation of Flow Diversion

Data outlining the quantity of water used for power generation was requested from Kruger Energy, however, no data was provided to this project in this regard. Internet searches were also conducted to search for similar information, but no useful data was obtained.

The water usage data that was made available from Newfoundland Power for the Petty Harbour Hydro System was used as a surrogate for the Corner Brook Stream Hydro System at Three Mile Dam. The Petty Harbour Generating Station has a capacity of 5.3 MW and uses a maximum of 11 m^3/s (when in peak power generation mode). The Watson's Brook Generating Station has a capacity of 9.6 MW suggesting a higher water usage potential. Linearly extrapolating the Petty Harbour water usage to the Corner Brook Hydro System suggests a water usage potential of about 19 m^3/s. It is understood that water usage for power generation purposes will vary throughout the year and will also vary dependent on the type of turbines installed at the power house. However, in the absence of data from Kruger Energy an approximate method of estimating power generation water usage was necessary to facilitate this assessment.

Single Site Frequency Analysis

Peak flow time series were generated for single site frequency analysis reflecting an all-year maximum instantaneous scenario. The time series were based on an adjustment of the daily maximum peak flow series using 1.8 and 2.5 peaking factors and the addition of 19 m^3/s of flow to each peak representing the amount of flow diverted for power generation. The addition of peak generation power usage is based on operating information provided by Newfoundland Power which indicates peak generation during times of high flow.

Table 4-6 summarizes the single site frequency analysis of the two maximum instantaneous flow series for station 02YL002. The results indicate a direct sensitivity to the value of the peaking factor which is to be expected.

Table 4-6: Single Site Frequency Analysis for Station 02YL002

Frequency (years)	**Streamflow Estimates (m^3/s)**	
	PF 1.8 + 19 (see Note 1)	**PF 2.5 + 19** (see Note 2)
20	94.4	124
100	112	149
	Upper Range Confidence Limit (m^3/s)	
20	113.6	150.1
100	143.8	194.5

NOTES:
1. PF 1.8 + 19 – daily maximum streamflows were adjusted using a peaking factor of 1.8 plus 19 m^3/s to represented diverted flow for power generation.
2. PF 2.5 + 19 – daily maximum streamflows were adjusted using a peaking factor of 2.5 plus 19 m^3/s to represented diverted flow for power generation.

4.1.3 Regional Flood Frequency Analysis

The approach documented in the *Regional Flood Frequency Analysis for the Island of Newfoundland* (RFFA) (WRMD, 1999) was also for streamflow estimation in the subject watersheds. The regional regression equations derived in this study are recommended for estimating return period flood flows on ungauged watersheds. However, these equations cannot be used on all watersheds as many ungauged watersheds have physiographic parameters which are outside the range of physiographic parameters which were used in the development of the regression equations.

Both the Petrie's Brook and Corner Brook Stream Watersheds lie within the south-west region as defined for the RFFA (see Figure 4.1 from the RFFA). The minimum drainage area in the south-west region for which the regional equations are valid is 89.6 km^2 (see Table 5.1 from the RFFA).

Therefore, the RFFA empirical equations should not be used to estimate streamflow for the Petrie's Brook Watershed because it is significantly smaller than the minimum RFFA recommended drainage area, with a total drainage area of 6.2 km^2.

The Corner Brook Stream Watershed has a similar drainage area issue in regard to use of the RFFA empirical equations. While the total Corner Brook Stream Watershed has a drainage area of 158.4 km^2 (larger than the RFFA minimum of 89.6 km^2), the largest unregulated portion of the watershed is only 65.1 km^2. Therefore, in the context of this assessment, streamflow estimates computed using the RFFA empirical equations were used for information purposes only and not relied upon.

The RFFA analysis for the subject watersheds (which lie in the southwest region) requires the drainage area (expressed as km^2) and an estimate of the Lakes and Swamps Factor (LSF) using the equation:

$$Q_{20} = 169.044 \times (\text{Drainage Area})^{0.648} \times (\text{LSF})^{-5.998}$$

$$Q_{100} = 374.973 \times (\text{Drainage Area})^{0.598} \times (\text{LSF})^{-6.533}$$

The LSF is computed as follows:

$$\text{LSF} = (1 + \text{FACLS}) - \frac{\text{FLSAR}}{(1 + \text{FACLS})}$$

where;

FACLS = fraction of watershed area occupied by lakes and swamps
FLSAR = fraction of watershed area controlled by lakes and swamps

The computed LSF factors for the Corner Brook Stream watershed were determined to lie outside of the range limits defined for application of the RFFA methodology. As such, again for qualitative comparison purposes, RFFA based flow estimates were computed using the upper and lower LSF bounds as defined in the RFFA user manual.

The results of the RFFA based streamflow estimation are provided in Table 4-7.

Table 4-7: RFFA based Streamflow Estimation

Watercourse	LSF	RFFA Streamflow Estimates (m^3/sec)	
		20 yr	100 yr
Petrie's Brook (6.2 km^2)	Not applicable due to watershed area		
Corner Brook Stream (12.9 km^2 – unregulated watershed area)	Not applicable due to watershed area		
Corner Brook Stream (65.1 km^2 – unregulated watershed area)	1.78	79.7	105.3
	1.51	213.7	308.5

4.2 Deterministic Analysis

The 1:20 year and 1:100 year AEP flow estimates were simulated using a deterministic numerical model. There are several numerical models available for the analysis of the rainfall-runoff response of a watershed. The United States Army Corps of Engineers (USACE) HEC-HMS model was selected since it is a non-proprietary model which has been extensively used and tested. The numerical model includes a selection of methods to simulate watershed, channel and water control structure behaviour to predict flow, stage and timing. The advantages of a numerical model include the following:

- Synthesis and routing of flood hydrographs (quantifying basin response, flood volume and flow over time)
- Flow simulation distributed over several sub-watersheds and tributaries
- Simulation of reservoir routing
- Accounting for spatial variations in soil type and land cover, and
- Accounting for peak flow attenuation in channel and floodplain.

An advantage of this model is the HEC-GeoHMS link which permits much of the model setup to occur within a GIS environment. This functionality was implemented for the current study and simplified the model development process. The following sections describe the model inputs, calibration and verification of the model and the resulting flood flow estimates.

4.2.1 Model Setup

Model Elements

The elements of the HEC-HMS model prepared for the current study were developed using the HEC-GeoHMS tool which allows one to process the watershed in ESRI ArcGIS 9.3/10.0 and develop the model for import into HEC-HMS. The parameters imported from Geo-HMS include sub-basins, river reaches, and junctions. A Digital Elevation Model (DEM) raster network with a resolution of 1x1 m^2, provided from the LiDAR mapping was used for model set up and parameterization. Terrain pre-processing was applied to prepare the appropriate DEM for model set-up. HEC-GeoHMS recommended steps were followed and sub-basins were delineated. Figures 4-3a and 4-4a depict the Corner Brook Stream and Petrie's Brook sub-basins respectively. Some of the delineated sub-basins were further discretized in HEC-GeoHMS to add a flow node at desired locations.

In the next step, several basin characteristics including river length, river slope, basin slope, longest flow path, basin centroid, basin centroid elevation and centroidal flow path were determined using HEC-GeoHMS.

The Muskingum-Cunge routing method was selected for simulation of routing in river reaches in the study area. The loss and transform method, selected to convert rainfall to runoff, was the Soil Conservation Service[8] (SCS) method which requires several input parameters including Curve Number, initial abstraction and lag time for each sub-basin.

River reach routing was simulated for the study reach of Corner Brook Stream and Petrie's Brooks. Channel shape, length, slope and roughness coefficients for the channel and overbanks were developed from survey cross sections along the reach in conjunction with the DEM for areas without survey.

Sub-basin Inputs

SCS Curve Number (CN) is an index of the basin's runoff generation potential and is a function of soil type and land use. National Resource Conservation Service (NRCS), known formerly as the US Soil Conservation Service (SCS), has tabulated Curve Numbers on the basis of soil type and land use. Four major hydrologic soil groups are defined which are briefly described as:

- Group A: Deep sand, deep loess aggregated soils
- Group B: Shallow loess, sandy loam
- Group C: Clay loams, shallow sandy loam, soils low in organic content and high clay soils
- Group D: Soils that swell significantly when wet, heavy plastic clays, and certain saline soils

Soil information for the study area has been provided through Canadian Soil Information Service (CanSIS) of Agriculture Canada. The Corner Brook Stream and Petrie's Brook watersheds were defined in the *Reconnaissance Soil Surveys of Stephenville – Port-Aux-Basques 1991* Report No. 12 (I2 B) and *Soils of the Red Indian Lake – Burgeo Area 1988* Report No. 9 (I2 A) [Agriculture Canada].

The detailed soil survey report along with a corresponding GIS soil layer have been provided by Agriculture Canada and used in the CN determination process. Hydrologic soil groups for different soil classes in the study area have been determined based on soil class descriptions in Ag Canada (1988) and Ag Canada (1991). Corner Brook Stream and Petrie's Brook soil mapping, as well as SCS hydrological soil group classifications, are presented in Figures 4-3b, 4-3c and Figures 4-4b and 4-4c respectively.

[8] The Soil Conservation Service is now known as the Natural Resources Conservation Service (NRCS)

From these reports (Ag Canada (1988) and Ag Canada (1991)) and soil mapping, the following soil associations and their classified hydrologic soil group are as follows:

For Petrie's Brook watershed:

- Cox's Cove (M28) – hydrologic soil group C

For Corner Brook Stream watershed:

- Cox's Cove (M28) – hydrologic soil group C
- North Lake (M35) – hydrologic soil group D
- Silver Mountain (M34) – hydrologic soil group D
- Lomond (M21) – hydrologic soil group C
- Rock Land (R2) – hydrologic soil group D

The soil associations noted above represent the "Dominant Soil Association" which indicates the soil series which is dominant within the spatial polygon in the GIS database occupying over 50% of the polygon by area.

Land use classification was completed using remote sensing data (see Appendix C) as input and eight land use classes were identified for the Corner Brook Stream and Petrie's Brook watershed areas as outlined in Table 4-8. Land use class coverage for each HMS model subcatchment is provided in Appendix C. Figures 4-3f and 4-4f illustrate the land cover across the Corner Brook Stream and Petrie's Brook basins respectively.

Table 4-8: Curve Numbers for Typical Land Uses

	Soil Type			
Land Use	**A**	**B**	**C**	**D**
Forest	30	55	70	78
Developed	99	99	99	99
Fields/Pastures	39	61	74	80
Wetlands	46	66	78	83
Water	100	100	10	100
Barren/Soil	76	85	89	91
Open Space	49	69	79	84
Deforested	49	69	79	84

Having both land cover and soil information in GIS form permitted efficient estimation of Curve Number values across the watershed for the hydrologic model. Table 4-8 presents Curve Numbers for some typical land covers and soil group based on values recommended in the current NRCS handbook for various hydrologic soil-cover complexes. Figures 4-3d and 4-4d illustrate the Curve Number grid across the Corner Brook Stream and Petrie's Brook basins respectively.

The empirical CN values are subject to variability resulting from rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth and temperature; these causes of variability are collectively called the Antecedent Runoff Condition (ARC). ARC II was used in this analysis representing average conditions.

Figures 4-3e and 4-4e illustrate the initial abstraction grid across the Corner Brook Stream and Petrie's Brook basins respectively. Initial abstraction is defined as losses from rainfall before runoff begins representing hydrologic elements such as infiltration, rainfall interception by vegetation, short term surface storage such as puddles, etc.

Table 4-9 summarizes the basin area, length, slope, weighted average CN and time lag for each of the model sub-basins.

Reservoir Starting Water Levels

Section 2.0 provides details on each of the four dams located in the Corner Brook Stream Watershed, namely Corner Brook Lake Dam, Three Mile Dam, Margaret Bowater Park Dam and Glynmill Pond Dam.

As each of these dams have specific operating conditions during the different months of the year and it is understood that these facilities have the potential to exert influence on streamflows and flood management throughout the watershed, a review of the temporal modelling basis for this project was completed. Re-stated, the single event modelling approach adopted for this project assumes the design rainfall event to occur during the warm period of the year when precipitation falls as rain and soils have completely thawed. Within this time frame, which lies approximately between late spring and early autumn (approximately May through October), the assumption of when the "single event" occurs is of importance in order that the modelling starting or boundary conditions can be defined in the context of starting water levels, gate settings and specific operational considerations for extreme weather at the dams. As an example, the gates at Margaret Bowater Park Dam are closed before Labour Day and completely open after that date. Similarly, Corner Brook Lake would be at full supply level in July and almost 2m lower at the end of September. These conditions need to be reflected in the hydrologic modelling.

As an initial step, a review of the seasonal frequency of documented floods in the study area was completed using the listing of floods provided in Appendix A. The seasonality of the thirty-eight (38) documented floods in the study area (ref. Table 4-10) shows an almost even split between the occurrence of floods over the spring, summer and fall (collectively – 21 events) and then the winter months (17 events). A review of the descriptions associated with the spring and winter flood events indicates one (1) spring event and (9) winter events were associated with rainfall and snowmelt conditions and therefore not relevant to this review. From this review, and in the context of single event hydrologic modelling, it is concluded that the primary flood producing seasons, where rainfall only is the catalyst, are summer and fall in the Corner Brook area. A review of the climate normals for Corner Brook (ref. Table 4-11) reinforces this conclusion as the summer and fall months represent the "wettest" months of the year for the area.

Table 4-9: Deterministic Model Basin Input Parameters
Corner Brook Stream

Sub-basin	Area (km^2)	Curve Number	Lag (min)
W7860	65.12	82.9	94.0
W8550	0.24	83.7	16.1
W8580	0.00	96.4	5.0
W12860	0.76	80.9	25.5
W12770	9.11	79.7	58.2
W7640	26.29	82.2	67.0
W12940	0.07	79.2	6.6
W6510	2.26	79.7	22.6
W6190	1.95	83.4	28.1
W11710	12.31	82.1	78.1
W6430	2.42	81.2	37.5
W6490	1.93	85.8	31.0
W12150	0.09	88.1	8.7
W5860	2.94	81.9	37.3
W6070	0.72	79.8	19.7
W6050	0.24	82.0	15.9
W1	0.24	81.0	18.2
W5730	0.16	79.1	12.4
W5680	0.58	83.8	22.6
W5720	0.07	78.6	6.6
W5630	1.91	80.3	20.3
W5640	0.65	74.6	17.6
W5790	8.65	80.1	56.9
W5550	0.93	76.7	18.2
W5410	0.46	71.6	19.4
W5340	0.34	77.2	20.1

Sub-basin, ctd.	Area (km^2)	Curve Number	Lag (min)
W5330	0.16	75.9	9.1
W5520	1.74	81.9	24.4
W5320	0.19	85.1	10.0
W5300	0.16	85.3	10.4
W5250	0.98	83.6	25.0
W5280	0.10	78.4	8.1
W5230	0.16	80.7	10.2
W5240	0.70	88.4	16.9
W5140	0.19	91.4	10.7
W5190	0.24	83.5	16.4
W5150	0.18	82.0	11.0
W5220	1.39	85.5	24.1
W5180	0.65	85.4	21.9
W5760	0.55	80.6	15.1
W5770	2.55	81.4	29.7
W5710	0.06	85.1	12.5
W5540	1.23	82.0	21.3
W5440	1.26	82.1	19.2
W5700	2.31	80.8	32.4
W5690	0.32	81.4	15.1
W5370	0.87	81.3	17.0
W5390	0.61	82.2	13.2
W5310	0.73	85.2	14.6
W5160	0.29	89.4	13.4
W5170	0.16	92.5	9.7
W5130	0.20	93.6	10.0

Petrie's Brook

Sub-basin	Area (km^2)	Curve Number	Lag (min)
W680	0.07	85.8	7.6
W690	0.02	82.7	3.7
W700	0.14	78.2	11.3
W740	0.48	80.2	20.1
W760	0.19	79.2	9.0
W770	0.00	76.5	1.6
W780	0.01	76.2	2.3
W800	0.26	76.3	15.4
W810	0.04	80.4	4.2
W820	0.12	77.1	13.7
W860	0.26	75.6	12.9
W880	0.09	78.3	10.1

Sub-basin	Area (km^2)	Curve Number	Lag (min)
W890	0.11	75.4	10.4
W900	0.00	70.2	1.7
W920	0.05	81.0	7.2
W930	0.16	74.3	14.8
W970	0.51	73.6	24.8
W990	1.51	77.3	30.6
W1100	0.46	73.0	16.4
W1210	1.06	73.2	27.9
W1320	0.64	71.9	23.7
W1360	0.03	83.4	3.9
W1460	0.04	84.8	7.0

Table 4-10: Seasonality of Documented Floods in the Corner Brook Area

Month	# of Floods	Season
January	4	Winter
February	5	Winter
March	5	Winter
April	0	Spring
May	2	Spring
June	1	Summer
July	0	Summer
August	5	Summer
September	4	Fall
October	3	Fall
November	5	Fall
December	4	Winter

Season	# of Floods
Spring	3
Summer	6
Fall	12
Winter	17

Table 4-11: Corner Brook Climate Normals

(source: Environment Canada[9])

Month	Rainfall (mm)	Snowfall (cm)	Extreme Daily Rainfall (mm)
January	37.5	110.8	52.3
February	23.4	76	49
March	39.2	56.6	47
April	45.6	25.1	53.5
May	72.2	5.3	51.7
June	83.9	0.2	82.8
July	91	0	64.3
August	98.6	0	72.4
September	104.2	0.1	82.6
October	115.7	7.9	79.8
November	84.6	41.1	63.5
December	53.1	98.8	51.9

Hurricanes represent a known flood producing threat to the Province. The Atlantic hurricane season begins in June and ends in late November[10], essentially representing the full temporal spectrum of the warm season rainfall period as defined above. As documented in the "Flood Risk and Vulnerability Analysis Project" completed for the Government of Newfoundland and Labrador (AMEC, 2012) the frequency of tropical storm occurrence in Newfoundland and Labrador, and the entire North Atlantic, can vary considerably from year to year and decade to decade. Tropical storm activity in Newfoundland and Labrador peaked in the 1960's and 1970's before reaching its lowest levels in the 1980's. But, activity in the past 20 years has increased considerably, especially over Eastern Newfoundland and the surrounding marine areas. 1997 was the last year where no tropical storms affected Newfoundland and Labrador. Since that

[9] Canadian Climate Normals 1971-2000, Corner Brook weather station (#8401300)
[10] US National Weather Service, National Hurricane Center website at http://www.nhc.noaa.gov/

time, an average of two or three storms have tracked across or near the province, including the peak year of 2006 when five (5) storms affected the region. The total number of tropical systems which have affected each region of Newfoundland and Labrador, by decade, is illustrated in Figure 4-2. The data indicates occurrence of tropical storms over the western part of Newfoundland over the months of July, August, September and October.

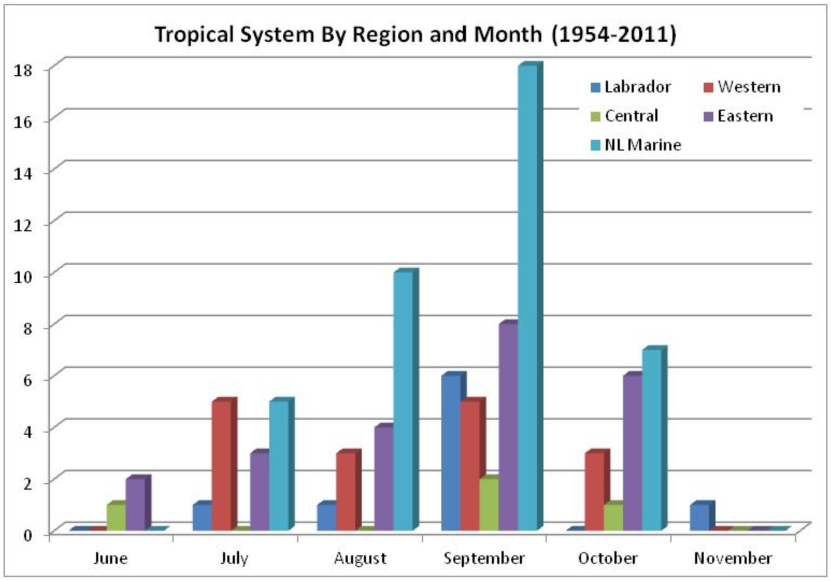

Figure 4-2: Tropical Storms by Region and Month (1954-2011)
(source: AMEC, 2012)

Based on this review, there is no clear evidence to select the summer or fall as the temporal modelling basis for this project.

The development of the temporal modelling scenarios started with a review of the flood operations at Corner Brook Lake Dam. As noted in Section 2.0, forecast of severe rainfall in the watershed initiates flood control operations at Corner Brook Lake Dam resulting in closing of the sluice gates, essentially shutting off all outflow from Corner Brook Lake. Water levels are then monitored and when/if water levels attain the Maximum Flood Level the gates are opened. To investigate the effects of dam operations three operational scenarios were assessed, namely; (#1) the gates fully closed for the duration of the event, (#2) the gates fully open for the duration of the event, and (#3) the gates partially open (to a 6 inch level) for the duration of the event. The latter scenario represents the typical gate settings (supporting downstream flow augmentation) which may be in place during normal operations and severe weather restricting operator access to the site negating the operation to close the gates. The simulations for all of these scenarios were started with a reservoir level in Corner Brook Lake equal to the Full Supply Level.

The HEC-HMS computed flows for these scenarios are outlined in Table 4-12.

Table 4-12: Results Summary for Various Corner Brook Lake Dam Operations

Location	Operation #1 (gates fully closed)		Operation #2 (gates fully open)		Operation #3 (gates set for downstream flow augmentation)	
	20 Yr	100 Yr	20 Yr	100 Yr	20 Yr	100 Yr
Near Watson's Brook Power House on Corner Brook Stream	127.5	178.3	175.1	225.7	132.7	183.4
Outlet of Corner Brook Stream	142.1	201.2	194.2	253.5	147.5	206.7
Computed Maximum Water Surface Elevation at Corner Brook Lake	326.3	326.4	< 326	<326	326.2	326.3

The gates fully open scenario (Operation #2) is considered an operational anomaly as having the gates fully open at the start of a forecasted severe rainfall event would be contrary to the current flood operation guidelines for the dam. As the results outlined in Table 4-12 also indicate, operation of the dam in this manner would result in the highest streamflow of the three scenarios evaluated.

Operation #3 is considered to be an exceptional circumstance whereby the operator is unable to reach the dam in advance of forecasted a severe rainfall event. Notwithstanding, the computed flows are only marginally higher than those computed for the gates closed scenario (Operation #1).

This evaluation of confirmed that Corner Brook Lake Dam has the capacity to absorb the total runoff from the 1:100 year runoff with only a minor increase in water level, even when the gates are completely closed (Operation #1) for the duration of the event. This situation is consistent with the current flood operation guidelines for the dam and, as such, was used for as the basis representing Corner Brook Lake Dam for subsequent modelling.

The following additional considerations were embodied within the scenarios

- No information regarding power generation at Watson's Brook Generating Station was made available this project. As such, development of the modelling scenarios assumed the turbines to be off for the duration of the modelled event. It was further assumed that the turbines could not be run in a "no load" condition. As such, no water usage for power generation is integrated into the HEC-HMS model.

- No operation of the gates at Margaret Bowater Park Dam for the duration of the modelled event. This is consistent with the flood operation information provided by the City of Corner Brook.

- No information regarding water level management at Glynmill Pond Dam was made available this project. As such, development of the modelling scenarios assumed the gates to be closed for the duration of the modelled event.

The four operational scenarios evaluated are outlined in Table 4-13.

Table 4-13: Dam Operation Scenarios

Operational Scenario #1a – Mid summer

Dam	Operational Characteristics
Corner Brook Lake Dam	• Starting water level = full supply level = 326.00m • All gates closed
Three Mile Dam	• Starting water level = full supply level = 210.85m • No turbine operation during extreme weather
Margaret Bowater Park Dam	• Starting water level = full supply level = 27.20m • All gates closed
Glynmill Pond Dam	• Starting water level = full supply level = 15.20m • All gates closed

Operational Scenario #1b – Mid summer

<table>
<tr><th>Dam</th><th>Operational Characteristics</th></tr>
<tr><td>Corner Brook Lake Dam</td><td>• Same as Operational Scenario #1a</td></tr>
<tr><td>Three Mile Dam</td><td>• Starting water level = full supply level = 212.01m
• No turbine operation during extreme weather</td></tr>
<tr><td>Margaret Bowater Park Dam</td><td rowspan="2">• Same as Operational Scenario #1a</td></tr>
<tr><td>Glynmill Pond Dam</td></tr>
</table>

Operational Scenario #2 – Late summer

<table>
<tr><th>Dam</th><th>Operational Characteristics</th></tr>
<tr><td>Corner Brook Lake Dam</td><td>• Starting water level = full supply level = 325.15m
• All gates closed</td></tr>
<tr><td>Three Mile Dam</td><td rowspan="3">• Same as mid-summer operation (scenario #1a)</td></tr>
<tr><td>Margaret Bowater Park Dam</td></tr>
<tr><td>Glynmill Pond Dam</td></tr>
</table>

Operational Scenario #3 – Early autumn

Dam	Operational Characteristics
Corner Brook Lake Dam	• Starting water level = full supply level = 324.40m • All gates closed
Three Mile Dam	• Same as mid-summer operation (scenario #1a)
Margaret Bowater Park Dam	• Starting water level = full supply level = 23.18m • All gates open
Glynmill Pond Dam	• Same as mid-summer operation (scenario #1a)

The results of the HEC-HMS modelling for the alternate operational scenarios are outlined in Table 4-14. The results for 'Brooks Brook at confluence with Corner Brook Stream' are provided for information purposes only as with no dams (i.e., no regulation in that portion of the watershed no changes would be expected). The results for the two locations noted on Corner Brook Stream do not indicate any substantially variation in computed flows across the alternate operational scenarios. This is not unexpected given the very limited storage available in the three head ponds (i.e., Three Mile, Glynmill Pond and Margaret Bowater Park). Operational scenario #1b does result in the most conservative computed flows and, as such, was deemed the appropriate operational basis for modelling of the dams at Three Mile, Glynmill Pond and Margaret Bowater Park.

Table 4-14: Alternate Dam Operations - HEC-HMS Results

Location	Computed Flows (m^3/s) associated with alternate Operational Scenarios			
	1a Mid Summer	1b Mid Summer	2 Late Summer	3 Early autumn
1:100 Year				
Brooks Brook at confluence with Corner Brook Stream	58.5	58.5	58.5	58.5
Corner Brook Stream near Watson's Generating Station	175.9	178.7	175.9	175.9
Corner Brook Stream at watershed outlet	199.7	201	199.7	199.7
1:20 Year				
Brooks Brook at confluence with Corner Brook Stream	42.5	42.5	42.5	42.5
Corner Brook Stream near Watson's Generating Station	126.4	127.5	126.4	126.4
Corner Brook Stream at watershed outlet	140.2	142.9	140.2	140.1

Rainfall Inputs

Environment Canada publishes intensity duration frequency (IDF) curves which are estimates of rainfall return period amounts in the form of design storm frequencies between 1:2 years and 1:100 years and for durations of 5 minutes to 24 hours. For this analysis, the precipitation estimates for the Deer Lake weather station (ID 5401501) were used for the following reasons:

- Deer Lake is the closest Environment Canada weather station to the project site for which there are published IDF estimates of rainfall for the short intervals necessary to model a design storm. Other weather stations closer to the site measure rainfall only on the basis of daily totals which is not of sufficient precision for flood runoff analysis.
- Individual design hyetographs were not available for the project location from other sources.

The 1:20 year precipitation amounts were estimated by interpolation (using the Power function trending option in Microsoft Excel[TM]) from the 1:10 year and 1:25 year amounts. The IDF estimates for the project area are shown in Table 4-15.

Table 4-15: Return Period Rainfall Amounts (mm)

Duration	Frequency	
	20 yr	**100 yr**
10 min	10.7	14.7
30 min	15.9	20.5
1 h	20.7	26.2
2 h	30.6	39.7
6 h	44.0	54.6
12 h	53.6	65.9
24 h	62.2	76.4

The 1:20 year and 1:100 year precipitation hyetographs were estimated by using the Alternating Block method and the 5-minute to 24-hour durations for the 1:20 year and 1:100 year precipitation amounts respectively. Rainfall was input to the model in the form of a hyetograph (rainfall amount over time). Precipitation was assumed to be uniform over the watershed with no areal reduction. Figure 4-4 includes the 24 hour hyetographs for the 1:20 year and 1:100 year precipitation events.

4.2.2 Model Calibration and Validation

Model calibration and validation are required to ensure that generated peak flows from HEC-HMS model are within an acceptable range. Unfortunately, it was not possible to conduct a conventional calibration process in this study due to insufficient measured flow, precipitation data and dam operation data for the Corner Brook study area on a storm by storm basis. As previously noted, no recording streamflow gauges are available for the Petrie's Brook watershed. Model calibration requires accurate measured flow data at points of interest within the watershed to be compared with corresponding computed flows from deterministic modeling. Of the two gauges located within the Corner Brook watershed, maximum instantaneous water level has been measured at Corner Brook Lake at Lake Outlet (02YL009) and maximum daily discharge has been measured at Corner Brook at Watsons Brook Powerhouse (02YL002). Neither gauge records the maximum instantaneous annual discharge which limits the value for calibration and validation.

In the absence of local measured data to support the calibration and validation efforts, estimation of streamflow was completed using statistical and regional flood frequency methodologies (as described in Section 4.1).

Two points of interest across the two subject watersheds were assessed as outlined in Tables 4-2 and 4-3. Table 4-16 summarizes the estimates of streamflow based on the deterministic model of the two watersheds at comparable points to those used for the statistical analysis.

Table 4-16: Summary of Streamflow Estimates

Watercourse	Streamflow Estimates (m^3/sec)							
	HEC-HMS		RFFA		Average from Statistical Estimates		Maximum from Statistical Estimates	
	20 yr	100 yr	20 yr	100 yr	20 yr	100 yr	20 yr	100 yr
Petrie's Brook (6.2 km^2)	10.2	16.7	Not applicable		8.4	14.1	9.1	15.3

Corner Brook Stream	HEC-HMS		RFFA		02YL011		95% Upper Confidence Limit	
	20 yr	100 yr	20 yr	100 yr	20 yr	100 yr	20 yr	100 yr
Partial Watershed (12.9 km^2 – unregulated watershed area with alignment to EC station 02YL011)	23.4	33.5	Not applicable		16.6	31.8	26.1	64.0
Partial Watershed (65.1 km^2 – unregulated watershed area only)	118.3	169.0	106.8	145.1	88.8	148.6	95.7	160.8
Entire Watershed (158 km^2)	142.9	201	Not applicable		Not applicable		Not applicable	

It is understood that the streamflow estimates which have been based on the RFFA and single station frequency analysis methodologies are approximate with the accuracy of the estimate is limited by the underlying data. The comparison of the streamflow estimates computed using the deterministic (HEC-HMS) model compare very well to those generated using statistical methods, particularly when compared within the confidence limits associated with the single station frequency estimates.

As outlined in Section 4.1.2.1, a review of the streamflow information associated with station 02YL002 was completed to determine its value in the context of a qualitative comparison to the HEC-HMS computed streamflows. The 1:20 year and 1:100 year HEC-HMS computed flows at the outlet from Three Mile Dam are 124.5 m^3/s and 174.4 m^3/s respectively. These values align reasonably with the statistical estimates for streamflow at station 02YL002 for the "PF 1.8 + 19" and "PF 2.5 + 19" scenarios when viewed within the upper confidence limit of the estimates.

Based on the foregoing comparative assessment, it was concluded that the base watershed parameterization be maintained without alteration as the current base data (from which the parameterization was developed) provides the best interpretation of current watershed conditions.

4.3 Conclusions and Recommendations

4.3.1 Conclusions

The 1:20 year and 1:100 year AEP flood flows were estimated for the subject watersheds, namely: Corner Brook Stream and Petrie's Brook, using both statistical and deterministic methodologies. Comparative assessment of the flow estimates over the range of methodologies concluded that the deterministic model results provided a good estimate of streamflow for these watersheds.

The streamflow estimates generated through the deterministic analysis were carried forward for use in the hydraulic model.

4.3.2 Recommendations

The development of deterministic watershed simulation models for Corner Brook Stream and Petrie's Brook were based on best available data, engineering judgment and parameterization founded upon field collected watershed data such as LiDAR and satellite and orthophoto imagery. The peak flows computed using the HEC-HMS model compared very well with independently determined peak flows at the Environment Canada gauge location in the watershed, falling within 95% confidence limits of the statistical estimates. It is, therefore. recommended that the streamflow estimates generated through the deterministic analysis be carried forward to the hydraulic analysis for computation of flood levels across the study areas.

The Deer Lake and Stephenville Environment Canada stations lie approximately 49 km and 65 km respectively from the approximate centroid of the Corner Brook watershed. Comparatively, the centroid of the Petrie's Brook Watershed also lies closer to the Deer Lake station, however, still a significant distance away from the watershed. As such, it is recommended that a rainfall station local to the Corner Brook Area be installed to support both the assessment of IDF relationships and the watershed analysis, as well as to give insight into local meteorological conditions specific to the area.

It is recommended that the City of Corner Brook engage in a field-based program to measure water levels at designated structures during flood events. This will provide for the development of a database of information which could be used to support both hydrologic and hydraulic modelling in the future.

It is also recommended that a program focused on unregulated streamflow data collection be developed for Corner Brook Stream. The only hydrometric station presently recording unregulated streamflow (with a usable period of record) in the Corner Brook Stream watershed is located at Environment Canada station 02YL011 (Copper Pond Brook Near Corner Brook Lake). The upstream drainage area to this station is 12.9 km^2 or only about 8% of the overall watershed. Additional recording stations at strategic locations (e.g., inflow to Corner Brook Lake, outflow from Bells Brook, and other large unregulated tributary areas) would provide a foundation of data that would enhance the hydrologic model calibration/validation process.

It is recommended that a program focused on unregulated streamflow data collection be developed for Petrie's Brook. No hydrometric stations are presently in operation in this watershed. Further, the size of the watershed precludes use of the RFFA methodology. A recording station at the outlet from the watershed would provide a foundation of data that would enhance the hydrologic model calibration/validation process.

It is recommended that WRMD engage a program to collect and develop stage-storage-discharge curves and operational data including rules curves, gates settings and reservoir water levels for all dams in the Province. Significant resources were utilized with the current project to first determine the ownership of the data (i.e., the contact person within the dam owner organization) and also to deal with delays that resulted from the time that was found to be necessary to obtain the information, once the most appropriate contact was established. If this information was already available through WRMD at the outset of the project, the development of the hydrologic model would have been more efficient.

Finally, it is recommended that that HEC-GeoHMS and HEC-HMS be used in future watershed and flood studies as these tools both simplify the development of deterministic models as well as provide for the generation of a significant warehouse of information that can be used for several of ancillary purposes, beyond hydrologic assessment.

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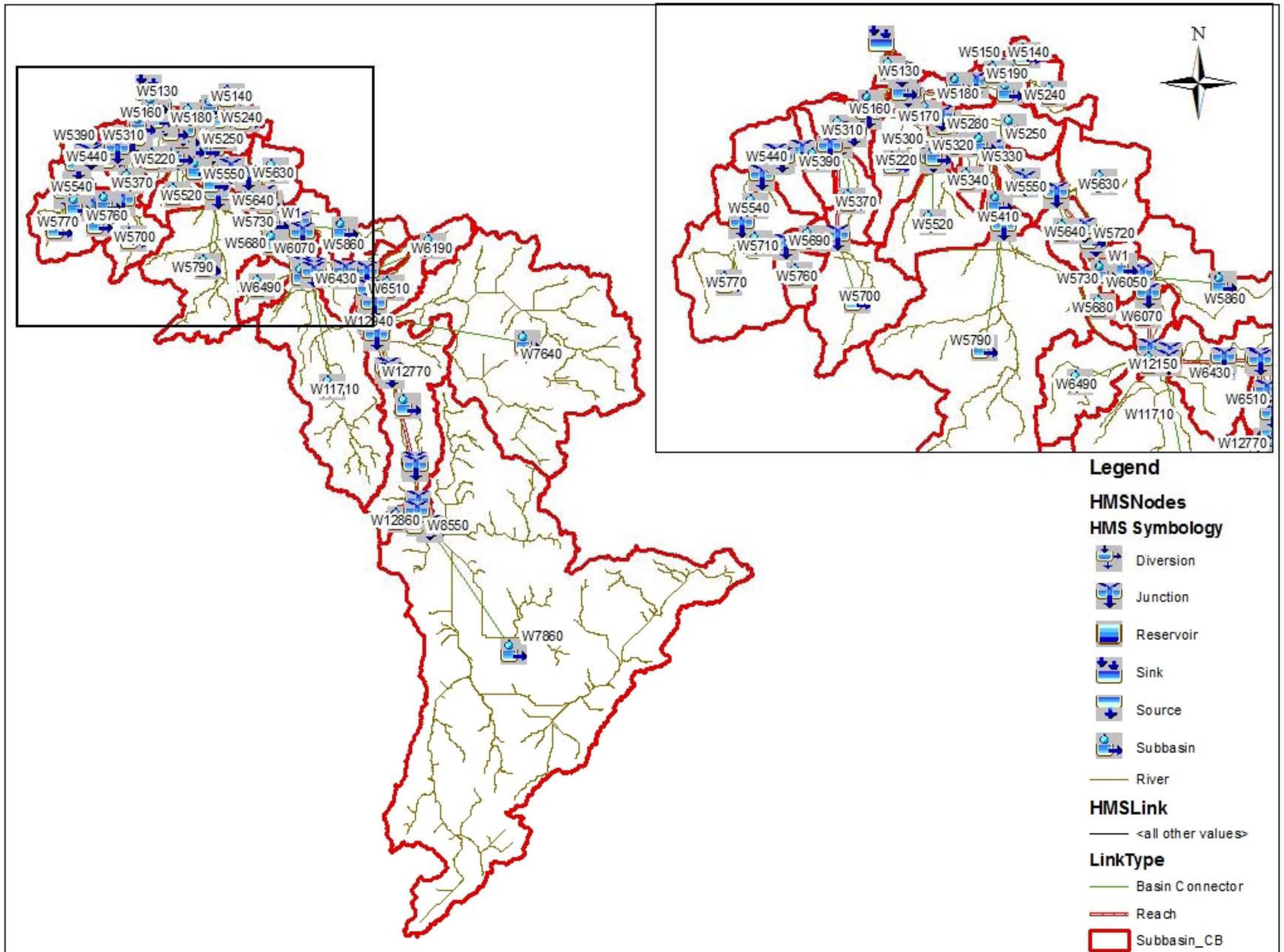
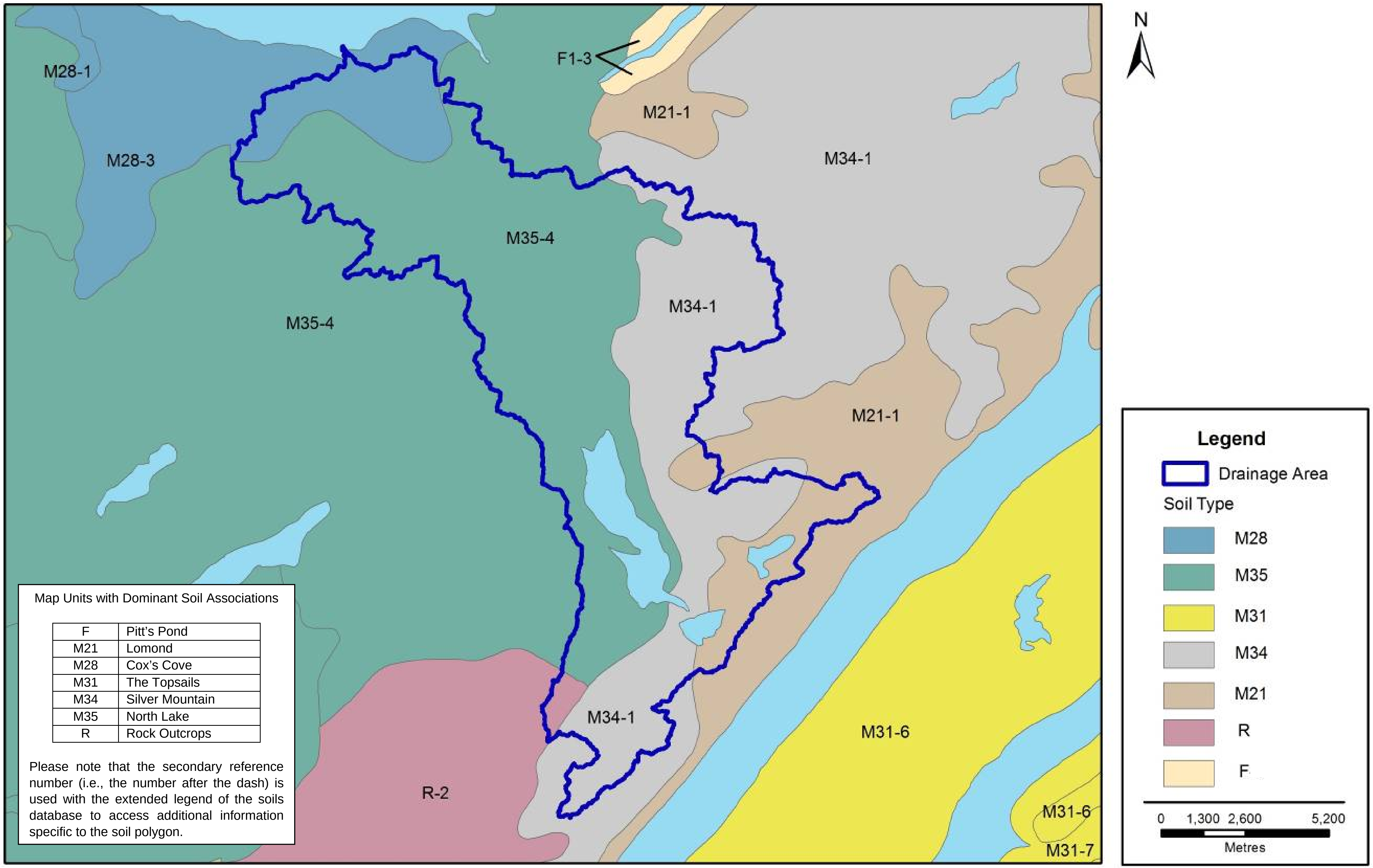


Figure 4-3a: Corner Brook Stream HMS Model Schematic



Map Units with Dominant Soil Associations

F	Pitt's Pond
M21	Lomond
M28	Cox's Cove
M31	The Topsails
M34	Silver Mountain
M35	North Lake
R	Rock Outcrops

Please note that the secondary reference number (i.e., the number after the dash) is used with the extended legend of the soils database to access additional information specific to the soil polygon.

Figure 4-3b: Corner Brook Stream Watershed Soils

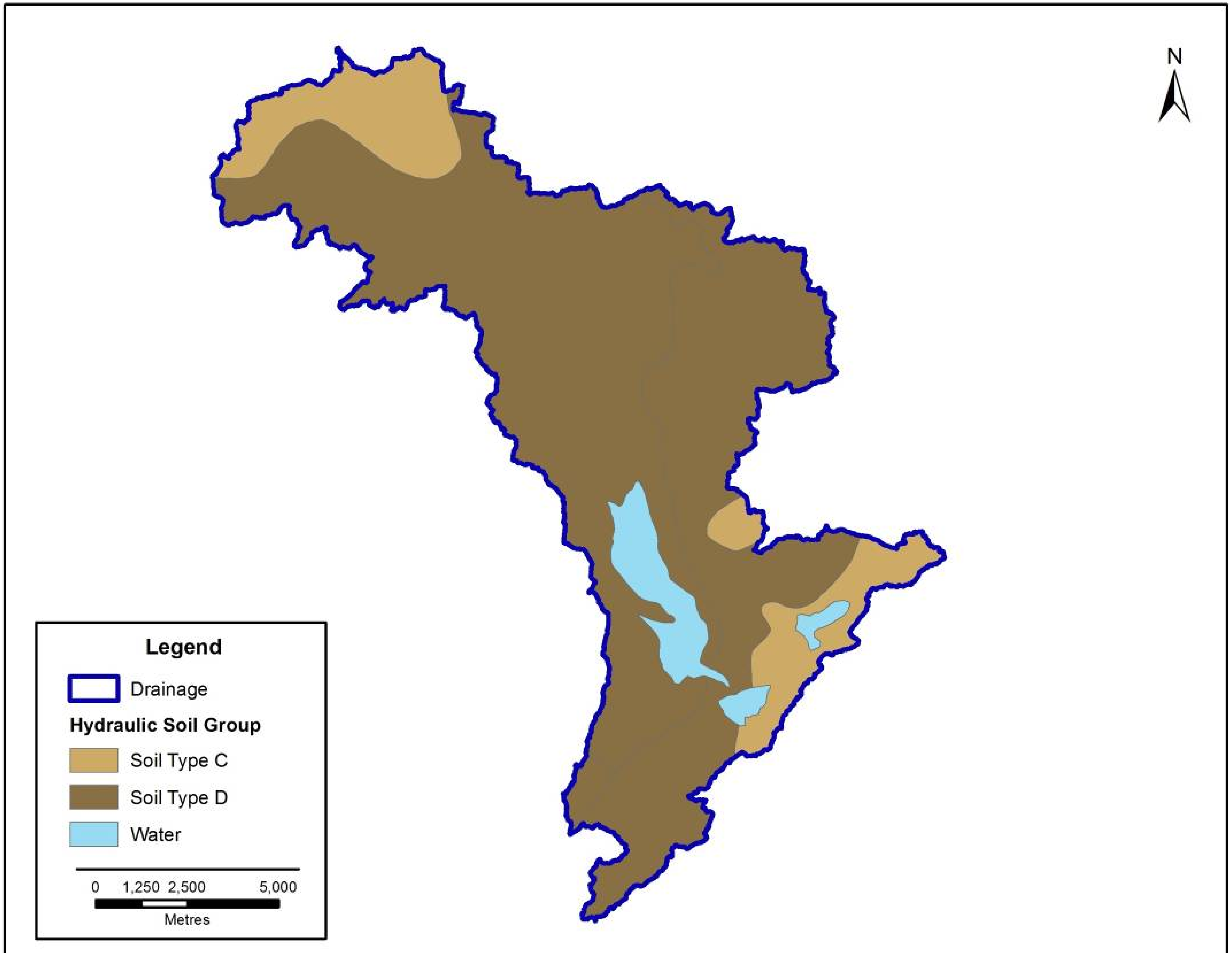


Figure 4-3c: Corner Brook Stream Watershed – Hydrologic Soil Groups

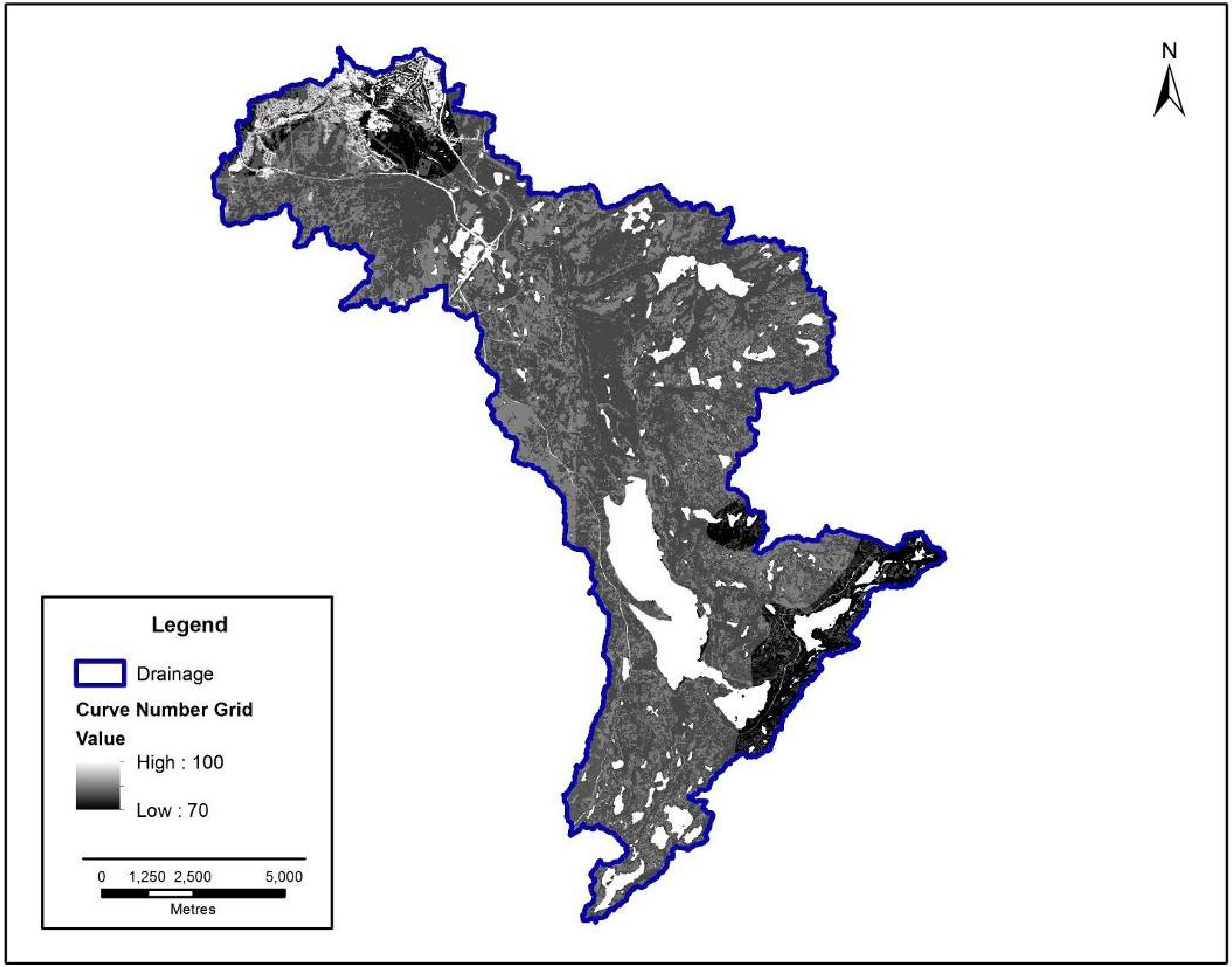


Figure 4-3d: Corner Brook Stream Watershed – SCS Curve Number Grid

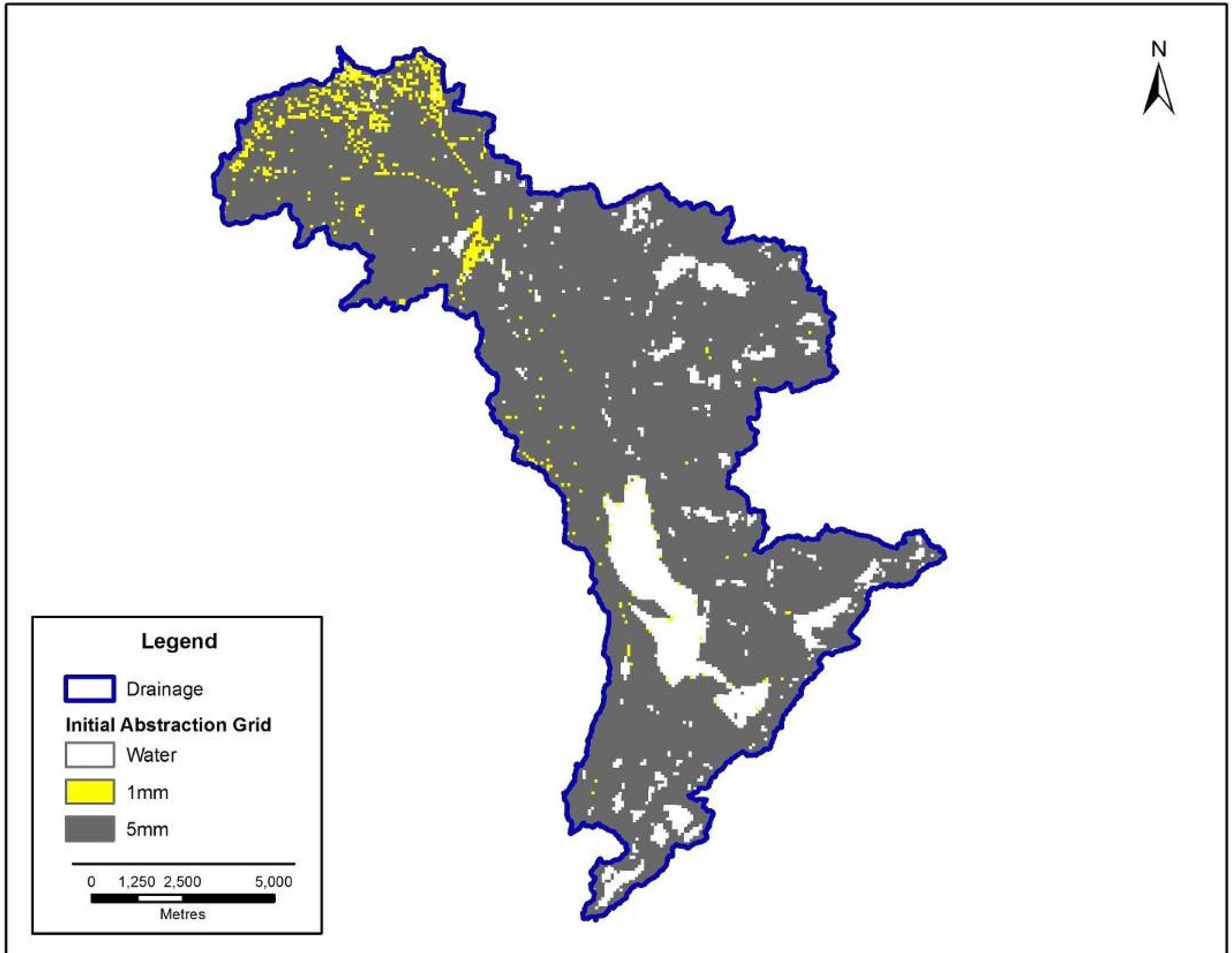


Figure 4-3e: Corner Brook Stream Watershed – Initial Abstraction Grid

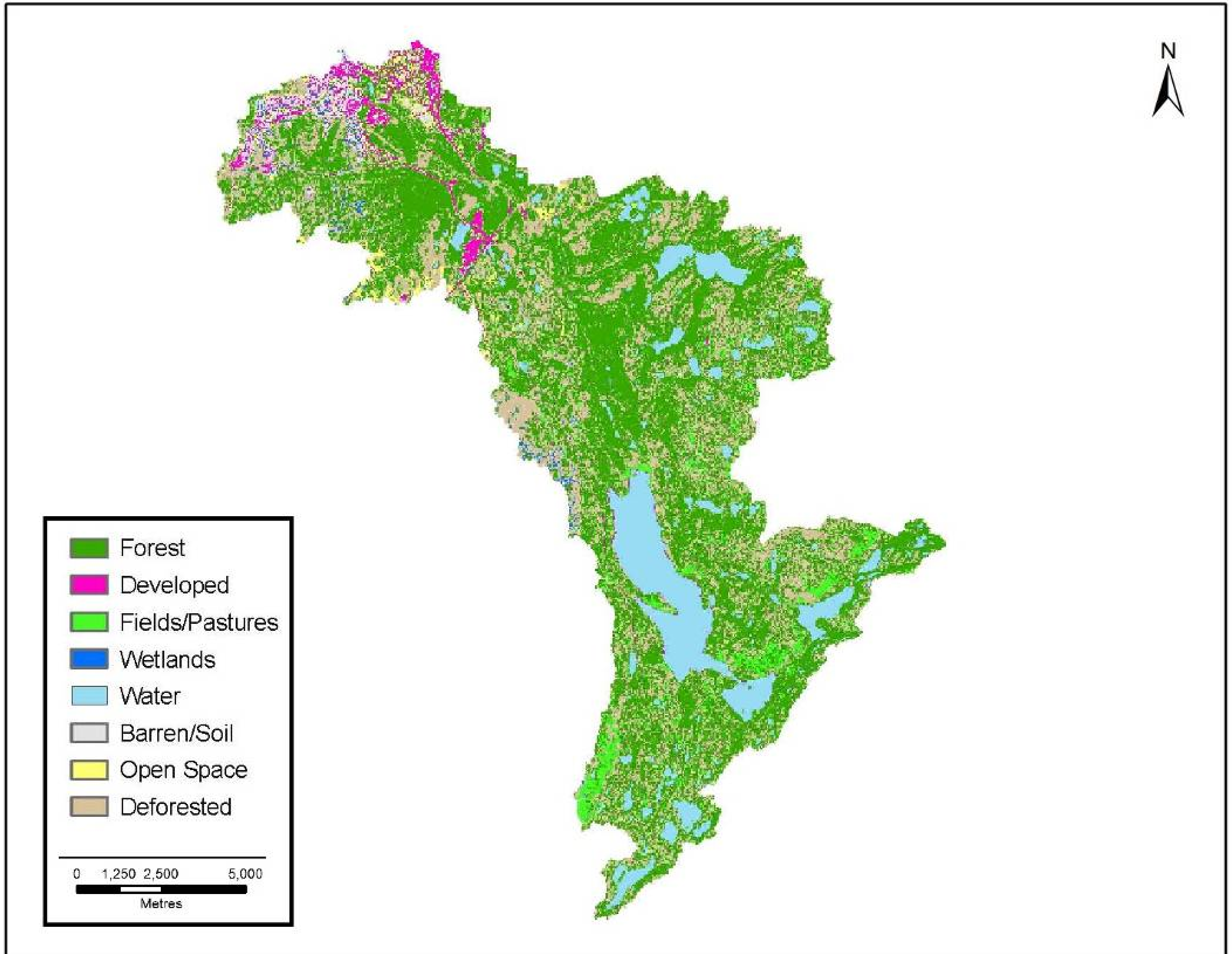


Figure 4-3f: Corner Brook Stream Watershed – Land Cover

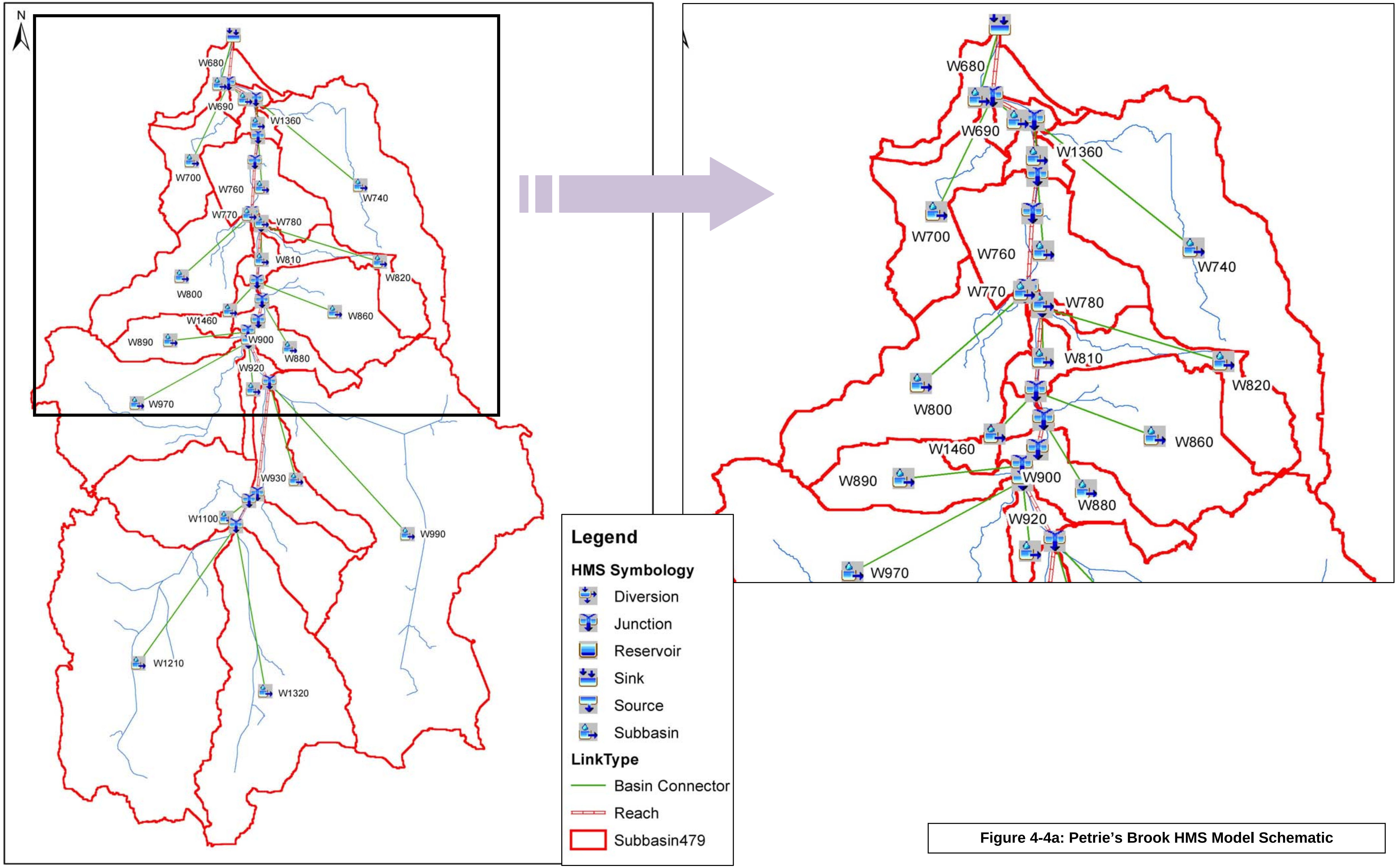


Figure 4-4a: Petrie's Brook HMS Model Schematic

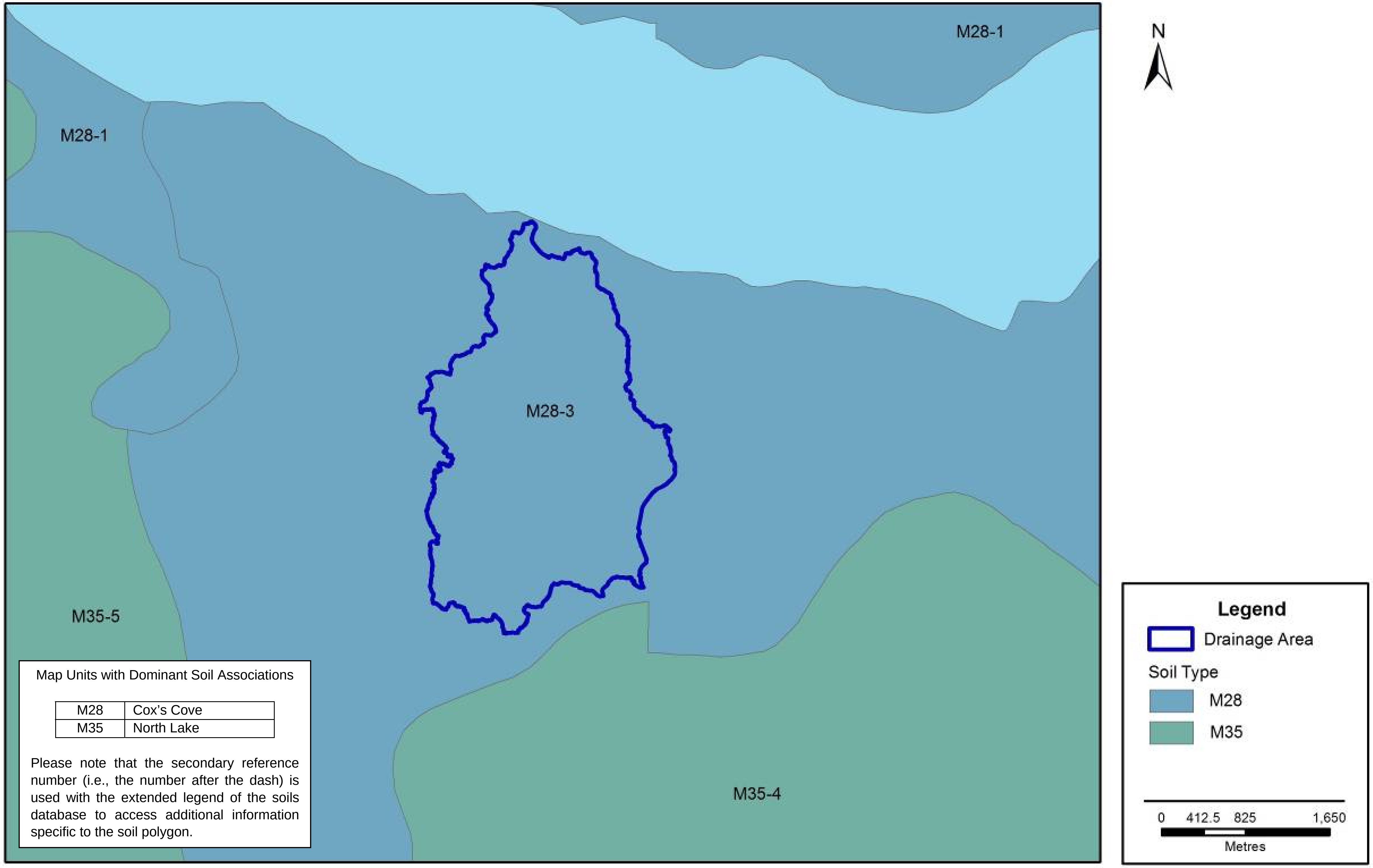


Figure 4-4b: Petrie's Brook Watershed Soils

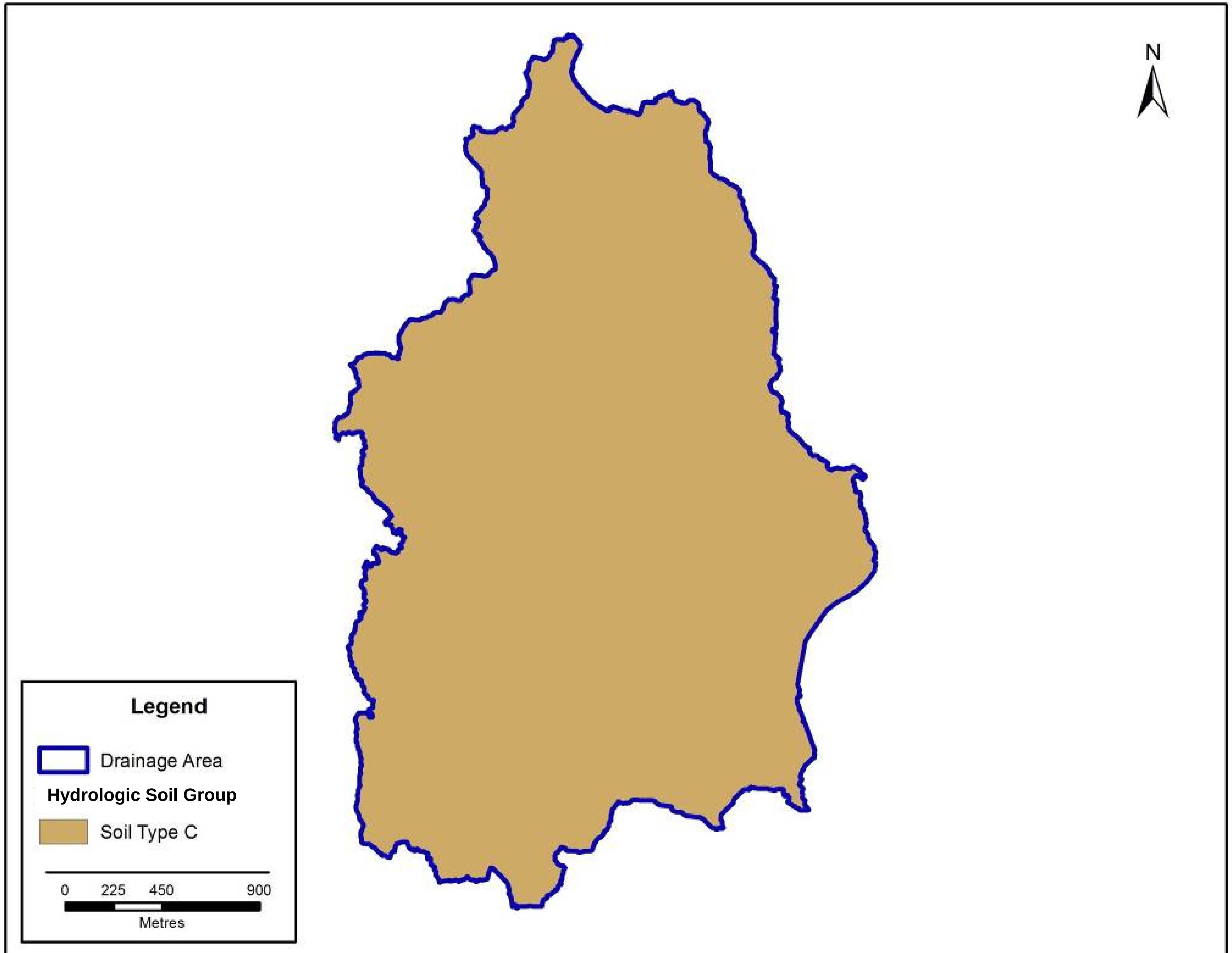


Figure 4-4c: Petrie's Brook Watershed – Hydrologic Soil Groups

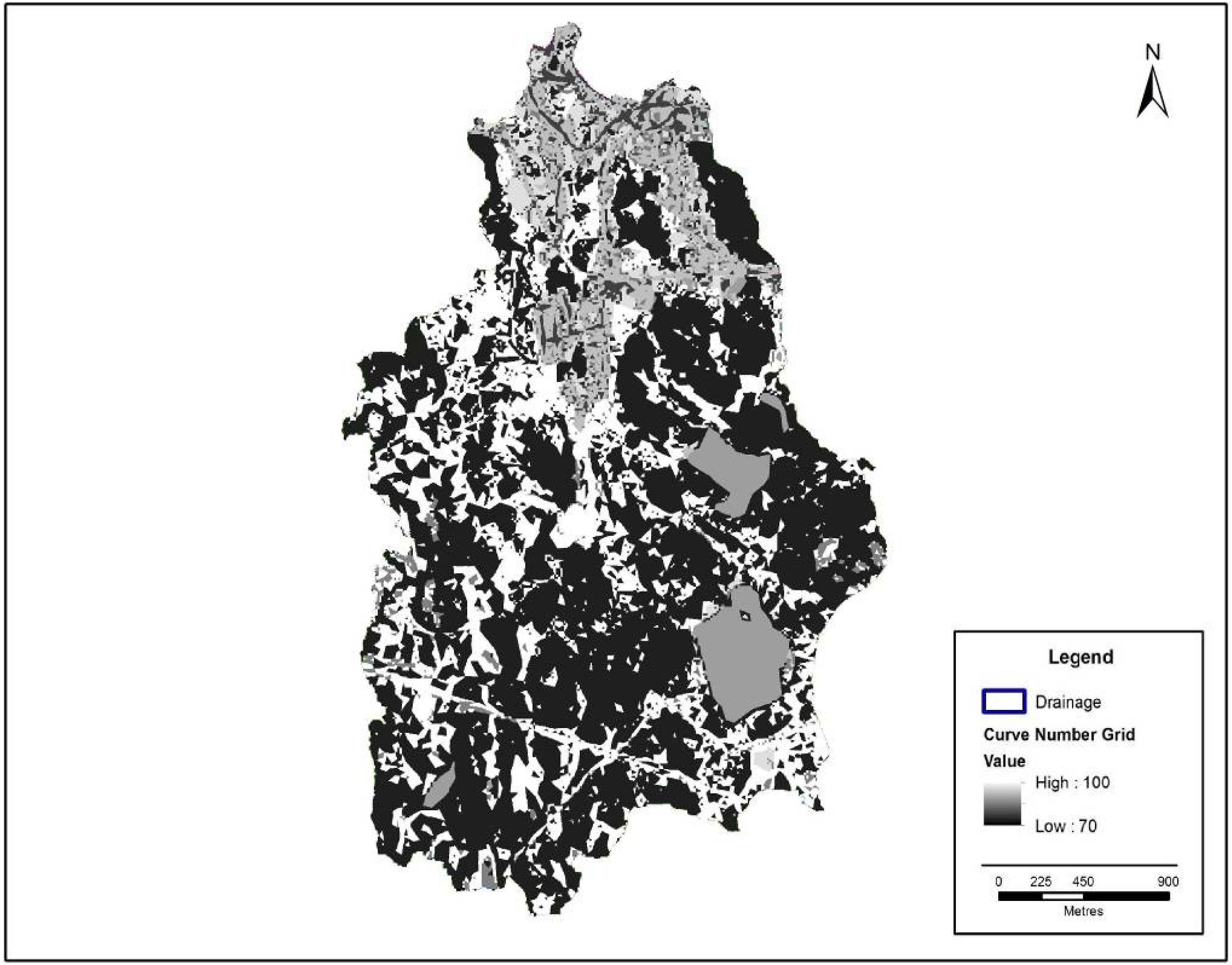


Figure 4-4d: Petrie's Brook Watershed – SCS Curve Number Grid

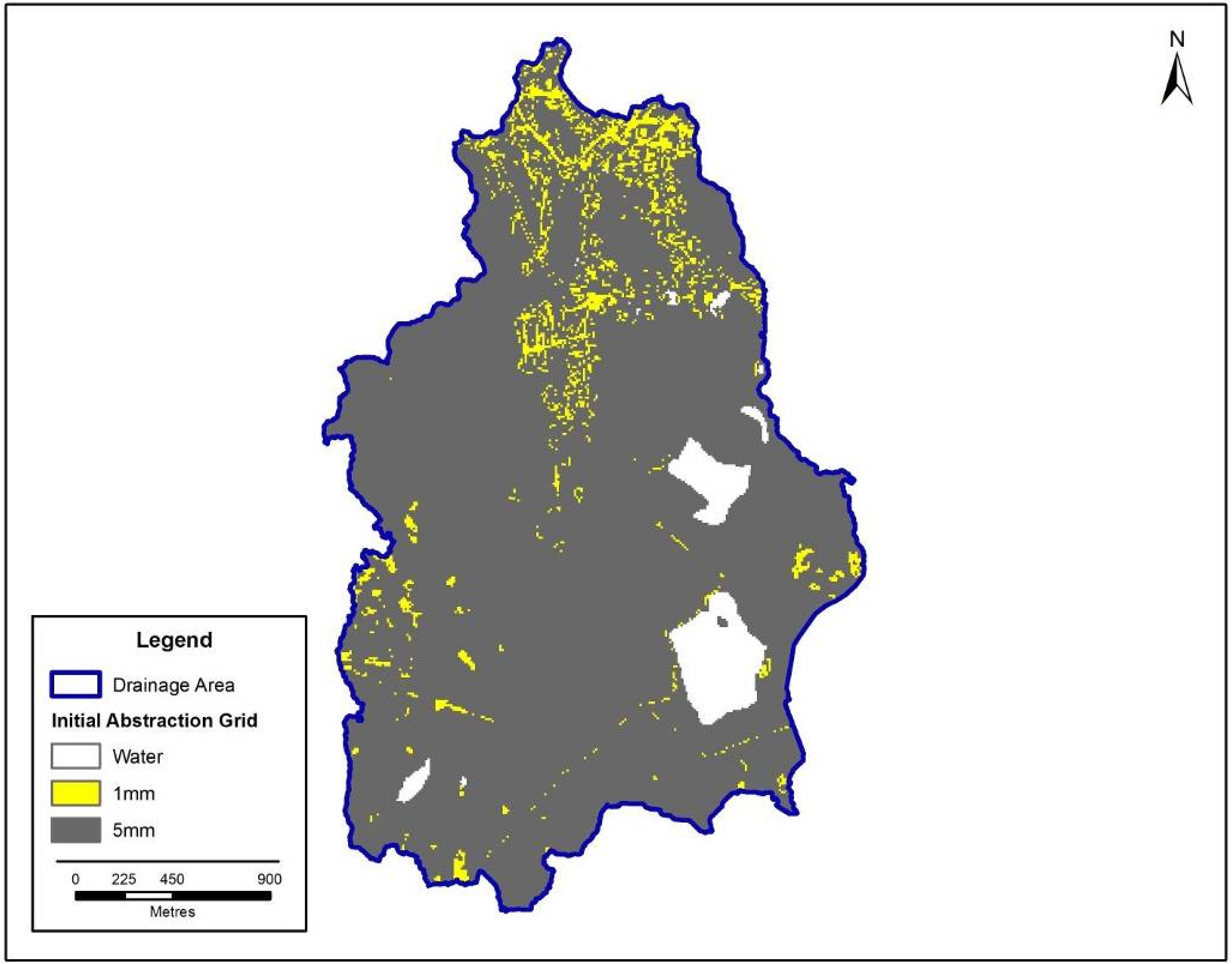


Figure 4-4e: Petrie's Brook Watershed – Initial Abstraction Grid

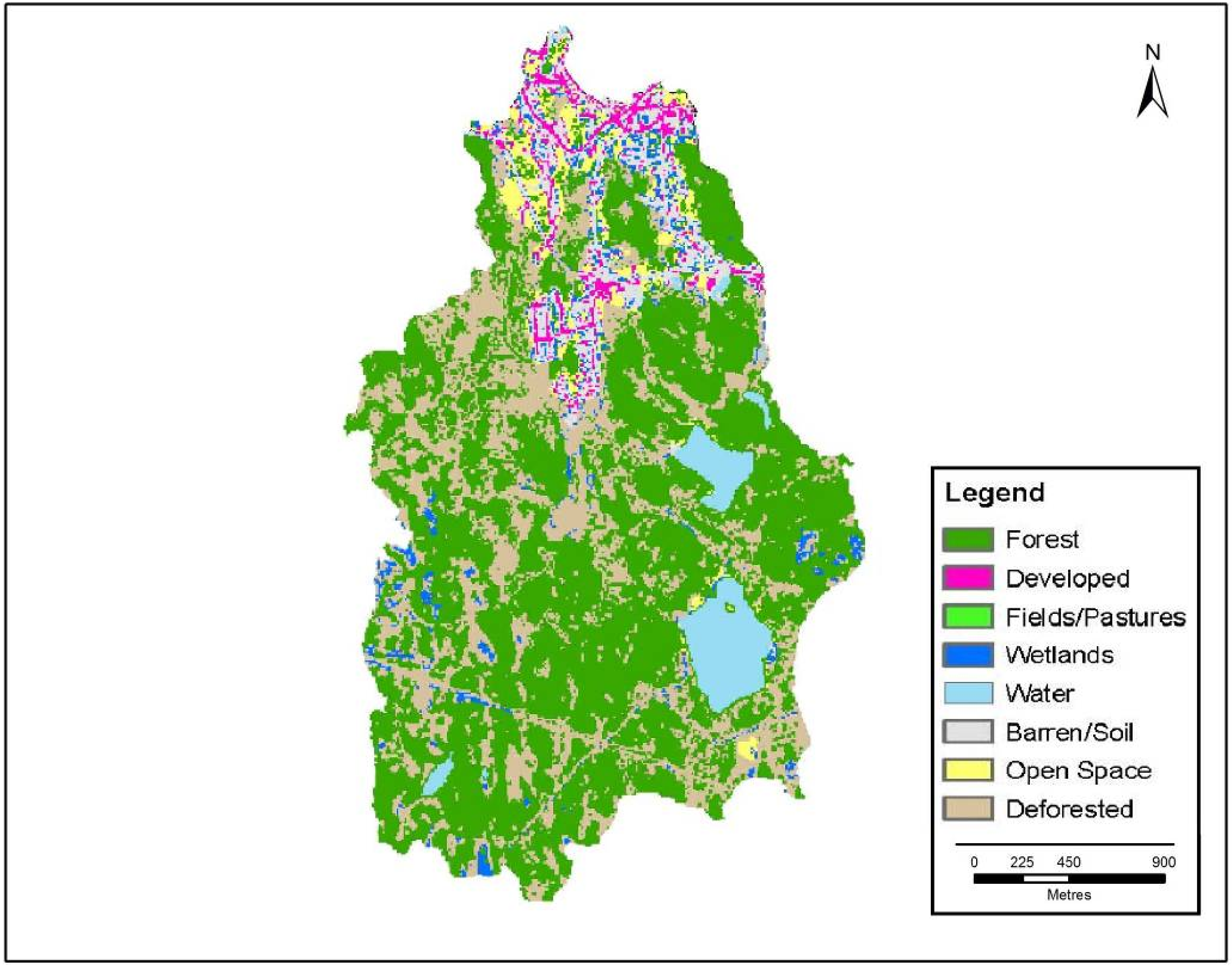


Figure 4-4f: Petrie's Brook Watershed – Land Cover

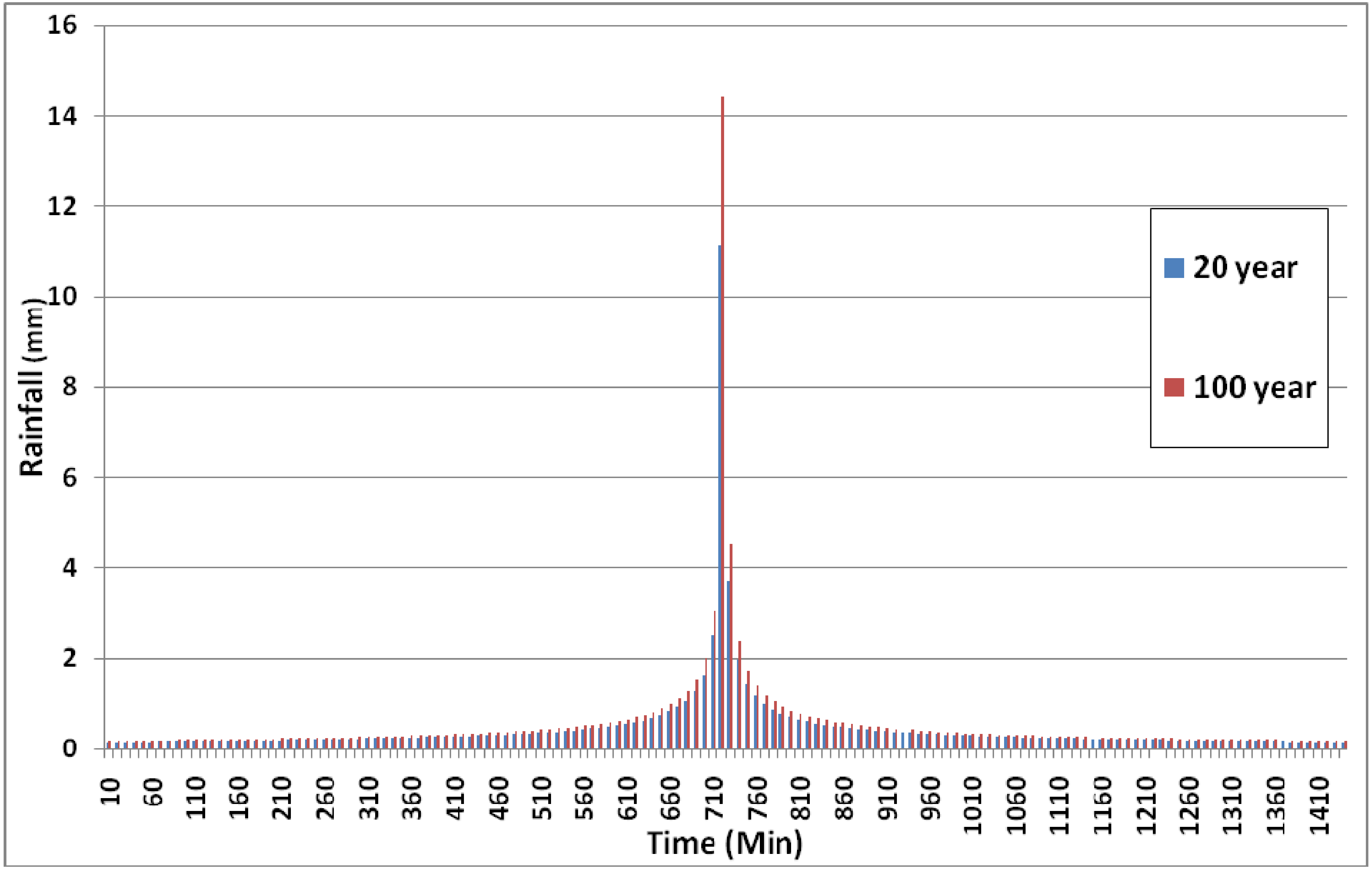


Figure 4-5: Existing Conditions Input Rainfall Distribution for Corner Brook and Petrie's Brook Deterministic Modelling

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5.0 HYDRAULIC ANALYSIS

The collection and processing of data, computational procedures and analysis of computed profiles is compliant with criteria and guidelines published by the Hydrologic Engineering Center in the User's Manual and Training Documents and the *'Hydrologic and Hydraulic Procedures for Flood Plain Delineation'* (Environment Canada, 1976).

The objective of the hydraulic analysis was computation of water surface elevations resulting from the 1:20 year and 1:100 year AEP flow estimates. The computed water surface elevations are then used in conjunction with the LiDAR database or other mapping to visualize the limits of the flooding on flood risk maps. To determine the water surface profile for a given flood condition, a backwater analysis is generally necessary. The USACE HEC-RAS one-dimensional backwater model was selected for this analysis.

The following sections describe the development and calibration of the HEC-RAS hydraulic model, as well as the details associated with the results of the hydraulic simulation of various flood events.

5.1 Hydraulic Model Development

5.1.1 HEC-RAS

HEC-RAS (USACE, 2002), the successor to HEC-2, is a hydraulic modelling computer program developed by the USACE to simulate water surface profiles for steady and gradually varied flow in open channel watercourses. The computational procedures used by HEC-2 and HEC-RAS to model steady state flow are generally similar and are based on solving the one-dimensional energy equation. The HEC-RAS computational software estimates water surface elevation and related output along a channel reach under sub-critical, supercritical or mixed flow regimes. The program is capable of modelling complicated networks with multiple reaches and tributaries. Flow through culverts, bridges, weirs and gated spillways can also be accommodated. Levees, blocked obstructions and ineffective flow areas can also be modelled, as can ice jam and debris flow conditions.

In simple terms, the model uses surface water flow rates to predict water surface elevations. These elevations can then be transferred to a DTM or topographic map to identify the limits of flood-prone areas.

HEC-RAS requires a terrain model with three-dimensional attributes (x, y, and z) for the area of interest. The terrain model commonly used in hydrologic modeling is a DTM. HEC-GeoRAS is a pre- and post-processing program developed co-operatively by the Hydrologic Engineering Center (HEC) of the USACE and the Environmental Systems Research Institute Inc. (ESRI) to:

- extract geometric data from a DTM for input into HEC-RAS, and;
- use output from the hydraulic model and generate a water surface elevation DTM that can be superimposed on the terrain DTM to identify flood-prone areas.

As noted previously, the DTM for this project was developed from the LiDAR database developed for this project, as described previously.

The HEC-GeoRAS 4.3.93 for ArcGIS 9.3 and HEC-RAS 4.1.0 were used to complete the one dimensional hydraulic modeling component of this project. HEC-RAS 4.1.0 represents the most up-to-date version of the software at the time of this project.

HEC-RAS is an approved model for flood plain calculations in Newfoundland and Labrador and was identified as the preferred modelling platform in the Terms of Reference for this project.

5.1.2 Cross Sections

Hydraulic sections were located in accordance with HEC-RAS modeling guidelines. Cross section data was abstracted from the LiDAR base mapping developed for this project supplemented with field surveyed cross-section data, as outlined in Section 3 of this report.

The locations of the sections are shown in Figures 5-1 to 5-4. One additional cross section was added at river station 0 m with an assumed bathymetry to extend the model far enough out into Humber Arm so as to ensure appropriate establishment of the downstream model boundary condition.

The LiDAR DTM developed for this project provides topographic information in a 1 m x 1 m grid to a vertical positional accuracy of +/- 0.1 m. Since the entire study watersheds were captured in the LiDAR survey, cross sections extending out past the floodplain extents were cut directly from the LiDAR without the need for supplementary field surveying.

As noted in Section 2, the below waterline survey data was integrated into the hydraulic models of the subject watercourses by adding a single cross-section X,Y point located at the centerline of the section along with a depth interpolated from the nearest surveyed cross-sections when compared with the LiDAR abstracted section elevation at that point.

An overview of the hydraulic models for each of the study watercourses follows:

<u>Corner Brook Stream</u>

- Overall study reach length of approximately 8.3 km
- 352 hydraulic sections across 9 reaches

- Minimum channel elevation of about -0.5 m at the start of the model
- Maximum channel elevation of about 36 m at the end of the model – Main Channel
- Maximum channel elevation of about 191 m at the end of the model – Bell's Brook

- Average inter-section reach length of about 24 m
- About 351 (about 100%) of sections having inter-section reach length less than 100 m
- About 340 (or about 97%) of sections having inter-section reach length less than 50 m
- About 230 (or about 65%) of sections having inter-section reach length less than 25 m

Petrie's Brook

- Overall study reach length of approximately 3.3 km
- 85 hydraulic sections across 5 reaches

- Minimum channel elevation of about -0.75 m at the start of the model
- Maximum channel elevation of about 129.94 m at the end of the model

- Average inter-section reach length of about 40 m
- 85 (100%) sections having inter-section reach length less than 100 m
- About 61 (or about 72%) of sections having inter-section reach length less than 50 m
- About 22 (or about 26%) of sections having inter-section reach length less than 25 m

5.1.3 Hydraulic Structures

Watercourse Crossings / Bridges

During the field survey, dimensions and elevations of each watercourse crossing listed in Table 3-1 were surveyed. This information is documented in the watercourse crossing sheets (available in Appendix B). Each of the structures was included in the hydraulic model. The rating curve, as generated by the hydraulic model, is included along with basic bridge survey data (invert, obvert, etc.) as components of the watercourse crossing information which allows for interpolation of bridge opening capacities (see Appendix B). Although the 1:20 year and 1:100 year AEP flows may exceed this value, the structure may still not be overtopped. This result is because the structures can become surcharged to gain additional head to pass the flow and/or there is a change in the flow regime whereby a higher flow results in a lower water level. Indication of overtopping of any watercourse crossing or bridge in the study reach is provided in Table 5-2.

Dams

Two dams are included in the hydraulic model of Corner Brook Stream[11], namely Glynmill Pond Dam and Margaret Bowater Park Dam. As documented in Section 4.2.1 [Reservoir Starting Water Levels] a number of alternate dam operational scenarios (ref. Table 4-13) were evaluated. The results of this evaluation identified operational scenario #1b (mid summer) as the most appropriate for overall modelling of the Corner Brook Stream watershed. For this scenario the water levels in the head ponds were initially set to the relevant full supply level and the gates were considered to be closed (for consistency with the HEC-HMS modelling).

The scenario around which the hydraulic modelling of the dams was developed was based on a variety of elements representing a reasonable worst case associated with the 1:20 year and 1:100 year rainfall events. The following additional elements, consistent between the two design rainfall events, were also considered:

[11] No dams are located in the Petrie's Brook Watershed.

- During extreme weather loss of power is typical. No information was made available from the dam owners/operators in regard to backup power availability. As such, it was assumed that loss of power would negate operation of gates at the dams. No information was provided by the dam owner/operators to indicate manual operation of the gates was possible.
- During extreme weather loss of communications is typical. It was noted in the dam safety report (AMEC, 2001) that gate operation at Glynmill Pond Dam is controlled remotely. No information was provided by the dam owner/operators to indicate if operation of the gates would be possible in the event of a loss of communications.

To summarize, the reservoirs were assumed at full supply, the gates were assumed to be closed and it was assumed no gate operation was possible during the event.

HEC-RAS provides functionality for modelling of in-line structures such as dams. However, the scenario (specific to dams) upon which the hydraulic model was based essentially removes gate operation from consideration. As such, the dam modelling functionality within HEC-RAS reverts to weir flow over the dam using a section defined across the dam crest, abutments and overbanks. Weir flow co-efficients are elements of the dam definition input which the program uses to determine a stage-discharge relationship for the dam.

As a stage-discharge relationship for the dams had already been independently calculated (to support hydrologic modelling), the dam crests were modelled as cross-sections with rating curves. Cross-sections upstream and downstream of the dams were also defined consistent with the in-line structure coding requirements. This approach maintained consistency with the stage-discharge relationships used for the hydrologic modelling.

5.1.4 Lateral Structures

No lateral structures are located in the study reaches for this project.

5.1.5 Energy Loss Coefficients

Energy loss coefficients are used in the HEC-RAS program to calculate changes in the water surface elevation between sections. The coefficients include Manning roughness coefficients, expansion and contraction coefficients, and weir and pressure coefficients for road / rail crossings. These coefficients were estimated based on published information, field reconnaissance and engineering judgment.

5.1.5.1 Expansion and Contraction Coefficients

Expansion and contraction coefficients for normal channel cross-section were set at 0.1 and 0.3, respectively, and 0.3 and 0.5 for cross-sections at hydraulic structures respectively. These ratios are used by HEC-RAS in the computation of energy losses due to flow contraction and expansion between adjacent cross sections. The noted values are consistent with those recommended in the HEC-RAS Technical Reference Manual.

5.1.5.2 Roughness Coefficients

Estimation of Manning roughness coefficients was based on field observation, review of satellite imagery (available via Google Maps^{TM}) and orthophotos, engineering judgment, previous modeling experience, and comparison of reach characteristics with the "Roughness Characteristics of Natural Channels" (Barnes, 1967). Images available via Google Streetview^{TM} were also helpful in this regard.

Roughness coefficients used for the hydraulic model were in the range 0.035 to 0.050 for channels and 0.055 to 0.080 for overbank areas. Channels through the study area range from clean, gravel bottom to large boulders with debris (represented by the low and high range of roughness co-efficient). For the overbank areas the lower range represented grassed areas clear of significant vegetation and the upper range represented forested overbank areas.

5.1.5.3 Weir Flow Coefficients

HEC-RAS defaults to a generic weir coefficient of 1.4 for watercourse crossing (i.e., bridge/culvert) modelling. For this project, weir flow coefficients were also estimated using the method outlined in the Connecticut Department of Transportation - Drainage Manual, Chapter 8, Section 8 (CONNDot, 2000) as a means of confirming this parameter value. Weir coefficient estimates were determined to be in the range of about 1.6 to 1.67 using this method. The final hydraulic models use the CONNDot method estimates given that they are linked to actual field conditions.

5.1.6 Starting Water Surface Elevations

Table 5-1 presents maximum tidal elevations for the study area. The sources of the values reported are noted at the bottom of the table. Tide table values are taken from the particular port (i.e., Corner Brook), or estimated from nearby ports, (e.g., Port Aux Basques or Harrington Harbour on the southern Quebec shore). For orientation, Figure 5-1 illustrates the relation between tidal surfaces (MWL[12], HHWMT[13], HHWLT[14]), charting datums, and physical features. Probable maximum storm surge is estimated from inspection of the 40 year return period hindcast values by Bernier and Thompson (2006) as illustrated in Figure 5-2. Future predictions for sea level rise are made based on predictions presented in Batterson and Liverman (2010) which include Intergovernmental Panel on Climate Change (IPCC) sea level predictions, potential accelerated ice melt, and regional trends of crustal rebound.

In the absence of an extremal analysis of water level measurements, it is noted that the HHWMT/LT (tidal water level, i.e., without surge) values quoted are generally representative of a 1:20 year return period (as they are based on 19 years of predictions) while the recorded extreme value (Recorded Extreme, HHW) from the Department of Fisheries and Oceans (DFO) tide tables are for the historical record at Port Aux Basques (1935 to 2012 or 67 years record) is reflective of a 1:100 year return period.

The guideline document for this study, *Hydrologic and Hydraulic Procedures for Flood Plain Delineation* (Environment Canada, 1976), provides no specific direction for establishing starting water levels for hydraulic modelling. For the purposes of this study, the starting water surface elevation was computed as the maximum high tide (large tide for higher high water - HHWLT) of 2.1m (geodetic) plus a storm surge of 0.7m for the Corner Brook area for existing conditions. It should be noted that, in the absence of tide and surge observations specifically at the downstream limits of the hydraulic models, both parameters were assumed to be the same as observed by the Canadian Hydrographic Service (CHS) at the locations noted in

[12] MWL: is the height above chart datum of the mean of all hourly observations used for the tidal analysis and that particular place (DFO, 2012a), or, the average of all hourly water levels over the available period of record (Forrester, 1983).

[13] HHWMT: is higher high water, mean tide, which is the average of all the higher high waters from 19 years of predictions (Forrester, 1983).

[14] HHWLT: is higher high water, large tide, which is the average of the highest high waters, one from each of 19 years of predictions (Forrester, 1983).

Table 5-1. This provides a combined total of 2.8m for the Corner Brook area which was used as the downstream boundary condition in the existing conditions hydraulic models for the 1:20 year and 1:100 year AEP flood simulations. This approach is consistent with previous hydrotechnical studies completed for WRMD such as the Flood Risk Mapping Project for Shearstown / Bay Roberts Area (Hatch 2012).

The inclusion of a surge component in the estimation of starting water levels is considered reasonable for the Corner Brook area. The surge from the Gulf would easily propagate into the Bay of Islands all the way to the head of the inlets. There could even be some amplification in the narrow inlets.. The assessment of the amplification component would require modelling that resolves the Bay of Islands and the inlets which the Bernier model doesn't. As such, the surge elevation estimate of 0.7 m for the Corner Brook area is actually not considered overly conservative.

The future conditions models also incorporate a sea level rise component resulting in starting water surface elevations or 2.85m, 3.03m and 3.36m, respectively, for the 2020, 2050 and 2080 time frames.

Table 5-1: Tidal Elevations

Description	Elevation (m)
MWL (m)	1.2 [(1)]
HHWMT (m)	1.8 [(2)]
HHWLT (m)	2.1 [(3)]
Recorded Extreme, HHW (m)	2.9 [(3)]
Probable Maximum Surge (m) [(5)]	0.7
Sea level rise 2020 (m) [(6)]	0.05
Sea level rise 2050 (m) [(6)]	0.23
Sea level rise 2080 (m) [(6)]	0.56

Notes:

1. Source: Corner Brook (DFO, 2012b)
2. Source: Harrington-Harbour (DFO, 2012b)
3. Source: mean of Harrington-Harbour (DFO, 2012b), Port Aux Basques (DFO, 2012a)
4. Source: Figure 10 in Bernier and Thompson (2006)
5. Source: Table 3 and Figure 4 in Batterson and Liverman (2010); Zone 2 for Petrie's Brook/Corner Brook Stream.

Acronyms (from Forrester, 1983) :

MWL: is the height above chart datum of the mean of all hourly observations used for the tidal analysis and that particular place (DFO, 2012a), or, the average of all hourly water levels over the available period of record

HHWMT: is higher high water, mean tide, which is the average of all the higher high waters from 19 years of predictions

HWLT: is higher high water, large tide, which is the average of the highest high waters, one from each of 19 years of predictions

HHW: higher high water

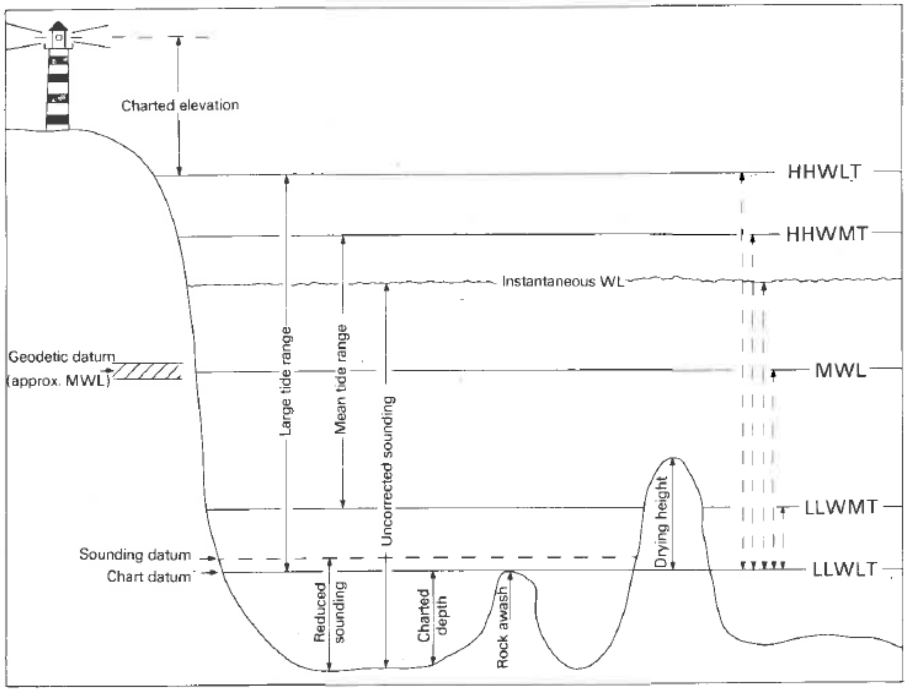

Figure 5-1 : Relation between tidal surfaces, charting datums and physical features (Source: Forrester, 1983)

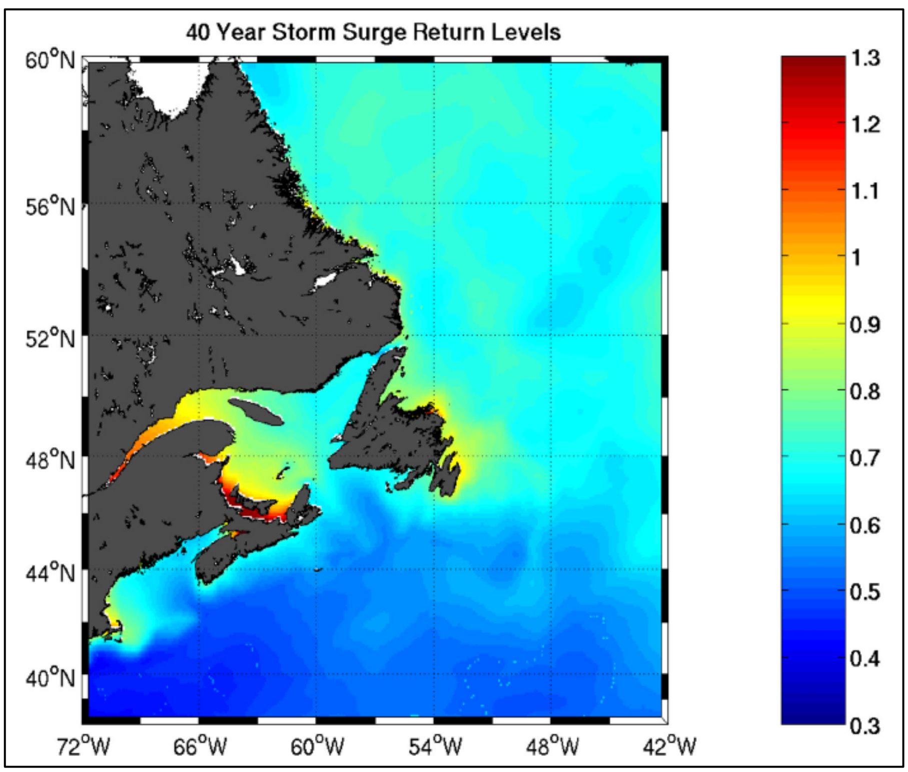

Figure 5-2 : 40 year return level of extreme storm surges (Source: Bernier and Thompson, 2006)

5.1.7 Hydraulic Model Calibration/Validation

Hydraulic data to support calibration andvalidation was not available for this study. No hydrometric stations are in operation within the study reach for which the hydraulic model was developed. Further, issues previously noted (see Section 3.3) precluded point streamflow level data collection during the course of the study.

5.1.8 Simulation of the 1:20 year and 1:100 year AEP Flood Events

Peak flows through the study reaches of Corner Brook Stream and Petrie's Brook were computed using the deterministic model developed for this project. These peak flows were input to a steady state hydraulic model for the purpose of estimating the water surface profiles corresponding to the 1:20 year and 1:100 year AEP flood events. The resultant water level output from the HEC-RAS model was used to delineate the extent of flooding on maps as discussed in Section 8.

HEC-RAS output defining computed water surface elevations for the 1:20 year and 1:100 year AEP events is provided in Appendix J. An outline of watercourse crossing / bridges and dams in the study reach and local computed water surface elevations, as a means of identifying which structures are overtopped, is provided in Table 8-2.

5.2 Ice Jam Assessment

Ice jams may develop when there is a rapid increase in discharge due to a rain or snowmelt event in winter that causes an intact ice cover to lift and break into pieces. The increased thickness and physical roughness of an ice jam often produces flood levels that exceed the 100 year open water flood level at considerably lower discharges. Available historical information related to ice jam occurrences in the Corner Brook Stream flood risk mapping area, along with the ice jam analysis approach employed, and the resulting flood profiles are described below.

5.2.1 Historical Context

A review of the Newfoundland and Labrador Flood Events Inventory and personal communication with Bob Picco of WRMD, indicated that there has not been any documented ice jam activity in the flood risk mapping area.

No ice thickness data was available along the study reaches; however, Water Survey of Canada (WSC) records ice thickness at nearby hydrometric stations. The closest available stations with pertinent data were:

- South Brook at Pasadena (02YL004), 25 km northeast of Corner Brook
- Rattler Brook near McIvers (02YL005), 17 km northwest of Corner Brook

Station 02YL004 reports 14 years of ice thickness data (1998 to 2012) and Station 02YL005 reports 13 years of ice thickness (1998 to 2012). Based on an assessment of the available information, 58 cm was selected as an upper-bound for ice cover thickness at Corner Brook.

This estimate was used to determine the maximum ice supply available to form an ice jam within selected sub-reaches.

5.2.2 Analysis Approach

Several factors were considered in developing plausible ice jam scenarios for modelling. These included historic evidence of ice jam activity, geomorphic conditions, in-stream structures, and an appropriate peak discharge during break-up. Since there is no documented ice jam activity, geomorphic conditions and the presence of in-stream structures (e.g. dams, bridges, tight bends) were used as the basis to identify potential ice jam initiation locations.

The characteristics of Petrie's Brook in combination with no identifiable ice jam history were the rationale for not assessing ice jam impacts along this study watercourse.

Within the Corner Brook Stream flood hazard mapping area, only the reach upstream of Glynmill Pond had a sufficient continuous length and stream characteristics conducive to ice jamming. Other reaches downstream of the Glynmill Pond were considered unlikely to experience ice jamming.

Using the flood risk topographic maps, an estimate of ice supply in the reach upstream of Glynmill Pond was compared against the ice volume associated with the longest ice jam from the pond upstream to the boundary of the flood risk mapping area. This computed maximum ice volume was 31,900 m^3. Based on the typical width and assumed intact ice cover thickness along this reach, this volume could be supplied from a 3.2 km reach. The nearest upstream obstruction to ice flow was determined to be approximately 4 km upstream, so it is plausible that the entire 1.1 km reach within the flood hazard mapping area upstream of Glynmill Pond could experience an ice jam.

For the purpose of estimating the discharge during an ice jam event in winter, a rain on snow event occurring in the month of March was assumed to generate the highest direct runoff during the ice-effected season. The HEC-HMS model developed for the basin was used along with a frequency storm of similar rainfall volume to the estimated March rain on snow runoff estimate. Peak discharges simulated for Corner Brook Stream and relevant tributaries contributing flow to the ice jam reach were obtained from the HEC-HMS model hydrographs for each event. The results representing the inflow discharge boundary conditions used in the HEC-RAS ice jam simulations are shown in Table 5-2.

The HEC-RAS model developed for the open water flood hazard mapping was applied directly for the ice jam modeling, using the same modeling parameters and boundary conditions, with the exception of inflow discharge as noted above. Multiple jam locations and lengths, constrained by the limit of available ice volume were simulated using the adopted ice jam modelling parameters shown in Table 5-3. These values were selected based on experience at other sites and a review of relevant prior ice jam analyses conducted for Newfoundland flood hazard mapping studies. The sensitivity of ice roughness, friction angle, jam porosity, and stress ratio were investigated and found not to be significant to the predicted water surface profile along Corner Brook Stream.

Table 5-2: Winter Peak Discharges in Corner Brook Stream

River	HEC-RAS Model Reach	Peak Discharge (m^3/s)	
		1:100 year	1:20 year
Bells Brook	TR001	6.1	3.5
Bells Brook	M001	26.0	14.8
Corner Brook	TR001	14.5	8.4
Corner Brook	TR002	5.2	3.0
Corner Brook	M003	95.5	58.4

Table 5-3: Ice Jam Parameters Adopted for Corner Brook

Ice Jam Parameter	Value
Intact Ice Thickness	58 cm
Ice Jam Roughness	0.06
Friction Angle	45°
Porosity	0.4
Stress Ratio	0.33
Maximum Velocity	3.0 m/s
Ice Specific Gravity	0.92
Ice Cohesion	0.0 kPa

5.2.3 Ice Jam Flood Profiles

Based on the ensemble results (ice jam and open water modelling results), the highest value at each river station is considered the ice jam flood level. For both the 1:20 year and 1:100 year events, the ice jam flood levels exceed the 1:100 year open water flood level along the ice jam reach, except between Stations 2530 and 2645.73 where there is a deep backwater pool caused by the Unnamed Access Road Bridge (Structure #2112). The average differences between the open water and ice jam flood levels along the main stem of Corner Brook are in the order of 1.3 m. Although jamming is not predicted along the two tributaries in this reach, flood levels are also projected to be higher locally due to the increased stage in the main stem reach. The detailed modeling results are shown in Table 5-4.

Table 5-4: Comparison between the Modelled Open Water and Ice Jam Flood Levels

Reach	River Station	1:100 year flood level (m)		1:20 year flood level (m)	
		ice jam	open water	ice jam	open water
M004	2888.71	**40.05**	39.1	**39.48**	38.77
M004	2838.71	**39.64**	38.34	**39.16**	38
M004	2796.61	**39.09**	38.42	**38.58**	37.99
M003	2689.92	**36.65**	35.63	**36.2**	35.42
M003	2645.73	36.23	**36.51**	35.62	**36.19**
M003	2602.09	36.15	**36.51**	35.52	**36.19**
M003	2557.73	36.07	**36.44**	35.47	**36.15**
M003	2537.73	36	**36.36**	35.38	**36.09**
M003	2530 BR U	35.06	**35.92**	35.04	**35.66**
M003	2530 BR D	35.11	**35.56**	**35.05**	33.57
M003	2527.22	**35.14**	34.35	**34.6**	32.95
M003	2507.21	**34.58**	32.91	**33.98**	32.2
M003	2459.31	**33.53**	32.83	**33**	32.56
M003	2411.41	32.83	**32.96**	32.36	**32.62**
M003	2363.51	32.28	**32.95**	31.81	**32.62**
M003	2315.61	31.83	**32.93**	31.33	**32.61**
M003	2267.71	31.53	**32.93**	30.8	**32.61**
M003	2263.01	30.98	**32.58**	30.36	**32.3**
M003	2260.98	**31.06**	30.25	**30.45**	29.71
M003	2240.88	**30.93**	30.18	**30.33**	29.53
M003	2212.25	**30.54**	30.1	**29.97**	29.46
M003	2183.63	**30.17**	29.18	**29.63**	28.62
M003	2163.63	**29.81**	29.19	**29.04**	28.52
M003	2150 BR U	**29.88**	29.06	**29.16**	28.44
M003	2150 BR D	**29.82**	28.25	**29.13**	27.71
M003	2141.65	**29.4**	27.77	**28.81**	27.43
M003	2131.66	**29.21**	27.05	**28.65**	26.74
M003	2119.46	**28.99**	26.18	**28.43**	25.89
M003	2115 BR U	**29.02**	26.21	**28.47**	25.93
M003	2115 BR D	**29**	26.4	**28.46**	26.1
M003	2114.73	**28.66**	26.46	**28.32**	26.19
M003	2080.62	**27.8**	25.62	**27.36**	25.36
M003	2068.44	**27.51**	25.58	**27.14**	25.38
M003	2022.25	**26.76**	24.87	**26.32**	24.52
M003	1991.14	**26.11**	24.69	**25.57**	24.2
M003	1985.82	**25.86**	24.26	**25.42**	23.84
M003	1975.95	**25.7**	23.9	**25.17**	23.52
M003	1929.72	**24.58**	22.4	**24.18**	22.01
M003	1883.49	**23.33**	21.99	**22.88**	21.54
M002	1826.39	**21.61**	18.56	**20.9**	18.36
M002	1790.92	**20.4**	19.25	**19.48**	18.96
TR001	206.04	44.69	**44.78**	44.51	**44.64**

Table 5-4: Comparison between the Modelled Open Water and Ice Jam Flood Levels (cont'd)

Reach	River Station	1:100 year flood level (m)		1:20 year flood level (m)	
		ice jam	open water	ice jam	open water
TR001	156.04	42.64	**42.7**	42.43	**42.58**
TR001	106.04	39.85	**39.86**	39.66	**39.74**
TR001	56.04	**38.35**	38.12	**38.39**	38
TR001	36.04	**38.41**	38.34	**38.41**	38.2
TR001	21.31	**38.03**	37.37	**38.03**	36.98
TR002	21.04	**23.11**	22.96	**22.9**	22.86
TR002	18.08	**22.63**	21.84	**22.52**	21.78

Note: the bold numbers indicate the higher levels between ice jam and open water conditions.

5.3 Conclusions and Recommendations

5.3.1 Conclusions

Hydraulic models based on the USACE program HEC-RAS were developed for reaches of Corner Brook Stream and Petrie's Brook covering linear distances of approximately 8.3km (with 352 cross-sections) and 3.3km (with 85 cross-sections), respectively.

The models were developed based on field surveyed bathymetric data and a LiDAR survey conducted in November and December of 2011. Field survey of water levels specifically to form a database upon which the hydraulic model could be calibrated/validated was not completed due to late season project start and freeze up of the waterways in the study area. As such, the hydraulic model has not been calibrated/validated, however, due care was taken during model development to accurately establish model parameterization.

The hydraulic model developed for this study was also used to evaluate the potential flood conditions (i.e., resultant water levels) associated with ice jamming events. Petrie's Brook was not deemed to have the potential for ice jam formation. The evaluation along Corner Brook Stream confirmed that along limited reaches of the watercourse, computed water levels associated with ice jams have the potential to generate water levels exceeding 1:100 year AEP open water event levels.

The hydrologic and hydraulic models developed for this study and relevant support data are included with the Project CD materials attached to this report. The models may be used in the future to evaluate the impact on water levels resulting from any structural changes to the subject watercourses, structures, or floodplain / overbank areas.

5.3.2 Recommendations

It is recommended that the City of Corner Brook engage in a field-based program to measure water levels at designated structures within the two subject watersheds during flood events. This data gathering effort will provide a basis for future calibration/validation of the models developed for this study.

It is recommended that a program focused on unregulated streamflow data collection be developed for Corner Brook Stream. The only hydrometric station presently recording unregulated streamflow in the Corner Brook Stream watershed is located at Environment Canada station 02YL011 (Copper Pond Brook Near Corner Brook Lake). This upstream drainage area to this station is 12.9 km^2 or only about 8% of the overall watershed. Additional recording stations at strategic locations (e.g., inflow to Corner Brook Lake, outflow from Bells Brook, and other large unregulated tributary areas) would provide a foundation of data that would enhance the hydrologic model calibration/validation process.

It is recommended that a program focused on unregulated streamflow data collection be developed for Petrie's Brook. No hydrometric stations are presently in operation in this watershed. Further, the size of the watershed precludes use of the RFFA methodology. A recording station at the outlet from the watershed would provide a foundation of data that would enhance the hydrologic model calibration/validation process.

In concert with the implementation of streamflow data collection, a program focused on field-based collection of ice thickness/accumulation data should be implemented in areas identified as ice jam prone. It was noted previously that no ice thickness data was available for either Corner Brook Stream or Petrie's Brook. A database of ice thickness/accumulation data would enhance and provide additional confidence the ice modelling process and results.

It is recommended that the water levels for existing conditions for the 1:20 year and 1:100 year AEP water surface profiles as defined on the flood plain maps and provided in tabular form in Appendix J, be adopted for regulatory and management purposes.

It is recommended that special consideration be given to higher water levels (than those based on the 1:100 year AEP flow) associated with ice jam conditions in the reach above Glynmill Pond Dam.

It is recommended that that HEC-GeoRAS be used in future watershed and flood studies as it both simplifies the development of deterministic models as well as provides for the generation of a significant warehouse of information that can be used for several ancillary purposes beyond hydraulic assessment.

6.0 SENSITIVITY ANALYSIS

The hydrologic and hydraulic models were developed based on a review of available data and selection of appropriate input data. However, as is the case in all numerical modelling of physical processes, there is the inherent potential for errors or uncertainty to be associated with the selection of input variables which could affect the resulting flood flows and subsequent computation of associated water levels. Sensitivity analysis can, hence, be useful for a range of purposes, including:

- Testing the robustness of simulation model results in the presence of uncertainty.
- Increasing the understanding of the relationships between input and output variables in the simulation models.
- Increasing confidence in simulation model results by identifying model inputs that cause significant uncertainty in the output. Increased attention to these specific model inputs can then be applied to ensure proper definition and/or parameterization.
- Ensuring the model is accurately reflecting watershed conditions and responses by identifying errors in the model output as reflected by unexpected relationships between inputs and outputs.

A sensitivity analysis of the hydrologic and hydraulic model inputs was completed to determine the effects of changing model parameters on the resulting flood levels. The results of the sensitivity analyses are summarized below.

6.1 Sensitivity to Hydrologic Model Inputs

6.1.1 SCS Curve Numbers

As previously described, a SCS Curve Number is required for each sub-basin within the hydrologic model. The Curve Number for a particular sub-basin is a function of soil type, land use, and antecedent runoff conditions. The Curve Number defines the amount of runoff and infiltration based on a given rainfall amount. The Curve Numbers for each sub-basin within the HEC-HMS model were increased and decreased by 10 percent for the 1:20 year and 1:100 year AEP events. The results of this analysis are presented in Table 6-1. As suggested by the results, the generated peak flows are very sensitive to the selection of an appropriate Curve Number; as demonstrated by a 10 percent change in Curve Number resulting in a change in peak flow of 20 to 40 percent.

Given this result, the input variables, associated with generation of the Curve Number grid (soils and land use), developed for the HEC-HMS model were reviewed. This review confirmed that the soils information used for model development was the best currently available; sourced from the Government of Canada. The land use data was based on the land classification project completed for this project. This assessment was based on 10-meter resolution SPOT imagery and not the high-resolution QuickBird satellite imagery originally intended for use with this project. With coarser resolution, spectral mixing exists meaning some pixels contain a mixture of different features and cover types, compared to higher resolution images where individual pixel values represent more homogenous materials. The overall impact of the satellite imagery resolution on land use classification is difficult to quantify. Impacts in subcatchment where the predominant land forest is forest (which represents a significant portion of the watershed in both Petrie's Brook and Corner Brook Stream) would not be expected to be significant. However, a greater degree of impact may be anticipated in urban areas where the 10 m resolution may not adequately capture impervious areas, resulting in potentially lower Curve Numbers, potentially leading to under-estimation of runoff.

Table 6-1: SCS Curve Number Sensitivity Analysis

Study Area	Event (AEP) (yr)	Base Case Flow (m^3/s)	Curve Number +10%		Curve Number -10%	
			Flow (m^3/s)	% Difference	Flow (m^3/s)	% Difference
Corner Brook Stream	1:20	142.9	197.1	37.9	105.9	-25.9
	1:100	201	276.6	31.8	153.0	-23.9
Petrie's Brook	1:20	142.9	20.4	33.3	11.8	-22.9
	1:100	201	28.7	28.1	17.5	-21.9

6.1.2 River Reach Roughness

The river reach roughness is an input into the hydrologic model which is used to determine the shape of the resulting hydrograph through the effect of channel routing from one basin to the next downstream computational node. The Manning's Roughness coefficients were increased and decreased by 10 percent for the 1:20 year and 1:100 year AEP events. The results of the analysis are presented in Table 6-2. As suggested by the results, the selection of the river reach roughness coefficient does not have a significant impact on the resulting peak flows.

Table 6-2: River Reach Roughness Sensitivity Analysis

Study Area	Event (AEP)	Base Case Flow (m^3/s)	Manning Coefficient +10%		Manning Coefficient -10%	
			Flow (m^3/s)	% Difference	Flow (m^3/s)	% Difference
Corner Brook Stream	1:20	148.4	140.7	-1.5	145.1	1.5
	1:100	209.9	276.6	-1.4	203.8	1.4
Petrie's Brook	1:20	15.3	15.1	-1.3	15.7	2.6
	1:100	22.4	22.0	-1.8	22.8	1.8

6.1.3 IDF Estimate Uncertainty

The 1:100 year AEP rainfall events that were simulated in the hydrologic model were taken directly from the Environment Canada Short Duration Rainfall Intensity-Duration-Frequency Data, published April 13, 2010 (with data range from 1966 to 2002). The 1:20 year AEP rainfall was estimated from the Environment Canada IDF data and as such, confidence limits were not available. The 95% Confidence limits estimates provided with the rainfall intensity data were used to establish upper and lower bounding 1:100 year AEP rainfall hyetographs (see Table 6-3) developed using the alternating block method.

Table 6-3: Sensitivity Analysis of IDF Rainfall

Duration	1:100 year AEP Rainfall Intensity (mm/hr)		
	Lower Bound	**Base**	**Upper Bound**
5 min	97.9	130.0	162.1
10 min	67.1	87.9	108.7
15 min	51.5	66.6	81.7
30 min	32.7	41.0	49.3
1 hr	21.2	26.2	31.2
2 hr	15.8	19.9	24.0
6 hr	7.5	9.1	10.7
12 hr	4.6	5.5	6.4
24 hr	2.7	3.2	3.7

Table 6-4 summarizes the results of the impact of varied rainfall inputs on computed peak flows for the Corner Brook Stream and Petrie's Brook watersheds. As suggested from the results, the model is only marginally sensitive to rainfall input within the confidence limits specified by Environment Canada. Although confidence limits were not available for the 1:20 year AEP rainfall, a similar result would be expected.

Table 6-4: Results of Rainfall Sensitivity Analysis

Watershed	1:100 year AEP Flow (m^3/sec) *% change from base estimate*		
	Lower Bound	**Base**	**Upper Bound**
Corner Brook Stream	193.2	201.0	206.6
	-4%	*0%*	*3%*
Petrie's Brook	21.0	22.4	23.5
	-6%	*0*	*5%*

The climate change analysis provided in Section 7 provides additional information outlining the sensitivity of peak flow estimates for the Corner Brook Stream and Petrie's Brook to additional variations in precipitation input.

6.1.4 Summary of Hydrologic Model Sensitivity

A sensitivity analysis of the hydrologic model inputs was completed to determine the effects of changing model parameters on the resulting flood flows. It was determined that peak flows are very sensitive to the selection of Curve Number but are not sensitive to changes in river reach roughness estimates. It was also determined that the hydrologic model is only marginally sensitive to variations in rainfall inputs within the confidence limits specified by Environment Canada.

It was noted that better estimates of Curve Number may be possible with the use of higher resolution satellite imagery to support the classification of land cover in the watersheds. This should be a consideration for future watershed modeling efforts.

6.2 Sensitivity of Hydraulic Model Inputs

6.2.1 Manning's Roughness

The Manning's Roughness input parameter of the hydraulic model defines the relative roughness of the main channel and floodplain areas. A higher Manning's Roughness coefficient will increase flooding levels and reduce velocities. The Manning's Roughness for the channel and overbank at each cross section were increased and decreased by 20 percent for the 1:20 year and 1:100 year AEP events. The results of the analysis are presented in Table 6-5.

The selection of Manning's Roughness coefficient generally has a limited overall impact. However, significant impacts in localized reaches is demonstrated through this analysis where changes in flow regime occur as a result of roughness variation (i.e. from supercritical to subcritical or vice-versa). Large changes in water surface can also occur in cross-sections near (typically upstream) critical culvert and bridge locations where flow changes from open surface flow to surcharged or overtopping situations. The analysis has demonstrated that alteration of Manning's Roughness coefficient by 20% (positive or negative) results in an average changes in computed water surface elevation of between 5 cm to 12 cm.

Table 6-5: Manning's Roughness Sensitivity Analysis

Study Area	Event (AEP) (yr)	Manning's n + 20%			Manning's n - 20%		
		Average Change in WL[1] (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)	Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)
Corner Brook Stream	1:20	+ 0.09	+ 1.28	- 0.09	- 0.10	+ 0.10	- 1.48
	1:100	+ 0.10	+ 1.67	- 0.11	- 0.12	+ 0.03	- 1.34
Petrie's Brook	1:20	+ 0.05	+ 0.38	- 0.02	- 0.06	+ 0.01	- 0.63
	1:100	+ 0.05	+ 0.39	- 0.01	- 0.06	+ 0.06	- 0.21

1. Water Level

6.2.2 Peak Discharge

There is uncertainty associated with the 1:20 year and 1:100 year AEP flows estimated in the study, as previously discussed. To determine the impact of the changes in peak flows on the resulting water surface profile, the peak flows for the 1:20 year and 1:100 year AEP events were increased/ decreased by 10, 20, and 30 percent. Tables 6-6, 6-7, and 6-8 summarize the changes in water levels for the 1:20 year and 1:100 year AEP events associated with the varying flow conditions.

As for Manning's Roughness, the selection of peak discharge generally has a limited impact on average (<0.3 m). However, significant impacts in localized reaches is demonstrated through this analysis where changes in flow regime occur (i.e., from supercritical to subcritical or vice-versa). Large changes in water surface can also occur in cross-sections near (typically upstream) critical culvert and bridge locations where flow changes from open surface flow to surcharged or overtopping situations.

Table 6-6: Peak Discharge Sensitivity Analysis (+/- 10%)

Study Area	Event (AEP) (yr)	Inflow + 10%			Inflow - 10%		
		Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)	Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)
Corner Brook Stream	1:20	+ 0.07	+ 1.05	- 0.10	- 0.08	+ 1.04	- 3.18
	1:100	+ 0.08	+ 0.65	- 0.96	- 0.10	+ 0.84	- 1.12
Petrie's Brook	1:20	+ 0.05	+ 0.47	- 0.17	- 0.04	+ 0.01	- 0.22
	1:100	+ 0.07	+ 1.87	- 0.25	- 0.05	+ 0.14	- 0.65

Table 6-7: Peak Discharge Sensitivity Analysis (+/- 20%)

Study Area	Event (AEP) (yr)	Inflow + 20%			Inflow - 20%		
		Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)	Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)
Corner Brook Stream	1:20	+ 0.14	+ 1.31	- 2.24	- 0.16	+ 0.48	- 3.26
	1:100	+ 0.17	+ 1.65	- 0.89	- 0.19	+ 2.19	- 1.78
Petrie's Brook	1:20	+ 0.10	+ 0.72	- 0.29	- 0.08	+ 0.17	- 0.42
	1:100	- 0.05	+ 0.14	- 0.65	- 0.12	+ 0.19	- 1.24

Table 6-8: Peak Discharge Sensitivity Analysis (+/- 30%)

Study Area	Event (AEP) (yr)	Inflow + 30%			Inflow - 30%		
		Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)	Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)
Corner Brook Stream	1:20	+ 0.21	+ 2.01	- 2.18	- 0.26	+ 0.71	- 3.33
	1:100	+ 0.26	+ 2.58	- 0.82	- 0.29	+ 2.13	- 2.62
Petrie's Brook	1:20	+ 0.14	+ 1.16	- 0.11	- 0.13	+ 0.12	- 0.62
	1:100	- 0.12	+ 0.19	- 1.24	- 0.18	+ 0.08	- 1.35

6.2.3 Tidal and Surge Influence

The downstream boundary condition was assumed to be a water level of 2.8 m for the Corner Brook Stream and Petrie's Brook hydraulic models (for existing conditions). This water level is comprised of the maximum high tide and storm surge as previously documented in Section 5.1.6. The downstream boundary condition was increased by 1.0 m for the 1:20 year and 1:100 year AEP events (3.8 m total for Corner Brook Stream and Petrie's Brook. The results of the analysis are presented in Table 6-9.

The resulting increase in water level is consistent with the incremental increase in the downstream boundary condition of 1.0 m. The maximum increase in water level is 1.09 m. In all results, the impact of the increase in the downstream boundary condition is relatively localized. In the Corner Brook Stream model, the changes in computed water surface elevations were limited to areas below cross-section 1194.69. In the Petrie's Brook model, the changes in computed water surface elevations were limited to areas below cross-section 200 (approximately 70 m upstream from Bartlett's Avenue).

Tables 6-10 and 6-11 detail a comparative assessment of computed water surface elevations for existing conditions, for Corner Brook Stream and Petrie's Brook respectively, based on three scenarios, namely:

- the starting water surface elevation described in Section 5.1.6 (HHWLT plus storm surge = 2.8m) and adopted for this study, and;
- a starting water surface elevation based on HHWMT plus storm surge or 2.5m
- a starting water surface elevation based on MWL plus storm surge or 1.9m

For both watercourses and both the 1:20 year and 1:100 year AEP floods, the change in starting water level does not influence computed water levels a significant distance upstream. In the case of Corner Brook Stream, the influence extends only to about section 274.62 (computed water levels within 5 cm) for the 100 year case and section 401.99 (computed water levels

within 5 cm) for the 1:20 year case. In the case of Petrie's Brook, the influence extends only to about section 164.9 for the 1:100 year case and section 300.08 for the 1:20 year case.
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Table 6-9: Starting Water Level Sensitivity Analysis (+ 1 m)

Study Area	Event (AEP)	Known Downstream Water Surface + 1 m		
		Average Change in WL (m)	Maximum Increase in WL (m)	Maximum Decrease in WL (m)
Corner Brook Stream	1:20	+ 0.04	+ 1.00	0.00
	1:100	+ 0.04	+ 1.00	- 0.07
Petrie's Brook	1:20	+ 0.08	+ 1.01	- 0.03
	1:100	+ 0.07	+ 1.01	0.00

Table 6-10: Starting Water Level Sensitivity Analysis (Corner Brook Stream)

Reach	Section	Starting Water Levels					
		20 Year AEP Flood			100 Year AEP Flood		
		1.9m	2.5m	2.8m	1.9m	2.5m	2.8m
M001	535.83	3.79	3.79	3.79	3.97	3.97	3.97
M001	520.22	3.79	3.79	3.79	3.98	3.98	3.98
M001	472.07	3.75	3.75	3.75	3.92	3.92	3.92
M001	460	Bridge					
M001	445.11	3.4	3.38	3.35	3.48	3.48	3.48
M001	425.41	3.41	3.4	3.36	3.52	3.52	3.52
M001	401.99	3.43	3.41	3.38	3.54	3.54	3.54
M001	381.26	3.37	3.36	3.31	3.47	3.47	3.46
M001	380	Bridge					
M001	375.14	2.94	2.96	3.04	3.24	3.25	3.29
M001	352.89	2.97	2.98	3.04	3.14	3.14	3.18
M001	324.13	2.97	2.98	3.04	3.11	3.12	3.14
M001	292.92	2.95	2.97	3.03	3.11	3.12	3.15
M001	274.62	2.91	2.93	3.01	3.09	3.09	3.14
M001	270	Bridge					
M001	266.99	2.85	2.87	2.98	3.04	3.04	3.1
M001	245.99	2.8	2.83	2.95	2.98	2.99	3.06
M001	210.89	2.75	2.79	2.92	2.92	2.93	3.02
M001	174.77	2.69	2.74	2.9	2.87	2.88	2.98
M001	155.66	2.65	2.72	2.89	2.84	2.85	2.97
M001	152.5	Bridge					
M001	150.09	2.62	2.7	2.88	2.82	2.84	2.96
M001	129.05	2.51	2.64	2.86	2.74	2.76	2.92
M001	80.73	2.39	2.57	2.83	2.61	2.66	2.86
M001	23.81	1.9	2.5	2.8	1.9	2.5	2.8

Table 6-11: Starting Water Level Sensitivity Analysis (Petrie's Brook)

Reach	Section	Starting Water Levels					
		20 Year AEP Flood			100 Year AEP Flood		
		1.9m	2.5m	2.8m	1.9m	2.5m	2.8m
M001	621.03	21.13	21.13	21.13	21.35	21.35	21.35
M001	599.17	15.55	15.55	15.55	15.64	15.64	15.64
M001	547.98	9.96	9.96	9.96	10.05	10.05	10.05
M001	500	8.66	8.66	8.66	8.86	8.86	8.86
M001	446.65	7.09	7.09	7.09	7.2	7.2	7.2
M001	399.97	5.82	5.82	5.82	5.93	5.93	5.93
M001	349.97	5.06	5.06	5.06	5.21	5.21	5.21
M001	300.08	4.31	4.33	4.33	4.54	4.54	4.54
M001	250	3.72	3.65	3.65	3.85	3.85	3.85
M001	200	3.87	3.61	3.61	3.9	3.9	3.9
M001	164.9	3.84	3.5	3.51	3.85	3.85	3.85
M001	130	Culvert					
M001	122.87	3.63	3.3	3.31	3.57	3.57	3.39
M001	121.82	2.67	3.15	3.17	3.61	3.61	3.43
M001	110	Culvert					
M001	108.55	2.14	2.16	2.79	2.6	2.6	2.79
M001	100	1.98	2.5	2.8	1.62	2.5	2.8
M001	50	1.88	2.5	2.8	1.86	2.5	2.8
M001	-33.87	1.9	2.5	2.8	1.89	2.5	2.8
M001	-115.21	1.9	2.5	2.8	1.9	2.5	2.8

6.2.4 Summary of Hydraulic Model Sensitivity

Average changes in computed water levels resulting from the sensitivity runs were close to base case results. More significant changes in computed water levels were attributed to changes in flow regime (i.e., from supercritical to subcritical or vice-versa) or changes in flow conditions around bridges and culverts (i.e., changes from open surface flow to surcharged or overtopping situations).

Standard HEC-RAS output tables, associated with hydraulic computations detailed for the hydraulic model sensitivity analysis, are provided in Appendix N.

6.3 Sensitivity Analysis Conclusions

As noted previously, sensitivity analysis is used to:

- *Test the robustness of simulation model results in the presence of uncertainty and increasing the understanding of the relationships between input and output variables in the simulation models.*

Three input variables were tested with the following results:

- o Sensitive to changes in Curve Number
- o Not sensitivity to river reach roughness
- o Marginal sensitivity to rainfall estimates within the confidence limits specified by Environment Canada

Some benefit may be gained regarding improved confidence in Curve Number estimation through the use of higher resolution satellite imagery for land classification. However, the difference between the two methods (i.e., use of low or high resolution data) in terms of Curve Number estimation cannot be quantified without parallel assessments.

- *Increasing confidence in simulation model results by identifying model inputs that cause significant uncertainty in the output thereby focusing increased attention towards estimation of these specific model inputs.*

  The sensitivity analysis results associated with river reach roughness and rainfall estimates did not justify any additional effort towards refining initial model estimates for these parameters.

- *Ensuring the model is accurately reflecting watershed conditions and responses by identifying errors in the model output as reflected by unexpected relationships between inputs and outputs.*

  The sensitivity analysis results did not demonstrate any unexpected relationships or model errors.

Overall, the hydrologic model input parameters were selected based on reliable background information, engineering judgment and field measured data and are considered to be a good and supportable reflection of watershed conditions. The sensitivity analysis results of the hydrologic models did suggest opportunities for future potential enhancement with regard to Curve Number estimation but, overall, did not suggest a need to alter the parameterization of the hydrologic models for the present study.

The sensitivity analysis results associated with the hydraulic model indicate a general insensitivity to changes in input parameters when viewed as average changes to computed water surface elevations. Some specific locations do experience larger variation in computed water levels but these are associated with changes in the flow regime between sub-critical flow and super-critical flow (and vice versa) and changes in bridge hydraulics associated with open water to pressure flow situations (and vice versa).

The sensitivity analysis results of the hydraulic models did not suggest a need to alter the parameterization of the hydraulic models for the present study.

6.4 Sensitivity Analysis Recommendations

It was noted that better estimates of Curve Number may be possible with the use of higher resolution satellite imagery to support the classification of land cover in the watersheds. This should be a consideration for future watershed modeling efforts.

7.0 CLIMATE CHANGE ANALYSIS

Newfoundland and Labrador is expected to experience changes in temperature, precipitation, sea level and other factors in the future as a result of climate change. These factors can influence the flood risk faced by a community directly or indirectly. Climate change may result in communities which are not presently at risk of flooding being included in the list of potential candidates for new flood plain mapping.

The climate change assessment for this project focused on the development of flood plain mapping for three future periods, namely: 2020, 2050 and 2080. It should be noted that the previously noted periods are not meant to represent exactly these years but the more general time frames of today through to 2035, 2036 to 2065, 2066 to 2095.

The HEC-HMS models of Petrie's Brook and Corner Brook Stream, developed for this project, were used to assess the impact of climate change by using projected rainfall data for the target periods. It can be argued that other parameters are also relevant in this analysis such as continued urban development and change of land cover.

Population statistics available through Newfoundland and Labrador Statistics Agency[15] were reviewed as an indication of potential future population growth. The available census data for Corner Brook (Petrie's Brook data was not available separately) is outlined in Table 7-1. The data suggest that the population of Corner Brook has been in decline over the past 20 years.

Table 7-1: Population Data for Corner Brook

Population by Year				
1991	**1996**	**2001**	**2006**	**2011**
22,410	21,893	20,103	20,083	19,886

Watershed runoff response will also be influenced by changes in land cover that may result from community development (increased imperviousness) or changes in terrestrial communities (such as forests to open meadows or vice versa). The land cover analysis completed as a component of this project was focused on one time period only. A land cover change detection analysis of at least two periods, if not more, would be required to determine if any trends in changes in land cover over the watershed were identifiable.

Broader changes in land cover as a result of changing terrestrial communities due to climate change are addressed in Vasseur and Catto (2008). However, the sensitivity and vulnerability of forest communities in Atlantic Canada is considered to be low to moderate. Further, given that the Vasseur and Catto (2008) assessment of climate change influences on forest systems provided no specific guidance on regional variation of potential impacts across the Province, there was not any means making projections regarding hydrologic model parameterization for future periods to reflect potential land cover changes.

[15] http://www.stats.gov.nl.ca/

The review of potential changes in population and land cover provided no definitive guidance towards alteration of the HEC-HMS to reflect future watershed characteristics. As such, the existing conditions HEC-HMS model was used for this assessment.

The estimates of future rainfall data were taken from three separate sources as outlined below:

- AMEC - Development of Projected Intensity-Duration-Frequency Curves

  In 2010, Environment Canada developed updated IDF curves based on historical observations from the stations at Deer Lake (data from 1966 through 2002) and Stephenville A (data from 1967 through 2007). The documentation for these historical IDF curves included the record of the intensity of annual extreme precipitation events for nine event durations ranging from five minutes to 24 hours. To obtain projected IDF curves, the precipitation intensities in the historical IDF curve were adjusted to reflect projected changes in climate using a statistical modeling technique that is described briefly in the following paragraphs. A detailed report outlining the techniques used and outcomes from this analysis is provided in Appendix D.

  The approach selected for this analysis uses a statistical model that derives the sensitivity of extreme precipitation to climate conditions from the historical climate information for a site. In this case the historical climate was characterized by observations of monthly average temperature and monthly total precipitation at the Deer Lake and Stephenville weather stations. The statistical model was fitted to the local climate data and the historical monthly precipitation maxima using a form of regression. Information about future monthly average temperature and monthly total precipitation was obtained from the output of 48 runs of Global Climate Models (GCMs). Each GCM run was compared to establish a projected future change in temperature and precipitation. These changes were used to adjust the historical record of temperature and precipitation to reflect future conditions, which resulted in 48 future climate scenarios that were based on the historical record but which reflected the projected future change in climate. This approach, which is referred to as the delta approach, is used to reduce some of the inevitable bias inherent in projections of future climate.

  The statistical model of extreme precipitation was then run against each of these adjusted records to obtain estimates of climate-impacted extreme precipitation intensities for each of the nine durations and six return intervals. These estimates reflect the bias in the statistical model, so one more run of the statistical model was made against the average historical climate conditions to provide a baseline set of extreme precipitation intensities and this set of baseline intensities was compared against each of the 48 estimates of climate-impacted intensities to determine the change in intensity attributable to the change in climate. These changes were then used to adjust the values in the historical IDF curve to obtain the final projected values of precipitation intensity. (This is another application of the delta approach.)

The 48 projections used to characterize future climate conditions produced an equal number of estimates of projected precipitation intensities for each duration and return interval. For reporting purposes, these results were aggregated into the mean, maximum and 90th percentile non-exceedence value of precipitation intensity for each duration and return interval.

The estimates of projected rainfall, for the Environment Canada Deer Lake station, determined through this assessment are presented in Table 7-2 and Appendix D.

- Joel Finnis, Associate Professor, Department of Geography, Memorial University, 2012

  As described by Dr. Finnis:

  "The estimates were extrapolated from available observations and climate simulations from the North American Regional Climate Change Assessment Project (NARCCAP). To ensure an appropriate baseline, probability distributions were first fitted to Environment Canada IDF curves. Projected changes in the distribution parameters were then calculated from the model data; these changes were then applied to the observed distributions, giving an estimated distribution for the mid-21st century. A mixed probability model was used, in which the probability of daily precipitation was first calculated, and a gamma distribution was then fitted to daily precipitation amounts for days in which precipitation occurs. The model uses three parameters; the probability of no precipitation, and the gamma shape and scale parameters.

  The projections are for 12 hour and 24 hour return periods for the mid-21st century ~2040-2060), using the official Environment Canada numbers as a baseline. There are two predictions: a 'fitted' value, which applies projected changes in the precipitation distribution to the 20th century baseline, and a 'raw model' value, which just applies the un-adjusted model projected change to the baseline. The fitted is a better assessment, and better accounts for model biases. The raw model is less useful, but could be taken as a low-end estimate of change."

  The Finnis projected rainfall estimates (provided for 2050 only) were provided (see Table 7-3) as event totals only (12 hour and 24 hour only). As such, hyetographs for the purposes of HEC-HMS modeling were generated using the alternating block method using the 2050 projected IDF data (produced by AMEC) and applying the resultant mass rainfall curve to the Finnis data.

  Further, the Finnis projected rainfall data was provided for Stephenville only. By comparison, the current 24 hour 1:100 year AEP rainfall estimates for Stephenville and Deer Lake are 135.5mm and 76.4mm, respectively. Nonetheless, the projected estimates for Stephenville were applied, unchanged, to the Corner Brook Stream and Petrie's Brook watershed models.

Table 7-2: AMEC Projected Rainfall Estimates for Deer Lake

		Rainfall Totals (mm) - Maximum, 2020 timeframe)						
		Return period (years)						
		2	5	10	20	25	50	100
Storm Duration	5 min	4.3	6.2	7.3	8.5	8.9	10.0	11.1
	10 min	6.1	8.5	10.1	11.6	12.0	13.5	14.9
	15 min	7.5	10.1	11.7	13.4	13.9	15.4	17.0
	30 min	11.5	14.3	16.1	17.9	18.4	20.1	21.8
	1 hr	15.7	19.0	21.3	23.3	24.0	26.1	28.1
	2 hr	22.2	28.0	32.0	35.4	36.6	40.0	43.8
	6 hr	34.8	41.4	45.6	49.8	51.0	55.2	59.4
	12 hr	43.2	50.4	56.4	60.0	62.4	67.2	72.0
	24 hr	50.4	60.0	64.8	69.6	72.0	79.2	84.0

		Rainfall Totals (mm) - Maximum, 2050 timeframe						
		Return period (years)						
		2	5	10	20	25	50	100
Storm Duration	5 min	4.4	6.2	7.4	8.5	8.9	10.0	11.1
	10 min	6.4	8.8	10.3	11.8	12.3	13.7	15.2
	15 min	7.6	10.1	11.8	13.4	13.9	15.5	17.0
	30 min	11.7	14.5	16.4	18.1	18.6	20.3	22.0
	1 hr	16.0	19.3	21.6	23.6	24.3	26.4	28.4
	2 hr	22.8	28.6	32.4	36.0	37.2	40.6	44.2
	6 hr	36.0	42.0	46.2	50.4	51.6	55.8	60.0
	12 hr	44.4	51.6	57.6	61.2	63.6	68.4	73.2
	24 hr	52.8	62.4	64.8	72.0	72.0	79.2	84.0

		Rainfall Totals (mm) - Maximum, 2080 timeframe						
		Return period (years)						
		2	5	10	20	25	50	100
Storm Duration	5 min	4.7	6.5	7.6	8.8	9.1	10.2	11.3
	10 min	6.8	9.2	10.7	12.2	12.7	14.1	15.5
	15 min	8.0	10.5	12.1	13.7	14.2	15.8	17.3
	30 min	12.9	15.7	17.5	19.2	19.7	21.4	23.0
	1 hr	17.7	21.0	23.2	25.2	25.8	27.8	29.8
	2 hr	25.2	31.2	35.2	38.8	40.0	43.4	47.2
	6 hr	39.6	45.6	49.8	54.0	55.2	59.4	63.6
	12 hr	45.6	51.6	57.6	62.4	63.6	68.4	73.2
	24 hr	52.8	62.4	67.2	72.0	74.4	81.6	86.4

Table 7-3: Finnis 2050 Total Rainfall Estimates (mm) for Stephenville

Location	Return Period (yr)	Current	Best Fit to Current	2050 Predictions (24 hour event)	
				Fitted	Raw Model
Stephenville	2	59.3	66.1	73.8	62.6
	5	79.7	81.7	91.5	83.5
	10	93.2	93.8	105.2	97.4
	20	110.3	110.1	119.1	114.9
	50	123.0	122.6	137.7	128.2
	100	135.5	135.2	152.0	141.1

Location	Return Period (yr)	Current	Best Fit to Current	2050 Predictions (12 hour event)	
				Fitted	Raw Model
Stephenville	2	46.6	51.1	56.6	48.7
	5	61.4	62.6	69.4	63.8
	10	71.1	71.4	79.3	73.8
	20	83.5	80.4	89.3	86.4
	50	92.6	92.4	102.8	95.8
	100	101.7	101.6	113.1	105.2

- Climate Change Scenarios for Atlantic Canada Utilizing a Statistical Downscaling Model Based on Two Global Climate Models, Gary S. Lines, Michael Pancura, Chris Lander, Lee Titus, Meteorological Service Of Canada, Atlantic Region, Science Report Series 2009-01, July 2008

  The project Terms of Reference required the use of the estimates outlined in the report above as one of the climate change scenarios to be evaluated for the purposes of determining flood plains in the subject watersheds. It was subsequently deemed by WRMD that the projected rainfall estimates determined by Lines et al (2008) were inappropriate for use by this project and assessment should continue using the AMEC and Finnis projected rainfall estimates only.

7.1 Hydrologic Summary

As noted previously the existing conditions HEC-HMS model for Corner Brook Stream and Petrie's Brook were used to determine peak flows for the three future periods, namely: 2020, 2050 and 2080, based on rainfall estimates for these future periods as determined by AMEC and Dr. Joel Finnis. Table 7-4 provides a summary of the calculated flows.

Table 7-4: Streamflow Summary for Existing and Future Conditions

Scenario	Streamflow (m^3/s)			
	Corner Brook Stream		Petrie's Brook	
	1:20 yr AEP	1:100 yr AEP	1:20 yr AEP	1:100 yr AEP
Existing Conditions	142.9	201	15.3	22.4
2020 (AMEC)	173.3	230.7	18.6	25.4
2050 (AMEC)	175	233.5	18.9	25.8
2050 (Finnis)	344.8	500	38.2	56.7
2080 (AMEC)	173.3	244.9	20.2	27.6

7.2 Hydraulic Summary

The flows determined for the future periods were then input to the HEC-RAS hydraulic model to evaluate the potential impact of climate change on computed water levels in the study reaches. Table 7-5 provides a summary of the changes in computed water surface elevations (from existing conditions) associated with each of the future conditions.

Table 7-5: Comparison of Existing and Future Computed Water Surface Elevations

Scenario	Changes in Computed Water Surface Elevation from Existing Conditions (m)			
	Corner Brook Stream		Petrie's Brook	
	Average Change	Maximum/Minimum Change	Average Change	Maximum/Minimum Change
1:20 year AEP Flood				
2020 (AMEC)	0.13	1.06 / -0.24	0.09	0.54 / -0.14
2050 (AMEC)	0.14	1.17 / -0.24	0.10	0.55 / -0.14
2050 (Finnis)	0.76	5.24 / -0.94	0.47	2.97 / -0.31
2080 (AMEC)	0.20	1.72 / -2.22	0.10	1.15 / -0.12
1:100 year AEP Flood				
2020 (AMEC)	0.10	0.75 / -0.95	0.10	2.05 / -0.23
2050 (AMEC)	0.12	1.10 / -0.94	0.12	2.12 / -0.21
2050 (Finnis)	0.96	6.92 / -1.15	0.48	3.15 / -0.25
2080 (AMEC)	0.20	2.38 / -0.89	0.15	2.06 / -0.17

The maximum changes in computed water surface elevations are typically experienced on the upstream side of culverts or where the flow regime changes from super-critical to sub-critical (and vice versa). Of particular interest is the significant increase in computed water levels associated with the 2050 (Finnis) 1:20 year AEP flood estimate which occurs on the upstream side of the Valley Mall culvert along Bells Brook (a tributary of Corner Brook Stream). Similarly, the maximum increase for the 1:100 year AEP flood occurs upstream of the Ring Road bridge along Bells Brook.

Table 7-6 provides a comparison between the 2050 computed water surface elevations associated with the Finnis and AMEC rainfall estimates.

Table 7-6: Comparison of 2050 Computed Water Surface Elevations

Statistic	Changes in Computed Water Surface Elevations for 2050 (m)			
	Corner Brook Stream		Petrie's Brook	
	1:20 yr AEP Flood	1:100 yr AEP Flood	1:20 yr AEP Flood	1:100 yr AEP Flood
Average	0.61	0.84	0.37	0.36
Maximum	4.75	6.62	2.84	1.49
Minimum	-1.08	-1.32	-0.37	-0.53

The maximum changes in computed water surface elevations remain consistent to those described for Table 7-5.

7.3 Conclusions and Recommendations

An evaluation of the potential impacts of climate change on flood risk was completed. Estimates of flood plains for the periods 2020, 2050 and 2080 were computed and delineated. Two sources of rainfall estimates for these future periods were determined. Dr. Joel Finnis, a Professor in the Department of Geography at Memorial University provided one set of estimates (12 hour and 24 hour durations) for Stephenville. AMEC, as a component of the current project, developed projected IDF relationships for the Environment Canada Deer Lake station.

It should be noted that there is a great deal of uncertainty with all climate models, statistical downscaling and projection of rainfall to point locations. The quantification of rainfall and, subsequently, flood plain estimates should not be interpreted as an accurate portrayal of possible future events. These estimates provide a good indication of upward and downward trends and general sense of the magnitude of the potential change but should not be considered absolute.

7.3.1 Conclusions

It is concluded from this assessment that climate change has the potential to increase flood risk in the Corner Brook Area.

7.3.2 Recommendations

It is recommended that meteorological conditions in the Corner Brook Area be monitored towards determination of changing trends in rainfall and generally extreme weather.

It is further recommended that climate change be integrated into municipal planning in those areas where increasing flood risk is relevant such as infrastructure and emergency planning.

8.0 FLOOD RISK MAPPING

Using the outputs of the hydraulic model, the 1:20 year and 1:100 year AEP water surface profiles were used to develop flood risk mapping. Flood risk maps illustrate the extent of flooding that is expected under the 1:20 year and 1:100 year AEP flood events and are available for use by all levels of government, private companies and other stakeholders. Additionally, climate change analyses were carried out for the 2020, 2050 and 2080 tri-decades, as outlined in Section 7, for both the 1:20 year AEP and 1:100 year AEP scenarios. Associated flood risk mapping was prepared for the most severe climate change water levels anticipated for the 1:20 year and 1:100 year AEP flood events.

HEC-GeoRAS enables the conversion of HEC-RAS results into GIS-based flood risk mapping. The program creates a polyline feature class to which the maximum water surface elevations are attributed. From this, triangulation is carried out which interpolates the water surface elevation between adjacent cross sections. A volumetric cut-fill analysis is then performed between the water surface and the topography to arrive at the resultant inundated area. It was determined that the generic functionality for the automated flood line generation routines within HEC-GeoRAS are based on a gridded approach to DTM processing. The gridded approach attempts to represent the terrain using a "smooth" mathematical model across the entire terrain surface. Gridded DTM processing has a tendency for over- and under-shoot (i.e. the grid elevation at a point is over or under the known elevation at that same point) in zones of rapidly changing terrain. The terrain in the subject watersheds, particularly in the flood plain, is considered rapidly varying. Initial results with the generic automated flood plain functionality yielded less than desirable results. As such, a manual procedure mimicking the generic HEC-GeoRAS functionality was employed with the exception that the DTM processing was based on the Triangulated Irregular Network representation of the terrain. The resultant flood lines were significantly improved in terms of the accuracy of their placement relative to the known terrain and associated elevations.

LiDAR was acquired for the entire study area and, as such, was used to accurately represent basin topography for the purposes of flood mapping development.

It should be noted that, although the automatically generated inundation polygon provides reliable inundation at each cross section location, manual post-processing is required to ensure that the water surface elevation between cross sections is represented properly. The following issues were noted as requiring manual post-processing:

- In areas where a tributary enters the main watercourse between cross sections, the triangulated water surface often overestimates the extent of flooding up the tributary which is caused by an increase in water level along the main watercourse.
- It is also common for low lying areas, which are located off the main watercourse and which would not realistically be inundated, to appear inundated as a result of the cut-fill analysis.

- Similarly, backwater areas, where flooding of low lying areas located off the main watercourses is reasonable, can be falsely extended if the extent of the backwater area traverses upstream sections beyond the point connection to the main watercourse.
- For the purpose of post processing, 0.5m contours were created from the LiDAR so that post processing in these areas can be carried out to approximately the same level of accuracy as is inherent in the LiDAR DTM.

Flood plain maps illustrating the extent of flooding expected under the 1:20 year and 1:100 year AEP flood events for Corner Brook Stream and Petrie's Brook are available in Appendix E (existing conditions). Two versions of the maps have been produced. One set uses the community scale (1:2,500) digital topographical (vector) mapping as the backdrop. The second set uses the 2011 orthophotos, captured as a component of the overall LiDAR data collection effort, as the backdrop.

Flood Risk Mapping was produced also for the most severe 1:20 and 1:100 AEP climate change precipitation scenarios for the 2020, 2050 and 2080 periods. These flood plain maps are available in Appendices F, G and H, respectively. Table 8-1 presents a list of the climate change scenarios for which flood lines were delineated, in addition to the percentage increase in area over each respective base case scenario.

It should be noted that hydraulic structures that are overtopped are covered by the flood polygon on the flood plain maps. If the structure is not overtopped, there is a break in the flood polygon so that the bridge deck is visible. Tables 8-2, 8-3, 8-4 and 8-5 details flood levels at all structures included in the modelling and provide additional details regarding overtopping (where this occurs).

The information on the flood plain maps provides explicit cross-section referencing for each section in the HEC-RAS model. Using this cross-section reference, flood plain map users can access secondary hydraulic data, provided in Appendix J, for all hydraulic sections which comprise the overall HEC-RAS model. The flood plain maps also identify the 1:20 and 1:100 year AEP water levels at each cross-section.

Flood depth maps are also provided in Appendices E, F, G, and H, as appropriate for each modelled scenario. Figure 8-1 through 8-8 provide overviews of the flood depth maps for the different scenarios included with this study.

Table 8-1: Climate Change Influence on Flood Inundation Area

Watercourse/ Period	20 Year AEP		100 Year AEP	
	Flooded Area (km^2)	% Change	Flooded Area (km^2)	% Change
Corner Brook Stream				
Existing (2012)	0.52	------	0.55	------
2020	0.54	4%	0.57	3%
2050[1]	0.61	18%	0.69	24%
2080	0.55	6%	0.59	6%
Petrie's Brook				
Existing (2012)	0.05	------	0.06	------
2020	0.05	0%	0.06	7%
2050[1]	0.07	29%	0.07	19%
2080	0.06	6%	0.07	10%

Notes:
1. Please refer to Section 7 [Climate Change] for details specific to hydrologic and hydraulic modelling that differentiates between the various modelling scenarios.

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Table 8-2: Watercourse Crossings - Overtopping Summary – Corner Brook Stream – 100 Year AEP Flood

Structure #	Structure Name / Location	Structure Type	Watercourse	HEC-RAS Tributary	HEC-RAS Structure Number	HEC-RAS Reference	Low Chord	Top of Road	Computed Water Surface Elevation by Scenario[1]				*Overtopping Depth* / Freeboard Available[2]			
									Existing	2020	2050	2080	Existing	2020	2050	2080
	20 Year AEP Flood															
2101	Corner Brook Pulp & Paper #1	Bridge	Corner Brook Stream	CornerB-M001	152.5	CornerB-M001-152.5	2.09	4.47	2.96	3.02	3.42	3.41	1.51	1.45	1.05	1.06
2103	Corner Brook Pulp & Paper #3	Bridge	Corner Brook Stream	CornerB-M001	270	CornerB-M001-270	1.49	1.88	3.12	3.2	3.65	3.47	*1.24*	*1.32*	*1.77*	*1.59*
2104	Corner Brook Pulp & Paper #5	Bridge	Corner Brook Stream	CornerB-M001	380	CornerB-M001-380	1.95	2.84	3.44	3.53	4.1	3.65	*0.60*	*0.69*	*1.26*	*0.81*
2105-B	Lewin Parkway	Bridge	Corner Brook Stream	CornerB-M001	460	CornerB-M001-460	2.00	2.67	3.9	3.95	4.53	3.99	*1.23*	*1.28*	*1.86*	*1.32*
2106	Main Street	Bridge	Corner Brook Stream	CornerB-M001	635	CornerB-M001-635	2.30	3.32	4.27	4.34	4.93	4.38	*0.95*	*1.02*	*1.61*	*1.06*
2107	Trail	Bridge	Corner Brook Stream	CornerB-M002	1070	CornerB-M002-1070	2.87	3.17	4.4	4.48	5.25	4.53	*1.23*	*1.31*	*2.08*	*1.36*
2108	Glynmill Pond Dam	Dam, Spillway	Corner Brook Stream	CornerB-M002	1354.11	CornerB-M002-1354.11	17.50	17.50	19.59	19.83	21.62	19.95	*2.09*	*2.33*	*4.12*	*2.45*
2109	Glynmill Pond Upstream Structure	Bridge	Corner Brook Stream	CornerB-M002	1772	CornerB-M002-1772	18.02	18.17	19.76	19.98	21.75	20.1	*1.59*	*1.81*	*3.58*	*1.93*
2110-A	Pedestrian Bridge	Bridge	Corner Brook Stream	CornerB-M003	2115	CornerB-M003-2115	29.06	29.36	26.18	26.34	29.38	26.4	3.18	3.02	*0.02*	2.96
2110-C	O'Connell Drive	Bridge	Corner Brook Stream	CornerB-M003	2150	CornerB-M003-2150	29.65	30.52	29.19	29.84	32.33	30.08	1.33	0.68	*1.81*	0.44
2111	Margaret Bowater Dam	Dam	Corner Brook Stream	CornerB-M003	2263.01	CornerB-M003-2263.01	31.32	31.32	32.58	32.7	33.38	32.75	*1.26*	*1.38*	*2.06*	*1.43*
2112	Unnamed Road	Bridge	Corner Brook Stream	CornerB-M003	2530	CornerB-M003-2530	33.96	34.86	36.36	36.45	37.06	36.51	*1.50*	*1.59*	*2.20*	*1.65*
2113	Unnamed Road	Triple CSP culverts	Corner Brook Stream	CornerB-TR001	25	CornerB-TR001-25	37.06	38.06	38.34	38.31	38.56	38.33	*0.28*	*0.25*	*0.50*	*0.27*
2114	Pedestrian Bridge	Bridge	Bell's Brook	BellsB-M001	43	BellsB-M001-43	2.61	2.80	4.3	4.38	5.02	4.42	*1.50*	*1.58*	*2.22*	*1.62*
2115	Valley Mall Culvert	Culvert	Bell's Brook	BellsB-M001	100	BellsB-M001-100	10.57	17.00	13.21	13.95	17.53	14.6	3.79	3.05	*0.53*	2.40
2118	Blackwood's Hill	Bridge	Bell's Brook	BellsB-M001	800	BellsB-M001-800	39.68	41.43	42.45	42.54	42.99	42.59	*1.02*	*1.11*	*1.56*	*1.16*
2119	Wellington Street	Twin CSP culverts	Bell's Brook	BellsB-M001	840	BellsB-M001-840	44.58	45.59	45.72	45.79	46.24	45.93	*0.13*	*0.20*	*0.65*	*0.34*
2120	Bliss Street	Single CSP culvert	Bell's Brook	BellsB-M002	1650	BellsB-M002-1650	88.52	95.86	96.26	96.31	96.72	96.36	*0.40*	*0.45*	*0.86*	*0.50*
2121-B	Walbournes Road	Bridge	Bell's Brook	BellsB-M002	2300	BellsB-M002-2300	115.06	115.68	116.18	116.21	116.57	116.24	*0.50*	*0.53*	*0.89*	*0.56*
2122	Boones Road	Pipe Arch	Bell's Brook	BellsB-M002	2890	BellsB-M002-2890	126.11	126.37	126.51	126.57	126.78	126.6	*0.14*	*0.20*	*0.41*	*0.23*
2123	Driveway	CSP culvert	Bell's Brook	BellsB-M002	2940.01	BellsB-M002-2940.01	127.62	127.72	127.99	127.97	128.34	128.04	*0.27*	*0.25*	*0.62*	*0.32*
2124	County Road / O'Connell Drive	CSP culvert	Bell's Brook	BellsB-M002	3250	BellsB-M002-3250	136.03	138.36	138.76	138.82	139.28	138.88	*0.40*	*0.46*	*0.92*	*0.52*
2126	Reids Road	CSP pipe arch	Bell's Brook	BellsB-M002	3375	BellsB-M002-3375	137.64	138.08	138.78	138.84	139.28	138.9	*0.70*	*0.76*	*1.20*	*0.82*
2127	Carberry's Road	CSP culvert	Bell's Brook	BellsB-M002	3650	BellsB-M002-3650	145.56	149.51	149.81	150.01	150.88	150.1	*0.30*	*0.50*	*1.37*	*0.59*
2129	Ring Road	CSP culvert	Bell's Brook	BellsB-M002	4850	BellsB-M002-4850	185.98	193.64	186.8	187.06	193.75	187.27	6.84	6.58	*0.11*	6.37
2130	O'Connell Drive / Mount Batten Road	CSP culvert	Bell's Brook – Tributary #1	BellsB-TR001	100	BellsB-TR001-100	93.52	97.05	95.14	95.74	97.05	96.12	1.91	1.31	0.00	0.93

Notes:

1. Computed Water Surface Elevation by Scenario – colour coding of table cells – clear cells indicate no overtopping, blue cells indicate a water level causing surcharged flow, red cells indicate structure which are overtopped.
2. Overtopping Depth / Freeboard Available - colour coding of table cells – black text entries indicate that freeboard is available above the computed water level, red italic text entries indicate overtopping depth.

Table 8-3: Watercourse Crossings - Overtopping Summary – Corner Brook Stream – 1:20 Year AEP Flood

Structure #	Structure Name / Location	Structure Type	Watercourse	HEC-RAS Tributary	HEC-RAS Structure Number	HEC-RAS Reference	Low Chord	Top of Road	Computed Water Surface Elevation by Scenario[1]				*Overtopping Depth* / Freeboard Available[2]			
									Existing	2020	2050	2080	Existing	2020	2050	2080
	20 Year AEP Flood															
2101	Corner Brook Pulp & Paper #1	Bridge	Corner Brook Stream	CornerB-M001	152.5	CornerB-M001-152.5	2.09	4.47	2.88	2.95	3.25	3.39	1.59	1.52	1.22	1.08
2103	Corner Brook Pulp & Paper #3	Bridge	Corner Brook Stream	CornerB-M001	270	CornerB-M001-270	1.49	1.88	3	3.08	3.43	3.42	*1.12*	*1.20*	*1.55*	*1.54*
2104	Corner Brook Pulp & Paper #5	Bridge	Corner Brook Stream	CornerB-M001	380	CornerB-M001-380	1.95	2.84	3.29	3.38	3.8	3.52	*0.45*	*0.54*	*0.96*	*0.68*
2105-B	Lewin Parkway	Bridge	Corner Brook Stream	CornerB-M001	460	CornerB-M001-460	2.00	2.67	3.73	3.83	4.22	3.81	*1.06*	*1.16*	*1.55*	*1.14*
2106	Main Street	Bridge	Corner Brook Stream	CornerB-M001	635	CornerB-M001-635	2.30	3.32	4.11	4.2	4.61	4.2	*0.79*	*0.88*	*1.29*	*0.88*
2107	Trail	Bridge	Corner Brook Stream	CornerB-M002	1070	CornerB-M002-1070	2.87	3.17	4.2	4.31	4.83	4.31	*1.03*	*1.14*	*1.66*	*1.14*
2108	Glynmill Pond Dam	Dam, Spillway	Corner Brook Stream	CornerB-M002	1354.11	CornerB-M002-1354.11	17.50	17.50	19.05	19.33	20.67	19.33	*1.55*	*1.83*	*3.17*	*1.83*
2109	Glynmill Pond Upstream Structure	Bridge	Corner Brook Stream	CornerB-M002	1772	CornerB-M002-1772	18.02	18.17	19.26	19.51	20.81	19.51	*1.09*	*1.34*	*2.64*	*1.34*
2110-A	Pedestrian Bridge	Bridge	Corner Brook Stream	CornerB-M003	2115	CornerB-M003-2115	29.06	29.36	25.89	26.04	26.74	26.04	3.47	3.32	2.62	3.32
2110-C	O'Connell Drive	Bridge	Corner Brook Stream	CornerB-M003	2150	CornerB-M003-2150	29.65	30.52	28.52	28.86	32.27	28.86	2.00	1.66	*1.75*	1.66
2111	Margaret Bowater Dam	Dam	Corner Brook Stream	CornerB-M003	2263.01	CornerB-M003-2263.01	31.32	31.32	32.3	32.45	33.04	32.45	*3.98*	*4.13*	*4.72*	*4.13*
2112	Unnamed Road	Bridge	Corner Brook Stream	CornerB-M003	2530	CornerB-M003-2530	33.96	34.86	36.09	36.22	36.79	36.22	*1.23*	*1.36*	*1.93*	*1.36*
2113	Unnamed Road	Triple CSP culverts	Corner Brook Stream	CornerB-TR001	25	CornerB-TR001-25	37.06	38.06	38.2	38.26	38.42	38.26	*0.14*	*0.20*	*0.36*	*0.20*
2114	Pedestrian Bridge	Bridge	Bell's Brook	BellsB-M001	43	BellsB-M001-43	2.61	2.80	4.14	4.23	4.67	4.23	*1.34*	*1.43*	*1.87*	*1.43*
2115	Valley Mall Culvert	Culvert	Bell's Brook	BellsB-M001	100	BellsB-M001-100	10.57	17.00	11.82	12.25	17.06	12.25	5.18	4.75	*0.06*	4.75
2118	Blackwood's Hill	Bridge	Bell's Brook	BellsB-M001	800	BellsB-M001-800	39.68	41.43	42.22	42.31	42.77	42.31	*0.79*	*0.88*	*1.34*	*0.88*
2119	Wellington Street	Twin CSP culverts	Bell's Brook	BellsB-M001	840	BellsB-M001-840	44.58	45.59	45.52	45.6	45.99	45.6	0.07	*0.01*	*0.40*	*0.01*
2120	Bliss Street	Single CSP culvert	Bell's Brook	BellsB-M002	1650	BellsB-M002-1650	88.52	95.86	96.11	96.16	96.48	96.16	*0.25*	*0.30*	*0.62*	*0.30*
2121-B	Walbournes Road	Bridge	Bell's Brook	BellsB-M002	2300	BellsB-M002-2300	115.06	115.68	116.06	116.11	116.34	116.11	*0.38*	*0.43*	*0.66*	*0.43*
2122	Boones Road	Pipe Arch	Bell's Brook	BellsB-M002	2890	BellsB-M002-2890	126.11	126.37	126.42	126.46	126.68	126.46	*0.05*	*0.09*	*0.31*	*0.09*
2123	Driveway	CSP culvert	Bell's Brook	BellsB-M002	2940.01	BellsB-M002-2940.01	127.62	127.72	127.64	127.72	128.16	127.72	0.08	0.00	*0.44*	0.00
2124	County Road / O'Connell Drive	CSP culvert	Bell's Brook	BellsB-M002	3250	BellsB-M002-3250	136.03	138.36	138.48	138.61	139.04	138.61	*0.12*	*0.25*	*0.68*	*0.25*
2126	Reids Road	CSP pipe arch	Bell's Brook	BellsB-M002	3375	BellsB-M002-3375	137.64	138.08	138.56	138.63	139.08	138.63	*0.48*	*0.55*	*1.00*	*0.55*
2127	Carberry's Road	CSP culvert	Bell's Brook	BellsB-M002	3650	BellsB-M002-3650	145.56	149.51	147.23	148.29	150.44	148.29	2.28	1.22	*0.93*	1.22
2129	Ring Road	CSP culvert	Bell's Brook	BellsB-M002	4850	BellsB-M002-4850	185.98	193.64	186.15	186.43	188.76	186.43	7.49	7.21	4.88	7.21
2130	O'Connell Drive / Mount Batten Road	CSP culvert	Bell's Brook – Tributary #1	BellsB-TR001	100	BellsB-TR001-100	93.52	97.05	93.83	94.25	96.58	94.72	3.22	2.80	0.47	2.33

Notes:

1. Computed Water Surface Elevation by Scenario – colour coding of table cells – clear cells indicate no overtopping, blue cells indicate a water level causing surcharged flow, red cells indicate structure which are overtopped.
2. Overtopping Depth / Freeboard Available - colour coding of table cells – black text entries indicate that freeboard is available above the computed water level, red italic text entries indicate overtopping depth.

Table 8-4: Watercourse Crossings - Overtopping Summary – Petrie's Brook– 1:100 Year AEP Flood

Structure #	Structure Name / Location	Structure Type	Watercourse	HEC-RAS Tributary	HEC-RAS Structure Number	HEC-RAS Reference	Low Chord	Top of Road	Computed Water Surface Elevation by Scenario[1]				*Overtopping Depth* / Freeboard Available[2]			
									Existing	2020	2050	2080	Existing	2020	2050	2080
	100 Year AEP Flood															
1101	Barletts Avenue	Single CSP culvert	Petrie's Brook	PetriesB-M001	110	PetriesB-M001-110	3.3	3.35	3.43	3.44	3.49	3.59	*0.08*	*0.09*	*0.14*	*0.24*
1101-1	N/A	Twin CSP culvert	Petrie's Brook	PetriesB-M001	130	PetriesB-M001-130	4.04	4.07	3.85	3.84	4.56	3.87	0.22	0.23	*0.49*	0.20
1102	Petries Street	Single span bridge	Petrie's Brook	PetriesB-M001	625	PetriesB-M001-625	21.5	22.14	22.73	23.07	23.12	22.81	*0.59*	*0.93*	*0.98*	*0.67*
1104	O'Conner Drive	Single CSP culvert	Petrie's Brook	PetriesB-M001	1295	PetriesB-M001-1295	75.09	83	77.06	78.01	79.07	78.03	5.94	4.99	3.93	4.97
1105	Candow Drive	Single CSP pipe-arch culvert	Petrie's Brook	PetriesB-M001	1560	PetriesB-M001-1560	84.83	87	87.3	87.35	87.71	87.38	*0.30*	*0.35*	*0.71*	*0.38*
1106	Georgetown Road	Single CSP pipe-arch culvert	Petrie's Brook	PetriesB-M001	1975	PetriesB-M001-1975	99.91	100.64	100.7	100.97	101.34	101	*0.06*	*0.33*	*0.70*	*0.36*
1108	Access Road	Timber bridge structure	Petrie's Brook	PetriesB-M002	2710	PetriesB-M002-2710	122.77	122.97	123.55	123.73	123.76	123.84	*0.58*	*0.76*	*0.79*	*0.87*
1109-B	ATV Trail	Single CSP culvert	Petrie's Brook	PetriesB-TR001	80	PetriesB-TR001-80	106.13	106.34	106.91	106.93	106.66	106.94	*0.57*	*0.59*	*0.32*	*0.60*

Notes:

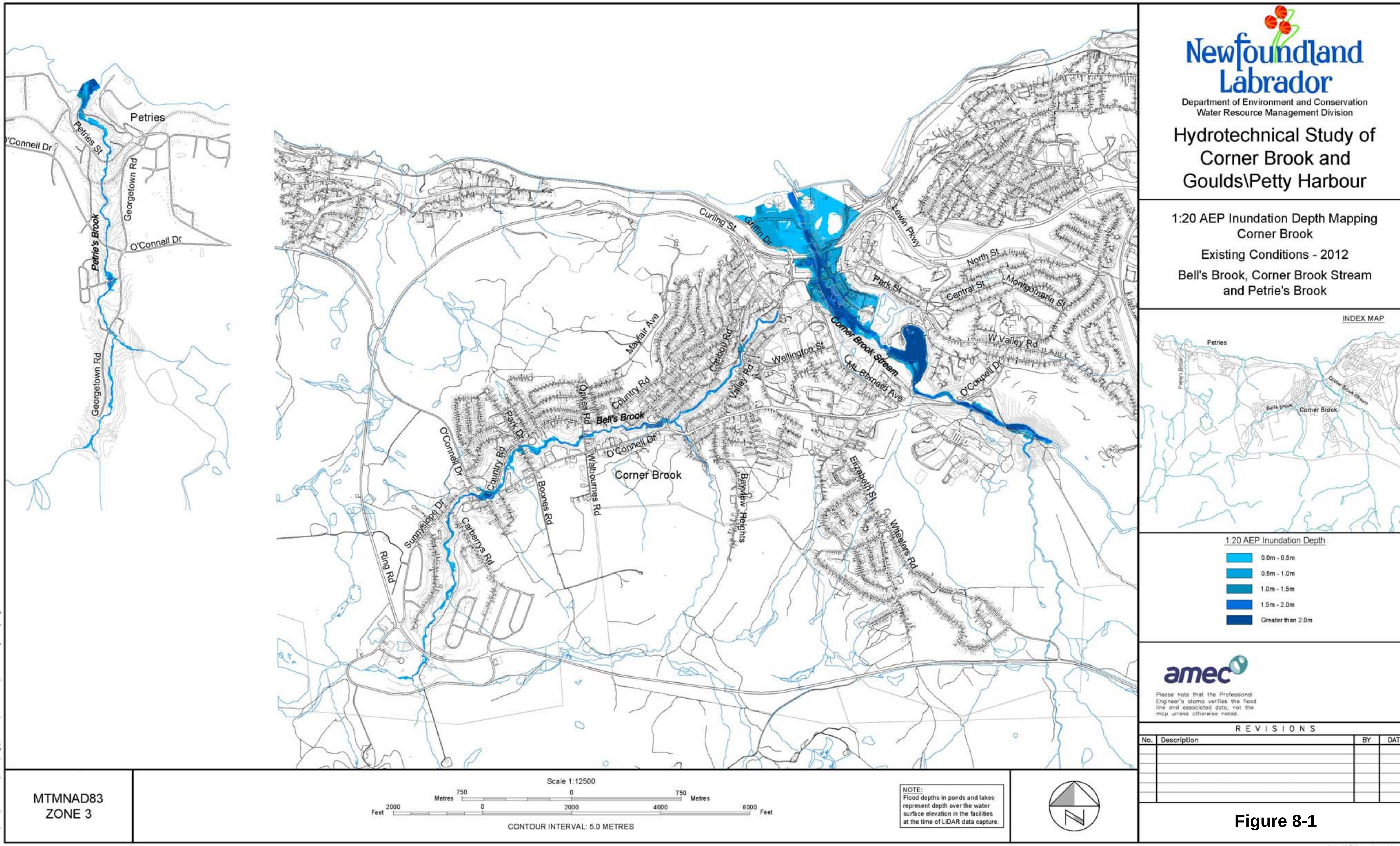
1. Computed Water Surface Elevation by Scenario – colour coding of table cells – clear cells indicate no overtopping, blue cells indicate a water level causing surcharged flow, red cells indicate structure which are overtopped.
2. Overtopping Depth / Freeboard Available - colour coding of table cells – black text entries indicate that freeboard is available above the computed water level, red italic text entries indicate overtopping depth.

Table 8-5: Watercourse Crossings - Overtopping Summary – Petrie's Brook– 1:20 Year AEP Flood

Structure #	Structure Name / Location	Structure Type	Watercourse	HEC-RAS Tributary	HEC-RAS Structure Number	HEC-RAS Reference	Low Chord	Top of Road	Computed Water Surface Elevation by Scenario[1]				*Overtopping Depth* / Freeboard Available[2]			
									Existing	2020	2050	2080	Existing	2020	2050	2080
	20 Year AEP Flood															
1101	Barletts Avenue	Single CSP culvert	Petrie's Brook	PetriesB-M001	110	PetriesB-M001-110	3.3	3.35	3.17	3.35	3.6	3.51	0.18	0.00	*0.25*	*0.16*
1101-1	N/A	Twin CSP culvert	Petrie's Brook	PetriesB-M001	130	PetriesB-M001-130	4.04	4.07	3.51	3.7	4.05	3.88	0.56	0.37	0.02	0.19
1102	Petries Street	Single span bridge	Petrie's Brook	PetriesB-M001	625	PetriesB-M001-625	21.5	22.14	22.05	22.25	22.89	22.51	0.09	*0.11*	*0.75*	*0.37*
1104	O'Conner Drive	Single CSP culvert	Petrie's Brook	PetriesB-M001	1295	PetriesB-M001-1295	75.09	83	75.7	76.13	78.62	76.42	7.30	6.87	4.38	6.58
1105	Candow Drive	Single CSP pipe-arch culvert	Petrie's Brook	PetriesB-M001	1560	PetriesB-M001-1560	84.83	87	87.2	87.25	87.57	87.28	*0.20*	*0.25*	*0.57*	*0.28*
1106	Georgetown Road	Single CSP pipe-arch culvert	Petrie's Brook	PetriesB-M001	1975	PetriesB-M001-1975	99.91	100.64	100.39	100.65	101.16	100.67	0.25	*0.01*	*0.52*	*0.03*
1108	Access Road	Timber bridge structure	Petrie's Brook	PetriesB-M002	2710	PetriesB-M002-2710	122.77	122.97	122.23	122.32	123.64	123.38	0.74	0.65	*0.67*	*0.41*
1109-B	ATV Trail	Single CSP culvert	Petrie's Brook	PetriesB-TR001	80	PetriesB-TR001-80	106.13	106.34	106.82	106.86	106.51	106.89	*0.48*	*0.52*	*0.17*	*0.55*

Notes:

1. Computed Water Surface Elevation by Scenario – colour coding of table cells – clear cells indicate no overtopping, blue cells indicate a water level causing surcharged flow, red cells indicate structure which are overtopped.
2. Overtopping Depth / Freeboard Available - colour coding of table cells – black text entries indicate that freeboard is available above the computed water level, red italic text entries indicate overtopping depth.


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:20 AEP Inundation Depth Mapping
Corner Brook
Existing Conditions - 2012
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
1:20 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
1.5m - 2.0m
Greater than 2.0m
amec
Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
No. Description BY DATE
Figure 8-1
MTMNAD83
ZONE 3
Scale 1:12500
CONTOUR INTERVAL: 5.0 METRES
NOTE:
Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
Petries
Petries St
Petrie's Brook
Georgetown Rd
O'Connell Dr
Curling St
Griffin Dr
Lewin Pkwy
North St
Park St
Central St
Montgomerie St
W Valley Rd
Corner Brook Stream
Mt Bernard Ave
Wellington St
Valley Rd
Caribou Rd
Mayfair Ave
Country Rd
Oakes Rd
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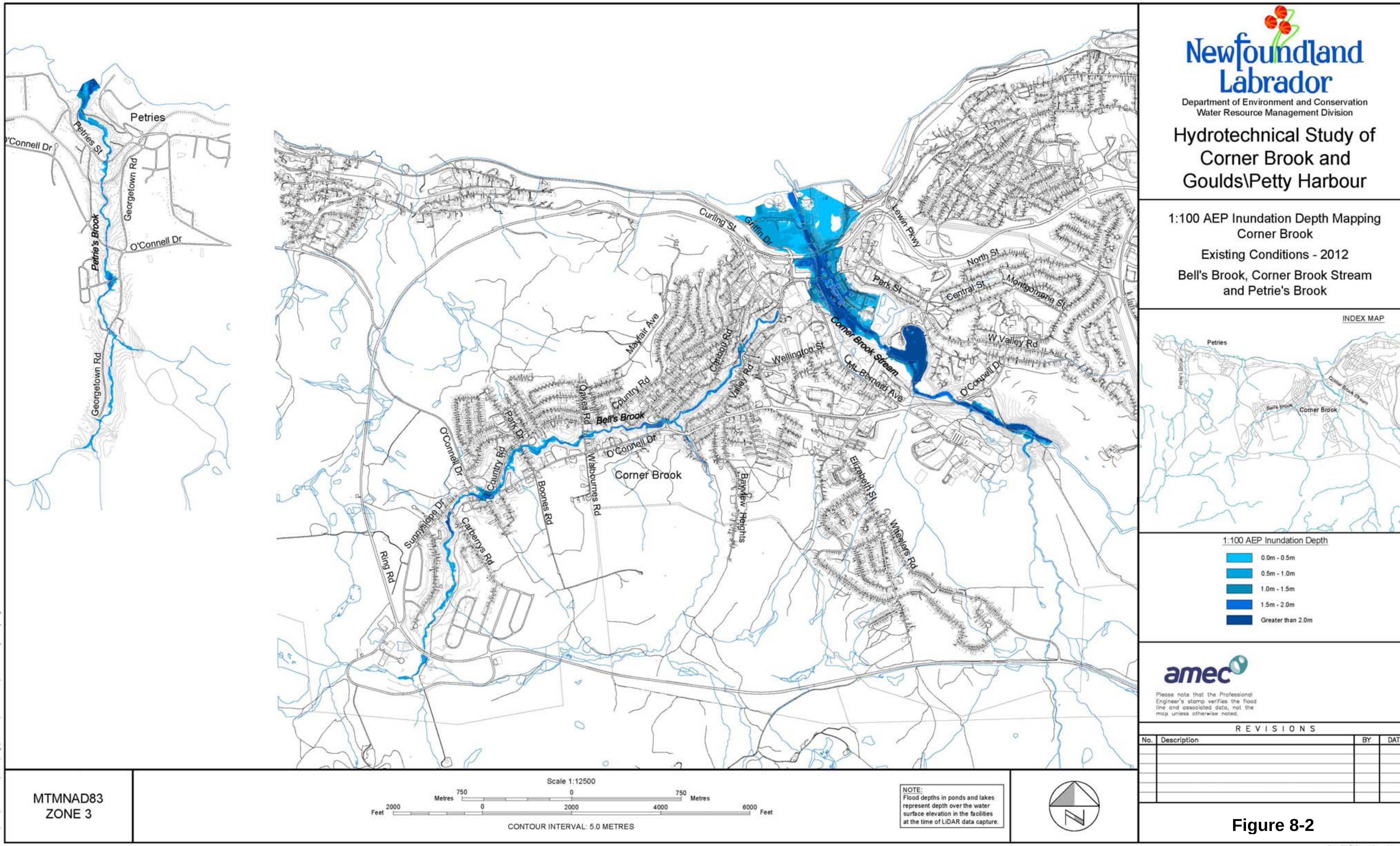
Park Dr
Corner Brook
Walbournes Rd
Boones Rd
Bayview Heights
Elizabeth St
Wheelers Rd
Sunnyslope Dr
Carberrys Rd
Ring Rd


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:100 AEP Inundation Depth Mapping
Corner Brook
Existing Conditions - 2012
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
Petries
Corner Brook
1:100 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
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Greater than 2.0m
amec
Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
No.
Description
BY
DATE
Figure 8-2
MTMNAD83
ZONE 3
Scale 1:12500
CONTOUR INTERVAL: 5.0 METRES
NOTE:
Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
Petries
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Petrie's Brook
Curling St
Griffin Dr
Lewin Pkwy
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Corner Brook Stream
Mt. Bernard Ave
Wellington St
Valley Rd
Caribou Rd
Mayfair Ave
Country Rd
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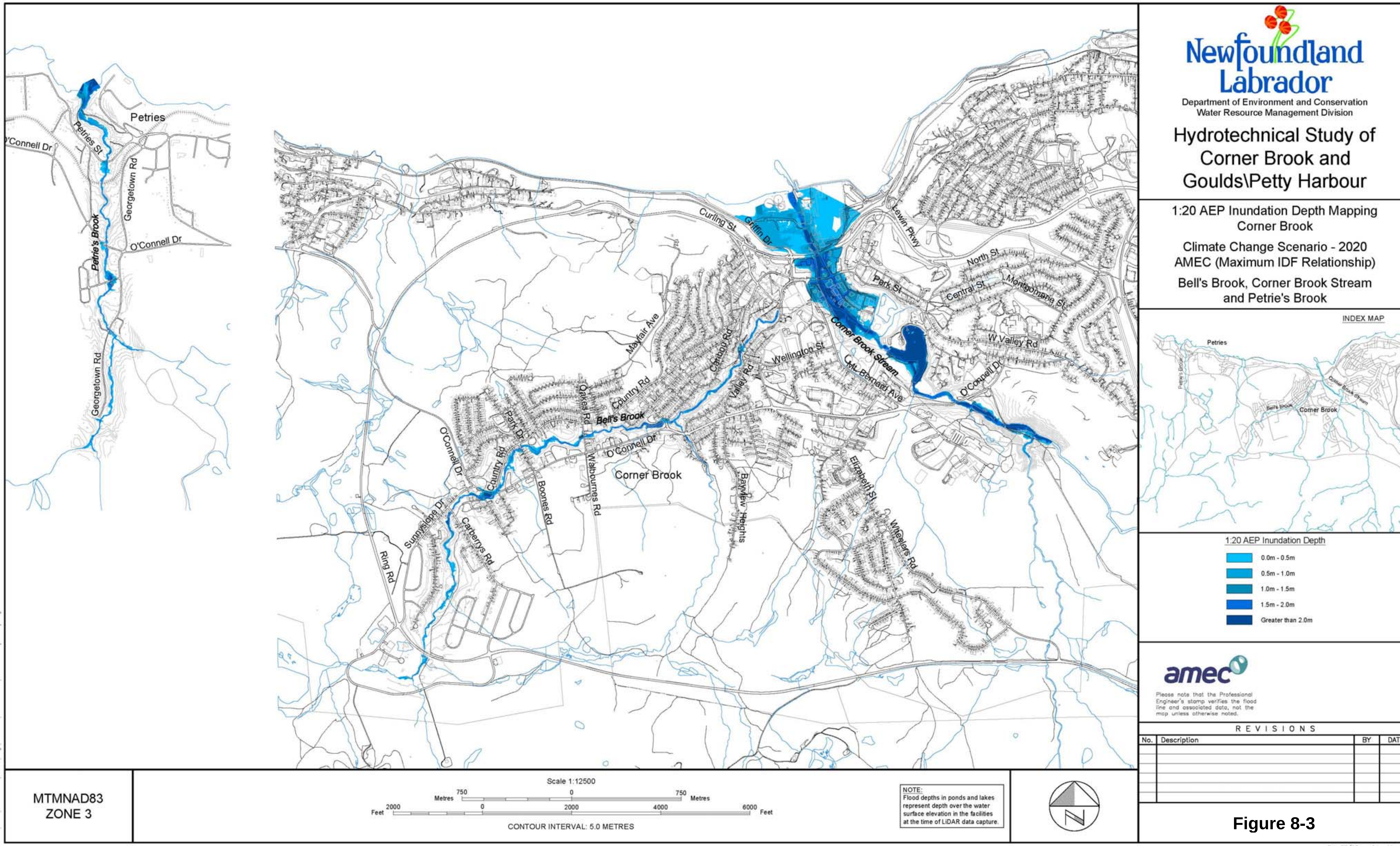
Carberrys Rd
Ring Rd


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:20 AEP Inundation Depth Mapping
Corner Brook
Climate Change Scenario - 2020
AMEC (Maximum IDF Relationship)
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
Petries
Corner Brook
1:20 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
1.5m - 2.0m
Greater than 2.0m
Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
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BY
DATE
Petries
Petries St
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Georgetown Rd
Petrie's Brook
Curling St
Griffin Dr
Lewin Pkwy
North St
Park St
Central St
Montgomerie St
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Corner Brook Stream
Wellington St
Mt Bernard Ave
Mayfair Ave
Caribou Rd
Valley Rd
Country Rd
Oakes Rd
Bell's Brook
Park Dr
Corner Brook
Walbournes Rd
Boones Rd
Bayview Heights
Elizabeth St
Wheelers Rd
Sunnyslope Dr
Carberrys Rd
Ring Rd
MTMNAD83
ZONE 3
Scale 1:12500
Metres
Feet
CONTOUR INTERVAL: 5.0 METRES
NOTE: Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
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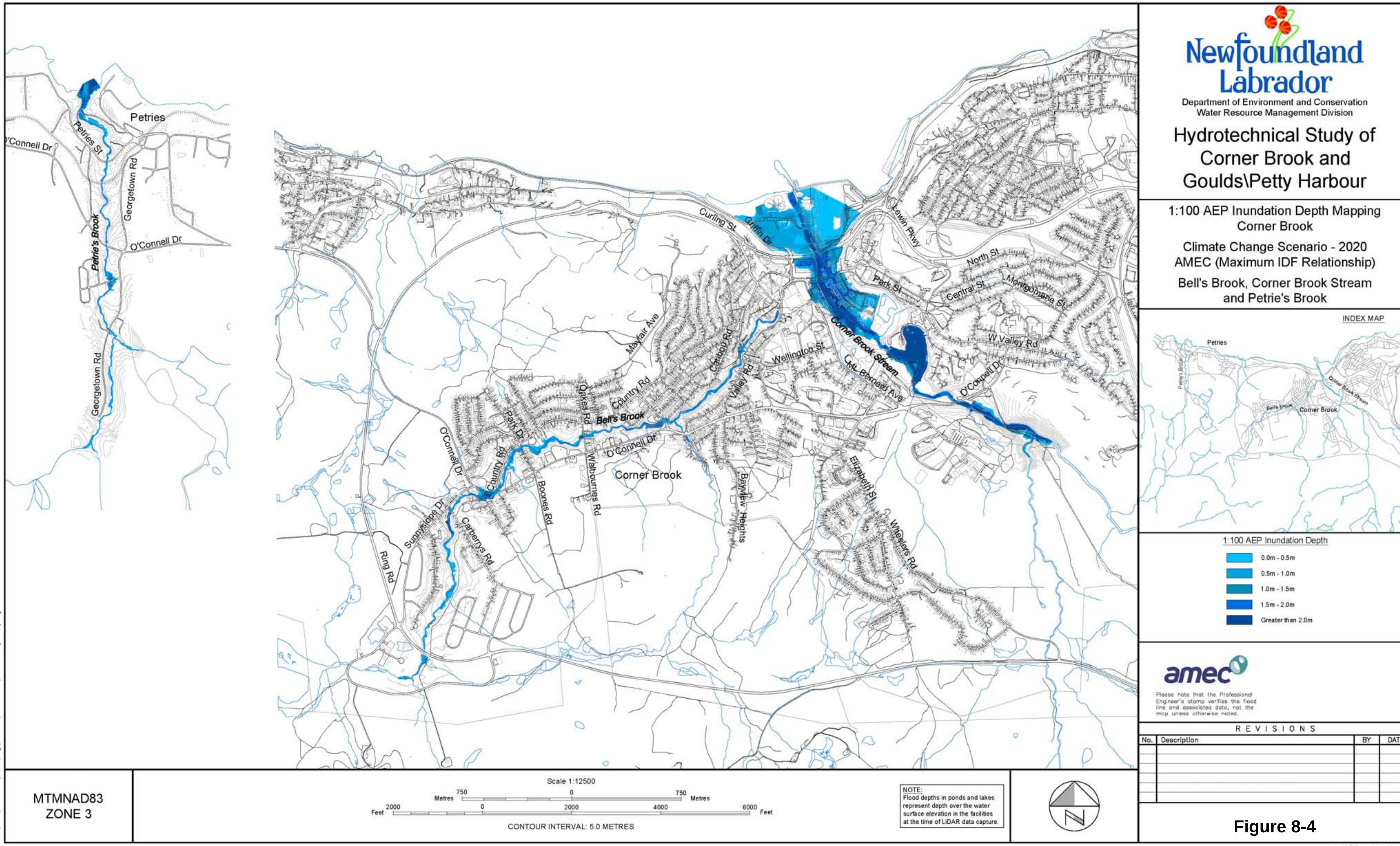
Figure 8-3


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:100 AEP Inundation Depth Mapping
Corner Brook
Climate Change Scenario - 2020
AMEC (Maximum IDF Relationship)
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
1:100 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
1.5m - 2.0m
Greater than 2.0m
Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
No. Description BY DATE
MTMNAD83
ZONE 3
Scale 1:12500
CONTOUR INTERVAL: 5.0 METRES
NOTE: Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
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Georgetown Rd
O'Connell Dr
Curling St
Griffin Dr
Lewin Pkwy
North St
Park St
Central St
Montgomerie St
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Corner Brook Stream
Mt Bernard Ave
Wellington St
Valley Rd
Caribou Rd
Mayfair Ave
Country Rd
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Bell's Brook
Park Dr
Walbournes Rd
Boones Rd
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Bayview Heights
Elizabeth St
Wheelers Rd
Sunnyslope Dr
Carberrys Rd
Ring Rd
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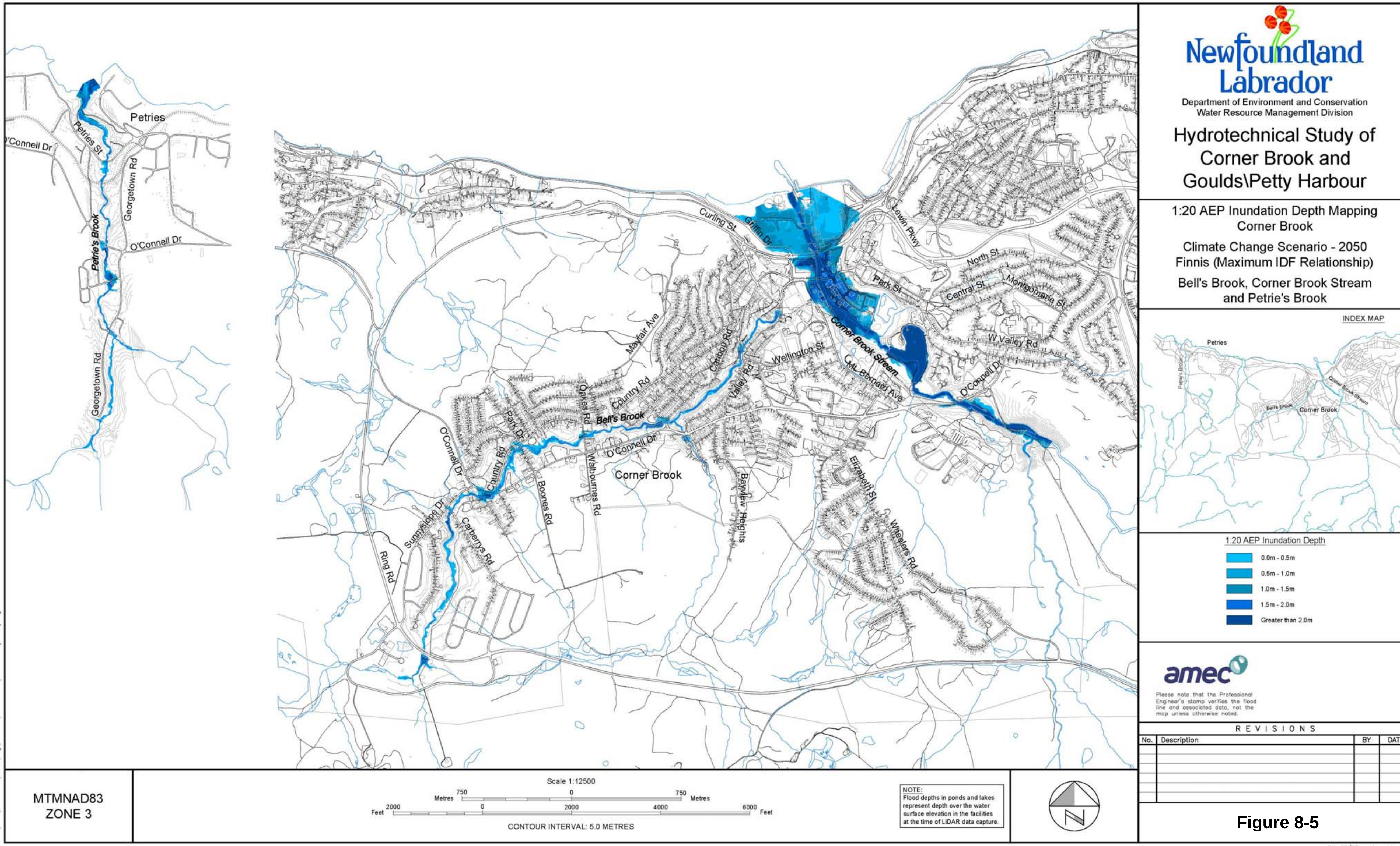
Figure 8-4


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:20 AEP Inundation Depth Mapping
Corner Brook
Climate Change Scenario - 2050
Finnis (Maximum IDF Relationship)
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
Petries
Corner Brook
1:20 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
1.5m - 2.0m
Greater than 2.0m
amec
Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
No.
Description
BY
DATE
Figure 8-5
MTMNAD83
ZONE 3
Scale 1:12500
Metres
Feet
CONTOUR INTERVAL: 5.0 METRES
NOTE:
Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
Petries
Petries St
Petrie's Brook
Georgetown Rd
O'Connell Dr
Curling St
Griffin Dr
Lewin Pkwy
North St
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Central St
Montgomerie St
W Valley Rd
Corner Brook Stream
Wellington St
Valley Rd
Caribou Rd
Mayfair Ave
Country Rd
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Bayview Heights
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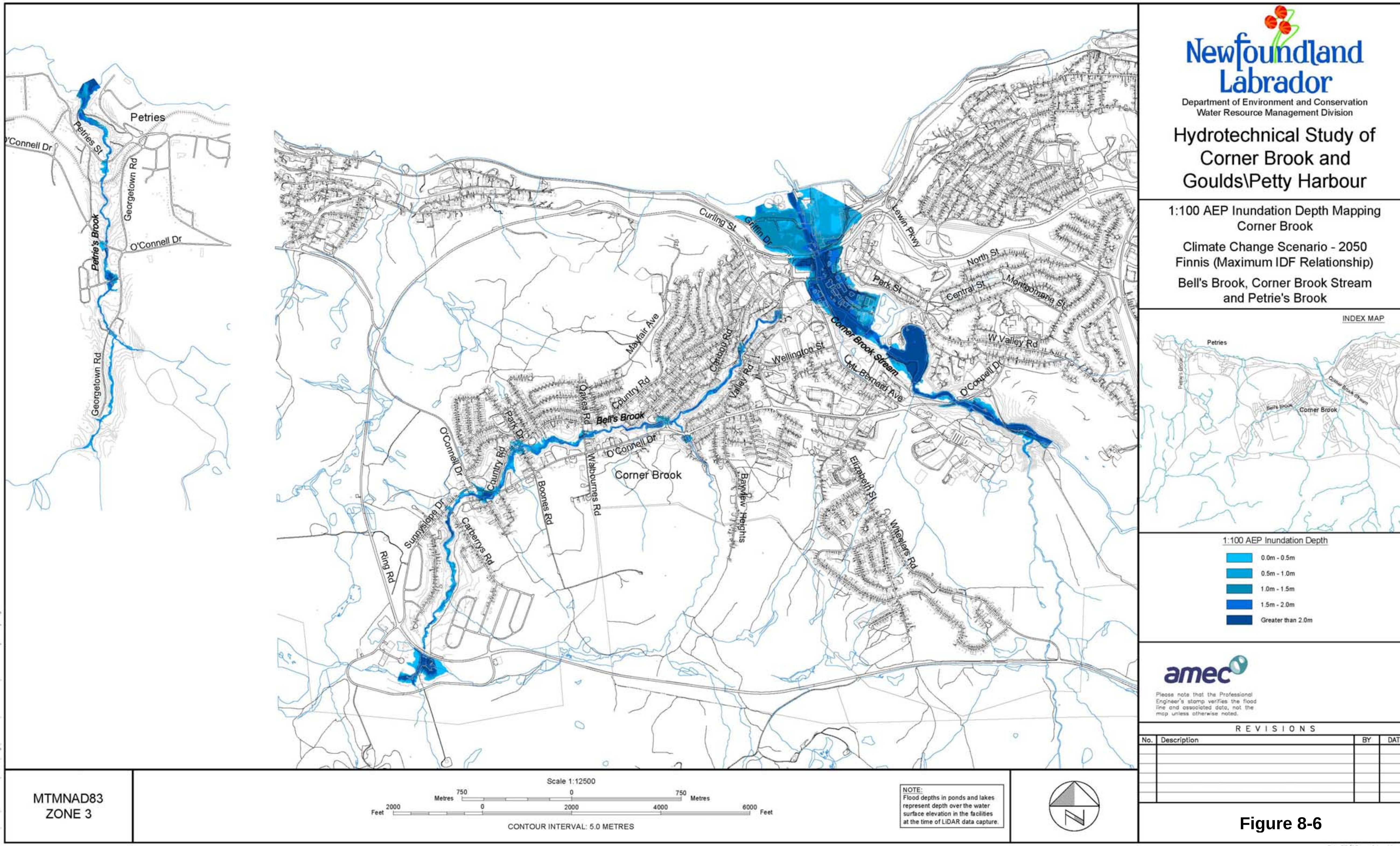
Sunnyslope Dr
Ring Rd


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:100 AEP Inundation Depth Mapping
Corner Brook
Climate Change Scenario - 2050
Finnis (Maximum IDF Relationship)
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
1:100 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
1.5m - 2.0m
Greater than 2.0m
Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
No. Description BY DATE
MTMNAD83
ZONE 3
Scale 1:12500
CONTOUR INTERVAL: 5.0 METRES
NOTE: Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
Petries
Petries St
Petrie's Brook
Georgetown Rd
O'Connell Dr
Corner Brook
Corner Brook Stream
Bell's Brook
Curling St
Griffin Dr
Lewin Pkwy
North St
Park St
Central St
Montgomerie St
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Wellington St
Mt Bernard Ave
Valley Rd
Caribou Rd
Mayfair Ave
Country Rd
Oakes Rd
Park Dr
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Bayview Heights
Elizabeth St
Wheelers Rd
Sunnyslope Dr
Carberrys Rd
Ring Rd
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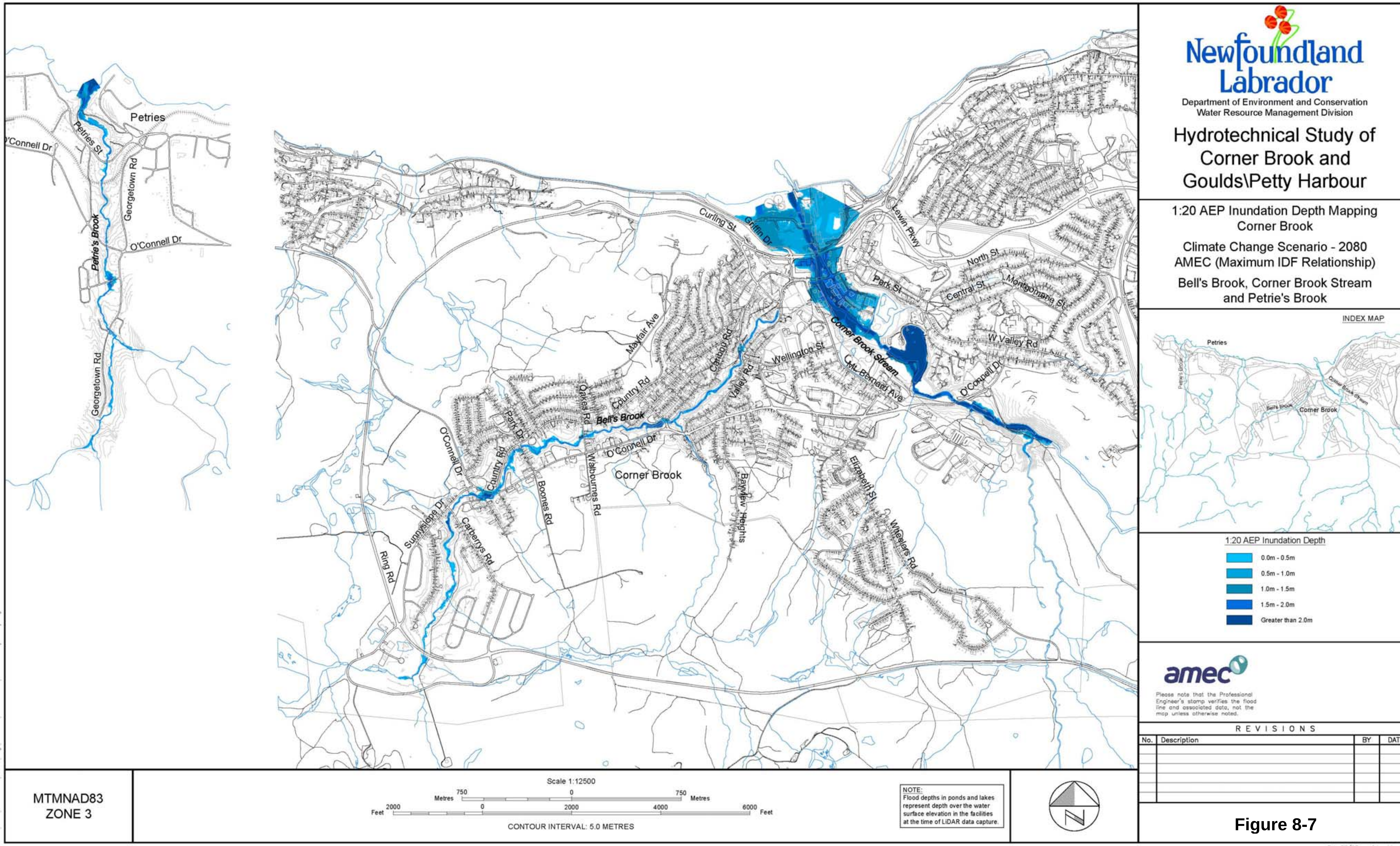
Figure 8-6


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:20 AEP Inundation Depth Mapping
Corner Brook
Climate Change Scenario - 2080
AMEC (Maximum IDF Relationship)
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
1:20 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
1.5m - 2.0m
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Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
No.
Description
BY
DATE
MTMNAD83
ZONE 3
Scale 1:12500
CONTOUR INTERVAL: 5.0 METRES
NOTE: Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
Petries
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Mayfair Ave
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Valley Rd
Oakes Rd
Bell's Brook
Park Dr
Walbournes Rd
Corner Brook
Boones Rd
Bayview Heights
Elizabeth St
Wheelers Rd
Sunnyslope Dr
Carberrys Rd
Ring Rd
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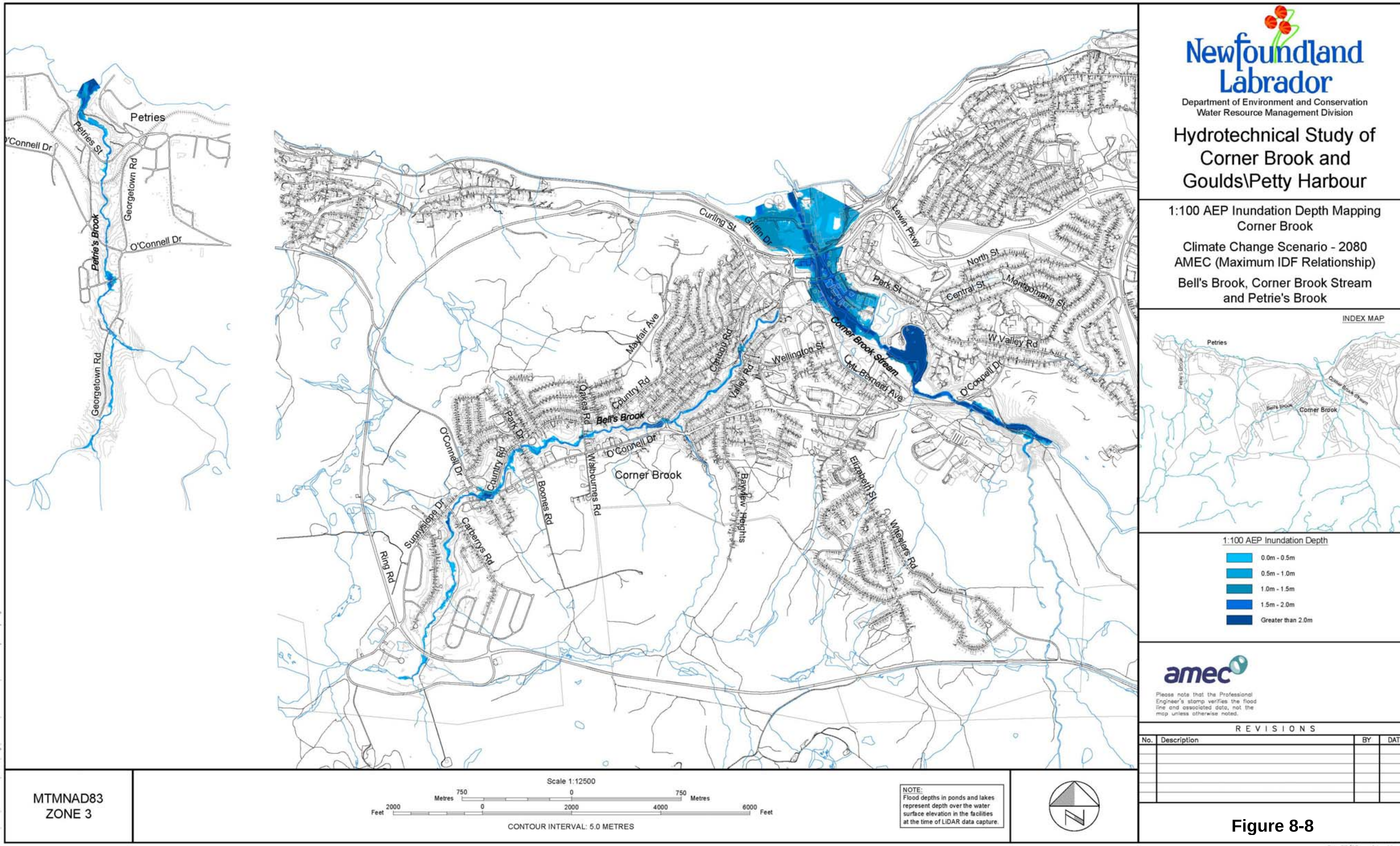
Figure 8-7


Newfoundland Labrador
Department of Environment and Conservation
Water Resource Management Division
Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour
1:100 AEP Inundation Depth Mapping
Corner Brook
Climate Change Scenario - 2080
AMEC (Maximum IDF Relationship)
Bell's Brook, Corner Brook Stream and Petrie's Brook
INDEX MAP
1:100 AEP Inundation Depth
0.0m - 0.5m
0.5m - 1.0m
1.0m - 1.5m
1.5m - 2.0m
Greater than 2.0m
amec
Please note that the Professional Engineer's stamp verifies the flood line and associated data, not the map unless otherwise noted.
REVISIONS
No.
Description
BY
DATE
Figure 8-8
MTMNAD83
ZONE 3
Scale 1:12500
CONTOUR INTERVAL: 5.0 METRES
NOTE:
Flood depths in ponds and lakes represent depth over the water surface elevation in the facilities at the time of LiDAR data capture.
Petries
Petries St
Petrie's Brook
Georgetown Rd
O'Connell Dr
Curling St
Griffin Dr
Lewin Pkwy
North St
Park St
Central St
Montgomerie St
W Valley Rd
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Mayfair Ave
Country Rd
Bell's Brook
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Park Dr
Walbournes Rd
Boones Rd
Corner Brook
Bayview Heights
Elizabeth St
Wheelers Rd
Sunnyslope Dr
Carberrys Rd
Ring Rd

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9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Key outcomes of the study are described below:

Background Information

- A review of the Flood Events Inventory identified forty-one (41) flood events in the Corner Brook area including one (1) in the Petrie's Brook area. Floods events have occurred in all seasons of the year. (14 in the period Jan/Feb/Mar; 3 in the period Apr/May/Jun; 9 in the period Jul/Aug/Sep; and 15 in the period Oct/Nov/Dec). There is only one documented flood event where ice jamming was deemed the primary cause.
- No previous flood or hydrotechnical studies have been completed for the Corner Brook study area, although, dam safety reporting is available for dams located within the Corner Brook Stream watershed.

Field Program

- Four (4) cross sections along each watercourse were field surveyed for below waterline information.
- It was anticipated that streamflow monitoring would be undertaken by the Water Survey of Canada. The late season start to this project and scheduling issues at Water Survey of Canada did not provide any opportunity for this aspect of the project to be completed in advance of freeze up of watercourses in the project study areas. As such, this task of the project was not completed and this limited the data available to this project for calibration and validation.
- A high-resolution LiDAR DTM of the entire Corner Brook Stream and Petrie's Brook watersheds was collected in November and December of 2011
- The field survey for Corner Brook Stream included thirty-one (31) structures and for Petrie's Brook included eight (8) structures.
- The Corner Brook Stream watershed is influenced by four (4) dams.

Hydrologic Assessment

- The 1:20 year and 1:100 year AEP streamflows were estimated for the subject watersheds, namely: Corner Brook Stream and Petrie's Brook, using both statistical and deterministic methodologies. Comparative assessment of the flow estimates over the range of methodologies concluded that the deterministic model results provided a good estimate of streamflow for these watersheds. The methods used in the current study led to comparable flood flow estimates which provide confidence in the results.

- The HEC-GeoHMS and HEC-HMS models developed for this study are included with the Project CD materials attached to this report. These models may be used in the future to evaluate the impact on streamflows resulting from changes to the watershed.

Hydraulic Assessment

- Hydraulic models based on the United States Army Corp of Engineers program HEC-RAS were developed for reaches of Corner Brook Stream and Petrie's Brook covering linear distances of approximately 8.3km (with 352 cross-sections) and 3.3km (with 85 cross-sections), respectively.
- The models were developed based on field surveyed bathymetric data and LiDAR survey conducted in November and December of 2011. Field survey of water levels specifically to form a database upon which the hydraulic model could be calibrated/validated was not completed due to late season project start and freeze up in the study area. As such, the hydraulic model has not been calibrated/validated, however, due care was taken during model development to accurately establish model parameterization.
- The hydraulic model developed for this study was also used to evaluate the potential flood conditions (i.e., resultant water levels) associated with ice jamming events. Petrie's Brook was not deemed to have the potential for ice jam formation. The evaluation along Corner Brook Stream confirmed that along limited reaches of the watercourse, computed water levels associated with ice jams have the potential to generate water levels exceeding 1:100 year AEP open water event levels.
- The HEC-GeoRAS and HEC-RAS model developed for this study is included with the Project CD materials attached to this report. The model may be used in the future to evaluate the impact on water levels resulting from any structural changes to the subject watercourses or floodplain / overbank areas.

Sensitivity Analysis

- It is understood that the hydrologic model is sensitive to a variety of input parameters including rainfall and Curve Number. These parameters have been developed upon the best available information from Environment Canada, as well as, soils and land cover data; the latter reflecting current conditions in late 2011.
- Since all hydraulic input parameters were selected based on reliable background information, it is expected that the error and uncertainty associated with model output is minimal.

Climate Change Assessment

- Climate change analysis was completed using two estimates of future rainfall for three tri-decades (i.e. 2020s, 2050s and 2080s) for both the 1:20 year and 1:100 year AEP flood events. Rainfall estimates of 12 hour and 24 hour duration events were provided to this project by Dr. Joel Finnis of Memorial University for Stephenville for the 2050 period. AMEC, as a component of this project, calculated estimates of future IDF relationships for the three subject periods for the Deer Lake station.

- It is concluded from this assessment that climate change has the potential to increase flood risk in the Corner Brook Area.

Flood Risk Mapping

- All information necessary to complete the Flood Risk Mapping Project for this project was available either through information provided by the WRMD, available background reports, contact with local municipalities or based on the comprehensive field data collection program.
- Flood risk mapping was developed using the LiDAR DTM, 1:2,500 scale community mapping, 1:50,000 topographic maps, and orthophotoimagery. These maps were based on the results of both the hydrologic and hydraulic analysis, and can be used by both the City of Corner Brook for municipal planning and the WRMD for flood risk identification.
- Climate change flood lines were delineated for the most severe climate change precipitation scenarios and mapping was developed using 1:2,500 scale community mapping in combination with the LiDAR DTM. A maximum increase in flooded area of 18% and 24% above the existing conditions scenario was observed for the 1:20 and 1:100 year AEP climate change scenarios, respectively for the Corner Brook Stream (through the study reach). Similarly, a maximum increase in flooded area of 29% and 19% above the existing conditions scenario was observed for the 1:20 year and 1:100 year AEP climate change scenarios, respectively for the Petrie's Brook (through the study reach).

9.2 Recommendations

Key recommendations stemming from the assessments completed for this study are outlined below:

1. It is recommended that the City of Corner Brook adopt the flood lines developed by the current study for its municipal plan and development regulations.
2. It is recommended that the City of Corner Brook and its partners make use of the up-to-date LiDAR topographic data and orthophotography which was collected for this study for relevant municipal initiatives.
3. The Deer Lake and Stephenville Environment Canada stations, relative to the Corner Brook Watersheds, lie about 49 km and 65 km, respectively from the approximate centroids of the watersheds. It is recommended that a rainfall station, local to the Corner Brook Area be installed to support assessment of IDF relationships, watershed analysis and give insight into local meteorological conditions specific to the area.
4. It is recommended that the City of Corner Brook engage in a program to measure water levels at designated watercourse crossing structures during flood events. This will provide a

database of information which could be used to support both hydrologic and hydraulic modelling in the future.

5. It is recommended that a streamflow continuous monitoring station be installed at the outlet of the two study watersheds and Bell's Brook watershed. The information gathered will provide for the development of a database which could be used to support both hydrologic and hydraulic modelling in the future.
6. It is recommended that that HEC-GeoHMS, HEC-HMS, HEC-GeoRAS and HEC-RAS be used in future watershed and flood studies as their use both simplifies the development of deterministic models, as well as provides for the generation of a significant warehouse of information that can be used for other ancillary purposes beyond hydrologic assessments.
7. It is recommended that special consideration be given to higher water levels (than those based on the 1:100 year AEP flow) associated with ice jam conditions in the reach above Glynmill Pond Dam. The ice jamming assessment concluded that water levels associated with ice jamming can exceed those generated by a summertime open water flood event (for both the 1:20 year and 1:100 year AEP conditions). However, there is no evidence of ice jamming as a primary flood causing factor in the Corner Brook area. As such, the community can opt to designate the "ice jam" flood inundated area as a special policy area which will allow the City of Corner Brook to enact specific policies/guidelines regarding development while recognizing the low expectation (base on historical occurrence) of ice jamming.
8. It is recommended that the City of Corner Brook consider stream and/or structure rehabilitation in the areas where water levels exceed the river banks during the 1:100 year AEP flood and spill over land. This will confine extreme flood flows to the river channel and avoid the risk of overland flooding.
9. It is recommended that meteorological conditions in the Corner Brook Area be monitored towards determination of increasing trends in rainfall and generally extreme weather.
10. It is recommended that climate change be integrated into municipal planning in those areas where increasing flood risk is relevant such as infrastructure and emergency planning.
11. It is recommended that this study should be revisited in approximately ten years, after which time additional detail may be available from rainfall and streamflow gauges in the basin.
12. It is recommended that flood studies be initiated in early spring. Starting these projects in early spring will provide the time necessary to better plan field programs that can be conducted over the summer months. This allows surveying to be conducted during low flow conditions and allows for easier and safer access during summer months. Another benefit is that it potentially allows for the collection of more model calibration data. Flow metering (when required) and water surface profiles can be conducted in the spring when river levels are typically high, and also in the late summer when river levels are low. This would help to provide a good range of model calibration and validation data.
13. It is recommended that LiDAR topographic survey and orthophoto databases continue to be used for future flood risk mapping studies as they provide an accurate means of collecting high quality topography information over large areas.

14. It is recommended, although fundamental principles remain the same, that the "1976 Hydrologic and Hydraulic Procedures for Flood Plain Delineation" be updated to reflect current technological and engineering practices in regards to flood plain delineation and development of flood plain mapping.

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