APPENDIX D

LiDAR Validation Report

GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

Climate Change Flood Risk Mapping Study for Placentia, Carbonear, Victoria and Salmon Cove
LiDAR Validation Report

Revision:

Final Rev 0

KGS Group Project:

21-3217-002

Date:

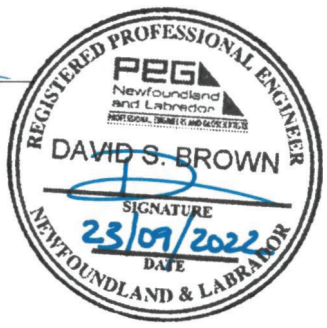
September 30, 2022

Prepared by:

Andrew Weiss, M.Sc., P.Eng.

Approved by:

David S. Brown, M.Eng., P.Eng.



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September 30, 2022

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Department of Environment and Climate Change
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Attention: Dr. Richard Harvey, Ph.D., P.Eng.
Manager – Water Rights, Investigations, and Modelling Section

Re: Climate Change Flood Risk Mapping Study for Placentia, Carbonear, Victoria and Salmon Cove
Draft LiDAR Validation Report - Final Rev 0

Dear Dr. Harvey:

We are pleased to submit an electronic PDF copy of our Final LiDAR Validation Report for the Climate Change Flood Risk Mapping Study for Placentia, Carbonear, Victoria and Salmon Cove project. This report describes our acquisition and review of the LiDAR data, our field survey program, and how the data from that survey program was used to validate the LiDAR data.

Should you have any questions regarding the enclosed deliverable please do not hesitate to contact the undersigned or our Mr. Andrew Weiss.

Yours truly,

David S. Brown, M.Eng., P.Eng.
Water Resources Department Head / Principal

ALW/go

Enclosure

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STATEMENT OF LIMITATIONS AND CONDITIONS

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This report is based on information made available to KGS Group by the Government of Newfoundland and Labrador. Unless stated otherwise, KGS Group has not verified the accuracy, completeness, or validity of such information, makes no representation regarding its accuracy, and hereby disclaims any liability in connection therewith. KGS Group shall not be responsible for conditions/issues it was not authorized or able to investigate or which were beyond the scope of its work. The information and conclusions provided in this report apply only as they existed at the time of KGS Group's work.

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1.0 INTRODUCTION

KGS Group was retained by the Government of Newfoundland and Labrador to develop flood risk maps for the communities of Victoria, Salmon Cove and Carbonear, as well as the communities located within the municipal boundary of Placentia (i.e. Placentia, Jerseyside, Freshwater, Ferndale, Dunville, and Southeast Placentia). The updated flood risk maps were developed considering both the current climate and climate change-affected conditions, as well as both current and anticipated future levels of development within the communities.

To complete the study, high resolution topographic data representative of the above-water ground surface was acquired from Natural Resources Canada (NRCan) via the High Resolution Digital Elevation Model (HRDEM). The HRDEM is derived from Light Detection and Ranging (LiDAR) data and includes both Digital Terrain Models (DTM), which represents the bare ground without any plants and buildings, and Digital Surface Models (DSM), which includes all objects on the ground surface. For this project, the DTM was acquired for use in the development of the models and maps. The LiDAR data that the HRDEM is based on was collected during June and July 2020. However, since the LiDAR data was not collected as part of this study, it was necessary to complete quality control checks on the HRDEM to ensure its suitability and applicability to this study. This was accomplished by comparing HRDEM ground elevations with corresponding ground elevations captured as part of the field survey.

The HRDEM data, field survey program, and quality control checks completed as part of this study are described in the following subsections of this report.

2.0 FIELD SURVEY AND QUALITY CONTROL OF HRDEM

2.1 HRDEM Acquisition

HRDEM data was acquired from NRCan for the Placentia, Carbonear, Salmon Cove and Victoria areas. The HRDEM provided continuous and seamless coverage in Carbonear, Salmon Cove and Victoria, while a separate section provided continuous and seamless coverage in Placentia. The HRDEM has a spatial resolution of 1 m by 1 m, and is provided by NRCan in the UTM NAD83 (CSRS) coordinate system and CGVD2013 vertical datum. For this flood risk mapping study the HRDEM data was reprojected into the NAD83 (CSRS) MTM Zone 1 coordinate system, consistent with project requirements. The HRDEM areas used for the study in Carbonear, Salmon Cove and Victoria is shown on Figure 1, while the area used for Placentia is shown on Figure 2.

FIGURE 1: CARBONEAR AREA WATERSHED DEM

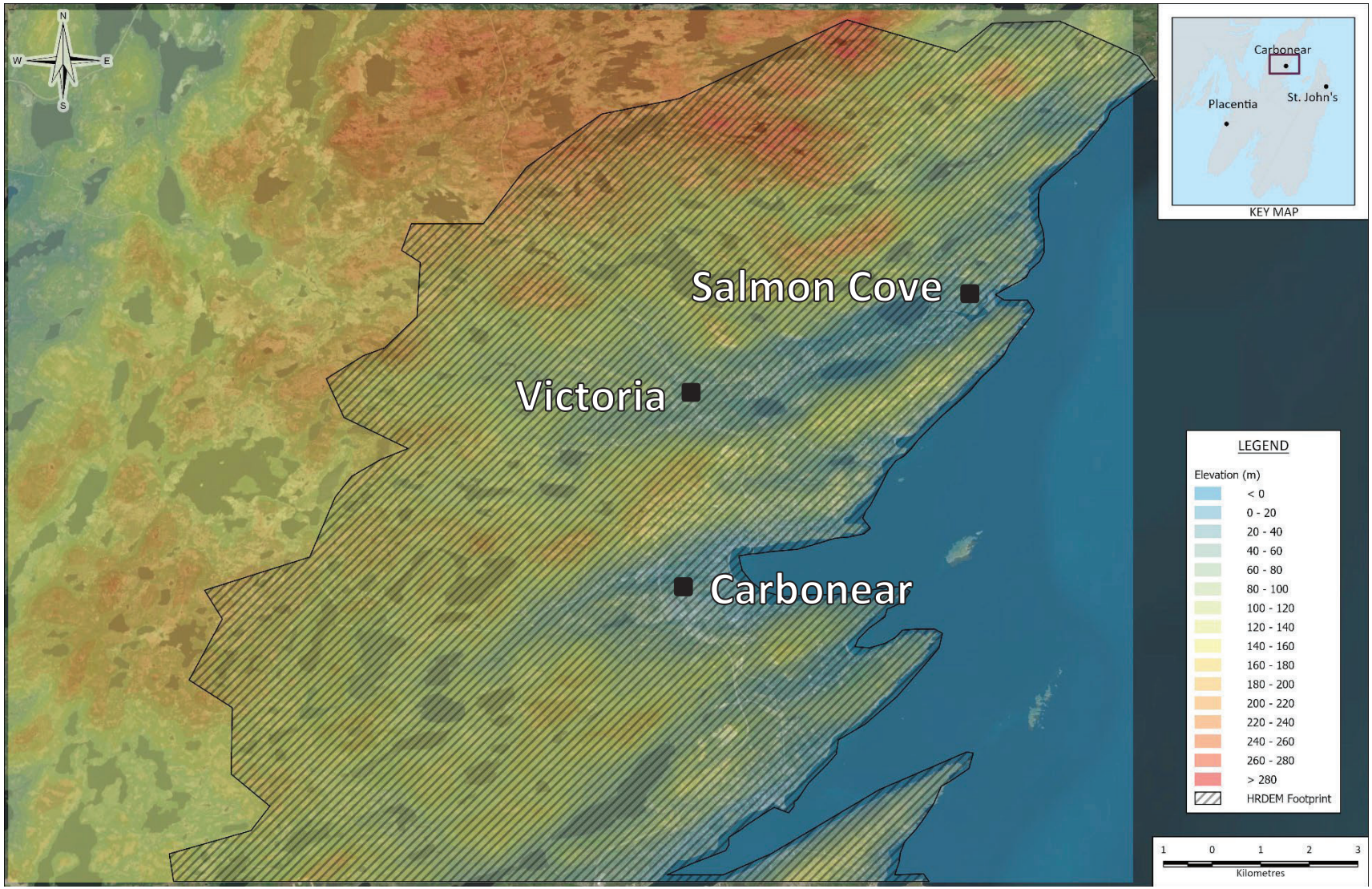
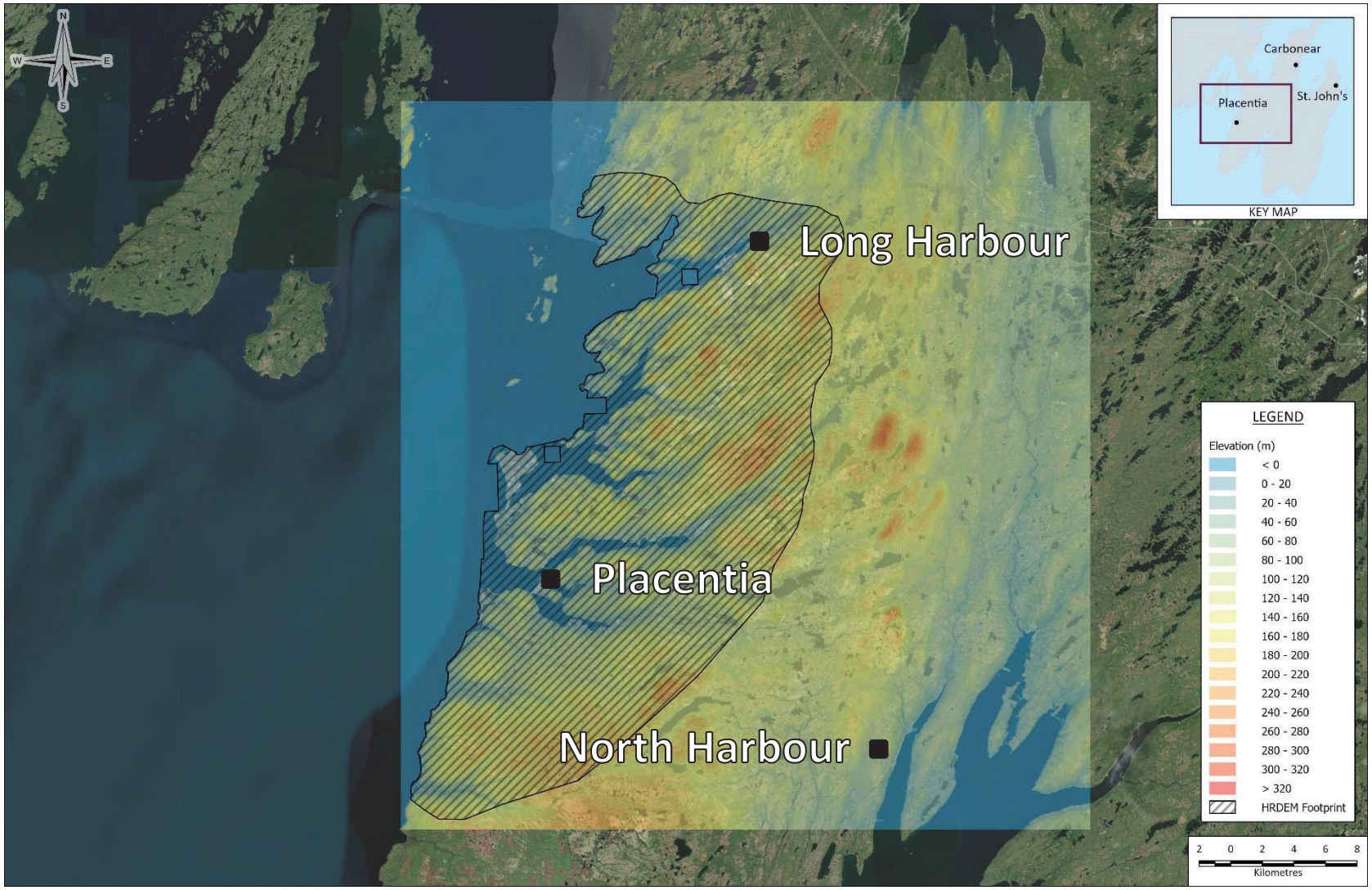


FIGURE 2: PLACENTIA AREA WATERSHED DEM



2.2 Field Survey Overview

An extensive field survey program was completed for this project to measure the ground level of key infrastructure throughout the study area, such as bridges and culverts, and to measure the riverbed elevation along several sections of rivers and creeks considered as part of the study. The field survey was executed by N. E. Parrott Surveys Limited (NEPSL), who were retained by KGS Group to collect and process the field survey data. Five hundred and twenty river cross sections were surveyed. Surveys of one hundred culvert and bridge crossings were completed on the rivers and creeks considered in the study area. Ground elevations were also surveyed throughout the study area to confirm the accuracy of the HRDEM data, and to ensure that the HRDEM data accurately represents the ground elevation throughout the study area. The field survey is described in detail in separate deliverables, specifically our Field Survey Report, and is also summarized in the Final Report for the study.

2.3 Field Survey Projections and Survey Control

The survey control used for this project consisted of provincial monuments and local benchmarks installed by NEPSL. The control established was used to support the bathymetric and topographic survey activities. NEPSL used L1/L2 dual constellation (GPS/ GLONASS) GPS receivers that were setup on the points and logged static data simultaneously. A total of four static occupations were completed. The static data was post processed in the office and referenced to existing 3D monuments in the area. All survey information was processed in 3-degree Modified Transverse Mercator (MTM) Zone 1, North American Datum 1983 (NAD83) Canadian Spatial Reference System (CSRS) projection system and Canadian Geodetic Vertical Datum 2013 (CGVD2013). The published vertical values of the monuments used were listed with the vertical datum CGVD28. Therefore, to coincide with the project requirements, the vertical datum for the points was processed to vertical datum CGVD2013. The absolute confidence levels for the data were 3mm horizontally and 2mm vertically.

Secondary control points included other provincial monuments that were not occupied for static logs. They were established and used as base reference points and helped reduce baseline distances between base and rover receivers.

Tertiary control points consisted of temporary installations of 12” spikes or 20” rebar. These were used when there were no permanent monuments near a given survey area. A total of eight tertiary points were installed for this project. Check shots were completed daily to ensure that both base and rover setups were correct and that the base was broadcasting the correct values.

A list of control points used to complete the topographic and bathymetric surveys are summarized in Table 1 and Table 2, while the locations of the Provincial control points used for this study are shown on Figure 3 and Figure 4.

TABLE 1: PROVINCIAL CONTROL POINTS

MONUMENT NAME	NORTHING (m)	EASTING (m)	ELEVATION (m)	DESCRIPTION	CLASS	SITE
82G2363	5236764.378	234792.206	3.522	C. CYLINDER	PRIMARY	PLACENTIA
82G2378	5234806.239	232039.480	0.932	C. CYLINDER	SECONDARY	PLACENTIA
81G2770	5290817.511	287967.858	122.549	BRASS PLUG	PRIMARY	CARBONEAR
82G2351	5237142.425	238449.552	14.953	C. CYLINDER	SECONDARY	PLACENTIA
82G2384	5232619.939	231481.820	20.948	BRASS PLUG	SECONDARY	PLACENTIA
82G2388	5231258.444	235724.923	6.370	C. CYLINDER	SECONDARY	PLACENTIA
81G2028	5287617.873	287175.486	21.652	BRASS PLUG	PRIMARY	CARBONEAR
81G2293	5293816.230	292052.119	27.880	BRASS PLUG	PRIMARY	CARBONEAR

TABLE 2: ADDITIONAL CONTROL POINTS

MONUMENT NAME	NORTHING (m)	EASTING (m)	ELEVATION (m)	DESCRIPTION	CLASS	SITE
NE ARM 1	5237386.605	241276.915	6.322	VARIES*	TERTIARY	PLACENTIA
SE ARM 1	5231764.900	233847.276	7.988	VARIES*	TERTIARY	PLACENTIA
SE ARM 2	5231554.232	236883.629	31.710	VARIES*	TERTIARY	PLACENTIA
FERRY 1	5238563.288	229579.801	12.960	VARIES*	TERTIARY	PLACENTIA
FERRY 2	5238760.045	230331.985	6.988	VARIES*	TERTIARY	PLACENTIA
PLACENTIA 1	5239609.578	239296.462	85.862	VARIES*	TERTIARY	PLACENTIA
PLACENTIA 2	5241242.624	240316.208	45.925	VARIES*	TERTIARY	PLACENTIA
CARBONEAR	5289638.370	289125.207	83.713	VARIES*	TERTIARY	CARBONEAR
SALMON COVE	5293060.174	290352.314	23.410	VARIES*	TERTIARY	CARBONEAR
VICTORIA	5292145.024	286375.161	64.355	VARIES*	TERTIARY	CARBONEAR

FIGURE 3: CARBONEAR, SALMON COVE AND VICTORIA CONTROL POINTS

FIGURE 4: PLACENTIA CONTROL POINTS

2.4 Topographic Survey

All topographic surveying was completed using Global Positioning System (GPS) Real Time Kinematics (RTK) style surveying. Stop and go kinematic occupations of three or more epochs was used for the topographic survey. Positions were collected by using real time correction with UHF radio links that communicate between the rover and the base. Daily check shots were completed on known control points at the beginning and end of each setup to ensure accuracy and reproducibility of survey data and again at the end of the day. Survey data was uploaded daily, reviewed for quality purposes, and used to determine whether there were any areas that required infill. The accuracy of all topographic points was within +/- 1.0 cm horizontal and +/- 2.0 cm vertically.

Topographic survey points included:

- Ground elevations on riverbanks at cross section locations,
- Top of bank elevations at cross section locations,
- Spot ground elevations near culvert and bridge crossings,
- Shore elevations at the edges of bathymetric transects on the Northeast Arm, Southeast Arm, and Swan Arm in Placentia, and
- Road crest, edge of road and shoulder elevations near and above culvert and bridge crossings.

In total, 520 river cross sections were surveyed throughout Carbonear, Placentia, Salmon Cove, and Victoria.

To supplement existing coastal bathymetric data, bathymetric cross sections were collected in Placentia. A total of 78 bathymetric transects were completed in Placentia along the Northeast Arm, Swan Arm, and Southeast Arm. Bathymetric data was not acquired along the western portion of Northeast Arm or into Placentia Bay, as existing bathymetric data was available from the Canadian Hydrographic Service (CHS). The bathymetric survey data points were collected at a range of every 1 m to 10 m along each transect lines using a single beam dual frequency Seafloor Hydrolite – TM Echosounder. This device can collect water depths from 0.5 m to 200 m. The sonar unit was mounted to a boat and coupled to a survey grade GPS receiver. All sonar readings were collected in a continuous manner with accurate RTK positions. When possible and safe to do so, additional RTK/GPS shots were captured along the shoreline and up the banks on both sides of the arms. Spot checks were also completed along the breakwater and sea wall in Placentia.

The topographic survey data collected in Placentia, Carbonear, Salmon Cove, and Victoria are shown on Figure 5 and Figure 6.

FIGURE 5: PLACENTIA BATHYMETRIC SURVEY

FIGURE 6: CARBONEAR, SALMON COVE AND VICTORIA SURVEY

2.5 HRDEM Quality Control

The GPS/RTK survey data that was collected by NEPSL was used by KGS Group to validate and confirm the accuracy of the HRDEM acquired from NRCan. This data included surveyed tops of roads, flat areas, and locations with varying heights of vegetation. The survey data was then compared to the HRDEM at the same location to ascertain the vertical accuracy of the HRDEM. Comparisons were made at 1,475 locations in Carbonear, Salmon Cove and Victoria, with 36 locations located on firm or flat ground (i.e. at bridge and culvert crossings) and the remaining 1,439 located in vegetated areas (i.e. at surveyed cross section locations). In Placentia, comparisons were made at 1,149 locations, with 58 of those located on flat and firm ground and the remaining 1,091 located in vegetated areas. The elevation comparisons between the surveyed ground elevations and HRDEM elevations are summarized in Table 3.

TABLE 3: HRDEM SURFACE STATISTICS

Monument Name	Count	Minimum Difference (m)	Maximum Difference (m)	Sum of Differences (m)	Mean Difference (m)	Standard Deviation of Differences (m)
Carbonear Firm/Flat Ground Stats.	36	-0.195	0.199	0.804	0.022	0.081
Carbonear Remaining Ground Stats.	1439	-0.483	0.493	-14.841	-0.010	0.133
Placentia Firm/Flat Ground Stats.	58	-0.160	0.187	-0.185	-0.003	0.068
Placentia Remaining Ground Stats.	1091	-0.499	0.479	-49.099	-0.045	0.169

The comparisons showed that differences between the surveyed ground elevations and HRDEM elevations at the same location fell within acceptable tolerances of 0.2 m for hard surface returns and 0.5 m for the remaining data set respectively. The HRDEM was thus considered to be accurate and acceptable for use in the flood risk mapping study.

3.0 CONCLUSIONS

The following conclusions can be made regarding the LiDAR validation completed as part of this project:

- HRDEM data was acquired for the Towns of Placentia, Carbonear, Salmon Cove and Victoria. However, it was necessary to complete quality control checks on the HRDEM to ensure that it was representative and appropriate for use in the study.
- An extensive field survey program was completed throughout Placentia, Carbonear, Salmon Cove and Victoria in support of subsequent hydraulic modelling, and the resulting field survey points were used to validate the HRDEM data.
- Comparisons were made at 1,475 locations in Carbonear, Salmon Cove and Victoria, with 36 locations located on firm or flat ground and the remaining 1,439 located in vegetated areas. The comparisons showed that differences between the surveyed ground elevations and HRDEM elevations at the same location fell within acceptable tolerances of 0.2 m for hard surface returns and 0.5 m vegetated areas.
- In Placentia, comparisons were made at 1,149 locations, with 58 of those located on flat and firm ground and the remaining 1,091 located in vegetated areas. The differences between the surveyed ground elevations and HRDEM elevations were within acceptable tolerances of 0.2 m for hard surface returns and 0.5 m for vegetated areas.
- The HRDEM was thus considered to be accurate and acceptable for use in the flood risk mapping study.

APPENDIX E

Remote Sensing Report

GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

Climate Change Flood Risk Mapping Study for Placentia, Carbonear, Victoria and Salmon Cove
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Approved by:

David S. Brown, M.Eng., P.Eng.

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Attention: Dr. Richard Harvey, Ph.D., P.Eng.
Manager – Water Rights, Investigations, and Modelling Section

Re: Climate Change Flood Risk Mapping Study for Placentia, Carbonear, Victoria and Salmon Cove
Draft Remote Sensing Report - Final Rev 0

Dear Dr. Harvey:

We are pleased to submit an electronic PDF copy of our Final Remote Sensing Report for the Climate Change Flood Risk Mapping Study for Placentia, Carbonear, Victoria and Salmon Cove project. This report describes the data acquisition and processing that was implemented to develop the land use and soil classification maps, as well as the SCS Curve Number maps.

Should you have any questions regarding the enclosed deliverable please do not hesitate to contact the undersigned or our Mr. Andrew Weiss.

Yours truly,

David S. Brown, M.Eng., P.Eng.
Water Resources Department Head / Principal

ALW/go

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1.0 INTRODUCTION

KGS Group was retained by the Government of Newfoundland and Labrador to develop flood risk maps for the communities of Victoria, Salmon Cove and Carbonear, as well as the communities located within the municipal boundary of Placentia (i.e. Placentia, Jerseyside, Freshwater, Ferndale, Dunville, and Southeast Placentia). The updated flood risk maps were developed considering both the current climate and climate change-affected conditions, as well as both current and anticipated future levels of development within the communities.

As part of the study, hydrologic analyses were completed to define the flood flows that were considered in the mapping. As part of the hydrologic analyses completed for the study, it was necessary to develop Soil Conservation Service (SCS) Curve Number maps for the communities. The SCS Curve Number, which represents how rainfall either infiltrates into the ground or is converted to runoff, is a key parameter that was considered in the hydrologic modelling completed as part of this project using the U.S. Army Corps of Engineer's HEC-HMS software. SCS Curve Number maps were defined based on a combination of land use classification mapping, which differentiates between different land types (i.e. forests, grasslands, lakes, etc.) and soil classification mapping, which in part describes how effectively the soils drains water that falls on the land. The SCS Curve Number maps that were developed based on the land use and soil classification maps served as initial estimates of the SCS Curve numbers in the HEC-HMS models, which were then subsequently adjusted as part of the model calibration.

The acquisition and processing of the satellite imagery to define land use classification, the acquisition and review of the soil classification data, and the synthesis of the land use and soil classification data to define SCS Curve Number maps are described in the following subsections of this report.

2.0 REMOTE SENSING AND LAND USE CLASSIFICATION

2.1 Acquisition and Processing of Remote Sensing Imagery

SPOT-6 satellite imagery was downloaded from the European Space Agency (ESA), specifically captures of the Carbonear, Salmon Cove and Victoria area completed on August 10, 2020, and the Placentia area capture completed on August 16, 2020. The SPOT-6 imagery target acquisition area extended 1.5 km beyond the drainage basins defined for the study to ensure that no gaps would be present for the development of the Curve Number maps.

The SPOT-6 satellite captures a 60 km swath per suite of sensors. Using both identical suites of sensors, the SPOT-6 satellite is capable of capturing data at up to 1.5 m spatial resolution for panchromatic and multispectral imagery. The SPOT-6 satellite completes an orbit approximately every 98 m, resulting in a repeating capture cycle every 26 days. The spectral bands that SPOT-6 captures are summarized in Table 1.

TABLE 1: SPOT-6 BAND WAVELENGTHS

Band	Wavelength (µm)
Panchromatic	0.45 – 0.75
Blue	0.45 – 0.52
Green	0.53 – 0.60
Red	0.62 – 0.69
Near Infrared	0.76 – 0.89

Considerable processing was completed by ESA to correct radiometric and sensor distortions, including optical and instrument distortions and atmospheric effects. Since each of the Carbonear, Salmon Cove, Victoria and Placentia area captures were completed during one pass, corrections were not required for temporal effects that would otherwise be required if captures from separate dates were to be used.

The SPOT-6 imagery was provided to KGS Group as two tiles covering the acquisition areas (i.e. one tile covering Placentia, and one tile covering Carbonear, Salmon Cove and Victoria). A review was completed to ensure that the SPOT-6 imagery aligned well with the Digital Elevation Model (DEM) that was used in the study, as well as the orthoimagery data. The review included a visual comparison of the orthoimagery and SPOT-6 satellite imagery, as well as visual comparisons of topographic features that were apparent in both the SPOT-6 imagery and DEM, such as roads and waterbodies. The SPOT-6 satellite imagery was found to be in good agreement with the DEM and orthoimagery.

2.2 Land Use Classification

Land use classification of the SPOT-6 imagery was completed using the Land Class Wizard tool in ArcGIS Pro developed by Esri. The Land Class Wizard tool automatically splits the SPOT-6 imagery into a large number of discrete classification polygons. These classification polygons are then manually assigned to the land use classes defined by WRMD in the terms of reference, which are summarized in Table 2.

TABLE 2: WRMD LAND USE CLASSES

WRMD Land Cover	Examples
Forest	Forests
Residential	Small homes and subdivisions.
Commercial	Large buildings and parking lots, schools, shopping malls, industries, plants, etc.
Deforested areas	Patches of treed and un-treed areas adjacent to forest roads, areas with open green fields in forested zones.
Barren land	Non-vegetated areas.

Fields/pastures/open spaces	Agricultural areas, farmer fields; parks, cemeteries, golf courses, etc. within urban areas, low lying grass areas near airports, vegetated areas.
Swamps/wetlands/waterbodies	Swamps, wetlands, lakes, ponds, and rivers
Unclassified	No data, cloud, shadow, snow/ice

The resulting land use classification map for Carbonear, Victoria and Salmon Cove are shown on Figure 1, while the classification map for Placentia is shown on Figure 2.

FIGURE 1: CARBONEAR, SALMON COVE AND VICTORIA LAND USE CLASSIFICATION MAP

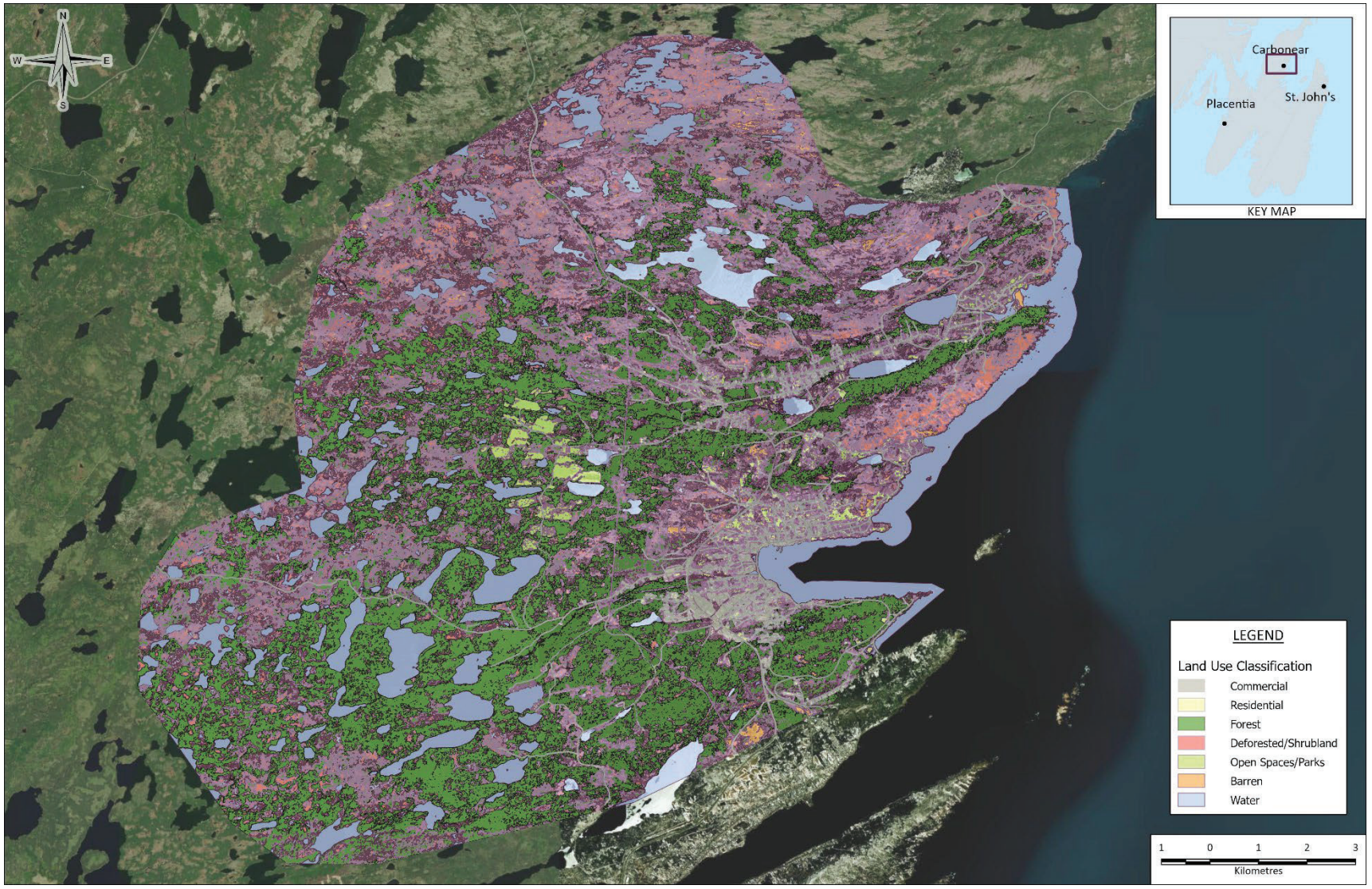
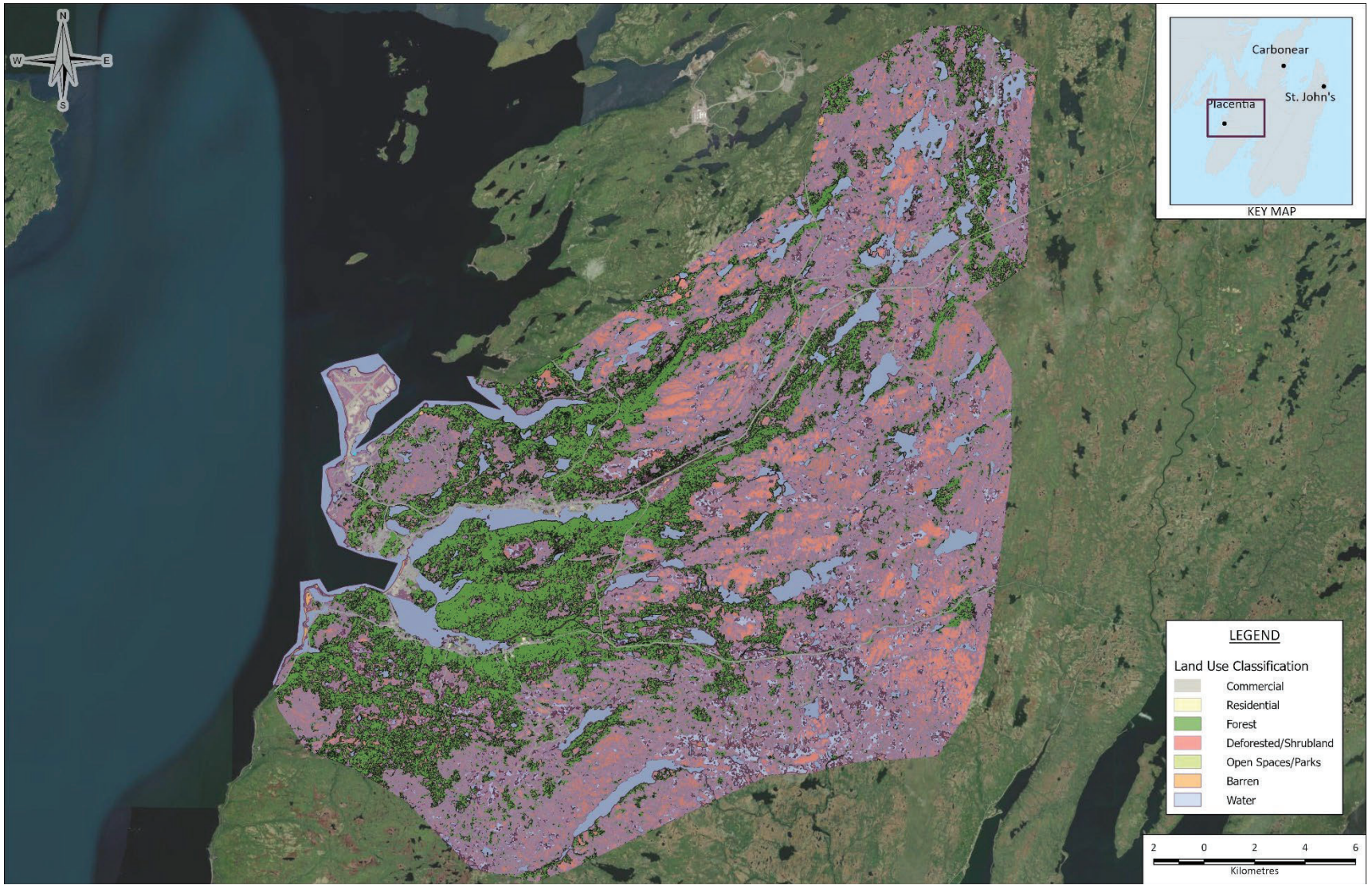


FIGURE 2: PLACENTIA LAND USE CLASSIFICATION MAP



2.3 Soils Classification

Available soil classification data included in the National Soils Database (NSDB) Version 2 were acquired for the study areas, matching the extents of the SPOT-6 satellite imagery. The NSDB data was processed to convert the soil classification scheme from the NSDB scheme to the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) soil classes. The soil classification schemes in both the NSDB and NRCS represent how each soil classification drains water, ranging from very rapidly to very poorly. The conversion of the NSDB soil classes to NRCS soil classes enabled the combination of the soil classification data with the land use classification data to develop SCS Curve Number mapping data for use in the hydrologic modelling. The conversion of NSDB soil classes to NRCS soil classes are summarized in Table 3.

TABLE 3: CORRELATION OF NSDB TO NRCS SOIL CLASSES

NSDB Soil Class	NRCS Soil Class
Very Rapidly	A
Rapidly	A
Well	A
Moderately Well	A
Imperfectly	B
Poorly	C
Very Poorly	D

The resulting soil classification map for Carbonear, Victoria and Salmon Cove is shown on Figure 3, while the soil classification map for Placentia is shown on Figure 4.

FIGURE 3: CARBONEAR, SALMON COVE AND VICTORIA SOIL CLASSIFICATION MAP

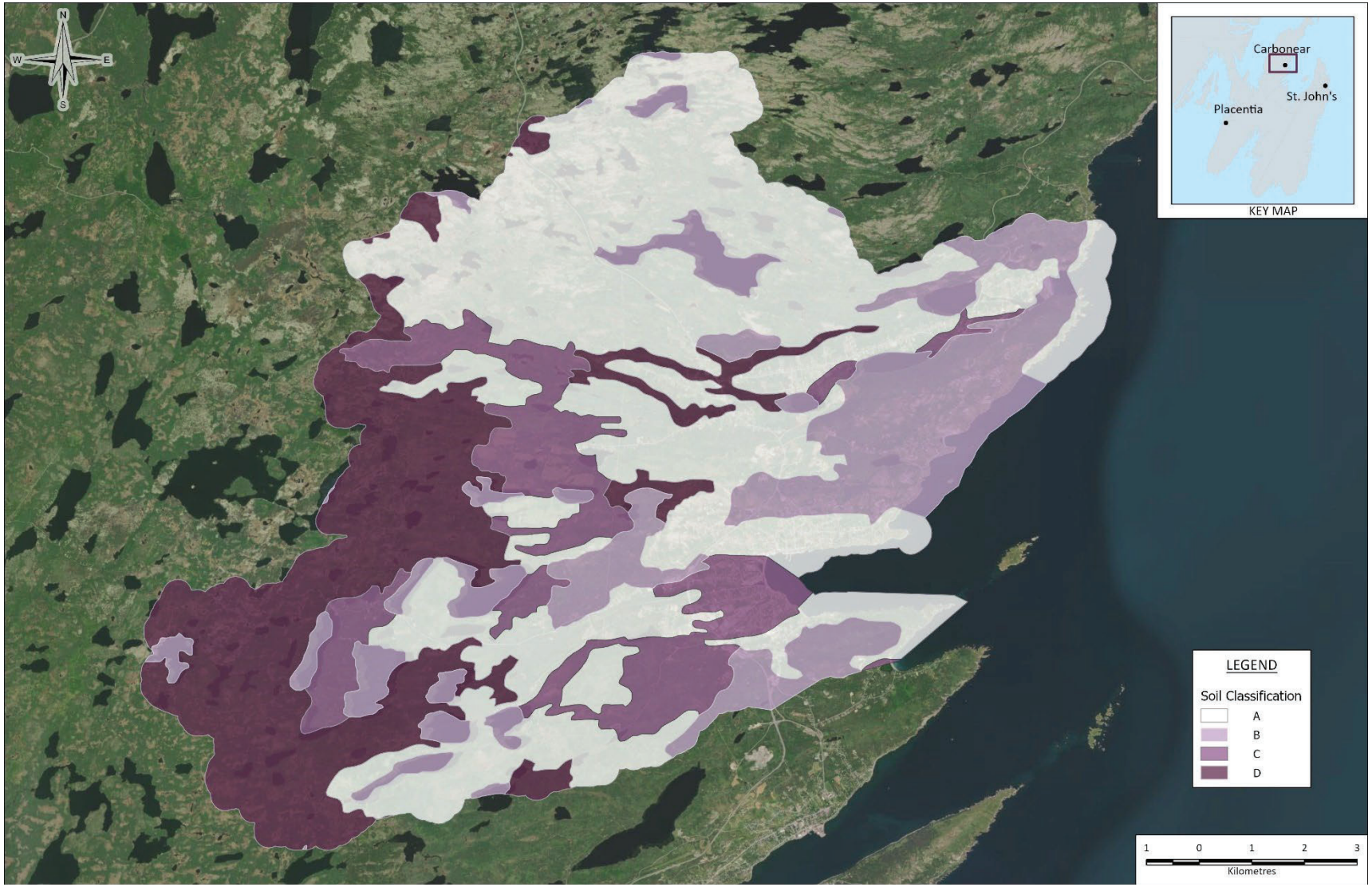
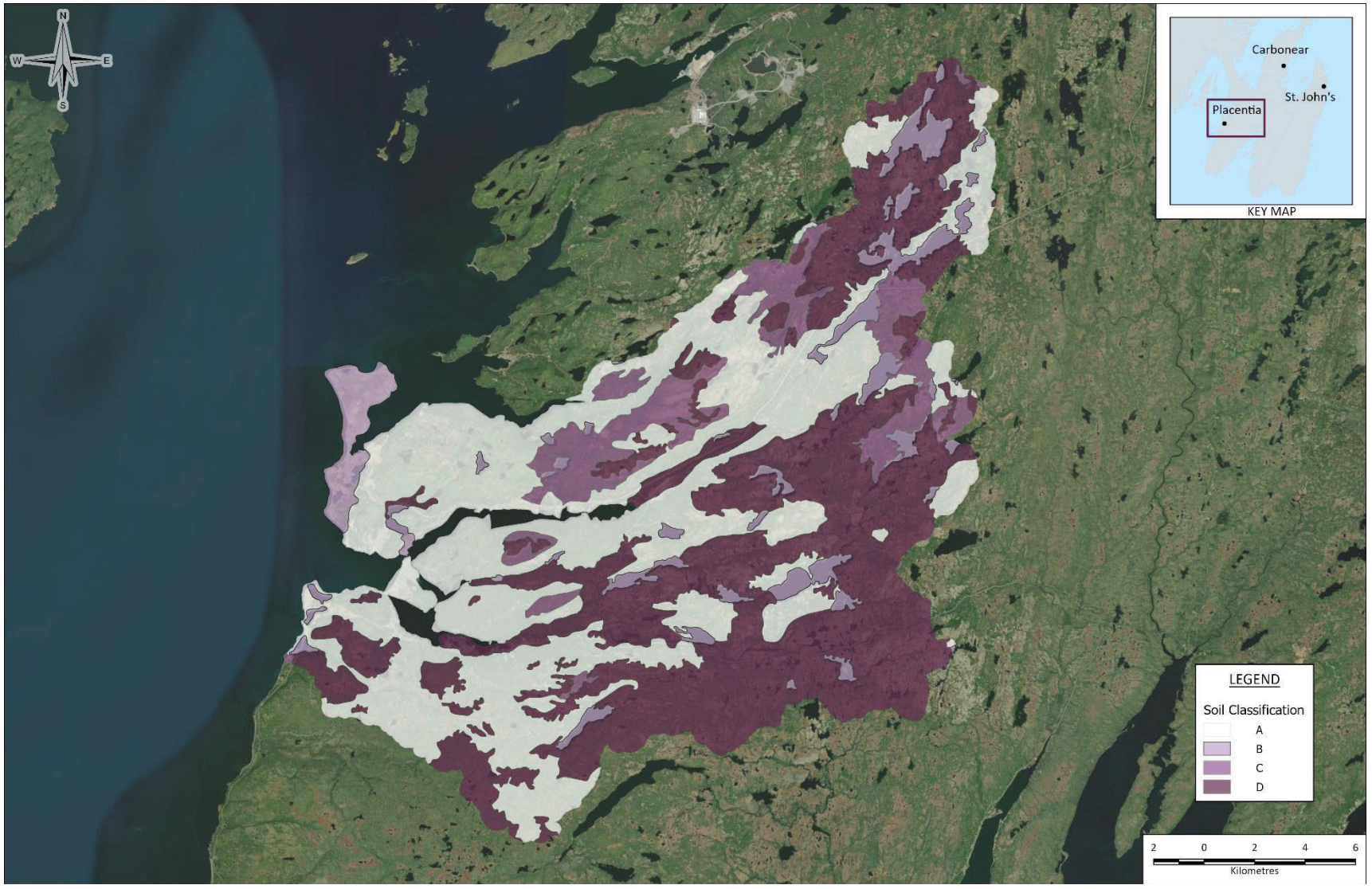


FIGURE 4: PLACENTIA SOIL CLASSIFICATION MAP



2.4 Curve Number Mapping

The land use classification data and NRCS soil classification data were combined based on the array provided by WRMD in the terms of reference to generate SCS Curve Number maps for Placentia, Carbonear, Salmon Cove and Victoria. The array relates the WRMD land use classes with the NRCS soil classes to define a Curve Number, which is used to translate rainfall to runoff in hydrologic models. The conversion table defined in the terms of reference is shown on Table 4.

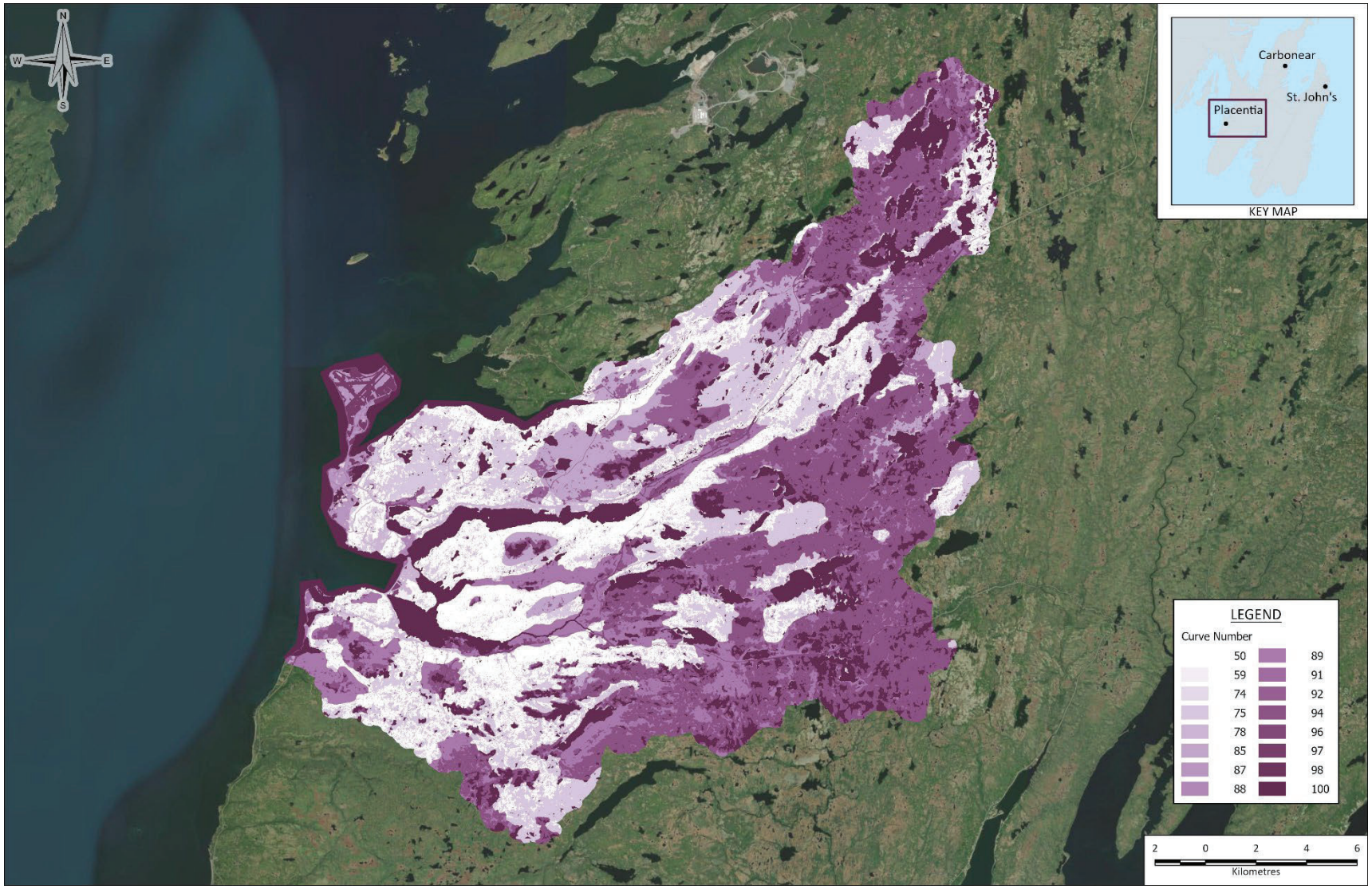
TABLE 4: CURVE NUMBER DEFINITION TABLE

Land Cover	NRCS Soil Type			
	A	B	C	D
Forest	50	74	85	89
Residential	78	88	94	96
Commercial	96	97	98	98
Deforested Areas	75	87	92	94
Barren Land	89	94	97	98
Fields/Pastures/Open Spaces	59	78	88	91
Swamps/Wetlands/Waterbodies	100	100	100	100
Unclassified	NA	NA	NA	NA

The resulting Curve Number map for Carbonear, Salmon Cove and Victoria are shown on Figure 5, while the Curve Number map for Placentia is shown on Figure 6.

FIGURE 5: CARBONEAR, SALMON COVE AND VICTORIA CURVE NUMBER MAP

FIGURE 6: PLACENTIA CURVE NUMBER MAP



3.0 CONCLUSIONS

The following conclusions can be made regarding the remote sensing work completed as part of this project:

- SPOT-6 satellite imagery was acquired from ESA covering the Placentia, Carbonear, Salmon Cove and Victoria areas. The Carbonear, Salmon Cove and Victoria satellite imagery was captured on August 10, 2020, while the Placentia area imagery was captured on August 16, 2020.
- The SPOT-6 imagery was classified using a supervised and automated Land Class Wizard tool in the ArcGIS Pro software developed by Esri. Land use classes were in accordance with those defined by the Government of Newfoundland and Labrador. Maps showing the resulting land use classification were developed for the communities and associated watersheds.
- Soil classification information for the Placentia, Carbonear, Salmon Cove and Victoria areas were acquired from the NSDB Version 2. The NSDB soil classes were converted to NRCS soil classes based on the conversion scheme defined by the Government of Newfoundland and Labrador. Maps showing the soil classification for the communities and associated watersheds were developed.
- SCS Curve Number maps were developed based on the synthesis of the land use and soil classification maps. Curve Numbers were defined based on the definition table defined by the Government of Newfoundland and Labrador.