

# Green Network Pilot Project

Engineering & Planning

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Saskatoon Water

Utilities & Environment Department

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## Executive Summary

The Green Network is an area identified on the Saskatoon North Partnership for Growth (P4G) Regional Land Use Plan and is a key feature to the region's drainage. The study area covered by this project was the Green Network north of Saskatoon which is bounded by the P4G limits to the north, Highway 16 to the west, and the South Saskatchewan River to the east. As a component of the Green Network Refinement Pilot Project the network boundaries were reviewed based on flood levels produced from a hydraulic model for a one hundred year return period.

In order to map these flooding levels a 2D hydraulic model was built for the study area with its extents based on watersheds delineated from LiDAR data. Culverts were surveyed throughout the study area and were included in the model to increase overland flow accuracy. Two scenarios were analyzed using the model, one assuming dry conditions and a second for wet conditions. The dry condition scenario simply had a single one hundred year storm applied. In order to simulate wet conditions in the second scenario an initial storm was applied to the model prior to the introduction of the one hundred year storm event. The purpose of the initial storm was to fill the local depressions in the topography therefore allowing the second storm, with a one hundred year return period, to produce runoff not mitigated by these storage areas. Infiltration was applied only during the second storm in order to prevent the depression storage from draining.

The results from the model have been mapped within the Green Network boundaries for the one hundred year flood levels. Included is the maximum water depth as well as the overall flow through the Green Network system. A hazard map was also produced which classifies potentially hazardous areas based on a combination of water depth and velocity. The Green Network delineation provides a general representation of the drainage system within the P4G study area. However, the modelled flood levels indicate that certain Green Network boundaries may be narrowed while others may be expanded based on the hydraulics of the system. The Green Network boundaries should encompass all low lying areas which pond to hazardous depths and then furthermore connect them after they have filled and spilled along the flow paths. Areas outside the Green Network also contain low spots and tributaries which must still be accounted for during development. In order to maintain the current boundaries of the Green Network, future development must not drain at an increased flow rate into the Green Network system.



Report Prepared By:

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Jeremy Ball, Engineer-In-Training  
Infrastructure Engineer



Report Reviewed By:

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Hossein Azinfar, PhD., P. Eng.  
Hydrotechnical Engineering Specialist

AJ McCannell, P. Eng.  
Engineering and Planning Manager

Galen Heinrichs, M. Eng., MBA, P. Eng.  
Water & Sewer Engineering Manager



## Statement of Qualifications and Limitations

The attached Report (the "Report") has been prepared by the City of Saskatoon ("the Consultant") for the sole benefit of the Saskatoon North Partnership for Growth ("P4G") in accordance with the P4G Green Network Pilot Project - Project Charter ("Project Charter"), and the scope of work detailed therein.

The information, data, recommendations and conclusions contained in the Report (collectively, the "Information"):

- is subject to the scope, schedule, and other constraints and limitations in the Project Charter and the qualifications contained in the Report (the "Limitations");
- may be based on information provided to the Consultant which has not been independently verified;
- has not been updated since the date of issuance of the Report and its accuracy is limited to the time period and circumstances in which it was collected, processed, made or issued;
- must be read as a whole and sections thereof should not be read out of such context; and
- in the case of hydrological, hydrogeological, topographical or environmental conditions, may be based on limited data and testing with the assumption that such conditions are uniform and not variable either geographically or over time.

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The Consultant agrees that the Report represents its professional judgement in accordance with generally acceptable engineering practices and in light of the Limitations and industry standards for the preparation of similar reports. The Information has been prepared for the specific purpose and use described in the Report and the Project Charter and the results of the Report may change if any construction takes place in the study area.



The Report is prepared in accordance with generally acceptable engineering practice and reflects the best judgment of the Consultant. Any use a third party makes of this Report, or any reliance on or decision to be made based on it, are the responsibility of such third party. The Consultant accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this Report.

This Statement of Qualifications and Limitations is attached to and forms part of the Report and any use of the Report is subject to the terms hereof.



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## 1. Introduction

### 1.1 Project Background

The Green Network is an area where storm water runoff from within the Saskatoon North Partnership for Growth (P4G) boundary accumulates before draining into the river. The P4G includes the City of Saskatoon, the Rural Municipality of Corman Park, the City of Martensville, the Town of Osler, and the City of Warman. The Green Network boundary was originally delineated by the P4G consultant using a Fill and Spill Model and a desktop environmental screening.

The City of Saskatoon has been tasked with performing further hydraulic modelling of the area with respect to the flooding conditions caused by a one hundred year storm. This report recaps the required input data incorporated into the hydraulic model and then describes the resulting depth, hazard, and flow maps produced.

### 1.2 Site Description

The Green Network within the P4G boundary is interconnected through a variety of features including culverts, sloughs, and channels. The overall watershed has characteristics that greatly impact the drainage conditions of the study area. Firstly the area has an average slope of roughly 0.2% towards the South Saskatchewan River Valley. This general drainage direction can be seen from the change in elevation shown in Figure A-1. Roadways and railroads act as barriers to the drainage which in turn means culvert locations and capacities become critical to direct flow downstream towards the river. Without culverts allowing flow to pass, the water instead must pond until it overtops the lowest adjacent roadway or barrier in order to drain.

Key factors that mitigate flooding are depression storage and infiltration. The landscape within the study area is dominated by potholes and as such this depression storage must fill before spilling and allowing water to drain further downstream. Average depression storage was calculated to be about 75 mm across the entire study area through the use of ArcGIS tools to process the LiDAR data. ArcGIS is a software used by the City of Saskatoon with functions to create, analyze, and manage geographic information. The existence of roadways in the LiDAR data increases this value beyond strictly natural depression storage.



Infiltration reduces the runoff volume as the water is absorbed into the ground. In general the majority of the land use throughout the study area is farmland which allows for infiltration to occur. The degree of infiltration depends on the specific area and its soil type; therefore mitigation of flooding also varies by area. Lastly the impervious percentage of an undeveloped area is very low, thus allowing a larger degree of infiltration compared to a fully paved development. Therefore development will increase runoff volume by decreasing infiltration as well as by removing the depression storage of an area. Development may also regrade areas to have higher slopes creating higher velocities and decreasing the time of concentration. All of these factors increase the runoff volume which must then be accounted for and handled as part of development.

### 1.3 Objectives

The objectives of the project are as follows:

- To develop the one hundred year flood depths within the Green Network; and
- To assess the hydraulic conditions of the major flow pathways and associated hydraulic structures.

### 1.4 Scope

The scope of this project includes the following engineering analysis:

- Flood boundary delineation/mapping within the Green Network for current conditions; and
- Within the study area north of Saskatoon bounded by the P4G limits to the north, Highway 16 to the west, and the South Saskatchewan River to the east.

The following items are not included in the scope of work for this project:

- Analysis of any location outside of the area bounded by P4G limits to the north, Saskatoon to the south, Highway 16 to the west, and the South Saskatchewan river to the east;
- Analysis of future post-development conditions; and
- Detailed design or modification of hydraulic structures or flow paths.



## 2. Model Components

XPSWMM is a hydraulic and hydrologic modelling software package which allows for a combination of 1D and 2D calculations and is used for all City of Saskatoon storm water modelling. A hydraulic model built using XPSWMM requires various input data and assumptions. It was possible to represent the Green Network area using a 2D model with 1D components from the available data. This model consisted of a 2D surface with 1D culverts.

### 2.1 2D Grid

The cell size and grid extents of the model were determined based on the available LiDAR data and limitations of the hardware used to run the model. LiDAR data collected in 2012 that covers 840 square kilometers was acquired for the study area from the Rural Municipality of Corman Park. The full extents of the LiDAR can be seen within Figure A-1. This contains elevation data at a 1m grid resolution and was provided as Bare Earth and Full Feature datasets. The Bare Earth dataset was used for all analysis because it better represented the ground level with obstructing features such as trees and buildings removed.

Tools within the ArcGIS Hydrology Toolset were used to determine major flow paths and delineate watershed areas within the extents of the LiDAR data. The delineation of the watersheds shown in Figure A-2 allowed the area to be split into three separate models which determined the extents of each 2D grid. Furthermore, each model had two extents, one with a smaller grid size for key focus areas and a larger grid size for areas simply draining into the key areas. The major flow paths and Green Network boundaries were used to determine the areas with a greater focus which were then assigned a smaller cell size of 10m. Areas outside these key focus areas were assigned a larger cell size of 50m.

The full extents of the area draining into the Green Network is not covered fully by the extents of the LiDAR data. Therefore an area of about 120 square kilometers was determined to fall outside of the LiDAR extents as delineated from a previous study within the Opimihaw Creek Report (KCB, 2014). This area was included in the analysis through modelling its runoff flowing into the 2D grid extents.



Key time control and configuration parameters were chosen to ensure a reasonable model run time while also maintaining stability within the model calculations. As suggested within the XPSWMM manual the time step for the 2D simulation was set to 5 seconds based on the cell size of 10 m (XPSolutions, 2013). Similarly the 1D hydraulics time step was set to match this with a time step of 5 seconds. The Manning's roughness of the 2D cells was set to 0.25 as per the suggested values for overland sheet flow through grass cover (XPSolutions, 2013). This roughness value was also used in order to prevent instability within the 2D calculations along areas with steeper slopes.

## 2.2 Culverts

City of Saskatoon staff surveyed 453 culverts within the focus area. All geodetic benchmarks within the North Corman Park area were found to be in poor condition or were not accessible. Therefore calibration of the GPS was performed at manhole rims within Saskatoon to verify the accuracy of the GPS device. Surveying was focused on the study area with areas far from the Green Network having a lower priority. Critical locations for surveying were determined from preliminary model results and processing of the LiDAR data. Not all culverts may have been found therefore any additional culvert data not modelled may alter the flood map results.

Data for 344 culverts along Highways 11, 12, and 16 was received from the Government of Saskatchewan, but was determined to be outdated and inaccurate. Invert elevations were also not provided therefore this data was not used.

Information was provided detailing the changes occurring at the new Martensville and Warman interchanges. In general the flow paths have been maintained and culvert capacity improved. All culverts shown in the report that were being installed underneath existing infrastructure were manually added to the model using the provided elevation, length, and location data (McElhanney, 2017).



## 2.3 Rainfall

Flooding during a one hundred year return period storm was the focus of this project. Thus the chosen intensity and duration of the storm was 95 mm/hr with a 1 hour duration. These values were determined from the results of a recent intensity-duration-frequency curve study performed by the University of Saskatchewan for the City of Saskatoon (Elshorbagy, 2015).

This rainfall was applied with an equal distribution across the entire extents of the model. For the watershed area outside of the LiDAR extents a 1D runoff simulation was performed and the resulting runoff was applied at the edge of the 2D extents as a flow boundary.

Two rainfall scenarios were analyzed. Within the first modelled scenario a single one hundred year storm was applied which simulated a dry condition. For the second scenario two rainfalls were applied at separate times during the model simulation which simulated a wet condition. The first storm at the beginning of the model was used to fill all depression storage. A dry period was included after this storm to allow for the runoff to drain. After this a second storm with a one hundred year return period was applied with another dry period to follow. This additional dry period accounts for the time of concentration required for the most remote points to drain to the river. Thus the model produced results based on a one hundred year runoff after all depression storage had been filled.

## 2.4 Infiltration

Infiltration was assumed to be 15 mm/hr across the entirety of the watershed area based on the City of Saskatoon design and development standards (COS, 2018). It was conservatively assumed that the ground would already be saturated such that the minimum constant infiltration value was already reached. An infiltration test was performed north of Saskatoon by City of Saskatoon staff and the results were compared to infiltration tests done throughout Saskatoon from previous years. Infiltration was applied as rainfall abstraction in order to ensure low lying areas with minimal infiltration that store water for long periods of time would not drain quickly between the two modelled storms. This ensured that all depression storage would stay filled after the first storm and prevent any further flood mitigation.



### 3. Model Results

The maps displayed within Figure B-1a and Figure B-1b show the maximum water depth throughout the extents of the Green Network for the dry and wet conditions, respectively. The dry condition represents a single one hundred year storm that is partially mitigated by depression storage. The wet condition displays the conservative scenario where depression storage is preemptively filled by an initial storm and then a one hundred year storm occurs after these wet conditions have been set up. Figure B-1c provides a comparison of the maximum water depths greater than 0.5 m from these two scenarios. Therefore depending on the conditions present in the field, the resulting flooding extents may fall in between these two extremes.

All water depths are in reference to the LiDAR elevation as zero. Therefore any area where the LiDAR elevation has been taken with a water depth already present has not had this additional depth accounted for. These maps display the low areas that act as storage ponds along the Green Network as well as flow paths where the depth of flow varies between shallow and deep. Development within any low areas will require regrading to ensure elevations are above flood levels. Otherwise these areas are ideal placements for storage ponds and other drainage infrastructure.

Any additional culvert data not found during the City of Saskatoon's surveying may impact the flooding boundaries and therefore should be investigated and further analyzed pending any nearby development. Within the hydraulic model all culverts were assumed to be in good condition. Any culverts in a poor condition where capacity is affected will have an impact on the flooding extents, potentially extending the flooding outside the Green Network boundaries. Due to the high level nature of this model, any future development should assess the local drainage conditions and infrastructure to ensure the modelled results accurately represent the real world system.

Within Appendix B two hazard maps have been shown based on the UK Hazard classification for the two different rainfall conditions discussed previously in Section 2.3. Hazard classifications aim to determine locations that are dangerous for people, vehicles, or structures based on a combination of flow depth and velocity. Therefore they estimate the force it would take for the flow to sweep away a person or damage a structure.

The United Kingdom (UK) Hazard classification accounts for depth, velocity, and a debris factor based on the land use. The exact values used to define the different criteria can be



seen within Table 1 and Table 2. The classification used to produce Figure B-2 and Figure B-3 has assumed that the study area has a pasture land use. Boundaries for the values of low, moderate, significant, and extreme hazard aim to categorize the level of danger to people (Wallingford, 2006).

**Table 1. Guidance on debris factors for different flood depths, velocities and dominant land uses**

(Wallingford, 2006)

Depths	Pasture/Arable	Woodland	Urban
0 to 0.25 m	0	0	0
0.25 to 0.75 m	0	0.5	1
$d > 0.75$ m and/or $v > 2$	0.5	1	1

**Table 2. Hazard to People as a Function of Velocity and Depth**

(Wallingford, 2006)

$d \times (v + 0.5)$	Degree of Flood Hazard	Description
$< 0.75$	Low	Caution <i>“Flood zone with shallow flowing water or deep standing water”</i>
0.75 - 1.25	Moderate	Dangerous for some (i.e. children) <i>“Danger: Flood zone with deep or fast flowing water”</i>
1.25 - 2.5	Significant	Dangerous for most people <i>“Danger: flood zone with deep fast flowing water”</i>
$> 2.5$	Extreme	Dangerous for all <i>“Extreme danger: flood zone with deep fast flowing water”</i>

Within Figure B-2 and Figure B-3 the hazardous areas are not fully interconnected through the Green Network to the river. Areas not appearing as hazardous may lack defined channels which results in low water depths and velocities. Due to the nature of the watershed there are areas where the overland flow is quite shallow and wide with a minimal grade thus not appearing as dangerous. It is important to still consider the flow through these areas which don't appear hazardous. Any development within these flood



plains must ensure that flow paths are not obstructed which could potentially increase upstream flooding depths. The Green Network boundaries should ensure that low areas are interconnected and allow flow to pass through the Green Network system. This interconnectivity should include the width of any shallow flow paths and these boundaries may be narrowed by implementing engineered conveyance.

The estimated flow rate through segments of the Green Network can be seen in Figure B-4. The flow values shown are estimations of the maximum flow in each of the two rainfall scenarios discussed in Section 2.3. The lower bound of the flow range is taken from the modelled dry condition and the upper bound is taken from the modelled wet condition. These flow rates do not all occur simultaneously due to a difference in the time of concentration for each area. In general the flow rate within a channel increases further downstream due to accumulating additional watershed area. Flow rates may also be higher at upstream segments where culvert capacity restricts the flow from travelling downstream. Instead these high flow rates are then mitigated by ponding in storage areas. However, peak flows and depths may be conservative in places where the 50 m grid size was used for the area's watershed due to roadways and culverts not restricting the flow. Any development proposed within or adjacent to the Green Network would need to consider how these flow rates can be accommodated.

The initial delineation of the Green Network boundaries is fairly representative of the areas with a high risk for flooding. The hydraulic model shows that areas exist for the one hundred year flood levels where the boundaries could be shifted and where alternative major flow paths should also be considered as part of the Green Network.

Areas directly adjacent to the Green Network boundaries that should be investigated further have been highlighted in Figure B-5. Expansion of the Green Network should be considered within these areas from a hydraulic perspective to account for existing flow paths and the higher risk for flooding. These areas were determined from the hydraulic model results and are based on a combination of the maximum depths, maximum hazard, and total flow rate throughout each area.

Based on the model results the Green Network bounds do not include all tributaries draining into the system. Therefore when development occurs outside the Green Network boundaries a detailed study into the local drainage should be conducted in order to not obstruct the smaller tributaries that drain into the Green Network. Development should always consider and properly manage the upstream watershed area draining to the



development site. Areas outside the Green Network may also see depths that are unsuitable for construction and require regrading or filling of low areas. This must be done in a way to not impede natural drainage paths. Any development should match the post development flow rate to the predevelopment flow rate in order to not flood the Green Network to greater extents than what has been modelled. The Green Network extents may be reduced by constructing defined channels that have been designed for the capacity of the total flow seen through the respective segment of the Green Network.

In order to gauge the impact of culvert capacity on the Green Network flooding extents a model was run with all culverts set to have an unlimited capacity. The results showed that culvert capacity does have an impact on the one hundred year ponding depths within the Green Network. Therefore culvert location and size are important and any changes to either should consider the effects on the overall system.

A broad take on the general ditch and culvert drainage direction has been included in Figure C-1. These directions of flow in the ditches along roadways have been estimated based on the 2012 LiDAR data with consideration for the locations of surveyed culvert data. Drainage channels should be maintained and flow through these ditches should not be obstructed.

## 4. Conclusion and Recommendations

A hydraulic model of the Green Network study area was built in order to determine flood levels pertaining to a one hundred year return period. Key components of the model included the watershed extents of the LiDAR data, surveyed culverts, a one hundred year storm event, and infiltration. The results of this model were mapped out using maximum depths, hazardous area classifications, and flow rate through the system. Areas within the Green Network should not be developed without improvements to the drainage and consideration of flood depths, flow rates, and existing flow paths. Additionally, outside of the Green Network bounds, low areas and the flow pathing between them should not be obstructed by development. Development should consider using low areas and the connecting flow paths for storm water retention and conveyance. In order to maintain the current predicted flood boundaries and levels, the flow into the Green Network must not be increased by development. Furthermore any changes to culvert location and capacity can affect the flood bounds both upstream and downstream. Therefore the overall Green Network system should be considered when upgrading infrastructure and expanding development.



Further study may include:

- Assess engineering solutions including those proposed in previous reports;
- Continue expansion of culvert inventory;
- Model individual areas of interest in further detail and with a reduced grid size;
- Assess physical parameters such as infiltration in more detail for specific areas of interest; and
- Assess other storm return periods.



## 5. References

City of Saskatoon (COS). 2018. City of Saskatoon Design and Development Standards Manual. City of Saskatoon, Saskatoon, SK.

Elshorbagy, A., Nazemi, A. and Alam, S. 2015. Analyzing the Variations in Intensity-Duration-Frequency (IDF) Curves in the City of Saskatoon under Climate Change. Centre for Advanced Numerical Simulation, Saskatoon, SK.

Klohn Crippen Berger (KCB). 2014. Opimihaw Creek Report. Klohn Crippen Berger, Saskatoon, SK.

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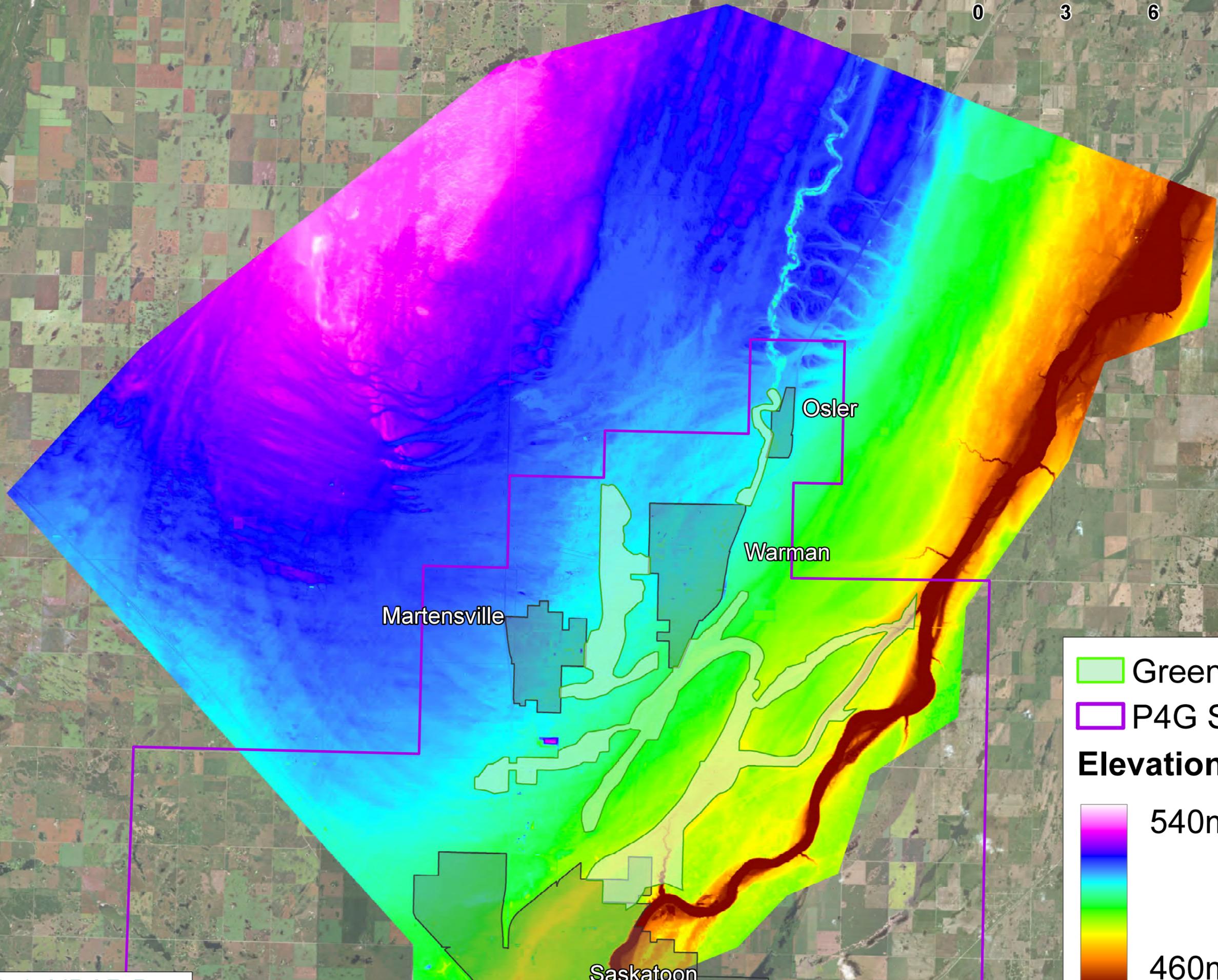
Wallingford, H.R., Flood Hazard Research Centre, Middlesex University, Risk & Policy Analysts Ltd. 2006. Flood Risks to People. Department for Environment, Food and Rural Affairs, London, ENG.

XPSolutions. 2013. XPSWMM Reference Manual. XPSolutions, Portland, OR.



## Appendix A

### Input Data



Green Network

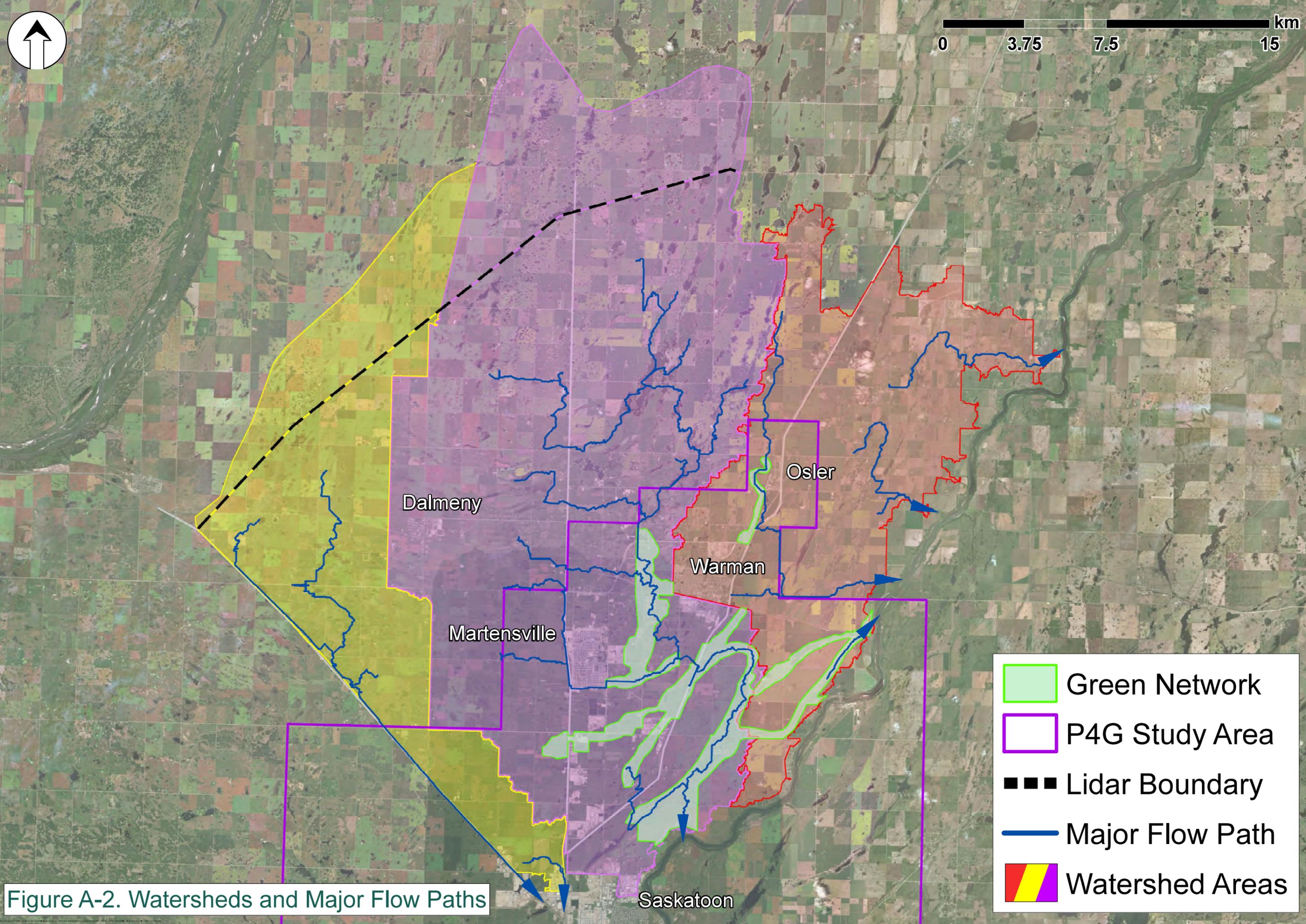
P4G Study Area

**Elevation**

540m

460m

Figure A-1. LiDAR Data



Dalmeny

Osler

Warman

Martensville

Saskatoon

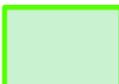
-  Green Network
-  P4G Study Area
-  Lidar Boundary
-  Major Flow Path
-  Watershed Areas

Figure A-2. Watersheds and Major Flow Paths



## **Appendix B**

### **Hydraulic Model Results**



Dalmeny

Osler

Warman

Martensville

Saskatoon

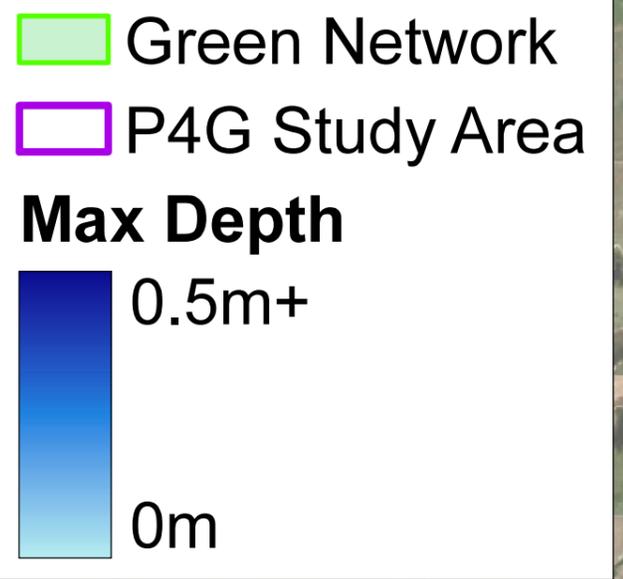


Figure B-1a. Green Network 100 Year Flood Depth Dry Condition



Dalmeny

Osler

Warman

Martensville

Saskatoon

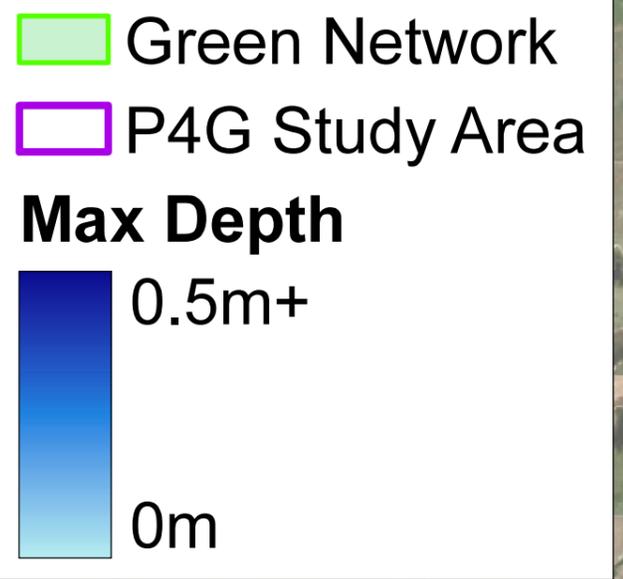


Figure B-1b. Green Network 100 Year Flood Depth Wet Condition



Dalmeny

Osler

Warman

Martensville

Saskatoon

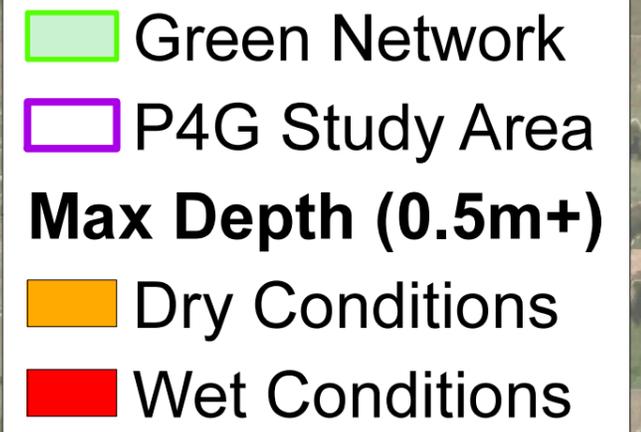


Figure B-1c. Green Network 100 Year Flood Depth Wet and Dry Condition Comparison



Dalmeny

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Warman

Martensville

Saskatoon

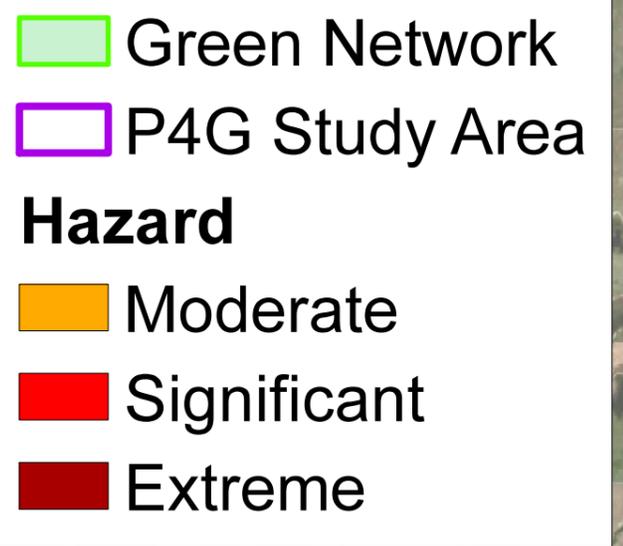


Figure B-2. Green Network 100 Year Dry Condition Hazard Levels - UK Hazard Classification



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Osler

Warman

Martensville

Saskatoon

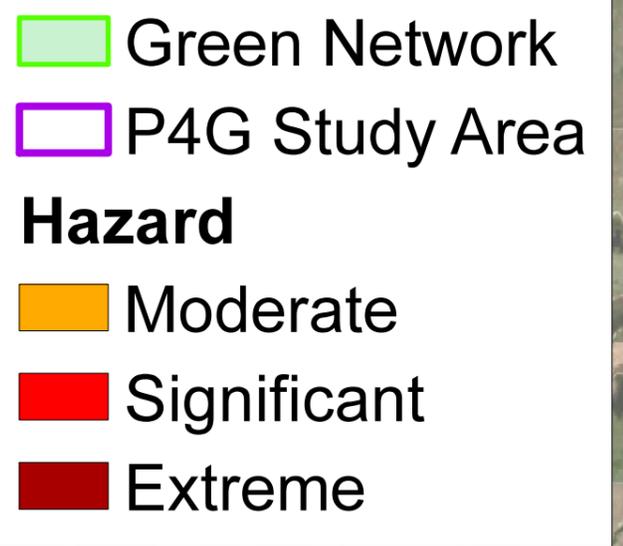


Figure B-3. Green Network 100 Year Wet Condition Hazard Levels - UK Hazard Classification

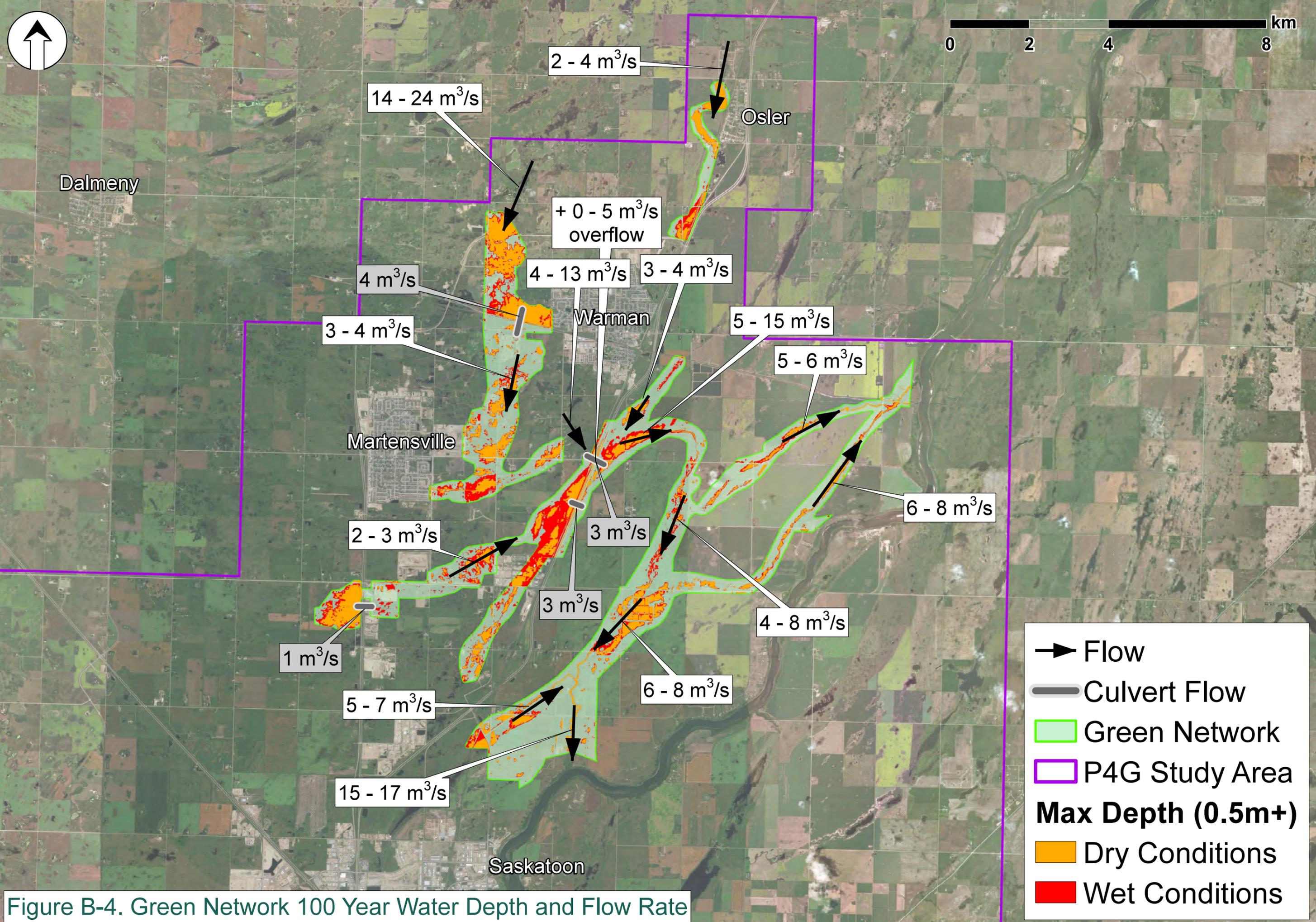


Figure B-4. Green Network 100 Year Water Depth and Flow Rate



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Warman

Martensville

Saskatoon

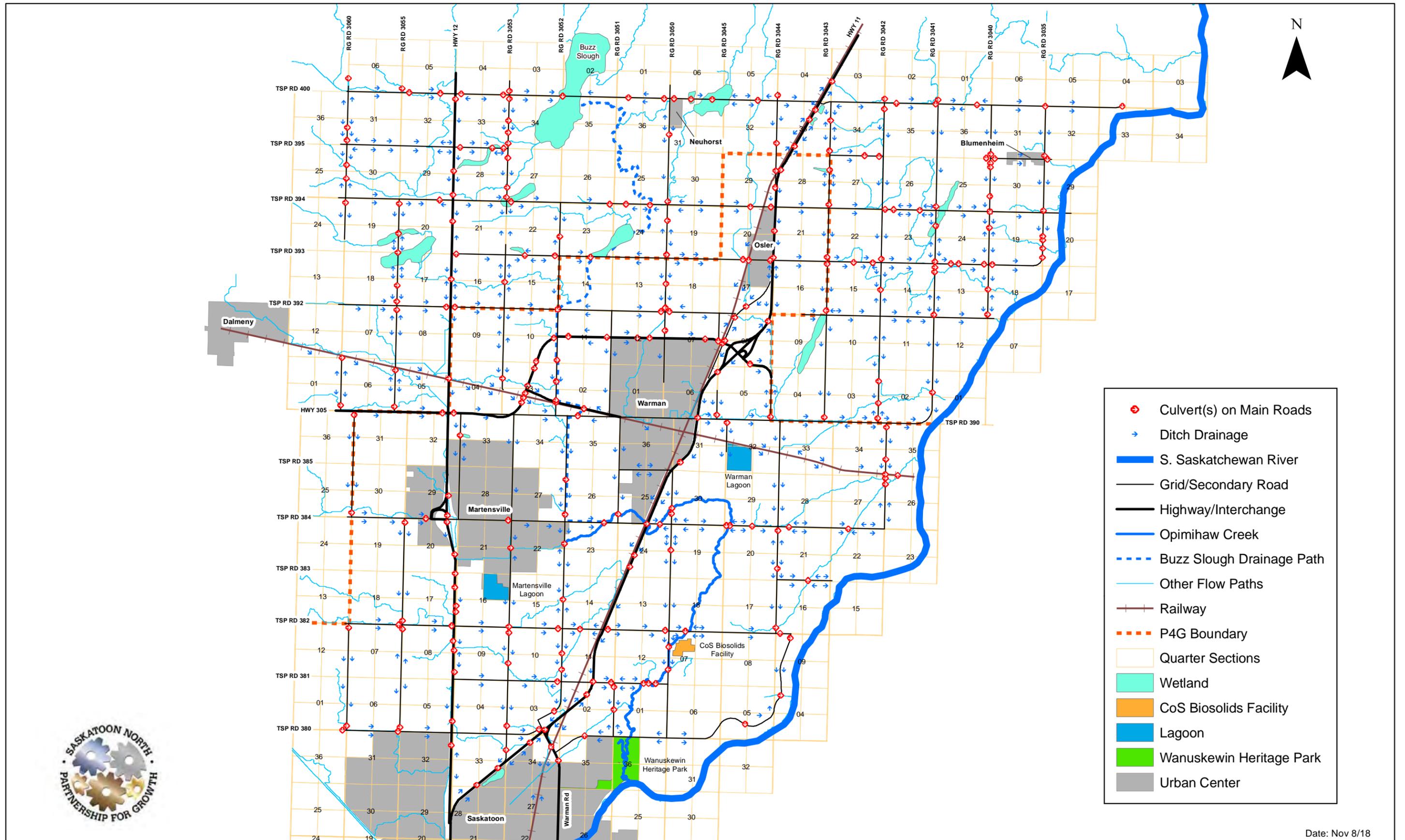


Figure B-5. Green Network Areas Requiring Further Investigation



## Appendix C

### P4G North Sector Drainage



**Figure C-1. P4G North Sector Drainage Map**

Not for engineering design or construction