Green Network
Phase 3 Drainage Study

Engineering & Planning

Saskatoon Water May 16, 2024

Utilities & Environment Division

City of Saskatoon

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 Phase 3 study area covered by this project was the Green Network west of Saskatoon which is bounded by the P4G limits to the west and south, Saskatoon to the east, and Highway 16 to the north. As a component of the Green Network Phase 3 study, the network boundaries were reviewed based on flood levels produced from a hydraulic model for a 100-year return period.

A 2D hydraulic model was built to map flooding levels 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 precipitation scenarios were modelled to produce maximum water depths in both storage areas and flow paths. A 100-year snowmelt scenario was considered a condition to produce the maximum water level in major wetlands. The total snowmelt volume was not mitigated by infiltration due to the ground being assumed frozen. An average snowmelt followed by a 100-year rainfall scenario was considered to produce the maximum water level within channels and local depressions. The ground was assumed to be thawed during the rainfall therefore infiltration was considered.

The flood level results from the model have been mapped within the watershed area of the Phase 3 study boundaries. Included is the maximum water depth throughout the Green Network system and its watershed area. Maps were produced to show the existing depression storage and drainage directions within each section of the study area. 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 and volume into the Green Network system.

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Statement of Qualifications and Limitations

The attached Report (the "Report") has been prepared by the City of Saskatoon ("the City") for the sole benefit of the Saskatoon North Partnership for Growth ("P4G") in accordance with the P4G Green Network Phase 3 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"):

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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 or infiltrating and evaporating. 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 100-year precipitation event scenarios. This report recaps the required input data incorporated into the hydraulic model and then describes the resulting depth 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. There are many low-lying areas that act as depression storage, therefore storing any precipitation until it infiltrates and evaporates. The majority of Phase 3 area drains into the Blairmore Swale (West Swale) which drains south and east into the South Saskatchewan River Valley. Area east of Highway 684 and along Highway 16 drains east and southeast towards the low lying swale areas near the Saskatoon airport. Study area near Highways 7 and 14 drains west and away from Saskatoon and the Blairmore Swale. These general drainage directions 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 or wetlands. Without culverts allowing flow to pass, the water instead must pond until it overtops the lowest adjacent roadway or barrier to drain. Culverts are especially critical to allow drainage along the major flow paths through the Phase 3 Green Network area shown in Figure A-2. Any absence of culverts under roadways, railways, or natural high points drastically impacts the depth of water required for segments of the Blairmore swale to drain to the South Saskatchewan River. The natural drainage path crosses CN Rail tracks in order to reach the river, therefore if culverts do not connect the upstream side of the land to the downstream end then there may still be a groundwater connection between the two sides. Installation or removal of culverts at critical locations can change whether watershed area drains through the Blairmore Swale to the South Saskatchewan River or towards the swales near the Saskatoon airport.

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 207 mm across the entire Phase 3 study area. This was estimated using 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 where culverts don't exist to allow the flow to pass.

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 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. Developments will increase runoff volume by decreasing infiltration as well as by removing the depression storage of an area. Developments 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 a part of these developments.

1.3 Objectives

The objective of the project is as follows:

- To develop the 100-year flood depths within the Phase 3 Study Area and its watershed.

1.4 Scope

The scope of this project includes the following engineering analysis:

- Flood boundary delineation/mapping within the Phase 3 Study Area, bounded by the P4G limits to the west and south, Saskatoon to the east, and Highway 16 to the north, with consideration of watershed areas beyond the study limits; and
- Analysis for current conditions

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 west and south, Saskatoon to the east, and Highway 16 to the north;
- 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 and its watershed 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. Existing LiDAR data was acquired from the Rural Municipality of Corman Park, the City of Saskatoon, the Water Security Agency, and the Ministry of Highways for the Phase 3 study area and watershed area draining from outside the boundaries into the study area. It was determined that an additional 450 km^2 of LiDAR data was required to cover the entire watershed area draining into the study areas and therefore was acquired in 2021. The full extents of the LiDAR can be seen within Figure A-1. This contains elevation data at a 1 m 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 two separate models at the South Saskatchewan River. One model encompassed the area west of the river whereas the second model covered the watershed east of the river. This determined the extents of each 2D grid with a cell size of 10 m.

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). The 1D hydraulics time step was set to a time step of 1 second. 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 to prevent instability within the 2D calculations along areas with steeper slopes.

2.2 Culverts

City of Saskatoon staff surveyed 356 culverts within the study area and its watershed. Culverts which were inaccessible were visually noted and included in the model using LiDAR data for the invert elevations. Geodetic benchmarks within the Corman Park area were used for calibration 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 culverts along Highways 14 and 16 was received from the Ministry of Highways from which 11 culverts were used. A total combined amount of 367 culverts are shown within Figure A-3 which were imported into the drainage model.

2.3 Precipitation

The focus of this study was the level of flooding during a 100-year return period precipitation. Two scenarios were considered, the first being a 100-year snowmelt and the second being an average snowmelt followed by a 100-year rainfall. The majority of the prairies' annual runoff is produced by snowmelt which therefore governs the maximum water level in natural depressions (Pomeroy 2005, Fang 2007). Based on historical data the 100-year equivalent melted snow cover is around 200 mm (Environment Canada 2022). With the average snowmelt runoff coefficient taken as 0.5 (Maulé 1994), a 100-year snowmelt runoff was then chosen with a depth of 100 mm for the first scenario. The second scenario then used 50 mm of equivalent snow depth as an average snowmelt based on historical data (Environment Canada 2022). This was followed by a 100-year storm of 80 mm rainfall depth over 1 hour using the Chicago distribution. This rainfall depth is taken from a recent Intensity Duration Frequency (IDF) curve update in light of a climate change study, which is part of the current City of Saskatoon design standards (U of S 2020). Considering past City of Saskatoon standard IDF curves, this rainfall depth is almost equal to a 500-year storm event over 1 hour (COS 2021). Due to the high intensity of the rainfall this scenario governed for water depths within flow paths and local depressions.

Within both scenarios the precipitation was applied across the entire extents of the model. This encompassed all watershed area that had the potential to fill and spill into the study area and the Green Network.

2.4 Infiltration

During the 100-year snowmelt scenario infiltration was assumed to be negligible across the entirety of the watershed area due to the ground being assumed frozen. Therefore zero infiltration was used throughout the extent and duration of the model within this first scenario. For the second scenario consisting of both a snowmelt and subsequent rainfall the ground was similarly assumed frozen during the snowmelt with zero infiltration. During the storm it was assumed that the ground would be thawed and that infiltration would occur, therefore 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 2021). It was conservatively assumed that the ground would already be saturated such that the minimum constant infiltration value was already reached.

3. Model Results

The map displayed within Figure B-1 shows the maximum water depth resulting from the 100-year snowmelt or the average snowmelt and 100-year rainfall, whichever scenario is greater within the area. This is displayed throughout the extents of the Green Network Phase 3 study area and its adjacent watershed area. In general the 100-year snowmelt maximum water depth governed within the major low lying storage areas such as wetlands and ponds. The 100-year rainfall depths governed in the flow paths, channels and local depressions with small catchment areas.

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 conveying water at varying flow depths. Development within any low areas will require regrading to ensure elevations are above flood levels. Otherwise these areas are ideal placements for storage areas such as wetlands or 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 Figure B-2 the areas with water depth greater than 5 cm are not fully interconnected through the Green Network to the river. Areas not appearing as having significant depth 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, although it is important to still consider the flow through these areas. Any development 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 labels within Figure B-2 show the 100-year return period maximum water elevations of major wetlands within the Green Network area. These water elevations may be considered when development occurs adjacent to the Green Network, ensuring that the development does not flood with proper freeboard implemented.

Peak flow rates within flow paths 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. 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 100-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 which pond with similar amounts of water as the Green Network should be investigated further. 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.

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 consider the post development flow rate and flow volume in comparison to the predevelopment conditions 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.

Culvert capacity does have an impact on the 100-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. Similarly, drainage channels should be maintained and flow through ditches should not be obstructed.

Figure C-1 represents the average depression storage in meters over each quarter section's entire area. Furthermore, the map displays where the deepest areas of depression storage exist based on the LiDAR data. In order to maintain predevelopment conditions any development should preserve the amount of storage required for increased flows and volumes created by the development. This increase may come from development removing existing depression storage or with hard surface such as pavement preventing infiltration. Analysis should be performed in order to determine if existing depression storage has excess available volume which may be used to manage the increased runoff volume from the development. If existing depression storage does not have any extra available volume then in order to maintain predevelopment conditions the development would need to create additional storage to manage its increased runoff.

A broad take on the general drainage directions within sections in the study area has been included in Figure C-2. These directions of flow show the natural grade along the edges of the sections as well as general directions of flow within the sections. When considering any individual section, it is important to look at where the section drains as well as whether any adjacent sections drain into it.

4. Conclusion and Recommendations

A hydraulic model of the Green Network study area was built to determine flood levels pertaining to 100-year return period precipitation scenarios. Key components of the model included the watershed extents of the LiDAR data, surveyed culverts, 100-year precipitation scenarios, and infiltration. The results of this model were mapped out showing maximum water depths. Areas within the Green Network should not be developed without improvements to the drainage and consideration of flood depths 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:

- Continue expansion of culvert inventory;
- Create and maintain a complete inventory of all culverts in the area and conduct regular inspections;
- Model individual areas of interest in further detail;
- Assess physical parameters such as infiltration in more detail for specific areas of interest; and
- Assess other storm return periods.

5. References

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Appendix A

Input Data

Figure A-1. LiDAR Data

Figure A-2. Watersheds and Major Flow Paths

Figure A-3. Culvert Data

Appendix B

Hydraulic Model Results

Figure B-1. 100 Year Flood Depth

Figure B-2. 100 Year Flood Depth Above 5cm and Max Water Elevations

Appendix C

Depression Storage and Drainage

Figure C-1. Quarter Section Average Depression Storage in Meters

Figure C-2. Section Drainage Directions