NewFields

Saskatchewan Water Security Agency
Saskatchewan Research Council

Hydrological Modelling Assessment

Demonstration Projects in Southern Saskatchewan

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Date: March 31, 2023

RE: Hydrological Changes from Agricultural Drainage

Ms. Wittrock,

This report is presented to the Saskatchewan Research Council (SRC) and presents the results of NewFields Canada Mining & Environment ULC (NewFields) assessment of hydrological changes due to agricultural drainage works. This work is presented to SRC in support of on-going work with the Saskatchewan Water Security Agency (WSA).

If you have any questions or require additional information, please contact the undersigned.

Best Regards,

NewFields Canada

Prepared By:	**Reviewed By:**
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TJL/EMT/tjl

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1. INTRODUCTION

The Saskatchewan Water Security Agency (WSA) is a crown corporation responsible for managing, reviewing and assessing water related matters for the province of Saskatchewan. Their purview covers a broad spectrum including hydrological monitoring, flood impact assessment and general water quality, among many other responsibilities. WSA is working with the Saskatchewan Research Council (SRC) to understand the potential changes to hydrological regimes as a result of drainage of "prairie pothole" geography in agricultural lands. SRC has retained NewFields Canada Mining & Environment ULC (NewFields) to complete an assessment of the potential effect of changes from those drainage works. This report discusses work completed for that effort.

2. BACKGROUND

Southern Saskatchewan consists of dominantly arable agricultural land and in many areas is commonly described as a "prairie pothole" geography. It is theorized that these potholes were formed during recession of ice from the last glaciation where pockets of ice were deposited within the soil matrix and, as they melted, formed local depressions in the ground surface. The depressions, in hydrologic terms, created storage pockets that would collect and retain water during runoff events.

These depressions range in both their temporal and volumetric magnitude: some will be infrequently filled with little noticeable difference to surrounding terrain while others will be large and retain water permanently, thus creating wetlands with markedly different vegetation and ecological potential. These depressions reduce the arable acreage from agricultural land for traditionally grown crops in Saskatchewan. Historically, agricultural producers have augmented their land to reduce or eliminate the storage in these pockets thus increasing their arable acreage. Often this practice was completed without permit from regulatory authorities.

Recently, Saskatchewan has experienced flooding events of sufficient magnitude to cause substantial damages to infrastructure. In many cases, complainants claim the magnitude of damages was worsened as a result of agricultural drainage projects that were completed without permit. This project seeks to understand the potential changes in hydrological regime for four demonstration projects where drainage works have been completed (with regulatory permission). These works are well understood by WSA from a technical perspective. WSA is developing an Agricultural Water Management Mitigation Policy which will be informed by the demonstration and research projects. These demonstration projects are implementing mitigation tools, including wetland retention and flow controls, and are being evaluated on a wide range of policy implications including agronomic/economics, infrastructure, water quality, downstream flooding and habitat management. This specific study evaluates wetland retention and the use of flow controls to manage water quality and flooding outcomes.

3. SCOPE OF THIS PROJECT

Assessment was completed at four demonstration projects identified as: 1) Arm River Farms (ARF) near Bethune, SK; 2) Gust Farms (Gust) near Davidson, SK; 3) Fort-a-la-Corne (FALC) near Melfort, SK; and, 4) Bauche near Redvers, SK. The demonstration projects have retained wetlands of 57%, 52%, 31% and 48% for ARF, Gust, FALC and Bauche, respectively. The WSA provided two grants to SRC to support this work.

Grant WSA-2020-0046 was provided to complete:

- Detailed hydrologic modelling for the ARF project for the temporal period 2009 to 2019, comparing pre-drainage, current condition and a fully drained site configuration; and,
- Water quality assessment for a simplistic estimate of the potential change in loadings based on changes to the flow regime for all four project sites.

Grant WSA-2021-0258 was provided to complete:

- Delineation of Gross Drainage Area (GDA) and Effective Drainage Area (EDA) for each of the four projects at varying temporal scales and potential augmentations (i.e:. drainage works); and,
- Basin transfer will be completed for each demonstration project for return period peak flows and annual flow volume.

This report will provide the results for Grant WSA -2020-0046 and should be considered adjacent to the Basin Transfer Report (Grant WSA-2020-0258; NewFields, 2023). This scope has deviated from the original proposal based on conversations with WSA and SRC and the deviations are the same for both WSA grants. The majority of these changes relate to methodology and were determined through discussion between WSA, SRC and NewFields. The most notable deviation from the proposal methodology is the lack of an evapotranspiration component for ground surface water losses. This component is not included due to challenges observed during model checks where the water losses from the system are substantial and limit the potential to generate runoff from ground surfaces. Other deviations were related to available climatic and hydrometric data dependent on the status of the existing records, as well as the source relative to a particular demonstration project.

Most of the data used for this project work were provided by WSA and SRC. Data provided included:

- Light Detection and Ranging (LiDAR) derived Digital Elevation Models (DEM);
- Various vector data packages (i.e. wetlands, drainage works, project boundaries, etc.) with associated geographical information system (GIS) data;
- Climate data local to each demonstration project;
- Return period peak flood and annual volume estimates;
- Various reporting data sources; and,
- Access to various imagery and topographic information.

Temporal periods referred to as Pre-drainage, Current and Fully Drained are defined by NewFields (2023). Drainage delineations considered with respect to those temporal periods are similarly presented by NewFields (2023).

4. FLOW CONTROL AUGMENTATIONS

WSA staff have estimated flow control augmentations to peak discharge for each of the demonstration projects (Appendix 1). The flow control estimates from WSA are based upon the Basin Transfer Assessment (NewFields, 2023) and serve as comparison to the modelling results presented in this report. Flow controls would result in lower peak flows for each of the demonstration projects (Table 1). The highest reduction from flow controls is expected at ARF with a reduction of 72% of peak flow in the current drainage scenario during the 1:5-year event. Data sheets for WSA's estimates are presented in Appendix 1. Flow control estimates for Bauche are yet to be completed and estimates for Gust are only presented for a Fully Drained condition due to the complexity of the watershed.

5. PROJECTED WATER QUALITY CHANGES FROM BASIN TRANSFER ASSESSMENT

Projected changes to water quality across the temporal scenarios is based on the assumption of chemostasis (Whitfield, 2022). This implies that the concentration of parameters does not change with increased runoff volume. For ARF, FALC and Gust, projections of changes to water quality are based on the 1:2-Year Flow Volume (Table 2 in NewFields, 2023). Bauche is a more complex site and includes mechanical pumping; for this reason the projected change to water quality is not provided. For ARF and FALC the Current and Fully Drained configurations are compared against the Pre-drainage scenario. The Pre-drainage scenario has an assigned water quality factor of 1.0 and the Current and Fully Drained are presented as multiples based on total volume. At Gust, the Pre-drainage and Current scenarios are based on EDA for the main drainage but the Fully Drained scenario is based on West and Main drainage combined as described in NewFields, 2023. Water quality multiples estimates based on basin transfer volumes are provided in Table 2.

6. HYDROLOGICAL MODELLING

Detailed hydrological modelling was used to characterize changes to flows from the ARF demonstration projects as a result of drainage works. The objective of the modelling exercise was to inform interpretation of the basin transfer analysis. Drainage works at the project typically consist of either surface or tile drains. This modelling follows the same three temporal periods used as modelling scenarios: Pre-drainage, Current arrangement and Fully Drained. The model chosen for this assessment is the Hydrologic Modelling System developed by the US Army Corps of Engineers colloquially known as HEC-HMS and all modelling was completed using version 4.9 of the software.

The dominant influence on the water balance in southern Saskatchewan is evaporation. To assess the effects of drainage augmentations for the ARF project, the dominant change across the temporal scenarios was related to reservoir storage and evaporation from those reservoirs. Also, between the pre-drainage and current scenarios there were some cross-watershed drainage features incorporated. Aside from these two scenario features, all other parameters are held constant for the modelling. The comparison across temporal scenarios is then made between peak flow and annual volumes as modelled for the years 2007 to 2019. The modelling begins in 2007 to allow the model, and specifically the reservoirs, to respond to the influence of the hydrologic cycle.

6.1. Climate Data

The closest climate station with a complete data record through the study period of 2009 to 2019 is Regina RCS, located approximately 40 km southwest of the ARF project. Hourly and daily climate data parameters were used for the modelling in the form of precipitation, air temperature, wind speed and relative humidity. Precipitation and temperature provided moisture input to the model and were discretized between precipitation as rainfall or snowfall. Air temperature, wind speed and relative humidity combine to estimate free water surface evaporation using a revised Meyer formula (Prairie Farm Rehabilitation Administration, 2002). All climate data used in this report can be provided electronically by NewFields upon request but are not included as an appendix to this report due to the volume of data. Annual precipitation totals are presented in Table 3. Lake evaporation for the model is based on monthly average data which are provided in Table 4.

6.2. Model Analyses

Model calibration and validation cannot be completed due to a lack of flow and water level data at the ARF demonstration project; however, to confirm that the model estimated reasonable flow responses, desktop checks are performed for peak discharge and flow volume. Peak discharges are compared in the Current temporal scenario while flow volumes are compared for both the Current and Pre-drainage scenarios.

Peak discharges were checked through visual examination of peak flows in the model time series as compared to the estimates completed during basin transfer (Table 1 in NewFields, 2023). Flow volumes were checked by reviewing the model time series results of reservoir features in the model which represent wetlands; any permanent wetlands in the model were checked that they frequently generated an outflow and always stored some water.

6.2.1. Digital Elevation Models and Subbasin Delineation

LiDAR data used for this assessment (provided by WSA) were the most accurate terrain data currently available to complete the modelling. The LiDAR data provided show existing drainage channels thus representing the Current scenario. The LiDAR data are incorporated into each of the three temporal scenarios but with edits for the Pre-drainage scenario to remove some augmentations. Other vector data provided by WSA present the alignment of drainage tiles in the study areas.

Modelling began with runs on the Current and Pre-drainage scenarios. The two differ from a geographical perspective such that the obvious existing channel works were “filled” for the Pre-drainage scenario using the GIS software Global Mapper. This filling results in slightly different overall drainage areas where the Pre-drainage total drainage area (23.49 km^2) is slightly smaller than that of the Current scenario (23.85 km^2 as used in the peak transfer estimates). This is due to two apparent cross-drainage boundary drainage works; however, the LiDAR does not cover the full study area and it is possible the drainage areas are not accurate. As the purpose of this study is to determine the reflected changes through temporal periods, it is not critical that the drainage areas be exact but rather that they are consistent through each scenario and the changes within each subbasin from drainage works are the dominant influence on model results.

To build the model, wetlands were modelled as reservoirs and their storage volume was estimated from the LiDAR surface. To manage time constraints each reservoir was represented through linear interpolation between three points: Zero storage, full storage at spill point and an elevated point nominally above the spill point. For each of these scenarios, the water level, surface area and storage volume were estimated and provided as input to each of the reservoirs. The models for each of the three scenarios differ in the number of reservoirs they incorporate. The reservoirs, like a wetland, intercept flow from the surrounding subbasin and store water up to the spill point. Water can only leave the reservoir through evaporation or outflow.

Areas of storage were determined by creating a “filled grid” on the Pre-drainage DEM. The Pre-drainage DEM was then subtracted from the filled grid, representing the depth of storage available throughout the DEM (subtracted grid). The subtracted grid was converted to individual points at a 5.0 m by 5.0 m resolution. Any point with a depth of storage greater than 0.25 m was incorporated into the reservoir volume assessment. Polygons were created around point clusters and at times augmented if it was apparent that a surface feature such as a road split the reservoir polygon. The initial output of the assessment resulted in 598 reservoirs with a total surface storage of 5.68 Mm^3. The total number of reservoirs used was reduced to 112 with a total surface storage of approximately 5.47 Mm^3 (96.3% of total), where the smallest reservoir hosts a volume of 0.003 Mm^3, the largest contains1.29 Mm^3 and the average is 0.054 Mm^3.

These 112 reservoirs define the storage areas for the ARF demonstration project and represent the Pre-drainage scenario. Subbasins in the HEC-HMS model were delineated based on the outlets of each reservoir. As drainage works are implemented across the project, the effect can be demonstrated as a removal of a reservoir, increasing the amount of water available to move downstream through the project. As such, the number of reservoirs decreases in each of the Current and Fully Drained scenarios to 46 and 5, respectively. In the Fully Drained scenario, the five reservoirs represent the wetted area running through the main stem of the drainage where the wetlands (Figure 1) are identified as permanent within the vector data provided by WSA. Figure 1 also presents the delineated subbasins for each reservoir as well as the reaches downstream (through) each subbasin.

The Current scenario differed in flow directions from a few subbasins where it was apparent that drainage works have created connection across pre-development drainage boundaries in the Pre-drainage scenario. A future Fully Drained condition was created simply by removing all reservoirs beyond those considered to be permanent.

6.2.2. Model Methods and Parameters

A variety of model methods are available to estimate inputs and outputs within the HEC-HMS model structure. These inputs and outputs represent influences to the water balance from evaporation, infiltration, snowmelt, precipitation, etc., and are often largely dependent on climate. As it is not possible to perform a proper calibration of the model, each model method was estimated based on professional judgment and the range of produced flows for the Current scenario were agreed upon by WSA, SRC and NewFields. The estimates of model method parameters were completed in consideration of appropriate ranges suggested for HEC-HMS (U.S. Army Corps of Engineers, 2022). To properly compare results between the surface augmentations of each temporal period, the model methods and parameters remain consistent between each temporal period. It is important to mention that subbasin canopy and evapotranspiration influences are not included in this assessment; their exclusion is discussed in greater detail in 6.4. For the purposes of this study, the following methods and parameters were incorporated:

- Subbasin Infiltration – Deficit and Constant Loss
    - Initial deficit – 0 mm
    - Maximum storage – 134 mm
    - Constant Loss Rate – 1.00 mm/hr
    - Imperviousness – 0%
- Subbasin Canopy Storage and Loss – Not included in model

- Subbasin Evapotranspiration – Not included in model
- Subbasin Transform – Clark Unit Hydrograph – Parameters are specific to each subbasin and available upon request
- Subbasin Baseflow – Constant Monthly
  - Assumed to be negligible (0.0 m^3/s) from November to March
  - Subbasins 7, 15, 25, 46, 49, 99, 101, 108 and 110 – 0.004 m^3/s from April to October
  - All other subbasins – 0.00001 m^3/s from April to October
- Reach Routing – Muskingum Routing
  - Muskingum K – parameter is specific to each subbasin and available upon request
  - Muskingum X – 0.05
- Specified Hyetograph – daily precipitation data sourced from RCS Regina
- Specified Thermograph – daily temperature data sourced from RCS Regina
- Reservoir Outflow – Elevation-Storage-Area Modelled as a Dam Top
  - Elevation-Storage-Area relationships are unique to each reservoir
  - Spill elevation is coincident to the geographic crest where water would first spill
  - Assumed dam top length – 5 m
  - Dam top coefficient – 1.1 $(m^{0.5})/s$
- Reservoir Evaporation – Monthly Average Evaporation
  - As estimated and presented in Table 4
- Snowmelt – Temperature Index
  - Lapse Rate – 5°C/1000 m
  - Index – 0 mm
  - Px Temperature – 2°C
  - Base Temperature – 0°C
  - ATI Coefficient – 1
  - Wet Meltrate – 1 mm/°C-day
  - Rain Rate Limit – 2 mm/day
  - Dry Meltrate – 1 mm/°C-day
  - Cold Limit – 20 mm/day
  - Coldrate Coefficient – 0.99
  - Water Capacity – 10%
  - Groundmelt Rate – 0mm/day

6.3. Model Results

The model was run for a time period between 2007 to 2020. The years 2007 and 2008 are "warm up" periods to allow hydrologic processes to exhibit their effects on model components such as reservoirs, as the initial condition of all reservoir storage is a "full" condition. The reporting period examined is 2009 to 2020 but data for 2007 and 2008 are also presented for reference.

The model is neither calibrated nor validated in the traditional sense. Rather, parameters related to infiltration and groundwater discharge (baseflow) were adjusted and modelling results were qualitatively compared to peak flow estimates (from basin transfer per NewFields, 2023) for the Current Scenario while modelled water levels in permanent wetlands were verified to maintain storage in the Current and Pre-drainage Scenarios (i.e. did not dry up). Through this visual process it was determined that:

- the Constant Loss Rate for Subbasin Infiltration should be 1.00 mm/hr; and,
- the Subbasin Baseflow occurs from April to October and is 0.004 m^3/s for Subbasins 7, 15, 25, 46, 49, 99, 101, 108 and 110 and 0.00001 m^3/s for all other Subbasins.

The resultant model outputs were visually reviewed against basin transfer peak flow data. Further analyses by WSA (Johnson, 2022) indicated that peak flows from modelling were acceptably comparable to the basin transfer estimates; however, annual volumes as compared to the median (1:2-year) were markedly different. WSA suggests this may be due to the low median annual unit runoff for 05JG015 (the source hydrometric station used for ARF basin transfer in NewFields, 2023).

The modelled hydrographs for each scenario are presented in Figure 2. In Figure 2, the Current and Fully Drained Scenarios are referenced on the left vertical axis while the Pre-drainage is referenced to the right vertical axis. As shown in Figure 2, the Pre-drainage Scenario is an order of magnitude lower in stream flow response than both the Current and Fully Drained Scenarios. The annual peak discharges are presented in Table 5 and annual flow volumes in Table 6. The increase in discharge and annual flow volume is substantial between the Pre-drainage and Current Scenarios. The increase in discharge and flow volumes between the Current and Fully Drained Scenarios ranges between negligible and 100% depending on the year. In some years, such as 2018, the peak discharge and annual flow volume are essentially unchanged indicating a very dry condition. Any runoff occurred at the last subbasin upstream of the final discharge point and immediately downstream of the last permanent wetland.

Overall, the detailed modelling confirms the general trends indicated by the basin transfer results (NewFields, 2023). Drainage substantially increased peak flows across many years and the Current scenario provides some reduction of flows over the Fully Drained scenario. In general, flow controls would reduce the peak flows but the magnitude of the reduction is substantially variable.

6.4. Sources of Error

The modelling is anticipated to have inaccuracies due to the lack of site data available for climate, snow pack, stream discharge and wetland water levels. Sources of error which are expected to have influenced the model results include:

- Lack of snowpack, precipitation, water level and discharge data to calibrate and validate the model;
- Assumed outflow configurations for the reservoirs;

- Free water surface evaporation cannot be adjusted for each year but rather incorporates monthly average evaporation; and,
- Exclusion of other land surface influences such as vegetation canopy losses or evapotranspiration.

6.5. Projected Water Quality Changes from Hydrological Modelling

The estimated change to the projected water quality is based on the assumption that water quality is chemostatic between the three scenarios (Whitfield, 2022). This results in loading increases to be a function of increase in annual flow volumes. If the unit loading for the Pre-drainage Scenario is 1, then based on average flow volumes (Table 6) the concentration loadings can be expected to increase by factors of 67.7 and 89.3 (Table 6) for the Current and Fully Drained Scenarios, respectively.

7. PROJECTED WATER QUALITY CHANGE COMPARISON

Though the modelling compared well to the basin transfer estimates for peak flows, the 1:2-year annual volume was substantially higher for the modelled result than the basin transfer estimate for ARF. As such, the projected increase to loadings for ARF based on the modelling is also higher than basin transfer estimates for the Current (water quality multiplier of 67.7 versus 3.1) and Fully Drained (water quality multiplier of 89.3 versus 10.9) temporal scenarios. As WSA indicates (Johnson, 2022), it may be possible to estimate lower volumes with a different source station.

8. RECOMMENDATIONS

In consideration of the purpose of this modelling, no recommendations are made for additional work. Should WSA or SRC require additional scenarios or adjustments to modelling parameters these changes can be incorporated into future work as and when required.

9. LIMITATIONS

NewFields Canada Mining & Environment ULC (NewFields) has prepared this document in a manner consistent with the level of care and skill ordinarily exercised by the engineering and geoscience professions practicing in similar conditions within the jurisdiction that the services are provided, subject to time limits and physical constraints applicable to this work. No other warranty, express or implied, is made.

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10. CLOSURE

NewFields would like to thank SRC and WSA for the support its personnel provided during this assessment. We trust that this information meets your needs at this time. Should any portion of this report require further information or clarification, please do not hesitate to contact the undersigned.

Sincerely,

NewFields Canada Mining & Environment ULC

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Reviewed by:

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APPENDIX 1

WSA FLOW CONTROL ESTIMATES

Arm River Peak Flow Estimates

The hydrologic assessment for the Arm River Project was done based on Pre-Augmentation, Current Drainage and Fully Drained Scenarios. The Drainage Areas were identified using imagery, LiDAR, and site visits by Tyrel Lloyd, WSA staff and the QP's.

The Drainage areas are listed in Table 1. The Peak flow estimates without flow controls are shown in Table 2. The peak flow estimates with flow controls are shown in Table 3. The effectiveness of the flow controls depends on the size of the wetland/storage volume behind the flow control structure, and depth of the storage. In some cases, the spill point is overtopped in a 1 in 5 flood event, in other cases the storage is large enough to handle larger flood events.

Table 1 Drainage areas for the Different Drainage Scenarios

Pre-Augmentation Drainage Scenario		Current Drainage Scenario		Maximum Drainage Scenario	
Effective Drainage Area (km^2)	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Gross Drainage Area (km^2)
2.20	23.85	6.90	23.85	23.85	23.85

Table 2 Peak Flow Estimates for Outlet of the Arm River Project, without Flow Controls

Event Return Period (years)	Pre-Augmentation Drainage Scenario (m^3/s)	Current Drainage Scenario Flows (m^3/s)	Maximum Drainage Scenario Flows(m^3/s)
1 in 2	0.094	0.223	0.566
1 in 5	0.229	0.539	1.368
1 in 10	0.347	0.819	2.080
1 in 25	0.521	1.229	3.120
1 in 50	0.646	1.524	3.868

Table 3 Peak Flow Estimates for Outlet of the Arm River Project, with Flow Controls

Event Return Period (years)	Pre-Augmentation Drainage Scenario (m^3/s)	Current Drainage Scenario Flows (m^3/s)	Maximum Drainage Scenario Flows(m^3/s)
1 in 2	0.094	0.123	0.366
1 in 5	0.229	0.152	0.607
1 in 10	0.347	0.585	1.61
1 in 25	0.521	1.129	2.89
1 in 50	0.646	1.5	3.80

Fort a la Corne Project Peak Flow Estimates

Without Flow controls, Peak Mean Daily flow estimates at the outlet of the Project						
Drainage Scenario	Contributing Area (km^2)	Peak Mean Daily Flows (m^3/s) for Return Periods (1 in 2 year to 1 in 50 year Events				
		2	5	10	25	50
Pre-Drainage	1.91	0.26	0.52	0.72	1.02	1.27
Current Situation	39.61	2.50	5.05	7.02	9.88	12.31
Fully Drained	71.36	3.89	7.85	10.92	15.36	19.14

With Flow controls, Peak Mean Daily flow estimates at the outlet of the Project						
Drainage Scenario	Contributing Area (km^2)	Peak Mean Daily Flows (m^3/s) for Return Periods (1 in 2 year to 1 in 50 year Events				
		2	5	10	25	50
Pre-Drainage	1.91	0.26	0.52	0.72	1.02	1.27
Current Situation	39.61	2.42	4.09	6.37	9.41	12.31
Fully Drained	71.36	3.80	6.73	10.26	14.89	19.14

Reductions in Events from Flow Controls		
Flow Event	Current Situation Flow Reduction (m^3/s)	Fully Drained Scenario Flow Reduction (m^3/s)
F:2	0.084	0.084
F:5	0.959	1.119
F:10	0.654	0.654
F:25	0.470	0.470
F:50	0.000	0.000

June 15, 2022
DJJ

Davidson Reservoir – Gust Farms Project

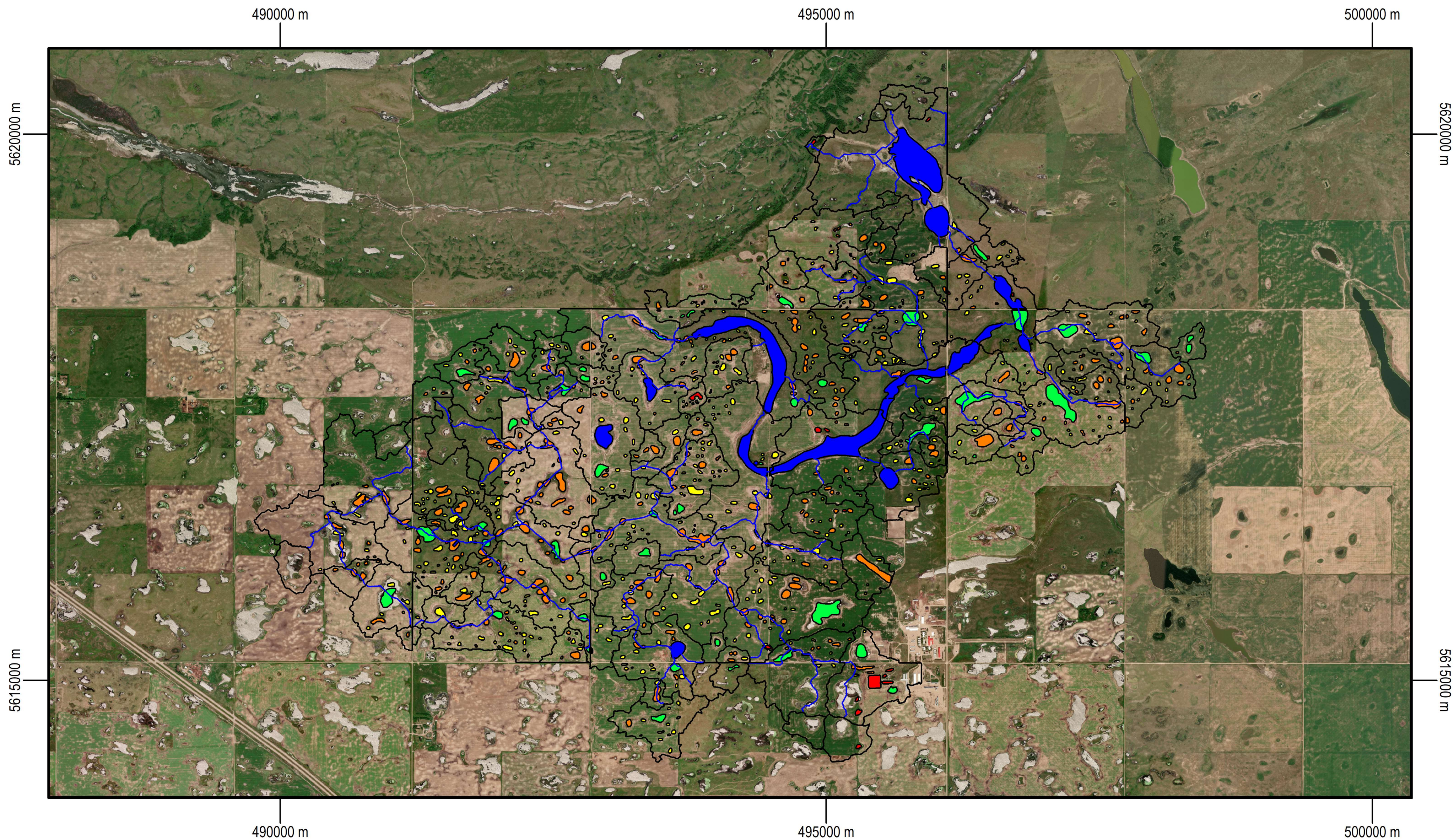
Different Flows for the Davidson Reservoir for the Different Drainage Scenarios						
Event Return Period (years)	Pre-Augmentation Drainage Scenario		Current Drainage Scenario		Maximum Drainage Scenario	
	Inflow (m^3/s)	Outflow (m^3/s)	Inflow (m^3/s)	Outflow (m^3/s)	Inflow (m^3/s)	Outflow (m^3/s)
1 in 2	0.13	0	0.54	0	1.06	0.7
1 in 5	1.0	0	1.42	1.06	2.82	2.54
1 in 10	1.90	1.56	2.27	2.20	4.50	4.44
1 in 25	2.90	2.88	3.59	3.56	7.13	7.09
1 in 50	3.50	3.49	4.88	4.85	9.70	9.67

Peak Flow Estimates for the Grid Road Downstream from the Davidson Reservoir and for Highway 11			
Event Return Period (years)	Pre-Augmentation Drainage Scenario (m^3/s)	Current Drainage Scenario Flows (m^3/s)	Maximum Drainage Scenario Flows(m^3/s)
1 in 2	0	0	0.7
1 in 5	0	1.06	2.54
1 in 10	1.56	2.20	4.44
1 in 25	2.88	3.56	7.09
1 in 50	3.49	4.85	9.67

Peak Flow Estimates for the Highway 747 Upstream from the Davidson Reservoir			
Event Return Period (years)	Pre-Augmentation Drainage Scenario (m^3/s)	Current Drainage Scenario Flows (m^3/s)	Maximum Drainage Scenario Flows(m^3/s)
1 in 2	0.026	0.413	0.962
1 in 5	0.804	1.27	2.66
1 in 10	1.68	2.09	4.29
1 in 25	2.69	3.38	6.85
1 in 50	3.30	4.67	9.39

APPENDIX 2

REPORT FIGURES



Subbasin Boundary
1 - Ephemeral/Not Classified
2 - Temporary
3 - Seasonal
4 - Semi-permanent
5 - Permanent
Stream Alignment

0.5 km 1.5 km 2.5 km

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Figure 1: Arm River Farms - Wetland Classifications

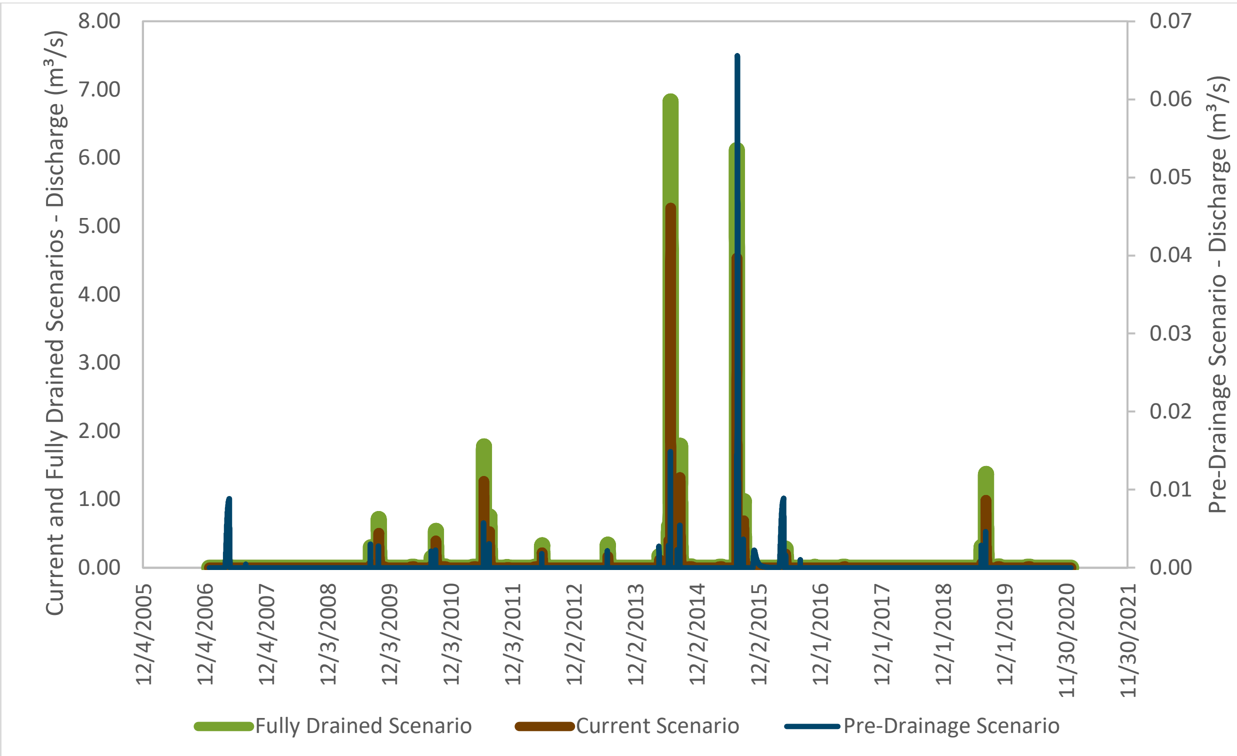
Project Number: 680.000034.000

Project Title: Hydrological Changes from Agricultural Drainage

Date: August 11, 2022

Projection: UTM NAD83 Zone 13
References: Global Mapper World Imagery

Figure 2: Modelled Hydrographs



APPENDIX 3

REPORT TABLES

Table 1: Flow Controls Efficacy

Demonstration Project	Temporal Scenario	Peak Flow Reduction (%)				
		1:2	1:5	1:10	1:25	1:50
Arm River Farms	Pre-Drainage	0.0	0.0	0.0	0.0	0.0
	Current	44.8	71.8	28.6	8.1	1.6
	Fully Drained	35.3	55.6	22.6	7.4	1.8
Fort-a-la-Corne	Pre-Drainage	0.0	0.0	0.0	0.0	0.0
	Current	3.3	23.5	10.2	5.0	0.0
	Fully Drained	2.4	16.6	6.4	3.2	0.0
Gust Farms	Fully Drained	42.8	21.5	14.3	13.5	13.3

Table 2: Water Quality Multiple based on Basin Transfer Volumes

Demonstration Project	Temporal Period and Spatial Representation	Drainage Area (km^2)	1:2-Year High Volume (m^3)	Water Quality Multiple
Arm River Farms	EDA - Pre-Drainage	2.2	8.2	1.0*
	EDA - Current	6.9	25.8	3.1
	Full Drained	23.9	89.3	10.9
Fort-a-la-Corne	EDA - Pre-Drainage	1.9	86.4	1.0*
	EDA - Current	39.6	1801.8	20.8
	Full Drained	71.4	3248.7	270.7
Gust Farms	EDA - Main Drainage - Pre-Drainage	3.6	40.6	1.0*
	EDA - Main Drainage - Current	20.8	234.6	5.8
	Fully Drained - West and Main Drainage	60.7	684.5	12.4

* denotes base case scenario

Table 3: Annual Precipitation (mm)

Month	Year													
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	4.9	5.1	14.8	10.0	19.2	3.3	15.1	5.6	12.8	5.9	3.8	3.3	4.8	5.8
Feb	7.7	6.6	6.8	2.4	8.5	1.7	9.7	2.6	14.1	6.3	8.4	4.3	12.3	2.8
Mar	14.2	1.6	2.5	0.8	5.0	7.5	15.4	13.8	19.4	19.4	4.4	21.0	0.8	4.9
Apr	19.2	11.4	26.0	43.5	11.1	45.4	10.6	62.4	13.2	10.2	20.2	5.1	20.2	5.4
May	81.5	11.6	25.3	89.0	58.8	100.4	11.0	37.2	9.6	73.5	6.9	25.4	11.3	13.2
Jun	21.4	68.8	44.2	72.7	135.6	27.0	72.4	207.7	19.9	58.3	46.0	43.9	76.7	44.7
Jul	33.8	100.8	30.6	57.1	53.5	61.4	42.4	19.9	129.1	74.3	1.8	19.5	50.3	76.1
Aug	52.2	46.6	63.8	104.2	52.7	18.3	24.2	134.8	55.8	58.3	11.1	17.4	95.7	16.2
Sep	12.8	20.2	29.3	79.9	16.8	0.4	41.6	30.7	55.0	54.0	11.1	27.6	78.5	11.2
Oct	15.6	35.0	77.3	11.1	24.2	16.4	4.4	23.2	31.4	64.5	22.2	22.6	10.6	2.7
Nov	3.8	11.4	4.5	21.7	8.4	28.5	11.2	18.7	12.0	6.7	11.2	8.2	11.3	11.7
Dec	6.7	10.5	9.6	10.5	14.2	11.7	10.5	5.0	9.9	5.7	4.3	5.2	2.3	8.1
Total	273.8	329.6	334.7	502.9	408.0	322.0	268.5	561.6	382.2	437.1	151.4	203.5	374.8	202.8

Table 4: Monthly Average Lake Evaporation (mm)

Month	Average
Jan	0.0
Feb	0.0
Mar	0.0
Apr	66.0
May	176.8
Jun	175.0
Jul	189.9
Aug	188.5
Sep	134.9
Oct	60.1
Nov	0.0
Dec	0.0

Table 5: Annual Peak Discharge

Year	Annual Peak Discharge (m^3/s)		
	Pre-Drainage	Current	Fully Drained
2007	0.009	0.017	0.018
2008	0.000	0.000	0.003
2009	0.003	0.507	0.715
2010	0.002	0.395	0.542
2011	0.006	1.264	1.776
2012	0.002	0.220	0.331
2013	0.002	0.163	0.339
2014	0.015	5.267	6.826
2015	0.066	4.534	6.115
2016	0.009	0.201	0.282
2017	0.000	0.017	0.018
2018	0.000	0.000	0.000
2019	0.005	0.989	1.373
2020	0.000	0.017	0.018

Table 6: Annual Flow Volume

Year	Annual Flow Volume (m³)		
	Pre-Drainage	Current	Fully Drained
2007	14256	33804	35801
2008	185	185	1108
2009	685	250048	387047
2010	598	261591	360342
2011	1023	591478	773926
2012	341	116384	152202
2013	371	62170	115375
2014	2596	1799707	2280590
2015	34302	1181951	1499935
2016	15275	113655	159977
2017	185	23743	36211
2018	185	185	185
2019	828	337223	500793
2020	185	34225	36218
Average	5072	343311	452836
Water Quality Multiple	1.0	67.7	89.3