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PHASE 1

DOWNSTREAM EFFECTS OF EXCESS MOISTURE IN MANITOBA

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BRANDON UNIVERSITY

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Manitoba Canola Growers

Manitoba Wheat and Barley Growers Association

Manitoba Pulse Soybean Growers

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Foreword

Manitoba's rapidly changing climate conditions are characterized by increased frequency and intensity of extreme moisture events. For instance, four of the top ten Assiniboine River floods and five of the top ten Red River floods took place during the last 25 years. In addition to these spring floods, other extreme moisture events include prolonged or intense periods of rain. Generally, from an ag-producer's perspective, these events result in soil moisture in extreme of field capacity for a period sufficient to significantly inhibit crop production.

Moreover, the impacts of such events can be local or regional as well as downstream. For producers, the impacts may be short-term, prolonged or persistent depending on the locale, previous moisture mitigation strategies, and the local and regional water infrastructure. These extreme water events harm farm livelihoods as well as the well-being of all downstream rural municipalities and urban centres having to deal with the social, economic and environmental costs due transportation interruptions, property damage, and agricultural run-off impacts on surface and ground water quality.

There are several longer term strategies producers can invest in to manage extreme moisture in their fields. Reducing the risk of crop loss or reductions in yield and quality are generally the main reasons why producers make such investments. Others at the local and regional levels may also benefit from these water management practices as well (e.g., reduced peak flows). This project aims to provide agricultural producers at the early stage of long-term planning with critical factors in estimating socio-economic costs and benefits of different on-farm extreme moisture practices, along with identifying other stakeholder considerations.

To achieve that goal, this project consists of three main activities and took place in two distinct phases. The focus of Activity 1 was to provide producers with an on-farm costs and benefits framework to help evaluate different investment strategies for managing extreme moisture. Activity 2 focused on using farm models to provide information on the impact on yield and farm income due to extreme moisture. Lastly, Activity 3 focused on identifying the downstream impacts and costs of extreme moisture events with a particular focus on the 2011 Assiniboine River flood. For each activity, Phase 1 consisted of gathering and synthesizing academic and other publicly available information and data. Phase 2 of the project sought to get feedback from producers and other stakeholders in an effort to validate the findings of the Phase 1 activities. Overall, the 2 phases of the 3 activities of this project resulted in the completion of 6 reports which are outlined in Figure 1.

Summary of the 6 reports indicating the main objectives for each phase and activity

	ACTIVITY 1	ACTIVITY 2	ACTIVITY 3
	Economic Costs and Benefits Analysis of Excess Moisture Investments	**Impacts of Excess Moisture on Crop Field and Farm Income**	**Downstream Effects of Excess Moisture in Manitoba**
PHASE 1	1. Identify farm investment options for excess moisture management. 2. Identify of on- and off-farm costs and benefits of investment options. 3. Quality costs and benefits of investment options and select suitable proxies for qualitative costs and benefits. 4. Develop a framework to assess costs and benefits of excess moisture investment options.	1. Identify, calibrate and adapt a farm model that could be simulating the impact of excess moisture events in southern Manitoba's field conditions.	1. Identify the physical and socio-economic impacts of excess moisture 2. Identify the direct the indirect costs excess moisture losses. 3. Identify the downstream economic impacts of excess moisture.
PHASE 2	1. Validate the economic cost-benefit framework of proposed investment options of farm-level extreme moisture management. 2. Determine what extreme moisture management strategies are currently being use. 3. Evaluate the willingness of producers to adapt their farm using proposed extreme moisture management strategies. 4. Conduct a Manitoba local market survey to validate cost estimations used in the development of cost-benefit framework.	1. Identify current yield forecasting tools available and being used by stakeholders at different scales of operations. 2. Evaluate the willingness of producers and other stakeholders in crop yield forecasting models.	1. Validate the completeness and accuracy of the physical and socio-economic impacts of excess moisture. 2. Assess the relevance and usefulness of the information for the procedures and stakeholders. 3. Identify other effects, outcomes, and strategies that producers and stakeholders considered in response to the 2011 Assiniboine River Flood

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Executive Summary

Changes in climatic conditions are now widely accepted with forecasts of increasing extremity and variability of weather events in the Prairies' provinces of Canada. Manitoba's rapidly changing climate conditions are characterized by increased frequency and intensity of excess moisture events. Excess moisture in the Prairies has occurred due to significant rainfall events in summer and fall and the impact of high volumes of snowmelt runoff in spring. Manitoba has a long history of flooding, including major floods in 1950, 1997 and 2009, and the most recent flood of 2011 was of a scope and severity never experienced in the province. According to the Manitoba 2011 Flood Review Task Force Report, costs associated with flood preparation, flood fighting, repair to infrastructure and disaster payments have reached $1.2 billion (Government of Manitoba, 2013). Also, eutrophication is another major issue in Manitoba. According to Bourne et al., 2002, Lake Winnipeg is the most eutrophic lake globally. Within Manitoba, watershed processes such as the runoff of nutrients from diffuse agricultural sources and natural processes contribute the most enormous mass of nutrients to both the Assiniboine and Red Rivers. Major flood damages were incurred in communities and infrastructure along the Assiniboine River basin during the 2011 Manitoba flood. The floods destroyed some First Nations communities along with the Lake St. Martin. Temporal flood control measures were implemented to mitigate the effect of the floods in communities along the Assiniboine River basin even though the damage caused to agriculture and individual property damage was extensive. This project has three main activities: determining on-farm investment options for managing excess moisture, examining on-farm events in detail, and downstream costs and benefits. This report aims to focus on the objectives of Activity – 3 by identifying the impact of excess moisture at on-farm downstream and community downstream. The report will focus on the Assiniboine River basin in Manitoba as the primary unit of analysis. Additionally, the direct and indirect losses of excess moisture will be assessed and the economic quantification of these impacts.

Activity 3

Identification of downstream costs and benefits of excess moisture event
Objectives:

1. Identification of impacts of excess moisture
2. Identification of direct and indirect excess moisture losses
3. Identification of downstream economic impacts of excess moisture

Introduction

Excess moisture as used in this report refers to soils where the volumetric water content exceeds field capacity for periods greater than 2- or 3-days giving rise to conditions that may be harmful to soils and crops (Bedard-Haughn, 2009). In some of the scientific literature, this phenomenon is referred to as waterlogging. When soil cannot transmit water, leading to the onset of saturated conditions harmful to topsoil and crops, excess water conditions develop. Negative agricultural impacts include reduced trafficability by tractors, physical damage to crops, increased soil erosion, reduced nutrient and chemical availability to plant, and increased loss in crop yields.

In recent years, major rainfall events during the summer and fall and high volumes of snowmelt runoff the following spring have resulted in excess water in some areas of the Prairies. The Manitoba Flood Review Report (2013) indicates antecedent conditions, winter snowpack and summer rains combined to produce the 2011 Manitoba floods. In summer and spring 2011, the Assiniboine River and its tributaries underwent a flood of unprecedented proportions. It was the largest recorded in the over 100 years that flow records have been kept on the Assiniboine River (Blais et al., 2016). The 2011 Assiniboine flood cost an estimated $1.5 billion in damages, millions of acres of crop drowned, accounting for $1 billion of the damages in addition to 2.3 million acres of unseeded land (MASC, 2011).

This project aims to assist Manitoba producers in better understanding on-farm investments to manage excess moisture and catalogue downstream impacts of such events. The analysis will take place in multiple phases. Three activities frame phase-1 of this project:

Activity – 1: A selection of 3-5 investment strategies to manage on-farm excess moisture.

Activity – 2: Adaptation of a farm model to assess the impact of excess moisture on crop yield and farm income.

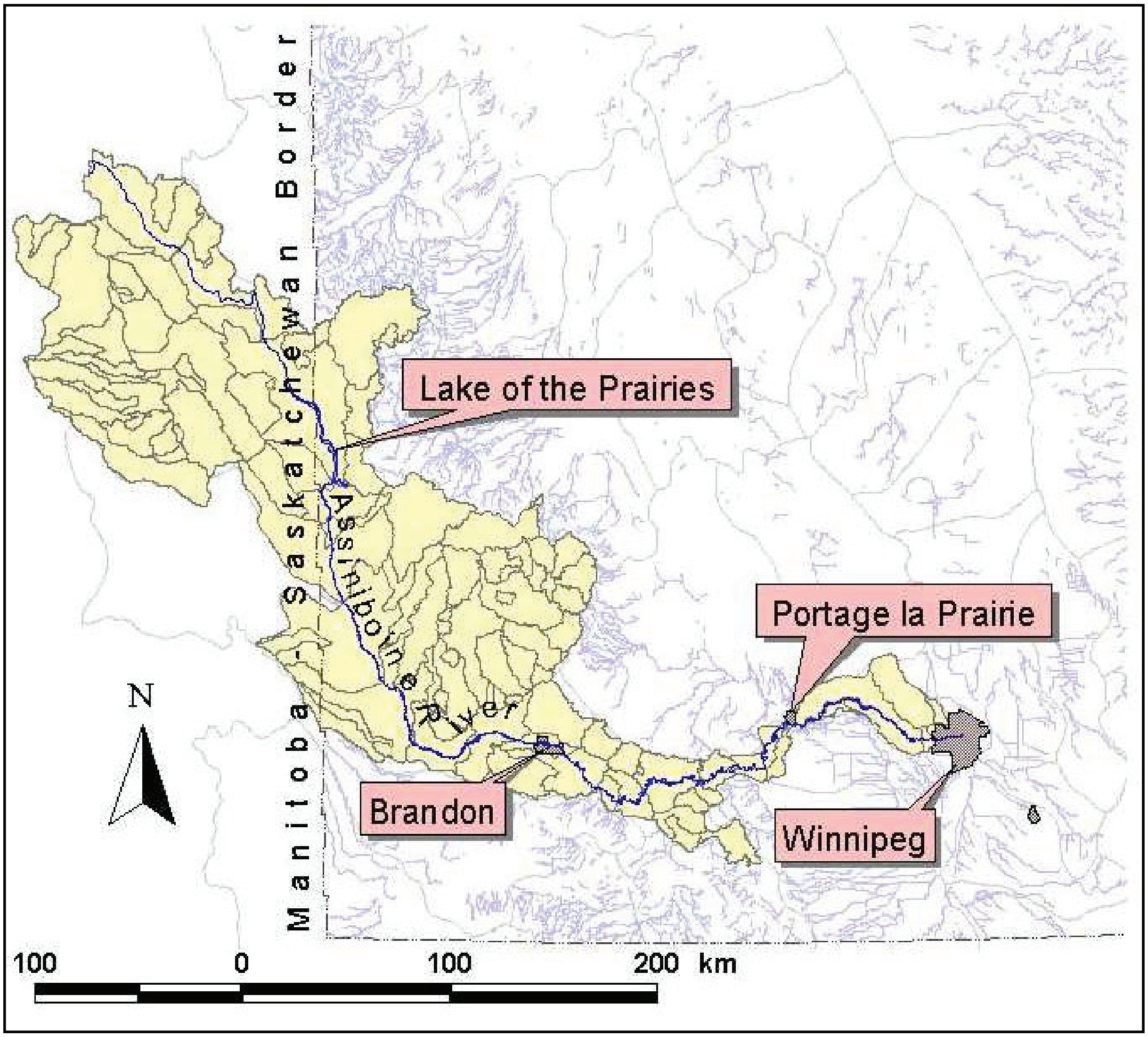
Activity – 3: Identification of downstream costs and benefits of excess moisture management.

The aim of this report is to focus the objectives of Activity – 3 by assessing the impact of excess moisture at on-farm downstream and community downstream. The report will focus on the Assiniboine River basin in Manitoba as the primary unit of analysis. Additionally, the direct and indirect losses of excess moisture will be assessed as well as the economic quantification of these impacts.

Study Area (Assiniboine River Basin)

The Assiniboine River watershed stretches from its headwaters in eastern Saskatchewan to the City of Winnipeg at the confluence with the Red River. The Assiniboine River basin is approximately 41,500 km^2 in size. About 60% of the basin is located within Manitoba (Figure 1). Land use in the basin is dominated by agriculture. The population in the basin is estimated to be about 849,534 including residents of the City of Winnipeg. The Assiniboine River provides essential habitat for about 40 species of fish, while its shoreline supports numerous plant and animal species. The Assiniboine River serves as the raw water source for the cities of Brandon and Portage la Prairie. Water drawn from the river is also used for irrigation and for facilities such as food processing industries (Assiniboine River Report, 2008; City of Winnipeg, 2020). The summary profile of the Assiniboine is shown in Table 1 and Table 2.

Figure 1: The Assiniboine River Basin



Source: (Assiniboine River Report, 2008)

Table 1: Characteristics of the Assiniboine River Basin

Area	41,500 km^2
Volume	Annual supply volume of 135.7 million cubic metres of which 86.3 million cubic metres are currently allocated to industrial, municipal, and agricultural needs.
Water Quality	Measured by the Water Quality Index (WQI), the Assiniboine river fall in the range of 60-94. Which is between fair and good on the water quality index scale.
Types of Soils	The Assiniboine series consists of imperfectly drained Gleyed Cumulic Regosol soils developed on moderately to strongly calcareous, stratified, clayey (SiC, C) alluvium deposits. Slightly water-eroded, non-stony, and non-saline. High availa-ble water holding capacity. Medium organic matter content, and medium natural fertility.
Farms	Predominant farms in Manitoba are Cattle (35.3%), Oilseeds (25.8%) and Wheat Farms (9.8%)
Agricultural Products	Wheat Hard Red Spring, Beef, Soybeans, Barley, Oats, Rye, Canola, Corn, Wheat Winter, Wheat Northern Hard Red.

Source: (Assiniboine River Report, 2008; Water Quality Report, 2010; AgriMap, 2010; Statistics Canada, 2014; MASC, 2011)

Table 2: Profile of the Assiniboine Basin at different locations

Location	Soil Type/ texture	Topography	Permeability	Permeability rates	Agricultural Activity
Brandon	Silty Clay Loam or Clay loam texture	Level to gentle undulat-ing	Moderately slow	12-48cm/day	Wheat
Portage la Prairies	Alluvia Silt to Silt Clay (Not differentiated)	Gently sloping to irregular sloping	Slow	3-12cm/day	Wheat, Oats, rye
Winnipeg	Silty Clay Loam or Sandy loam	Gently sloping to irregular sloping	Slow to Moderate	3cm/day-151cm/day	Canola, Wheat, Barley, Oats, Flaxseed

Source: (Canada Manitoba Soil Survey, 1976; Canada Manitoba Soil Survey, 1972; FAO, 2019)

Identification of impacts of excess moisture

Too much moisture in plants and the soil can have negative effects on your agricultural efforts. Excessive moisture can be caused by several factors. For example, prolonged rainfall, snowmelt runoff, and flooding from rivers/dams overflowing can cause massive damage all at once, and leave crops oversaturated. The effects of excess moisture downstream are summarized in Table 3.

Table 3: Comparing the effects of excess moisture events on-farm and downstream

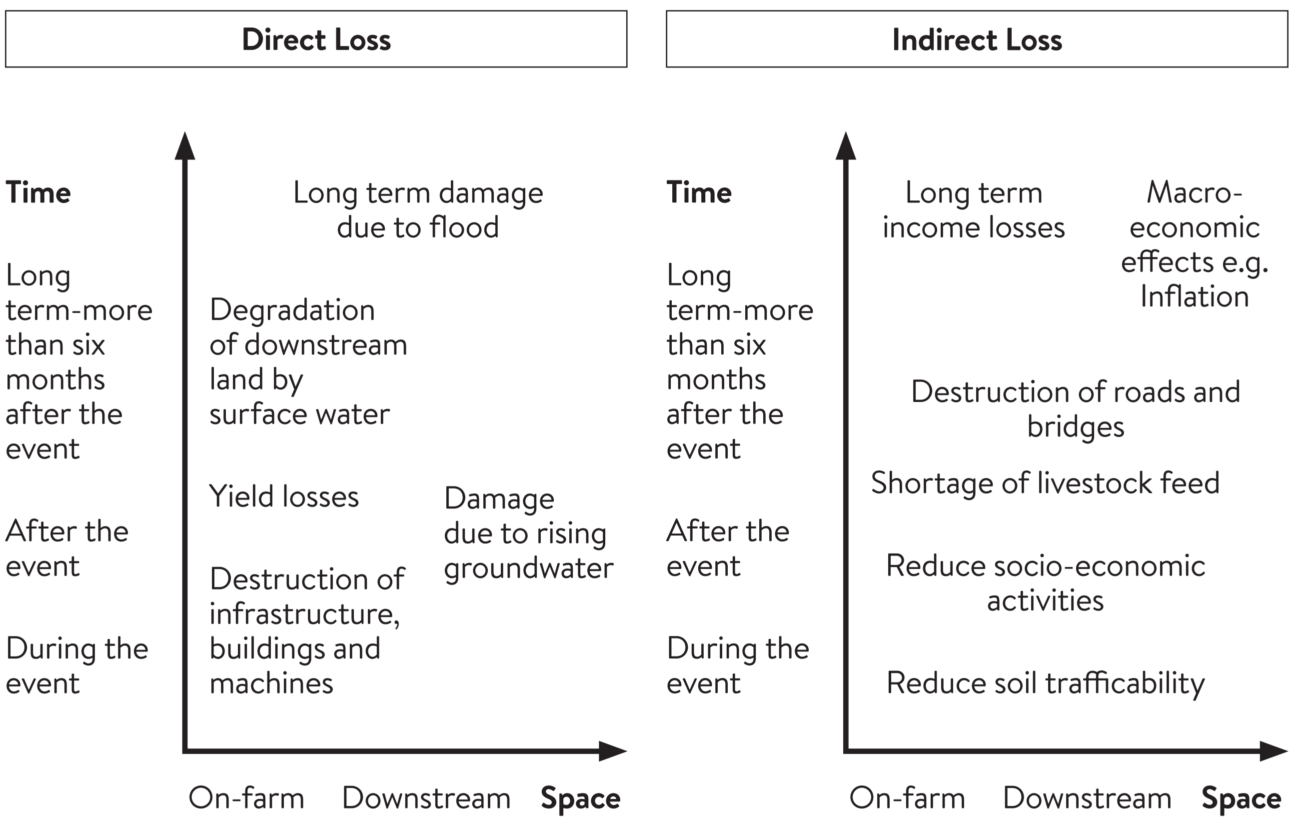
Effects	On-farm downstream	Community downstream
Degradation of downstream land by surface water	On-farm excess moisture caused 600,000 acres of land to be unseeded. (MASC, 2011) Soil carbon losses In the range of 29–35%. (Jacinthe et al., 2004)	Destruction of community river dikes (Manitoba Flood Report, 2013)
Groundwater pollution	In the absence of subsurface drain, nitrate concentration will increase the groundwater level of nitrate above 10mg/l, nitrifying ammonium is estimated to cost City of Winnipeg $100 million (Schindler et al., 2012; Schubert et al., 1999)	Nitrate infiltration into groundwater can affect the quality of drinking water and pose a severely low level of oxygen in infants (Spalding and Exner, 1993)
Land Erosion	Runoff water increases the amount of topsoil loss by a factor 10 on a 10% (Skaggs & Broadhead, 1982)	Damage to roads and bridges. 2011 floods of Manitoba damages 650 roads and 600 bridges (Blais et al., 2015)
Damage to Infrastructure, buildings, and machines	Damage to irrigation systems, buildings, machinery and equipment, drainage systems (Thieken et al., 2009)	Damage to community infrastructure and private properties. (MASC, 2011) Decrease of 2–5% of property value for all properties in the flood plain. (Braden & Johnston, 2004)
Nutrients and Chemicals Losses and Leaching	The farmer loses 1% - 5% of herbicide to surface runoff (Bowman et. al., 1994)	Phosphorus and nitrogen removal and denitrification by the City of Winnipeg has been estimated to cost $400 million (Schindler et. al., 2012)

Effects	On-farm downstream	Community downstream
Reduce soil trafficability	Reduction in optimum stocking rate by 0.6–0.9 cows/ha. Damage to fields by wheels can range in extent from 20 to 35% for each operation. (Tullberg, 2000; Fitzgerald et al., 2008)	Provision of bridges for affected communities (Manitoba Flood Report, 2013)
Loss in Yield	In 2011 excess moisture caused 73 percent of the crop losses in Manitoba. (MASC, 2011)	N/A
Soil compaction	Soil Clogging	Waterlogging
Reduced Socio-economic activity	Financial assistant to farmers in the flood zone (MASC, 2011)	Financial assistance to landowners and business owners in a flood zone (MASC, 2011)
Shortage of feed for Livestock	Shortage in livestock feed due to excess moisture. $9,551, 000 paid to livestock producers (MASC, 2011)	Damage to livestock barns and stored feed (Flood Facts Sheet, 2017)

Assessment of direct and indirect flood losses

While direct flood damage occurs due to the physical contact of objects with the floodwater, indirect damage is induced by flooding but occurs in space or time outside the actual event (Thieken et al., 2009). Other studies have assessed direct and indirect flood costs using space and time diagrams (van der Veen et al., 2003). The cost of the flood is explained with time; during the event, after the event and more than six months after the event. The direct and indirect tangible costs associated with the excess moisture events; space-time diagrams are shown in Figure 2.

Figure 2: Direct and Indirect flood losses and their spatial and temporal occurrence



Source: (Thieken et al., 2009)

All the costs for the 2011 Manitoba flood are classified based on direct and indirect costs and it is represented in Table 4.

Table 4: Identification of direct and indirect cost of excess moisture of the 2011 Manitoba flood

Direct Cost	Indirect Cost
Damage to Infrastructure	Reduce socio-economic activity
Yield losses	Reduce Soil trafficability
Chemical and Nutrient Losses	Shortage of Livestock feed
Eutrophication of Lake Winnipeg	Land Erosion
Groundwater Pollution	Shortage of livestock feed Soil quality decline

Downstream Economic Impacts of Excess Moisture (2011 Manitoba Floods)

The 2011 flood on the Assiniboine River was called a one-in-350-year event. Through much of that spring, Lake Manitoba was being fed by floodwaters from the bloated Assiniboine River. Water from the river was channeled north via the Portage Diversion. As a result, the lake level was pushed to record heights and coupled with a major storm, it spilled into cottages, businesses and across farms in nearby communities. Many First Nations people were displaced from their homes including communities of Lake St. Martin. This caused the federal and provincial governments to invest in flood mitigating structures and support packages to affected individuals and farmers. Table 5 summarizes the extent of investments at both the local and regional levels and the cost of these investments. The graph of the 2011 Manitoba excess moisture losses is shown in Figure 3.

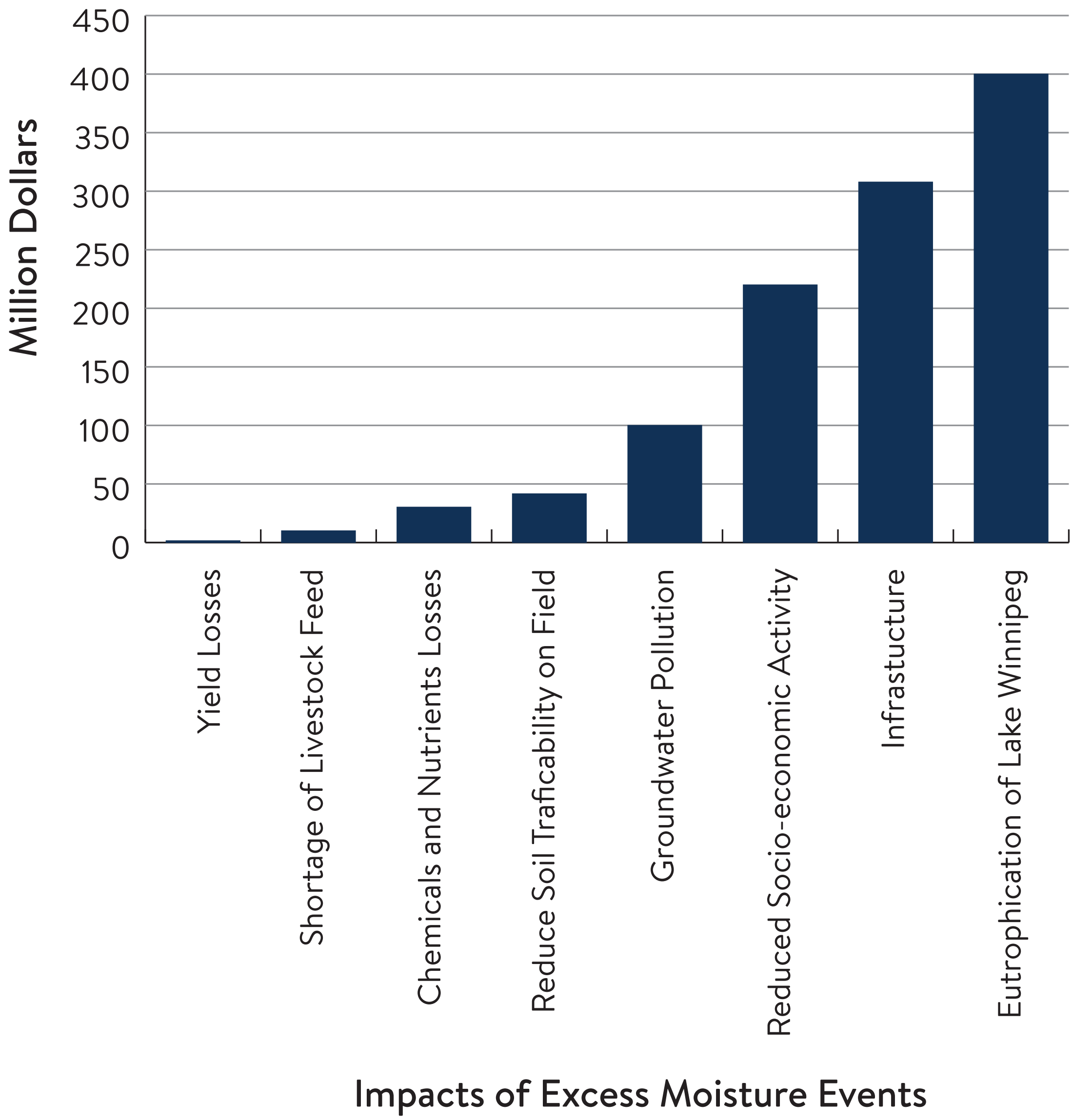
Table 5: 2011 Manitoba Excess Moisture Events and Mitigating Investments

Location on Assiniboine Basin	Impact of Excess Moisture	Downstream excess moisture mitigation Investment/impact	Level of impact	Amount of investment/lost
Brandon	Damage to Infrastructure	Provision of Community diking worth.	Local	$27 million (Government of Manitoba, 2014)
Portage la Prairies	Damage to Infrastructure	Portage Diversion: assessment and upgrading	Local	$7.4 million (Manitoba Water Stewardship, 2013)
Winnipeg	Damage to Infrastructure	Winnipeg secondary ring dikes Petersfield Community dikes	Local	$10.4 million (Manitoba Water Stewardship, 2013)
Shellmouth	Damage to Infrastructure	Install gates on the spillway Wave Breaking Trial Program	Local	$8 million (Manitoba Water Stewardship, 2013)
Lake St. Martin	Damage to Infrastructure	Emergency channel to drain water to Lake Winnipeg	Regional	$100 million (Manitoba Flood Report, 2013)
Fair ford	Damage to Infrastructure	A control bypass to draw down on Lake Manitoba	Local	$60 million (Manitoba Flood Report, 2013)
Souris, Melita, Wawanesa, Lake Manitoba Narrows, Peltz Drive/St. Peter's Road	Damage to Infrastructure	Converting emergency dikes into permanent dikes	Regional	$20 million (Manitoba Water Stewardship, 2013)
Individual Flood Protection	Damage to Infrastructure	For raising, diking, terracing or moving Homes, and farm and business buildings, cottages	Regional	$75 million (Manitoba Flood Report, 2013)
Disaster Financial Assistance	Reduce Socio-Economic Activity	Financial assistance to business owners, homeowners, and agricultural claims	Regional	$45 million (Manitoba Flood Report, 2013)
Manitoba Farms	Chemicals and Nutrients losses	Fertilizer (phosphate) losses	Local	$9M

Location on Assiniboine Basin	Impact of Excess Moisture	Downstream excess moisture mitigation Investment/impact	Level of impact	Amount of investment/lost
Manitoba	Eutrophication of Lake Winnipeg	Nutrient leaching to lake	Regional	Denitrification cost $400 million (Schindler et. al., 2012)
Manitoba	Groundwater pollution	Nitrate leaching into groundwater	Regional	Nitrate removal cost $100 million (Schindler et. al., 2012)
Assiniboine Valley Producers Flood Assistance Program	Loss of Yield	Provide Manitoba producers with financial assistance for yield losses	Regional	$1.5 million (MASC, 2011)
Manitoba feed and transportation Assistance program	Shortage of Livestock feed	Assist producers who had a shortage of overwinter feed for a breeding herd	Regional	$10 million
Manitoba Farms	Chemicals and Nutrients losses	Herbicide losses from farms	Local	$600,000 - $3,000,000 (Appendix)
Manitoba farms	Reduce Soil trafficability on field	Excess moisture Insurance program for 2.92 million acres unseeded agricultural land	Regional	$41.6 million (MASC, 2011)
Building and Recovery Action Plan at Manitoba	Reduce Socio-economic activity	• Hoop and Holler Compensation. • Property Tax Relief • Business Principal and Non-Principal Residence • Manitoba Pasture Flooding Assistance • Lake Manitoba Ag Infrastructure Transportation and Crop/ Forage Loss • Shoal Lakes Agriculture Flooding Assistance • Excess Moisture Economic Stimulus • Dauphin River Flood Assistance	Regional	$175 million (Manitoba Flood Report, 2013)

Source: (Manitoba Flood Report, 2013; MASC, 2011; Schindler et. al., 2012; Water Quality Report, 2016; Muir and Baker, 1976; Government of Manitoba, 2014)

Figure 3: 2011 Manitoba Excess Moisture Losses



Conclusion

The impact of excess moisture in Manitoba was identified through ten (10) on-farm and downstream effects focusing on the Assiniboine River Basin as the primary unit of analysis. The 2011 Manitoba Flood caused devastating effects on farms and communities along the Assiniboine River basin. The estimation of economic losses due to the flood indicates that the damage cost is likely over $1 billion. The damage costs were categorized into direct and indirect costs based on approaches of other authors in the field of flood mitigation. Flood control measures and investments implemented by the Manitoba Government were identified and grouped based on the ten on-farm and downstream effects mentioned. This is a need to understand outcomes of negotiations between upstream and downstream under certain regulatory regimes. This can ultimately contribute to better land and water management for retention and resilience on the Assiniboine River's catchment scale. A better farm intervention adapted to manage excess moisture at upstream level could overcome the reactive, disaster-driven character of flood at downstream level and contribute towards developing flood risk management that works on a pre-emptive basis.

References

Assiniboine River Report. (2008). Retrieved from https://www.gov.mb.ca/sd/waterstewardship/water_quality/quality/assiniboine_river-across_the_watershed.pdf (1/14/20).

AgriMap. (2010). Soil Series Description. Retrieved from https://agrimaps.gov.mb.ca/agrimaps/extras/info/Soil_Series_Descriptions.pdf (1/14/20).

Bedard-Haughn, A. (2009). Managing excess water in Canadian prairie soils: A review. Canadian journal of soil science, 89(2), 157-168.

Blais, E. L., Greshuk, J., & Stadnyk, T. (2016). The 2011 flood event in the Assiniboine River Basin: causes, assessment and damages. *Canadian Water Resources Journal/Revue canadienne des ressources hydriques*, 41(1-2), 74-84.

Braden, J. B., & Johnston, D. M. (2004). Downstream economic benefits from storm-water management. Journal of Water Resources Planning and Management, 130(6), 498-505.

Bowman, B. T., Wall, G. J., & King, D. J. (1994). Transport of herbicides and nutrients in surface runoff from corn cropland in southern Ontario. Canadian journal of soil science, 74(1), 59-66.

Canada Manitoba Soil Survey. (1976). Soils of the Brandon Region Study Area. Retrieved from http://sis.agr.gc.ca/cansis/publications/surveys/mb/mb30/mb30_report.pdf (1/12/20).

City of Winnipeg. (2020). Retrieved from https://winnipeg.ca/cao/pdfs/population.pdf (08/04/20).

Crop Production Cost. (2020). Cost of Production Retrieved from https://www.gov.mb.ca/agriculture/farm-management/production- economics/pubs/cop- crop-production.pdf (01/14/20).

FAO. (2019). Soil Permeability. Retrieved from http://www.fao.org/tempref/FI/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e09.htm (1/28/20).

Flood Facts Sheet. (2017). Preparing a Beef Farm for Flood Conditions in Rural Manitoba Retrieved from http://www.manitoba.ca/asset_library/en/spring_outlook/preparing_beef_farm.pdf (06/04/20).

Fitzgerald, J.B., Brereton, A.J. & Holden, N.M. (2008). Simulation of the influence of poor soil drainage on grass-based dairy production systems in Ireland. Grass and Forage Science, 63, 380– 389.

Jacinthe, P. A., Lal, R., Owens, L. B., & Hothem, D. L. (2004). Transport of labile carbon in runoff as affected by land use and rainfall characteristics. *Soil and Tillage Research, 77*(2), 111-123.

Manitoba Flood Reports. (2013). Retrieved from https://www.brandonu.ca/rdi/files/2016/01/ToppingSteve-Manitobas-Flood-of-2011.pdf (1/14/20).

Manitoba Agricultural Services Corporation. (2011). Lending and Insurance Report. Retrieved from https://www.masc.mb.ca/masc.nsf/annual_report_2010_11.pdf (13/03/2020).

Manitoba 2011 Flood Review Task Force. (2013). Report to the Minister of Infrastructure and Transportation plus appendices, Manitoba Government Publication.

Muir, D. C., & Baker, B. E. (1976). Detection of triazine herbicides and their degradation products in tile-drain water from fields under intensive corn (maize) production. *Journal of agricultural and food chemistry, 24*(1), 122-125.

Manitoba Soil Survey. (1972). Soils of the Portage la Prairie Area. Report No 17 Retrieved from http://sis.agr.gc.ca/cansis/publications/surveys/mb/mb17/mb17_report.pdf (1/12/20).

Manitoba Soil Survey. (1975). Soils of the Winnipeg Region Study Area. Retrieved from http://sis.agr.gc.ca/cansis/publications/surveys/mb/mbd14/mbd14_report.pdf (1/12/20).

Manitoba Water Stewardship. (2013). Recent flooding and flood mitigation in Manitoba. Retrieved from https://www.parc.ca/rac/fileManagement/upload/1_11_PRAC%20FloodMitigationInManitoba%20Sept21%2711_Kozera_complete.pdf (1/14/20)

Government of Manitoba. (2014). Brandon to enhance flood protection system. Retrieved from https://news.gov.mb.ca/news/index.html?item=31565&posted=2014-06-27 (03/21/20).

Schindler, D. W., Hecky, R. E., & McCullough, G. K. (2012). The rapid eutrophication of Lake Winnipeg: Greening under global change. *Journal of Great Lakes Research, 38*, 6-13.

Schubert, C., Knobeloch, L., Kanarek, M. S., & Anderson, H. A. (1999). Public response to elevated nitrate in drinking water wells in Wisconsin. Archives of Environmental Health: An International Journal, 54(4), 242-247.

Skaggs, R.W. & Broadhead, R.G. (1982). Drainage strategies and peak flood flows. ASAE, Paper, St. Joseph, MI.

Spalding, R.F., & M.E. Exner. “Occurrence of Nitrate in Groundwater--A Review,” *Journal of Environmental Quality*, 22, July-September 1993, pp. 392-402.

Statistics Canada. (2014). Sharp Decline in Number of Farms in Manitoba. Retrieved from https://www150.statcan.gc.ca/n1/ca-ra2001/first-premier/regions/farmman-fermeman- eng.htm#2 (01/14/20).

Thieken, A. H., Ackermann, V., Elmer, F., Kreibich, H., Kuhlmann, B., Kunert, U., & Schwarz, J. (2009). Methods for the evaluation of direct and indirect flood losses. In *RIMAX Contributions at the 4th International Symposium on Flood Defence (ISFD4).* Deutsches Geo Forschungs Zentrum GFZ.

Tullberg, J. N. (2000). Wheel traffic effects on tillage draught. *Journal of agricultural engineering researc*h, 75(4), 375-382.

van der Veen, A., Steenge, A. E., Bockarjova, M., & Logtmeijer, C. J. (2003). Structural economic effects of large-scale inundation: a simulation of the Krimpen dike breakage. *DC1-233.12.*

Water Quality Report. (2010). Retrieved from https://www.gov.mb.ca/sd/water/watershed/iwmp/central_assiniboine/documentation/water_quality.pdf (1/14/20).

Water Quality Report. (2006). Retrieved from https://fcpp.org/files/9/PProcessesBMPsinMB2006.pdf (3/3/20).

Appendix

Herbicide lost without excess moisture management

Without excess moisture management 1% - 5% of total herbicide will be lost to surface runoff (Bowman et. al., 1994). Fow wheat production, herbicide requirement for an acre of land is $68.44 (Crop Production Coat, 2020). If 100% of Herbicide=$68.44, therefore for 1% - 5% lost will amount to about 1$ - 3$ per acre of land. With about 600,000 acres of unseeded land due to excess moisture in 2011 (MASC, 2011), herbicide lost is estimated to be between $600,000 - $3,000,000.

Phosphate loss without excess moisture management Calculation

For Mono Ammonium Phosphate (11-52-0)-Manitoba P requirements

Recommended rate of P 2O 5 is 18.14kg/ac Using 11-52-0, the rate of fertilizer required is: (18x 100) / 52 = 34.62 kg/ac, 34.62kg/ac of 11-52-0 would also supply (11/100) x 34.62 = 3.8kg/ac of N.

NPK applied per acre of field = 38. 43kg which is (34.62+3.8)kg/ac

Phosphate applied per acre =34.62 kg/yr

Cost per lb. of P 2O 5 is = $0.264

Cost of Phosphate per kg = $0.581

Cost of Phosphate per acre = 34.62*$0.581= $20.11

Phosphate applied per acre =34.62 kg/yr

- Three quarter of phosphate is lost on Manitoba farmlands to surface runoff (Water Quality Report, 2016). Therefore, phosphate lost due to surface runoff= 26kg/ac/yr.
- Cost of Phosphate per kg = $20.11 If 34.62kg → $20.11, then 26kg → $15"

Therefore, a farmer who does not apply excess moisture management will lose $15/ac/yr. With 600,000 acres of unseeded land due to excess moisture in 2011, Phosphate lost is estimated at $9,000,000.

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