RURAL DEVELOPMENT INSTITUTE

PHASE 1

ADAPTING RISK TO RESILIENCE

A Study Report of Economic Costs and Benefits Analysis of Proposed Investment Options for Farm-Level Extreme Moisture Management

RURAL DEVELOPMENT INSTITUTE

BRANDON UNIVERSITY

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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 as a result of major rainfall events in summer and fall and also 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 before 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). In addition, eutrophication is another major issue in Manitoba. According to Bourne et al. (2002), Lake Winnipeg is the most eutrophic lake in the world, and within Manitoba, watershed processes such as runoff of nutrients from diffuse agricultural sources and from natural processes contribute the largest mass of nutrients to both the Assiniboine and Red Rivers. These issues necessitate the management of excess moisture at farm level to reduce the potential disaster as a result of a flood event in Manitoba.

The overall aim of this project is to assist Manitoba producers in better understanding on-farm investments to manage excess moisture and to 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 event

The aim of this report is to focus the objectives of Activity – 1 by demonstrating how different farm investment options adopted for excess moisture management could mitigate the negative impacts of floods and can also provide significant nutrient management and other types of co-benefits on the farm. With the base case representing current conditions, four other strategies are selected and used in southern Manitoba, namely: water reservoir, tile drainage, landscaping or cut and fill, and cover cropping. The size of the farm and intensity of excess moisture event will help in deciding the drainage options best suited for the area in order to reduce risk to farmers and the region. Initial costs for adaptability measures can be prohibitive for some operations and a thorough understanding of all operating costs and potential cash-flow are central to such a decision. The focus of this report is to quantify and monetize benefits, where data exists. We recognize when choosing an excess moisture management option, any current issues on the farm must be clearly identified in order to choose one or more approaches to invest in to address and solve on-farm problems. This report aims to provide farmers and decision makers the knowledge to make and support on-farm investment decisions related to managing times of excess moisture.

Activity 1

An Economic Costs and Benefits Analysis of Proposed Investment Options for Farm-Level Excess Moisture Management

1. Identification of farm investment options for excess moisture management
2. Identification of on- and off-farm costs and benefits of investment options
3. Quantify costs and benefits of investment options and select suitable proxies for qualitative costs and benefits
4. Development of a framework to assess costs and benefits of excess moisture investment options

Beginning at the beginning with defining excess moisture

In an agricultural setting, a significant amount of soil moisture that is sufficient to cause negative effects on agricultural operations, including excessive soil erosion, equipment trafficability, loss of seed, reduced crop yield/quality, and subsequently loss of farm income is regarded as excess moisture. Prolonged rainfall, spring snowmelt, and flooding from rivers/dams overflowing are biggest causes of excess moisture in the soil, and leave crops oversaturated.

Background

Agriculture is an important sector of Canada's economy and plays a vital socio-economic role in the Canadian Prairies. The Prairie region of Canada represents the northern geographic limit of arable land in North America and spans 550,000 km^2 across Alberta, Saskatchewan, and Manitoba (Tarnoczi, 2009). It makes up approximately 80% portion of agricultural land in Canada. Climate change and extremes in weather are continuously affecting Prairie agroecosystems. Agriculture is among the most vulnerable sectors to climate change due to its dependency on weather conditions. Climate change is likely to contribute substantially to food insecurity in the future, by increasing food prices, and reducing food production. Extreme weather conditions resulting from climate change effects create challenging decision-making situations for the agriculture industry in Canada. Climate models show that Canada's agricultural regions will likely see drier summers from coast to coast, but increased winter and spring precipitation. This means that farmers may have to deal with both too much water during the seeding season and too little water during the growing season, all in the same year (Climate Atlas of Canada, 2019).

Flooding can be viewed as an environmental risk and remains the most significant natural hazard worldwide. Manitoba's rapidly changing climate conditions are characterized by increased frequency and intensity of excess moisture events. These changes result in soil moisture in excess of field capacity or below wilting point for a period sufficient to inhibit crop production significantly. Effects of excess moisture events usually extend beyond the time and place in which they occur (e.g., affect investment planning, necessitate rejuvenate land back to health). Farm receipts statistics from Statistics Canada indicate that farm insurance receipts have increased by 126 % up to $73,777,000 over the last twenty years. Although, farm insurance receipts do not only cover damages resulting from excess moisture events, adapting to these changing conditions is hence a timely challenge for farmers.

Problem Statement

In Manitoba, main drivers of excess moisture conditions are intensive rainfall, and spring snow melt which result in flooding conditions at arable lands. Manitoba has a long history of flooding including major floods in 1950, 1997, 2009, and 2011. Four of the top ten Assiniboine River floods and five of the top ten Red River floods took place during the last twenty-five years. Manitoba's most recent flood of 2011 was of a scope and severity never before experienced in the province. Three million acres of cultivated farmland went unseeded in 2011. Thousands of cattle had to be relocated. More than 650 provincial and municipal roads and nearly 600 bridges were damaged, disrupting transportation networks throughout 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).

In addition to on-farm losses, eutrophication resulting from overland flow of excess water is another major issue in Manitoba. According to Bourne et al. (2002), Lake Winnipeg is the most eutrophic lake in the world, and within Manitoba, watershed processes such as runoff of nutrients from diffuse agricultural sources and from natural processes contribute the largest mass of nutrients to both the Assiniboine and Red Rivers. Within the Assiniboine River basin, watershed processes contribute 71 % of total nitrogen and 76 % of total phosphorous, while in the Red River basin they contribute 59 % of total nitrogen and 73 % of total phosphorus (Bourne et al., 2002).

Phosphorus is the main driver of the eutrophication issue in the downstream water bodies from predominantly agricultural land use areas, primarily because its dissolved form easily moves from land into water bodies and its particulate form readily attaches to sediment (Hively et al., 2006). Kokulan et al. (2019a) reported that overland flow was responsible for more than 90 % of annual phosphorus losses in the nearly flat southern Manitoban landscapes with clay rich soils over a three-year period. Manitoba's Lake Winnipeg Stewardship Board also recognizes addressing phosphorus loading as an initial priority for reducing downstream nutrient loading. In order to overcome the vulnerabilities caused by excess moisture, there is a need of developing the best management practices to prevent flood hazards and provide significant nutrient management and other types of co-benefits. Additionally, a strategy for excess moisture management designed on a multifunctional vision of agriculture would result in the production of positive externalities that would benefit other stakeholders at the local and regional levels.

The anatomy of excess moisture on farms

Spring snowmelt and intense precipitation conditions are major causes of excess moisture conditions in Manitoba, which can damage agricultural crops, prevent seeding/harvesting activities, and carry away productive top soil, as well as damaging infrastructure and property. Because wet soils are slow to warm up, seeds may germinate poorly and plant root systems may be stunted, leading to the possibility of inadequate nutrient uptake. Similarly, plants that develop shallow root systems due to excess spring moisture will be unable to extract deeper soil water if conditions are dry later in the growing season. In areas where plant growth has begun, flooding can drown the crop which is referred as waterlogging condition. Waterlogging causes oxygen deficiency in the root zone, which may lead directly to death or low productivity due to underdeveloped root systems. Conversely, drier soils warm faster, providing an environment for earlier germination and growth in spring in comparison to wetter soils.

Different crops have different survivability and tolerance level towards prolonged exposure to excess moisture conditions. Table 1 shows the tolerance levels of crops within a crop type group for same level of excess moisture exposure. For example, oats are more tolerant to the same level of excess moisture than wheat and barley in cereals; and fababeans are more tolerant to the same level of excess moisture than peas. Farmers often use this information to make a crop choice considering the forecast of wet or dry year.

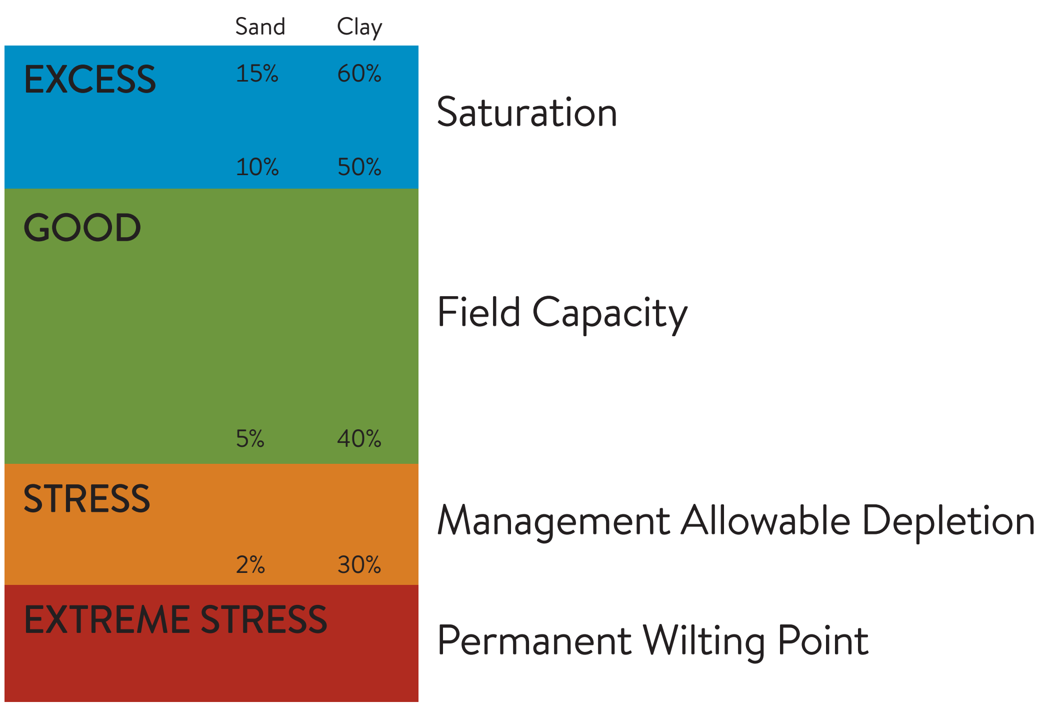
Table 1: Relative Crop Tolerance to Extreme Moisture Conditions

Crop Type	Excess Moisture Tolerance Level
Cereal crops	oats > wheat > barley
Pulse crops	fababeans > soybeans > field beans > peas
Oilseed crops	canola > sunflower > flax
Forage crops	grasses > legumes, with reed canary grass > timothy > orchard grass = per-ennial ryegrass; and birds foot trefoil/red clover > alsike clover > sweet clover > alfalfa

Source: Government of Manitoba, 2020

In the soil-plant system, amount of water above the threshold of field capacity is regarded as excess moisture. Figure. 1 shows different soil moisture conditions at different levels of volumetric soil moisture content. If soil moisture increases above the field capacity, saturation or excess moisture condition prevails.

Figure. 1: Soil Moisture Conditions at Different Levels of Volumetric Soil Moisture Content



Source: Pitts, 2016

Excess soil moisture affects several processes in the soil, which in turn, influences the crop yield potential. Cavers and Heard (2001) studied processes affected by excess soil moisture and found that the problems associated with excess moisture are poor aeration, reduced root respiration, changes in the soil redox potential, and production of phytotoxic compounds within the root zone. When the excess moisture occurs during the middle of the growing season (i.e., during the time of flowering and seed set), the negative effect on crop yield is even more magnified. The extent of crop failure due to excess soil moisture within the growing season depends on soil type, plant species, stage of plant growth, temperature, and day length (Osborne et al., 2003). Cavers and Heard (2001) found that water logging over five days during the flowering stage of peas reduced the yield to 25% compared to the control (non-flooded), while two days of water logging had insignificant effect on yield. Consequences of excess moisture have a negative impact on rural community and agricultural production, which may include:

- Damaged (decreased) agricultural production: crops, livestock, range / pasture
- Seeds washed away
- Plants drowned out or washed away
- Waterlogging
- Inability to access saturated land due to low trafficability
- Soil erosion
- Net farm losses
- Decreased employment
- Decreased economic performance e.g. lowers the GDP

Inability to access saturated land due to low trafficability results in delayed spring seeding, which subsequently cause lower yield, and decreased farm income. Manitoba Agricultural Services Corporation (MASC) has estimated the effect of delayed spring planting on Manitoba crop yields in Table 2.

Table 2: Effect of delayed planting on Manitoba crop yields (MASC).

Planting Date	% Yield Reduction			
	Corn	Canola	Flax	Peas
1st Week of May	-	-	-	-
2nd Week of May	5	-	-	5
3rd Week of May	10	5	5	15
4th Week of May	20	10	15	20
1st Week of June	30	20	25	30

Source: Manitoba Agriculture, 2015

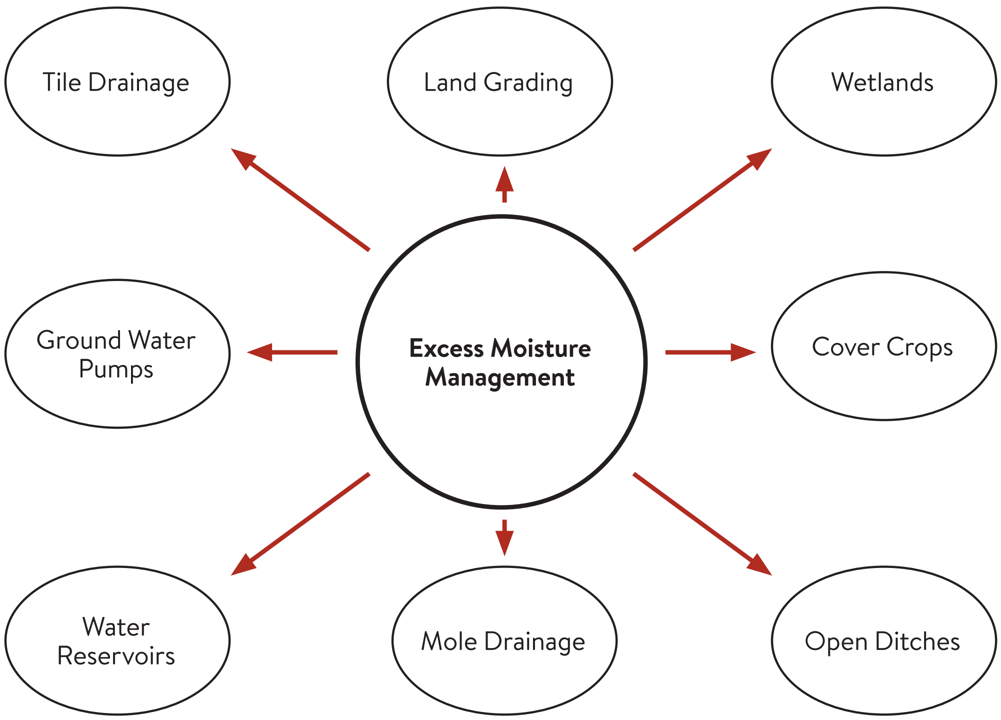
Most of the challenges wet soils present can be managed through the use of beneficial management practices (BMPs). BMPs are science-based farm practices that minimize environmental risk while ensuring the long-term sustainability of the land and the economic viability of the producer. Cost-benefit analysis are considered a useful and necessary tool in BMP projects' evaluation and public decision making in Canada. Controlling the peak flow of spring snowmelt using BMPs is of primary concern for flood prevention, while still addressing the impacts of extreme precipitation events later in the season (Manitoba Sustainable Development, 2012). This report demonstrates that how different farm investment strategies adopted for excess moisture management could mitigate the negative impacts of floods and can also provide significant nutrient management and other types of co-benefits. The focus of this report is to quantify and monetize these benefits, where data is available. The main objective of this report is to provide a decision-support tool by the information dissemination about the technology, design principles, and economic factors involved in adapting a drainage system for farm level excess moisture management.

Excess Moisture Management Strategies

The process of removing excess water from a farmland to improve the crop productivity is referred as drainage. Properly drained soils reduce excess water stress on crops, and promote root development necessary for maximizing yields and quality of production. Drainage systems can be categorized into natural or artificial drainage systems. Natural drainage is a process that occurs in any landscape and is a key component of water cycling. However, natural drainage is less effective on many farmlands due to soils with lower hydraulic conductivities, and soil compaction. Removal of excess water from farmland using an artificial or manmade drainage system approach can help addressing extreme soil moisture issues caused by extensive precipitation, spring snowmelt, and storm water.

Efficient field drainage system helps in rapid removal of excess soil moisture to reduce or eliminate waterlogging and return soils to their natural field capacity. The demand for agricultural drainage has increased recently to tackle uncertainties in precipitation patterns that are anticipated under a changing climate. A good drainage system will reduce the risk of detrimental waterlogging to acceptable levels. Besides drainage systems, there are also several in-situ field management techniques to reduce the extreme soil moisture stresses during the growing season by improving soil physical properties, and increasing the plant water uptake e.g. zero-tillage, change in cropping system, growing moisture tolerant crops, cover cropping etc. Figure. 2 shows different forms of field management and drainage systems applicable for excess moisture removal at farm level in Manitoba.

Figure. 2: Common On-farm Excess Moisture Management Strategies in Manitoba



Farm adaptation via excess moisture management systems add numerous benefits to the agricultural land in the context of water management. Timely field access allows the crop seeding on time, providing full growing season window for maximum yield potential. It is important to consider the economic costs and benefits associated with different adaptation strategies as management decisions are often based on this information (Belcher, 1999). In order to maximize the benefits while limiting the initial costs of adopting an excess moisture management option, size of agricultural farm and flood frequency of the area should be taken into account. Initial costs for adaptability measures can be prohibitive for some operations and a thorough understanding of all operating costs and potential cash-flow is imperative in making an economic decision. PAMI (2016) proposed that an effective drainage management strategy should have the following targets:

- Maintaining an effective soil structure to promote permeability
- Reducing soil erosion and increasing nutrient retention
- Remaining within the capacity of the surrounding drainage systems
- Fulfilling legal requirements and adopting BMP’s

Proposed Strategies to Manage Excess Moisture

An efficient drainage system should remove excess water from agricultural farm within 24-48 hours to avoid crop damage (PAMI, 2016). When choosing a water management or drainage strategy, any current issues in the system must be clearly identified in order to choose an appropriate option to address and solve these problems. The size of the farm and intensity of excess moisture event will help in deciding the management strategy best suited for the area in order to reduce the risk level to farmers and the region. Besides excess moisture due to weather, uneven soil moisture, moisture-sensitive crops, naturally high water tables, land depressions, impermeable soils, and seepage areas are conditions that should be addressed through drainage improvement. Considering historical flood events, Manitoba's diverse soil and crop conditions, and long-term benefits of adopting excess moisture management strategies; following four farm investment options are proposed and analysed for farm level excess moisture management:

1. Water reservoirs
2. Tile drainage
3. Land grading
4. Cover Cropping

Water Reservoirs

Water storage involves capturing and holding floodwater on the farm in dam or reservoir structure that might ordinarily be accumulated at farm causing excess moisture in soil or lost as runoff or in-stream flow, and causing flooding conditions at farm's downstream level. In Manitoba, channelized drainage systems (ditches and culverts) are used to mitigate the effect of floodwaters. These drainage systems increase nutrient transport from agricultural lands and cause a negative impact on water quality at downstream level. They can also increase the negative effects of floods by boosting-up flood peaks via increased streamflow and reduced infiltration rates, which then have greater force to cause damage (Venema et al., 2010). Of growing concern in Manitoba is the increasing transport of nitrogen (N) and phosphorus (P) into Lake Winnipeg, the 10th largest freshwater lake in the world. To tackle the twin problem of flood peaks and nutrients transportation, Canadian Prairies need more sustainable methods to manage excess water at agricultural lands.

In order to mitigate the effect of excess moisture events resulting from intensive precipitation and spring runoff, creation of local farm water reservoirs (water retention systems) designed to capture and store surface water, may be a viable adaptation strategy for Canadian Prairies. When strategically located in the landscape, water storage reservoirs reduce the transport of sediment and particulate nutrients while improving water quality to downstream water bodies (Hoffmann et al., 2009; Bechmann et al., 2008; Verstraeten and Prosser, 2008; Ulen et al., 2007; Sharpley et al., 2000). These water storage systems serve to reduce downstream peak flow and help in retaining floodwaters, which can reduce associated flood risks at downstream level. According to AAFC (2012), a system of water reservoirs within a watershed provided a reduction in peak flow of 9-19 % from spring snowmelt runoff and 13-25 % from rainfall runoff. Chretien et al. (2016) reported the reduction in peak flow by 38 % resulting from an on-farm retention pond in Saint-Samuel, Quebec.

The nature of water storage reservoirs become multifunctional when these systems are used for bio-production, nutrient retention, and to enable farmers to draw water from the reservoirs to support crop irrigation under drought conditions. During storm water run off, soil nutrients are also washed away from farm production area and deteriorate the water quality at downstream level. Surface water retention systems act as a catchment area of these nutrients that subsequently allow maximum nutrient removal from bio-products such as cattails. Using water reservoirs as an excess moisture management measure has shown success in reducing nutrient and sediment loading in America and Europe, with a reduction in total nitrogen by 38-56 %, and total phosphorus by 17-82 % (Aviles and Niell, 2007; Kovacic et al., 2006). According to AAFC (2012), water reservoirs are effective in reducing total suspended sediment (65-85 % reduction), particulate nitrogen (41-43 % reduction during snowmelt, 7-11 % reduction from summer rainfall events), and particulate phosphorus (27-38 % reduction in snowmelt runoff) on the Canadian Prairies.

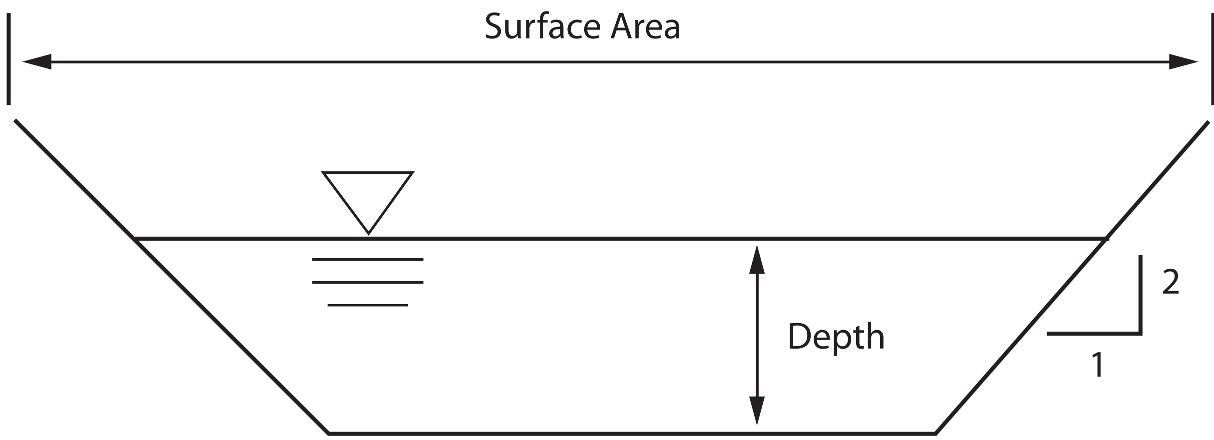
Biomass production is another merit of multi-purpose surface water retention systems. Cattails are getting attention in Manitoba for bio-production and nutrient management as the plant grows successfully on marginal cropland and in wet areas (Grosshans et al., 2014). A research by the International Institute for Sustainable Development (IISD) has found that cattails at Pelly's Lake, Manitoba, absorb up to 20 kg/hectare of phosphorus and remove 160 kg/hectare of captured nitrogen as they grow. They also provide 15-20 tonnes/hectare of biomass. The resulting biomass can be used for various bio-products such as solid fuel with a heat capacity of 17-20 MJ/kg (Grosshans et al., 2014). The removal of phosphorus from watersheds is essential to reducing nutrient loading to Lake Winnipeg, Manitoba (Government of Manitoba, 2014).

In order to maximize the benefits while limiting the initial costs of building a surface water retention system, size and holding capacity of retention systems need to be considered (Gohar et al., 2013). The size of the farm and intensity of excess moisture event will influence the size of retention pond best suited for the area in order to reduce risk to farmers and the region. Runoff characteristics of drainage area can vary greatly. In areas like Southern Manitoba, where snow contributes to the bulk of seasonal runoff 1 acre of forage land will yield at least 113,500 L of runoff water per year. On the other hand, on stubble land the runoff yield will be about 68,080 L per year. Unless the area has a history of extreme flood frequencies, and very large amounts of water are required for irrigation purpose; the construction of water reservoir over 100 acres should be avoided whenever possible.

Basic Design Considerations:

Earth moving is a primary cost factor for any constructed reservoir. Several variables are involved in estimating the required excavation for a target storage capacity, such as depth of reservoir, surface area, and side slope. Different variables used in the design consideration of a water reservoir are shown in Figure. 3.

Figure. 3: Definition Sketch for Reservoir Dimension Variables



When using this option as an excess moisture management strategy, following design parameters should be considered.

Reservoir Size:

Reservoir size should be selected based on flood frequency in the area, runoff volume, and other secondary uses of reservoir e.g. irrigation, livestock watering, bioproduction etc.

Reservoir Shape:

The shape of a reservoir can affect the quantity of stored water. A deeper reservoir is more efficient because it has less surface area for the same capacity, and subsequently farmer looses less land to accommodate water reservoir at farm. However, earthwork expense would increase.

Runoff Volume:

Runoff volume is determined by the amount and timing of snowmelt or precipitation, plus vegetation, soil type, soil moisture, and topography. The uncertainty of runoff should be kept in mind when planning a reservoir size as runoff volume greatly varies from year to year in a watershed basin

Reservoir Capacity:

For water budgeting, always assume the usable volume is 10 % less than the calculated volume to consider evaporation losses and accumulation of silt and organic material in the base with time. A simple rule for determining the approximate capacity of a water reservoir with a standard reservoir slope (1:2) is based on the following model:

$V = 650 * A * D$

Where,

V= Volume (Litres)

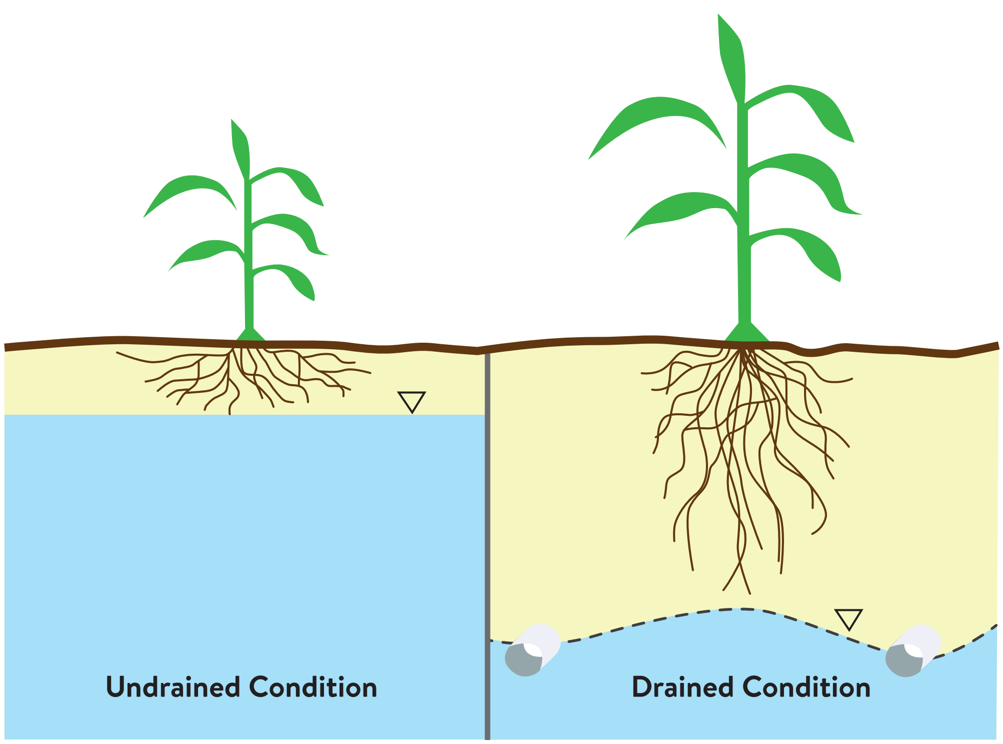
A = Surface area of water reservoir (m^2)

D = Maximum depth of water reservoir (m)

Tile Drainage

Tile drainage refers to a subsurface conduit of perforated corrugated plastic pipes installed in the vadose zone (unsaturated soil profile) for removing excess moisture from the soil profile. The removal of excess moisture results in timely planting, better aeration by keeping water table at desired depth (Figure. 4), improved soil porosity and facilitate improved crop growth and extended cropping and grazing seasons (King et al., 2015). Tile drained fields have more water storage capacity than their undrained equivalents. A tile-drained field is able to remove excess moisture within few days through the tile drains' structure during wet periods and provide storage volume within the soil profile. On the other hand, an undrained field relies on evaporation to remove excess moisture; that can take weeks. One advantage of having increased storage capacity in the soil is flood control. In the presence of underground tile drainage structure, flood water takes more time to move through the soil and drain out of a tile than to run across the surface and into a channel. Therefore, there is more time between the start of rainfall and peak flow.

Figure. 4: Comparison of water table and root development in tiled and untiled conditions



Source: Sands, 2001

The removal of excess vadose zone water by tile drainage increases the effective soil hydraulic conductivity resulting in suppression of surface runoff. Tile drains can modify both the volume and pathways of runoff at the edge-of-field. Depending on initial conditions, peak flow can be reduced by as much as 87 % compared to undrained fields. Tile flow accounted for 73 % of the total flow in a clay loam soil and 86 % of the total flow in a sandy loam soil in a two-year study conducted in Quebec (Eastman et al., 2010). In southern Ontario, Plach et al. (2019) reported that ~80 % of annual runoff at the edge-of-field occurred through tile drains in a range of soil textures. By removing excess water from the upper layers of the soil more quickly than undrained soils, tile drainage can improve the trafficability of soil. Heavy machinery use and tillage on wet soil can result in soil compaction, which damages the soil structure. Tile drainage reduces the risk of this damage. Because machinery works more efficiently on drier soil, tile drainage reduces labour hours and helps to minimize fossil fuel consumption and associated costs.

When a simple flow control system is installed at tile drain outlets, it is referred as controlled tile drainage structure. By implementing the controlled drainage (Figure. 5), part of the water, which would have otherwise drained by free drainage (Figure. 6), is stored within the soil profile to be used later by the crop when needed. In controlled drainage, water table depths are regulated by an adjustable raised structure at the tile outlet. Maintaining desirable water depths through controlled drainage has agronomic and environmental advantages (Sunohara et al., 2016). Nutrients, such as nitrogen (N), phosphorus (P) and potassium (K) and some pesticides are often dissolved in runoff water or attached to suspended sediments. If delivered to surface water, they can contaminate the water they run into. Controlled drainage can significantly reduce P loads due to controlled flow (Corderio et al., 2014). Controlled drainage also reduces P losses when combined with a wetland reservoir (Tan et al., 2007) and wood chip bioreactors with alum-based drinking water plant residues (Gottschall et al., 2016).

As runoff water travels down to ditches or riverbanks, high amounts of erosion can occur. This can diminish surface water quality. Another advantage that controlled drainage coupled with increased storage capacity offers is that runoff volumes and associated soil erosion can be reduced. Tile drainage has been recommended as a best management practice (BMP) for erosion reduction and water quality control.

Figure. 5: Controlled drainage using stop log control structures

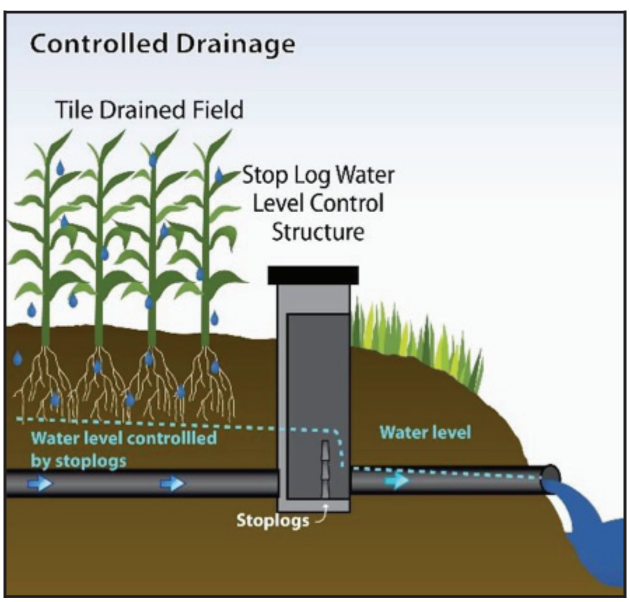
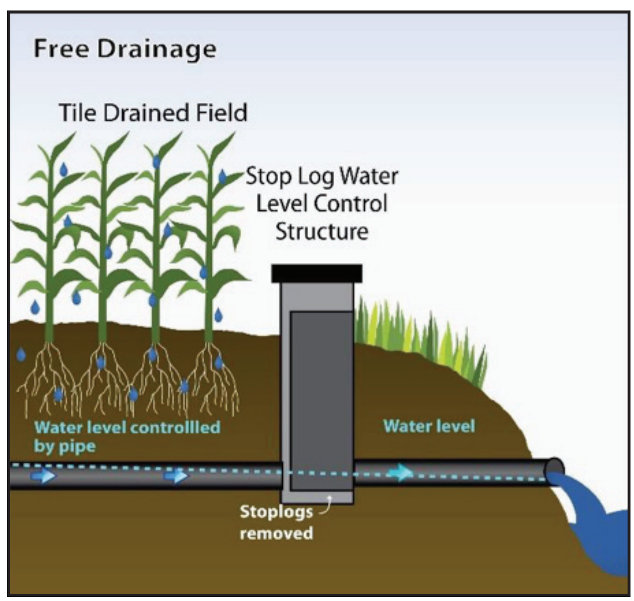


Figure. 6: Free drainage with stop logs removed.



Source: PAMI, 2018

Sub-surface irrigation application is another advantage of controlled type tile drainage system, which uses same infrastructure for the dual purpose removing and adding water to the field. It provides increased control over water entering and exiting the field and mitigation of both drought and flood conditions within the same system. Subsurface irrigation operates on the principle of capillary action. When water is pumped through the underground perforated pipe network, it rises through the soil particles and becomes available in the root zone for plant uptake. The water level in the field is maintained by a control structure.

Enhancing drainage tiles may increase the edge of field runoff leading to increased risk of downstream flooding (Rahman et al., 2014). Re-routing tile effluent to retention structures like in-farm retention ponds or constructed wetlands is also a viable alternative to control edge of field tile nutrient losses. This retained water can be recycled for irrigation during water demanding periods. Research done in Canada shows controlled drainage combined with another best management practice such as bioreactors or sub-irrigation could reduce edge of field nutrient loads without compromising crop yield.

The cost of installing a tile drainage structure varies significantly in different areas and is very site specific. Costs of installation with a contractor in Western Canada can vary from $900 - $1200/acre, generally 2/3 material costs and 1/3 labour costs (Fraser, 2020). Moving the equipment to the site is a large part of the contractor cost and installing a larger amount of tile at one time, on a single farm or collectively in an area, can reduce the cost per acre. Items that influence the overall cost of a tile drainage system include tile spacing and depth, self-installation vs. contractor installation, and additional features (sub-irrigation, control structures, etc.). Although tile drainage has not frequently been used in the Canadian Prairies historically, an increasing frequency of excess moisture events as a result of spring and summer storm (Shook and Pomeroy, 2012) has caused farmers in provinces such as Manitoba and Saskatchewan to install tile drains at an accelerated rate to tackle the unprecedented waterlogging conditions in their crop fields (Kokulan et al., 2019b).

Basic Design Considerations:

When using this option as an excess moisture management strategy, following design parameters should be considered.

Tile Spacing:

When installing a tile drainage infrastructure to manage the excess moisture, the recommended tile spacing is 15 m in Manitoba (Cordeiro et al., 2014). Tile spaced close together will provide a higher drainage coefficient, and therefore a more aggressive system.

Installation Depth:

The most common depth in Manitoba designs is 0.9 m, though this is not necessarily optimal for all cases, depending on the goals of the system (Cordeiro et al., 2014). Deeper tile is better suited for excess moisture management to drain water fully out of the root-zone. However, if the tile is going to be used for the dual purpose of sub-irrigation, it should be as close to the surface as possible without crowding the root zone.

Pipe Size of Lateral:

Diameter of lateral depends on the purpose of tile drainage system in a field. In Manitoba, 4 inch diameter piping is the standard size for sub-surface drainage systems.

Drainage Outlet:

The location of the outlet must be considered during the design. The most economical and ideal outlet is a gravity outlet into the ditch adjacent to the field.

Control Structures:

Usually, one control structure is needed for every 30 to 45 cm (1 to 1.5 ft) elevation change along the main line. Controlled drainage is best suited to nearly level land, ideally with an average slope of less than 0.5 %. A single control structure can typically manage 4 to 8 ha; assuming slopes are flat enough to be controlled by one structure.

Expansion Option:

When installing a tile drainage system at farm, it should be designed with the planning and foresight to expand or modify the capacity in later years.

Land Grading

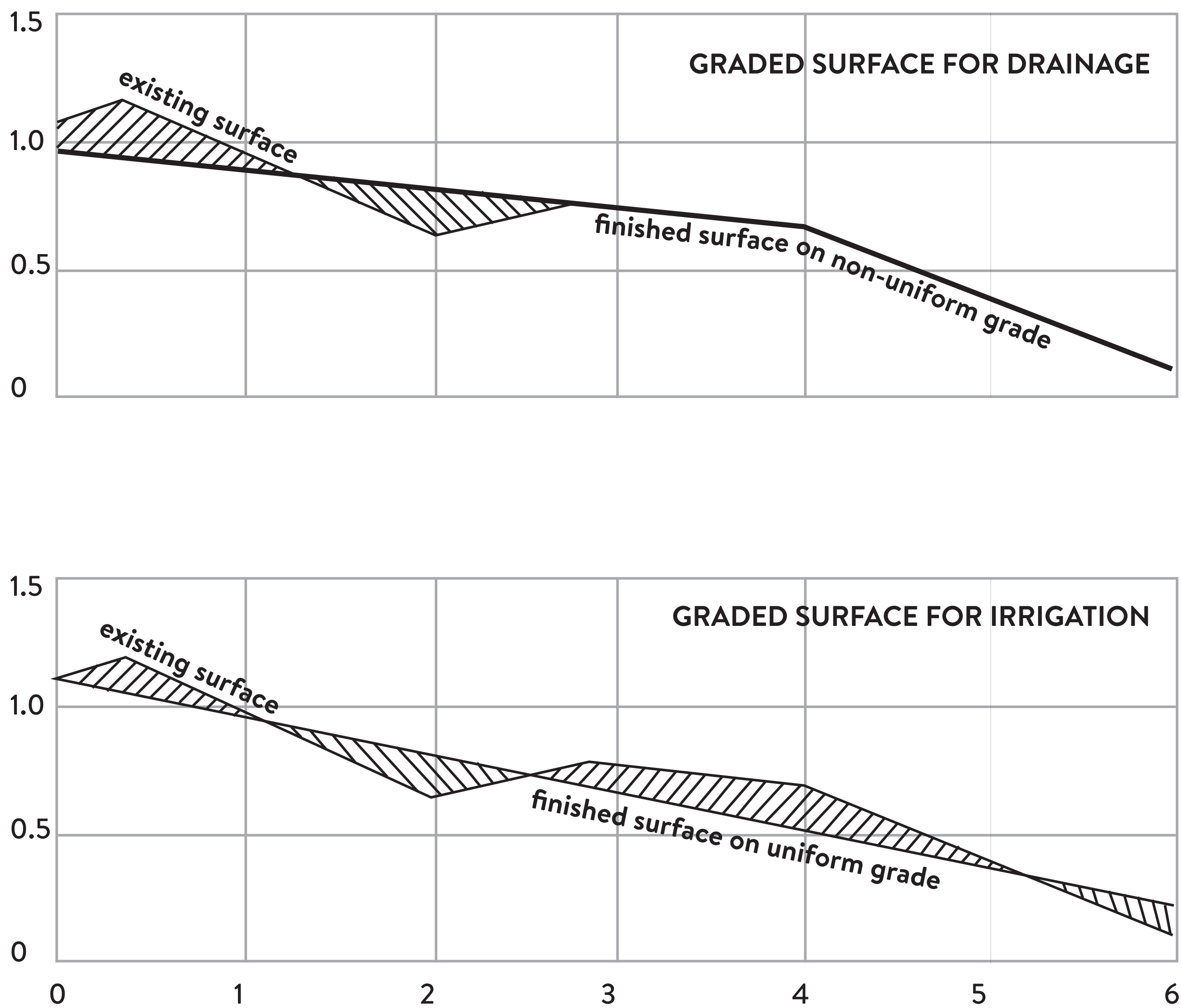
In an agricultural setting, land grading as a measure of excess moisture management is a one-time operation of mechanical forming and shaping the surface of farmland to predetermined grades, so that drainage water can flow by gravity to a field drain. Mechanical forming or transport of earth involves cutting, filling, and smoothing an agricultural field to planned continuous surfaces; in order to improve the distribution of water and/or to direct overland flow to ditches or drains. This process eliminates minor depressions and irregularities of the landscape and formulates a continuous slope. The purpose of establishing continuous surface grades is to accelerate the runoff so that water does not pond after a precipitation or flood event. In order to prevent ponding in the downstream level of the field, surface runoff from graded fields needs to be transported through field drains towards the drainage outlet of the area.

Land grading promotes the orderly movement of water over the surface and the efficient use of machinery. In this process, dirt is cut from higher spots and used to fill in low spots; thus, it is also known as “cut and fill” grading. When grading land for surface drainage, the slope does not need to be made uniform, as for irrigation; a non-uniform grade will suffice (Figure. 7). The grades can be varied as much as is necessary to provide drainage with the least amount of earthmoving. Scarification may be required after land grading to break up the soil which has become compacted by the construction machinery.

Land grading is a major effect factor in soil erosion and phosphorous (P) transport on slope farmland. Many studies have noted the importance of a continuous slope in soil erosion and P loss (Shipitalo et al., 2013). P is the element primarily responsible for water eutrophication. The loss of P with soil erosion can cause environmental problems due to their effect on water eutrophication. The amount of total erosion tends to stabilize with an increase in slope gradients, which implies there is probably a threshold slope gradient at which soil erosion begins to shift from strong to weak (He et al., 2016). He et al. (2020) reported a reduction of 50 % to 57 % in phosphorous loses, when using land grading of multiple slopes.

Land grading operation can be performed by farmers as normal farm equipment can handle small-scale grading operations or the maintenance of already established grades. Large-scale land grading is done by contractors with conventional earthmoving equipment or with laser-guided motorized graders. Grading operations involve a number of steps.

Figure. 7: Non-uniform Grading for Drainage Compared with Uniform Grading for Irrigation



Source: Sevenhuijsen, 1994

1- The first step is to prepare the site. If the land has already been cleared, the work mainly involves removing or destroying vegetation and other obstacles, and levelling ridges or rows. This can normally be done with farm equipment. The surface should be dry, firm, and well pulverized to enable the equipment to operate efficiently.

2- The second step is rough grading. This can be done with various types of equipment (e.g. dozers, motor graders, scrapers). The choice will depend on the soil conditions, the amount of earthwork needed, the time and equipment available, the size of the fields to be graded as one unit, and local experience.

3- The third step is the finished grading. On small fields, drags, harrows, and floats can be used. These implements can be pulled by a farm tractor or by animal traction. On larger fields, a land plane (a bottomless scraper) pulled by a farm tractor is used. For the final smoothing, several passes are usually made at angles to one another.

When extensive grading is done with heavy equipment, it is likely to cause soil compaction. This compaction should be relieved in order to eliminate differences in soil productivity. If not done with great care, productive top soil can be removed leading to a decrease in productivity in affected areas for a few years. Ideally, topsoil should be removed first and stored separately until earth moving is complete. This topsoil should be added back on the surface with minimal mixing of subsoil to ensure crop productivity is protected. The benefits derived from land grading will often depend on good maintenance in the subsequent years. The land should be smoothed each time a field has been ploughed. This will ensure settlement in fill areas and will erase dead furrows and back furrows. A small leveller or plane powered by a farm tractor can be used for this purpose.

Basic Design Considerations:

When using this option as an excess moisture management strategy, following design parameters should be considered.

Land Slope:

In the design of land grading for surface drainage, it is not required to establish a uniform slope as for irrigation. A continuous grade is necessary to assure uniform flow of runoff water over the land surface or along crop rows without ponding.

Planting Scheme of Row Crops:

In order to receive the maximum benefit of land grading with the aim of controlling the excess moisture and erosion, crops should be planted in rows and the field surface is shaped into small furrows (Figure. 8). This strategy works best for row crops i.e. corn, buckwheat, soybeans, potato, vegetables, etc.

Planting Scheme of Grain Crops:

Small grains (e.g. wheat, barley, oats, rye, etc.) and forages are grown by broadcast sowing or in rows, but on an even surface (i.e. no furrows). For such crops, surface drainage takes place by sheet flow. This flow is always in the direction of the maximum slope. With sheet flow, the flow resistance is much higher than in small furrows, and the flow velocity on the same land slope is less. Even after careful land grading and smoothing, however, sheet flow always has a tendency to concentrate in shallow depressions, and gullies are easily formed. With the transport duration for low flow velocities in mind, it is recommended that the field length in the flow direction be limited to 200 m or less.

Figure. 8: Land grading in corn field seeded on furrows or ridges

Source: Larson, 2015

Row Length:

The length and slopes of the field to be graded should be selected in such a way that erosion and overtopping of the small furrows is avoided. Recommended grade, and row lengths for different soil types are given in Table 3.

Table 3: Row grades and row lengths for land grading

Soil type	Grade (%)	Row length (m)
Sandy or coarse-textured soil	0.1 - 0.3	300
Clayey or fine-textured soil	0.05 - 0.25	200
Loamy or medium-textured soil	0.05 - 0.25	300
Silty loam	0.5	150
Sandy loam	≥ 0.15	200

Source: Coote and Zwerman, 1970

To prevent erosion, flow velocities in furrows should not exceed 0.5 m/s. In highly erodible soils, the row length should be limited to about 150 m in order to decrease the water travel/conveyance time in the field. Slightly erodible soils allow longer rows, up to 300 m. In these long furrows, adequate head should be available to ensure that the water flows towards the field drains. Following table lists recommended row lengths and slopes for different soil types.

Cover Cropping

Cover cropping is an effective excess moisture management tool for farmers facing flooded or very wet soils in the spring, as cover crops aid in improving wet and cold soil conditions early in the spring. Cover crops have the potential to conserve water by taking up excess moisture from the soil and by contributing to improved infiltration, and soil water holding by building soil organic matter and improving soil structure. In Manitoba's climatic conditions, cover crops can serve as a mechanism to extract excess water from the topsoil, providing drier conditions that can contribute to the increase in soil temperature. Conservation practices involving cover crops have long been used as a means of reducing the excess soil moisture during the growing season by improving soil physical properties, and increasing the plant water uptake (Dabney, 1998; Bargar et al., 1999; Boquet et al., 2004). Out of numerous advantages of growing cover crops, some are listed below:

Erosion control - A cover crop protects soil susceptible to wind and water erosion. It is typically planted later in the growing season to provide enough leafy top growth to protect the soil. It may be planted just before a fallow year or following crops that leave little residue cover, such as potatoes and pulses.

Trafficability - Growing cover crops can use excess soil moisture, drying the soil and improving trafficability across the field providing the opportunity of early access to the field for equipment dependant operation.

Soil Structure - After a cover crop is incorporated or desiccated, the decomposing biomass provides organic matter to the soil, which increases microbiological activity and improves soil structure.

Infiltration - Root channels from a cover crop will improve soil structure and create pathways for water movement.

Crusting - Growing cover crops provides an increase in organic matter content, infiltration and aggregate stability that will reduce the risk of soil crust formation.

Weeds - Cover crops during the fallow period reduce competition from weeds.

The use of cover crops combined with no-till conservation practice have also been reported to reduce excess moisture, prevent soil erosion and nutrient leaching, increase organic carbon, modify soil temperature, increase water holding capacity, improve soil trafficability, and reduce machine compaction (Unger and Vigil, 1998; Dabney et al., 2001; Boquet et al., 2004). Soil temperature is highly influenced by soil moisture conditions, and any practice that removes excess moisture, especially early in the spring, can improve crop establishment and potentially reduce the effect of soil-borne diseases driven by cold temperatures. Al-Kaisi (2019) conducted a study of tillage and cover crop (fall rye) to demonstrate the impact of cover crop on increasing soil temperature and reducing moisture, especially with no-till (NT), where soil temperature increased by 2.1 °F degrees, but cover crop has less effect with chisel plow (CP) at the top two inches. The effect of both NT and cover crop in improving soil porosity and thus water infiltration and soil aeration is a contributing factor as compared to CP, where lack of soil permeability can limit cover crop effect on soil moisture. In conclusion, the best combination of tillage and cover crop appears to be when NT and cover crops are used to enhance the inherent best soil functions and properties provided by NT systems.

Kahimba et al. (2008) reported that areas experiencing excess soil water in the form of both rainfall and snow could use an annual cover crop such as berseem clover as a means to reduce excess moisture during the growing season. This cover crop could also be used for enhancing spring snowmelt infiltration, deep percolation, and early warming of the soil by having warmer soils during the winter, shallower depths of frozen soil layers, and less frozen water content within the root zone. This in turn, will allow earlier farm operations. A field based cover cropping study conducted by Lawley (2016) following the 2011 spring flooding conditions in Manitoba demonstrated that a full season treatment can reduce soil moisture in the shallow rooting zone (30 cm) in the late summer to fall period when compared to no cover crop. In addition, soil moisture close to the soil surface (5 cm) was consistently drier in the no cover crop treatment. This demonstrates an additional benefit of reduction in evaporative loss from the soil surface, which in turn would result in a reduction in salt accumulation at the soil surface. Kahimba et al. (2008) evaluated the water use and nutrient recovery by cover crops in Manitoba where a clover cover crop was under-seeded with an oat crop. They found following benefits from cover crops:

- a reduction in soil moisture compared to oats alone;
- a shallower frozen soil layer by the spring, earlier thawing and enhanced early soil warming;
- deeper infiltration of spring snowmelt.

The use of cover crops in an intercropping system provides a protective cover that reduces runoff, erosion, and nutrient losses, thereby facilitating more infiltration (Bargar et al., 1999). In the case of excess soil moisture, cover crops work with the main crop to uptake more water from within the root zone. Osborne et al. (2003) found that the addition of a cover crop assists in reducing the excess moisture that could otherwise negatively affect the main crop yield potentials. The same study reported that no-till cultivation delayed soil warming in the spring and resulted in excess soil moisture during the spring growing season. They further noted that the use of cover crops with a no-till system helped to reduce the excess soil moisture.

Cover crops are also referred as "nutrient catch crop" as they have capacity to uptake and retain nutrients in plant species coming from the soil, and shallow groundwater. This uptake recycles nutrients back into the crop production system, reducing the potential of nutrients loss with surface water runoff. During a flood event, nitrogen can be lost from agricultural fields in runoff water and groundwater. This displaced nitrogen may then travel into waterways and cause imbalances in the nutrient levels of these sensitive ecosystems. Farmers want nitrogen to remain on the land to fertilize their crops and support productive growing systems, and society as a whole does not want excess levels of nitrogen in the water. Cover crops retain soil nitrogen and prevent it from being leached, and they can provide natural sources of nitrogen to cash crops and thus reduce the amount of fertilizer needed for production. In southwestern Minnesota, Strock et al. (2004) found a 13% reduction in nitrate load and an 11% decline in drainage discharge due to a fall rye cover crop added to a corn-soybean rotation. In southern Ontario, Drury et al. (2014) reported that controlled drainage in combination with a winter wheat cover crop reduced nitrate concentrations in tile water by 47% over a simple corn-soybean rotation. Cover crops can reduce the amount of nitrogen, and phosphorous leaving a field by 1% to 89% (with a median value of 48%), and 15 % to 92 % (with a median value of 54 %), respectively (SARE, 2012).

Cover crops in crop rotations are not a common practice primarily because growing cover crops usually includes crops that do not result in economic return and often do not allow sufficient time for soil preparation for cash crops. However, relay and double cropping (inter cropping) represent an option for incorporating legume crops into annual cropping systems without sacrificing a season of grain production. Cover crops are often spring cereals, which are relatively inexpensive to seed, competitive with fall weeds, and killed by winter freezing. Manitoba farmers are also beginning to use fall-seeded crops such as winter wheat, fall rye and winter triticale to achieve an economic return the following year. Nutrients absorbed by cover crops are recycled into the soil through decomposition and become available to the subsequent crop.

Basic Design Considerations:

When using this option as an excess moisture management strategy, choosing right cover crop species and seeding time are two crucial factors to consider.

Crop Species:

Different species of cover crop have qualities that make them useful in different situations. For instance, legumes and pulses host nitrogen-fixing bacteria, while deep-rooted crops can scavenge nutrients from the subsoil and create root channels that improve drainage and infiltration to reduce the harmful impact of excess moisture. Crops that grow rapidly prevent nutrient losses from the soil and help suppress weed growth. Crops that differ from the current income-producing species may help break pest and disease cycles. Cereal rye removes water from the soil through transpiration when it starts growing in the fall and then again in the spring after over-wintering (Wick, 2017). Most of the moisture removal will come in spring when rye is growing quickly.

Seeding Time:

Cover crops can be seeded at various times during the growing season. They can be under-seeded with the main crop, inter-seeded into the main crop (inter cropping), or planted after harvest. By growing in late summer and fall, cover crops may reduce excess moisture the following spring and enable earlier access (improved trafficability) for seeding and other field operations. In Manitoba, cover crop is typically planted later in the growing season to provide enough leafy top growth to protect the soil. It may be planted just before a fallow year or following crops that leave little residue cover, such as potatoes and pulses.

Costs and Benefits Components

The initial step in the analysis was to determine which costs and benefits should be taken into account based on ease of quantification. This was done mainly in the light of recommendations provided by economic experts, and policy makers available through review of literature in order to support the decision-making. Other sources of gathering the information include Manitoba Agriculture and Resource Development reports, published research, interviews with industry professionals, academics and research experts, workshops and seminars, extension events and publications, thesis reports, and news reports with a focus on Manitoba origin. The various costs and benefits that we deemed to be worthy of inclusion are discussed in detail below.

Costs:

1. Capital costs
2. Operating and maintenance costs
3. Lost farmland

Capital costs:

This cost is fixed, one-time expense incurred on the adoption of any of four investment options including civil work, system installation cost, and testing. In other words, it is the total cost needed to bring the excess moisture management structure to an operable status. Labour cost is included in the capital cost.

Operating and maintenance costs:

Once the initial construction phase is completed, there will be ongoing operational costs, including administrative, maintenance, logistical, negotiating and coordinating costs. These are also communicated on an annual basis.

Lost farmland:

Investment option of water reservoir involves displacing the farmland. It is calculated based on average cost of productive farmland (per acre) in the province of Manitoba (Government of Manitoba, 2020). It refers to the opportunity cost in terms of the productive use of lost farmland that land could have otherwise been put to.

Quantifiable/Monetized Benefits:

- Reduction in excess moisture
- Avoided flooding costs
- Avoided drought
- Reduced eutrophication
- Production of cattails
- Carbon credits
- New wetland habitat

Reduction in excess moisture:

Prolonged rainfall, spring snowmelt, and flooding from rivers/dams overflowing are biggest causes of excess moisture in the soil, and leave crops oversaturated. Soil moisture extremes cause negative effects on agricultural operations, including excessive soil erosion, equipment trafficability, loss of seed, reduced crop yield/quality, and subsequently loss of farm income is regarded as excess moisture. Adopting suitable pro-active risk management approaches will prepare for and mitigate short term and long-term impacts and vulnerabilities to excess moisture on agricultural lands.

Avoided flooding costs:

Flooding is a major issue in Manitoba, and the management of floodwater upstream offers the significant benefit of mitigating flooding downstream. Flooding costs that could be avoided because of upstream water retention include backup of sewage into homes, infrastructure damage, and lost economic output from associated disruption. Value of using flood control infrastructures or techniques may be regarded as avoided flood damage costs. These techniques include diversion channels, wetland formation, expanded ditches, and building berms around the perimeter of the agricultural land. Wetlands function as natural sponges that trap and slowly release surface water, rain, snowmelt, groundwater and flood waters. Trees, root mats and other wetland vegetation slow the speed of floodwaters and distribute them more slowly over the floodplain.

Avoided drought:

Storing water in on-farm water reservoir and controlled tile drains would offer the unique benefit of reducing the risk of drought. Water that travels downstream during an excess moisture event, may be retained on or near farms in a storage structure e.g. water reservoir, or controlled tile drains. This stored water would be at the disposal of farmers should drought conditions arise. However, installation of an irrigation infrastructure is required to supply this stored water to plants. The cost assessment of irrigation infrastructure is beyond the scope of this study.

Reduced eutrophication:

Nutrient runoff from farmland is a serious problem in Manitoba because of the associated downstream eutrophication that causes negative ecosystem impacts. Eutrophication can effectively create dead zones in a watershed and decrease the watershed ecosystem's resilience to other stressors. Problems of nutrient runoff would be mitigated with a portion of floodwater retained at upstream in tile drains, water reservoirs, and wetlands. Retaining water upstream would help in reducing the significant damage caused by eutrophication.

Production of cattails:

Harvested cattail biomass can provide a renewable feedstock for small-scale distributed heat and combined heat and power generation in Manitoba, with the combined benefit of phosphorus capture and recovery to reduce loading to watersheds (Grosshans, 2013). Cattail production offers a distinct category of benefits and can occur around water retention ponds and wetlands. Cattails would be produced and then harvested and sold to organizations able to process them into energy and recovered phosphorus.

Carbon credits:

As discussed above, cattail production is beneficial because the plants can be sold by weight and processors can produce energy from them and recover phosphorus. The energy produced from the cattails also provides the additional benefit of reduced carbon emissions. Because the energy produced from cattails displaces energy (predominately derived from fossil fuels) that would have been used in its place, the avoided emissions can be sold in carbon markets, offering a distinct benefit.

New wetland habitat:

An assumption is made that each of the investment option for excess moisture management proposed in this report involve the establishment of a new or expanded water surface, which would in time become wetland. Wetlands offer a range of benefits such as nutrient cycling, flood mitigation, habitat provision, and recreation such as hunting and fishing.

Un-quantifiable/Non-monetized Benefits:

In interpreting the results of the study, it is important to acknowledge some recognized benefit excluded from the cost-benefit calculation because they were difficult or impossible to measure and/or monetize. Depending on the investment option selected, all or few of these benefits would certainly be received to varying degrees. However, it is difficult or impossible to determine the degree to which they would impact results.

These variables include the following:

- Recovered soil
- Reduced sedimentation
- Aquaculture
- Watering livestock
- Avoided water treatment costs

Recovered soil:

Water reservoirs would accumulate nutrient rich soil particles in time which would have a resale value. Securing nutrient rich soil from the bottom of water reservoir, in the process of reservoir cleaning, would have an associated cost (accounted in maintenance cost), but it would also have a distinct benefit in terms of the retained nutrient-rich soil that would have previously washed downstream. However, this benefit was excluded from the analysis as the precise estimation of the processing and transportation costs and anticipated resale value was not easy to obtain.

Reduced sedimentation:

Related to the recovered soil benefit is the benefit of reduced downstream sedimentation. If more earth is being retained upstream, less is ending up downstream where it silts up downstream waterways. Since it is less localized downstream, its removal (once it accumulates enough) can be more costly than when it is found in a localized area upstream. While reduced downstream sedimentation is an objective benefit, however it is very difficult to estimate the volume of reduced sediment and value the reduction. For these reasons, this variable was excluded.

Aquaculture:

There is also potential for aquaculture (fish raising) production in water reservoirs and wetlands. Fish could be raised to assist in nutrient cycling in these structures, or they could be raised for consumption, or resale. Manitoba has little aquaculture experience, and therefore cost estimates would have been unreliable. This, combined with the likely lack of interest on the part of farmers, led this variable to be excluded from the analysis.

Watering livestock:

Another potential use for the retained water would be to water livestock. Because of the difficulty of assessing the ease of leading animals to the retention structures (which would differ on each farm), this benefit was excluded.

Avoided water treatment costs:

Concentrated nutrient runoff can lead to increased downstream water treatment costs. Processing water for human use and consumption requires that phosphorus levels be reduced to certain threshold levels. The higher the baseline level, the more costly the water treatment is and vice versa. This benefit is excluded from the analysis as water treatment costs for a varying nutrient transport load is difficult to estimate.

Estimating costs and benefits of the four excess moisture strategies

This section help to quantify and monetize the costs and benefits for the four investment strategies. It discusses the assumptions employed in the analysis, the data sources used and how data from other contexts was converted to suit the context of the four proposed investment options. Following assumptions for the cost benefit analysis are based on review of the latest literature, local market, and expert analysis. All monetized values and figures are accurate in late 2019 and early 2020.[1]

1. All investment options are analysed on an area of 100 acre except water reservoir, which is analysed on 20-acre land.
2. Average inflation rate in Canada is 2.24 % per year (Plecher, 2019).
3. Cattails produce 12 tonnes of dry biomass per hectare per year (Pratt et al., 1988).
4. Out of unit mass of cattail, 0.22 % is phosphorus. (Pratt et al., 1984).
5. Emissions associated with energy from cattails are equivalent to the Intergovernmental Panel on Climate Change emission factor for other primary solid biofuels.
6. Cattails' value is $50 per tonne of dry biomass (Dion and McCandless, 2013). Cost for the reporting year (2020) is estimated as $58.
7. Carbon offsets are valued at $15 per tonne (Dion and McCandless, 2013). Cost for the reporting year (2020) is estimated as $18.
8. A capital recovery factor of 2.5 per cent is assumed for amortizing capital costs.
9. Annual operating costs can be assumed to be 2 % of amortized capital costs.
10. Earthwork costs can be estimated to be $18 per cubic metre of earth moved.
11. It is assumed that a natural or constructed wetland is present at downstream of watershed area.
12. A 2 % ratio of wetland/watershed area (Tyndall and Bowman, 2016) is made part of this analysis, which is translated as 2 acre of wetland for a watershed area of 100 acre.
13. In case of an excess moisture event, yield loss potential is 100 % to quantify the maximum achievable benefit.
14. Where required, soil type is sand clay loam.

1 We recognize at this writing, early spring 2020 in the middle of a pandemic, these values may change and will need updating periodically.

Each of the costs and benefits are quantified and monetized based on the explanation below, by the four proposed water management strategies.

Cost:

Capital Costs:

Water Reservoir:
Since earth moving is a primary cost factor for any constructed reservoir, we first developed a spreadsheet analysis (using Microsoft Excel) to determine the amounts of excavation required for different storage volumes. We selected a surface area of 20 acre, reservoir depth of 10 m, and a standard side slope of 1:2 to analyze cost and benefits of this option. Total excavation volume is estimated to be 160344.96 m^3. Based on the excavation volume, total capital costs were estimated to be approximately $2.89 million at the proposed scale of water reservoir structure, or $183,311.28 per year once amortized (20-year amortization).

Tile Drains:
We surveyed Manitoba's local tile drains contractors and found an average cost of tile drainage installation is $980 to $1200 with a median of $1090/acre (including contractor's cost, tile, fittings, filter material, catch basins, etc). We assumed the tile drainage installation cost is $1090/acre. Controlled structures are made part of this analysis to receive the co-benefit of irrigation, and reduced eutrophication. Controlled structures' cost is based on the number of structures necessary (depending on the elevation change in the field) as well as what type are used (Robert, 1996). The greater the unevenness of the land, the more control structures that will be necessary. We found that the cost of a medium quality control structure is $1,800 and one controlled structure is sufficient for every 8 acre of land. Cost benefit framework established by RDI calculates that a total amount of $128,400 is required to install tile drainage infrastructure on an area of $100 acre, or $8,155.08 per year once amortized (20-year amortization).

Land Grading:
The cost of land grading for excess moisture management (rapid drainage) is usually estimated based on the soil type, the cut to fill ratio, slope, and the total number of cubic yards to be cut. We assumed the earthwork costs can be $18 per cubic metre of earth moved. Touch-up land leveling usually costs less than $50 per acre and most commonly $35 per acre. We assumed that earthwork is carried out to move a soil depth of two inches to manage cuts and fills of land to form a continuous slope. Cost benefit framework established by RDI calculates that a total amount of $373,545.88 is required for earthmoving on an area of $100 acre, or $23,724.84 per year once amortized (20-year amortization) to form a continuous slope.

Cover Cropping:
Cost benefit framework established by RDI calculates that a total amount of $22,630.67 is required for cover cropping on an area of $100 acre, when using fall rye as a cover crop specie.

Operating and maintenance Costs:

Annual operating and maintenance costs can be assumed to be 2 % of the annualized capital costs.

Water Reservoir:
Total amortized capital cost of $183,311.28 per year multiplied by 2 per cent results in $3,666.23 in operating costs.

Tile Drains:
Total amortized capital cost of $8,155.08 per year multiplied by 2 per cent results in $163.10 in operating costs.

Landscape Designing:
Total amortized capital cost of $23,724.84 per year multiplied by 2 per cent results in $474.50 in operating costs.

Cover Cropping:
Total annual capital cost of $22,630.67 per year multiplied by 2 per cent results in $452.61 in operating costs.

Lost Farmland Cost:

The opportunity cost of farmland being converted for use in the water reservoir investment option was calculated using the Government of Manitoba's Cost of Production Guide (Government of Manitoba, 2020) that states that the average value of farmland in the province of Manitoba in terms of productivity is $67.06 per acre. Total cost of lost farmland (20 acres) in adopting this investment option is estimated as $1341.20.

Benefits:

Reduction in excess moisture:

Several field studies have reported that when prolonged excess moisture conditions occur during the middle of the growing season, crop yield is reduced up to 53 % of the total potential yield (Cannell et al., 1980; Collaku and Harrison, 2002; Cavers and Heard, 2001). However, if excess moisture condition prevails during the beginning of crop growing season, farm is at the risk of loosing 100 % of the crop or crop year due to reduced trafficability, delayed seeding, significant portion of seeds washed away, poor germination, unaerated root-zone, and plants drowned out or washed away (Government of Manitoba, 2013). In order to generalize the cost benefit analysis for all crop types of Manitoba and ease of quantification, analysis of this benefit component is framed based on former assumption. Benefit of reduction in excess moisture is calculated using Government of Manitoba's "Crop Production Cost" guide (Government of Manitoba, 2020). Gross revenue per acre of most commonly grown field crops in Manitoba is averaged as $413.50. Same monetized value of gross revenue per acre is considered for each of four proposed excess moisture management strategies.

Water Reservoir:
We estimated that a farm reservoir with an area of 20 acre and depth of 10 m is sufficient to collect the water volume that could produce saturated conditions in an area of 302.45 acre of sand clay loam soil. Total gross revenue for this area is estimated as $125063.08.

Tile Drainage:
When using tile drainage as an excess moisture management option, total gross revenue for the proposed scale of infrastructure is estimated as $41,350.

Land Grading:
When using land grading as an excess moisture management option, total gross revenue for the proposed scale of adaptation is estimated as $41,350.

Cover Cropping:
When using cover cropping as an excess moisture management option, total gross revenue for the proposed scale of cropping is estimated as $41,350.

Avoided Flooding Costs:

Out of four excess moisture management strategies, only water reservoirs option have the capacity of storing significant amount of water at farm level. Avoided downstream flooding was valued by using data from the North Ottawa project, which involved an impoundment that controlled 75 square miles of the 320 square mile Rabbit River Watershed in Grant and Otter Tail Counties in Michigan by storing the excess runoff on 1,920 acres of land. The construction costs of this project were used to establish willingness to pay for flood risk mitigation and led to the value of $1297.14 per megalitre of water storage (Dion and McCandless, 2013). Cost for the reporting year (2020) is assumed as $1500.53 per megalitre of water storage.

For other three strategies, it is assumed that a natural or constructed wetland is present at downstream of watershed area. A constructed wetland is scaled according to its treatment drainage area; typically, a 0.5 % - 2 % range in wetland/watershed area ratio is the standard (Tyndall and Bowman, 2016). A 2 % ratio of wetland/watershed area is made part of this analysis, which is translated as 2 acre of wetland for a watershed area of 100 acre. Value of using wetlands would be regarded as value of flood control, based on avoided damage costs. The value of wetland flood control, based on avoided damage costs is $741.30 per ha per year (Brander et al., 2013). Cost for the reporting year (2020) is assumed as $857.54 per ha per year, or $347.18 per acre per year.

Water Reservoir:
A 20-acre water reservoir has a potential to store 160.34 megalitres of floodwater. Using this option, avoided flooding cost for flood risk mitigation is $240,594.98.

Tile Drainage:
A 100-acre farm segment under tile drainage system has a potential to contribute to 2 acre of wetland. Using this option, avoided flooding cost for flood risk mitigation is $694.36.

Land Grading:
A 100-acre farm segment with a continuous grade has a potential to contribute to 2 acre of wetland. Using this option, avoided flooding cost for flood risk mitigation is $694.36.

<u>Cover Cropping:</u>
A 100-acre farm seeded with cover crop has a potential to contribute to 2 acre of wetland. Using this option, avoided flooding cost for flood risk mitigation is $694.36.

Avoided Drought:

The potential of using water stored in retention pond or controlled tile drain structure for irrigation purpose was used as a benefit of avoiding drought. Kulshreshtha (2006) found that the monetized impact of irrigated water on productivity $150 per megalitre in Saskatchewan and Manitoba settings. Considering the inflation rate calculation, we assumed that the reasonable proxy for valuing the potential use of retained water as irrigated water in Manitoba is $197.

<u>Water Reservoir:</u>
A 20-acre water reservoir has a potential to store 160.34 megalitres of floodwater. Using this option, avoided drought cost is $31,586.98.

<u>Tile Drainage:</u>
A 100-acre farm segment under tile drainage system has a potential to store 0.22 megalitres of floodwater. Using this option, avoided drought cost is $43.34.

<u>Land Grading:</u>
This investment option does not have on-farm water storage capacity.

<u>Cover Cropping:</u>
This investment option does not have on-farm water storage capacity.

Reduced Eutrophication:

Berry et al. (2017) reported the cost of phosphorus removal from Pelly's lake is $60 per kilogram (average of source values) (Olewiler, 2004; Wilson, 2008; Sohngen et al., 2015). It is assumed that there exists the social willingness to pay for removal of phosphorus from water, since if the phosphorus was not treated at the plants, it would be discharged into the watershed, as is currently the case with phosphorus runoff in Manitoba. Considering the inflation rate calculation, we assumed that the reasonable proxy for valuing the phosphorus removal per kilogram in Manitoba is $64 per kilogram.

<u>Water Reservoir:</u>
Cattail's harvested yield from palley's lake was used to calculate the cattail's production for this option. Each metre of ditch was estimated to produce 0.0384 tonnes of cattail dry biomass. Cattail production for this option was estimated to be 92.4 tonnes per year; using the above assumption that phosphorus is 0.22 per cent of cattail weight, estimated phosphorus removal is 203.28 kilograms per year.

Tile Drains:
Tanner & Sukias (2011) reported that subsurface drainage system losses up to 2.9 kg total phosphorous per hectare, or 1.17 kg per acre. An area of controlled tile drain of 100 acre stores 117.4 Kg of total phosphorous at farm, which has a monetized value of $7,513.60.

Landscape Designing:
He et al. (2020) reported a reduction of 50 % to 57 % in phosphorous loses, when using land grading technique of multiple slopes. We used a median value of 54 % for analysis. Using total phosphorous losses estimates reported by Tanner & Sukias (2011) (1.17 Kg/acre), land grading option reduces 0.63 Kg/acre of phosphorous loss that might ordinarily be lost as runoff or in-stream flow, and causing eutrophication at farm's downstream level. An area of 100 acre under land grading saves 63.18 Kg of total phosphorous at farm, which has a monetized value of $4,043.52.

Cover Cropping:
Cover crops can reduce the amount of phosphorous leaving a field by 15 % to 92 % (with a median value of 54 %) (SARE, 2012). Using total phosphorous losses estimates reported by Tanner & Sukias (2011) (1.17 Kg/acre), cover crops retain 0.63 Kg/acre of phosphorous at farm that might ordinarily be lost as runoff or in-stream flow, and causing eutrophication at farm's downstream level. An area of 100 acre under cover cropping saves 63.18 Kg of total phosphorous at farm, which has a monetized value of $4,043.52.

Production of Cattails:

We monetized cattail production using International Institute for Sustainable Development's knowledge and reports around cattail production and harvesting for use as bioenergy. Cattails' value was assumed as $58 per tonne of dry biomass for the analysis year (2020). Grosshans (2013) found that total cattail production costs (including nutrient value, harvest cost, custom baling, custom field moving, custom hauling, repairs and maintenance, miscellaneous costs and interest) were $33.41 per tonne. Therefore, the, after deducting costs, was found to be $16.59 per tonne. Considering the inflation rate calculations, we assumed that the reasonable proxy for total cattail production costs in Manitoba is $38.76 and total value of dry cattail biomass is $19.24.

Water Reservoir:
Cattail production for this option was estimated to be 92.4 tonnes per year, which is accounted as a revenue of $1,777.78 per year.

Tile Drains:
Cattail production for this option was estimated to be 18.48 tonnes per year, in the downstream wetland area, which is accounted as a revenue of $355.56 per year.

Landscape Designing:
Cattail production for this option was estimated to be 18.48 tonnes per year, in the downstream wetland area, which is accounted as a revenue of $355.56 per year.

Cover Cropping:
Cattail production for this option was estimated to be 18.48 tonnes per year, in the downstream wetland area, which is accounted as a revenue of $355.56 per year.

Carbon Credits:

We monetized the value of carbon credits produced via cattail production using International Institute for Sustainable Development's knowledge and reports around cattail production and harvesting for use as bioenergy. Grosshans (2013) found that one tonne of biomass replaces 0.54 tonnes of coal, which produces 1.05 tonnes of carbon dioxide equivalent per tonne of cattail biomass. For the analysis reporting year, these carbon offsets were assumed to be valued at $18 per tonne of carbon dioxide equivalent.

Water Reservoir:
For this option, we estimated that cattail production would be 92.4 tonnes per year, or 97.02 tonnes of carbon dioxide equivalent per year, which is accounted as a revenue of $1746.36 per year.

Tile Drains:
For this option, we estimated that cattail production in the wetland would be 18.48 tonnes per year, or 9.7 tonnes of carbon dioxide equivalent per year, which is accounted as a revenue of $174.60 per year.

Landscape Designing:
For this option, we estimated that cattail production in the wetland would be 18.48 tonnes per year, or 9.7 tonnes of carbon dioxide equivalent per year, which is accounted as a revenue of $174.60 per year.

Cover Cropping:
For this option, we estimated that cattail production in the wetland would be 18.48 tonnes per year, or 9.7 tonnes of carbon dioxide equivalent per year, which is accounted as a revenue of $174.60 per year.

New Wetland Habitat:

A monetized value of per-acre wetland habitat is stablished as a benefit transfer in this analysis. According to Borisova-Kidder (2006), wetland offers an average value of USD 262.43 per acre. Woodward & Wui (2001) reported that the contributions of habitat function in wetlands' total value is 24 %. The per-acre figure found in the first study was therefore adjusted for currency and inflation to a value of $483.39 (2020), and then multiplied by 24 per cent to produce the resultant wetland habitat monetization figure of $116.01 per acre.

Water Reservoir:
The ponds in this proposed option has a surface area of 20 acres, which is accounted as a revenue of $2320.20 per year.

Tile Drains:
It is assumed that establishment of wetland in this proposed option has a surface area of 2 acres, which is accounted as a revenue of $232.02 per year.

Landscape Designing:
It is assumed that establishment of wetland in this proposed option has a surface area of 2 acres, which is accounted as a revenue of $232.02 per year.

Cover Cropping:
It is assumed that establishment of wetland in this proposed option has a surface area of 2 acres, which is accounted as a revenue of $232.02 per year.

Results and Discussions:

Results presented in Table 1, 2, 3, & 4 are developed to estimate economics of each of the four investment options using the above information. Cost benefit ratios are provided to develop the understanding of the amount of return that can be expected on each dollar of investment for each of the four proposed options. It is worth mentioning here that we estimated costs using the best knowledge available based on the 2019-20 market analysis, but both the ultimate capital and operating costs would very much depend on local economic and geographic conditions. Better cost estimates would be useful in helping confirm the results presented below.

Table 4: Costs and Benefits Framework of Water Reservoirs

Variable	Units	Monetary Value	Impact (In Units)	Monetized Impact
Costs				
Annual Capital cost	Capital costs	$2,890,000.00	20 year Amortization	$183,311.28
Annual Operating Costs	Operating costs	$73,324.51	20 years	$3,666.23
Opportunity Costs	Acres of lost farmland	$67.06	20	$1,341.20
Total				**$188,318.71**
Benefits				
Reduction in Excess Moisture	Acres	$413.50	302.45	$125,063.08
Avoided Flooding Costs	Megalitres of water	$1,500.53	160.34	$240,594.98
Avoided Drought	Megalitres of water	$197	160.34	$31,586.98
Reduced Eutrophication	Kilograms of phosphorus	$64.00	203.28	$13,009.92
Cattails Produced	Tonnes of cattails (total biomass)	$19.24	92.4	$1,777.78
Carbon Credits	tonnes of carbon credits	$18	97.02	$1,746.36
New Wetland Habitat	Acres of wetland	$116.01	20	$2,320.20
Total				**$416,099.29**
Annual Net Benefit				**$227,780.59**
Benefit: Cost			**220.95%**	

Table 5: Costs and Benefits Framework of Tile Drainage

Variable	Units	Monetary Value	Impact (In Units)	Monetized Impact
Costs				
Annual Capital cost	Capital costs	$128,400.00	20 year Amortization	$8,155.08
Annual Operating Costs	Operating costs	$3,262.03	20 years	$163.10
Opportunity Costs	Acres of lost farmland	N/A		
Total				**$8,318.18**
Benefits				
Reduction in Excess Moisture	Acres	$413.50	100	$41,350.00
Avoided Flooding Costs	Wetland Area	$347.18	2	$694.36
Avoided Drought	Megalitres of water	$197	0.21	$41.37
Reduced Eutrophication	Kilograms of phosphorus	$64.00	117.4	$7,513.60
Cattails Produced	Tonnes of cattails (total biomass)	$19.24	18.48	$355.56
Carbon Credits	tonnes of carbon credits	$18	9.7	$174.60
New Wetland Habitat	Acres of wetland	$116.01	2	$232.02
Total				**$50,361.51**
Annual Net Benefit				**$42,043.32**
Benefit: Cost			**605.44%**	

Table 6: Costs and Benefits Framework of Land Grading

Variable	Units	Monetary Value	Impact (In Units)	Monetized Impact
Costs				
Annual Capital cost	Capital costs	$373,544.88	20 year Amortization	$23,724.84
Annual Operating Costs	Operating costs	$9,489.94	20 years	$474.50
Opportunity Costs	Acres of lost farmland	N/A		
Total				**$24,199.34**
Benefits				
Reduction in Excess Moisture	Acres	$413.50	100	$41,350.00
Avoided Flooding Costs	Wetland Area	$347.18	2	$694.36
Avoided Drought	Megalitres of water	$197	0	$0.00
Reduced Eutrophication	Kilograms of phosphorus	$64.00	63.18	$4,043.52
Cattails Produced	Tonnes of cattails (total biomass)	$19.24	18.48	$355.56
Carbon Credits	tonnes of carbon credits	$18	9.7	$174.60
New Wetland Habitat	Acres of wetland	$116.01	2	$232.02
Total				**$46,850.06**
Annual Net Benefit				**$22,650.72**
Benefit: Cost			**193.60%**	

Table 7: Costs and Benefits Framework of Cover Cropping

Variable	Units	Monetary Value	Impact (In Units)	Monetized Impact
Costs				
Annual Capital cost	Capital costs	$22,630.67		$22,630.67
Annual Operating Costs	Operating costs	$452.61		$452.61
Opportunity Costs	Acres of lost farmland	N/A		
Total				**$23,083.29**
Benefits				
Reduction in Excess Moisture	Acres	$413.50	100	$41,350.00
Avoided Flooding Costs	Wetland Area	$347.18	2	$694.36
Avoided Drought	Megalitres of water	$197	0	$0.00
Reduced Eutrophication	Kilograms of phosphorus	$64.00	63.18	$4,043.52
Cattails Produced	Tonnes of cattails (total biomass)	$19.24	18.48	$355.56
Carbon Credits	tonnes of carbon credits	$18	9.7	$174.60
New Wetland Habitat	Acres of wetland	$116.01	2	$232.02
Total				**$46,850.06**
Annual Net Benefit				**$23,766.77**
Benefit: Cost			**202.96%**	

Conclusion

Climate change is expected to cause increasing variability and extremity in weather patterns in the coming decades, particularly in the form of more frequent and widespread flood events. Manitobans live with natural variability inherent in our climate. It is a province subject to extreme flooding events with devastating impacts. The vast majority of crop insurance claims in Manitoba are moisture-related and are increasing in number. Manitoba's producers are already facing the effects of extreme moisture conditions and looking for sustainable, adaptable, and resilient approaches in order to respond appropriately to overcome the disaster. This report manifested how different farm investment options adopted for excess moisture management could mitigate the negative impacts of floods and can also provide significant nutrient management and other types of co-benefits on the farm. This report quantifies and monetizes benefits of these investment options, where data exists. With the base case representing current conditions, four other strategies were selected and used in southern Manitoba's conditions, namely: water reservoir, tile drainage, land grading or cut and fill, and cover cropping. We recognize when choosing an excess moisture management strategy, any current issue on the farm must be clearly identified in order to choose one or more approaches to invest in to address and solve on-farm problems. The frequency, magnitude, and trend analysis of floods, and size of the farm will help in deciding the investment option best suited for the area in order to reduce risk to farmers and the region. Initial costs for adaptability measures can be prohibitive for some operations and a thorough understanding of all operating costs and potential cash-flow are central to such a decision. This report is designed to provide farmers and decision makers the knowledge to make and support on-farm investment decisions related to managing times of excess moisture. All monetized values and figures are accurate in late 2019 and early 2020. Costs of installation are site specific and largely depend on soil characteristics, land topography, acres being drained, and Manitoba's local contractor prices.

The four farm level flood management strategies featured in this report can reduce damages and human suffering in the rural setting particularly. Farm investment strategies in league with other actions can reduce the public costs of flood damage. It is also essential to have adequate framework, such as those examine in this report, so producers can make informed decisions of management planning. All four farm strategies proposed in this report have long infrastructure life and provide more benefits over costs. With this framework in hand, an important next step is to receive feedback from producers in terms of how this might be useful to their decision making.

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