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Cost-Benefit Analysis of Three Proposed Distributed Water Storage Options for Manitoba

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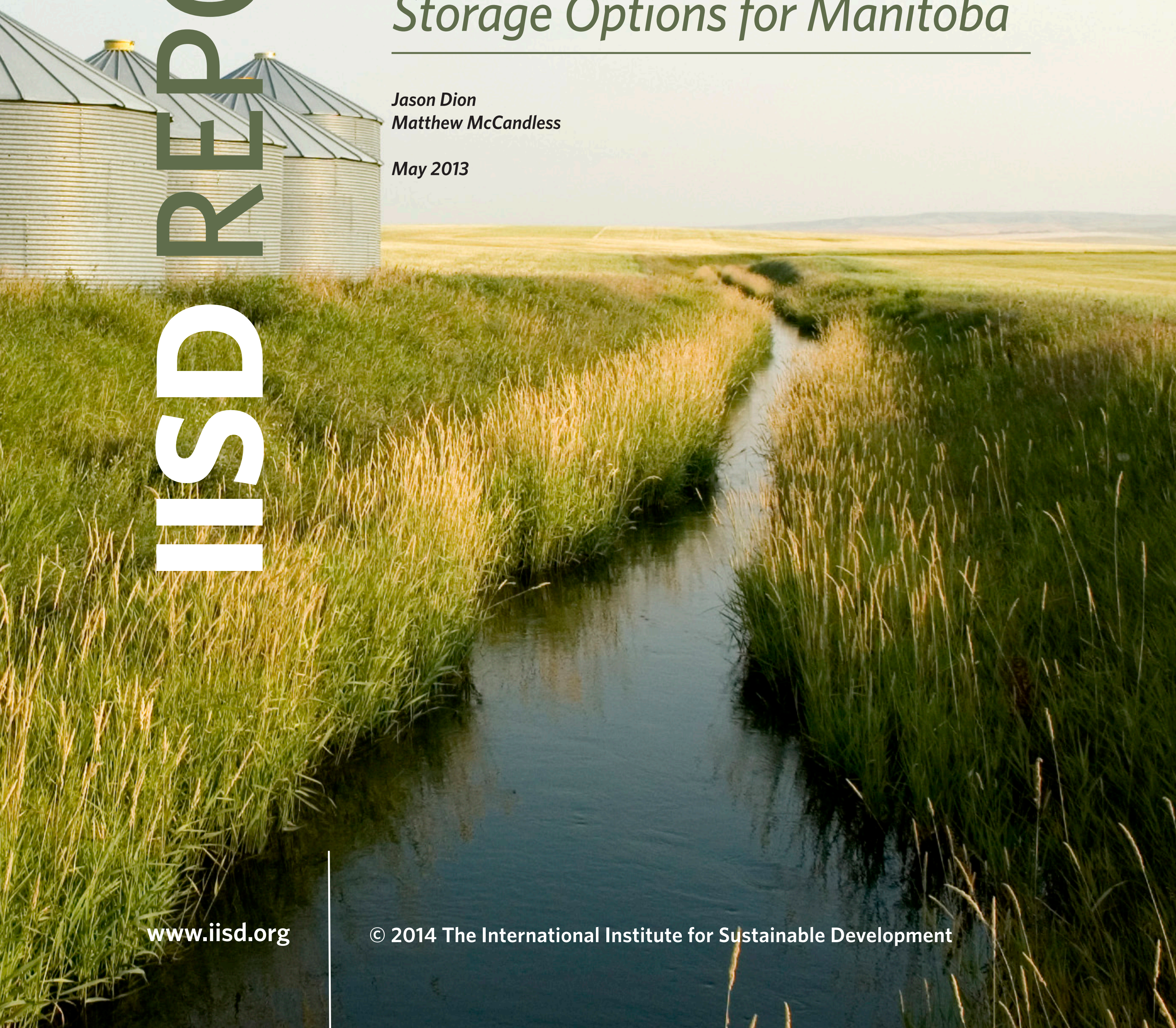
May 2013



Published by the International Institute for Sustainable Development.

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Written by Jason Dion and Matthew McCandless

Executive Summary

Manitoba has long had a history of flooding, including major floods in 1950, 1997 and 2009, and the recent flood of 2011 was of a scope and severity never before experienced in the province. Costs associated with flood preparation, flood fighting, repair to infrastructure and disaster payments have reached $1.2 billion.[1] (Government of Manitoba, 2013b). In addition, eutrophication is a major issue. According to Bourne, Armstrong and Jones (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.

This report attempts to demonstrate how land management best practices to prevent floods and droughts can also provide significant nutrient management and other types of co-benefits. It provides a cost-benefit analysis of three potential interventions in the province of Manitoba for mitigating flooding through distributed water storage, as proposed by Dr. David Lobb of the University of Manitoba:

- **OPTION 1** uses the concept of expanding current established drainage systems surrounding agricultural lands. It involves **expanded ditches** and various other forms of drainage systems to capture larger amounts of runoff and nutrients that would be recycled for irrigating purposes in agricultural production. Cattails or other crops would grow for biomass production around the ditches to capture the nutrients (phosphorous) and purify the nutrient-rich runoff.
- **OPTION 2** promotes the creation of large **retention ponds** on farmland to capture nutrient-rich runoff on the farm itself. The runoff captured in the retention ponds would be recycled on agricultural lands and would promote the growth of biomass fuel sources such as cattails around the ponds.
- **OPTION 3** requires agriculture producers to build **berms** around the perimeter of the agricultural lands. These berms would capture the nutrient-rich spring runoff, and dependent on the season and the amount of moisture, would allow the field boundaries to hold in the excess water to either drain to support livestock or soak back into the soil.

The relevant associated benefits and costs included in the analysis are as follows:

Benefits	Costs
Avoided drought	Up-front capital costs
New wetland habitat	Operating costs
Production of cattails	Lost farmland (opportunity cost)
Carbon credits	
Reduced eutrophication	
Avoided flooding costs	

Using best practices in benefits transfer techniques, the cost-benefit analysis arrived at the following results for the proposed three options.

[1] All dollar values are in CAD.

COSTS AND BENEFITS OF OPTION 1: RE-GRADED DITCHES[2]

VARIABLES	UNITS	MONETARY VALUE	IMPACT (IN UNITS)	MONETIZED IMPACT
Benefits				
Avoided drought	Megalitres of water	$150.00	201.91	$30,286
New wetland habitat	Acres of wetland	$82.13	50.61	$4,156
Cattails produced	Tonnes of cattails	$16.59	122.90	$2,039
Carbon credits	tonnes of carbon credits	$15.00	129.05	$1,936
Avoided flooding costs	Megalitres of flood mitigation	$1,297.14	201.91	$261,903
Reduced eutrophication	Kilograms of phosphorus	$10.00	270.38	$2,704
Total				**$303,024**
Costs				
Capital costs (annualized)	Capital costs	$150,000.00	20 year amor.	$150,000
Annual operating costs	Operating costs	$3,000.00	2% of cap. cost	$3,000
Opportunity costs	Hectares of lost farmland	$60.00	50.61	$3,037
TOTAL				**$156,037**
ANNUAL NET BENEFIT	Dollars			$146,988
BENEFIT: COST	Ratio			194%

COSTS AND BENEFITS OF OPTION 2: FILTER FIELD AND PONDS

VARIABLE	UNITS	MONETARY VALUE	IMPACT (IN UNITS)	MONETIZED IMPACT
Benefits				
Avoided drought	Megalitres of water	$150.00	100.95	$15,143
New wetland habitat	Acres of wetland	$82.13	7.17	$589
Cattails produced	Tonnes of cattails (total biomass)	$16.59	93.60	$1,553
Carbon credits	tonnes of carbon credits	$15.00	98.28	$1,474
Avoided flooding costs	Megalitres of flood mitigation	$1,297.14	100.95	$130,952
Reduced eutrophication	Kilograms of phosphorus	$10.00	205.92	$2,060
Total				**$151,770**
Costs				
Capital costs (annualized)	Capital costs	$150,000.00	20 year amor.	$115,000
Annual operating costs	Operating costs	$2,300.00	2% of cap. cost	$2,300
Opportunity costs	Hectares of lost farmland	$60.00	26.44	$1,586
TOTAL				**$118,886**
ANNUAL NET BENEFIT	Dollars			$32,884
BENEFIT: COST	Ratio			128%

[2] Figures in this and other tables are rounded to the nearest dollar.

COSTS AND BENEFITS OF OPTION 3: BACK-FLOODED DAMS

VARIABLE	UNITS	MONETARY VALUE	IMPACT (IN UNITS)	MONETIZED IMPACT
Benefits				
Avoided drought	Megalitres of water	$150.00	0.00	$ -
New wetland habitat	Acres of wetland	$82.13	80.00	$6,570
Cattails produced	Tonnes of cattails (total biomass)	$16.59	388.50	$6,445
Carbon credits	Tonnes of carbon	$15.00	407.93	$6,119
Avoided flooding costs	Megalitres of flood mitigation	$1,297.14	12.77	$16,561
Reduced eutrophication	Kilograms of phosphorus	$10.00	854.70	$8,547
Total				$44,242
Costs				
Capital costs (annualized)	Capital costs	$7,000.00	20 year amor.	$7,000
Annual operating costs	Operating costs	$140.00	2% of cap. cost	$140
Opportunity costs	Hectares of lost farmland	$60.00	80	$4,800
TOTAL				$11,940
ANNUAL NET BENEFIT	Dollars			$32,302
BENEFIT: COST	Ratio			371%

The findings emphasize that Option 3, back-flooded dams, is preferable from a cost-benefit perspective, mainly due to its relatively low cost and comparable ecological goods and services (EGS) related benefits.

However, in interpreting the results of the study it is important to bear in mind that some recognized benefit types were excluded from the cost-benefit calculation because they were difficult or impossible to measure and/or monetize. These variables include the following:

- Recovered soil
- Aquaculture
- Watering livestock
- Avoided water treatment costs
- Reduced sedimentation
- Enhanced provision of broad EGS

Each of these benefits would certainly be enjoyed, to varying degrees, under each of the three options. However, it is difficult or impossible to determine the degree to which they would impact results or whether they would alter the merit order of the three options.

The results presented, while not indisputable, provide an instructive means of assessing the relative merits of each proposed option and can form the basis of subsequent analysis of the three proposed options, such as attempts to include the excluded variables outlined above.

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1.0 Introduction

This report provides a cost-benefit analysis of three proposed interventions in the province of Manitoba for mitigating flooding through distributed water storage, as proposed by Dr. David Lobb of the University of Manitoba. This report attempts to demonstrate how land management best practices to prevent floods and droughts can also provide significant nutrient management and other types of co-benefits. As such, it attempts where possible to quantify and monetize these benefits. This report provides an overview of the three proposed options and of cost-benefit analysis in general; discusses the overall approach and specific methodology of the study; offers the results of the study, complemented by a sensitivity analysis and a discussion; and closes with a conclusion. As is presented below, the three options offer a range of benefits beyond the narrow goal of flood/drought mitigation, some of which lend themselves to quantification and monetization and some of which do not.

2.0 Rationale

This section provides the rationale for this study, outlining the context in Manitoba in terms of flooding and Lake Winnipeg's eutrophication. It then discusses the existence of ecological goods and services (EGS) and their relevance to this study, and finally it provides an overview of the three proposed options, namely, re-graded ditches, filter fields and ponds, and back-flooded dams.

Manitoba Context

Two issues dominate the question of applying the three proposed options to the Manitoba context: flooding and eutrophication. As discussed below, both issues are extremely important in Manitoba, and therefore a cost-benefit analysis must consider the impact of the three proposed interventions on these key dimensions.

Flooding

Manitoba has long had a history of flooding, including major floods in 1950, 1997 and 2009. But the recent flood of 2011 was of a scope and severity never before experienced in the province. At the height of the flood there were more than 7,100 evacuees, primarily from First Nations communities. Three million acres of cultivated farmland went unseeded in 2011. Tens of 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. Costs associated with flood preparation, flood fighting, repair to infrastructure and disaster payments have reached $1.2 billion (Government of Manitoba, 2013b).

The three proposed interventions all involve the retention of water upstream and as such have flood mitigation as one of their primary benefits. The degree to which they are able to mitigate flooding in the aggregate will depend on the scale to which they are deployed and where they are deployed, and thereby the total amount of water that would be retained. In a province like Manitoba where flooding is a long-standing and ongoing issue, an analysis of the three proposed interventions that did not consider the three options' effect(s) on flooding would be incomplete. Impacts on flood mitigation will therefore figure prominently in the analysis.

Eutrophication

Eutrophication occurs when waters become rich in mineral and organic nutrients such as nitrogen and phosphorus (often due to runoff from surrounding land), causing dense growth in plant life such as algae, whose decomposition chokes the supply of oxygen and leads to the depletion of animal life in the water. All healthy ecosystems require nitrogen and phosphorus; they are essential to life. But several human activities have the potential to increase nutrient levels found within an ecosystem. Agriculture tends to import nutrients through the use of various types of fertilizer, and some of these nutrients may be introduced into watersheds through different land use practices and land management techniques.

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 per cent of total nitrogen and 76 per cent of total phosphorous, while in the Red River basin they contribute 59 per cent of total nitrogen and 73 per cent of total phosphorus.

Phosphorus has been widely recognized as the logical first priority in addressing eutrophication in water bodies downstream 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 (Flaten, 2003; Hively, Gérard-Marchant, & Steenhuis, 2006; Soranno, Hubler, Carpenter, & Lathrop, 1996). Manitoba's Lake Winnipeg Stewardship Board (2006) makes a clear case for addressing phosphorus loading as an initial priority for reducing downstream nutrient loading.

The three proposed options can influence both the rate at which nutrients enter watersheds and the rate at which nutrients become available for algal growth downstream, a major issue for Lake Winnipeg and Manitoba in general. As such, issues of phosphorus loading and eutrophication are extremely important in Manitoba and form a major part of this analysis.

Ecological Goods and Services (EGS)

EGS are things with value that are delivered free via natural systems, such as nutrient cycling, purification of air and water, maintenance of biodiversity, decomposition of wastes, soil and vegetation generation and renewal, pollination of crops and natural vegetation, groundwater recharge through wetlands, seed dispersal, greenhouse gas mitigation and so on. They are traditionally excluded from economic decision making, since effects on them usually occur as externalities (a cost or benefit that results from an activity or transaction and which affects an otherwise uninvolved party who did not choose to incur that cost or benefit).

When the impact of an externality does not get accounted for, transactions may occur that would be otherwise uneconomic; for example, a certain industrial technology with high pollution and/or health impacts may seem preferable to a more high cost, lower impact option. Similarly, transactions may not occur at all when externalities are not accounted for; for example, investing in a superior industrial technology may remain uneconomic until the cost of the pollution and adverse health impacts are accounted for. It is this second situation that this analysis hopes to avoid. The three proposed interventions all come at fairly substantial costs, but to accurately assess their merits, which will certainly involve the presence of positive (desirable) externalities, the analysis must include all EGS-related externalities.

Accounting for the impact of the three proposed options on EGS will be vital in accurately assessing the total anticipated benefits relative to costs. It is only once these broader EGS co-benefits are included and valued that a meaningful picture of the net impact and resultant economic viability will emerge.

Three Proposed Interventions

The three potential interventions proposed are re-graded ditches, filter fields and ponds, and back-flooded dams. These three options are presented below.

Re-Graded Ditches

This option uses the concept of expanding current established drainage systems surrounding agricultural lands, as seen in Figure 1. The approach involves expanding the ditches and various other forms of drainage systems to capture larger amounts of runoff and nutrients that would be recycled for irrigating purposes in agricultural production. Cattails or other crops would grow for biomass production around the ditches to capture the nutrients (phosphorous) and purify the nutrient-rich runoff. For the purposes of this analysis, this option will be examined at a scale of one section with ditches on two sides, for a total of 3,200 metres of ditch to be expanded.

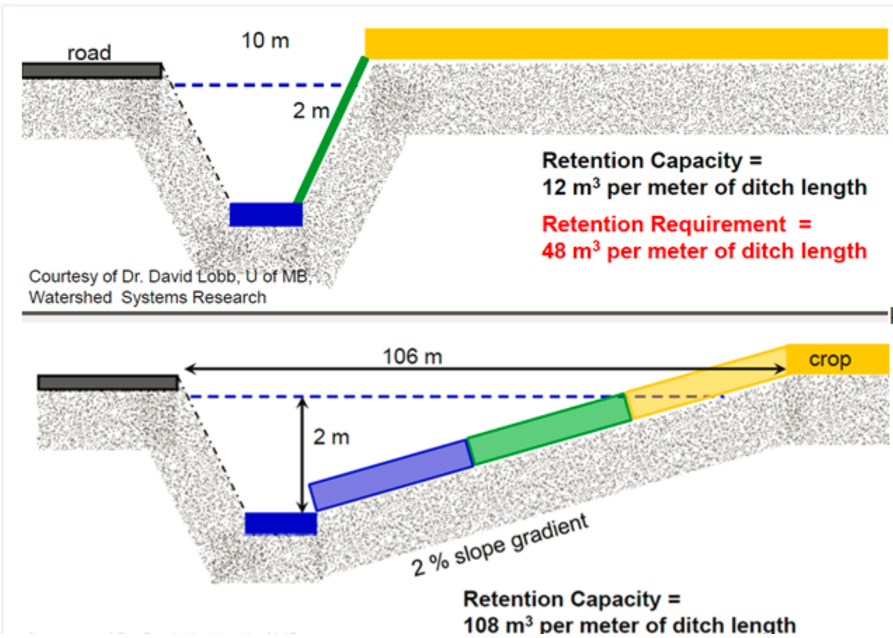

FIGURE 1: RE-GRADED DITCHES

Source: Ali, English, Lobb, Randall, Sheppard, & Flatten (2013).

Filter Fields and Ponds

The second option promotes the creation of large retention ponds on farmland to capture nutrient-rich runoff on the farm itself, as seen in Figure 2. The runoff captured in the retention ponds would be recycled on agricultural lands and would promote the growth of biomass fuel sources such as cattails around the ponds.

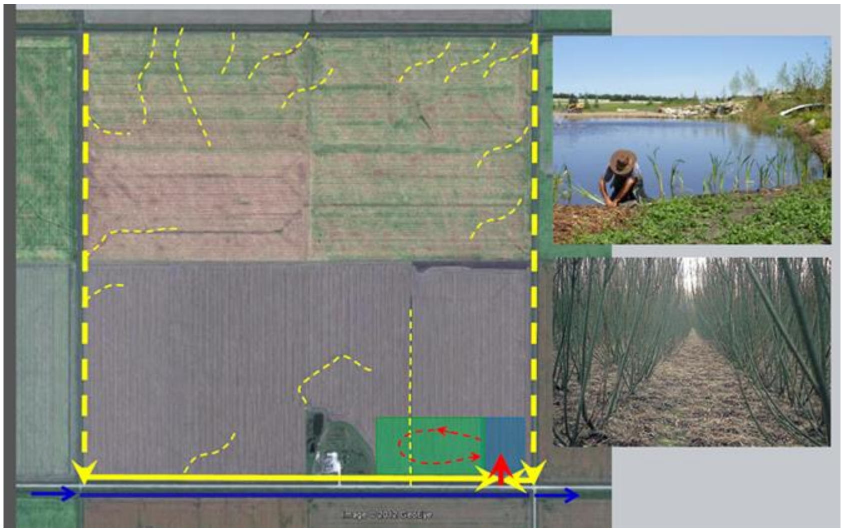

FIGURE 2: FILTER FIELDS AND PONDS

Source: Ali et al. (2013).

Back-Flooded Dams

The third option, as seen in Figure 3, requires agriculture producers to build berms around the perimeter of the agricultural lands. These berms would capture the nutrient-rich spring runoff, and dependent on the season and the amount of moisture, allow the field boundaries to hold in the excess water to either drain to support livestock or soak back into the soil.

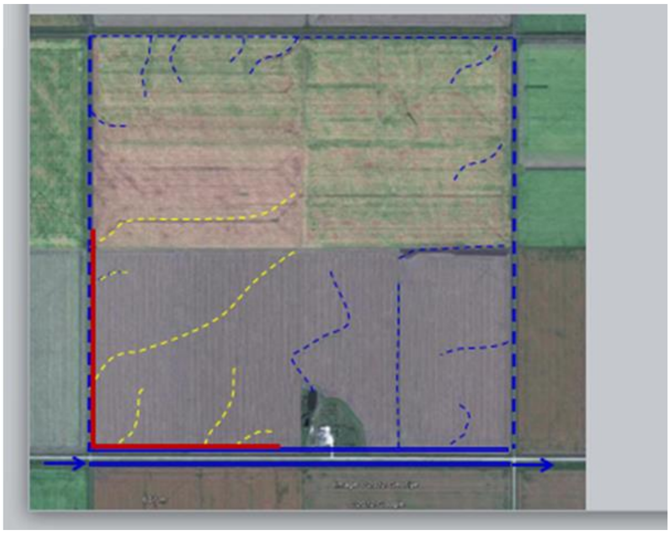

FIGURE 3: BACK-FLOODED DAMS

Source: Ali et al. (2013).

3.0 EGS Cost-Benefit Analysis

This section provides a brief overview of EGS cost-benefit analysis methods. Cost-benefit exercises seek to weigh all the anticipated benefits of a given option against the anticipated costs. In some cases this is a straightforward exercise, for example in weighing an investment decision where there is a knowable cost and a knowable return. But in other contexts it can be quite complex, especially in considering ecological goods and services, where costs of benefits are difficult to quantify, are qualitative by nature or are difficult to attribute a monetary value to. This section reviews some of the methods for valuing variables that may not lend themselves to quantification and/or monetization.

Market Prices and Revealed Willingness to Pay

A number of approaches for trying to value variables do not easily lend themselves to valuation, and they are divided into three broad categories. The first category is referred to as ***market prices and revealed willingness to pay,*** which includes prices directly set in markets as well as those that can be inferred from market prices. Methods include the following:

- **Direct estimation of producer and consumer surplus:** This can be done for markets where there is a reasonable amount of data and supply and demand curves can be calculated.
- **Productivity method:** Here, the ecosystem value being calculated is one input to a marketed product, so it is necessary to estimate the value of the input as a portion of the value of the marketed product. For example, an increase in the quality of water in a river will decrease the costs of treatment at a municipal treatment plant, thus contributing to an overall cost savings for drinking water users.
- **Hedonic pricing method:** This can be used to estimate the values of changes in the characteristics of a good. For example, the value that people derive from a nice view from their house can be estimated from data on the cost of houses both with and without a view. The same methodology can be used to value (or derive costs for) such things as air pollution or noise.
- **Travel cost method:** This is best suited to valuing ecosystems or sites that are used for recreation. Basically, the approach uses the costs that people incur in visiting a place as an indicator of its value.

Circumstantial Evidence and Imputed Willingness to Pay

The second category is ***circumstantial evidence and imputed willingness to pay***. For example, the amount that people are willing to pay to avoid floods can suggest the value of wetlands that will perform this service. The specific methods in this category include **damage cost avoided, replacement cost** and **substitute cost methods.** These methods estimate ecosystem costs by estimating the cost of damages due to lost services, the cost of replacing services or the cost of substituting for such services. For example, the damage that might be caused by flooding after the removal of a wetland can be estimated by looking at the area or property that might be flooded, and the cost of replacing the flood control capacity of the wetland can be estimated from engineering estimates of other sorts of control systems.

Surveys

The third category of valuation methods is ***surveys***, which capture people's statements of their willingness to pay. The types of survey methods include the following:

- **Contingent valuation method:** This method involves direct surveys of individuals, asking them what they would be willing to pay for certain specific environmental services. The word "contingent" refers to the fact that people are asked how much they would pay for something like an environmental service, contingent on a specific scenario and description of the service. While the methods discussed above try to derive values from market behaviour and engineering cost calculations, the contingent valuation method depends on what people say they would pay for something. The results are controversial, because it is easy to argue that what people say and what they might actually do is different. However, such studies are the only way to get some sort of estimates of non-use values.
- **Contingent choice method:** In this case, the survey does not ask for specific values but inquires about the choices or tradeoffs that people might make and infers value figures from this information. The survey will define two or more outcomes, including their costs and benefits, and will ask the respondents to rank the outcomes.

Benefits Transfer

While the above are all legitimate means of conducting valuation reliant on best practices from the literature, they are all beyond the scope of this report since they require preliminary research. Therefore, this report will use another valuation concept: ***benefits transfer.*** Benefits transfer is a valuation concept involving the transposition of benefits from one study site to another (Brouwer, 2000). Benefits transfer provides a methodology by which valuations obtained in one study can be used elsewhere, in situations shown to be similar enough that such a transfer is reasonable. The depth of analysis required for benefits transfer can take place on three levels (Genty, 2005):

- **Transfer of statistically estimated benefits:** Values that have been determined for one context are directly applied to a similar context.
- **Transfer of estimated functions:** A function that has been determined for one area is used in another. The types of functions that are transferred generally consist of the willingness to pay per household, or the value per hectare, for example.
- **Transfer of meta-models:** Meta-models are developed for the purpose of benefits transfer. They are constructed by performing surveys of existing valuation studies to determine factors. Regression analysis is performed to determine the relevance of each factor before constructing a model that can predict values for other areas using the relevant factors.

Transferring values essentially involves directly applying values calculated elsewhere to specific cases. This method can be effective where the similarity of the locations can be clearly demonstrated, but it becomes less reliable when the values being transferred are vastly different (for example, applying the value of a coastal mangrove wetland to a boreal forest wetland). For this reason the transfer of functions can be a more reliable way of estimating values. If the function of the value of land varies according to the number of species present, then a value of dollars per species can be applied to similar land elsewhere.

Meta-models are a means of systematizing the transfer of functions. At this point in the study of environmental valuation, established values for certain goods and services have yet to be firmly established for all contexts, so meta-models provide a way to develop defensible estimates for valuating ecosystem services when resources do not allow for comprehensive study. Recent efforts in the area of valuation meta-analysis include work by Johnston et al. (2005) at determining relevant factors of interest in water quality improvements. This is followed up with work by Thomassin and Johnston (2008), with the development of a methodology for conducting benefits transfer using meta-analysis. Van Houtven, Powers, and Pattanayak (2007) similarly conducted a meta-analysis of water quality improvements that can form the basis of a meta-model. Borisova-Kidder (2006) created a methodology to estimate the value of various types of habitat based on several characteristics.

This study will rely heavily on benefits transfer methods. The Approach section and Methodology section discuss the ways in which this analysis was conceived and executed, and the results of the analysis can be found in the Results section, which sums costs and benefits individually and offers a benefit-cost ratio so that the three proposed interventions can be understood in terms of their expected return. However, this will only offer a partial view of the total benefits offered, since a number of benefits will not be able to be valued, as discussed in the section below. The implications of this for the results are explored in the Discussion section.

4.0 Approach

This section discusses the broad approach to this cost-benefit exercise and outlines the thinking around what specific costs and benefits are likely to be associated with the three proposed interventions. It presents all of the anticipated costs and benefits, outlines the literature review process that was conducted, and provides the rationale for why specific costs and benefits were included or excluded from the analysis.

Costs and Benefits Considered

The initial step in the analysis was to determine which costs and benefits should be considered. This was done mainly via a process of expert analysis, at times drawing on research materials to support decision making. The thinking on what should be included in the analysis was captured in a mind map, using Mindjet's MindManager software. The three figures below describe the evolution of the thinking around what the various relevant costs and benefits were.

Figure 4 shows the first iteration. Anticipated environmental changes are in purple, impacts resulting from these changes are in blue, benefits are in green, and costs are in red.

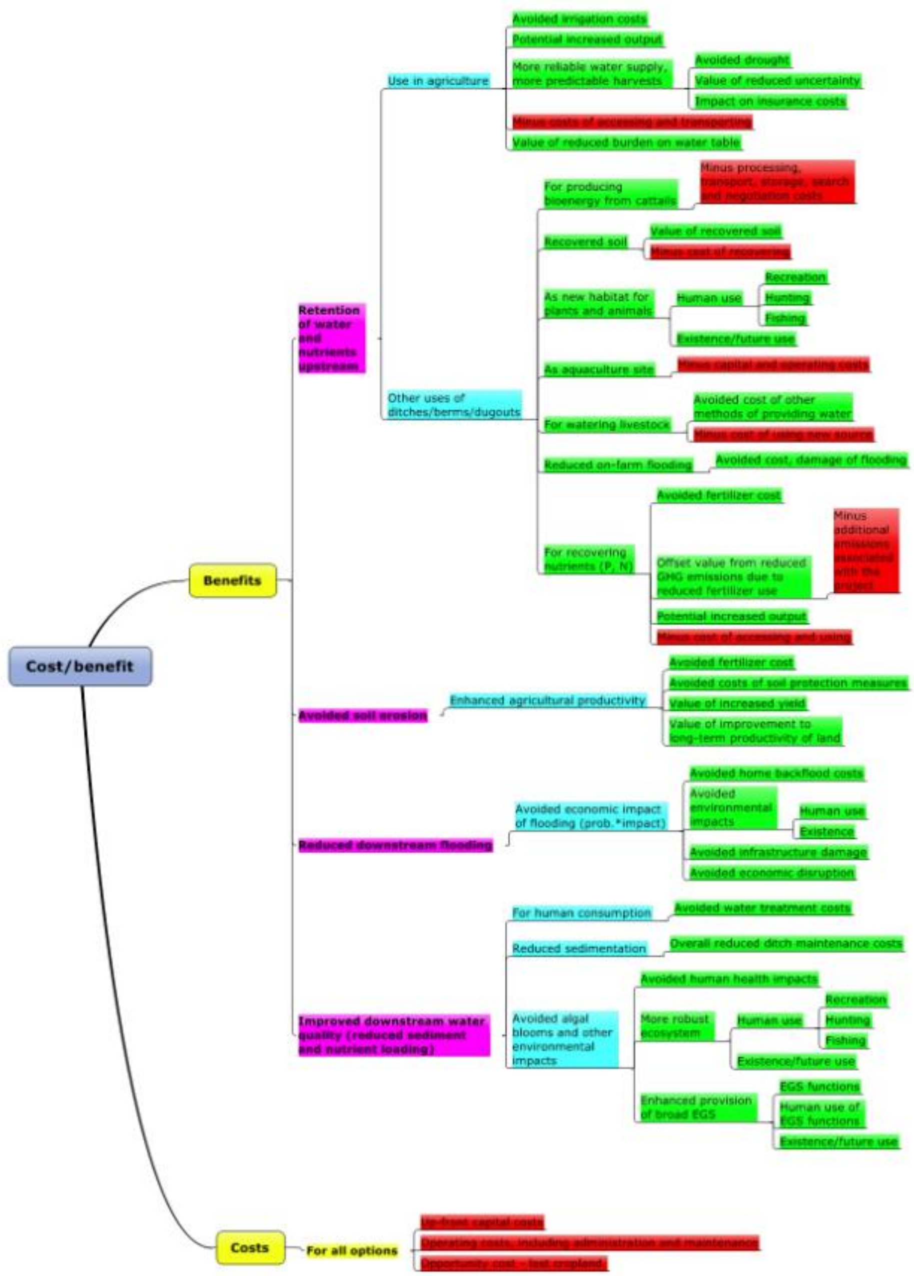

FIGURE 4: FIRST ITERATION OF ANTICIPATED COSTS AND BENEFITS

Source: Authors' figures.

After this initial iteration and further analysis, we made the following changes, as seen in Figure 5:

- The environmental change and associated economic impact distinction (which was put in place just to facilitate early thinking) was dropped, replaced instead for simplicity with a generic anticipated impact.
- Human use and existence values were removed, since these were typically found to be embodied in the figures in the valuation literature (see below for a description of the literature review), rather than broken out as distinct elements.
- Future use values were removed; they could only be calculated for a limited number of variables and so it was decided they would be outside the scope of the analysis.
- Relationships between elements were drawn (seen in red) to identify where there may be issues of double counting or other kinds of noteworthy overlap between elements.

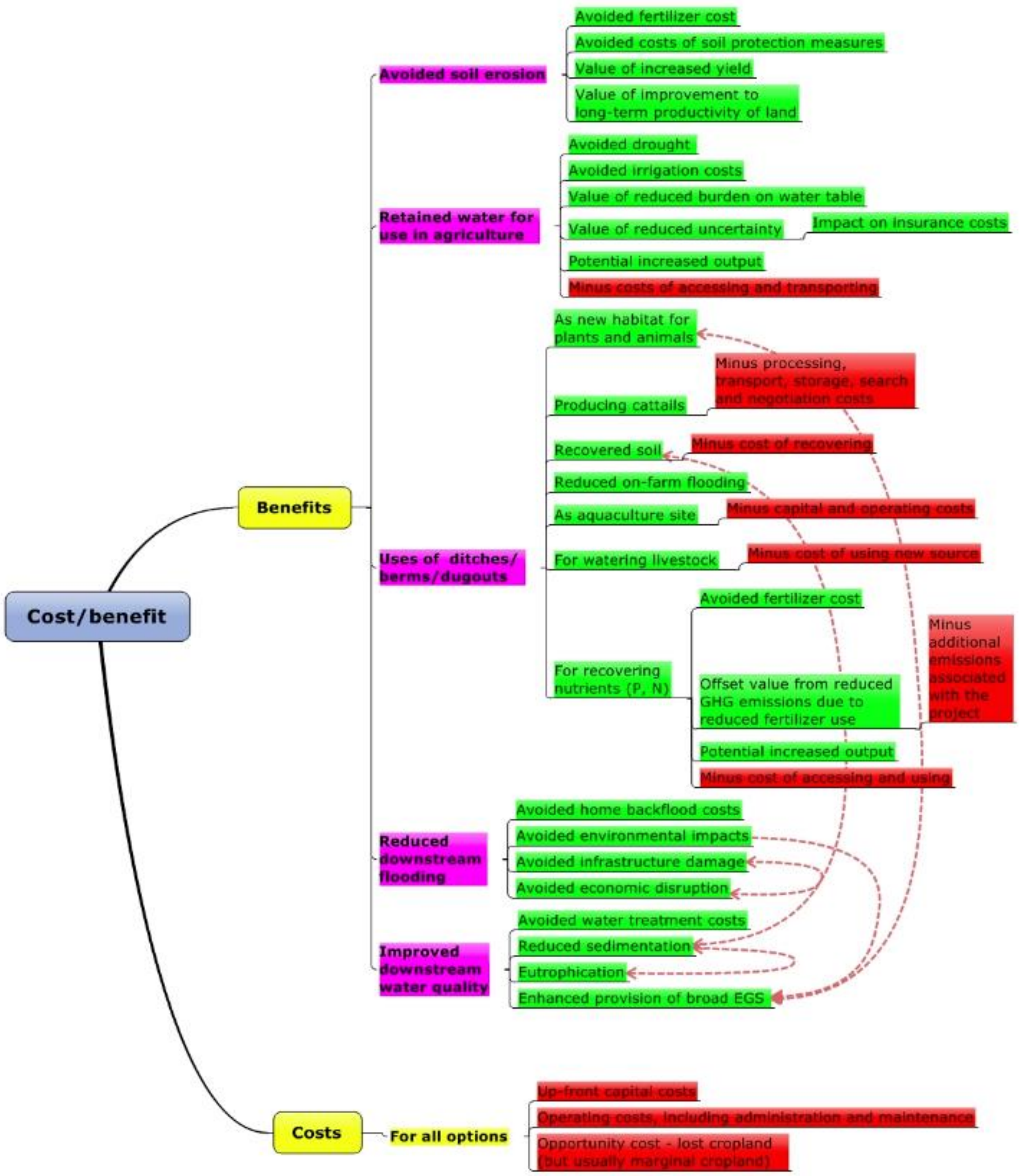

FIGURE 5: SECOND ITERATION OF ANTICIPATED COSTS AND BENEFITS

Source: Authors' figures.

We then made the following changes to move from the second to the final iteration, as seen in Figure 6:

- Soil erosion was removed as a benefit category, since we determined that issues of soil erosion would persist under all three interventions; the soil would simply now be retained upstream instead of reaching further downstream.
- The benefit category of retained water for use of water in agriculture was reduced to the benefit of avoided drought, since much of the agricultural sector in Manitoba does not employ irrigation and therefore would not enjoy the benefit of having to rely less on irrigated water sources—it would instead simply enjoy the benefit of having the water on hand to mitigate drought conditions should it be needed.
- Reduced on-farm flooding was removed as a benefit type, since we determined that on-farm flooding is not a major issue in Manitoba (downstream flooding being the greater issue).
- "Recovering nutrients" was renamed "carbon credits," since nutrient recovery would be achieved via cattail production and processing and was therefore subsumed in the cattail production benefit; the separate benefit of carbon sequestration through cattail production was therefore listed as a distinct element.
- The reduced flooding benefits were reduced to a single benefit type, since the literature (see below for a description of the literature review) seemed to value flood mitigation generically, rather than in terms of specific sub-elements.

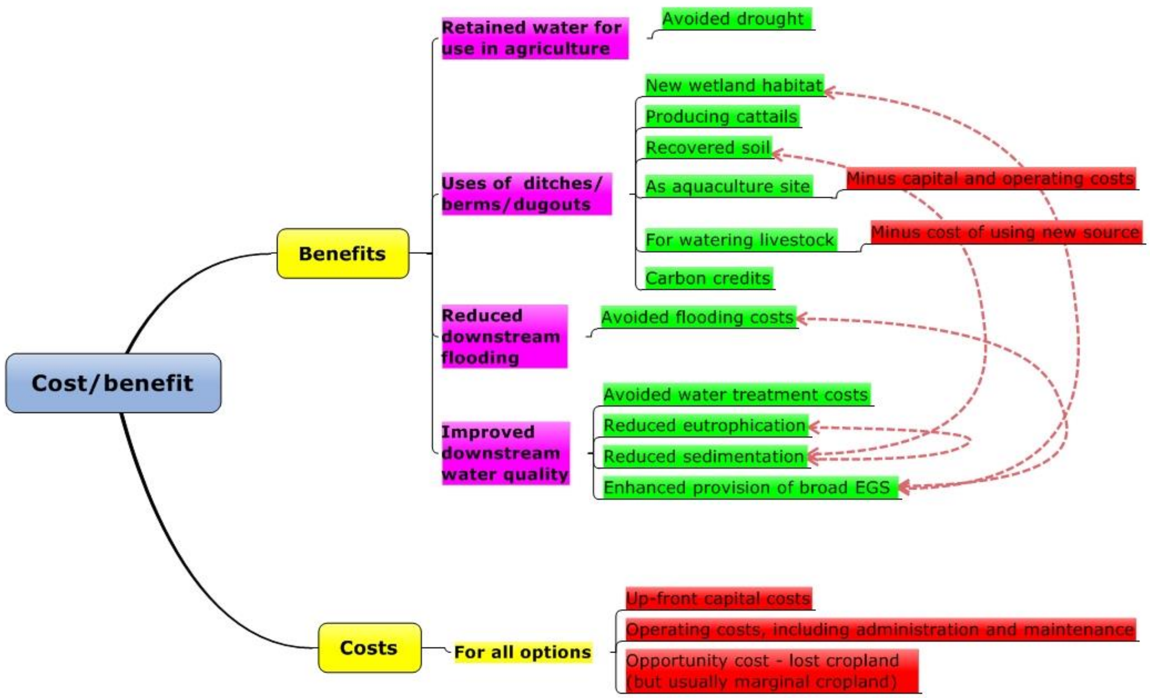

FIGURE 6: FINAL ITERATION OF ANTICIPATED COSTS AND BENEFITS

Source: Authors' figures.

The various costs and benefits that we deemed to be worthy of inclusion (as seen in Figure 6) are discussed in detail below.

Benefits

Avoided drought: Storing water in ditches and on-farm retention structures would offer the unique benefit of reducing the risk of drought. Water that would have previously washed downstream would now be retained on or near farms and would therefore be at the disposal of farmers should drought conditions arise. This is complicated by the fact that little irrigation is practiced in Manitoba, and therefore the infrastructure would in many cases be lacking. Nevertheless, if farmers were able to marshal the means of tapping these water resources, they would be at farmers' disposal in times of drought, and therefore this warrants inclusion as a benefit type.

New wetland habitat: Each of the proposed interventions involves the creation 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. However, since flood mitigation nutrient cycling effects are captured by *avoided flooding costs* and *cattail production* below, and since it is unlikely that ditches and on-farm retention structures would be used for recreation, this benefit will be valued solely for its habitat provision dimension, since expanded ditches and on-farm water retention structures would certainly be used by waterfowl and come to support their own localized ecosystems with plants, amphibians and other organisms.

Production of cattails: As has been demonstrated in previous work by IISD, harvested cattail biomass can provide a viable sustainable 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 can occur around new and expanded wetlands that result from the three proposed interventions and therefore offers a distinct category of benefit. Cattails would be produced and then harvested and sold to organizations able to process them into energy and recovered phosphorus.

Recovered soil: Because ditches and on-farm retention structures would accumulate silt in time and have to be maintained, there would be a benefit in acquiring the earth that would be dredged from them, which would be nutrient-rich and viable for resale. Of course this would have an associated cost (captured below in operating costs, which would include maintenance), but it would also have a distinct benefit in terms of the retained nutrient-rich sediment that would have previously washed downstream.

Aquaculture: There is also potential for aquaculture (raising of fish) in these retention structures. Fish could be raised to assist in nutrient cycling in these structures, or they could be raised for consumption, resale or use in animal feed.

Watering livestock: Another potential use for the retained water would be to water livestock. Again, the lack of irrigation infrastructure could potentially interfere with this, but this could be offset assuming that animals could to some degree be led to the water source.

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. But the energy from cattails also provides the additional benefit of reduced carbon emissions. Because the energy produced from the 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.

Avoided flooding costs: Flooding is a major issue in Manitoba, and the retention of water upstream offers the significant benefit of mitigating flooding downstream. Flooding costs that could be avoided as a result of upstream water retention include backup of sewage into homes, infrastructure damage, lost economic output from associated disruption and so on. Reduction of peak flow volumes due to water being retained in ditches and on-farm retention structures would greatly benefit downstream persons, businesses and communities.

Avoided water treatment costs: In addition to eutrophication, 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. Reduced sediment load also helps lower water treatment costs.

Reduced eutrophication: With more water being retained in ditches and in on-farm retention structures, problems of nutrient runoff would be mitigated, since some of the previously released nutrients would be retained along with the water being retained upstream. Nutrient runoff from farmland is a serious problem in Manitoba because of the associated downstream eutrophication (algae blooms) that causes negative ecosystem impacts. Eutrophication can effectively create dead zones in a watershed and decrease the watershed ecosystem's resilience to other stressors. Retaining water upstream would help mitigate the significant damage caused by nutrient runoff.

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.

Enhanced provision of broad EGS: While this benefit significantly overlaps with some of those above, it warrants mentioning. This benefit constitutes the delivery of stronger and/or more resilient EGS, such as air and water purification, biodiversity maintenance, waste decomposition, soil and vegetation generation and renewal, crops and natural vegetation pollination, groundwater recharge through wetlands, seed dispersal, greenhouse gas mitigation and so on. The proposed interventions are most likely to impact EGS associated with downstream wetlands, but there can also be feedback mechanisms whereby a healthier wetland ecosystem creates a healthier riparian ecosystem that delivers its own host of EGS. It is particularly necessary to be mindful of double counting with this benefit, since, for example, avoided eutrophication is at least partly in and of itself communicating the notion that EGS has been enhanced. But this broad category of enhanced EGS should be included as a distinct benefit type and indeed could be considered one of the more important, although difficult to quantify and value, potential benefits.

Costs

Up-front capital costs: This cost is an obvious one in that there will inevitably be up-front costs associated with any of these options. However, since many of the benefits discussed are communicated in per-year figures, it is necessary to adjust these up-front costs by a capital recovery factor in order to provide an annualized capital cost. This is discussed in greater detail below.

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

Lost farmland (opportunity cost): Many of these options will involve displacing farmland. This has an opportunity cost in terms of the productive use that that land could have otherwise been put to.

Literature Review

With the relevant costs and benefits established, it was then necessary to draw on the literature and available data to determine which of these costs and benefits could be quantified and monetized and which would have to be included qualitatively only. We reviewed a wide range of documentation to seek out reliable figures for quantifying and monetizing benefits and costs. We gathered literature via Google search, by drawing on previous research experience, and through the Environmental Valuation Reference Inventory database. The literature reviewed included the following documents, broken down by benefit or cost type. The literature that we eventually employed in the cost-benefit analysis is detailed in the Methodology section.

Avoided drought:

- "Hydrologic and Economic Impacts of Drought Under Alternative Policy Responses" (Booker, 1995)
- *Reclaimed Wastewater and the WTP to Avoid Summer Water Restrictions: Incorporating Endogenous Free-Riding Beliefs* (Dupont, 2011)
- "Quantifying the Costs of Drought: New Evidence from Life Satisfaction Data" (Carroll, Frijters, & Shields, 2009)
- *Irrigation Water Productivity in Saskatchewan and Manitoba — An Economic Perspective* (Kulshreshtha, 2006)

New wetland habitat:

- *Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal: Case Study 3 – Valuing Environmental Benefits of a Flood Risk Management Scheme* (Eftec, 2010)
- "The Economic Benefits of Wetland Retention and Restoration in Manitoba" (Pattison, Boxall, & Adamowicz, 2011)
- *Meta-Analytical Estimates of Values of Environmental Services Enhanced by Government Agricultural Conservation Programs* (Borisova-Kidder, 2006)
- "Economic Valuation of Regulating Services Provided by Wetlands in Agricultural Landscapes: A Meta-Analysis" (Brander, Brouwer, & Wagtendonk, 2013)
- "The Benefits and Costs of Riparian Analysis Habitat Preservation: a Willingness to Accept/Willingness to Pay Contingent Valuation Approach" (Amigues, Boutaloff, Desaigues, Gauthier, & Keith , 2002)
- "Economic Valuation of the Non-Use Attributes of a Wetland: A Case-Study for Lake Kerkini" (Oglethorpe & Miliadou, 2000)
- *An Estimation of the Non-Market Economic Value of Wetland Habitats and Recreation Sites in the Spring Valley, NV, Basin Using Secondary Data Sources* (Moeltner, 2006)
- "The Economic Value of Wetland Services: A Meta-Analysis" (Woodward & Wui, 2001)
- "Willingness to Pay for Non-Angler Recreation at the Lower Snake River Reservoirs" (McKean, Johnson, Taylor, & Johnson, 2005)

- *Valuing Wetlands in Southern Ontario's Credit River Watershed: A Contingent Valuation Analysis* (The Pembina Institute and Credit Valley Conservation, 2010)
- "Option Value and Non-User Benefits of Wildlife Conservation" (Willis, 1989)
- "Economic Benefits of Sport Fishing and Hunting Near Irrigation Developments in Southern Alberta" (McNaughton, 1995)

Production of cattails:

- Technical and Economic Viability of Cattail (Typha spp.) Biomass: A Novel Renewable and Sustainable Feedstock in the Manitoba Bioeconomy (Grosshans, 2013)

Aquaculture:

- "External Costs of Aquaculture Production in West Virginia" (Smearman, D'Souza, & Norton, 1997)

Carbon credits:

- *Technical and Economic Viability of Cattail (Typha spp.) Biomass: A Novel Renewable and Sustainable Feedstock in the Manitoba Bioeconomy* (Grosshans, 2013)

Avoided flooding costs:

- *Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal: Case Study 3 – Valuing Environmental Benefits of a Flood Risk Management Scheme* (Eftec, 2010)
- "The Benefit: Cost Analysis of River Maintenance" (Dunderdale & Morris, 1997)
- "The Quantification of Indirect Benefits from Flood Protection in the Lower Waikato" (Quazi, 2002)
- *The Feasibility of Wetland Restoration to Reduce Flooding in the Red River Valley: A Case Study of the Maple River Watershed, North Dakota* (Shultz & Leitch, 2001)
- *Economic Value of Stormwater in Delaware* (Kauffman, 2011)
- "Effects of Flood Hazards on Property Values: Evidence Before and After Hurricane Floyd" (Bin & Polasky, 2004)

Avoided water treatment costs:

- *Customer Preference and Willingness to Pay for Selected Water and Sewerage Services* (Green, Tunstall, Herring, & Sawyer, 1993)

Reduced eutrophication:

- *The Value of Floodplains as Nutrient Sinks: Two Applications of the Replacement Cost Approach* (Dehnhardt & Bräuer, 2008)
- *An Experiment in Contingent Valuation: Willingness to Pay for Stormwater Management* (Lindsey, 1992)

- "Estimating the Demand for Protecting Freshwater Lakes from Eutrophication" (Boyle, Poor, & Taylor, 1999)
- "An application of contingent valuation and decision tree analysis to water quality improvements" (Atkins, Burbon, & Allen, 2007)
- *Modeling Certainty-Adjusted Willingness to Pay for Ecosystem Service Improvement from Agriculture* (Ma, Lupi, Swinton, & Chen, 2011)
- "Willingness to Pay for Water Quality Improvements in the United States and Canada- Considering Possibilities for International Meta-Analysis and Benefits transfer" (Johnston & Thomassin, 2010)
- *Reducing Phosphorus Pollution in the Minnesota River- How Much is it Worth?* (Mathews, Homans, & Easter, 1999)
- *Valuation of Ecosystem Services Provided by Biodiversity Conservation: An Integrated Hydrological and Economic Model to Value the Enhanced Nitrogen Retention in Renaturated Streams* (Bräuer & Marggraf, 2004)
- "Elasticities of Demand and Willingness to Pay for Environmental Services in Sweden" (Hokby & Soderqvist, 2003)
- "Agricultural producers and the environment: A stated preference analysis of Colorado corn producers" (Bond, Hoad, & Kipperberg, 2011)
- *Recreational Benefits from Improved Water Quality: A Random Utility Model of Swedish Seaside Recreation* (Sandstrom, 1996)
- "The Impact of Water Quality and Water Level on the Recreation Values of Lake Hume" (Crase & Gillepsie, 2008)
- "Environmental Costs of Freshwater Eutrophication in England and Wales" (Pretty et al., 2003)

Reduced sedimentation:

- "The Off-Site Costs of Soil Erosion" (Clark, 1985)
- *The Economics of Soil Erosion and Sedimentation in the Great Lakes Basin* (Great Lakes Commission for the U.S. Army Corps of Engineers Great Lakes & Ohio River Division, 2008)
- *Reducing Soil Erosion: Offsite Benefits* (Ribaudo, 1986)
- *Soil Erosion in the Maumee River Basin in the Revealing the Economic Value of Protecting the Great Lakes* (Cangelosi, Wiher, Taverna, & Cicero, 2001)
- "Economic Costs of Reservoir Sedimentation: A Regional Approach to Estimating Cropland Erosion Damages" (Crowder, 1987)
- "Off-Site Costs of Soil Erosion: A Case Study in the Willamette Valley" (Moore & McCarl, 1987)

Enhanced provision of broad EGS:

- *Meta-Analytical Estimates of Values of Environmental Services Enhanced by Government Agricultural Conservation Programs* (Borisova-Kidder, 2006)
- "Economic Valuation of Regulating Services Provided by Wetlands in Agricultural Landscapes: A Meta-Analysis" (Brander et al., 2013)

- "The Economic Value of Wetland Services: A Meta-Analysis" (Woodward & Wui, 2001)
- *Valuing Wetlands in Southern Ontario's Credit River Watershed: A Contingent Valuation Analysis* (The Pembina Institute and Credit Valley Conservation, 2010)
- "Community attitudes towards water management in the Moore Catchment, Western Australia" (Burton, Marsh, & Patterson, 2007)
- "Agricultural producers and the environment: A stated preference analysis of Colorado corn producers" (Bond et al., 2011)
- "A Valuation of Ecological Services in the Laurentian Great Lakes Basin with an Emphasis on Canada" (Krantzberg & De Boer, 2008)
- "Valuing the Puget Sound Basin. Revealing our Best Investments" (Batker, Kocian, McFadden, & Schmidt, 2010)
- "The Natural Economy of the Nisqually Watershed" (Batker, De la Torre, Kocian, & Lovell, 2009)
- *A New View of Our Economy: Nature's Value in the Snoqualmie Watershed* (Earth Economics, 2010)
- "Flood Protection and Ecosystem Services in the Chehalis River Basin" (Batker, Kocian, Lovell, & Harrison-Cox, 2010)

Lost farmland (opportunity cost):

- *Cost of Production: Budget Guidelines and Guidelines for Estimating Costs of Production* (Government of Manitoba, 2013a)

This literature review process, as well as a process of expert review and analysis, informed the decisions as to which costs and benefits warranted inclusion in the quantitative analysis. Those that were excluded and the rationale(s) for their exclusion are detailed in the next section.

Costs and Benefits Excluded from Quantification and Monetization

We excluded the following costs and benefits from the analysis. While they therefore do not factor into the cost-benefit figures presented in the Results section, they are nevertheless plausible benefits, and the impact of their exclusion on the results is explored at length in the discussion section.

Benefits

Recovered soil: While figures on the cost of excavation were straightforward to obtain, processing and transportation costs and anticipated resale value were less easily obtainable. Since this was expected to be a benefit with only minor impact anyway, it was excluded from the analysis.

Aquaculture: 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: Because of the irrigation infrastructure cost uncertainty issue and 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: As will be presented below, the valuation methodology for avoided eutrophication involves looking at water treatment costs to establish the manifest willingness to pay for removal of phosphorus. Therefore, we believe that to separately value water treatment costs would be double counting, since this is embodied in the value of the reduced eutrophication. Therefore, this variable is not excluded from the analysis per se, but rather is subsumed elsewhere.

Reduced sedimentation: While reduced downstream sedimentation is an objective benefit, we found it very difficult to estimate the volume of reduced sediment and value the reduction, were it even feasible to quantify it. For these reasons this variable was excluded.

Enhanced provision of broad EGS: While this is undoubtedly one of the most important benefit categories, it is not feasible to include it in the analysis because it is difficult to measure and value. EGS can involve complex threshold effects (for example, EGS provision may be strongly affected once a certain level of nutrient load is crossed, but not before) that can make valuation highly complex. Furthermore, some of the benefits selected for inclusion in the cost-benefit analysis implicitly or explicitly include EGS dimensions. This variable has therefore been excluded from the analysis but will be an area of significant focus in the discussion below because of its unquestionable significance.

Costs and Benefits Selected for Quantification and Monetization

The above exclusions resulted in the following final list of benefits and costs we selected for inclusion in the cost-benefit analysis. We believe that they form a rich picture of the types of costs and benefits that can be expected and that their valuation will be highly instructive in assessing and weighing the three options. The methodology for the quantification and monetization of the selected variables with respect to each of the three water retention options is presented in the next section.

Benefits

- Avoided drought
- New wetland habitat
- Production of cattails
- Carbon credits
- Reduced eutrophication
- Avoided flooding costs

Costs

- Up-front capital costs
- Operating costs
- Lost farmland (opportunity cost)

5.0 Methodology

This section presents the methodology used to quantify and monetize the costs and benefits described above. 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 three proposed options.

We made a number of assumptions for the purposes of this analysis based on previous project experience and expert analysis. As much as possible we verified their plausibility and they can be taken to represent best practices in this type of exercise and current knowledge. They include the following:

- Cattails produce 12 tonnes of dry biomass per hectare per year
- 0.22 per cent of cattail mass is phosphorus
- Emissions associated with energy from cattails are equivalent to the Intergovernmental Panel on Climate Change emission factor for other primary solid biofuels
- Cattails are valued at $50 per tonne of dry biomass
- Carbon offsets are valued at $15 per tonne
- A capital recovery factor of 2.5 per cent is appropriate for amortizing capital costs
- Annual operating costs can be assumed to be 2 per cent of amortized capital costs
- Earthwork costs can be estimated to be $12 to $15 per cubic metre of earth moved, depending on whether fill is used or not

The methodology for quantifying and monetizing each of the costs and benefits listed above is provided below, broken down by the three proposed interventions.

Benefit: Avoided Drought

We established the value of a megalitre of water for use in avoiding drought via benefits transfer by using the study *Irrigation Water Productivity in Saskatchewan and Manitoba — An Economic Perspective* (Kulshreshtha, 2006). By estimating the impact of irrigated water on productivity, Kulshreshtha found its worth to be **$150 per megalitre**. We believe that this finding is a reasonable proxy for valuing the potential use of retained water as irrigated water in Manitoba.

- **Re-graded ditches:** Ditches in the province have an existing storage capacity of 12 cubic metres per metre of ditch length, which would increase to 108 cubic metres under this option, a net gain of 96 cubic metres per metre of ditch length; at the proposed scale of intervention this would mean **201.91 megalitres** of additional water storage capacity.
- **Filter field and ponds:** Assuming ponds would be sized to capture 60 millimetres of runoff, at the given pond size this would mean **100.95 megalitres** of additional water storage capacity.
- **Back-flooded dams:** Because water is backflooded onto agricultural land and not retained on an ongoing basis, the potential for irrigated water under this option is **0 megalitres.**

Benefit: New Wetland Habitat

We established per-acre wetland habitat values via benefits transfer. After an extensive literature review, we identified two particular studies as being optimal for use in this context. The study *Meta-analytical Estimates of Values of Environmental Services Enhanced by Government Agricultural Conservation Programs* (Borisova-Kidder, 2006), which contains a meta-analysis of 30 different wetland valuation studies in the United States, offers an average per-acre wetland value of $262.43 per acre. A second study, "The Economic Value of Wetland Services: A Meta-Analysis" (Woodward & Wui, 2001), offers a breakdown of the different types of values and services wetlands provide, considering the independent value of their provision of habitat, flood control, amenity, water quality, and water quantity services and functions, and finds that the habitat function in isolation provides 24 per cent of wetlands' total value.

The per-acre figure found in the first study was therefore adjusted for currency and inflation to a value of $338.13 (2012), and then multiplied by 24 per cent to produce the resultant wetland habitat monetization figure of **$82.13 per acre.**

- **Re-graded ditches:** We found that farmland was reduced (and converted to water cover) at 64 square metres per metre of ditch; at the proposed scale of intervention this would mean an expanded wetland habitat area of **50.61 acres**.
- **Filter field and ponds:** The ponds in this proposed option would measure 145 metres by 200 metres, or **7.17 acres.**
- **Back-flooded dams:** The area of wetland habitat was estimated to be an eighth of a section, or **80 acres**.

Benefit: Cattails Produced

We monetized cattail production using IISD's knowledge around cattail production and harvesting for use as bioenergy. The IISD study *Technical and Economic Viability of Cattail (Typha spp.) Biomass: A Novel Renewable and Sustainable Feedstock in the Manitoba Bioeconomy* (Grosshans, 2013) was combined with the above assumption of a cattail value of $50 per tonne (developed through expert consultation). The study 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 total value of dry cattail biomass, after deducting costs, was found to be **$16.59 per tonne**.

- **Re-graded ditches:** We estimated that every metre of ditch would allow production of 0.0384 tonnes of cattail dry biomass per year; at the proposed scale of intervention this would be **122.9 tonnes** per year.
- **Filter field and ponds:** For this option we estimated that cattail production would be **93.6 tonnes** per year.
- **Back-flooded dams:** With 80 acres of land open to cattail production under this option, and an assumed 12 tonnes of cattail dry biomass production per year, this means cattail production can be estimated to be **388.5 tonnes** per year.

Benefit: Carbon Credits

The value of carbon credits produced via cattail production was estimated from the study *Technical and Economic Viability of Cattail (Typha spp.) Biomass: A Novel Renewable and Sustainable Feedstock in the Manitoba Bioeconomy* (Grosshans, 2013) and used Intergovernmental Panel on Climate Change emission factors for dry biomass and coal (the fuel which the biomass would be displacing, thereby creating carbon credits). This work 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. These carbon offsets were assumed to be valued at **$15 per tonne of carbon dioxide equivalent.**

- **Re-graded ditches:** We estimated that every metre of ditch would allow production of 0.0384 tonnes of cattail dry biomass per year; at the proposed scale of intervention this is 122.9 tonnes per year, or 1**29.05 tonnes of carbon dioxide equivalent per year.**
- **Filter field and ponds:** For this option we estimated that cattail production would be 93.6 tonnes per year, or **98.28 tonnes of carbon dioxide equivalent per year.**
- **Back-flooded dams:** With 80 acres of land open to cattail production under this option, and an assumed 12 tonnes of cattail dry biomass production per year, this means cattail production can be estimated to be 388.5 tonnes per year, or **407.93 tonnes of carbon dioxide equivalent per year.**

Benefit: Avoided Flooding Costs

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 (which itself was taken to be reasonable proxy for avoided flooding costs) and led to the value of **$1297.14 per megalitre** of water storage.

- **Re-graded ditches:** We found ditches in the province to have an existing storage capacity of 12 cubic metres per metre of ditch length, which would increase to 108 cubic metres under this option, a net gain of 96 cubic metres per metre of ditch length; at the proposed scale of intervention this would mean **201.91 megalitres** of additional water storage capacity.
- **Filter field and ponds:** Assuming ponds would be sized to capture 60 millilitres of runoff, at the given pond size this would mean **100.95 megalitres** of additional water storage capacity.
- **Back-flooded dams:** Assuming berms would be built to store 60 millilitres of water in an 80-acre cell this would mean **12.77 megalitres** of additional water storage capacity.

Benefit: Reduced Eutrophication

The value of reduced eutrophication was established using the study *Review of Phosphorus Removal at Municipal Sewage Treatment Plants Discharging to the Lake Simcoe Watershed* (Water Environment Association of Ontario, 2010). The study considers the cost of upgrades to a number of sewage treatment facilities near Lake Simcoe in southern Ontario and contains useful data on the cost of removing phosphorus at various sewage treatment facilities. This was taken to represent well 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.

Data on the cost of phosphorus removal per kilogram at each plant was combined with the total volume of phosphorus removed at each plant to produce a weighted average of phosphorus removal costs. These removal costs were found to be **$10 per kilogram**.

- **Re-graded ditches:** Each metre of ditch was estimated to produce 0.0384 tonnes of cattail dry biomass, which at the proposed scale of intervention meant cattail production of 122.9 tonnes annually; using the above assumption that phosphorus is 0.22 per cent of cattail weight, estimated phosphorus removal is **270.38 kilograms per year.**
- **Filter field and ponds:** Cattail production for this option was estimated to be 93.6 tonnes per year; using the above assumption that phosphorus is 0.22 per cent of cattail weight, estimated phosphorus removal is **205.92 kilograms per year.**
- **Back-flooded dams:** With an area of 80 acres suitable to cattail production, and using the assumption of 12 tonnes of cattail dry biomass per year, this option can be expected to involve cattail production of 388.5 tonnes; using the above assumption that phosphorus is 0.22 per cent of cattail weight, estimated phosphorus removal is **854.7 kilograms per year.**

Cost: Capital Costs (Annualized)

For capital costs, we employed the assumption presented above that a capital recovery factor of 2.5 per cent was appropriate for amortizing capital costs over a 20 year period, along with the assumed construction costs of $12 to $15 per cubic metre of earth moved.

- **Re-graded ditches:** Total capital costs were estimated to be approximately $2.43 million at the proposed scale of intervention, or **$150,000 per year** once amortized.
- **Filter field and ponds:** Total capital costs were estimated to be approximately $1.86 million at the proposed scale of intervention, or **$115,000 per year** once amortized.
- **Back-flooded dams:** Total capital costs were estimated to be approximately $113,000 at the proposed scale of intervention, or **$7,000 per year** once amortized.

Cost: Operating Costs (Annual)

For operating costs, we employed the assumption presented above such that operating costs were estimated to be **2 per cent of amortized capital costs.**

- **Re-graded ditches:** Total amortized capital costs of $150,000 per year multiplied by 2 per cent results in **$3,000** in operating costs.
- **Filter field and ponds:** Total amortized capital costs of $115,000 per year multiplied by 2 per cent results in **$2,300** in operating costs.
- **Back-flooded dams:** Total amortized capital costs of $7,000 per year multiplied by 2 per cent results in **$140** in operating costs.

Cost: Lost Farmland (Opportunity Cost)

The opportunity cost of farmland being converted for use in the three proposed interventions was calculated using a Government of Manitoba study (Government of Manitoba, 2013a) that states that the average value of farmland in the province of Manitoba in terms of productivity is **$60 per acre**.

- **Re-graded ditches:** Each additional metre of expanded ditch was found to decrease farmland by 64 square metres and therefore has an opportunity cost of **50.61 acres** of farmland at the proposed scale of intervention.
- **Filter field and ponds:** Assuming one filter field and pond per section, the total lost farmland associated with this intervention over one section would be 26.44 acres.
- **Back-flooded dams:** The opportunity cost of a berm was estimated to be **80 acres**.

6.0 Results

We developed the following results using the above information. Benefit-cost ratios are provided to give a sense of the amount of return that can be expected on each dollar of investment for each of the three proposed options.

TABLE 1: COSTS AND BENEFITS OF RE-GRADED DITCHES INTERVENTION

VARIABLES	UNITS	MONETARY VALUE	IMPACT (IN UNITS)	MONETIZED IMPACT
Benefits				
Avoided drought	Megalitres of water	$150.00	201.91	$30,286
New wetland habitat	Acres of wetland	$82.13	50.61	$4,156
Cattails produced	Tonnes of cattails	$16.59	122.90	$2,039
Carbon credits	tonnes of carbon credits	$15.00	129.05	$1,936
Avoided flooding costs	Megalitres of flood mitigation	$1,297.14	201.91	$261,903
Reduced eutrophication	Kilograms of phosphorus	$10.00	270.38	$2,704
Total				**$303,024**
Costs				
Capital costs (annualized)	Capital costs	$150,000.00	20 year amor.	$150,000
Annual operating costs	Operating costs	$3,000.00	2% of cap. cost	$3,000
Opportunity costs	Hectares of lost farmland	$60.00	50.61	$3,037
TOTAL				**$156,037**
ANNUAL NET BENEFIT	Dollars			$146,988
BENEFIT: COST	Ratio			194%

Source: Authors' calculations.

TABLE 2: COSTS AND BENEFITS OF FILTER FIELD AND PONDS INTERVENTION

VARIABLE	UNITS	MONETARY VALUE	IMPACT (IN UNITS)	MONETIZED IMPACT
Benefits				
Avoided drought	Megalitres of water	$150.00	100.95	$15,143
New wetland habitat	Acres of wetland	$82.13	7.17	$589
Cattails produced	Tonnes of cattails (total biomass)	$16.59	93.60	$1,553
Carbon credits	tonnes of carbon credits	$15.00	98.28	$1,474
Avoided flooding costs	Megalitres of flood mitigation	$1,297.14	100.95	$130,952
Reduced eutrophication	Kilograms of phosphorus	$10.00	205.92	$2,060
Total				**$151,770**
Costs				
Capital costs (annualized)	Capital costs	$150,000.00	20 year amor.	$115,000
Annual operating costs	Operating costs	$2,300.00	2% of cap. cost	$2,300
Opportunity costs	Hectares of lost farmland	$60.00	26.44	$1,586
TOTAL				**$118,886**
ANNUAL NET BENEFIT	Dollars			$32,884
BENEFIT: COST	Ratio			128%

Source: Authors' calculations.

TABLE 3: COSTS AND BENEFITS OF BACK-FLOODED DAMS INTERVENTION

VARIABLE	UNITS	MONETARY VALUE	IMPACT (IN UNITS)	MONETIZED IMPACT
Benefits				
Avoided drought	Megalitres of water	$150.00	0.00	$ -
New wetland habitat	Acres of wetland	$82.13	80.00	$6,570
Cattails produced	Tonnes of cattails (total biomass)	$16.59	388.50	$6,445
Carbon credits	Tonnes of carbon	$15.00	407.93	$6,119
Avoided flooding costs	Megalitres of flood mitigation	$1,297.14	12.77	$16,561
Reduced eutrophication	Kilograms of phosphorus	$10.00	854.70	$8,547
Total				**$44,242**
Costs				
Capital costs (annualized)	Capital costs	$7,000.00	20 year amor.	$7,000
Annual operating costs	Operating costs	$140.00	2% of cap. cost	$140
Opportunity costs	Hectares of lost farmland	$60.00	80	$4,800
TOTAL				**$11,940**
ANNUAL NET BENEFIT	Dollars			$32,302
BENEFIT: COST	Ratio			371%

Source: Authors' calculations.

As seen in the Tables 1, 2, and 3, under the methodology and assumptions employed back-flooded dams are the most beneficial, offering a cost-benefit ratio of 371 per cent; re-graded ditches are the second most beneficial, offering a cost-benefit ratio of 194 per cent; finally, filter fields and ponds are the least beneficial, offering a cost-benefit ratio of 128 per cent.

7.0 Sensitivity Analysis

This section presents the results when the parameters in the analysis are adjusted to reflect other plausible values for variables of interest. These variables include the value obtained for cattails and for carbon credits, the value of avoided eutrophication and the opportunity cost of land.

Value of Cattails

The value at which cattails are sold could go up if the energy they produce were to become more highly valued (i.e., if the price of alternatives rose substantially), if the value of the phosphorus captured as a by-product were to rise (i.e., if fertilizer costs were to rise), or both. Therefore, we tested the results for sensitivity to a situation in which the value of cattails was to rise substantially. As seen in Table 4, the ranking of the three options would not change, but the preferred option of back-flooded dams would become significantly more valuable.

TABLE 4: SENSITIVITY ANALYSIS FOR VALUE OF CATTAILS

OPTION	VALUE OF ONE TONNE OF CATTAILS			
	$16.59 (ORIGINAL)	$25	$40	$70
Re-graded ditches				
Annual benefit (cost)	$148,988	$148,021	$149,985	$153,552
Cost: benefit ratio	194%	195%	%196	%198
Filter fields and ponds				
Annual benefit (cost)	$32,884	$33,671	$35,073	$37,883
Cost: benefit ratio	128%	128%	130%	132%
Back-flooded dams				
Annual benefit (cost)	$32,302	$35,569	$41,397	$53,052
Cost: benefit ratio	371%	398%	447%	544%

Source: Authors' calculations.

Carbon Credit Value

The value of carbon credits could rise dramatically if public policy on emissions were to put a higher price on carbon. Therefore, we tested the results for sensitivity to a situation in which the value of a carbon credit was to rise substantially. As seen in Table 5, the ranking of the three options would not change, but again the preferred option of back-flooded dams would become significantly more valuable.

TABLE 5: SENSITIVITY ANALYSIS FOR VALUE OF CARBON CREDITS

OPTION	VALUE OF A ONE-TONNE CARBON CREDIT			
	$15 (ORIGINAL)	$30	$60	$100
Re-graded ditches				
Annual benefit (cost)	$148,988	$148,923	$152,795	$157,956
Cost: benefit ratio	194%	195%	198%	201%
Filter fields and ponds				
Annual benefit (cost)	$32,884	$34,358	$37,306	$41,238
Cost: benefit ratio	128%	129%	131%	135%
Back-flooded dams				
Annual benefit (cost)	$32,302	$38,421	$50,659	$66,976
Cost: benefit ratio	371%	422%	524%	661%

Source: Authors' calculations.

Value of Avoided Eutrophication

Avoided eutrophication could become more highly valued if existing problems of eutrophication were to become more severe (i.e., if the value to users of downstream water mitigating the marginal unit of phosphorus were to rise). Therefore, we tested the results for sensitivity to a situation in which the value of avoided eutrophication was to rise substantially. As seen in Table 6, the ranking of the three options would not change, but the preferred option of back-flooded dams would once again become significantly more valuable.

TABLE 6: SENSITIVITY ANALYSIS FOR VALUE OF AVOIDED EUTROPHICATION

OPTION	VALUE OF AVOIDED EUTROPHICATION FROM ONE KILOGRAM OF PHOSPHORUS			
	$10 (ORIGINAL)	$15	$30	$50
Re-graded ditches				
Annual benefit (cost)	$146,988	$148,339	$152,395	$157,803
Cost: benefit ratio	194%	195%	198%	201%
Filter fields and ponds				
Annual benefit (cost)	$32,884	$33,913	$37,002	$41,121
Cost: benefit ratio	128%	129%	131%	135%
Back-flooded dams				
Annual benefit (cost)	$32,302	$36,576	$49,396	$66,490
Cost: benefit ratio	371%	406%	514%	657%

Source: Authors' calculations.

Land Opportunity Cost

As viable agricultural land becomes increasingly scarce or food itself rises in price, the value of a productive unit of farmland could increase. Therefore, we tested the results for sensitivity to a situation in which the opportunity cost of land used to retain water was to rise substantially. As seen in Table 7, the ranking of the three options would not change.

TABLE 7: SENSITIVITY ANALYSIS FOR LAND OPPORTUNITY COST

OPTION	OPPORTUNITY COST OF ONE HECTARE OF FARMLAND			
	$60 (ORIGINAL)	$80	$100	$150
Re-graded ditches				
Annual benefit (cost)	$146,988	$145,975	$144,963	$142,433
Cost: benefit ratio	194%	193%	192%	189%
Filter fields and ponds				
Annual benefit (cost)	$32,884	$32,355	$31,826	$30,504
Cost: benefit ratio	128%	127%	127%	125%
Back-flooded dams				
Annual benefit (cost)	$32,302	$30,702	$29,102	$25,102
Cost: benefit ratio	371%	327%	292%	231%

Source: Authors' calculations.

Under all tests for sensitivity to plausible changes in key variables, the merit order of the three options does not change, no matter how strong the deviation from original values used. In fact, the preferred option becomes even more compelling under these various scenarios, increasing the degree to which this option is preferable to the others, since anticipated benefits increase dramatically for this option when key variables are varied in entirely plausible ways.

8.0 Discussion

The first item that warrants discussion is the fact that some variables worthy of inclusion in this exercise were in the end excluded because they were difficult or impossible to either measure or monetize. The following benefits were excluded:

- Recovered soil
- Aquaculture
- Watering livestock
- Avoided water treatment costs
- Reduced sedimentation
- Enhanced provision of broad EGS

Each of the three options would certainly provide each of these benefits. However, it is difficult or impossible to determine the degree to which they would impact results, or whether they would alter the merit order of the three options. But even though their impact cannot be accurately assessed, the fact that they would indeed be felt should be borne in mind when studying the above results.

The second item worth discussing is that we estimated costs using the best knowledge available, 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 above.

Finally, when interpreting and weighing the results one must remain cognizant of the inherent limits of benefits transfer techniques. Many of the quantified impacts and their corresponding monetization figures were derived from contexts that don't directly correspond with Manitoba's. While we have partially offset this by converting figures to better suit the Manitoban context where possible, there will inevitably be inaccuracies when trying to make one figure suit the context of another. That being said, great care was taken to ensure the accuracy and defensibility of the analysis, and while the results are not indisputable, they are certainly a highly instructive means of assessing the relative merits of each proposed option.

Conclusion

This analysis has shown that under a plausible set of assumptions and using the most reliable figures available in the literature, it is possible to meaningfully weigh the three proposed land management options of re-graded ditches, filter fields and ponds and back-flooded dams when accounting for the following set of costs and benefits:

Benefits

- Avoided drought
- New wetland habitat
- Production of cattails
- Carbon credits
- Reduced eutrophication
- Avoided flooding costs

Costs

- Up-front capital costs
- Operating costs
- Lost farmland (opportunity cost)

The results of this analysis indicate that back-flooded dams are the preferred option in terms of cost-benefit ratio, followed by re-graded ditches, and finally filter fields and ponds. The relatively low cost of back-flooded dams compared to the other options, in combination with their comparable EGS benefits, make them the preferred option.

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