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Financing High Performance Climate Adaptation in Agriculture: Climate Bonds for Multi-Functional Water Harvesting Infrastructure on the Canadian Prairies

Anita Lazurko [1] and Henry David Venema [2,*]

[1] Department of Environmental Sciences and Policy, Central European University, Budapest 1051, Hungary; anita.lazurko@mespom.eu
[2] Prairie Climate Centre, International Institute for Sustainable Development, Winnipeg, MB R3B 0T4, Canada
* Correspondence: hvenema@iisd.ca

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Abstract: International capital markets are responding to the global challenge of climate change, including through the use of labeled green and climate bonds earmarked for infrastructure projects associated with de-carbonization and to a lesser extent, projects that increase resilience to the impacts of climate change. The potential to apply emerging climate bond certification standards to agricultural water management projects in major food production regions is examined with respect to a specific example of multi-functional distributed water harvesting on the Canadian Prairies, where climate impacts are projected to be high. The diverse range of co-benefits is examined using an ecosystem service lens, and they contribute to the overall value proposition of the infrastructure bond. Certification of a distributed water harvesting infrastructure bond under the Climate Bond Standard water criteria is feasible given climate bond issue precedents. The use of ecosystem service co-benefits as additional investment criteria are recommended as relevant bond certification standards continue to evolve.

Keywords: climate change; agriculture; climate bonds; investment; distributed infrastructure; water harvesting; Canada

1. Introduction

The political success achieved by the 2015 Paris Climate Accord with respect to a broad political consensus to reduce greenhouse gas emissions and accelerate adaptation to climate change, was followed by further political commitments in 2016 to increase climate financing. The 2016 G20 Hangzhou Leader's summit communique stated, "We believe efforts could be made to…provide clear strategic policy signals and frameworks, promote voluntary principles for green finance, support the development of local green bond markets and promote international collaboration to facilitate cross-border investment in green bonds" [1].

The G20 leaders expressed support for a well-established trend—the rise of a new class of labeled infrastructure investment bond aligned with de-carbonization and climate de-risking objectives. Between 2011 and the 2015, the volume of "green" or "climate" labelled bonds issued increased from $3 billion to $95 billion, a large increase but still a small fraction of the estimated $93 trillion infrastructure investment requirements frequently cited as necessary to meet Paris accord objectives of limiting global warming to under 2 °C [2].

The large majority of labeled green and climate bonds have been designated for renewable energy, energy efficiency and low-carbon transport. In 2015 these sectors comprised 79% of the value of bond issues [3], whereas bonds specifically designated for climate adaptation had only a 4% market share—despite compelling evidence that investments in adaptation can provide very high rates of return [4]. The underlying issue is that although climate change is a global issue and its mitigation requires collective global action, climate change impacts are inherently localized and adaptation is necessarily a granular design process requiring highly localized climatic, socio-economic and ecosystem information—a challenge for harnessing the larger scale investment flows commensurate with the scale of the opportunity. In addition, bond financing requires that a large number of relatively small individual projects be aggregated to reach a sufficient scale. The scale at which local adaptation projects require financing is typically two to four orders of magnitude lower than the scale at which bonds are issued [3].

The Canadian Prairies are an interesting geographic context to analyse the logic for increasing market share for climate adaptation bonds and the associated challenges, by referencing the specific case of multi-functional water retention structures for agriculture. The Canadian Prairies comprise about 90% of Canada's agricultural land base, produce approximately 20% of internationally traded grains and oilseeds and thus are an important component of world food security. The Canadian Prairies also have a history of high vulnerability to climate shock for anthropogenic and climatological reasons, and a history of innovative ecosystem and water resources management based on distributed water harvesting (DWH) that could be revived in the context of climate adaptation [5]. Berry et al. [6] review a multi-purpose surface water retention system at Pelly's Lake, in the Canadian Prairie province of Manitoba that illustrates the economic case for water harvesting. Berry et al. conclude that when all economic benefits are evaluated; flood and drought risk reduction, irrigation and other ecosystem service benefits, the net value of retention storage (more than CAD $25,000/hectare) far exceeded its land value as conventional agriculture. Nonetheless, the total investment requirement for this high performance, but highly local, climate adaptation project at under CAD $1 million falls below the threshold for prioritization as conventional infrastructure spending. The urgency and logic for aggregating large numbers of such "precision infrastructure" projects for innovative climate financing through bond issues on the Canadian Prairies is, therefore, the focus of this paper.

This paper aims to explain and analyse the opportunity to finance high performance climate adaptation projects like multi-functional DWH infrastructure with certified climate bonds under the Water Criteria of the Climate Bond Standard, and to explore the concept of informing the project or bond value proposition with the economic value of ecosystem services and co-benefits. In addition, this paper aims to demonstrate the logic for aggregating a large number of relatively small projects to a scale appropriate for bond financing. This paper uniquely combines concepts and provides a new iteration upon leading solutions from seemingly disparate entities: engineers and scientists turning to distributed, localized, green infrastructure solutions, climate modelers increasingly understanding the importance of temporal variability and downscaling data to regional impacts, financers seeking to open new markets for green infrastructure and to find ways to aggregate localized projects into large-scale financing structures, and new entities like the Climate Bonds Initiative providing a new platform to set standards and increase visibility. The methodology of this paper includes articulating the direct benefits and enhanced ecosystem services of DWH solutions, presenting a general framework for a project and bond value proposition that aggregates those benefits using downscaled climate change data for assessing the value generated over future scenarios, and providing recommendations for the institutional, regulatory, and technical elements needed to finance this solution with government-issued bonds certified under the Water Criteria Climate Bond Standard Phase 1: Engineered Infrastructure [7]. This paper concludes with recommendations for implementation of DWH systems on the Canadian prairies and future development of CBS criteria for natural and semi-natural water infrastructure. The broad conclusions drawn in this report can be used to disseminate the DWH solution to other regions with similar climatic stressors and agricultural conditions.

2. Distributed Water Harvesting on the Canadian Prairies

2.1. Introduction to the Canadian Prairies

Climate change on the Canadian prairies manifests as temperature increases and changes to precipitation patterns that demand greater climate resilience in the agricultural sector. The size and shape of the continent of North America, its proximity to the Arctic Ocean, and other factors accelerate the climatic warming felt on the prairies. The Prairie Climate Centre has shown that Winnipeg may experience summer temperatures similar to the panhandle of Texas by the year 2080 [8]. The prairies are also vulnerable to precipitation changes, including an increase of spring precipitation and decrease of rainfall during the summer. Farmers will be forced to adapt their farming practices to stretch a variable hydrologic budget across a long, dry growing season. These rainfall challenges will be further exacerbated by the heightened temperatures through increased evapotranspiration rates [9]. In Saskatchewan and Manitoba, a large majority of agriculture is rain fed [10], and the patchwork of 150-acre quarter-sections of land separated by drainage ditches and culverts is designed to allow for limited groundwater percolation and rapid runoff into large reservoirs or natural water bodies. The use of fertilizer inputs in the region also results in accumulation of nutrients in runoff water and water bodies resulting in frequent eutrophication problems [11]. New precipitation patterns have already begun to strain the agriculture sector and government risk management practices, as seen during the Manitoba floods of 2011 [12]. Evidently, the current 'drainage culture' is in tension with the rainfall variability that will be introduced with the climatic pressures of the future, presenting the 21st century challenge of adaptation for farmers and governments.

2.2. The Engineered Solution

Multi-functional DWH infrastructure is a semi-natural climate adaptation solution that aims to overcome the climatic stresses that challenge the excessive drainage culture of agriculture in the region. It is a system of many small, controllable earthen dams that have been located and sequenced to enable control over current and future hydrologic cycles based on aggregated hydrologic and climate data. DWH mitigates floods in a similar manner to wetlands, but with a higher degree of control to overcome the risk of saturation and snow melt patterns that inhibit the ability of wetlands to buffer peak flows. By encouraging more groundwater percolation, maintaining a potentially higher groundwater table, and retaining standing water throughout the landscape, farmers will have the ability to access water during drought conditions. DWH is expected to have significantly less environmental disruption than hard infrastructure like dams and reservoirs, as well as a much lower infrastructure cost. Farmers upstream of the water harvesting system could have the option to drain their land more quickly to take advantage of early seeding dates, while farmers downstream of the system will be protected from seasonal flooding via controlled, intentional drainage patterns. Though innovative for the Canadian prairies, this solution is not new. India has met demand for seasonal water storage and lack of food security with similar technologies for millennia, though these systems were left abandoned or unmaintained in favor of groundwater irrigation in recent decades [13]. Sustainable development principles, cost-effectiveness, and environmental considerations are incenting a shift back toward such common-sense, localized solutions. Fortunately, the 21st century context of modern DWH systems presents new opportunities with this historic solution. For example, farmers may harvest biomass from "low spots" for energy generation, nutrient recovery, and profit, expanding the "bioeconomy" demonstrated in the Lake Winnipeg delta [14]. The multi-functional distributed water harvesting infrastructure as a climate adaptation solution inherently generates co-benefits and a business case at the intersection of the water–food–energy nexus.

2.3. Climate Change Adaptation and Enhanced Ecosystem Services

Climate change introduces new risks for governments, demanding innovative techniques for assessing and mitigating risk through adaptation. A higher frequency and severity of floods and droughts introduces significant challenges for governments, including infrastructure damage and loss of productivity in the agriculture sector. The 2011 floods in Manitoba caused CAD $1.2 billion of distributed infrastructure damage [12], triggering financial and stakeholder management challenges for the Province of Manitoba and the Government of Canada. Droughts may not directly cause property damage, but they have the potential to severely strain the agricultural sector and rural economies [15]. Assessing the impact of these climate change effects in terms of property and crop damage merely scratches the surface of the potential value of a well-managed flood mitigation and drought resilience program; assessing multiple dimensions of ecosystem services can highlight the full value of climate adaptation solutions. In addition, the economic valuation of such ecosystem services can inform a water pricing scheme that incorporates externalities and reflects full cost recovery [16], further incenting change toward water conservation and more appropriate water management. Robust assessments of risk and proposed value enable innovative solutions to emerge. These solutions demand resources, presenting the challenge of financing climate adaptation projects—a challenge insurance companies and the broader financial sector continue to grapple with. Balancing traditional institutional financing structures with the need to encourage granularity of high-performance adaptation projects informed by robust data and climate projections presents a unique design challenge for engineers, governments, and financers.

The main functional purpose of a multi-functional water harvesting system is to increase control over the hydrologic cycle to overcome climate change challenges to the agricultural sector. Climate change adaptation, a benefit derived from direct use of the infrastructure, is only part of the equation. An ecosystem services lens generates a more well-rounded picture of benefits and supporting services derived from DWH, generating a much stronger value proposition and informing better water management. Figure 1 depicts the network of potentially quantifiable climate change adaptation benefits and enhanced ecosystem services generated by a DWH system. The benefits in this figure could manifest similarly in different watersheds across the Canadian prairies, and so should be interpreted as a broad estimate of direct and co-benefits generated. In addition, this list of direct use and co-benefits could vary depending on the presence of agricultural irrigation or other climate adaptation measures in the region. The co-benefits in black typeface are significant and potentially quantifiable, while the co-benefits in grey typeface exist but are more difficult to quantify in economic terms in the value propositions described later in this paper. The following sections describe Figure 1 in more detail, which includes brief descriptions of the ecosystem services classified under the Millennium Ecosystem Assessment [17].

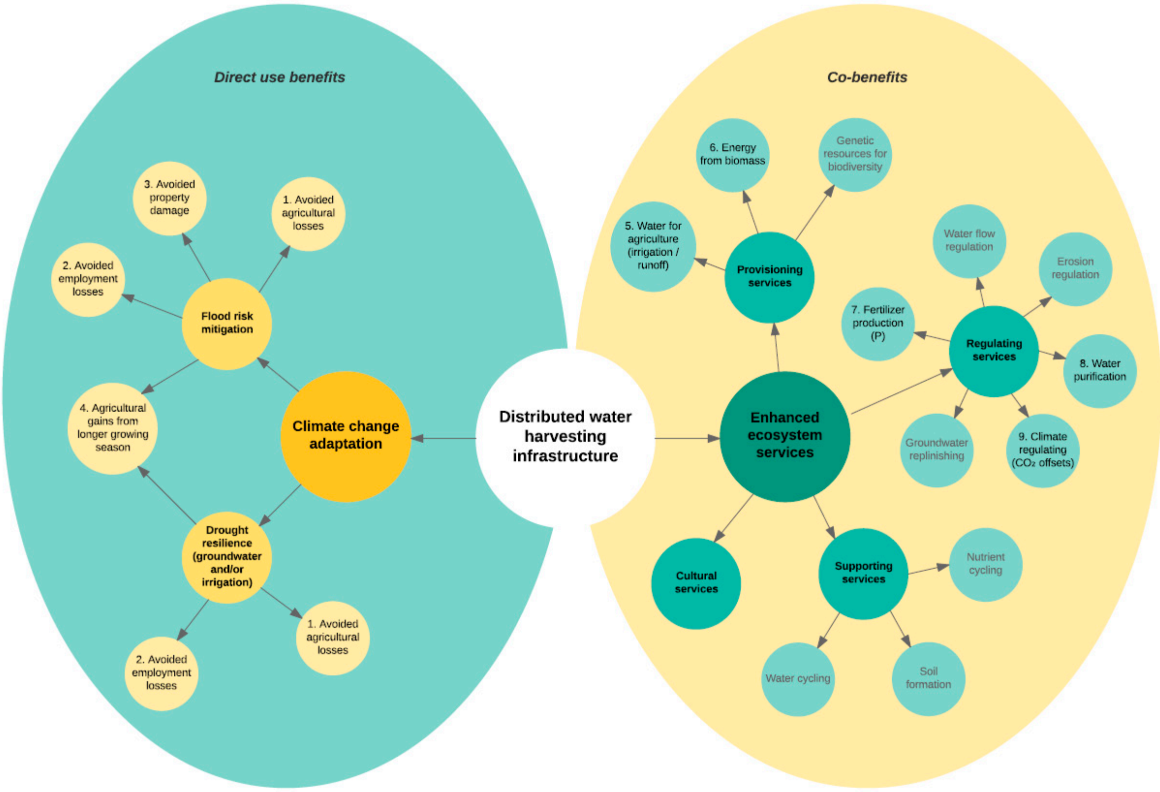

Figure 1. Distributed water harvesting infrastructure system as a network of direct use benefits and enhanced ecosystem services described in the following sections.

2.3.1. Flood Risk Mitigation and Drought Resilience

Climate change adaptation for flood risk mitigation and drought resilience can be easily connected to risk identification and management for governments and insurance entities. The need to consider climate change impacts, particularly property damages and crop loss but also ecosystem service benefits, will be increasingly important as governments begin to feel the monetary impacts. The flood risk mitigation benefit of the water harvesting system manages or avoids multiple hazards described in Figure 1, including agricultural losses due to loss of cultivable land or crop yield damages, property damages due to severe flood events or longer-term changes to the regional hydrology, and employment losses due to a decline in or local industry. The drought resiliency function of water harvesting systems manages similar hazards, including agricultural losses from lack of precipitation events that diminish crop yield and employment losses from reduced agricultural activity. DWH introduces the ability to control the hydrologic cycle with greater precision, presenting a valuable opportunity to increase crop yields with earlier seeding times and a longer growing season.

2.3.2. Provisioning Ecosystem Services

Provisioning ecosystem services are defined as 'the products obtained from ecosystems' [17]. These are the most relevant services provided in agriculture-based regions because of the direct economic benefit. Beyond agricultural crop yields, DWH may allow for provision of water for other uses such as irrigation or controlled runoff. The accumulation of biomass in low spots where water is retained by small earthen dams is an opportunity for farmers or private entities to harvest biomass seasonally for energy generation, similar to the bioeconomy of Lake Winnipeg [14]. This can lead to the secondary provisioning of phosphorus nutrients from the ash. Lastly, avoiding the environmental disruption of large dams and reservoirs may have a positive impact on the natural provision of biodiversity and genetic resources in the region, though this is difficult to quantify.

2.3.3. Regulating Ecosystem Services

Regulating ecosystem services are 'the benefits obtained from regulation of ecosystem processes' [17]. Water harvesting systems behave as a wetland during high water flow conditions, which can facilitate the natural purification of water and buffer peak water flows. Additional water purification functions are derived from biomass harvesting, by avoiding accumulation of phosphorus nutrients that are introduced to the landscape as chemical fertilizers in drainage basins. Water flow regulation is optimized by the higher degree of control over the hydrologic cycle facilitated by DWH systems. This flow regulation function may be a step away from the current, engineered drainage culture and closer to natural flow conditions, depending on the siting, sequencing, and control design of the system. Additional regulating services enhanced by the water harvesting infrastructure include erosion regulation from the more intentional drainage patterns and maintenance of the ground water table by encouraging more time for groundwater percolation.

2.3.4. Cultural Ecosystem Services

Cultural ecosystem services are 'the non-material benefits obtained from ecosystems', such as existence value, altruism, cultural benefits, educational value, and sense of place [17]. Because DWH is an engineering solution for a previously engineered landscape, it is very difficult to quantify the cultural services provided by this solution. However, opportunities may exist to derive cultural benefits, like educational value, if the systems are used intentionally by stakeholders in the social context.

2.3.5. Supporting Ecosystem Services

Supporting ecosystem services are 'the services necessary for the production of all other ecosystem services' [17]. For DWH, these supporting ecosystem services include the natural cycles enhanced by partially reversing or altering the current engineered drainage culture of the agricultural landscape on the Canadian prairies. This should improve the function of several supporting ecosystem services, including water cycling, nutrient cycling, and soil formation.

It is important to note that in addition to established monetary valuation techniques of many direct use and co-benefits, cultural ecosystem services are difficult to value in monetary terms. 'Willingness-to-pay' and related techniques have been used to justify monetary value of intangible assets. However, it cannot be assumed that an unwillingness to pay for an ecosystem service means that the service does not have value [18]. Several non-monetary valuation techniques exist, including Social Network Analysis, preference ranking, or the Q-methodology [18]. There is significant need for plural valuation that considers non-monetary value from such techniques alongside monetary values. However, until financing institutions are restructured to absorb such value into their more rigid frameworks, other important stakeholders may need to compromise and continue to use more easily quantified, less nuanced, monetary valuation techniques. The full list of ecosystem services depicted in Figures 1 and 2 is shown in Table 1.

Table 1. Key ecosystem services and monetization options from Figures 1 and 2.

Theme	Service	Examples of Service Monetization
Climate adaptation	Flood mitigation & drought resilience	Avoided agricultural losses *(estimated area loss x $ yield per unit area)* Avoided employment losses *(estimated job loss x employment insurance)* Avoided property damage *(estimated property damage as function of flood risk)* Crop yield increase from longer growing season *(Estimated yield increase x total affected area)*
Provisioning services	Irrigation water	Cost of equivalent agricultural irrigation *(Estimated irrigation costs for affected crop area)*
	Biomass harvesting	Cost of equivalent energy production

		(Estimated energy from biomass x cost of alternative production)
Regulating and supporting services	Nutrient cycling	Cost of purchasing chemical phosphorus fertilizers *(Estimated kg equivalent nutrient harvest from biomass x market price per kg)*
	Water purification	Cost of equivalent water treatment *(Estimated water quality improvement x cost of conventional water treatment methods)*
	CO_2 offsets	Cost of equivalent CO_2 offsets *(Estimated CO_2 offsets x price of carbon)*
Cultural services	Educational value, intrinsic natural value	Monetary valuation of cultural services *Willingness-to-pay* Non-monetary valuation of cultural services *Q-methodology, social network analysis, mental models*, etc.

2.4. The Design and Value Proposition of Climate Adaptation

Government risk management and strategic planning requires a balance of priorities. Robust quantification of the value proposition of climate change adaptation projects in economic terms, considering the direct benefits of flood risk mitigation and drought resilience, and the co-benefits of enhanced ecosystem services, can drive planning that reflects the multidimensional interests of society. This planning can feed into the project value proposition for DWH and better inform integrated water resource management via water pricing and other market-based mechanisms. The value proposition for DWH requires breaking down complexity and uncertainty with models informed by decades of detailed climate data that has been aggregated, downscaled to the appropriate region, and analyzed. The results of these models should quantify the difference between the impacts of future climate change scenarios with and without climate adaptation measures, such as a proposed distributed water harvesting system. The difference, in monetary terms, generates the measurable climate adaptation benefit over the long term with a relatively high degree of certainty.

Figure 2 below provides a broad framework to quantify the broad benefits derived from a DWH system. Internal rate of return (IRR) is the primary measure of the value or worth of an investment based on yield over the long term. Rather than quantifying the present worth or annual worth as separate entities, IRR calculates the break-even interest rate for which the project benefits are equal to the project costs [19]. In other words, IRR sets the sum of the Net Present Value (NPV) of all cash flows of a particular project equal to zero. The characterization of the NPV functions that make up the larger IRR function inherently takes into account the time-value of money, as the present value of each discrete Present Value function requires discounting the future value. This type of calculation is critical for DWH harvesting; without considering the up-front capital cost alongside the gradual increase of benefits over time, the true value of the project will not be revealed. The suggested formula for internal rate of return (IRR) as a function of {infrastructure cost, flood damage reduction, reservoir cost, drought resiliency benefit, employment benefits, crop yield benefits, ecosystem benefits from biomass, P, CO_2} offset on the diagram is thus an expansion of the more traditional IRR of flood mitigation infrastructure, with IRR as a function of {infrastructure cost, flood damage reduction}. In addition, the ability of governments to establish an institutional environment that supports innovation for biomass harvesting, energy production, and nutrient recovery significantly increases this project value proposition. There is uncertainty inherent in any IRR calculation given the use of NPV, which uses assumed interest rates. A robust assessment of uncertainty requires assessment of fluctuations of various categories of localized data, which can be assessed according to various interest rates. For example, Holopainen et al. [20] perform an uncertainty assessment for NPV calculations of forests. The study relates uncertainty to inventory data, growth models, and timber price fluctuation under assumed of 3, 4, and 5% interest rates. Similar studies must be performed to understand fluctuations of NPV, and ultimately IRR calculations, based on project valuation of DWH systems. For example, variability in hydrologic data or climate change projections will present uncertainty that must be addressed and understood to present a well-rounded assessment of present value and rate of return.

The mathematical expression for internal rate of return Figure 2 above is intentionally general, but further characterization of the mathematical expression may reflect the following, where r is the rate of return of the project, C_t is the net cash inflow during the period t, and C_0 is the net cash outflow during the same time period. As previously mentioned, the calculated IRR will be subject to uncertainty, which must be assessed on a case-by-case basis.

$$IRR = r \text{ when } \left[\sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0\right]_{\text{employment losses}} + \left[\sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0\right]_{\text{purchasing fertilizer}} + \left[\sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0\right]_{\text{CO2 offsets}} + \cdots = 0 \quad (1)$$

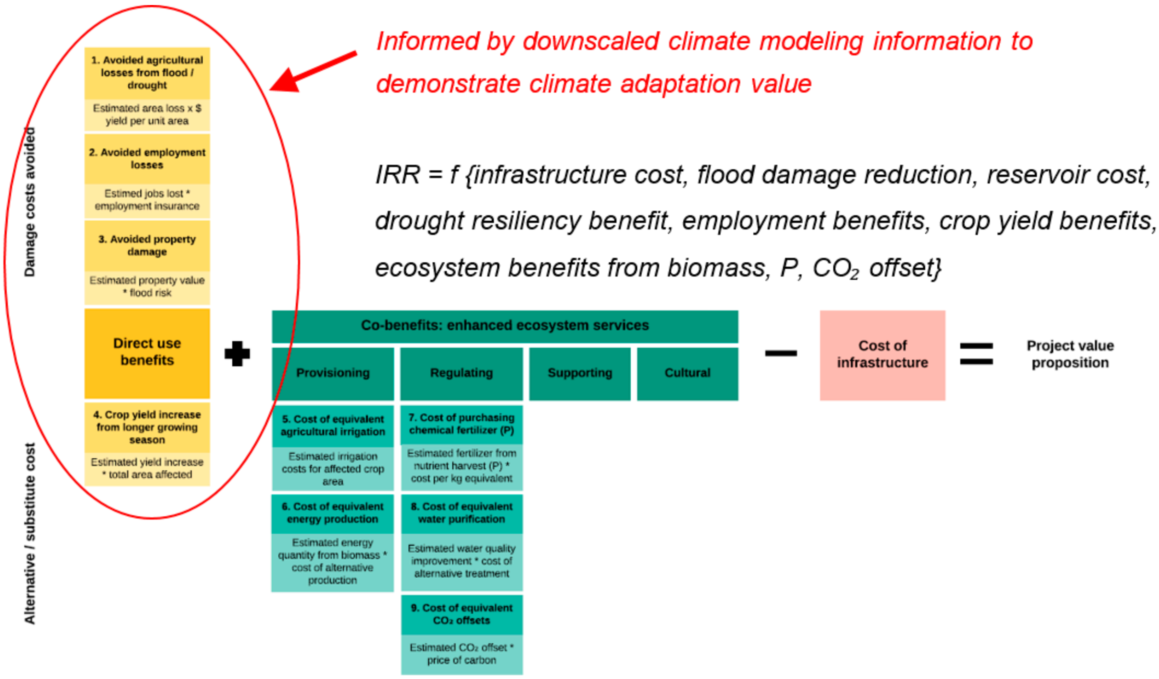

Figure 2. Framework for value proposition of distributed water harvesting infrastructure for consideration when quantifying project value in comparison to more traditional flood risk mitigation methods.

The overall value derived from the methods described above inherently require a long-term view. This is particularly important considering the need for comparability between more conventional solutions for flood mitigation as governments choose between alternatives. High performance climate adaptation solutions require that the boundaries around the cost benefit analysis expand to include the co-benefits previously described, with an understanding of the full value proposition over several decades, hence the logic of a long-term view and bond finance. The threats of climate change manifest as significant costs for governments and individuals, but only if quantified over long time horizons informed by accurate data [8]. The IRR calculation described above helps capture this characteristic in monetary terms. Figure 3 below attempts to visualize the net increasing benefits over time, by separating the short term, medium term, and long term costs and benefits. The figure clearly shows that the peak monetary costs would likely occur within the first five years of the DWH project, while the maximum benefit may be realized on a much longer time horizon. The Red River Floodway in Manitoba, Canada, is a proven historical example of such benefits. The original floodway was built to protect the City of Winnipeg between 1962 and 1968 at a cost of CAD $63 million (in 2011 Canadian dollars) [21]. Premier Duff Roblin spearheaded project development, which required significant political persistence due to the massive project scale. Since 1969, "Duff's Ditch" has prevented over CAD $40 billion of flood damage in the City of Winnipeg [21]. The Red River Floodway is an excellent example of high up-front capital costs reaping long-term benefits, grounding the concept of Figure 3 in historical context.

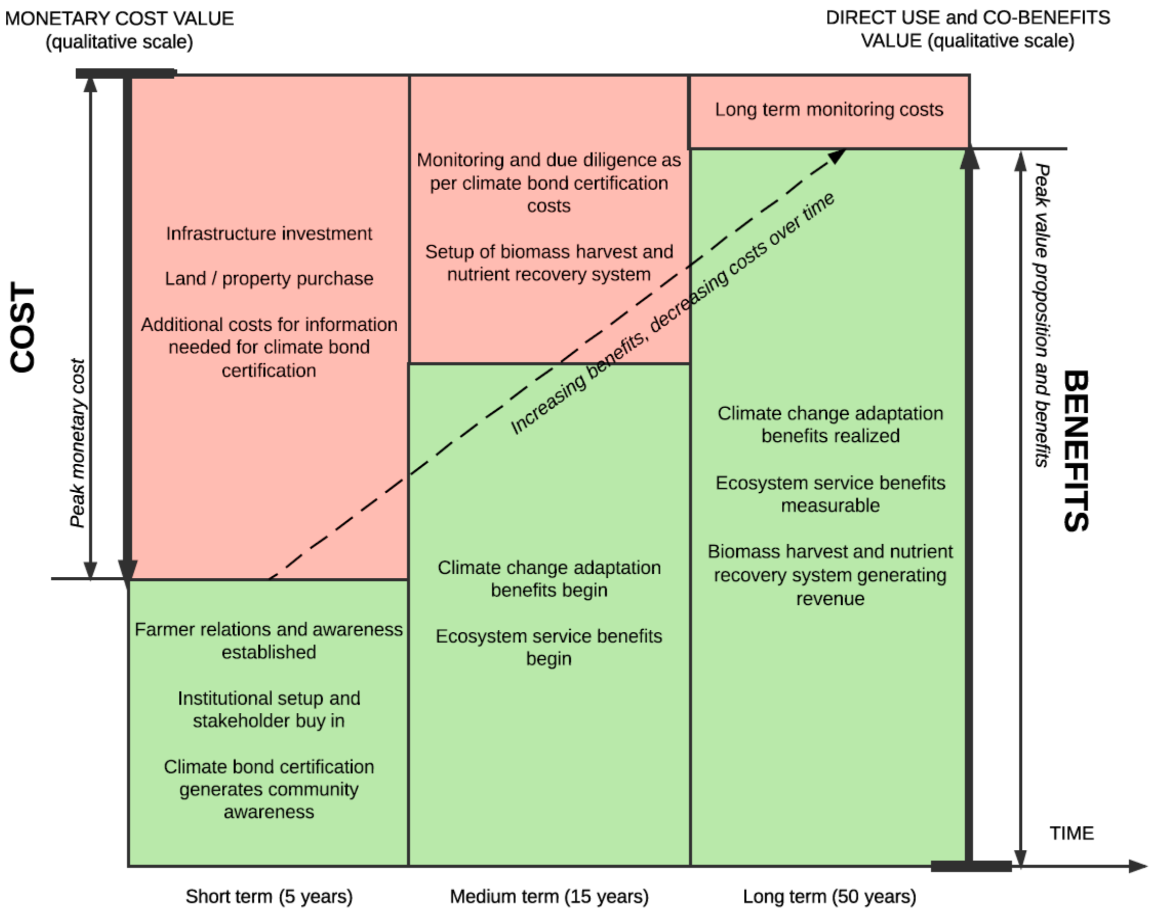

Figure 3. Temporal diagram depicting increasing benefits and decreasing costs over time, emphasizing the need to integrate the long term to understand the changing cost:benefit ratio of climate adaptation.

3. Climate Bonds for Financing Distributed Water Infrastructure

Multi-functional distributed water harvesting lies at the intersection of many challenges that are difficult for traditional debt instruments and government institutions to finance. Better climate adaptation solutions demand the sustainable development principle of subsidiarity, which in turn demands granularity in adaptation projects. Taking advantage of access to robust climate data and projections enables better engineering solutions, but it also places high demands on most aspects of financing including internal rate of return calculations, comparability to conventional projects, and the nuances of risk assessment. An emerging financing solution for climate-resilient and low carbon solutions is to use "climate-aligned bonds"—a twist on the traditional bond, a debt instrument when an investor loans money to a corporation or government for a predefined period of time on a fixed or variable interest rate [22]. These climate-aligned bonds are often unlabeled, but increasingly these bonds are certified as either "green" or "climate" bonds to provide a clear, reliable signal to investors.

3.1. Water Climate Bonds

The Climate Bonds Standard from the Climate Bonds Initiative ear-marks bonds that fund projects with very specific climate change adaptation and mitigation qualities [23]. The Canadian green bond market is growing, with Canadian labeled green bonds amounting to CAD $2.9 billion and Canadian unlabeled climate-aligned bonds amounting to CAD $30 billion [22]. The green bond label has been called into question recently, with some stakeholders questioning whether its criteria are restrictive enough to avoid "greenwashing" [22]. The Climate Bonds Initiative (CBI) uses its Climate Bond Standard (CBS), a rigorous certification and reporting process for climate adaptation and mitigation projects, to demonstrate the value of certification, incent a shift in public and investor perception, and provide a platform to highlight innovative climate-related projects. The Water Criteria under the Climate Bonds Standard were released in 2016, providing investors with "verifiable, sector-specific eligibility criteria to evaluated water-related bonds for low-carbon, climate resilient criteria" [23], with the first phase targeted toward engineered infrastructure. Adherence to the standard is determined after bond originators submit water-related issuances for certification of third party auditors [23]. Successful certification is a clear signal to investors that the project has rigorously considered its role in adapting to and mitigating climate change.

3.2. Government-Issued Bonds for Distributed Infrastructure

The water sector is beginning to embrace decentralized infrastructure as an emerging solution for modern water and climate challenges. For example, water utilities have found that distributed natural or semi-natural systems can help manage fluctuating demand and the strain on storm water and wastewater systems at a relatively low cost [24]. The decentralized nature of these systems, shared by many climate adaptation projects including DWH, is a major design challenge for financers. DWH systems are also distributed across many properties, some of which are privately owned, adding to the legal complexity. Statutory definitions that govern infrastructure projects and management of water systems have a long history, with some water governance regimes unable to accommodate for these project characteristics. As a result, many water utilities in the United States are forced to rely on cash financing of conservation and green infrastructure efforts and to save debt instruments for conventional infrastructure [24]. A report issued by Ceres identified four major themes that may enable legal authority for the issuance of bonds for distributed water infrastructure in the United States [24]. More legal analysis into public finance law and bond issuance requirements in various provinces in Canada is necessary to determine where uncertainties within the legal framework lie, but it can be assumed that the challenges are similar. The legal considerations for issuing bonds for distributed water harvesting infrastructure are outlined in Table 2 below. Financing distributed water infrastructure with bonds issued by public authorities presents some challenges, but to move forward with high performance climate adaptation and mitigation projects it is important to tap into these liquid markets.

Table 2. Legal considerations for issuance of bonds for distributed infrastructure [24].

Legal Consideration	Applicability to Distributed Water Harvesting
Bond issuer must have the legal authority to issue bonds for distributed infrastructure on private property.	Water harvesting requires financing to construct earthen dams on private property or to directly acquire the land.
The bond issuer or water utility must not be legally restrained from using enterprise revenue bonds to finance distributed infrastructure on private property, if applicable.	The provincial and federal government financing structure in Canada may limit acquisition of certain types of debt until existing debts are repaid.
	Constitutional clauses may prohibit the use of public credit for private benefit, though justifying based on the public benefit is possible (see Case Study Section 3.3.2)
Bond issuer must structure the bond to maintain federal income tax exemptions.	Care must be taken to understand the role of farmers as private business, and to intentionally highlight and quantify public benefit.

Bond issuer must establish 'control' of the financed asset to conform to Generally Accepted Accounting Principles.	Conservation easements may act as intangible assets to ensure intended function of property and infrastructure.
	(Rebates have also been constituted as contracts with final customers in water efficiency programs.)

3.3. Case Studies

The available literature does not contain a precedent for funding DWH systems with bonds, in Canada or elsewhere. However, case studies from a variety of angles may inform the feasibility and methods for approaching the structure of a bond for this application.

3.3.1. Water Climate Bond Certified—San Francisco Public Utilities Commission [25]

The San Francisco Public Utilities Commission issued the first bond certified under the Water Criteria for the Climate Bond Standard in May of 2016. The USD $240 million will help fund projects under the Sewer System Improvement Program. The sewer and storm water systems in San Francisco are currently nearly 100 years old, and the aging infrastructure is expected to present increasingly significant risks to the region. In addition, San Francisco is located in a seismic zone and the aging structures are seismically vulnerable. By investing in large scale capital improvements now, the utilities commission hopes to avoid emergency repairs and regulatory fines, while creating broader public benefit from the improved system design. From a climate change perspective, San Francisco will experience increasing temperatures and greater intensity of downpours and storm systems that directly threaten the storm and waste water systems [26]. Certification of this project under the CBS Water Criteria is a positive signal for the possible certification of a bond financing DWH systems. Storm water and wastewater systems are distributed and decentralized by nature, involve many stakeholders, require long time horizons, and are informed by significant hydrologic complexity. These factors all exist as key institutional and technical considerations with DWH systems.

3.3.2. Bond Distributed on Private Property: Southern Nevada Water Authority [24]

The Southern Nevada Water Authority has financed its Water Smart Landscapes Program with government issued bonds. The water authority rebates customers USD $2 per square foot of grass removed and replaced with desert landscaping up to the first 5000 square feet converted per property per year. To satisfy the legal requirement to maintain control of the 'financed asset', a conservation easement is recorded against the property if the converted landscape is funded by bond funds. Again, this unique bond structure is a positive signal for the possibility to finance DWH with government bonds. The Southern Nevada Water Authority has justified the individual private benefit with the claim that public funds generate much greater public benefit. In addition, the use of conservation easements is a pertinent example of a legal structure that can overcome the legal requirement to maintain control of the asset being financed, which is also a pertinent consideration for DWH systems.

3.3.3. Canadian Green Bond: Province of Ontario [27]

The Province of Ontario Green Bond Program is leading the green bond market in Canada. The first bond issued as part of this program was a CAD $500 million bond to fund the Eglington Crosstown Light Rail Transit (LRT) project, which aims to generate public benefit and mitigate climate change impacts from multiple angles [28]. The new transit corridor will move people up to 60 percent faster than the current bus system. The LRT vehicles are electric and produce zero emissions, reducing the greenhouse gas footprint compared to the bus system. In addition, the shift of transport mode from auto to LRT is expected to further reduce the carbon footprint of the transport system. This project, and the successful issuance of a second CAD $750 million bond through the

Province of Ontario Green Bond Program, demonstrates the potential liquidity of the market for financing rural projects certified under the international Certified Climate Bond Standard.

3.3.4. Asian and the Pacific Climate Bond: Asian Development Bank [29]

In early 2017 the Asian Development Bank (ADB) backed a climate bond for AP Renewables, Inc. of the Philippines. The local currency bond, equivalent to USD $225 million, is the first bond certified by the Climate Bonds Initiative to any country in Asia and the Pacific, and it is also the first ever single-project Climate Bond issued in an emerging market. The bond will finance AP Renewables' Tiwi-MakBan geothermal power generation facilities in the form of a guarantee of 75% of the principle and interest on the bond, in addition to a direct local currency ADB loan of USD $37.7 million equivalent. This landmark project demonstrates innovation in the financing realm from multiple dimensions—the opportunity for development institutions to assist developing and emerging economies in accessing new capital, the use of credit enhancement risk from the Credit Guarantee Investment Facility that has been established by ASEAN+3 governments and ADB to develop bond markets, and the proven importance of 'green' financing in emerging economies. The applicability of this financing mechanism, in addition to the DWH concept, is clearly transferable to economies all of the world with similar climatic and agricultural challenges, despite their different institutional structures and capacities.

4. Designing the System to Support Multi-Functional Distributed Water Harvesting Infrastructure and Climate Bond Certification

Implementation of a distributed water harvesting system is a complex design challenge with consideration of the engineering, property rights, environmental, institutional, and regulatory contexts. The following sections outline the starting point for implementing a DWH system on the Canadian prairies and ensuring that this setup increases the likelihood of successful bond certification under the Water Criteria of the Climate Bond Standard.

4.1. Engineering Considerations, Land and Property Ownership, and the Environment

There are several practical considerations when moving to implement water harvesting infrastructure. The list in Table 3 is not exhaustive but begins to frame the types of considerations to be made to successfully design and implement the technology solution, while incorporating the needs of various stakeholders and the technical requirements listed under the Climate Bond Standard.

Table 3. Considerations for technical/practical factors in implementing water harvesting infrastructure.

Theme	Relevant Factors to Consider
Engineering considerations	Hydrological modeling project boundaries must operate within provincial boundaries while considering river basin boundaries.
	Hydrological modeling must consider present and multiple climate change impact scenarios.
	Hydrological modeling and engineering must take into account changes to water quality and water supply to all downstream.
	Siting and sequencing of location and scale of water harvesting dams and flow patterns should be optimized for physical context.
	Siting and sequencing of water harvesting dams and flow patterns should be adjusted based on external social or environmental factors if optimized physical considerations does not fit.
	Siting and sequencing of projects must meet regulated hydrological budgets based on current and future projections of water allocations.
	Farmers or other property owners must be willing to sell land to municipal or provincial government.

Land and property ownership	Farmers must be consulted on willingness to lease land back during periods when land is suitable for cultivation.
	Governments must be willing to consider easements or other mechanisms to incent farmers to allow for modifications to land and the landscape.
Environmental considerations	Siting and sequencing of projects must meet regulations on minimum environmental flows, water quality, etc.
	Water quality and flow monitoring must be in place to enable due diligence in project design and implementation.
Profit generating activities	System for harvest of biomass for local heating and/or sale for energy production must be set up for farmers to take advantage of the possible business case.

4.2. Institutional and Legal Structure

A multi-functional distributed water harvesting system requires the coordination of various stakeholders. The proper institutional and legal structure can ease project implementation and increase the likelihood of sustainable project outcomes. In addition to the institutional environment within Canada, it will be critical to consider the transboundary effects, given the shared water basins along the Canada–US border and the potential for changes to transboundary water allocation and environmental impacts. In addition to designing and implementing the technology solution, issuing bonds for the distributed, rural infrastructure and receiving certification for the bonds under the Climate Bond Standard requires an additional layer of stakeholder coordination. Table 4 identifies and explains key stakeholders involved and includes suggestions for possible stakeholders who may be well positioned to take on these roles and functions.

Table 4. Stakeholders involved with institutional and legal structure of water harvesting infrastructure.

Role	Function	Possible Stakeholders
Project initiator	A government entity to initiate project under mandate to protect public and manage hydrology of a region.	Relevant municipal and provincial branches of governance, such as the Province of Manitoba, Province of Saskatchewan, or relevant municipalities.
Financing authority	A public lending institution that issues bonds on behalf of government entities.	Provincial lending institutions like Alberta Capital Financing Authority (ACFA), Ontario Financing Authority (OFA), or Infrastructure Ontario (IO).
Watershed management and environmental agencies and advisory committees	A broad role, this covers all agencies involved in watershed management, hydrological planning and monitoring of the region.	Canadian watershed-level entities such as Alberta Watershed Planning and Advisory Committees, Saskatchewan Watershed Advisory Committees, Manitoba Conservation Districts, Manitoba Water Council; Inter-province entities such as the Prairie Provinces Water Board; United States watershed-level entities such as North Dakota Water Resource Boards.
Regulator	Regulatory agencies that operate within and between jurisdictions with regulatory power.	A federal government agency such as Environment Canada; provincial government agencies such as Alberta Environment and Sustainable Resource Development and Department of Conservation and Water Stewardship in Manitoba; United States agency such as United States Environmental Protection Agency; transboundary agency such as International Joint Commission.

Property owners	Any individual or agency with private or public property involved with water harvesting project.	Individual property owners such as farmers; other property owners such as Ducks Unlimited.
Monitoring and verification	An agency that provides ongoing oversight into the operations, maintenance, and upgrades involved with water harvesting project.	An entity that already has monitoring responsibilities such as the Prairie Provinces Water Board, provincial water and environmental government bodies.

In addition to the key stakeholders in Table 3, the institutional environment for financing infrastructure includes several limitations and challenges. Provincial and federal governments may have limits to their debt, and bonds are only one of many avenues from which to obtain funding. If local governments are included in financing considerations, many municipal governments also face a patchwork of funding sources including provincial and federal grants. Perhaps most importantly, governments generally expect a 'net drain' on investments from infrastructure, unlike investments in other sectors such as electricity. This 'net drain' highlights the importance of implementing the biomass harvest and nutrient recovery system as soon as possible once the DWH system is operational [30]. A fundamental consideration for project design is the uncertainty of future system performance given future climate uncertainty, therefore, IRR estimates will necessarily have estimates of uncertainty that associate with the range of future climate projection, which investors should recognize and understand. The current state-of-the-art in hydraulic design is to use ensemble climate projections to analyze expected performance and variability [31,32]. A key hypothesis with respect to DWH design, and its bond value and risk management proposition is that the higher the degree of climate impact, the greater the system benefit as this class of infrastructure is designed specifically to modulate climate impacts.

4.3. Climate Bond Standard Certification

Upon examination of the Climate Bond Standard Phase 1 Water Criteria [7] and the San Francisco Public Utilities Commission case, the DWH concept has the potential to be an eligible candidate for certification. Certainty requires a more in-depth analysis of the river basin in question and full scoring by the independent third party auditors commissioned by the CBI. In the case of the Canadian prairies, key stakeholders for certification include governmental stakeholders including the Government of Canada, the environmental departments of the provincial governments of Alberta, Saskatchewan, and Manitoba, inter-provincial or international (US-Canada) agencies of interest and all others listed in Table 3 above. If these stakeholders approach the project with the intention of bond financing and climate bond certification, several unique considerations emerge. For example, the CBS requires that the project boundaries for assessment only include the direct effect of the proceeds of the bond [33]. It is likely that the most suitable project boundary for a DWH system is a river basin, with additional consideration of provincial boundaries prompted by the CBS criteria. The project must also qualify under criteria for all certified bonds, criteria for sector-specific bonds, and broader human rights and environmental considerations for water management before being considered for CBS certification [33]. This requirement may also prompt more intentional engagement with community members and civil society.

The CBS Water Criteria are separated into two streams: projects primarily for climate adaptation and projects primarily for climate mitigation. Water harvesting clearly falls under the climate adaptation criteria. Evaluation for CBS certification is based on a Scorecard system, in which a range of criteria are evaluated for no points, half points, or full points. The evaluation starts with a Vulnerability Assessment, followed by an Adaptation Plan if deemed necessary by the Vulnerability Assessment. Rough consideration of the criteria and the integrated nature of DWH systems indicate that they would likely require the Adaptation Plan. The Vulnerability Assessment is split into three major categories described in Table 5 below.

In some cases, the water harvesting concept may exceed the criteria in the way they are currently written, while in other cases the criteria are limiting. In addition, DWH projects are inherently climate adaptation projects, and thus the requirement for an Adaptation Plan presents an opportunity to highlight this functional purpose. The following sections are based on the CBS Water Criteria for Phase 1: Engineered Infrastructure [7], and may inform upcoming iterations of the criteria for natural or semi-natural systems. The applicability of CBS water criteria to the water harvesting system is broken out in more detail in the following sections. This evaluation is partially informed by the 2015 Organization for Economic Cooperation and Development (OECD) report, *Water Resources Allocation: Sharing Risks and Opportunities* [34], which evaluates institutional gaps in water allocation policy in Alberta and Manitoba. The sections below focus on these two provinces.

Table 5. Vulnerability Assessment section themes (as per Climate Bonds Initiative (CBI) requirements).

Theme	Description
Allocation	Assesses how water is shared by users within a given basin or aquifer, concentrating on the potential impacts of bond proceeds on water allocation.
Governance	Assesses how or whether the proceeds of the bond take into account the ways in which water will be formally shared, negotiate, and governed.
	Assesses compliance with allocation mechanisms that protect water resources.
Diagnostic	Assesses how or whether the use of the proceeds takes into account changes to the hydrologic system over time.
Adaptation Plan	If Vulnerability Assessment reveals significant climate change impacts on the project, the Adaptation Plan must be created as a management response plan to the conclusions and findings of the Vulnerability Assessment, noting how identified climate risks will be addressed.

4.3.1. Meeting the Criteria

A strong institutional environment on the Canadian prairies already exists, increasing the likelihood for a DWH system on the Canadian prairies to be certified under the CBS criteria. Accountability mechanisms for management of water allocation at different institutional, spatial, and temporal scales are established by water management plans, water code statutes, and compliance mechanisms that are in place in the regions in question. For example, water monitoring is performed by the Prairie Provinces Water Board, Alberta Environment and Sustainable Resource Development (ESRD), and the Department of Water Conservation and Stewardship in Manitoba. Scientific hydrological services that inform monitoring of adherence to codes already exist in current institutions like Manitoba's Water Stewardship Division. Furthermore, some elements of water allocation policies are already designed as required by the CBS criteria. For example, Alberta and Manitoba have differentiated entitlements based on the level of security of supply or risk of water shortage [34]. Both provinces have sanctions for withdrawal over limits. New entitlements or the increase of existing entitlements requires assessment of third party impacts, an environmental impact assessment, and that existing users forgo use [34]. In Alberta, minimum environmental flows are considered, and monitoring and enforcement mechanisms are in place in both Manitoba and Alberta [34]. Manitoba's Water Use Licensing Section monitors compliance for agriculture, domestic, and industrial water use by metering [34]. Allocation is enforced through sanctions with fines, and conflicts are resolved through the normal application of principles of good governance [34]. Alberta ESRD monitors and enforces water allocation for agriculture, domestic use, energy production, and the environment through metering and drawing penalties for contravening the enforcement order. Part of the sanction actions may also include fines or imprisonment, and formal conflict resolution is included under Section 93 of the Alberta Water Act. These existing institutional frameworks are key components of climate bond certification.

4.3.2. Exceeding the Criteria

The nature of the multi-functional water harvesting solution for the Canadian prairies exceeds the CBS criteria in several ways, though these are not necessarily captured in the formal CBS

Scorecard. For example, the CBS criteria requires a connection between water resource management at the project and hydrologic scale. Because a DWH system is based entirely upon the hydrologic scale, the boundaries of the bond proceeds and the hydrologic scale are one and the same. The criteria also include requirements for specific data, flow criteria, modeling scenarios, and water users to be included in hydrologic modeling. The hydrologic models used to design the DWH systems on the Canadian prairies would easily integrate these requirements in a manner that complies with the CBS criteria. For example, a dynamic simulation model of a DWH climate adaptation system was recently conducted for a portion of a watershed downstream of Pelly's Lake, Manitoba, Canada. This simulation model integrates physical variables related to the landscape, energy balance, moisture fluxes, hydrologic cycle with operational climate forecasting tools to understand the multi-purpose benefits of the system and to estimate their economic value [6]. Furthermore, the use of downscaled climate data and quantification of future climate impact scenarios with and without the system increases certainty about the future success of the system, beyond the requirements of the CBS criteria. The quality and breadth of information put into these hydrological models, environmental impact assessments, and other assessment mechanisms that are part of the planning and design process benefit the climate bond certification process by informing a rigorous Adaptation Plan. More importantly, the use of downscaled climate change data with rigorous hydrologic modeling to design DWH systems demonstrates a fundamental shift towards greater certainty for context-specific system functionality as a climate adaptation solution under long range climate impacts.

4.3.3. Challenges with the Criteria

Some institutional gaps in water management on the Canadian prairies and the current structure of the CBS Water Criteria present some challenges for certification. Water allocation agreements must be dynamic to accommodate changes to flow scenarios with new water harvesting infrastructure, so adherence to the criteria may not be clear until the planning process is mature. Additionally, inconsistent provincial water allocation policies reveal weaknesses in water governance in some provinces. Manitoba does not define its environmental flows, and while freshwater biodiversity is considered on a project-by-project basis, terrestrial biodiversity is not considered. Return flow obligations are not specified, and the nature of water entitlements is based on the purpose of water allocation, maximum area irrigated, and the maximum volume removed, rather than as a proportion of total flow conditions. Alberta has a more rigorous policy framework, but its water allocation is currently classified as 'over-allocated'. These institutional gaps should not only be addressed to allow for climate bond certification, but also as part of an effort to establish best practices for water management.

5. Distributed Water Harvesting and Climate Bonds in the International Context

The Canadian Prairies are not the first or only agricultural region to be confronted with increasing pressure driven by climate change impacts—globally 80 percent of agricultural land is rainfed making up 65 to 70 percent of staple food crops [35]. Model output of mean climatic changes are far more robust than changes to climate variability, meaning that the full impacts of climate change are likely seriously underestimated [35]. However, just as with the Canadian example, the interactions of different climatic stresses on biological and food systems over time in different regions all over the world require investigation of localized changes over time. Variability in rainfall is demonstrated as the principle cause of inter-annual variability in crop yields at both aggregate and plot level [35]. Semi-arid and arid environments around the world are projected to face similar challenges that may be solved by DWH solutions or other distributed agricultural adaptation solutions financed by ear-marked climate bonds. For example, rainfall variability in the Middle East and the Mediterranean region is projected to result in an overall drier climate, with an impact on major river systems and food productivity [36]. Specific impacts are disparate across this region—rainfall is expected to decrease in southern Europe, Turkey, and the Levant, while rainfall in the Arabian Gulf may increase [36]. Still, in the former example, rainfall is expected to increase in the winter and decrease in the summer [36], affecting crop productivity differently in each growing season. In another locale, studies have also shown one of the highest agricultural productivity losses due to climate change scenarios is predicted in India [37]. Though temperatures are expected to rise and annual precipitation rates to remain stable, regional variability is expected to result in extreme changes to both surface and groundwater due to the changes in temporal rainfall variability [37]. Several countries in sub-Saharan Africa also rely heavily on rainfed agriculture, and expect a higher frequency of droughts and rainfall variability in the future [38]. DWH solutions, or some derivate of the technology, is likely to be necessary in regions with high dependence on rainfed agriculture and projected rainfall variations.

The existence of rainfed agriculture and current or projected climate change impacts is not enough to determine the suitability of DWH solutions or financing via the use of labeled or unlabeled climate bonds. An institutional environment conducive to such multi-stakeholder, rural-based solutions must exist or be managed to achieve the maximum return on project investment and ensure the system is used appropriately. Any institution or entity that is set up to issue a bond has the ability to issue a green bond, and if institutional capacity meets the requirements, may be certified under the Climate Bond Standard. Southern Europe and the Middle East may be well-served by such distributed engineering solutions, and may also be set up to access the pool of capital offered by green or climate bonds. In addition, developing countries face low visibility on low carbon projects because of the high cost of capital and higher interest rates, despite a significant need for climate-friendly infrastructure investment [39]. Development institutions, as demonstrated by the Asian Development Bank, are well positioned to facilitate and support such enabling environments. This paper has demonstrated the application of DWH harvesting and climate bond certification and financing in one locale, but several other contexts requires a similar approach, adapted to the local agricultural and climate system, institutional circumstance, and financing environment.

6. Conclusions and Recommendations

A multi-functional distributed water harvesting system on the Canadian prairies financed with government-issued bonds that are certified under the Water Criteria for the Climate Bond Standard presents a feasible, innovative climate adaptation solution for the increased temperatures and variable precipitation expected to strain agriculture in the region in the coming decades. Successfully implementing this solution requires stakeholder coordination, an institutional lens, and innovative engineering methods. In addition, lessons learned from the analysis contained in this paper can inform the establishment of CBS criteria for natural and semi-natural water infrastructure.

It is recommended that institutions involved with water management and public infrastructure on the Canadian prairies think creatively about their role in driving and supporting innovative climate adaptation projects. Taking advantage of the growing green bond market potential and learning from the success of the green bond initiatives in the Province of Ontario requires that more financial institutions recognize their value and build programs to support them. For example, the Liberal government's proposed Canadian Infrastructure Bank and other existing financers can consider green bonds as an opportunity to aggregate projects for risk reduction and public benefit and to access an otherwise exclusive pool of private capital. Assessing the true value of innovative solutions, particularly distributed climate adaptation projects, requires that governments consistently establish a long-term view that quantifies direct monetary ecosystem service benefits and co-benefits. This lens should not only be adopted to inform the full economic value for projects with direct environmental or climate adaptation benefits. A report from the Ministry of Environment in Sweden recommends the inverse view; that "...government should investigate different strategies to improve transparency regarding the dependence and impact of bond investments on the ecosystem services, including investments by the national pension funds" [40]. Taking care to involve existing stakeholders through all phases of visioning and implementation of a DWH system will take advantage of existing institutional capacity and help anticipate demands to fill institutional gaps. Stakeholder involvement should also include a comprehensive community benefits framework and active community engagement, as was established alongside the Eglington Crosstown LRT project under the Province of Ontario Green Bond program. Prairie Provinces may need to also consider tightening up water allocation policies to fill the identified gaps. Engineers, hydrologists, and environmental scientists must also consider their role in designing an effective system and using the requirements of the CBS Water Criteria to inform robust hydrological modeling and engineering practices. These stakeholders must also take care to build the business case and supply chain connections for farmers to harvest biomass, generate bioenergy, and recover nutrients, in order to capitalize on long-term project value and protect downstream water bodies from excess nutrient accumulation. All stakeholders that have a potential role in the design and implementation of a water harvesting system, financing the project under certified climate bonds, or creating an appropriate policy environment, must be aware of the complexity of the space and importance of demonstrating effective climate adaptation solutions.

A multi-functional distributed water harvesting system can enable agricultural productivity on the Canadian prairies in the face of climate change. Successfully implementing and financing a DWH project requires that stakeholders understand the value of the direct climate adaptation benefits and enhanced ecosystem services, actively pursue the business case generated alongside the public benefit, and generate buy-in and momentum through active institutional and community engagement. Financing a DWH project, and other distributed water infrastructure, with government bonds is possible if the bond is structured with consideration of the legal authority of the bond issuer. Seeking Climate Bond Standard certification creates an additional incentive for robust project design, takes advantage of an untapped pool of private capital, and demonstrates the full value that decades of climate data and refined hydrologic knowledge can bring to infrastructure solutions. Lastly, the Phase 1 Water Criteria for the CBS rewards water and wastewater projects that have shown adequate proof that climate adaptation and mitigation have been considered as design constraints. It is recommended that as the Climate Bonds Initiative develops water criteria for natural or semi-natural infrastructure, it might consider finding ways to explicitly reward projects that have a functional purpose of climate adaptation or mitigation rather than simply as a design consideration of a project with a different functional purpose. The analyses and recommendations contained in this paper are directed toward implementation of a DWH systems on a hypothetical river basin on the Canadian prairies, but it is evident that this solution is transferable to many regions with similar climate change effects and agricultural systems that will cause climate adaptation challenges in the future.

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