Expanding Irrigated Agriculture in Alberta: An Economic Impact Assessment

by

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Abstract

This study assessed the economic impacts of Alberta's irrigated agriculture industry as of 2011 and evaluated the economic viability of expanding the irrigated crop land by 10% within the 13 irrigation districts in southern Alberta. Results of the economic impact assessment revealed that irrigation, directly or indirectly, generated $3.2 billion to the national gross domestic product. The distribution of these benefits was 17% for producers and 83% for the province and the nation. Results of the economic viability analysis revealed that with the existing government subsidy of 75% to the irrigation rehabilitation program, investment for expansion of irrigated crop land would be economically viable for producers. However, in the absence of this effective government subsidy, the investment would be unattractive. The results are consistent with the fact that irrigation expansion is a capital-intensive project and as such its economic viability for producers is contingent upon the levels of subsidy and the opportunity costs of capital. The results have important policy implications for the provision of economic incentives for producers investing in water saving irrigation technologies.

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Acronyms

AAF	Alberta Agriculture and Forestry
AEP	Alberta Environment and Parks
CBA	Cost-benefit analysis
CPR	Canadian Pacific Railway
EU-DG RUP	European Union-Directorate General for Regional and Urban Policy
GDP	Gross domestic product
I-O	Input-output
IRP	Irrigation rehabilitation program
IRR	Internal rate of return
IWM	Irrigation Water Management Study Committee
NPV	Net present values
O & M	Operation & maintenance
PVC	Polyvinyl Chloride
VA	Value-added
WCD	World Commissions on Dams
WTP	Willingness to pay

Chapter 1 Introduction

1.1 Background

The southern part of Alberta is a semi-arid region, which has limited water supply that is under pressure with the continuously growing demand from various users including agriculture, municipalities, and various types of industry (e.g., oil and gas) (AMEC 2009). Increasing population and economic activity in that region coupled with adverse climate change are expected to put additional pressure on the water resources in the future (AMEC 2009; 2014). To address these challenges, in 2003, the government of Alberta established a new water management action plan called "Water for Life". The plan has three goals "safe, secure drinking water, health aquatic ecosystems, and reliable, quality water supplies for a sustainable economy". Improving efficiency in water use in all sectors is promoted to achieve the goals (AEP 2010).

Irrigation is the highest water consuming sector in Alberta, representing 43% of the province's total water licensed allocation (AEP 2010).The irrigation sector provides important socio-economic and environmental benefits to southern Alberta as well as to the provincial economy (AAF 2001; 2004). Without irrigation development in southern Alberta, the regional population and associated services would be reduced by 65-75% (AAF 2004). In 2014, irrigated land covered only 5% (680,000 hectares) of Alberta's cultivated land but contributed 20% ($3.6 billion) to the provincial agri-food GDP (Paterson Earth & Water Consulting Ltd 2015). In addition to the agri-food production, irrigation infrastructure provides multiple non-irrigation services including water supplies for industry, livestock enterprises, municipal uses, wildlife habitats, and recreation facilities (AAF 2004; 2014a).

Alberta's irrigation development has seen significant growth since the establishment of the irrigation rehabilitation program (IRP) in 1969 (AAF 2004). However, the IRP placed a significant burden on government funding. The provincial government in Alberta has taken responsibility for the full costs of irrigation headworks and 75% of capital costs for the rehabilitation of irrigation district works. Producers, through the irrigation districts, are responsible for the remaining 25% of capital costs and the full operational costs of the district works. In addition, producers are responsible for the full costs of on-farm operation and maintenance activities (O & M) for irrigation (AMEC 2009).[1]

Both government and producers have been investing in improvements for irrigation infrastructure. From 1969 to 2009, a total of about one billion dollars has been invested for the rehabilitation of district conveyance works. Producers have invested an additional one billion dollars for improvements in on-farm irrigation methods (Hohm 2010). As a result of this continuous investment, about 60% of open irrigation canals have been replaced with pipelines and lined with membrane materials. Approximately 80% of irrigated land has been converted from low water efficient, surface irrigation systems to highly water efficient, center-pivot systems (AAF 2015a). These improvements in irrigation infrastructure have resulted in a significant amount of water-savings, which in turn have contributed to the expansion of irrigated crop land (Bennett et al 2015). The government of Alberta and producers are committed to continue investing in irrigation water-saving technologies (AAF 2014a).

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[1] Irrigation headworks are defined as "works required diverting the water from the mainstem source streams and conveying it the districts" (AMEC 2009, 17). District works are defined as "works generally within the boundaries of the districts that are required to distribute water to the producers" (AMEC 2009, 17). Operation and maintenance is defined as all equipment, materials and works necessary for the day-to-day delivery of water to users that includes replacement of short term structures, maintenance and repair of buildings, administration of project business, and the purchase of all equipments and tools (McAndrews 1967).

The investment made in the irrigation sector creates not only direct economic impacts on the agriculture sector but also secondary impacts or "ripple effects" on other sectors through backward and forward linkages in the provincial and national economies. Backward economic impacts are created through the purchase of inputs (e.g., fertilizer, energy, seeds, machinery, equipment) that are required to support the increased irrigated agriculture. Forward economic impacts are created as irrigated agriculture produces goods and services that are used as inputs by other sectors (e.g., agri-food processing, transport, storage) (Clifton Associates Ltd 2008). Moreover, irrigation provides several socio-economic benefits such as increasing employment, stabilization of income, increasing food security, and decreasing food prices (Hussain and Bhattarai 2001).

The provincial government in Alberta has recognized the significance of the secondary benefits of irrigation and this is one reason why the government has been contributing to the rehabilitation of irrigation infrastructure in a cost-sharing arrangement with producers. The cost-sharing formula was derived based on the relative distribution of benefits of irrigation between producers and the province. Several irrigation economic impact analyses were undertaken in the past to derive an appropriate cost-sharing formula (e.g., McAndrews et al 1967; Russell et al 1984; Kulshreshtha et al 1985; Kulshreshtha et al 1993). These studies assessed the economic impacts of Alberta’s irrigation using input-output (I-O) analysis and determined the relative distribution of benefits of irrigation.

1.2 Problem Statement

Scarcity of water has become a chronic problem in the world. The World Economic Forum ranks the lack of adequate water supply for food production among the top global risks (Pacific Northwest Project 2013). In Alberta, increasing water scarcity is posing a serious problem for meeting the continuously growing demand for water from all sectors. Irrigation is a major water consuming sector and hence there is interest in the potential for water savings in this sector. As a result of improvements in irrigation water saving technologies, the irrigated land within the irrigation districts is expected to expand by 10% over the next two decades (AAF 2014a). Historically, the irrigated land in the irrigation districts has increased by 0.7% annually (AAF 2015a).

An assessment of the question of economic viability of irrigation expansion necessitates an examination of the social benefits and opportunity costs of water, land and capital from the public point of view. This type of economic analysis would assist in decision making to ensure that the limited resources are employed to their best uses. However, one relevant dimension of larger problem is question of financial viability of potential expansion from producers' perspective since the decision for expansion is subject to the vote of producers in a district plebiscite.

In evaluating irrigation rehabilitation and expansion projects, two key questions are "Who benefits from irrigation?" and "Who pays for it?". In most Organization for Economic Co-operation and Development (OECD) countries, full irrigation costs are paid by agricultural producers. In Alberta, however, irrigation capital costs for rehabilitation of conveyances are shared between producers and the provincial government. As noted earlier, the cost-sharing formula is based on the relative distribution of irrigation benefits, with the split currently being set at 75%-25% between the provincial government and producers. This formula dates back to the 1990s and there are ongoing concerns both from the government and producers with respect to the current split. The government requires the limited public money and water resources to contribute a significant economic value to the provincial or national economy. At the same time, producers question whether the existing government financial support is sufficient to secure financial profitability from expanding irrigated land.

The current cost-sharing formula is at least partly based on previous research on relative benefits from irrigation (Russell et al 1984; Kulshreshtha et al 1985; Kulshreshtha et al 1993). However, the results from these studies may not reflect the current contribution and impacts of irrigation. Recently, Paterson Earth & Water Consulting Ltd (2015) assessed the economic impacts of Alberta's irrigation using I-O analysis. The study assessed the average impact for the 2000-2011 time period. However, the study was limited to provincial level impacts of irrigation and did not consider impacts at a national level. More importantly, the study was silent on the economic viability of investing in irrigation expansion. There is a dearth of study on the economic viability of expanding the irrigated land in southern Alberta in spite of the growing interest for expansion.

These concerns require an up-to-date economic analysis to justify the economic efficiency and economic equity impacts of Alberta's irrigation. Therefore, the current study is undertaken to evaluate the financial viability of expanding the irrigated crop land from a producers' perspective as well as assessing the magnitude and distribution of economic benefits of Alberta's irrigation on the provincial and the national economies.

1.3 Research Questions and Objectives of the Study

The overall objective of the current study was to assess the economic impacts of Alberta’s irrigated agriculture industry on the provincial and national economies, and to evaluate the economic viability of further expanding the irrigated crop land in southern Alberta. Based on this overall objective, three specific research questions are identified:

1. Who benefits from Alberta’s irrigation? Does the current 75-25% cost sharing arrangement still reflect the allocation of benefits attributable to irrigation in Alberta?
2. Will the direct incremental benefits of irrigated crops compensate the investment costs for irrigation expansion?
3. Is government subsidization required for expansion to be economically viable and, if so, what is the minimum required level of government subsidy?

These questions are addressed through the examination of the following specific study objectives:

1. To assess the direct and secondary economic impacts of four irrigation-related activities in southern Alberta: crop production, livestock production, agricultural food-processing, and irrigation infrastructure rehabilitation and maintenance;
2. To determine the distribution of the benefits of irrigation among producers, and the province and the nation;
3. To calculate the costs and benefits of expanding the irrigated crop land within the 13 irrigation districts in southern Alberta and use these in a financial analysis to examine economic viability of expansion of irrigated crop land from the producers' perspective;

4. To examine the need for subsidization of the costs of irrigation expansion and, if necessary, the required level of subsidization in order to make the planned expansion economically viable.

1.4 Thesis Organization

The remainder of this thesis constitutes seven chapters. Chapter 2 provides a review of relevant theoretical and empirical literature. Chapter 3 provides a description of irrigation development and management in the study area; southern Alberta. Chapter 4 provides a discussion of I-O multipliers and the data used for the assessment of the economic impacts of irrigated agriculture. Chapter 5 provides a discussion of the cost-benefit analysis (CBA) and the data used for analyzing the economic viability of irrigation expansion. Chapter 6 presents the results and provides a discussion of these results. Finally, conclusions and implications are presented in Chapter 7, along with a discussion of study limitations and areas of future research.

Chapter 2 Literature Review

This chapter serves two purposes. A review is provided of relevant literature on the questions (raised in the previous chapter) of "Who benefits from irrigation?" and "Who should pay for it?". In regard to these questions, the experiences of different countries in the world are reviewed. Secondly, literature is reviewed that examines cost-benefit analysis and input-output analysis, which are the two areas of empirical analysis that are employed in the current study. The conceptual foundations and the empirical applications of these two economic analysis techniques are reviewed and explained.

The chapter is structured into four sections. The first section provides a review of literature on the theory of irrigation cost-recovery from an international perspective. The second section provides a review of literature on the theoretical foundation of cost-benefit analysis. The third section provides a review of literature on the theoretical foundation of input-output analysis. Finally, the previous empirical works are reviewed in section four.

2.1 Irrigation Cost-Recovery: International Perspective

The aim of this section is to provide an international perspective of the principles of irrigation cost-recovery. The section describes the problem of negative cycle in publicly funded and managed irrigation systems that gave rise to the development of different pricing and institutional reforms to achieve two major objectives: improve cost-recovery and control water demand.

Over the last five decades, irrigated agriculture has been vital to meeting fast-rising global food demand. Irrigated production provides about 40% of the world's food from only 17% of the global cropped land (Asian Development Bank 2008). With the global population expected to increase to 7.9 billion by 2025, irrigation will have to provide approximately 80% of the additional food requirement (Asian Development Bank 2008).

However, in recent years, the pace of irrigation development has been declining (Brelle and Dressayre 2014) due to a number of challenges such as rising costs (Rosegrant 2002), aging infrastructure (Ward 2010), and increasingly constrained water resources (Lenton 2014). Besides these challenges, the irrigation sector has been confronted with three deep-rooted problems: a high reliance on government financing, low water use efficiency, and poor standards of management and maintenance (World Bank 2007). A high reliance on limited government funding has led to a negative cycle of underfunding, poor service delivery, declining productivity, low cost recovery and poor financial sustainability (Easter and Liu 2005; Asian Development Bank 2008). To resolve these problems a number of irrigation policy reforms have been undertaken in many developed and developing countries (World Bank 2007; Brelle and Dressayre 2014; Lenton 2014). Irrigation cost-recovery and water pricing have been at the heart of the policy reforms (Rosegrant 2002; Cornish et al 2004; Easter and Liu 2005).

The full costs of providing irrigation water include investment, operation, maintenance, rehabilitation and modernization costs[2] (Easter and Liu 2005). The desired extent of irrigation cost-sharing among farmers, other beneficiaries, and government is widely debated in literature (Easter 1993; Bhattarai et al 2007; Easter and Liu 2007; Ward 2010).

In 1971, the World Bank established an initial cost recovery policy for irrigation projects financed by the Bank. The policy required "recovery of operation and maintenance costs as a minimum, and investment costs to the extent practicable, recovery being measured in terms of direct charges collected from irrigators" (Duane, 1986, 2). Other international policy institutions, such as World Water Forum 2000, EU Water Framework Directive 2000, and OECD policy

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[2] See Section 2.2.2.

2002, also recommended the full cost recovery principle (OECD 2002; Bostworth et al 2002). The principle requires famers to pay all capital, operation and maintenance costs of irrigation. However, this principle was not successful in most cases (Easter and Liu 2005). Evidence shows that farmers were most often unable to pay the full costs of irrigation. For instance, Duane (1986) reported that of the 48 World Bank supported irrigation projects in East Asia and the Pacific, South Asia and the Middle East, and South America only half of the projects recovered the operation and maintenance costs.

Similarly, Dinar and Subramanian (1997) rated the cost-recovery experiences of 22 developed and developing countries with varying characteristics. They reported that farmers pay in the range of 20-75% of operation and maintenance costs of irrigation. The authors also categorized the selected countries into three scales of "water pricing program index"[3] (low, medium and high). Canada was the only developed country categorized as "low", characterized by high reliance on government funding and slow water policy reform (Dinar and Subramanian 1997).

The FAO Water Report in 2004 indicated that the wealthier member countries of the OECD succeeded in recovering full costs of irrigation. These countries are Japan, France, Australia, Spain and the Netherlands. However, majority of the remaining countries were not able to recover even the annual operation and maintenance costs (Cornish et al 2004).

Opponents of the full cost recovery principle designed a cost-sharing principle, which justifies the irrigation costs to be shared among the farmers, other beneficiary groups, and the government (Easter and Liu 2005; Bhattarai et al 2007). The principle is based on the idea that

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[3] The index is based on two criteria: current pricing practices and current mode of funding. A country is placed in a "high" category if it employed at least some economic pricing, recovering full O & M costs, and part of capital costs. On the other hand, a country is placed in "low" category if it financed water systems primarily with government funding (Dinar and Subramanian 1997).

irrigation benefits extend to the national economy beyond the farm gate and hence the government or other beneficiary groups should contribute to irrigation investment and operation costs. The allocation of costs among the beneficiaries is made based on the relative distribution of benefits of irrigation (Easter and Liu 2005). This principle is mainly applied in Africa and Asia, where irrigation projects serve multiple purposes and produce huge economic benefits to the national economy (Easter and Liu 2005). In Asia, about 90% of irrigation dams serve multiple purposes (e.g., hydroelectric power generation, industrial and domestic uses) (Perry 2001). Also, in Africa, about 70% of irrigation dams serve multiple purposes (Perry 2001).

Effective cost recovery for irrigation requires appropriate pricing mechanisms and institutional arrangements (Easter and Liu 2005). Area-based and volumetric pricing methods are commonly applied in pricing irrigation water (Easter and Liu 2005). Area-based pricing involves a flat rate charge based on the area irrigated. It is determined by dividing the total operation and maintenance costs of providing irrigation water by the total area irrigated. Volumetric water pricing is charged based on the volume of water supplied and it requires accurate water metering. In addition, there is increased interest in market based approaches for pricing irrigation water. A market based mechanism is a formal or informal trade of water, which requires a well-defined structure of water rights, a clear set of rules for trading, an entity to manage water delivery, and a judicial body to oversee trading activities and resolve disputes (Easter and Liu 2005).[4]

The choice of pricing methods depends on pricing objectives. There are two common objectives for irrigation water pricing (Cornish et al 2004). The first objective is to achieve financial sustainability by recovering the cost of providing irrigation services from farmers so that irrigation system can be effectively operated and maintained without reliance on government

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[4] A detailed discussion of the advantages and disadvantages of different pricing mechanisms is provided by the World Bank (2007).

funding. The second objective is to achieve water resource sustainability by controlling irrigation water consumption and encouraging water use efficiency, cost-effectiveness and conservation practices (Perry 1996; Cornish et al 2004). In areas where the objective is simply to recover the costs, area-based methods are used. However, in areas where water demand controlling is sought particularly in water-scarce regions, volumetric pricing and tradable water allocations are applied (Bostworth et al 2002; Cornish et al 2004).

The target of level of cost recovery and magnitude of water consumption reduction vary across irrigation projects and countries (Cornish et al 2004). Historically, the cost recovery objective has been paramount, but as water scarcity increases, the water use efficiency objective is likely to grow in importance (Easter and Liu 2005). Generally speaking, the objective of water pricing in developed countries (e.g., Australia, USA, Spain) is often to allocate a scarce water resource between sectors. However, in less-developed countries, the objective is to recover costs (Johnson 1990, cited in Bostworth et al 2002). Dinar and Subramanian (1997) indicated that almost all developed countries consider the need for volumetric pricing and increasing water charges. However, in Canada, the area-based pricing mechanism is commonly applied (Horbulyk 1997). The 2004 FAO Water Report indicated that Canada charges the lowest irrigation water prices, by far below the average rate recommended for developed countries (Cornish et al 2004).[5]

In addition to water pricing mechanisms, appropriate institution arrangements are necessary for effective cost recovery and water demand management. As Easter and Liu (2007) indicated low cost recovery rates appear to be caused mainly by "a lack of willingness to pay rather than by inability to pay" (297). Farmers' willingness to pay for recovering irrigation costs

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[5] The average water rate for developed countries was US$40-50 per hectare per year (in 1998 price) (Cornish et al 2004).

is determined not only by their ability to pay but also by their confidence in the services delivered and financial management (Bostworth et al 2002). Appropriate institutional arrangements are required to involve famers in ensuring that the irrigation systems are responsive to farmers’ current and future needs (FAO 2002).

Over the past few decades, many countries adapted different institutional reforms, targeted at devolution of irrigation management and investment responsibilities from the central government down to irrigators (Cornish et al 2004). The common objectives for the reforms were to cut the government subsidies for irrigation and to improve the management and sustainability of irrigation systems (Svendsen et al 1997; Meinzen-Dick 1997). These reforms have varied in terms of degree of effort and success in improving cost recovery in many countries (Poddar et al 2011). A detailed discussion of the lessons of five representative countries (United States, Australia, Mexico, Ethiopia, and Canada) is provided in Appendix H.

2.2 Theoretical Framework of Cost-Benefit Analysis

In its broadest sense, cost-benefit analysis (CBA) is defined as “an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits in order to assess the welfare change attributable to it” (EU-DG RUP 2015, 25). CBA is an applied economic analysis tool that utilizes the theory of welfare economics. This section presents the conceptual foundation of CBA by discussing how the theory of welfare economics can be used in applying CBA for evaluating the economic efficiency of policy interventions. The section then provides the basic steps involved in constructing CBA. The difference between financial CBA and economic CBA is also provided. Finally, the section highlights the major limitations of CBA.

2.2.1 Conceptual Foundation for Cost-Benefit Analysis

CBA is a decision making tool that seeks to maximize net benefits to the society. This concept of CBA is connected to the theory of welfare maximization called Pareto efficiency (Young 2005; Boardman et al 2011). Before looking at the connection, it is important to understand the Pareto efficiency condition. Pareto efficiency or optimality is defined as "allocation of resources such that no further reallocation would make any one in a society better-off without making someone worse-off" (Hussain and Bhattarai 2001, 6). Pareto efficiency can be expressed in terms of the achievement of (a) economic efficiency in the production of goods and services, (b) economic efficiency in consumption of goods and services, and (c) economic efficiency in the distribution of goods and services (Young 2005).

Pareto efficiency relies on three major value judgments. The first judgment underlies that the economic welfare of society is the aggregate of the economic welfare of its individual citizens. The second judgment underlies that the individual is the best judge of his/her own well-being. The third judgment is related to the optimality criteria, defined earlier (Young 2005). Welfare is an abstract concept and is measured in terms of money. The beneficial and adverse effects of projects are monetized using money as a common unit. Benefits are the "good" or "desirable" effects, whereas, costs are the "bad" or "undesirable" impacts (Young 2005). Benefits are measured in terms of willingness to pay (WTP) which reflects the sum of the maximum amounts that people would like to pay to gain outcomes they view as desirable. The costs are measured in terms of opportunity costs which reflect the returns forgone when scarce resources are used to implement a policy. The net benefit is the difference between the WTP and the opportunity costs (Boardman et al 2011).

Applying the standard Pareto efficiency condition as a decision rule for CBA would require adopting only policies that yield positive benefits after providing full compensation to all who bear the costs so that no one is made worse off and at least one person is better off. In short, the strict Pareto efficiency requires the policy change to result in only winners, not losers (Young 2005; Boardman et al 2011). Although this is theoretically attractive, not all policy change would in practice meet the strict Pareto efficiency condition (Boardman et al 2011).

Welfare theorists developed an alternative decision rule for CBA that works in the real world situation. This decision rule is called potential Pareto efficiency or potential Pareto improvement (Boardman et al 2011). The potential Pareto efficiency rule is based on the compensation test; that is, if gainers could in principle compensate losers and still be better off, then the policy change would be acceptable (Young 2005). In a practical CBA, the compensation test is done by comparing the incremental benefits generated by a policy change with the incremental costs of the policy change. If the incremental benefits are greater than the incremental costs, then the policy change is said to be Pareto superior or potential Pareto improvement as it leads to a condition superior to the status quo (Young 2005).

The relationship between the Pareto efficiency and CBA criteria, as well as the concept of potential Pareto improvement, is depicted in Figure 2-1. In Figure 2.1, the curve $B(Q)$ represents aggregate benefits and the curve $C(Q)$ represents aggregate costs. The shape of the curves reflects the conventional assumption that benefits increase as the level of output increases but at a decreasing rate, and costs increase at an increasing rate. In principle, the Pareto efficient solution is attained at Q^*, where the marginal benefit is equal to the marginal cost. At Q^*, the distance between the aggregate benefits curve and aggregate costs curve is at the highest level, which reflects the maximum level of net benefits. The marginal benefit is measured by the slope of the aggregate benefits curve, $\frac{dB}{dQ}(Q^*)$, and the marginal cost is measured by the slope of the aggregate costs curve, $\frac{dC}{dQ}(Q^*)$.

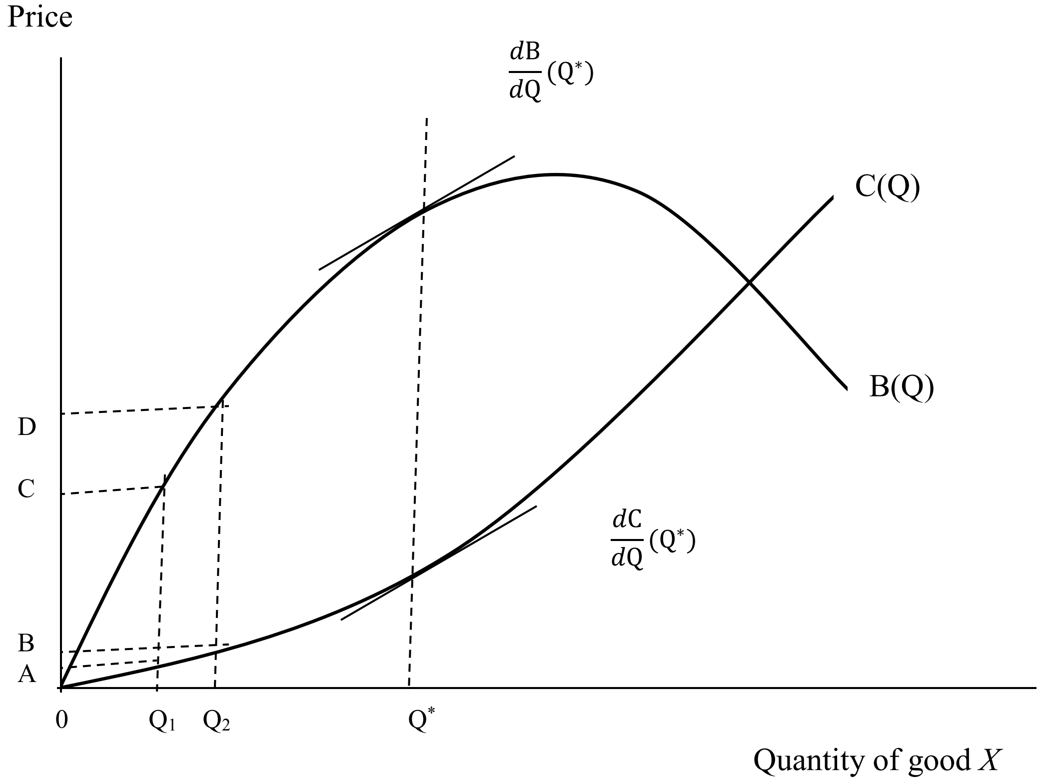

Figure 2-1: Pareto efficiency and cost-benefit analysis criteria
Source: Adapted from Young (2005)

As noted earlier, in a practical cost-benefit analysis of a given policy change, the incremental benefits are compared with the incremental costs and if the former exceeds the latter, then the change is considered to be desirable or Pareto improvement. For example, a policy change that increases the scale of output from Q_1 to Q_2 in Figure 2-1, is said to be a desirable policy, because the incremental benefit (*CD*) is greater than the incremental cost (*AB*). In this manner, the net benefit maximization criteria of CBA facilitate a more efficient allocation of resources.

Thus far, the net benefit maximization criterion of CBA is made clear. What follows provides the conceptual foundation of CBA using the microeconomic concepts of the demand curve and supply curve (Boardman et al 2011). The microeconomic theory is based on the underlying assumption of a perfectly competitive market structure. The demand curve represents the sum of willingness to pay for a good by various members of society. The supply curve represents the opportunity costs of inputs incurred by various members of society to implement a policy or supply a good. Producers receive revenues by selling the good to the consumers. The objective of producers is to maximize the net benefits which are given by the difference between the total revenues and total costs. The objective of consumers is to maximize their net benefits which are given by the difference between the total benefits (measured by their willing to pay for the good) and the total expenditures they actually spend for purchasing the good. These net benefit maximization concepts are utilized in CBA. These concepts are clearly depicted in Figure 2-2.

In Figure 2.2, the demand curve represents the market demand for good X while the supply curve represents the market supply of good X. Market equilibrium occurs at point where the demand curve equals the supply curve, resulting in an equilibrium price of P^* and quantity of Q^*. At the equilibrium, consumers spend $P^*Q^*$to purchase the equilibrium quantity at the equilibrium price. Total benefits to consumers is given by the area under the demand curve from the origin to Q^* (area of $0ACQ^*$). The difference between the total benefits and consumers' actual expenditures is called consumer surplus (area of AP^*C).

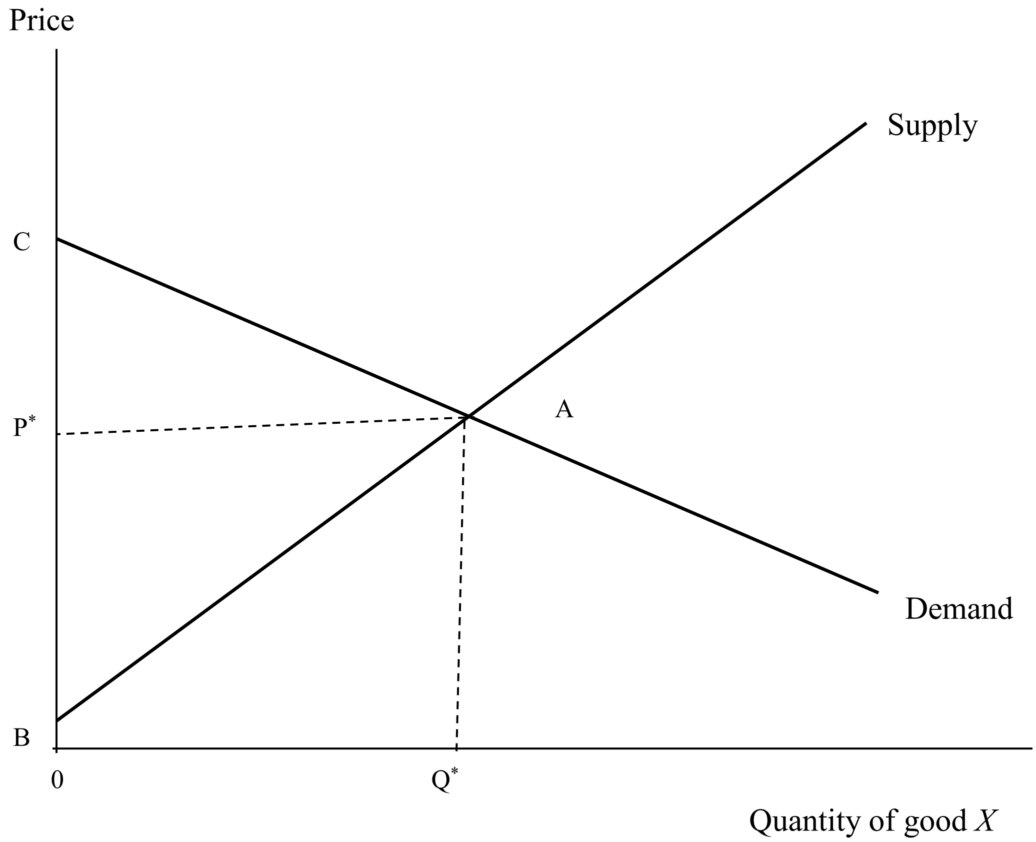

Figure 2-2: Social surplus and Pareto efficiency
Source: Adapted from Boardman et al (2011)

Consumers' actual expenditures are revenues to firms who supply the good. The total cost of supplying Q^* is given by the area of $0BAQ^*$. The difference between the total revenues and total costs is called producer surplus (area of AP^*B). Producer surplus is the net benefit to producers which is the difference between actual revenues and the minimum amount of money that producers would be willing to accept for the good (Boardman et al 2011). The sum of consumer surplus and producer surplus is called social surplus or net social benefits. Social surplus is given by the area of *ABC*. At the equilibrium point, the social surplus is maximized and the Pareto efficiency condition is attained at this equilibrium point.

A policy change affects consumer and producer surplus. The impact on consumer surplus reflects the incremental benefits to consumer and the impact on producer surplus reflects the incremental benefits to producers. The sum of the changes in consumer surplus and producer surplus indicates change in economic well-being to the society. Hence, in a practical cost-benefit analysis, the net benefits of any policy change are estimated by measuring the changes in consumer surplus and changes in producer surplus against the status quo (Boardman et al 2011).

In the CBA undertaken in the current study, the concept of producer surplus was employed to measure producers' benefits arising from expanding irrigated crop land against the status quo, dryland crop production system. This concept is illustrated by Samarawickrema and Kulshreshtha (2008). Figure 2-3 depicts how the concept of producer surplus can be used to measure the net benefits for irrigation production system.

In Figure 2-3, the supply curve under the dryland production system is depicted by line *ab*. Irrigation increases supply of crops and this is reflected by the line *dc*. The market price is reflected by the horizontal line (*P*). Producer surplus under dryland production is given by the area of *Pba* and producer surplus under irrigation production is reflected by the area of *Pcd*. Hence, the incremental benefit from irrigation production system is the area of *abcd*. The accrued incremental benefits over the life span of the proposed expansion project are further compared with the investment costs in order to evaluate the economic efficiency of irrigation expansion.

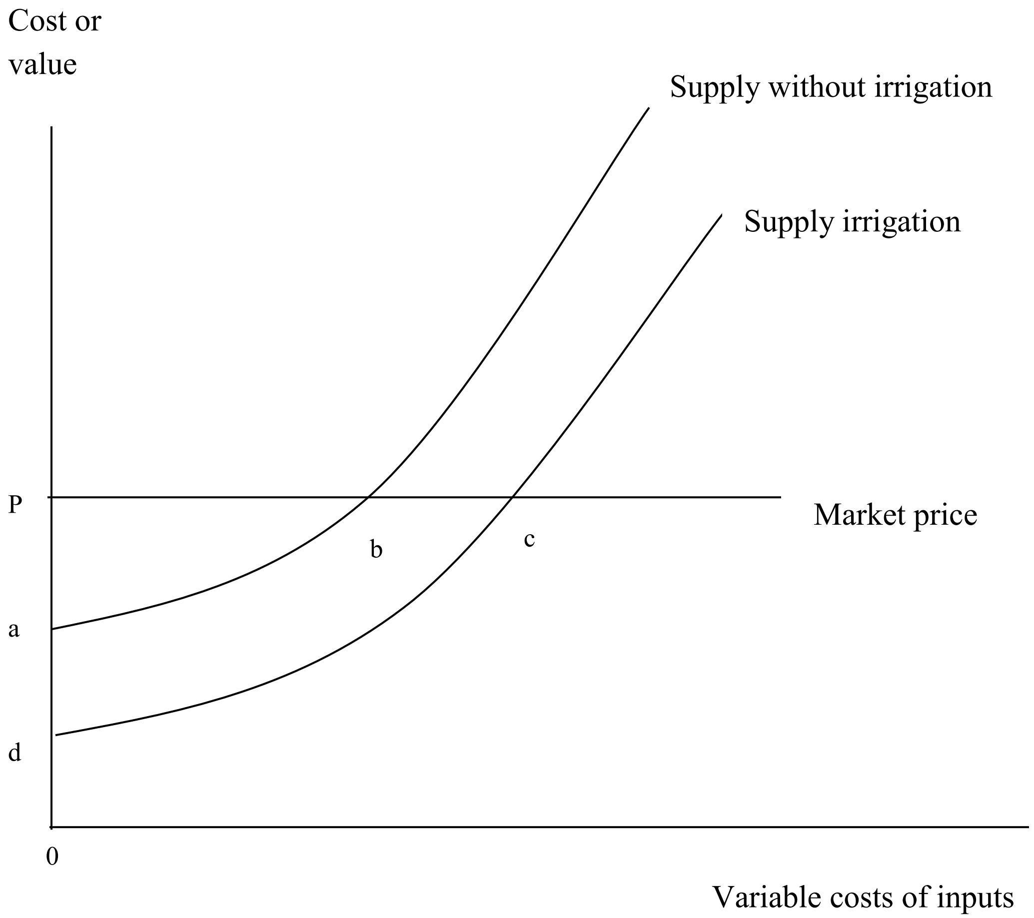

Figure 2-3: Producer surplus as a measure of net benefits of water used for irrigation
Source: Samarawickrema and Kulshreshtha (2008, 261)

2.2.2 The Basic Steps of Cost-Benefit Analysis

Constructing CBA involves nine basic steps, given in Table 2-1 below. Some of the steps may overlap each other. For the purpose of the current report, only the basic steps are provided in detail mainly focusing on irrigation projects.

Table 2-1: The major steps in cost-benefit analysis

1. Specify the sets of alternative projects
2. Decide whose benefits and costs count (standing)
3. Identify the impact categories, catalogue them, and select measurement indicators
4. Predict the impacts quantitatively over the life of the project
5. Monetize (attach dollar values) all impacts
6. Discount benefits and costs to obtain present values
7. Compute the net present value of each alternative
8. Perform sensitivity analysis
9. Make a recommendation

Source: Boardman et al (2011, 6)

1. Specify the sets of alternative projects. CBA underlines the principle of incremental net impact by measuring the difference between a scenario “with-the-project” and a counterfactual baseline scenario “without-the-project” (EU-DG RUP 2015). In the context of irrigation, the project can be development of new infrastructure or rehabilitation of the existing infrastructure. In the case of initial irrigation development, the costs and benefits of the "with irrigation" scenario are compared to the "without irrigation" scenario, which is usually dryland or rain-fed agriculture. However, in the case of rehabilitation, the costs and benefits of the "with rehabilitation" scenario are compared with the "without rehabilitation" scenario. The costs of not rehabilitating could be higher than the costs of not irrigating the land. This is because the costs of not rehabilitating include not only declining benefits from crop production but also increasing maintenance costs and risk of catastrophic failure in water supply. In practice, however, it is difficult to quantify the costs associated with maintenance costs and catastrophic failure, and hence the costs are mostly ignored (Olivares and Wieland 1987).

2. Decide whose benefits and costs count (standing). The question of accounting stance is a critical issue in CBA of irrigation projects (Veeman 1978). It has been widely recognized that irrigation projects bring significant changes at various levels, from the farm to national levels (Hussain and Bhattarai 2001). The analyst must decide who has a “standing”; that is, whose benefits and costs should be included (Boardman et al 2011).

3 & 4. Identification and quantification of impacts over life of the project. CBA measures the impacts in the long-term perspective. Thus, it requires setting an appropriate time horizon and forecasting future benefits and costs that occur over the life span of the project (EU-DG RUP 2015). Irrigation generates multiple benefits to the society that extend beyond the farm-gate point. The benefits extend to the national economy, consumers welfare and other beneficiaries. On the other hand, there is also a “downside” to irrigation. Irrigation project incurs high costs for the construction, rehabilitation and operation. In addition, irrigation development inflicts adverse environmental effects (e.g., loss of biodiversity and obstruction on hydrological cycle) and puts pressure on the limited resources (Hussain and Bhattarai 2001). A comprehensive list of the benefits and costs of irrigation projects is provided in Table 2-2.

5. Monetize (attach dollar values) all impacts. Once the impacts are identified and quantified, the next step is to value them in monetary terms. The term “value” has meaning in relation to scarcity of resources (Hussain and Bhattarai 2001). As noted earlier, the benefit or value of an output is measured in terms of WTP and the cost for an input is monetized using the concept of the opportunity costs (Boardman et al 2011).

Table 2-2: Costs and benefits of irrigation

Benefits of Irrigation	Costs of Irrigation
• Increased agricultural production: o Increased crop productivity o Expansion of crop area o Increase in crop intensity o Increase in crop diversification • Increased uses of the irrigation water supply systems for: o Livestock o Municipal o Industrial o Tourism and environment • Secondary benefits: o Increased employment in irrigated agriculture o Increased employment outside agriculture through backward and forward linkages o Stabilization of farm incomes o Increased food security at the national and local levels o Lower food prices for consumers o Improved nutrition and welfare	• Capital construction and operating costs for distribution and on-farm works • Capital and operating costs for other value chain development • Secondary costs: o Irrigation-induced land degradation problems such as soil salinity and water logging o Alternative opportunity costs for the use of water that could include the generation of hydro-electric power and the application to wetland habitats o Adverse environmental impacts such as loss of biodiversity and obstruction on the natural hydrological flows

Source: Adapted from (Hussain and Bhattarai 2001) and (Clifton Associates Ltd 2008)

6. Discount benefits and costs to obtain present values. When the costs and benefits associated with a project are attained or incurred over time, their values are influenced by time. As a consequence, there is a need to aggregate and compare the costs and benefits that arise in different years (Boardman et al 2011). In CBA, future costs and benefits are discounted relative to present costs and benefits in order to obtain their present values. This procedure is called discounting and the factor used for discounting is called the discount rate. A benefit or cost that occurs in year t from now is converted into its present value by dividing it by $(1+r)^t$, where r is the discount rate. Suppose a project has a life of n years and let C_t denote the costs and B_t the benefits in year t. Then, the present value of the costs, $PV(C)$, and the present value of the benefits, $PV(C)$, are determined using the formula given below (Boardman et al 2011, 12):

$$\mathrm{PV(C)} = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

$$\mathrm{PV(B)} = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t}$$

Irrigation expansion is a long-term project which has financial impacts that extend over several years. Costs and benefits occur in different time periods. While investment costs are typically incurred in the first years of the project's life, recurrent costs and benefits show up later. This situation leads initially to large negative net cashflows, which then become progressively smaller and eventually positive (Olivares and Wieland 1987). Hence, the financial analysis of irrigation expansion requires intertemporal comparison of costs and benefits. Future costs and benefits are discounted back to present using the above discounting formulae. The discounted costs are then deducted from the discounted benefits to judge the economic efficiency or profitability of the project (Olivares and Wieland 1987; EU-DG RUP 2015).

2.2.3 Financial and Economic Cost-Benefit Analysis

CBA can be undertaken from the point of view of an individual/s or society as a whole. The former is called financial CBA and the latter is called economic or social CBA (Boardman et al 2011). In the context of irrigation, financial CBA aims at assessing the financial effects of a given project on the farmers, government agencies, and private firms who participate in it (Savva and Frenken 2002). In contrast, economic CBA aims at assessing the additional income to the nation resulting from the irrigation project. In other words, economic CBA address a question of "is the proposed project good from the viewpoint of national development interest?" (Savva and Frenken 2002, 3). The calculation of costs and benefits differ between the two types of CBA. The major sources of the variation are direct transfer payments, price distortion, and externalities (Gittinger 1984; Savva and Frenken 2002).

In a financial CBA analysis, payments of taxes and interest on debt reduce farmers' net benefits and hence they are considered as costs. On the other hand, receipt of subsidies on inputs or outputs increases farmers' net benefits and hence they are considered as benefits. In the economic CBA, the direct transfer payments do not represent a real resource flow and hence they are excluded from the calculation. Besides transfer payments, when the market is not competitive, market prices for outputs and inputs can be distorted and fail to reflect the economic prices. So, the actual market prices used in the financial CBA cannot reflect the true economic price required for economic CBA. Financial CBA considers only direct costs and benefits (marketed resources) to the project owner. However, economic CBA considers in addition external costs and benefits that lie outside of the project and accrue to the society (Savva and Frenken 2002).

2.2.4 Limitations of Cost-Benefit Analysis

CBA has two major limitations that need to be considered when using CBA in practice (Boardman et al 2011). First, technical limitations in theory, data, or analytical resources may make it impossible to monetize all relevant costs and benefits. In a typical CBA, the estimates of costs and benefits are limited to the sectors that are directly affected by the project, and economic impacts on other sectors generally fall outside the scope of CBA (Hussain and Bhattarai 2001). In reality, however, public and private projects generate significant impacts on other sectors in an economy (Boardman et al 2011). Second, CBA mainly deals with economic efficiency from a policy change. A typically CBA does not account for distributional impacts of a project or equity, and other relevant social issues. In reality, however, several projects have significant impacts on the distribution of gains, which cannot be ignored (Hussain and Bhattarai 2001). To address these limitations of CBA, economists developed several supplementary economic impact analysis techniques (Boardman et al 2011). Input-output analysis is one of the techniques recommended to address the distribution issue, which is discussed in detail below.

2.3 Theoretical Framework of Input-Output Analysis

Input-output analysis is an analytical framework developed by a Nobel Laurette, Professor Wassily Leontief in the late 1930s. In its basic form, an input-output model consists of "a system of linear equations, each one of which describes the distribution of an industry's product throughout the economy" (Miller and Blair 2009, 1). The main purpose of input-output model is to do economic impact analysis. It measures how changes in industry output or final demand for commodities impact the economy in terms of gross output, gross domestic product, employment, households income and government revenue (Miller and Blair 2009).

This section provides the basic concept of the input-output analysis by illustrating the flow goods and services in an economy. The section also provides a detail discussion of the conceptual foundation of an input-output analysis by discussing how the input-output model can be mathematically constructed from observed data in a given economy. The basic assumptions pertaining to the input-output model are also highlighted.

2.3.1 Basic Concept of Input-Output Analysis

An input-output model is developed based on transaction tables that describe the flow of commodities through an economy from producer in one industry to another industry, and to final demand (GOA 2015). Table 2-3 below shows a simplified input-output framework table. To understand the table, it is important to understand what is meant by the terms commodity, industry, final demand, and sector. Commodity refers to any goods and services purchased or sold by a firm. Industry refers to a group of firms that sell similar types of commodity. Final demand refers to final demanders in an economy who purchase commodities. Final demand includes household consumption, government consumption, private enterprise consumption, and net export consumption. A sector is a general term used for grouping industries and/or final demand from demanders' perspectives or suppliers' perspectives (Miller and Blair 2009).

Table 2-3: Simplified I-O accounting framework

		Buying Sector		
		Industries	Net Final demand	Total Output
Selling Sector	Industries	Z	F	X
	Value-added (Primary Inputs)	V		
	Total Input	X		

Source: Adapted from Miller and Blair (2009) and GOA (2015)

In the above table, industries listed in the top row are purchasing (or consuming) sectors, whereas industries listed in the first column are producing (or supplying) sectors. Matrix *Z* maps out the flow of commodities from supplying sectors to consuming sectors. Total output is the sum of output consumed by industries, and plus final demand. The outputs of an industry consumed by other industries and by itself are called intermediate consumption. Total input is the sum of inputs supplied by industries and value-added inputs. The inputs of an industry purchased from other industries and from itself are called intermediate inputs. The value-added inputs are primary factors of production used for production and include wages and salaries, profit, interest, depreciation, rent, and indirect taxes. Theoretically, the total value of input in an economy equals the total value of output. This is the fundamental principle of an input-output model. Based on this equilibrium condition, "fixed coefficients" are developed that represent the proportion of commodities being produced and consumed by each industries. These coefficients are then used to derive input-output model to do economic impact analysis (Miller and Blair 2009; GOA 2015). This concept is provided in detail below.

2.3.2 Conceptual Foundation of Input-Output Analysis

An input-output model is constructed from observed data for a given geographical unit that could be a nation, province, region, etc. The prerequisite data are the flow of commodities from each of the supplying sectors to each of the purchasing sectors. The flow of commodities is measured in terms of money for a particular period, usually a year (Miller and Blair 2009).

Assume that an economy can be categorized into *n* sectors. Then, the flow of commodities in the economy can be expressed by the set of linear equations (Miller and Blair 2009, 12):

$$\begin{aligned} x_1 &= z_{11} + \cdots z_{1j} + \cdots z_{1n} + f_1 \\ &. \\ &. \\ x_i &= z_{i1} + \cdots z_{ij} + \cdots z_{in} + f_i \\ &. \\ &. \\ x_n &= z_{n1} + \cdots z_{nj} + \cdots z_{nn} + f_n \end{aligned} \tag{2.1}$$

where i, j=1,2,3....n, x_i is the total output of sector i, z_{ij} represents interindustry sales by sector i to all sectors j, and f denotes the final demand for commodity of sector i.

Equation (2.1) describes the total output of each supplying sector as the sum of output sold to the other purchasing industries and output sold to final demand. For example, the total output of the first industry (x_1) equals the sum of output consumed by itself (z_{11}), output sold to the second industry (z_{12}),..., and output sold to the n^{th} industry (z_{1n}), and also output sold to final demanders (f_1). The equation corresponds with the concept of input-output table given in Table 2-3 above. That is, from the row point of view, the equation represents each sector's output as the sum of intermediate sales and sales to final demand. From the column point of view, it represents each sector's inputs as sum of intermediate inputs and value-added inputs.

The fundamental assumption made in input-output model pertains to the relation between the interindustry sales of a sector and the total outputs of this sector (Miller and Blair 2009). The relationship is derived as the ratio of the interindustry sales to the total outputs of the sector:

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{2.2}$$

The ratio (a_{ij}) is called the technical input-output coefficient. The technical coefficients for each sector along column *j* represent the inputs required from each of the sectors to produce \$1 output of sector *j*. For example, let z_{ij} be fertilizer input bought by agriculture sector and x_j be the total value of agricultural outputs. Then, the ratio of z_{ij} to x_j represents the value of fertilizer required to produce one dollar of agricultural output. The technical coefficient assumes a constant return to scale. That means output and inputs of a sector increase by the same proportion (Miller and Blair 2009). In equation (2.2), the interindustry sale can be written as the product of technical coefficient and total output (i.e., $a_{ij}\, x_j$). Hence, replacing z_{ij} with $a_{ij}\, x_j$, and bringing all *x* terms to the left side, equation (2.1) can be rewritten as:

$$\begin{aligned}
&x_1 - a_{11}x_1 - \cdots a_{1i}x_i - \cdots - a_{1n}x_n = f_1\\
&.\\
&.\\
&x_i - a_{i1}x_1 - \cdots a_{ij}x_i - \cdots - a_{in}x_n = f_i\\
&.\\
&.\\
&x_n - a_{n1}x_1 - \cdots a_{nj}x_i - \cdots - a_{nn}x_n = f_n
\end{aligned} \tag{2.3}$$

Grouping x_1s in the first equation, x_2s in the second, and so on, yields:

$$\begin{aligned}
&(1 - a_{11})\, x_1 - \cdots - a_{1i}x_i - \cdots - a_{1n}x_n = f_1\\
&.\\
&.\\
&-a_{i1}x_1 - \cdots + (1 - a_{ij})x_i - \cdots - a_{in}x_n = f_i\\
&.\\
&.\\
&-a_{n1}x_1 - \cdots - a_{ni}x_i - \cdots + (1 - a_{nn})x_n = f_n
\end{aligned} \tag{2.4}$$

In the input-output model, the target is to compute outputs x_1, ..., x_n for specified final demands f_1, ..., f_n and for given constant coefficients a_{11},.., a_{nn}. The computation is done mathematically using matrix algebra notation:

$$(I - A)x = f \tag{2.5}$$

where

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}, f = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix} \tag{2.6}$$

and where I is the n x n identity matrix.

With specified final demands and given constant coefficients, the unknown output vector is solved using the inverse of (I-A) matrix:

$$x = (I - A)^{-1} f \tag{2.7}$$

where $(I\text{-}A)^{-1}$ is known as the Leontief inverse or interdependence coefficient or total requirements matrix (Miller and Blair 2009). If the Leontief inverse is labeled by l, the equation summarized in (2.7) can be written in detail as:

$$\begin{aligned} x_1 &= l_{11}f_1 + \cdots l_{1j}f_j + \cdots l_{1n}f_n \\ &. \\ &. \\ x_i &= l_{i1}f_1 + \cdots l_{ij}f_j + \cdots l_{in}f_n \\ &. \\ &. \\ x_n &= l_{n1}f_1 + \cdots l_{nj}f_j + \cdots l_{nn}f_n \end{aligned} \tag{2.8}$$

This equation clearly shows the dependence of industry's total output on the values of each of the final demands. The interdependence coefficients, l_{ij}, indicate the magnitude of the total output required when demand for commodities of another industry or same industry increases or decrease by one dollar (Miller and Blair 2009). Using this equation, the total output effects of any exogenous shock in the final demands can be can be estimated.

The resultant outputs represent both the direct and indirect effects. Direct effects are those first level effects resulting from an increase in demand for an industry's output. The indirect effects are effects created through linkages between industries. As an example, when the demand for agricultural products increases, production of agricultural products increases. The increased agricultural production requires additional inputs such as fertilizer and machinery from manufacturing sector. That means manufacturing sector will increase production of fertilizer and machinery. The increased manufacturing production will, in turn, cause an increasing demand for agricultural products. This circular relationship continues until the inter-industry effect is completely exhausted. Hence, indirect effects for agriculture would be the sum of several rounds of circular effects created on manufacturing sector.

There is also another type of effect called induced income effects. Induced income effects measure the effects of additional consumption from spending the wages generated by the new demand. These effects are created when the household sector that supplies labour inputs is endogenous to the model. When the household sector is endogenous like other producing sectors, then there will be a circular income effect arising from the increased demand (Miller and Blair 2009). The Leontief inverse matrix is designed to capture the direct, indirect, and induced effects generated on an economy. The computation is done with the use computer software.

2.3.3 Basic Assumptions of Input-Output Model

Input-output models are constructed based on several assumptions about the economy and the linkages among industries and commodities. The three major assumptions are: (1) the technical input-output coefficients are constant, (2) the model is not dynamic, and (3) industries do not have a capacity constraint (Miller and Blair 2009). Assuming constant coefficients implies that the relationship between industry inputs and outputs is linear and fixed. This further implies technology is fixed, constant returns to scale exist throughout the economy, and each industry produces output with no substitution possibilities. Hence, the model cannot account for economies or diseconomies scale, and structural changes in the production technologies (Miller and Blair 2009; Trau 2014). The second assumption is that the demand and supply functions are static and they cannot be modified for any price changes. The third assumption implies no displacement of exiting industries as new projects are completed. This might be unrealistic particularly for an economy operating at full level of employment (Miller and Blair 2009; GOA 2015).

2.4 Empirical Literature

2.4.1 Cost-Benefit Analysis Studies

CBA has become a standard economic appraisal technique in empirical analysis. In Canada, the federal government has instituted a policy that CBA must be carried out for all significant regulatory proposals (Treasury Board of Canada Secretariat 2007). Similarly, the European Commission has established CBA as a requirement for appraisal of several regulatory projects (EU-DG RUP 2015). United States and Australia also recommended CBA for regulatory proposals (Treasury Board of Canada Secretariat 2007).

Several academic research works were undertaken in the past using CBA for the appraisal of irrigation projects (Young 2005). In Alberta, most of the CBA studies were undertaken back in the 1970s and 1980s inolving extensive irrigation developments. Many of these studies were undertaken by Marv Anderson & Associates Ltd. The main purpose of the studies was to evaluate the economic feasibility of developing additional water storage capacity to increase water supplies for irrigated agriculture in Oldman River Basin, Little Bow River, and Willow Creek Basin (Anderson 1978; 1986a; 1986b). The studies were undertaken mainly from the provincial point of view. Incremental benefits and incremental costs of the proposed irrigation projects were computed. Net present values were then estimated by assuming a time frame of 50 years and a baseline discount rate of 5%. The costs included in the studies were: dam construction and operating costs, water delivery construction and operating costs, purchase of on-farm irrigation equipment, on-farm production costs, and external costs of irrigation development mainly flooding of agricultural lands. On the other hand, the included benefits were: direct incremental benefits from the expansion of irrigated agriculture (crop production and livestock production), and secondary economic benefits generated by the irrigated agriculture industry. The incremental benefits were measured as the difference between irrigated agriculture and dryland agriculture. The key finding of the studies was that investments in water storage would be economically efficient to the province when including the secondary benefits. However, without considering the secondary benefits, most of the investment alternatives were not economically efficient.

A similar economic CBA was also undertaken by Clifton Associates Ltd (2008) to evaluate the economic viability of an extensive irrigation expansion proposal in Saskatchewan, again from the provincial point of view. The nature of the costs and benefits of this study are similar with the studies undertaken by Anderson (1978; 1986a; 1986b). The only difference was that the benefits in the Clifton Associates Ltd study included benefits created through agricultural food processing and the costs did not include the external costs of flooding. The study assumed a time frame of 40 years for the adoption of the expansion plan. The findings revealed that investments for irrigation expansion projects would be economically viable for the province considering the direct benefits at a 5% discount rate. The study emphasized that inclusion of the secondary benefits of irrigation expansion would significantly increase the economic viability.

However, these economic CBA studies were criticized for improper inclusion of the secondary benefits. There is a strong controversy as to whether or not the secondary benefits of irrigation should be included in CBA. Several economists strongly criticized the inclusion of the secondary economic benefits (e.g., Veeman 1978; Phillips et al 1981; Grady and Muller 1988; Young 2005). Young (2005) argued that "In a properly functioning competitive economy, with fully employed resources, a new investment yields no net benefits beyond its own net income. Any expansion in secondary sectors in one region is offset in the long run by a fall in activity and profits elsewhere." (95).

There are only a few studies undertaken in the past to evaluate financial viability of irrigation expansion from the perspective of producers (e.g., Rescan 2012; Rudenko et al 2015). Rescan (2012) evaluated the financial profitability of replacing old irrigation canals with buried pipelines in some irrigation districts in Saskatchewan. The study compared the incremental benefits (i.e., increased irrigated crop production in excess of dryland crop production) with the investment costs for pipelines. The study estimated the net present values of costs and benefits assuming a time frame of 10 years for implementing the proposed pipeline replacement projects. The estimated net present value was negative at a discount rate of 2%. Similarly, Rudenko et al (2015) analyzed the financial profitability of lining old canals with plastic materials in Uzbekistan (in Asia). The study indicated that the expected annual incremental benefits of canal lining, such as increased crop production, saved maintenance and energy costs would not compensate the annual investment costs for canal lining. The major limitation of these studies is that they did not properly count the benefits that could potentially occur over the life span of the projects. For instance, Rescan (2012) considered the benefits and costs within the implementation period and the study did not consider the potential benefits of pipelines that would accrue beyond the implementation period. Moreover, these studies indicated the need for government subsidization for the investment in canal improvements but they did not provide a detailed economic calculation for the required government subsidy. The CBA in the current study was therefore undertaken to fill the existing research gaps in the financial viability of expanding irrigated crop land in southern Alberta.

2.4.2 Input-Output Analysis Studies

Like CBA, several I-O studies were undertaken in the past in Alberta to assess the economic impacts of irrigation development (McAndrews et al 1967; Russell et al 1984; Kulshreshtha et al 1985; Kulshreshtha et al 1993; Anderson 2002). The ultimate objective of the I-O studies was to determine an appropriate level of irrigation cost-sharing ratio between the provincial government and producers. The first study prepared by McAndrews et al (1967) indicated that the benefits of irrigation accrued 14% to irrigation producers, 41% to the provincial economy (excluding producers), and 45% to the national economy (excluding Alberta). Based on this relative benefit sharing, the first cost-sharing formula was established for the IRP. The provincial government contributed 86% to the IRP fund and producers within the irrigation districts contributed the remaining 14% (McAndrews et al 1967).[6]

The study was then revised by Russell et al (1984). This study estimated that Alberta's irrigated agriculture industry, directly or indirectly, produced around $1.2 billion GDP annually on the national economy in 1981. The study considered the direct, indirect, and induced economic impacts generated by irrigated agriculture industry including crop production,

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[6] The cost-sharing was revised in 1970, where the cost-sharing was changed to 89% from government and 11% from producers (McAndrews et al 1967).

livestock production and agricultural food processing sectors. The study showed the distribution of the benefits of irrigation to be: 15% for producers, 66% for the province, and 19% for other Canadian provinces. Based on this distribution, the study suggested the cost-sharing formula to be 85-15% split between the provincial government and producers (Russell et al 1984).

Recently, Paterson Earth & Water Consulting Ltd (2015) conducted a comprehensive economic impacts assessment of Alberta's irrigated agriculture using I-O analysis. The study indicated that irrigation generated about $3.6 billion to the provincial GDP. According to this study, 10% of the impacts accrued to the producers, and the 90% accrued to the province. The study considered the direct, indirect, and induced economic impacts generated by irrigation related activities such as crop production, livestock production, agricultural food processing, expenditures on irrigation infrastructure rehabilitation and operation, investments in irrigation machineries and equipment, and other non-irrigation activities such as drought mitigation, water use, recreation, hydropower generation and commercial fishing. The study assessed the economic benefits based on the average value for the period of 2000-2011. Unlike the previous studies, this study was limited to the provincial level impacts of irrigation and did not consider the impacts at a national level.

Other studies also assessed the economic impacts of irrigation (e.g., Clifton Associates Ltd 2008; Pacific Northwest Project 2013). Clifton Associates Ltd (2008) assessed the economic impacts of irrigated agriculture in Saskatchewan. The study assessed the direct, indirect and induced economic impacts generated by irrigation activities, such as crop production, livestock production, agricultural food processing, investment and operation of water supply works, and investment in irrigation machineries and equipment. Similarly, Pacific Northwest Project (2013) assessed the economic impacts generated by irrigated agriculture industry in the Western United

States (Pacific Northwest Project 2013). The study assessed the direct, indirect and induced economic impacts generated by irrigated crop production, livestock production, and agricultural food processing.

Chapter 3 Description of the Study Area

This chapter provides a detail information about Alberta's water resources used for irrigation development, the socio-economic importance of irrigation, the irrigation management policies adopted in the past and present, the irrigation infrastructure system that support the irrigated agriculture industry, and the potential for irrigation expansion in southern Alberta. These points provide basic information for the subsequent two chapters that deal with the economic impact assessment of Alberta's irrigation and the cost-benefit analysis of expanding irrigated crop land in southern Alberta.

3.1 Alberta’s Water Resources and Irrigation Development

Alberta holds about 2.2% of the Canada's fresh water supply. Although Alberta has a good supply of water, variations in geography, climate, and hydrologic cycle create spatial and temporal water scarcity (AEP 2010). Also, the availability of water supply and the demand for water varies across different parts of the province. While more than 80% of Alberta’s water supply is concentrated in the northern part of the province, about 80% of the demand is found in the south where fertile agriculture land is located (AEF 2010). Large portions of the southern region of Alberta's fertile land are classified as being semiarid (Ring 2006; AMEC 2009).

As of 2010, about 97% of the volume of licensed water use in Alberta was from surface water and the remaining 3% from groundwater sources (AEP 2014). There are seven major river basins in Alberta namely, Hay, Peace/Slave, Athabasca, Beaver, North Saskatchewan, South Saskatchewan River Basin (SSRB), and Milk (AEP 2010). Figure 3-1 below shows the locations of the seven river basins in Alberta.

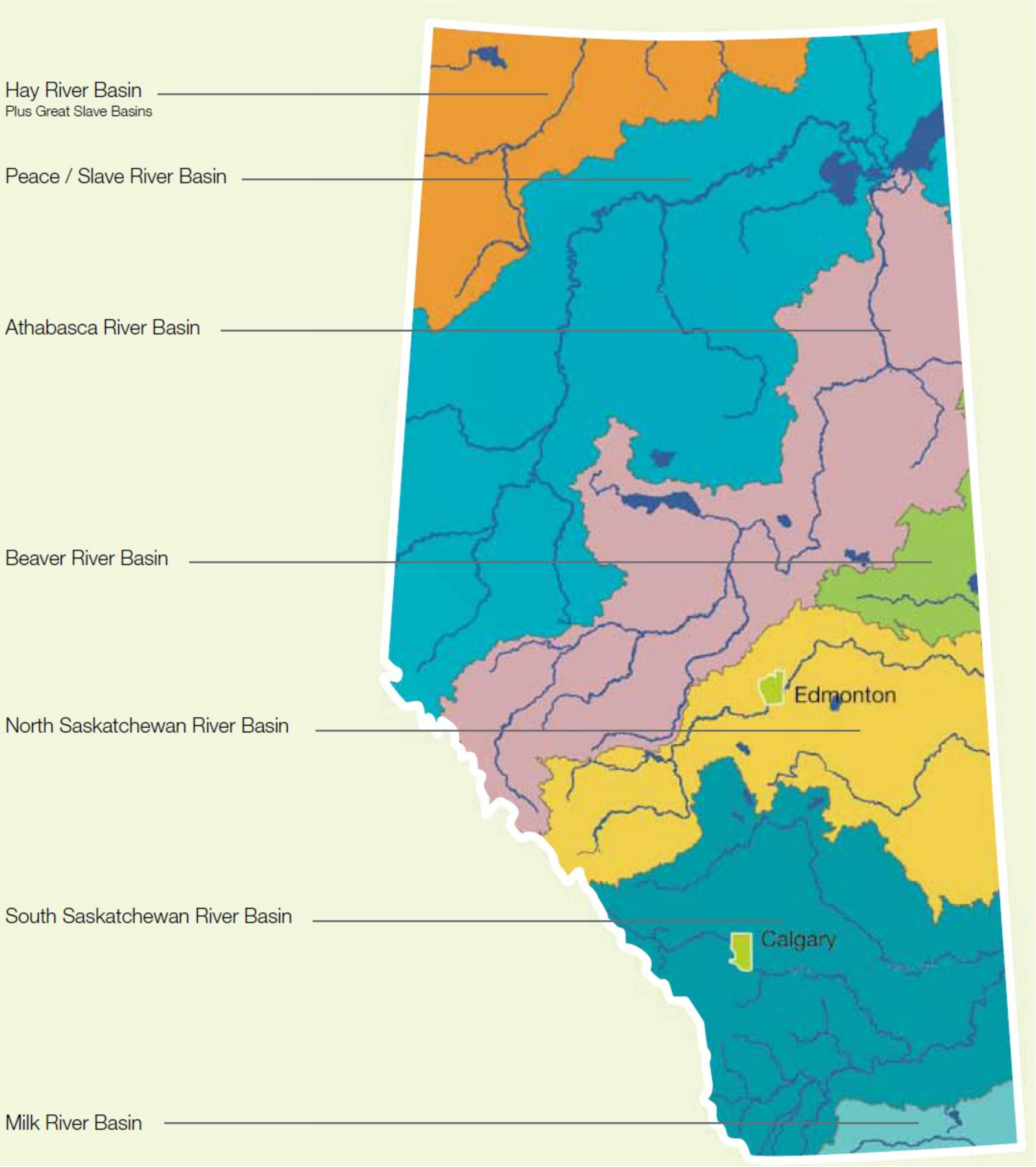

Figure 3-1: Major river basins in Alberta
Source: AEP (2010, 8)

Water in the SSRB is shared equally between Alberta and Saskatchewan based on the 1969 Prairie Provinces Master Agreement on Apportionment (AMEC 2009). From 1970-2006, on average, Alberta passed 81% (2.6 billion m^3) of the apportionable flow to Saskatchewan (AMEC 2009). Water in St. Mary River and Milk River are shared between Canada and the United States based on the 1909 Boundary Waters Treaty (changed to the 1921 Order). According to the 1921 Order, Canada is entitled to the 75% of the natural flow of St. Mary River during irrigation season and when the natural flow in the river is 18.86 m^3/s or less. Otherwise the excess water is to be shared equally between the two countries. A reciprocal agreement was made for the Milk River (AMEC 2009).[7]

In Alberta, the irrigation sector is the largest consumer of water resources, accounting for 43% of the province's total water license allocation from surface sources. Other major consumer sectors include cooling for thermal power generation (24%), municipal drinking uses (11%), and industrial uses (6%) (AEP 2010). In Alberta, the irrigation sector is divided into irrigation districts and private irrigators (AIPA 2013). There are 13 irrigation districts in southern Alberta. Each irrigation district is an organization that owns and manages a water delivery system for a given region. Each district is independently controlled by the irrigation famers (GOA 2000). There are also nearly 3,000 individual privately-licensed projects (AIPA 2013). A private irrigator is an individual famer or farm company that has received a water license from AEP to divert water, mainly for growing crops (AIPA 2013).

The SSRB is the most important water source for irrigation in Alberta (AMEC 2009). The SSRB contains four sub-basins; the Bow River, Red Deer River, Oldman River, and South

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[7] From 1950 to 2004, Canada has received 26% more than its share of the natural flow of the St. Mary River. This was compensated by the United States receiving more than its allotted share from the natural flow of the Milk River (AMEC 2009).

Saskatchewan River (AEP 2010). The SSRB supports about 97% of the irrigated land in Alberta (Bennett et al 2013). New applications for water use are closed in the Bow, Oldman, and South Saskatchewan sub-basins due to increasing pressure for water in the past few decades (AMEC 2014).

In 2014, Alberta's irrigated land was 680,000 hectares (AAF 2014b). The 13 irrigation districts constitute 85% of the total irrigated area while private irrigators cover 15% (AAF 2014b). Figure 2-2 below shows the location of the 13 irrigation districts in Alberta. As the map shows, the irrigation districts are concentrated in the southern Alberta.

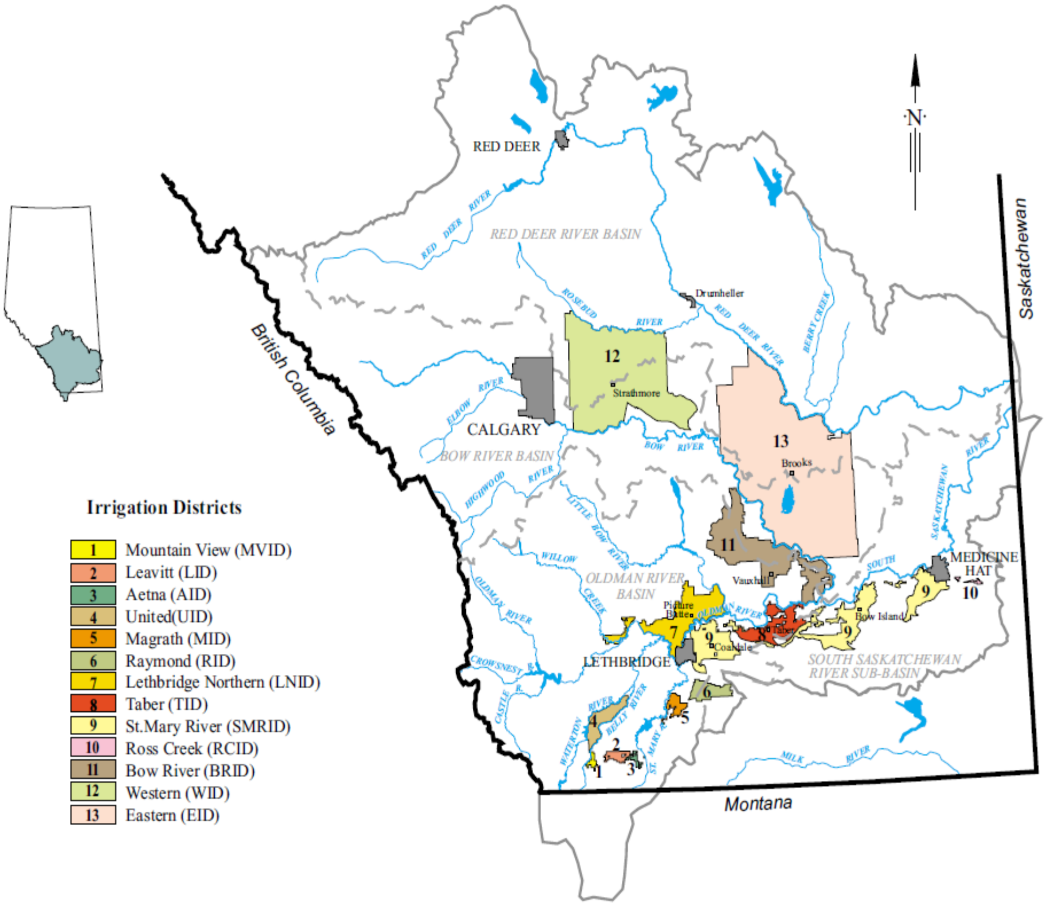

Figure 3-2: Location of the 13 irrigation districts in Alberta
Source: IWMSC (2002, 4)

3.2 Socio-economic Values of Irrigation in Alberta

Irrigation is one of the primary methods for improving agricultural productivity and crop diversification in southern Alberta (AAF 2014a). Over 41 different crops are grown under irrigation in Alberta (AIPA 2013). Figure 3-3 below depicts the proportion of total irrigated area attributable to four major groups of crops (cereals, oil seeds, forages, and specialty[8]) grown in the period 1990-2012 in Alberta.

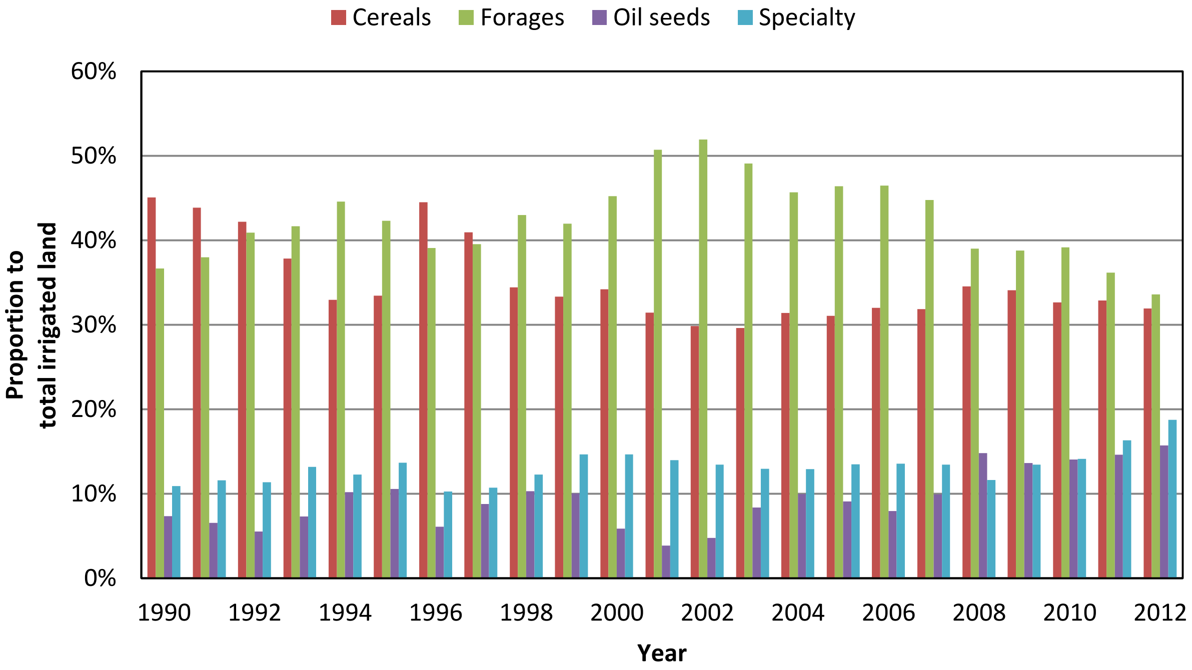

Figure 3-3: Historical cropping pattern within the 13 irrigation districts
Source: AAF (2012a)

As can be seen in Figure 3-3, there has been a shift from cereals and forages into high-value specialty and oilseed crops. The transition in cropping pattern is related to Alberta's agricultural policy strategy that aims to increase value-adding in the agricultural food processing sector (AAF 2014a). Specialty and oilseed crops are processed into high value-products for domestic consumption and export. Forage crops support livestock production and the livestock

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[8] Specialty crops include fruits, vegetables, horticulture, seed production and pulse crops (AAF 2014b).

products are further processed into meat products. The processing industries create high employment opportunities (AAF 2014a).

In addition to crop production, irrigation infrastructure in the irrigation districts provides multiple non-irrigation services, including water supplies for industry, livestock enterprises, municipal uses, wildlife habitat, and recreation facilities (AAF 2013; 2014b). Paterson Earth & Water Consulting Ltd (2015) indicated that in all, irrigation related activities in Alberta contribute 20% ($3.6 billion) of the province's agri-food GDP.

3.3 History of Irrigation Development in Alberta

Irrigation in Alberta has a history that spans more than a century (IWMSC 2002; AAF 2013). The irrigation development and management has gone through four unique phases; private companies (1880s-1920), irrigation districts (1920-50), governments (1950-70), and irrigation rehabilitation program (1970-present) (Ring 2006). Table 3-1 summarizes the four phases and followed by a discussion of the phases in detail.

The development of Alberta's major irrigation system was initiated in 1880s by corporate enterprises, mainly Canadian Pacific Railway (CPR) companies, with the aim of increasing productivity and land values thereby attracting settlers in the area (Thiessen and Smith 1982; IWMSC 2002; Ring 2006). Several irrigation projects were constructed by the CPR in the western and eastern regions of southern Alberta prior to 1920. In this early period, corporately managed irrigation enterprises experienced financial and administrative challenges, such as poor returns of corporate investments, low fee collection of irrigation services, and cumbersome administration of irrigation projects (Thiessen and Smith 1982; Percy 1996; Ring 2006).

Table 3-1: History of Alberta's irrigation development and management

Year	Major irrigation policies
	Phase 1: Private corporate enterprises (1880s-1920s)
1880s	Riparian rights (British common-law)
1894	Northwest Irrigation Act: first-in-time, first-in-right
	Phase 2/3: Irrigation district (1920s-50s) & Government involvement (1950-70)
1914/20	Alberta Irrigation District Act
1931	Water Resource Act: natural resources transferred from federal to province
1948	Prairie Province Water Board
1935	Prairie Farm Rehabiliation Administration (PFRA):
1968	New Irrigation Act: allocated 1/3 of the total surface water for consumptive uses and the remaining for downstream flows.
	Phase 4: Irrigation rehabiliattion program (1970-present)
1969	Cost-sharing program: first cost-sharing ratio (86/14%)
1995/96	The cost-sharing ratio changed to 80/20% and then to 75/25%.
1999	Water Act: conservation, environment and economic growth
2000	Irrigation District Act
2003	Water for Life: Alberta's Strategy for Sustainability
2006	SSRB water management plan: water conservation objectives

To address the problems, a number of adjustments in legislation, administration, and financial management of irrigation projects were undertaken in the period 1920-1950. The province established the Irrigation District Act in 1914. The Act provided a mechanism for farmer owned and operated irrigation organizations. A number of irrigation districts were formed on this basis in the following three decades (Ring 2006). The Act was successful in addressing the administrative problems but not the financial problems. To solve the financial problems government assistance was inevitable (IWMSC 2002).

Following World War II, both the provincial government and federal government started providing financial assistance for the construction of new irrigation projects, and maintenance of the existing projects (IWMSC 2002). The federal government formed the Prairie Farm Rehabilitation Administration (PFRA) and developed different large dams (Ring 2006) until 1970s. In 1969, the irrigation rehabilitation program was established by the government of Alberta (AAF 2004). At that time the government agreed to cover 86% of the costs for irrigation rehabilitation and the remaining 14% to be covered by producers. The cost-sharing arrangement was changed to 80-20% and then to 75-25% in the 1990s (IWMSC 2002). The 75-25% cost-sharing arrangement is still in place.

Irrigation water use in Alberta is authorized under two basic legislative tools: the Water Act 1999 (GOA 1999) and the Irrigation Districts Act 2000 (GOA 2000). The Water Act defines the licensing requirements and allocations to all water users based on the principle of "first-in-time, first-in-right" (GOA 1999). The Irrigation Districts Act defines the water management responsibilities and authorities of irrigation districts and private projects, based on their licenses provided the Water Act (GOA 2000). Alberta's Water Act was adapted considering water legislations experiences of Australia and the United Sates as such it supports and promotes the conservation and management of water (AEP 2010).

In 2003, Alberta established a new water management strategy called, "Water for Life: Alberta's Strategy for Sustainability", to address the increasing pressure of population growth, agricultural and industrial development, and drought on the finite water supply. The strategy has three goals: "safe, secure drinking water supply; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy" (AEP 2003; 2008; 2012).

In 2006, a water management plan for the SSRB was established. The plan set water conservation objectives (WCOs)[9] within the major sub-basins of the SSRB (AMEC 2009). As a result of the WCOs, new applications for water uses in all sub-basins of the SSRB are closed except in Red Deer (AMEC 2009).

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[9] A water conservation objective is defined as the quantity and quality of water in the water body required to protect a natural water body and its aquatic environment; to protect tourism, recreation and other services; support fish and wildlife (AEP 2010).

3.4 Alberta's Irrigation Infrastructure

Alberta has a sophisticated irrigation infrastructure system that diverts, stores and delivers water to the 13 irrigation districts and private irrigation projects in southern Alberta.

The irrigation infrastructure works are divided into three major components: headworks, district works, and on-farm application (AAF 2004). The three components are described below.

3.4.1 Irrigation Headworks

The headworks include structures and facilities that divert, store and convey water to the irrigation districts and other downstream users. These works are owned and operated by the Government of Alberta Ministry of Environment and Parks (AEP). The Water Management Operation team of the Ministry is responsible for managing, operating and maintaining the headworks. The team also partners with the irrigation districts, private contractors and Ministry of Transportation. Supervisory Controls and Data Acquisition System (SCADA) is built in some of the headworks structures to facilitate monitoring. Construction of new projects and rehabilitation of existing projects is undertaken in partnership with the Regional Infrastructure Support's Capital Planning team and the Ministry of Transportation (AEP 2004). The headworks include on-stream reservoirs, off stream reservoirs, weirs, drainage ditches, lake stabilization, flood control, erosion control, major diversions, pump houses, check structures, turnouts, waste ways, and drain inlet works (AAF 2004; AEP 2004; AMEC 2009).

In the southern Alberta region, AEP manages a total of over 45 provincially owned water management infrastructure projects, of which 11 headworks supply water to 11 irrigation districts (excluding Eastern Irrigation District and United Irrigation District, which own their headworks system). The ministry also owns and manages 345 kilometres of inter-connecting main canals that convey water to the start of irrigation districts and other downstream users (AMEC 2009; AAF 2015a).

The estimated replacement cost or the capital value for the total water management headworks is about $8.5 billion and the capital value for irrigation headworks is estimated to be around $5.9 billion (Douglas 2015).[10] Table 3-2 below shows the major irrigation headworks with their replacement capital costs.

Table 3-2: Estimated replacement cost of irrigation headworks system owned and operated by Alberta Environment and Parks (in 2012)

Headworks	**Replacement costs (Million Dollars)**
Women's Coulee	35
Little Bow	14
Waterton - St. Mary	3,335
Carseland Bow River Headworks	1,849
Lethbridge Northern Headworks	464
Mountain View Leavitt	129
Sheerness Canal	48
Deadfish Canal	29
Total Irrigation Cost	**5,900**

Source: Douglas (2015, personal com.)

3.4.2 Irrigation District Works

This section has three parts. The first part describes the irrigation district works and the expenditures made for the improvement of the district works. The second part explains the water-saving advantage of irrigation pipelines. The last part outlines components of irrigation pipelines.

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[10] This was estimated assuming that irrigation headworks capital represents about 70 per cent of the total expenditures of the province's total water management headworks. There is no straightforward estimate for the expenditure made on irrigation headworks system since the total expenditure is allocated to the whole water management (Douglas 2015, personal com.).

3.4.2.1 Irrigation District Works and Expenditures

District works are defined as "works generally within the boundaries of the districts that are required to distribute water to the producers" (AMEC 2009, 17). The 13 irrigation districts own and operate 40 off-stream reservoirs, 7,578 kilometres of conveyance canals and pipelines, 4,738 kilometres of drainage channels and pipelines, and 130 other major structures.[11] These constitute the irrigation district works. As of 2012, 68% of the conveyance works were in good condition, 28% in fair condition and 4% in poor condition.[12] The replacement cost for the total districts works is estimated to be $3.6 billion (AAF 2015a).

Management of the irrigation district works is divided into capital works and operation works. The capital works include construction of new works, replacing the existing old canals by buried pipelines and lining with membrane, and upgrading of major control structures (AIPA 2013). The capital costs for the rehabilitation of irrigation of district works are financed by the 75-25% cost-sharing formula, where the government of Alberta (i.e., the Ministry of Alberta Agriculture and Forestry) covers 75% of the costs and producers cover the remaining 25%. The O & M costs include maintenance of irrigation works, water delivery, and administration costs (EID 2013; WID 2013). [13] The O & M costs for irrigation district works are fully covered by producers. A flat rate irrigation water fee is charged annually, based on the irrigated acres. The collected fee is spent on the rehabilitation and O & M of irrigation district works (AAF 2015a).

Hohm (2016) provided the annual rehabilitation expenditures paid by the government and the producers in the 75-25% cost sharing arrangement as well as the annual maintenance costs

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[11] These include outlet gates and turnouts, pump stations, major drop and control structures, SCADA, etc.

[12] The assessment of the condition of irrigation district works was determined based on criteria in the Irrigation Works Condition Evaluation Guidelines. The valuation is updated every five years, with the last valuation being done in 2012 (AAF 2015a).

[13] Maintenance works include canal cleaning, bank levelling and seeding; gravel armour placing on canal side-slopes and on canal banks; canal fencing; chemical weed control on canal banks; mowing of canal banks; installing canal lining and others (EID 2013).

paid by the producers in the period of 2008-20013 (Personal com.).[14] The expenditures are provided in Table 3-3 below. The average annual expenditure paid by the government and the producers was $85 million.[15]

Table 3-3: Expenditures on the rehabilitation and maintenance of irrigation district works in the 13 irrigation districts (Nominal Dollars), 2008-2013

Irrigation Districts	Irrigation rehabilitation program expenditure and district maintenance expenditure (Million Dollars)						
	2008	2009	2010	2011	2012	2013	Average
Aetna	0.7	1.3	0.1	0.1	0.1	0.1	0.4
Bow River	6.6	8.9	47.9	7.9	10.7	6.4	14.7
Eastern	14.3	24.8	21.0	34.9	32.9	27.8	26.0
Leavitt	0.2	0.2	0.1	0.2	0.2	0.1	0.2
Lethbridge Northern	11.1	6.8	5.5	8.6	10.5	8.8	8.5
Magrath	0.6	0.7	0.6	0.6	0.7	0.5	0.6
Mountain View	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ross Creek	1.1	1.1	0.9	0.9	1.1	0.7	1.0
Raymond	0.2	0.2	0.2	0.2	0.2	0.2	0.2
St. Mary River	13.8	16.5	16.9	16.1	18.4	13.6	15.9
Taber	2.1	2.5	2.3	2.7	2.4	2.1	2.3
United	1.0	1.2	0.9	0.9	0.9	0.8	1.0
Western	14.9	17.3	14.5	17.0	16.6	18.0	16.4
Total	63.8	74.2	110.7	89.3	94.1	78.0	85.0

Source: Adapted from Hohm (2016)

3.4.2.2 Water Saving Potential of Irrigation Pipelines

The irrigation rehabilitation program played an important role in modernizing and upgrading irrigation water distributing canals in Alberta. From 2000 to 2014, on average, 100 kilometres of canals were replaced with pipeline annually (AAF 2014c). Currently, about 60% of the total open canals (7,600 kilometres) are rehabilitated, where 50% are replaced with pipelines

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[14] The costs for other operational activities were not available for all irrigation districts.

[15] The expenditure was for the purchase of goods and services such as materials and supplies, engineering and construction contracts, land acquisition, right of way, labour, equipment pool, consulting services, and other associated services (AAF 2014c).

and 10% are lined with membrane[16]. Figure 3-4 below depicts the percentage of rehabilitated canals in the period of 1980-2014.

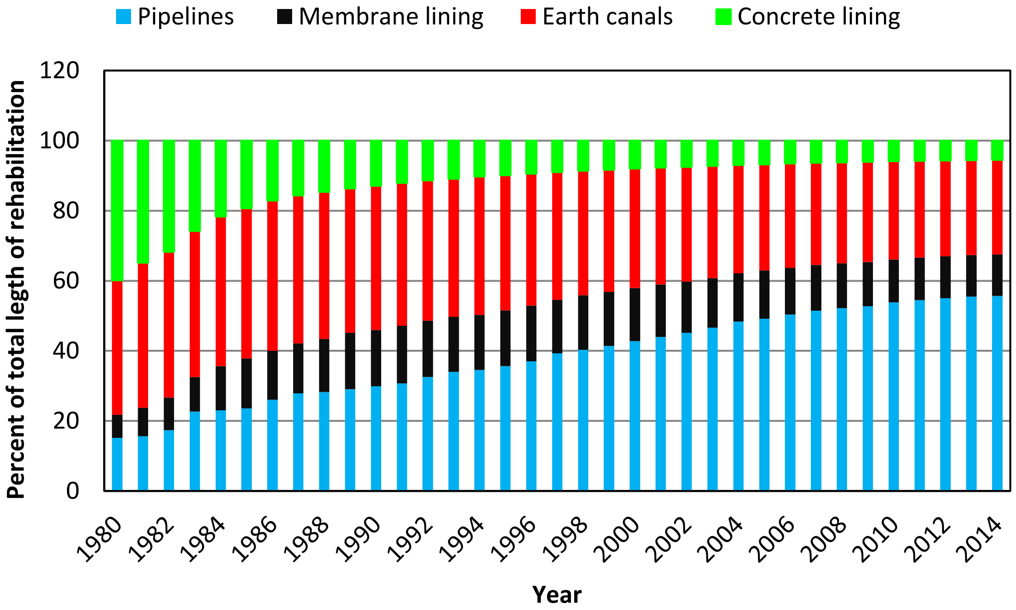

Figure 3-4: Irrigation rehabilitation methods in Alberta (cumulative rehabilitation since 1980)
Source: AAF (2014c)

The remaining un-rehabilitated canals are expected to be replaced with pipelines in the future. The government of Alberta has set a strategy to replace all technically feasible open canals with pipelines by 2035. The ultimate goal of pipeline replacement is to conserve water for irrigation expansion (AAF 2014a).

Buried pipeline replacement is the preferred rehabilitation approach in southern Alberta. It offers several benefits against open canals. The major benefit is water-saving by reducing evaporation losses, seepage losses, and operational spills. The other benefits are eliminating water logging and water salinity, decreasing maintenance costs, allowing flexibility of water delivery, eliminating weed problems, reducing land disturbances, allowing irrigation on steep

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[16] Membrane lining involves coating the open canals with a membrane material to prevent water seepage (AAF 2014b).

slope farmland and bringing more land under irrigation (Ring 2006; AIPA 2014; AAF 2014a). Studies indicated that the water losses in unlined canals to be up to 40% while in pipelines the loss is almost zero (Phocaides 2000).

Bennett et al (2015) estimated the amount of water saved from conveyance loss (return flow, seepage, evaporation) as a result of rehabilitation of the conveyances of the 13 irrigation districts from 1999 to 2012. The study found that the rehabilitation resulted in annual water savings of 50 million cubic meters by reducing the volume of water demanded from 1.84 billion cubic meters in 1999 to 1.7 billion cubic meters in 2012. The water savings are attributed mainly to pipeline replacement. Other studies also indicated that replacing open canals by pipelines or lining with other materials could save a significant amount of water (e.g., Knudson 2010; Jadhav et al 2014; Rudenko et al 2015).

3.4.2.3 Components of Pipeline

This section provides supporting information about the components of pipeline.
A typical pipeline replacement involves a network of installment of four components that are properly designed and installed to convey water from the water sources and distribute to the farm turnouts. These four components are head control, main and submain pipelines, hydrants, and feeder pipelines. These components replace the counter components of open canals; that is, the main gate, the main and submain canals, the canal gate, and the field ditches (Phocaides 2000).

Head control is equipped with several devices, which ensure that the water reaches the desired destination, at the proper time, and in the required flow rate. The major devices include flow controlling valves (e.g., shut-off values, check values, and regulating valves), water measuring devices (e.g., meters and gauges), filtering devices that avoid blockage problem of weeds, and other automation equipment. Main pipelines replace the function of open main canals that convey water from reservoir to the distribution pipelines (submain or branch pipelines). Submain pipelines distribute water to feeder pipelines. Off take hydrants are installed in the main or submain pipelines and they are equipped with shut-off valves to control water delivery to the feeders. Feeder pipelines deliver water to various farm plots (Phocaides 2000).

The pipes are the basic component of pipeline. In Alberta, the pipelines are constructed using Polyvinyl Chloride (PVC) pipes. Nearly all of the pipeline projects in the 13 irrigation districts are gravity system. There are only five pipelines projects that operate using pumped pressure, and these projects represent only 3-4% of the total irrigated land (Hohm 2016, personal com.).

The capital works of pipeline installment include the design and field engineering besides installing the above four component parts. The capital works of pipeline projects are undertaken during fall, winter, and early spring, when there is no irrigation activity. The maintenance works include inspection, clearing, replacement and repair of the pipes, water flow controlling valves and devices, filters, electric engines, pumps, etc. Maintenance of the pipelines and related equipment is carried out in early spring to prepare the system for use in the next irrigation season and in the fall to prepare the system for the off-season shut down (AAF 2014c).

In Alberta, the life of pipelines is expected to be in a range of 60-100 years. This is based on past experience from pipelines built in the town to deliver water for drinking purposes. The first pipelines were built in the irrigation districts in the 1970s and are now around 40 years old. These pipelines are still being used without any serious problem (Hohm 2016, personal com.). The generic life span for a typical PVC pipeline is estimated to be 50 years (Phocaides 2000).

3.4.3 On-farm Irrigation System

On-farm irrigation application is the third component of the irrigation infrastructure system. Producers cover the capital costs for purchase of sprinkler systems, machinery and other equipment, and operation costs associated with on-farm improvements. The replacement capital value of all the on-farm irrigation systems within the 13 irrigation districts is estimated to be \$3.0 billion (AIPA 2013). From 1999 to 2012, producers in the irrigation districts invested about \$375 million for improvements in on-farm irrigation systems, mainly for the purchase of low pressure pivot systems (AAF 2014a). What follows discusses the advantages and disadvantages of different on-farm irrigation systems; and highlights the historical trend of irrigation systems and associated change in water-use efficiency within in the 13 irrigation districts.

3.4.3.1 Advantages and Disadvantages of Different On-farm Irrigation Systems

In southern Alberta, there are four major types of on-farm irrigation systems; surface irrigation, wheel move sprinkler, high pressure center-pivot sprinkler, and low pressure center-pivot sprinkler. The choice of the right irrigation system for a certain producer depends on topography, soil, types of crops being grown, and the availability of capital and labour (AAF 2015a).

Surface or flood irrigation systems use gravity to deliver water from the canals to the field. This system works well only on leveled land. Surface irrigation systems can be developed or undeveloped. Developed surface irrigation involves land leveling and construction of furrows to facilitate water flow to the field. Undeveloped surface irrigation does not require any land modification (AAF 2015b). Surface irrigation system was the most dominant system in southern Alberta before the introduction of sprinkler system in 1970s. It is now the least preferred method because of its several limitations (AAF 2015b). The major limitations include low water application efficiency, high labour intensity, environmental problems (soil erosion, water logging, loss of crop nutrients, salinity, etc), and the lack of effectiveness in irrigating unlevelled land. However, surface irrigation is less expensive than sprinkler systems and it is ideal on smaller farms (AAF 2014a).

Sprinkler irrigation was introduced to address the limitations of surface irrigation systems. Sprinkler irrigation systems use pumps to deliver water to the crops. Wheel move sprinkler systems operate by moving the wheel mounted lateral pipes. In a center-pivot sprinkler system, the lateral pipes and sprinklers rotate in a circular or pivotal fashion. The most common center-pivot in southern Alberta is a quarter-mile (or 400 meter) sized pivot system. This system can irrigate approximately 53 hectares of a square of quarter sections (AAF 2015b). There are two types of center-pivot systems: low pressure and high pressure. Low pressure pivot applies a pressure less than 30 pounds per square inches (psi), whereas, high pressure pivot applies a pressure greater than 50 psi. Low pressure pivot is relatively less expensive, and more water-use efficient and energy efficient than high pressure pivot. Farmers in southern Alberta prefer low pressure pivot and the use of use high pressure pivot is being phased out (GOA 2011; AAF 2015b).

The advantages and disadvantages of low pressure pivots can be seen by comparing the capital costs, variable costs and application efficiency with the other systems. This is shown in Table 3-4. Irrigation water application efficiency measures the ratio of the irrigation water needed by the crop to the water delivered to the field. In other words, it relates the actual storage of water in the root zone to meet the crop water needs in relation to the water applied to the field (Howell 2003).

Table 3-4: Capital costs, variable costs, and application efficiencies for different on-farm irrigation systems in southern Alberta (costs are in 2011)

Methods	Capital cost ($\$ha^{-1}$)	Variable cost Labour	 R & M ($\$ mm^{-1} ha^{-1}$)	 Energy	Application efficiency[a] (%)
Surface–undeveloped	370	0.138	0.007	0.000	30
Surface – developed	1,190	0.109	0.025	0.000	62
Sprinkler– wheel move	1,630	0.091	0.072	0.279	70
Sprinkler– high pressure pivot	2,070	0.03	0.131	0.235	73
Sprinkler– low pressure pivot	2,010	0.03	0.133	0.180	84

a-Irrigation water application efficiency measures the ratio of the irrigation water needed by the crop to the water delivered to the field (Howell 2003).
Source: Bennett et al (2013)

As can be seen in Table 3-4, the major advantages of low pressure pivot are reduced labour cost and improved water-use efficiency. It also offers other advantages such as ability to irrigate unleveled land, easy to apply agro-chemicals, and uniform water distribution (AAF 2014a). However, high capital and variable costs (relative to surface irrigation) are the major disadvantages.

Installing a pivot system in the field involves placing several components that include water supply pipeline, pivot tower, control panel, pumping system, pivot, pivot span, trusses to support the span, and tower drive wheels (Scherer 2013). Figure 3-5 depicts the structure of a typical pivot system in southern Alberta.

Farmers irrigating crops using remote/mobile application with low pressure pivots in Lethbridge Northern Irrigation District

Figure 3-5: A typical low pressure pivot system in southern Alberta
Source: Author (August 2015)

3.4.3.2 Water Savings Potential of Low Pressure Pivot System

Low pressure pivot systems have received attention for conserving water in southern Alberta. The historical relationship between improvements in on-farm irrigation systems and water-use efficiency in the 13 irrigation districts can be seen for the period of 1999-2014 in Figure 3-6 & 3-7 below.

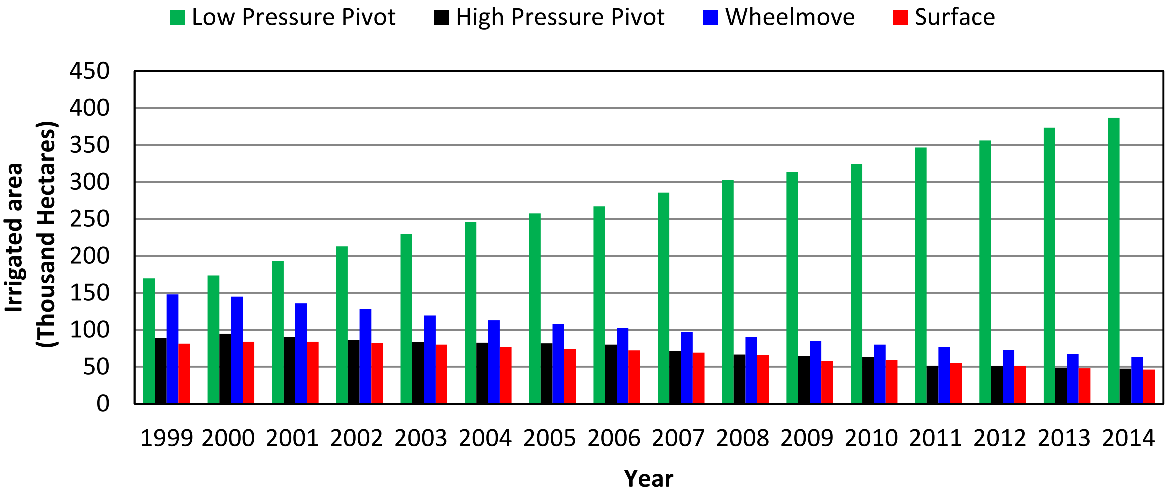

Figure 3-6: Area for alternative on-farm irrigation methods in the 13 Alberta irrigation districts, 1999-2014

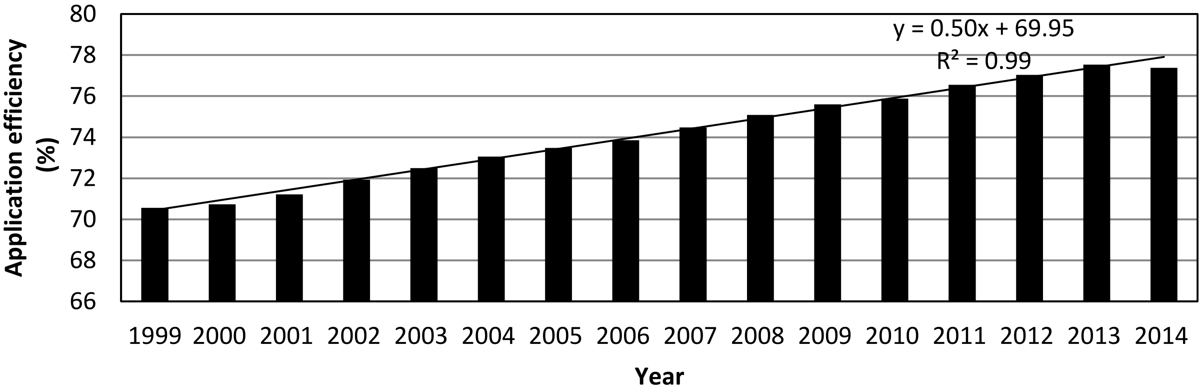

Figure 3-7: Area-weighted average on-farm application efficiency in the 13 Alberta irrigation districts, 1999-2014
Source: Adapted from AAF (2015a) and GOA (2011)

Low pressure pivot systems, introduced in 1990s, are now the most dominant irrigation method, accounting for about 70% of the total irrigated land (Figure 3-6). As a result of the transformation from low water-use efficient, surface irrigation system to highly efficient, low pressure pivot system, the average on-farm application efficiency has improved from 71% in 1999 to 77% in 2014 (Figure 3-7). This is significantly higher than the world average irrigation efficiency, which is 43% (AAF 2014a).

The improvement in water-use efficiency has resulted in a significant reduction in on-farm water demand. Bennett et al (2015) estimated the amount of water-saved as a result of the improvement of on-farm irrigation methods in the 13 irrigation districts from 1999 to 2012. The study revealed that the improvement resulted in an annual water savings ranging from170 to 200 million cubic meters, even with a 30,300 hectare increase in irrigated area.

3.5 Irrigation Expansion

This section provides information regarding the potential for future irrigation expansion in southern Alberta. A summary of the arguments for the need for expanding irrigated land, means for expansion, expert opinion on future expansion, historical relationship between water-use efficiency and expansion of irrigated land are provided below.

As noted in Section 3.2, irrigation makes a significant contribution to the Alberta's agri-food GDP. The role of irrigation is expected to be even higher in the future in order to meet the continuously increasing demand for food and fiber products (AMEC 2009; 2014). To meet the growing demand, the government of Alberta has set a strategy to improve water conservation in the irrigation sector and increase irrigated land in the future (AMEC 2009; McMullin 2012).

A critical question raised in irrigation expansion is where the land and the water come from? There are three ways of increasing the irrigated lands, namely intensification, extensification and expansion. Intensification "fills-in" the existing parcels mainly by switching from surface irrigation system which is limited to leveled land into low pressure pivot system that can irrigate unlevelled land. Extensification involves extending water delivery service to new non-irrigated parcels. Extensification occurs within the boundary of the irrigation districts by constructing new water delivery pipelines or replacing the existing open ditches that have a limited water delivery capacity with pipelines. Expansion expands the irrigated land outside of the districts' boundary by constructing additional major water conveyances as well as headwork system (AMEC 2009).

Hohm (2016) explained that when an irrigation district applies to use a government grant of IRP in southern Alberta, one of the questions that they are asked is "when you are designing this pipeline are you taking into account potential expansion of acres that could be served of the pipeline?". The irrigation council will not allow a district to build pipeline unless they take into account any potential expansion in acres that will be covered by the designed pipeline. Most of the pipelines that are being installed are being installed for a higher capacity than they are being currently used. In other words, the pipelines are built now in a higher capacity in anticipation of future irrigation expansion. The reason for this is that the Alberta government believes that the irrigation districts will continue to ask to expand. In a lot of cases, pipelines are oversized on purpose to meet those expansion acres and reduce friction losses (Hohm 2016, personal com.).

Hohm (2016) also indicated that when farmers ask for irrigation expansion, they are subject to a number of factors and must pass a plebiscite vote. Farmers are required to answer several questions to ensure that there will not be any risk to water users as a result of irrigation expansion. The major questions include: “How many acres are irrigated today?” “How much water is saved using rehabilitation or other on-farm improvements?” and “How much is crops water requirements?”

The historical relationship between the diverted water and irrigated land in the 13 irrigation districts is shown in Figure 3-8. Gross diversion refers to "all water diverted into the works of an irrigation district from a water source" (AAF 2015b, 28). It includes water used for irrigation purposes and water supplied for other uses such as municipal, domestic, other agricultural, industrial, and environmental uses (AAF 2015b).

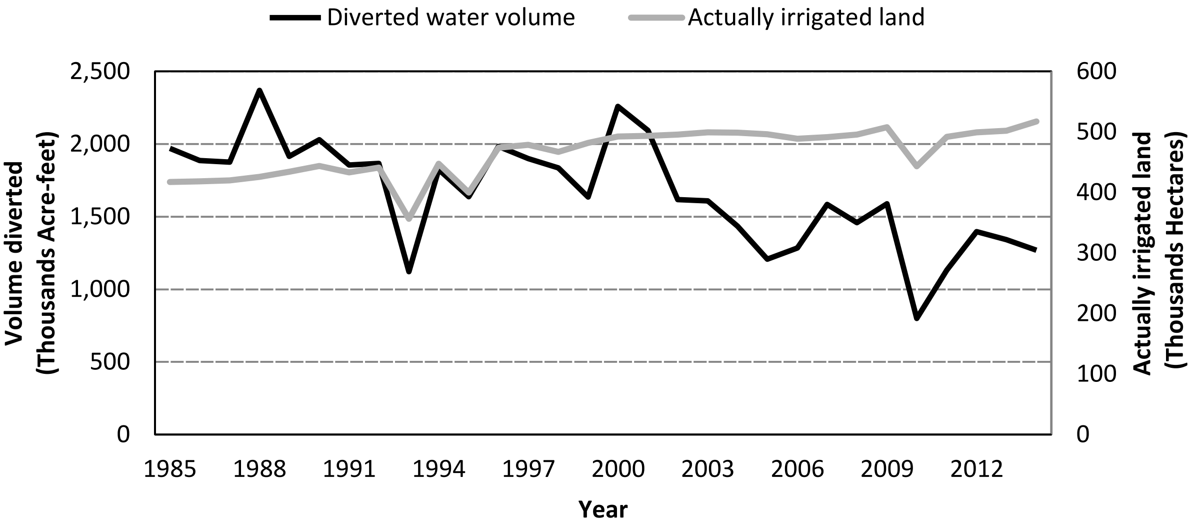

Figure 3-8: Annual gross diversion of water and actual irrigated land within the 13 irrigation districts in southern Alberta, 1985-2014
Gross diversion is defined as all water diverted into the works of an irrigation district from a water source for different purposes that include irrigation, municipal, domestic, other agricultural, industrial, and environmental uses.
Source: Adapted from AAF (2015a)

As shown in Figure 3-8, the annual water diversion has generally declined over time while the irrigated land has increased. In particular, in the period of 2000-2014 the diverted water has been significantly reduced. As of 2014, the annual diverted water was around 1.5 million of acre-feet, which is almost half the allocation license[17] (2.797 million acre-feet) (AAF 2015b). The increased irrigated land over the past few decades was the result of water savings through replacing open canals with pipelines and switching to highly water-efficient, low pressure pivots (AMEC 2009; AECOM 2009; AIPA 2013). From 2000 to 2014, on average, the assessed irrigable land covered by irrigation systems has increased by 3,623 hectares (or 0.7%) annually (see Figure 3-9 below).[18]

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[17] Water license allocation refers to "the total volume of water that an irrigation district is licensed to divert annually" (AAF 2015b, 30).

[18] There was unusual case in 2009/10. Hohm (2016) indicated that the reason for this was that one of the districts over-reported the assessed land than it was allowed to irrigate.

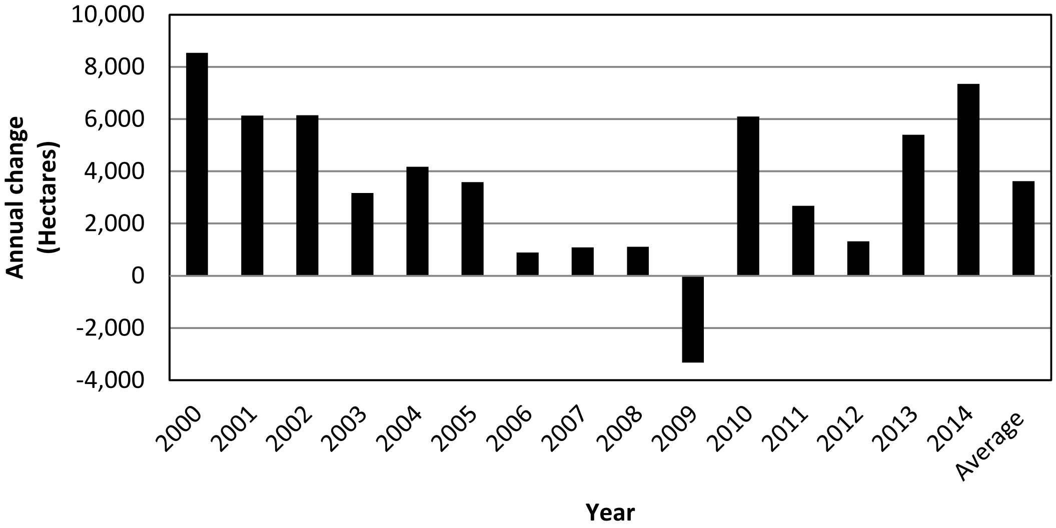

Figure 3-9: Annual changes in lands covered by irrigation systems within the 13 irrigation districts in southern Alberta
Source: Adapted from AAF (2015a)

Chapter 4 Economic Impact Assessment of Irrigated Agriculture

This chapter provides an explanation of the methods used to undertake the economic impact assessment. The analysis involves using economic multipliers based on input-output analysis. The chapter is composed of seven sections. The first two sections explain the concept of multipliers and their derivation from an input-output model, and the application of multipliers for impact analysis. The third section presents the framework of the economic impacts of the irrigation activities considered in the current study. The remaining four sections present how the economic impacts of crop production, livestock production, food processing, and irrigation infrastructure rehabilitation can be estimated using input-output multipliers.

4.1 Economic Multipliers

Input-output multipliers are derived from an input-output model and used for economic impact analysis (GOA 2015). Hence, the same assumptions and limitations made for the input-output model (Section 2.3) also apply for the multipliers. The concept of multipliers is based on the difference between the initial or direct effect of an industry and the total economy-wide effects including direct, indirect, and induced effects created by the direct effect. In other words, multipliers provide a measure of the interdependence of an industry and the rest of an economy (GOA 2015). There are several types of input-output multipliers. The most commonly used ones are the output multiplier, value-added or GDP multiplier, and household income multiplier (Miller and Blair 2009). These multipliers are described below.

An output multiplier for a sector in a given economy is defined as "the total value of production in all sectors of the economy that is necessary in order to satisfy a dollar's worth of final demand" for that sector's output (Miller and Blair 2009, 245). In short, output multiplier is the ratio of the total output effects to the initial output effect. For example, if an industry directly increases its output by $2 million and if this results in a total increase of $3.6 million outputs on the overall economy, then industry's total output multiplier would be 1.8 (i.e., 3.6 divided by 2). The multiplier figure, 1.8, includes both the initial effect on the industry, and the indirect and induced effects on all other sectors. Specifically, for a $1 increase in output the initial direct effect of that increase is $1 while the remaining 80 cents represents the indirect and induced effects or secondary effects. In an input-output model, output multipliers are derived from elements of the Leontief inverse matrix. The output multiplier for a sector *j,* denoted as $m(o)_j$ is given as the sum of all industries' outputs required to satisfy a one dollar increase in output of sector *j* (Miller and Blair 2009).

In addition to the output effects, the economic impacts of new economic activity can be measured in terms of new value-added created in each sector in response to the initial shock to that sector. This is called value-added multiplier (Miller and Blair 2009). The concept of value-added multiplier is identical with output multiplier except the derivation requires a set of sectorial value-added coefficients instead of technical input-output coefficients. Value-added multipliers are calculated by dividing the total value-added by the initial effect. In value-added multipliers, the initial effect can be expressed either in terms of output effect or value-added effect. When the total value-added effect is divided by the initial output effect, the multiplier is called total value-added multiplier. When the total value-added effect is divided by the initial value-added effect, the multiplier is called Type II value-added multiplier. For example, if an industry directly increases its value-added by $1.5 million and if this results in a total increase of $3.0 million value-added on the overall economy, then the Type II value-added multiplier for the industry would be 2.0 (i.e., 3 divided by 1.5). If the initial increase in the industry’s output was

$3.5 million, then the total value-added multiplier for the industry would be 0.86 (i.e., 3 divided by 3.5). The Type II value-added multiplier is always greater than the total value-added multiplier as the value-added initial effect is less than the output effect.

Another type of multiplier relates the new household income created in each sector in response to the initial shock. This is called the income multiplier. Like the value-added multiplier, the income multiplier can be measured in terms of total income multiplier when the initial effect is expressed in terms of output or Type II income multiplier when the initial effect is expressed in terms of household income (Miller and Blair 2009).

The current study relied on input-output multipliers to assess the economic impacts of irrigation activities in Alberta. There are two main reasons for employing multipliers instead of doing a new input-output model.

First, the ultimate aim of the impact analysis was to assess the total impacts of the irrigation activities on the national GDP and thereby estimate the distribution of benefits among producers, and the province and the nation. With a proper estimation of the direct effects generated by the specified activities and a proper application of the multipliers, the economic impacts of irrigation activities can be estimated without necessarily getting into the detail of the input-output model. Previous studies used multipliers to assess the economic impacts of irrigation related activities. For instance, Serecon (2014) assessed the economic impacts of the agriculture sector in Lethbridge county using input-out multipliers from Alberta Treasury Board and Finance. Anderson (2002) assessed the economic impacts of Alberta's irrigated agriculture industry using multipliers from the same source. Similarly, in the United Sates, some studies assessed the economic impacts of irrigated agriculture using input-output multipliers (Guerrero et al 2010; Pacific Northwest Project 2013).

Second, recall equation (2.8), constructing an input-output model from observed data requires a number of data, such as national and provincial input-output tables, and the input requirements or technical coefficients for each activity. To construct an input-output model for irrigation activities, the analyst would require costs and returns for different crop types (cereals, oil seeds, specialty and forages), different livestock enterprises (cattle and calves, dairy, hogs, sheep and lambs, chickens, etc.) and for different food processing industries (meat processing, gain milling, animal food processing, fruit and vegetable processing, etc.). In addition, if the analyst would like to incorporate the interprovincial trade effects into the input-output model, the trade flow tables for all the provinces and for all sectors of the economy would be needed. Hence, the accuracy of the outcomes of the input-output model is contingent upon the availability of all the data. Unfortunately, all of the data were not readily available especially for livestock and food processing sectors for the irrigated farms in Alberta. A first hand survey and expert opinion is required to gather the required data for these sectors and this was beyond the scope of the current study. New input-output model would be feasible for economic impact analysis of irrigation that require in-depth analysis about the sectoral distribution of the economic impacts of each irrigation activity on several aspects of the economy, such as the government revenues (taxes) generated directly or indirectly by each activity, the jobs created directly or indirectly by each activity, the household incomes generated directly or indirectly by each activity, and so on. Such detailed economic impact analysis of Alberta's irrigated agriculture industry was done by Paterson Earth & Water Consulting Ltd (2015). Yet, the impact analysis was limited to the provincial level.

4.2 Using Multipliers for Impact Analysis

One of the major applications of the information in an input-output model is to assess the economy-wide effects of a given exogenous change to the model (Miller and Blair 2009). There are two types of analysis undertaken using input-output models: impact analysis and forecasting. Impact analysis deals with the economic impacts of a particular economic activity when the economic impacts are caused by the actions of just one "impacting agent" or a small group of agents, and when the changes are expected to happen in short run, usually a year. Examples of questions that could be addressed using impact analysis include “What is the economic impact of investing $1 billion for the expansion oil pipelines in Alberta in next year?” or “What is the economic impact of increasing oil production by $1 billion in Alberta?”. Conversely, forecasting deals with projections of the economic impacts that involve a longer term and broader sectoral changes. For example, the analyst may apply the input-output model to estimate the effect of projected final demand changes for all sectors in an economy over a five year period (Miller and Blair 2009). Impact analysis is of a particular interest in the current study.

Input-output multipliers, derived from an input-output model, are usually employed in the economic analysis. Many advanced countries publish input-output multiplier tables for the impact analysis purposes (Miller and Blair 2009).

In Canada, input-output multiplier tables are issued by Statistics Canada at the national and provincial levels. The multipliers are issued annually. The most recent input-output table was released in 2014 for year 2010 (Statistics Canada 2015b). The multiplier table presents the different types of multipliers described earlier, for all categories of industries classified under the North American Industry Classification System (NAICS). NAICS is a standard industry classification system used in input-output tables to code industries at different levels of aggregation and disaggregation. NAICS was collaboratively developed by the United States, Canada, and Mexico in order to was harmonize business activity classification systems within the three countries (Statistics Canada 2012).

The multipliers in Canada are derived from an interprovincial input-output model. The interprovincial model is constructed by considering the interprovincial trade as an endogenous factor to the model. By doing so, the model captures the feedbacks generated by the economic transactions that cross provincial boundaries (Ghanem 2010). The concept of interprovincial circular relationship is similar to the interindustry circular relationship demonstrated for indirect effects in Section 2.3.2. For example, an increase in demand for agricultural products from Alberta may increase the imports of machinery from other provinces, such as Ontario or Saskatchewan. The increased imports of machinery may, in turn, lead Ontario and Saskatchewan to increase their demand for steel from Alberta. This circular interprovincial trade effect is realized in the interprovincial input-output model. Hence, the multipliers for each province measure both the domestic provincial effects and the trade effects generated on the other provinces.

In addition to the multipliers provided by Statistics Canada, the Alberta Treasury Board and Finance publishes provincial input-output multipliers using input-output data from Statistics Canada. However, unlike the Statistics Canada, the multipliers measure only the provincial effects (GOA 2015).

The economic impact of a particular economic activity that has a direct impact on sector *j* is determined by multiplying the multiplier effect of sector *j* by the projected direct impacts. For example, if there was a $1 million increase in the output of the "crop and animal production" sector in Alberta in 2011, the total impacts on the provincial output, GDP, and household income can be estimated using multipliers. The first step of the exercise is to find the multipliers for output, GDP and household income for crop and animal production industry in Alberta in 2011. The total output multiplier for output is 1.984, the total GDP multiplier is 0.760, and the total income multiplier is 0.277. These multipliers are obtained from Alberta Treasury Board and Finance (GOA 2015). The total impacts for each indicator can then be estimated by multiplying the multipliers by the direct effects as follows:

The impact on output= 1.984*$1,000,000=$1,984,000.

The impact on GDP=0.760*$1,000,000=$760,000.

The impact on household income=0.277*$1,000,000=$277,000.

The accuracy of the economic impacts assessed by multipliers is contingent upon the correctness of the specified direct impacts and the multipliers (Miller and Blair 2009). Temporal variation between the specified direct effect and the given multipliers is a major problem. If there is a time gap and high price variability, then the estimated direct impacts need to be converted to constant price using consumer price index (GOA 2015).

The other concern with the use of multipliers is the similarity between the new activity and the industry to which the activity belongs. Recall that multipliers are obtained from the elements of a Leontief inverse matrix. These elements are constructed using the fixed technical input-output coefficients. In conducting impact analysis through multipliers, it is assumed that the technical input-output coefficients of the specified subsector business activity are equal to the technical coefficients of the major sector to which the new activity belongs. In the current study, the costs and returns or input requirements for livestock production associated with irrigated farms and dryland farms was assumed to be same by following previous studies (e.g., Paterson Earth & Water Consulting Ltd. 2015). As a result, the multiplier for the provincial livestock production sector represents the livestock production for irrigated farms. However, the livestock production per unit area differs between irrigated farms and dryland farms. This difference is accounted for in the direct impacts. By the same token, in estimating the economic impacts of the money spent for the rehabilitation and maintenance of irrigation infrastructure, it was assumed that the multiplier for the provincial "water, sewage, and other systems" industry represents the irrigation rehabilitation activity. According to the 2012 NAICS, irrigation water infrastructure is classified under "water, sewage, and other systems" (Statistics Canada 2015b). The impacts for the same activity were modeled by Paterson Earth & Water Consulting Ltd (2015) by assuming the provincial input-output coefficient for this industry.

However, the economic impacts for irrigated crops may not be accurately reflected by the provincial multipliers for the crop production sector. This is because the costs and returns for irrigated crops differs from that of dryland crops due to higher input requirements, higher yields, higher composition of specialty crops in the irrigated farms than in dryland farms. As a result, the multipliers were modified based on the reality of irrigated crops.

4.3 Framework of Economic Impacts of Irrigation

The current study estimated the economic impacts of four irrigation-related activities on the provincial economy as well as on the national economy, using input-output multipliers. The activities include crop production, livestock production, agricultural food processing, and irrigation infrastructure rehabilitation and maintenance. The economic impacts were assessed in terms of value-added, gross domestic product in 2011 (VA or GDP). VA for a given industry measures the residual value after deducting the intermediate consumption from the gross output or expenditure of that industry. Intermediate consumption is the value paid to the industries that supply intermediate inputs such as intermediate products, raw material, energy, transportation, and other goods and serves. In other words, VA is the value paid for the primary factors employed in the production activity such as wage and salaries, rents accrued to (land, water, and other resources), interest, profits, depreciation, and taxes and subsidies on production (GOA 2015). The reason for choosing a VA measure is twofold. First, the previous studies undertaken in Alberta used the VA measure to derive the irrigation-cost sharing formula so that the results of the current study can be compared directly with them. Second, the provincial VA for the agriculture and food processing sector is readily available so that the calculated values can be validated using the actual provincial figures. The economic impacts created by the four activities are illustrated in Figure 4-1 below.

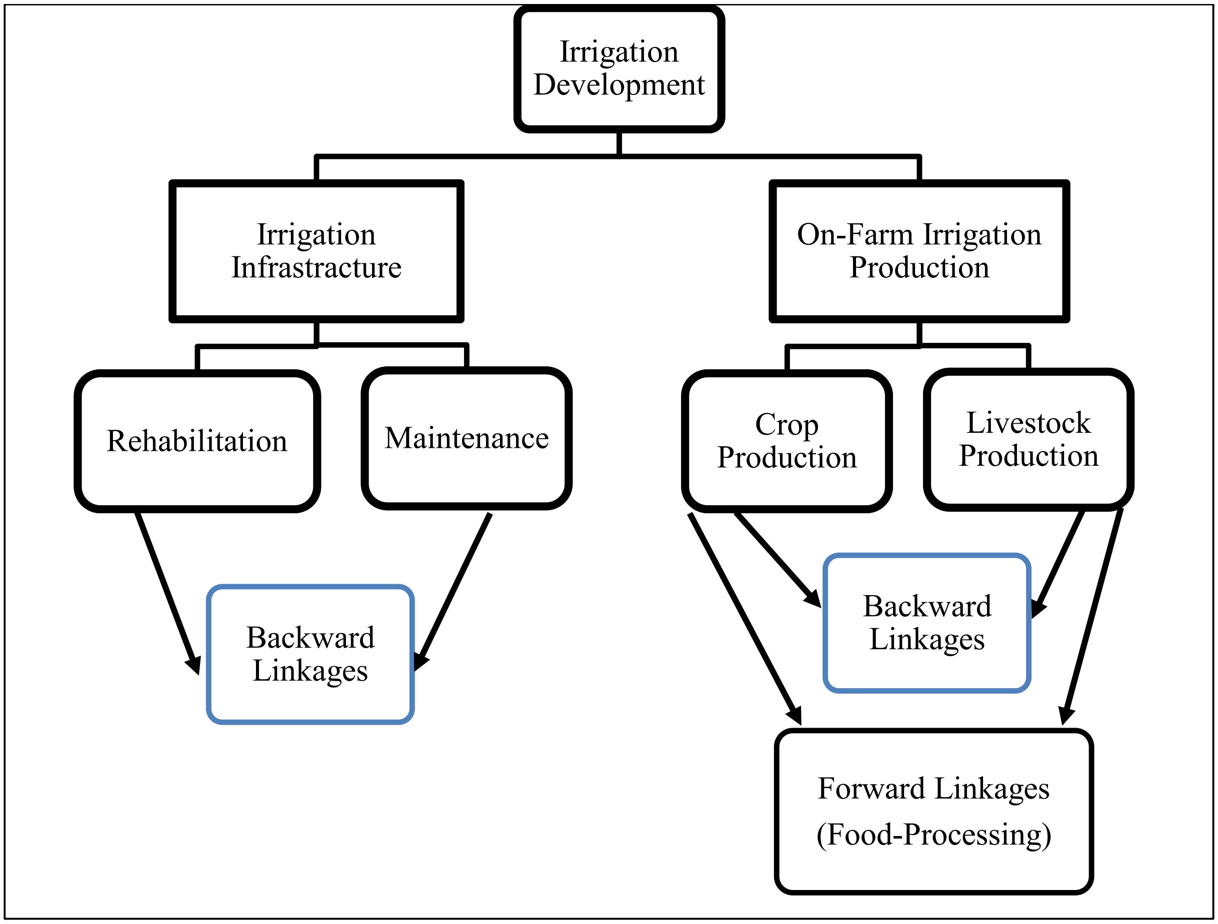

Figure 4-1: Economic impacts of Alberta's irrigated agriculture industry
Source: Adapted from Paterson Earth & Water Consulting Ltd (2015)

As shown in Figure 4-1, the economic impact of irrigation can be categorized into two parts; the impacts created by agricultural production and the impacts created by the investment in infrastructure rehabilitation and maintenance. The impacts of agricultural production include both the direct impacts of crop production and livestock production as well as the indirect and induced effects created through backward linkages. Direct primary production also creates an economic impact through forward linkages (i.e., food processing). The economic impacts of infrastructure rehabilitation and maintenances are created through backward linkages with other sectors. What follows discusses the economic impact assessments for crop production, livestock production, and food processing and irrigation infrastructure rehabilitation and maintenance.

4.4 Crop Production

Irrigated crop production has a significant direct contribution to the primary production sector through the production of high-value specialty crops as well as various other types of crops (Section 3.2). The production of irrigated crops requires intensive inputs such as fertilizer, chemical, electricity, transport, machinery and equipment, labour, etc. Purchasing these inputs creates secondary economic impacts through backward linkages between the crop production sector and other sectors supplying the inputs. The current study assessed both the direct and secondary economic impacts of Alberta's irrigated crops on the provincial GDP as well as on the national GDP, and then compared them with the impacts of Alberta's dryland crops. The assessment involved three steps. First, the direct impacts of crop production for irrigated crops and dryland crops were assessed by developing crop budget models. Second, economic multipliers for irrigated crops and dryland crops were obtained from Statistics Canada. Third, the total impacts (including the secondary impacts) were assessed by applying multipliers on the direct impacts.

4.4.1 Crop Budget Model

Crop budgets were developed for irrigated crops and dryland crops in Alberta for the year 2011.[19] This year was chosen to be consistent with the I-O multipliers. Crop budgets were developed by using data such as crop areas, yields, prices and production costs, collected from secondary sources. The study assessed the direct benefits in terms of value-added based on selected crops for which there are complete data. The assessed value-added for the selected crops was then adjusted for the area of entire irrigated crops and the area of the entire dryland crops. The adjusted value-added estimates for the total irrigated crops and total dryland crops were summed to calculate the provincial value-added for crop production. Finally, the calculated provincial value-added was corrected for the actual provincial value-added for crop production obtained from Canadian Socioeconomic database (CANISM) (Statistics Canada 2016c). This ensured consistency with the actual provincial figure for crop production. The procedures are discussed in detail below.

The budgets were prepared for major crops that had complete information. The irrigated area for the major crops grown within the 13 irrigation districts over the period of 2000-2011 was obtained from AAF (2012a). The total irrigated area for private irrigators was also obtained from AAF (2012a). Since there were no data available for crops types grown by the private irrigators, the privately irrigated area was allocated to major crops by assuming the same cropping pattern as in the irrigation districts. Moreover, there were no data available for dryland crops. To determine the crop area for the dryland region, Alberta's total cropped area for the major crops was obtained from Statistics Canada (2016a). The dryland crop area was then determined as the difference between the total cropped area and cropped area under irrigation.

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[19] The budgets were also prepared for the previous ten years, 2000-2010, to understand the temporal variation of crop costs and returns for irrigated and dryland crops.

Crop yields for the irrigated crops and Alberta's dryland crops were obtained from Agricultural Financial Services Corporation (AFSC 2014). The provincial nominal crop prices were obtained from Statistics Canada (2016a) and AFSC (2015). Costs of production for irrigated crops and dryland crops were obtained from AAF (2015b). Detailed information about the crop budgets and data is provided in Section 5.3.

Based on the above crop budget information for the major crops, value-added was estimated for the irrigated crops and dryland crops by crop group (i.e., cereals, oil seeds, specialty and forage crops). The estimated value-added for each crop group was then extrapolated to the total crop area for the group. In making this adjustment, the selected crops were considered as representative of the remaining crops for which there were not complete data.[20] Then, total VA for the total irrigated crops and total dryland crops was calculated by summing the values for the four crop groups. Finally, the provincial VA was calculated by summing the total VA for the irrigated crops and the total VA for the dryland crops. The calculated provincial VA was compared with the actual provincial VA for crop production obtained from Statistics Canada (2016c). The calculated value was slightly higher than the actual value reported. Hence, the VA for the irrigated crops and dryland crops was corrected by adjusting for the actual value. The corrected VA for the irrigated crops and dryland crops were then used as direct impacts to determine the total VA impacts (including secondary impacts) for irrigated crops and dryland crops, respectively. The reason for correcting the value-added for irrigated crops is to ensure consistency with the value-added effects of the other irrigation activities (i.e., livestock production, food processing, and food processing). As indicated earlier (Section 4.3), the current study estimated the total economic effects (i.e., direct and secondary

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[20] There was a lack of economic data for some miscellaneous crops, especially for some irrigated specialty crops. However, their area was obtained from data sources indicated above.

effects) in terms of value-added. The direct effect that is used to estimate the secondary effect needs to be consistent with the provincial official value published by the Statistics Canada. Since the provincial official value does not differentiate between irrigated and dryland crops, the current study calculated the value-added for irrigated and dryland crops and then corrected the estimates for the provincial value.

4.4.2 Economic Impacts of Crop Production

In March 2015, a request was made to Statistics Canada to derive the multiplier effect for Alberta's irrigated crops and dryland crops, as the existing provincial multiplier for crop production did not distinguish between irrigated and dryland crops. Crop budgets for representative irrigated crops and dryland crops were provided to Statistics Canada. Based on the provided crop budgets, Statistics Canada modeled the multiplier effects for irrigated crops and dryland crops. The I-O model was used, based on the 2011 economic transactions. The estimated GDP (VA) multiplier effects are provided in Table 4-1.

Table 4-1: Gross domestic product multipliers for irrigated crops and dryland crops (2011)

	Irrigated		Dryland	
GDP multipliers	Within Alberta	Within Canada	Within Alberta	Within Canada
Type II multiplier	1.38	1.58	1.52	1.82

Source: Statistics Canada (2015a)

The GDP multiplier effect (Type II) for irrigated crops was estimated to be 1.38 within Alberta and 1.58 within Canada as a whole. This implies that a one dollar increase in the GDP of irrigated crops would generate a total impact of 1.38 dollars on the provincial GDP or a total impact of 1.58 on the national GDP. The GDP multiplier effect for dryland crops was estimated to be 1.52 within Alberta and 1.82 within Canada as a whole. It is noteworthy that irrigated crops have a slightly smaller GDP multiplier effect than dryland crops. This might be because irrigated crops have a relatively higher denominator or direct GDP than dryland crops. As discussed earlier (Section 4.2), the Type II GDP multiplier measures the ratio of total GDP effects to direct GDP effect. The higher the denominator, the lower the ratio will be. The findings of previous studies indicated that irrigated crops with relatively higher net returns have lower Type II GDP multiplier than dryland crops. For instance, Guerrero et al (2010) estimated the Type II GDP multiplier for irrigated crops at 2.82 and for dryland crops at 3.49 for the regional economy of Texas in the United States.

The total economic impacts of Alberta's irrigated crops and dryland crops on the provincial GDP and on the national GDP were then estimated for year 2011. This was done by multiplying the calculated direct GDP impacts by the corresponding GDP multipliers provided in Table 4-1.

4.5 Livestock Production

Irrigated crops supply feed inputs for livestock production. There are several livestock enterprises that depend on the crop production in the southern Alberta irrigated region. Livestock production creates both direct impact, and secondary impact through backward linkages. The current study assessed both direct and secondary impacts of livestock production caused by irrigation farms. The assessment involved three steps, which are described below.

The first step was determining the direct impact of livestock production for irrigated farms. This was done by collecting secondary data. The value of provincial livestock sales was obtained for year 2011 from Statistics Canada (2016b). The sale value was disaggregated into seven enterprises: cattle and calves, dairy, hogs, lambs, poultry, honey and other miscellaneous animal activities. The share of each type of livestock enterprise in the irrigated region was obtained from a previous study (IWMSC 2002).[21] These shares are given in Table 4-2. The shares were used to derive the dollar value of livestock sales for the irrigated farms using the actual provincial livestock sale data obtained from Statistics Canada. The share for each livestock enterprise indicates the proportion of cash receipts produced by the irrigated farms. For example, in Table 4-2 the 18.3% for cattle and calves indicates that irrigated farms accounted for 18.3% of the sale of cattle and calves in Alberta.

Table 4-2: Share of irrigation in Alberta's livestock production (based on cash receipts)

Livestock activity	Share of irrigated farms to provincial total (%)
Cattle and calves	18.3
Dairy	15.0
Hogs	13.7
Sheep and lambs	19.6
Poultry and eggs	9.3
Honey	10.0
Others	16.5

Source: IWMSC (2002)

The second step was to determine the economic multiplier effect for Alberta's livestock production sector from Statistics Canada (2015b). The latest release was in 2010 and so this value was used as a proxy for the 2011 value. According to the 2012 North American Industry Classification System (NAICS), livestock production sector is classified as "Animal production". The total GDP multiplier for this sector was 0.72 within Alberta and 1.04 within Canada as a whole. The total GDP multiplier measures the total impact of a one dollar increase in the output of Alberta’s livestock production on the provincial or national GDP.

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[21] There were no up-to-date data available for livestock production in the irrigated farms in southern Alberta. As a result, the current study used the estimate available from IWMSC (2002). This reference was also used in a recent study by Paterson Earth & Water Consulting Ltd (2015).

The total GDP impact for the livestock production was determined by multiplying the calculated direct livestock sale for the irrigated farms by the multiplier effects. Detailed calculations are provided in Appendix B.

4.6 Food Processing

Agricultural food manufacturing industries process the primary agriculture products, which further adds value to the products. Irrigated primary production creates economic impacts through forward linkages by supplying the raw materials for the processor. Major processing plants in Alberta are associated with the irrigated areas to ensure a stable supply of raw materials for their operation (Paterson Earth & Water Consulting Ltd 2015). Paterson assessed the total economic impacts created by irrigation related food manufacturing industries in southern Alberta. The current study relied on the multiplier effect estimated by Paterson's study. The reason for using this study was because the estimation of the secondary impact of the food processing sector is complicated by the fact that it needs to avoid double-counting the backward-linkage effect of primary production, which is already accounted in the primary production. Paterson Earth & Water Consulting Ltd (2015) assessed the secondary economic impact of food processing by removing both crop production and livestock production sectors. However, the direct GDP impact of food processing estimated by Paterson was higher than the actual provincial figure reported by Statistic of Canada (2016d). Therefore, in the current study, the estimate of Paterson study was scaled down by the difference factor. Detailed calculations are provided in Appendix C.

4.7 Infrastructure Rehabilitation

The government and producers (through irrigation districts) spend millions of dollars every year for the improvement of irrigation infrastructures in Alberta. This expenditure not only induces a direct economic activity on the construction sector in the irrigation region but also contributes to secondary economic activities in other sectors in the provincial and national economies through backward linkages. The total economic impacts of irrigation rehabilitation expenditures were assessed in the current study. The assessment involved three steps.

First, the expenditures made on the rehabilitation and maintenances of irrigation headworks and irrigation district works were obtained from different sources (Section 3.4.1 and 3.4.2). Table 4-3 presents the annual expenditures for the rehabilitation of irrigation headworks and for the rehabilitation and maintenance of irrigation district works.

Table 4-3: Expenditures on rehabilitation and maintenance of irrigation headworks and district works (2011 constant dollars)

Year	Headworks (Million Dollars)	District works[a] (Million Dollars)	Total (Million Dollars)
2000	23		
2001	20		
2002	21		
2003	26		
2004	21		
2005	21		
2006	27		
2007	32		
2008	27	66	93
2009	19	77	96
2010	15	99	114
2011	17	89	107
2012	11	75	86
2013	8	76	84
Average	23	80	104

a- A complete expenditure for district works was not available for 2000-2007. So, the average of 2008-2013 was considered.

Source: Douglas (2015, personal com.); Hohm (2016, personal com.)

From 2000 to 2013, on average, the government spent $23.2 million annually for rehabilitation of irrigation headworks. In addition, both the government and producers spent $80.4 million annually for the rehabilitation and maintenance of irrigation district works. Hence, a total $103.6 million is spent annually for the improvements of irrigation infrastructure.

Second, the multiplier effect for the rehabilitation of irrigation infrastructure was obtained from Statistics Canada (2015b). The latest release was in 2010 and this was used as a proxy for a 2011 value. According to the 2012 NAICS, irrigation water infrastructure is classified under "water, sewage, and other systems" (Statistics Canada 2015b). The total GDP multiplier for this sector was 0.86 within Alberta and 1.03 nationally. By the same logic described earlier, this multiplier implies that a one dollar expenditure made in the construction activity in Alberta would generate a total impact of 86 cents to the provincial GDP or 1.03 dollars to the national GDP. The total GDP impact of the rehabilitation expenditure was then determined by multiplying the average annual expenditure by the multiplier effects.

Chapter 5 Financial Analysis of Irrigation Expansion

This chapter discusses the procedures involved in undertaking a financial CBA of irrigation expansion. As presented in Section 2.2.2, constructing a CBA involves a series of procedures starting from identifying the project to undertaking the sensitivity analysis of the results.

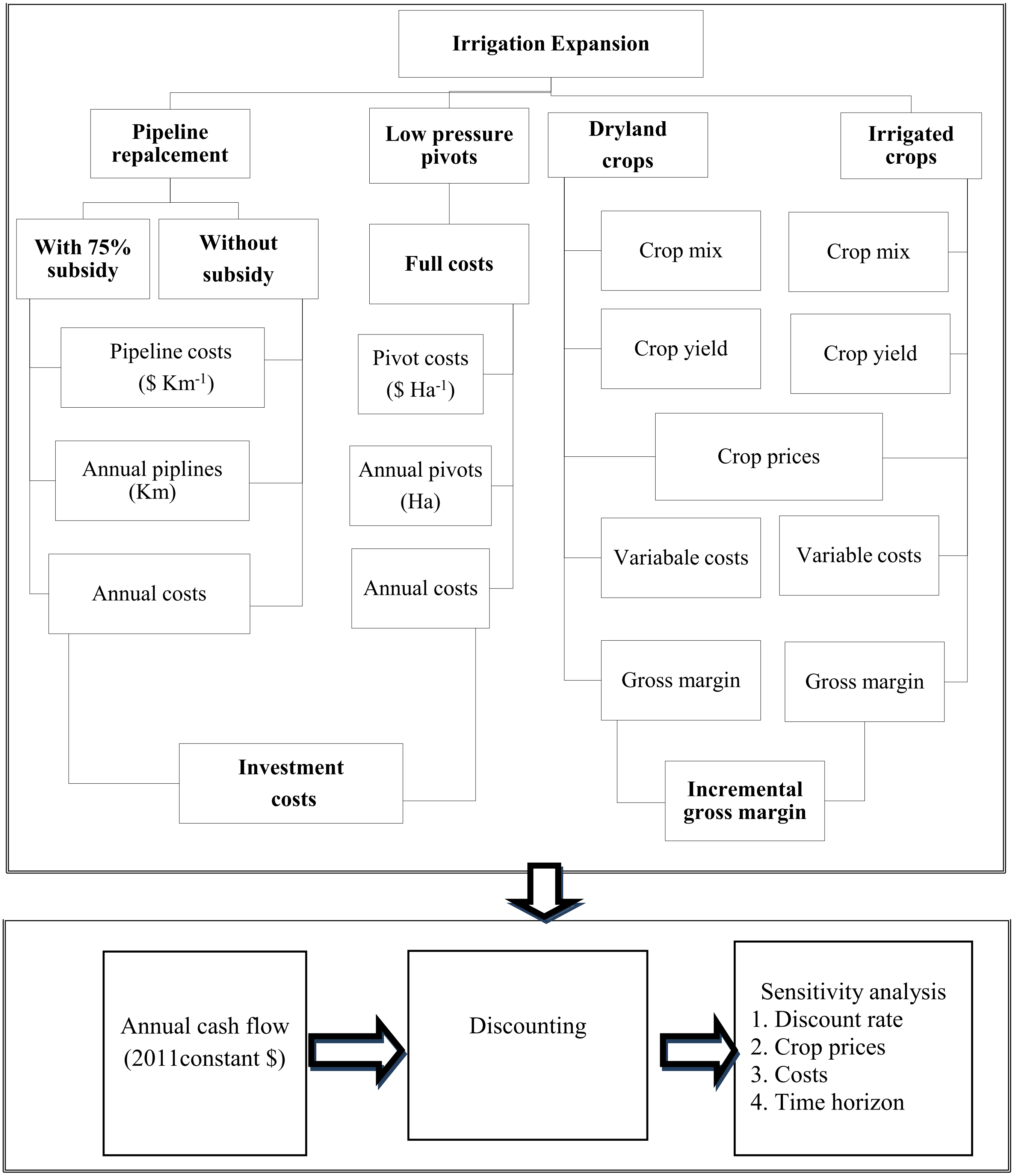
This chapter is composed of seven sections. The first section illustrates the methodological framework of CBA. The second section describes the irrigation expansion project. The third section deals with the calculation of costs for irrigation expansion. The fourth section deals with the calculation of benefits of irrigated crops and dryland crops. The fifth section presents the calculation of net present value. The sixth section highlights the areas for sensitivity analysis. Finally, the seventh section provides a summary of the relevant assumptions.

5.1 Methodology Framework

Financial CBA was chosen in the current study to evaluate the financial profitability of irrigation expansion from a producers' perspective. The main reason for choosing this analysis is that producers are primarily responsible for irrigation expansion and hence it is useful to investigate whether expansion would be economically profitable for them with or without government subsidization for expansion.

Figure 5-1 below illustrates the financial CBA adapted in the current study. The figure shows the steps involved in calculating the costs and benefits of the expected irrigation expansion plan in southern Alberta. The costs include capital costs for replacing the existing old canals with pipelines and the purchase of new low pressure pivots required for expansion. The costs for pipelines were calculated assuming two scenarios. The business-as-usual scenario assumed that the government will continue to provide 75% subsidy for water delivery pipelines that will be required for expanding the irrigated land. The alternative scenario assumed the absence of subsidy. The benefits include the incremental net benefits of irrigated crops. The incremental net benefits were calculated as the difference between the gross margin for irrigated crops and gross margin for dryland crops. The annual benefits and costs were calculated in 2011 constant dollars. Then, the benefits and costs were discounted to determine the net present values. Finally, sensitivity analysis was undertaken for some of the uncertain variables.

Figure 5-1: Framework of cost-benefit analysis



5.2 Project Description

The government of Alberta, along with the 13 irrigation districts, has set an objective to increase the irrigated crop land by 10% over the next 20 years. This will be done by investing in water-saving technologies such as pipelines and low pressure pivot system (AAF 2014a). The projected increase in pipelines, low pressure pivots and expected increase in irrigated land were obtained from Phillips (2015). The current CBA was undertaken based on this information.

5.2.1 Irrigated Crop Land

The expected increase in irrigated land within the 13 irrigation districts in southern Alberta is given in Table 5-1 below.

Table 5-1: Projected increase in irrigated land in the 13 irrigation districts

Districts	**Covered by irrigation (2014) (Hectares)**	**Projected irrigation (2030)[a] (Hectares)**	**Change (Hectares)**
Aetna	1,308	3,035	1,727
Bow River	94,058	105,218	11,160
Eastern	120,539	125,857	5,319
Leavitt	1,448	2,428	980
Lethbridge Northern	72,510	91,864	19,354
Magrath	7,406	7,406	0
Mountain View	1,482	1,716	234
Ross Creek	363	490	127
Raymond	18,101	18,818	717
St. Mary River	151,393	166,731	15,338
Taber	31,913	37,312	5,399
United	13,800	13,921	121
Western	33,492	38,445	4,953
Total	547,804	607,029	59,225

a-The projected irrigated land represents the land that is expected to be irrigated in 2030. This year was projected based on a projected annual rate of expansion that is consistent with the historical pattern. See the accompanying text for more details.
Source: AAF (2015a) and Phillips (2015)

The irrigated land will increase by 59,225 hectares (from 547,804 hectares covered by irrigation method in 2014 to 607,029 in the future).[22] The expected increase in irrigated land will happen as a result of replacing the open canals which have a limited capacity, with pipelines which have a higher capacity for extending irrigated land (Section 3.5). As Table 5-1 shows, the assessed irrigated land which is actually covered by irrigation methods is by far below the potential expansion limit which is supposed to be irrigated. With the projected pipelines replacement all the potentially irrigable lands are expected to be irrigated. The majority of the increase in irrigated area will occur within the Bow River, Eastern, Lethbridge Northern, St. Mary River, Taber, and Western Irrigation Districts. The other districts have limited potential for expanding the irrigated land due to constraints in water infrastructure and lack of suitable irrigable land. As McMullin (2012) indicated, to expand the irrigated land a district must have water available and capacity to deliver the required water; the land must be classified as suitable for irrigation; and irrigators must be willing to contribute to the capital works for expansion.

The time period over which expansion is expected to take place is not specified in any documentation from the provincial government or the irrigation districts. For the purposes of the analysis in the current study, the increase in irrigable land (59,225 hectares) was evenly allocated over time by dividing it by the average annual increase in irrigated crops for the period of 2000-2014. The historical average annual increase in irrigated land was 3,623 hectares (see Section 3.5). Thus it is assumed that it will take 16 years (i.e., 59,225 divided by 3,623) to completely add the new expected irrigable land.

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[22] Irrigated land covered by irrigation system includes a parcel of land recorded as having irrigation land and has some type of irrigation systems (AAF 2015a).

5.2.2 Pipelines

The projected increase in pipelines replacement is provided in Table 5-2 below.

Table 5-2: Projected pipeline replacement and canal lining in the 13 irrigation districts

	Projected rehabilitation (Kilometres)		
Rehabilitation type	**2014**	**2030[a]**	**Change**
Pipelines	3,913	5,500	1,587
Lined canals	710	800	90
Unlined canals	2,954	1,400	-1,554
Total	7,577	7,700	123

a-The date (i.e., the year 2030) is based on a projected annual rate of replacement/rehabilitation that is consistent with the historical pattern. See the accompanying text for more details.
Source: AAF (2015a) and Phillips (2015)

The government of Alberta aims to replace all technically feasible open canals that are in a poor and fair condition with buried PVC pipelines (see Section 3.4.2.2). Canals for which it is not feasible to undertake replacement with pipelines will be rehabilitated with membrane lining. It is expected that the use of pipelines will increase from 3,913 kilometres in 2014 to 5,500 in the future. This means a total increase of 1,587 kilometres. Canal lining will increase only by 90 kilometres. The sum of pipelines and lining is 1,677 kilometres (AAF 2015a; Phillips 2015).

To be consistent with the process used for projected irrigated land, the total projected replacement/rehabilitation of pipeline and lining (1,677 kilometres) was also evenly allocated over time. The projected distance was divided by the average annual increase in pipelines and lining for the period of 2000-2014. The average annual increase in pipelines (including lining) over this period was 106 kilometres (see Section 3.4.2). The ratio indicates that it will take 16 years (i.e., 1,677 divided by 106) to completely replace the open canals with pipelines.

5.2.3 Low Pressure Pivots

The projected increase in the use of low pressure pivot system is given in Table 5-3 below.

Table 5-3: Projected on-farm irrigation methods in the 13 irrigation districts

	Projected irrigation methods (Hectares)		
Irrigation systems	**2014**	**2030**[a]	**Change**
Low Pressure Pivot	387,051	546,326	159,276
High Pressure Pivot	47,393	0	-47,393
Wheel-move	63,558	36,422	-27,137
Surface	46,184	24,281	-21,902
Other	3,618	0	-3,618
Total	547,804	607,029	59,225

a- The date (i.e., the year 2030) is based on a projected annual rate of irrigation system that is consistent with the historical pattern. See the accompanying text for more details.
Source: AAF (2015a) and Phillips (2015)

Farmers have a goal of increasing the use of low pressure pivot system in the future (Nicol et al 2010). Surface and wheel-move systems will be maintained only in areas that are constrained by financial, physical and technical constraints for the adaptation of pivot irrigation system (AAF 2014a). It is expected that the land irrigated with low pressure pivot system will increase from 387,051 hectares in 2014 to 546,326 in the future. This means a total increase of 159,276 hectares. Of this, 100,050 hectares will involve switching from existing low efficient systems while the remaining 59,225 hectares will involve installing low pressure systems on the expected new additional irrigable lands. However, for the purpose of the current CBA, only the low pressure pivots that are required to irrigate the new addition irrigable lands were considered (see Section 3.5).[23] This is to be consistent with the projected increase in irrigated land described earlier. The projected low pressure pivots required (for 59,225 hectares) of land was evenly

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[23] The conversion from low efficiency to low pressure pivots was not considered in the current study.

allocated over 16 years by assuming the average annual increase in low pressure pivots in the period of 2000-2014 (see Section 3.5).

5.3 Costs of Irrigation Expansion

In the current CBA, costs for the irrigation expansion project include capital costs for the construction of pipelines and capital costs for purchase of pivots. The calculations of the two costs are discussed below.

5.3.1 Pipelines Costs

The capital costs for the projected pipelines were estimated based on two approaches. The first approach was based on the capital costs obtained from the annual reports of Eastern and Western Irrigation Districts. These districts were chosen as they are the only districts which have complete cost data for pipelines. The second approach was based on the capital replacement costs of the pipeline projects of the 13 irrigation districts, which were obtained from AECOM (2009).

Using the first approach, the capital costs for various pipeline projects completed in the period of 2002-2014 were collected from the annual reports of the Eastern and Western irrigation districts.[24] Based on these data, the average capital cost per kilometre of pipelines was estimated to be \$260,052 in 2011 dollars. Approximately 100 different pipeline projects (most of them constructed in the Eastern Irrigation District) were considered in the calculation. The costs per kilometre for these projects are shown in Figure 5-2.

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[24] The capital cost for pipelines are estimated by the contractors, who undertake the majority of the construction activity. In some cases, the engineering department of the irrigation districts also undertakes the construction. The capital costs include all the costs for designing and installing the four components of pipeline network layout discussed in section 3.4.2.3.

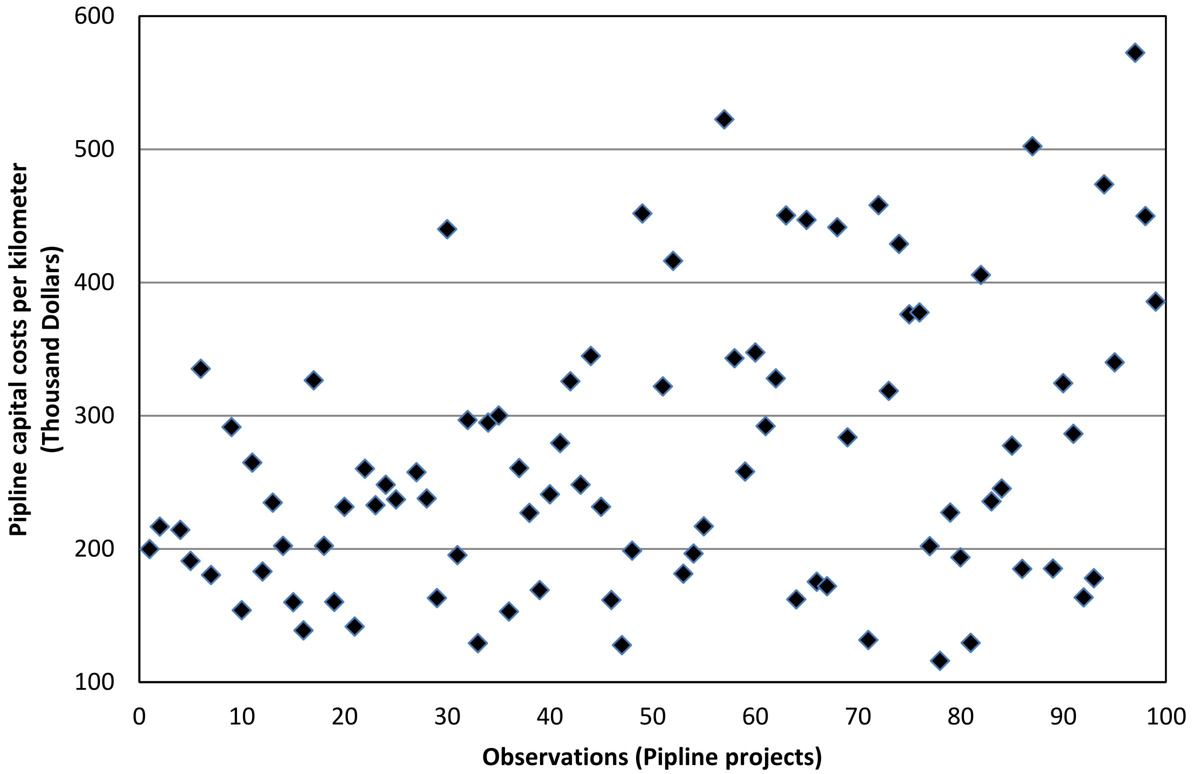

Figure 5-2: Capital costs for pipeline projects constructed in Eastern and Western Irrigation Districts in the period of 2002-2014 (2011 Constant Dollars km^{-1})
Source: Author's estimate based on annual reports of Eastern Irrigation District & Western Irrigation District (2002-2014)

Based on the capital replacement approach (i.e., the second approach), the capital cost per kilometre of pipelines was estimated to be $280,768 in 2011 dollars. This was determined by dividing the capital replacement costs[25] of pipelines by the total kilometres of pipelines replaced (AECOM 2009), and then converting to 2011 dollars using Alberta's consumer price index. The estimated capital cost for pipelines using this approach was approximately 10% higher than the estimate from the first approach. [26]

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[25] Replacement costs measure the capital value required to replace the works (AECOM 2009).

[26] The difference might be attributed to the fact that the replacement cost approach considered the costs for the accrued length of pipelines of the 13 districts constructed since 1969 while the first approach is based on the pipeline projects constructed in only two districts from 2002 to 2014.

Expert opinion was obtained regarding the estimated costs. Hohm (2016) supported the estimated cost obtained using the first approach. He said that using the average estimate is a good approach as there is no one number that fits all, at least in part because land terrain varies from district to district. Where a district has a very flat terrain, then large diameter pipes with large capacity are required and the costs will be high. On the other hand, where the district has a significant drop in elevation, then small diameter pipes can work and the costs will be lower (Hohm 2016).

In the current study, the average cost estimated in the first approach was used in the main analysis. Moreover, given the variability of pipelines costs (Figure 5-2), sensitivity analysis was undertaken using values that are 10% lower and 10% higher than the average cost. Two scenarios were considered in regard to the recovery of the capital costs for the projected pipelines:

- The baseline scenario assumes the continuation the current 75-25% cost-sharing arrangement between the government and producers (hereafter named as "with 75% subsidy").
- The alternative scenario assumes absence of government subsidy and producers pay the full capital costs for the projected pipelines (hereafter named as "without subsidy").

As discussed in Section 3.4.2.1, with the existing government subsidization for irrigation water delivery pipelines, producers normally cover only quarter of the capital costs through payment of the annual water fees to the irrigation districts. The business-as-usual scenario assumes this realty. However, if the full capital costs for water delivery were to be covered by producers alone, then producers would need to pay higher water rates than before. The alternative scenario represents this situation.

5.3.2 Pivots Costs

The costs for the pivot system include both the initial capital investment cost and on-going annual operating costs. The capital costs include both the purchase and installment of the equipment such as the pivot system, pipeline, power and control, pump and motor (Section 3.4.3.1). The capital cost for a pivot system includes set up of concrete pivot pads on the field, purchase and installment of pivots, check valve, flow meter, shut-off valve, pressure gauge and fittings, and air and pressure relief valves. Capital costs for on-farm pipeline include purchase and installment of pipes that delivers water from the main pipeline to the pivot system. Capital cost for power and control system include the cost for electrical control panels, wire, electrician costs, etc. The capital cost for pump and motor includes the costs for purchasing and installing the pumping unit. Other costs include costs for site selection, drilling, testing and developing, screen and casing (Scherer 2013). The operating costs include the costs incurred for energy, repair and maintenance, and labour. The operating costs for pivot system are already included in the crop production costs (see Section 5.4.4).

The estimate of capital costs for low pressure pivots was obtained from two sources; Bennett et al (2013) and Hohm (2016, personal com.). Based on these sources, the average capital cost for installing a center pivot system ranges from $2,010 to $2,277 per hectare in 2011 dollars. This system would on average irrigate 53 hectares of land. The capital cost varies with the length of pivots, larger length pivots being more costly than smaller length pivots. As indicated earlier, capital costs are incurred to install the components of low pressure pivot system on the field whenever the producers expand irrigated parcels. Producers in the current study were assumed to install a brand new pivot system for the projected irrigation expansion.

The current study used the \$2,010 cost estimate for pivots in the main analysis. Sensitivity analysis was undertaken using a cost of \$2,277, which is approximately 10% higher than the \$2,010 estimate. Producers are responsible for the full costs of pivots as it is the case in the current situation (Section 3.4.2.1).

5.4 Crop Benefits

The incremental gross margin from the expanding the irrigated crop land within the 13 irrigation districts in southern Alberta was estimated using the concept of producer surplus. As discussed in Section 2.2.1, the change in producer surplus resulting from switching dryland crop production into irrigated crop production system measures the incremental gross margin attributable to the water used for irrigation. This approach is called the residual method or net crop return method. This method was applied in the previous studies in southern Alberta (e.g., Samarawickrema and Kulshreshtha 2008; Klein et al 2012b).

Following the previous studies, the incremental gross margin is specified as the difference between the gross margin of crop production on the irrigated land and the gross margin of the crop production without irrigation (or dryland), as described in the following Equations.

$$
\begin{aligned}
&IR = RI - RD \\
&RI = \textstyle\sum_{i=1}^{13} AI_i YI_i P_i - \sum_{i=1}^{13} AI_i VCI_i \\
&RD = \textstyle\sum_{d=1}^{9} AD_d YD_d P_d - \sum_{d=1}^{9} AD_d VCD_d
\end{aligned}
\qquad (5.1)
$$

where:

IR is incremental gross margin from irrigation in 2011;

RI is gross margin on irrigated land in 2011 (a total of 13 types of crops were considered);

RD is gross margin on dryland in 2011 (a total of 9 types of crops were considered);

AI_i is area irrigated for crop i in 2011;

YI_i is average crop yield on irrigated land for crop i;

P_i is average price of irrigated crop crop i;

VCI_i is variable cost of production on irrigated land for crop i in 2011;

AD_d is area of dryland for crop d in year 2011;

YD_d is average crop yield on dryland for crop i;

P_d is average price of dryland crop d in year 2011;

VCI_d is variable cost of production on dryland for crop i in 2011.

The incremental gross margin was estimated in 2011 dollars. To estimate the incremental gross margin, it was assumed that expansion would happen through conversion from the adjacent dryland crops within the irrigation districts. The gross margin for irrigated crops was estimated by developing a crop budget for the projected new irrigable land (59,225 ha). The gross margin for dryland crops was estimated by developing a crop budget for the same land. Gross margin was calculated as the gross income (the product of crop yield and price) minus variable costs of production. In calculating gross margin, only the variable costs that are directly associated with the crop production were considered. The net investment in fixed assets (i.e., machinery and buildings) required to support the increase in irrigated crop production was assumed to be zero. In other words, it was assumed that the fixed costs do not change between irrigated and dryland crops.

The data sources used for the crop budget models are similar with the data used for the economic impact assessment of crop production in Section 4.2.1. However, it should be noted that CBA is focused on the expected increase in irrigated land within irrigation districts. So, the budgets were tailored specifically to this projected land. What follows describes the major modifications involved in the crop areas, yields, prices and costs of production.

5.4.1 Crop Area

The crop budget for dryland crops was developed based on the cropping pattern for southern dryland crops that existed in 2011. The crop budget for irrigated crops was developed based on the cropping pattern for the irrigated crops within the 13 irrigation districts that existed in 2011. The budget for irrigated crops used in the CBA was then modified every year as new irrigable land added and this continued until the projected irrigation expansion plan is completely implemented. The projected new irrigable land was allocated between cereals, oilseeds, and forages based on the proportions of these crops on irrigated land in 2011.[27] The area of specialty crops was assumed to remain unchanged throughout the period of irrigation expansion. This assumption was made based on limited processing capacity in the region for specialty crops such as potatoes and sugar beets. Table 5-4 presents the crop mix scenarios considered for dryland crops and irrigated crops.

Table 5-4: Crop-mix scenarios for dryland and irrigated crops in southern Alberta

		Irrigation districts	
Major crops	South Dryland[a] (2011%)	Before expansion[b] (2011%)	After Expansion[c] (Future%)
Cereals	62	32.78	33.51
Oil seeds	19	14.68	15.01
Specialty	6	17.10	15.25
Forages	13	35.44	36.24
Total	100	100	100

a-Author's estimate based on Statistics Canada (2016a) (see Section 4.2.1)
b-AAF (2012a)
c-Author's projection considering the effect of new irrigable land, as discussed in the accompanying text

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[27] The allocation was made by considering the agronomically sustainable practices (Bennett et al 2013).

5.4.2 Crop Yields

Crop yield data for the irrigated crops within the 13 irrigation districts were obtained from Paterson Earth & Water Consulting Ltd (2015), who provided the average estimate for the period of 2000-2011 based on the AFSC and other sources. The annual crop yield data for southern dryland crops was obtained from AFSC (2014) and the average yield was derived for the period of 2000-2011.[28] The average crop yields for irrigated crops and dryland crops are given in Table 5-5. The current study used these average yields to calculate the crop budget. This average yield is expected to reflect the long-term condition in the future. As it can be noted from Table 5-5, average irrigated crop yields were significantly greater than dryland yields.

Table 5-5: Crop yields for irrigated and dryland crops in southern Alberta [Average 2000-2011]

Crops	Irrigated (tonne ha^{-1})	Dryland (tonne ha^{-1})
Durum	6.70	2.45
Hard Wheat	6.30	2.53
CPS[a]	6.73	3.19
Soft Wheat	7.45	2.67
Barley	6.00	2.90
Oat		2.15
Canola	3.36	1.52
Beans	2.80	
Potatoes	51.50	
Sugar Beets	51.10	
Field Peas		2.28
Alfalfa Hay	13.40	5.55
Barley Silage	20.00	13.45
Corn Silage	33.70	
Grass Hay	10.10	

a- CPS represents the Canada Prairie Spring class of wheat, which was established in 1985 as a lower protein alternative to hard wheat (Klein et al 2012b).

Source: AFSC (2014) and Paterson Earth & Water Consulting Ltd (2015)

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[28] Since the yield for dryland crops in the period of 2000 to 2002 was observed to be much lower than the average over the rest of the period, these yields were excluded.

5.4.3 Crop Prices

Alberta nominal crop prices for the period 2000 to 2011 were obtained from Statistics Canada (2016a) and AFSC (2015). These prices were converted to real 2011 dollars using Alberta's consumer price index (Statistics Canada 2016e). Figure 5-3 below shows the fluctuation of real prices for the principal crops (wheat, barley, canola, potatoes, sugar beets, field peas, and alfalfa hay).

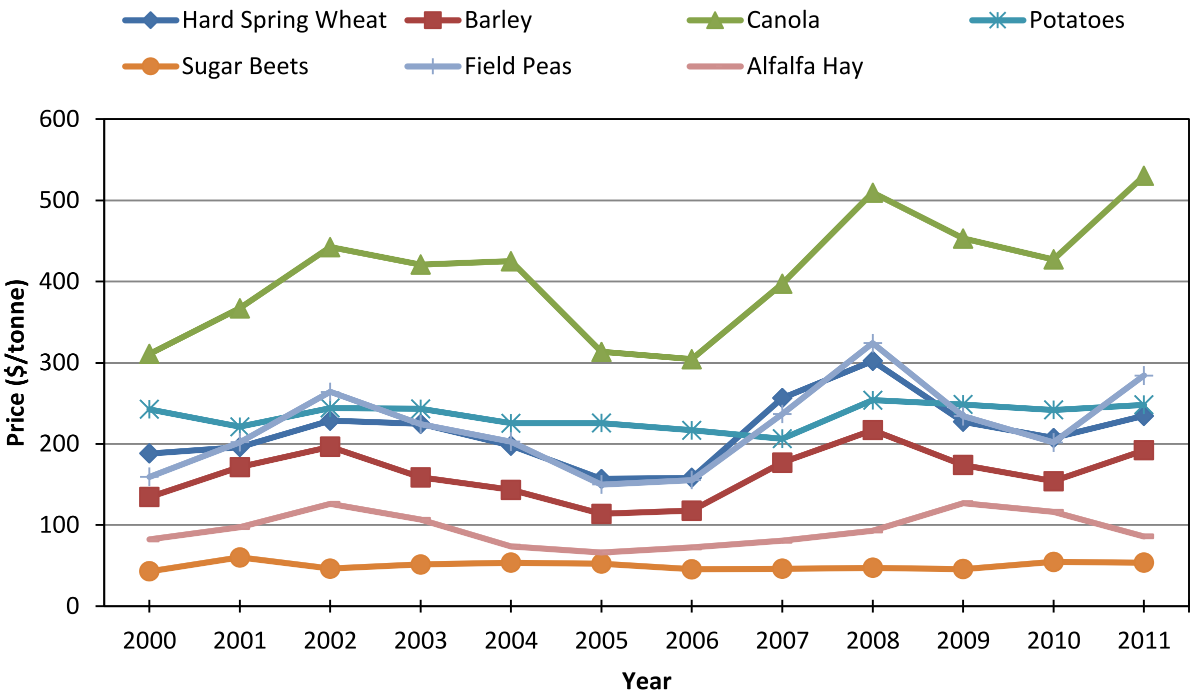

Figure 5-3: Alberta real crop prices
Real crop prices were calculated by converting nominal crop prices to constant 2011 dollars using consumer price index. See the accompanying texts for more details.

As Figure 5-3 shows, the majority of the crops experienced relatively lower prices in 2000, 2005 and 2006 and higher prices in 2008 and 2011. Table 5-6 provides the average, maximum and minimum real (2011) prices for the various crops. The average real prices were used in the main CBA analysis. However, sensitivity analysis was undertaken using the minimum and maximum real prices.

Table 5-6: Alberta real crop prices [Constant 2011 Canadian dollars]

	Crop prices constant dollars tonne^{-1}		
Major crops	**Average (2000-2011)**	**Minimum**	**Maximum**
Durum	239	162	419
Hard Wheat	215	157	302
Barley	162	114	217
Oats	170	115	250
Canola	408	304	530
Beans	681	524	800
Potatoes	235	206	254
Sugar Beets	50	43	60
Field Peas	220	150	324
Alfalfa Hay	94	66	127
Barley Silage	47	29	83

Source: Author’s estimate based on AFSC (2015) and Statistics Canada (2016a)

5.4.4 Crop Production Costs

Crop production costs for irrigated soil and dryland soils in southern Alberta were obtained from Alberta’s CropChoice$ crop budgeting software program[29] (Version 3.9) (AAF 2015b). The costs from that program were converted from 2015 to 2011 values using the Alberta farm input price index (Statistics Canada 2016f).

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[29] Cropchoice$ is a regional crop planning software that contains updated crop cost profiles for the crop enterprises in different soil zones in Alberta. It ontains up to 40 dryland and irrigated crops. Crop costs are based on data collected by the AgriProfit$ Business Analysis and Research Program, and Alberta's Agriculture Financial Service Corporation (AAF 2015b).

In the current financial CBA, variable costs of production were considered. Variable costs include seed, fertilizer, chemical, crop insurance, truck and marketing, fuel oil and lube, irrigation fuel and electricity, machinery and building repair and maintenance, utilities and miscellaneous and hired labour (AAF 2015b). The total variable costs for irrigated crops and dryland crops are shown in Table 5-7 below.[30] Detailed components of variable costs for each crop are given in Appendix A.

Table 5-7: Total variable costs for irrigated land and dryland in southern Alberta [2011 dollars ha^{-1})

Crops	Irrigated	Dryland	Crops	Irrigated	Dryland
Durum	938	496	Potatoes	5,138	
Hard Wheat	925	491	Sugar Beets	1,878	
CPS	920	494	Field Peas	797	458
Soft Wheat	938		Alfalfa Hay	703	240
Barley	897	477	Barley Silage	1,026	498
Oat	820	387	Corn Silage	1,026	
Canola	1,007	584	Grass Hay	711	
Beans	1,378				

Source: AAF (2015b)

Annual input costs are more stable than crop product prices. Previous studies used a single-year cost over long-term in the financial risk analysis of irrigated crop production in southern Alberta (e.g., Anderson 2002; Bennett et al 2012). In the current study, the 2011 costs were used in the main analysis. Sensitivity analysis was conducted for a 10% increase in costs of production for both irrigated and dryland crops. In addition, sensitivity analysis was conducted for a 10% increase in costs of energy used for irrigated crops. The purpose of this analysis was to see particularly the effect of energy costs on the profitability of irrigation as irrigation is heavily dependent on energy.

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[30] The costs for irrigated soil represent the 13 irrigation districts but the costs for dryland crops vary across different soil zones (Klein et al 2012b). Hence, the average costs for Dark Brown and Brown soils in southern dryland were considered as these soils are the most dominant soil zones in the region (Klein et al 2012b).

5.5 Discounting Costs and Benefits

The current study performed the financial profitability analysis of the projected irrigation expansion following the principle of discounting discussed in Chapter 2. The investment costs and annual costs (cash out flows) for the projected pipelines and pivots were discounted and summed. Similarly, the annual incremental gross margins (net cash inflows) were discounted and summed. The net present value (NPV) and internal rate of return (IRR) were then calculated to evaluate the profitability. While the NPV was calculated to determine the worth of irrigation expansion in monetary terms, the IRR was calculated to compare the rate of return of irrigation expansion directly with the assumed opportunity cost of investment. NPV is defined as the sum that remains when the expected investment and operating costs of the project (discounted) are deducted from the discounted values of the expected benefits. IRR is defined as the discount rate that results in a zero NPV (Boardman et al 2011).

NPV was calculated as the difference between sum of discounted net cash inflows and the sum of discounted cash out flows, using the following formula (Boardman et al 2011, 13).

$$NPV = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \qquad (5.2)$$

Where:

B_t is the net cash flow or incremental gross margin over year T;

C_t is the investment cash out flow for pipelines and pivots over year T;

r is the financial discount rate.

IRR was calculated by solving for the discount rate that equates the NPV to zero in the above Equation. This was solved using Solver or Goal Seek, data analysis tool in the Microsoft Excel.

If the calculated NPV is positive, then the investment in irrigation expansion is sufficiently profitable to producers in terms of earning a greater return than the opportunity cost represented by the discount rate. If the NPV is negative, then expansion will not be a sufficiently profitable project. In other words, the net accumulated wealth that producers will gain from expanding the irrigated crop land will be less than the net wealth that they will otherwise obtain by continuing the baseline business, dryland cropping activity. The calculated IRR is compared with the financial opportunity costs of capital. An IRR that is greater than the actual discount rate has the same implication as a positive NPV, and vice versa for an IRR less than the actual discount rate. It should be noted that even if the NPV is positive, it may be the case that expansion should not be undertaken, as there may be even better investment opportunities for the initial capital outlay (i.e., that have a greater NPV).

5.5.1 Discount Rate

The discount rate reflects the opportunity cost of capital or the sacrificed return from an alternative investment. The choice of an appropriate discount rate for CBA is an important issue and subject to debate. This is because the size of the discount rate is so important in determining whether the NPV of a project is positive or negative (Burgress and Jenkins 2010). The choice of the discount rate depends on the type of investment ventures (government, corporate, or smallholders) as each venture has different source of capital, source of risk, and time preference for money (Boardman et al 2011).

There are two types of discount rates used in CBA: a financial or corporate discount rate and an economic or social discount rate (EU-DG RUP 2015). A financial discount rate is used in a CBA to discount financial benefits and costs. It reflects the opportunity cost of capital from a private investors' perspective, which is valued as the loss of income from an alternative investment with similar risk. A social discount rate is used in the economic analysis of public investment projects to discount economic costs and benefits. It reflects the opportunity cost of capital from an inter-temporal perspective for society as a whole (EU-DG RUP 2015).

A financial discount rate is used in the current study since the CBA was undertaken from the producers' perspective. Recent Alberta studies have used a discount rate of 10% in the financial analysis of crop production in Alberta (e.g., Koeckhoven 2008; Trautman 2012; Xie 2014). This discount rate was derived considering the risks involved in farming practices, based on the theory of a capital market line (CML).[31]

The Federal Treasury Board of Canada Secretariat recommends using a real economic discount rate of 8%, with sensitivity analysis of 3 and 10%. The discount rate was derived as a weighted average of the returns on forgone domestic investments, the rate of interest on domestic savings, and the marginal cost of additional foreign capital inflow (Treasury Board of Canada Secretariat 2007). However, these discount rates are recommended for social CBA. The baseline discount rate (8%) is lower than the financial discount rate (10%) derived previously for crop producers in Alberta.

Following the previous financial studies, the current study used the 10% as a baseline financial discount rate to calculate the NPV. In addition, sensitivity analysis was undertaken using discount rates of 7.5% and 12.5%. This range of discount rate was suggested for sensitivity analysis by previous studies (e.g., Koeckhoven 2008). Moreover, the effects of a discount rate regime from 7% to 13% were modeled when considering the subsidy requirement for investment

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[31] This method estimates the opportunity cost of the capital invested for a given activity as the sum of the risk-free rate of return and risk premium multiplier for that activity (Burgess and Jenkins 2010). Risk-free market asset refers to the government borrowing rates or returns on long-term government bonds. The risk premium is the difference between the return on risk-free investment and the return on risky market portfolio (e.g., stock markets). The risk premium is further multiplied by the ratio of the risk parameters for the investment in question (e.g., farming) and for the market portfolio. Risk is measured by the standard variation for the returns (Burgess and Jenkins 2010).

in pipelines. These discount rates were assumed to represent different levels of risk that producers may face in the future.

5.5.2 Project Life Span

Time horizon for the investment project is also an important factor that affects the NPV calculations and resulting values. The time horizon in the current study was based on the expected life span of PVC pipelines in Alberta. Experts in southern Alberta expected the life span of PVC pipelines to be in the range of 60-100 years, as discussed in Section 3.4.2 (Hohm 2016, personal com.). In the current study discounting was done assuming a time horizon of 80 years, including implementation (16 years)[32] and operation (64 years). Sensitivity analysis was undertaken using a shorter period of 60 years. The lower lifespan was considered by taking the high opportunity cost of capital into account.[33] The residual value of pipelines at the end of the expected life was assumed to be zero. This is often a reasonable assumption in a financial CBA. As Boardman et al (2011) argued "project evaluation requires only the consideration private benefits and costs that may approach zero fairly quickly" (155).[34]

The life expectancy of low pressure pivots is 25 years (Hohm 2016, personal com.). As a result, pivots are assumed to be replaced every 25 years throughout the life span of the pipeline. As described in Section 5.2.3, pivots will be installed annually in the period of 16 years to irrigate the projected irrigable land. Afterwards, pivots installed from the first to the 16th year will be continuously replaced after the respective systems have been operating for 25 years. For example, pivots installed in the first year will be replaced in the 26th year; pivots replaced in the

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[32] As discussed in Section 5.2.2, pipelines replacement is expected to be completed in 16 years.

[33] Theoretically, at high discount rate (e.g., 10%) approximately 90% of the cumulative present value of the cashflows of a project happens in 25 years. To this effect, some studies suggest taking into account the magnitude of the discount rate in determining the relevant time horizon to use in the NPV analysis (e.g., Anderson 1986b; EU-DG RUP 2015).

[34] However, the social impacts of government projects may last many years and the residual value cannot be omitted (Boardman et al 2011).

26th year will be replaced in the 51st year; and pivots replaced in the 51st year will finally be replaced in the 76th year. Similarly, pivots installed in the 16th year will be replaced in the 41st year; pivots replaced in the 41st year will be replaced in the 66th year; and pivots replaced in the 66th year will finally be replaced in the 91st year. The salvage value of pivot at the end of the expected life span was assumed to be zero.

5.6 Sensitivity Analysis

CBA was conducted to evaluate the financial profitability of increasing the irrigated land by 10% over the period of 16 years. The annual cash inflows and outflows were calculated in 2011 constant dollars (see Appendices E and F). Based on these cash flows, NPV was calculated.

The calculation of NPV associated with irrigation expansion, as a long-term economic efficiency measure, is composed of several components or parts, described in the previous sections. However, there is uncertainty associated with some of these variables that might be caused by changes in the socio-economic conditions, technical development, climatic conditions, policy shifts, etc. Sensitivity analysis is important to test the effects of uncertain variables on the calculated NPV. Sensitivity analysis involves recalculating the NPV under the new assumptions made for the values of the uncertain variables (Savva and Frenken 2002). In the current study, the effects of key variables that are believed to have a considerable effect on the NPV were examined in the sensitivity analysis. These variables include the cost of pipelines, cost of low pressure pivots, crop prices, crop production costs, energy costs for irrigation, the discount rate, and the life span of pipelines. The assumed values for the sensitivity analysis of each of the variables were justified in the respective sections.

5.7 Summary

Financial CBA for the expansion of irrigated crop land in southern Alberta was undertaken based on several assumptions about the potential for irrigation expansion, the infrastructure required for the expansion, the investment costs for expansion, the difference in the crop returns and production costs for irrigated and dryland crops, and so on. Table 5-8 provides the summary of all relevant assumptions made in the current study.

Table 5-8: Summary of relevant assumptions for the financial cost-benefit analysis

Items	**Assumptions**
1. Scenarios	The baseline scenario reflects the existing cropping pattern (irrigated and dryland) in 2011 in southern Alberta. The expansion scenario assumes expanded irrigated crop area, converted from dryland crop production, within the 13 irrigation districts in southern Alberta.
2. Irrigated land	Irrigated land area is increased by 59,225 hectares within the 13 irrigation districts in southern Alberta, over a 16 year period (2014-2030). The additional irrigable land was allocated to cereals, oil seeds, and forages.
3. Irrigation pipelines	The use of pipelines was expected to increase by 1,677 kilometres; this is accomplished mainly by replacing existing unlined irrigation canals.
4. Irrigation system	Producers are expected to purchase new low pressure pivot systems to support the additional irrigated land. The life span of low pressure pivot systems is assumed to be 25 years, after which the systems are replaced.
5. Benefits	Benefits of irrigation expansion are calculated as the difference between gross margin for irrigated crops and the gross margin for dryland crops being replaced. Returns are calculated based on average annual crop yields and crop prices (in real prices) for the period 2000-2011. Production costs are based on 2011 values.
6. Costs	The costs for irrigation expansion include the capital costs for the construction of pipelines and for the purchase of low pressure pivots. The capital costs for pipelines was estimated to be \$260,052 per kilometres and the capital costs for low pressure pivot system was estimated to be \$2,010 per hectare. The salvage values for both pipelines and pivots were assumed to be zero.
7. Base year	All benefits and costs were valued in 2011 constant prices.
8. Time horizon	The time horizon for the analysis is 80 years, based on the expected useful life of pipelines.
9. Discount rate	The baseline financial discount rate was assumed to be 10%.

Chapter 6 Results and Discussions

6.1 Economic Impacts of Alberta's Irrigated Agriculture Industry

This section provides the estimated economic impacts of Alberta’s irrigated agriculture industry on primary producers, and the provincial and national economies. The results are structured into seven subsections. The first section provides an overview of the direct benefits of crop production. The second section provides an overview of the direct benefits of livestock production. The third section presents the total economic impacts of primary production. The fourth section presents the total economic impacts generated by food processing sectors. The fifth section provides the total economic impacts of irrigation infrastructure rehabilitation and maintenance. The sixth section summarizes the aggregate economic impacts of irrigated agriculture industry and presents the relative distribution of benefits of irrigation. The last section provides a discussion of findings of the current study by comparing with previous studies.

6.1.1 Direct Benefits of Crop Production

The steps involved in the calculation of the direct benefits of irrigated crops and dryland crops were described in Section 4.4.1. The study assessed the direct benefits in terms of value-added based on selected crops that have complete data. The assessed value-added for the selected crops was then adjusted for the area of entire irrigated crops and the area of the entire dryland crops. The adjusted value-added estimates for total irrigated crops and total dryland crops were summed to calculate the provincial value-added for crop production. Finally, the calculated provincial value-added was corrected for the actual provincial value-added for crop production. This section presents the results obtained in these steps.

Table 6-1 below presents the calculation of gross returns and value-added for the selected major irrigated crops in 2011. The calculated values for each of the crops are also aggregated by major crop groups: cereal, oil seed, specialty and forage.

Table 6-1: Value-added for selected major irrigated crops in Alberta (2011)

Crops	Crop areas (Ha)[a]	Crop yields (Tonne Ha^{-1})	Crop prices ($\$Tonne^{-1}$)	Production costs ($\$Ha^{-1}$)[b]	Gross returns (Million dollars)	Value-added (Million dollars)[c]
Durum	21,141	6.70	238	659	34	20
Hard Wheat	99,182	6.30	234	645	146	82
CPS[d]	4,761	6.73	234	641	8	4
Soft Wheat	6,168	7.45	234	663	11	7
Barley	55,032	6.00	192	618	63	29
Canola	80,502	3.36	530	721	144	86
Beans	15,465	2.80	735	969	32	17
Potatoes	21,866	51.50	248	4,235	279	187
Sugar Beets	18,406	51.10	54	1,454	50	24
Alfalfa Hay	80,610	13.40	86	431	93	58
Barley Silage	36,555	20.00	38	733	28	1
Corn Silage	27,970	33.70	38	733	36	15
Grass Hay	15,650	10.10	86	440	14	7
Cereals	186,284				262	143
Oilseeds	80,502				144	86
Specialty	55,737				361	227
Forages	160,785				170	81
Total[e]	483,307				937	536

a-Irrigated land includes land irrigated by the irrigation districts and private irrigators
b-Crop production costs represent the intermediate costs that include seed, fertilizer, chemicals, insurance premium, trucking & marketing, fuel, irrigation fuel, maintenances and repairs, utilities, custom work, and storage (Appendix A).
c-Value-added =gross returns minus intermediate costs.
d- CPS represents for the Canada Prairie Spring class of wheat, which was established in 1985 as a lower protein alternative to hard wheat (Klein et al 2012b).
e-Total is the sum of cereals, oil seeds, specialty, and forages. Cereals include: durum, hard wheat, CPS, soft wheat, and barley. Oilseeds include only canola. Specialty crops include: beans, potatoes and sugar beets. Forages include: alfalfa hay, barley silage, corn silage, and grass hay.

As it can be seen in Table 6-1, total selected irrigated crops represented 483,307 hectares of land and generated $937 million gross returns and $536 million value-added. Specialty crops contributed $227 million to the value-added. Potatoes production is responsible for majority of the value-added for specialty crops accounting for \$187 million. Other specialty crops, such as beans and sugar beets account for the remaining \$40.4 million. Cereal crops generated \$143 million value-added. Hard wheat production contributed to majority of the value-added for cereals. Oilseeds, which are represented by canola production, generated \$86 million value-added. Forage crops altogether generated \$81 million value-added. When comparing the value-added on a per hectare basis[35], it appears that specialty crops generated \$4,074, oilseeds \$1,062, cereals \$767, and forages \$503. Clearly, specialty crops generated by far the highest value-added whereas forage crops generated the lowest value-added.

Once the value-added is estimated for the selected crops, an adjustment was done to account for the area of the entire irrigated crop land; that is, to correct for crops not explicitly included in the calculations. Table 6-2 below presents the adjustment.

Table 6-2: Value-added for all irrigated crops in Alberta (2011)

	Selected crops		All crops	
Major crops	Crop area (Hectares)[a]	Value-added (Million dollars)[a]	Crop area (Hectares)[b]	Value-added (Million dollars)[c]
Cereals	186,284	143	204,204	157
Oil seeds	80,502	86	91,474	97
Specialty	55,737	227	106,528	434
Forages	160,785	81	172,112	87
Total	483,307	536	574,317	774

a-Table 6-1.
b-Area of entire irrigated crops grown by the irrigation districts and private irrigators (Section 4.4.1).
c-Value-added for entire crops=value-added for selected crop times the ratio of area of entire crops to area of selected crops.

As can be seen in the last column of Table 6-2, the adjusted value-added for the irrigated cereal crops was estimated to be \$157 million (i.e., \$143 million multiplied by the ratio of 204,204 to 186,284 hectares). Similarly, the adjusted value-added for oilseeds, specialty crops

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[35] This was done by dividing the calculated total value-added for each crop group by the total crop area of the corresponding group.

and forages were estimated to be $97 million, $434 million and $87 million, respectively. Summing the adjusted value-added for the four groups results in $774 million. This represents the total value-added for all irrigated crops in Alberta in 2011. The adjustment for cereals accounts for minor cereal crops (oat, corn, rye, and triticale), for oilseeds accounts for minor oil seeds (flax and mustard), for specialty crops accounts for other specialty crops (vegetables, forage seeds, and other miscellaneous specialty crops), for forages accounts for other forage crops (timothy hay and green feeds). Given data limitations for specialty crops, the area of the selected crops represents only half of the total area of specialty crops.

In a similar way, the gross returns and value-added for the selected major dryland crops in Alberta are presented in Table 6-3 and the adjustments for the entire dryland crops are provided in Table 6-4. As shown in the bottom of Table 6-3, the major dryland crops generated $6.8 billion gross returns and $3.4 value-added. Cereals and oilseeds have a predominant share while specialty and forage have a minimal share. On a per hectare basis, oilseeds generated $600, specialty $364, cereals $353, and forages $222.

As can be seen in Table 6-4, the adjusted value-added for cereal dryland crops was estimated to be around $1.6 billion, for oilseeds $1.5 billion, specialty $132 million, and for forages $442 million. The sum of these adjusted values yields $3.6 billion and this represents the value-added for all dryland crops in 2011.

Table 6-3: Value-added for selected major dryland crops in Alberta (2011)

Crops	Crop areas (Ha)[a]	Crop yields (Tonne Ha^{-1})	Crop prices ($\$Tonne^{-1}$)	Production costs ($\$Ha^{-1}$)[b]	Gross returns (Million dollars)	Value-added (Million dollars)[c]
Durum	195,759	2.80	238	378	131	57
Hard Wheat	2,061,818	3.25	234	398	1,572	752
CPS[d]	169,239	4.14	234	396	164	97
Barley	1,405,968	3.46	192	366	933	418
Oat	358,155	3.64	202	302	264	155
Canola	2,376,598	2.03	530	477	2,559	1,424
Field Peas	278,960	2.50	284	347	198	101
Alfalfa Hay	1,427,989	5.25	86	190	644	373
Cereal Silage	550,669	15.02	38	449	314	67
Cereals	4,190,939				3,063	1,479
Oil seeds	2,376,598				2,559	1,424
Specialty	278,960				198	101
Forages	1,978,658				958	440
Total[e]	8,825,156				6,779	3,445

a-Dry land cropped land =total cropped area minus cropped area under irrigation (Section 4.4.1)

b-Crop production costs represent the intermediate costs that include seed, fertilizer, chemicals, insurance premium, trucking & marketing, fuel, maintenances and repairs, utilities, and custom work (Appendix A).

c-Value-added =gross returns minus intermediate costs

d- CPS represents for the Canada Prairie Spring class of wheat, which was established in 1985 as a lower protein alternative to hard wheat (Klein et al 2012b).

e-Total is the sum of cereals, oil seeds, specialty, and forages. Cereals include: durum, hard wheat, CPS, and barley. Oil seeds include only canola seeds. Specialty include only field peas. Forages include: alfalfa hay and cereal silages.

Table 6-4: Value-added for all dryland crops in Alberta (2011)

	Selected crops		All crops	
Major crops	Crop area (Hectares)[a]	Value-added (Million dollars)[a]	Crop area (Hectares)[b]	Value-added (Million dollars)[c]
Cereals	4,190,939	1,479	4,457,696	1,574
Oil seeds	2,376,598	1,424	2,419,226	1,450
Specialty	278,960	101	368,266	134
Forage	1,978,658	440	1,989,488	442
Totals	8,825,156	3,445	9,234,676	3,600

a-Table 6-2.

b-Area of all dryland crops in Alberta that belong to each crop group (Section 4.4.1).

c-Value-added for entire crops=value-added for selected crop times the ratio of area of entire crops to area of selected crops.

The sum of the value-added for all irrigated crops and all dryland crops gives $4.7 billion. This represents the provincial value-added for crop production in 2011.The actual value-added for provincial crop production was reported to be $3.7 billion in 2011 (Statistics Canada 2016c). This official provincial estimate, however, does not differentiate between irrigated and dryland crops—it just represents the provincial crop production. The current study is interested in disaggregated values for irrigated and dryland crops. Hence, the calculated value-added estimates for irrigated and dryland crops were adjusted for the actual value-added for the provincial crop production. This was done to ensure consistency with the official provincial estimate as the calculated provincial value-added for crop production (i.e., $4.7 billion) was by 18% higher than the official provincial value. Table 6-5 shows the corrected value-added estimates for irrigated and dryland crops. The corrected value-added for irrigated crops is $655 million and for dryland crops is $3 billion. These are called direct value-added impacts, which are then used as a base value to estimate the total[36] value-added effects using multipliers for irrigated crops and dryland crops, respectively. This calculation is provided in Section 6.1.3.

Table 6-5: Total cropped area and value-added for irrigated and dryland crops in Alberta (2011)

	Total values			Share to the province	
Particulars	Irrigated	Dryland	Alberta	Irrigated	Dryland
Area (Hectares)	574,317	9,234,676	9,808,993	6%	94%
Value-added (Million dollars)	655	3,046	3,701	18%	82%
Value-added ($ per hectare)	1,141	330			

As Table 6-5 shows, total irrigated crop land accounted for 6% of Alberta's cropped land but contributed to 18% of the provincial crop value-added.[37] This implies that the share of irrigated crops to Alberta's crop value-added is about three times higher than its share of total

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[36] The total effects include both the direct and secondary effects (Section 2.3.2).

[37] The cropped land does not include tame pasture and native pasture land.

cropped land. Irrigated crops generated $1,141 value-added per hectare. However, dryland crops generated only $330 per hectare. This implies that irrigated crops generated about three times higher value-added than dryland crops per hectare. The advantage of irrigated crops over dryland crops is mainly attributed to high intensity of specialty crops and improved yields (Tables 6-1 and 6-3).

Besides the value-added measure, the net crop return is calculated. The net return represents the farm profit that producers realize after paying the expenses for all factors of production; both intermediate factors (seed, fertilizer, chemical, crop insurance, truck and marketing, fuel oil and lube, irrigation fuel and electricity, machinery and building repair and maintenance, utilities and miscellaneous) and value-added factors (hired labour, operating interest, cash rent, and capital interest) (Anderson 2002). The difference between value-added and net return is that the former does not subtract labour, rent, and interest costs from the gross returns as these payments are considered to be elements of the gross domestic product or value-added. However, these outlays are considered as costs from the producers' point of view (Anderson 2002). In determining the distribution of benefits of irrigation, previous studies (e.g., Russell et al 1984; Anderson 2002; Paterson Earth & Water Consulting Ltd.) used net return to measure the direct benefits to producers. Following these studies, the net return for irrigated crops was calculated. A parallel net return calculation was done by subtracting labour, interest, and rent costs besides the intermediate costs from the gross returns in Table 6-1. Following the same adjustment and correction procedure done for value-added, the corrected net crop return for irrigated crops was estimated to be $476 million.[38]

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[38] See Appendix B.

6.1.2 Direct Benefits of Livestock Production

The procedures involved in calculating the benefits of livestock production for the irrigated farms and dryland farms were described in Section 4.4.2. Table 6-6 below shows the estimated livestock sales for the south irrigated region and rest of Alberta region in 2011.

Table 6-6: Livestock sales in the south irrigated and rest of Alberta (2011)

	Sales (Million dollars)[a]			Proportion (%)	
Livestock types	South Irrigated	Rest of Alberta	Alberta Total	South Irrigated	Rest of Alberta
Cattle and calves	554	2,472	3,026	75	67
Dairy products	75	429	504	10	12
Hogs	57	359	417	8	10
Sheep and lambs	4	17	22	1	0
Poultry and eggs	28	273	300	4	7
Honey	6	52	58	1	1
Others	15	77	93	2	2
Total	740	3,679	4,419	100	100
Share to Alberta (%)	17	83	100		

a-For detail see Appendix C.

Of the total livestock sales of about $ 4.4 billion in Alberta, the sale from the irrigated farms was estimated to be $740 million and from the rest of Alberta was about $3.7 billion. That means the irrigated region accounts for about 17% of Alberta's total livestock sales. The cattle industry that includes cow-calf and feedlot operations accounts for 75% of the livestock sales in the irrigated region. Dairy, hog and poultry altogether account for 22%. Other animal products such as sheep and lamb, honey, etc. account for the remaining 3%.

In 2011, the value-added of livestock production in Alberta was estimated to be around $348 million (Statistics Canada 2016c). Assuming the 17% share of the irrigated farms to the provincial livestock production (Table 6-6), the value-added impact of livestock production in the irrigated farm was calculated to be $58 million (Appendix C). This value-added was used as a proxy of the direct benefit to producers due to lack of data required to calculate the net returns for different livestock enterprises.

6.1.3 Economic Impacts of Primary Production

The total economic impacts of crop production and livestock production were estimated by using the input-output multipliers[39]. Table 6-7 shows the estimated total impacts of the irrigated agriculture on the provincial and national GDP. The table also shows the total impacts of dryland agriculture and the incremental impacts of irrigated agriculture. The impacts of dryland agriculture were converted into the irrigated cropped land-equivalence to allow comparison. This was done by multiplying the per hectare value-added for dryland crops ($330) by the total irrigated land (574,317 hectares).[40]

Table 6-7: Total impacts of Alberta's irrigated agriculture and dryland agriculture on the provincial and national GDP (2011, Million Dollars)

Primary production	Irrigated		Dryland		Difference	
	Alberta	Canada	Alberta	Canada	Alberta	Canada
Crop[a]	906	1,035	288	345	619	690
Livestock [b]	639	770	177	256	355	513
Total	1,545	1,803	465	601	973	1,202

a- Total economic impacts of crop production=value-added multiplier times direct value-added. See the accompanying text for more details.
b-Total economic impacts of livestock production=value-added multiplier times direct sales. See the accompanying text for more details.

As Table 6-7 shows, irrigated crop production generated around $0.9 billion to the provincial GDP and $1 billion to the national GDP. These were estimated by multiplying the direct value-added of irrigated crops by the provincial and national-wide value-added multiplier effects for irrigated crops, respectively. The direct value-added for irrigated crops was estimated

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[39] These are discussed and provided in Sections 4.4 and 4.5.
[40] See Table 6-5.

to be $655 million (Table 6-5). The provincial value-added multiplier effect for irrigated crops in Alberta was 1.38 and the national-wide value-added multiplier effect was 1.58 (Table 4.1).

However, dryland crop production system would generate only $288 million to the provincial GDP and $345 million to the national GDP (Table 6-7). These were calculated by multiplying the direct value-added of dryland crops by the provincial and national-wide value-added multiplier effects for dryland crops, respectively. The direct value-added effect was converted into irrigated cropped land-equivalence. The converted value-added was $189 million. The provincial value-added multiplier for dryland crops was 1.52 while the national-wide value-added multiplier was 1.82 (Table 4.1).

The difference between the impact of irrigated crops and the impact of dryland crops represents the incremental benefits of irrigation. As can be seen in last column of Table 6-7, irrigated crop production generated an incremental benefit of $690 million to the national GDP, of which about $620 million realized in Alberta while the remaining $70 million accrued to other Canadian provinces.[41]

Livestock production on the irrigated farms generated $639 million to the provincial GDP and $770 to the national GDP (Table 6-7). This was calculated by multiplying the livestock sales in irrigated farms by the provincial and national value-added multipliers for livestock production, respectively. The livestock sales for irrigated farms were approximated to be $740 million (Table 6-6). The provincial value-added multiplier for livestock production was 0.72 while the national-wide value-added multiplier was 1.04 (Section 4.5).

However, the livestock production in dryland farms would generate only $177 million to provincial GDP and $256 million to the national GDP (Table 6-7). This was estimated by

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[41] The impacts on other provinces occurred as a result of inter-provincial trade effects (see Section 4.2).

multiplying the livestock sales for dryland farms in Alberta by the provincial and national-wide value-added multipliers for livestock production, respectively. The livestock sale for dryland farms was converted into irrigated cropped land-equivalence. The converted livestock sale was around $246 million (Appendix C).[42] Livestock production in the irrigated farms generated an additional benefit of $513 million to the national GDP; $355 million of the benefits are realized in Alberta while the remaining $158 million occurred in other provinces.

In general, as can be seen in the bottom of Table 6-7, primary production in the irrigated region of Alberta generated a total of about $1.5 billion to the provincial GDP or $1.8 billion to the national GDP. The otherwise dryland primary production would generate only about $0.5 billion to the provincial GDP or $0.6 billion to the national GDP. This implies that irrigation has the advantage of producing additional $1.2 billion to the national GDP.

6.1.4 Economic Impacts of Food Processing

Paterson Earth & Water Consulting Ltd (2015) assessed the total economic impacts created by the irrigation-related food manufacturing industries in Alberta. The impacts include both the direct impacts created on the food processing industries, and the secondary impacts created on other sectors through the backward linkages as well as through induced effects. The results are given in Table 6-8 below.

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[42] The total livestock sales approximated for dryland farms, $3.8 billion (Table 6-6), was divided by the total dryland cropped land, 9,141,401 hectares, calculated based on the 2011 Census of Agriculture. This was multiplied by the total irrigated crop land, 612,447 hectares, which includes irrigated pasture lands (Appendix C).

Table 6-8: Direct and secondary impacts of irrigation-related food processing industries on the provincial GDP (2011, Million Dollars)

Food Processing Industry	Direct	Indirect & Induced	Total
Meat processing	231	517	748
Grain Milling	131	201	332
Animal Food	21	54	75
Fruits and Vegetables	63	110	173
Other Food	80	285	365
Total	525	1,169	1,693
Total adjusted[a]	403	898	1,301

Source: Paterson Earth & Water Consulting Ltd (2015)

a-This figure is adjusted down by 23% to be consistent with Statistics Canada (2016c) (Appendix D)

According to Paterson's study, the food processing industries in the southern irrigated region generated $1.7 billion to Alberta's GDP. Of this, $525 million was created directly in the food processing sector and the remaining $1.2 billion was created in other sectors though indirect and induced effects. However, the estimated direct GDP impact seemed to be 23% higher than the actual GDP of food-processing sector as reported by Statistics Canada (2016c).[43] By relying on the official provincial estimate, the total GDP impacts were scaled down by 23%. With this adjustment, the total GDP impact of irrigation-related food processing activity was estimated to be about $1.3 billion (see Appendix D).

6.1.5 Economic Impacts of Irrigation Infrastructure Rehabilitation

Table 6-9 below presents the estimated economic impacts caused by the annual expenditure made on the rehabilitation and maintenance of irrigation infrastructures in southern Alberta. As shown in Table 6-9, the expenditure on irrigation infrastructure improvement generated $89 million to the provincial GDP or $107 million to the national GDP as a whole.

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[43] Paterson did not provide detailed information about the calculation of provincial GDP for food processing sectors. Thus, it was not possible to determine the source of the difference from the official provincial estimate.

These effects were estimated by multiplying the direct expenditure of $104 million made for infrastructure improvements by the provincial value-added multiplier effect for water infrastructure activity, which equals 0.86, and the national-wide multiplier effect, which equals 1.06.[44]

Table 6-9: Direct and secondary impacts of Alberta's irrigation infrastructures rehabilitation on the provincial and national GDP (2011, Million Dollars)

	Direct	Indirect & induced	Total
Alberta	38	51	89
Canada	38	69	107

6.1.6 Aggregated Economic Impacts of Alberta's Irrigation

The total GDP impacts generated by the four irrigation-related activities (crop production, livestock production, food processing, and infrastructure rehabilitation and maintenance) are summarized in Table 6-10 below.

Table 6-10: Total GDP impacts of Alberta's irrigation-related activities (2011, Million Dollars)

Activities	Producers[a]	Total Alberta	Total Canada
Primary production	534	1,435	1,803
Agri-food processing		1,301	1,301
Infrastructure rehab.		89	107
Gross	**534**	**2,828**	**3,211**
Primary producers			534 (16.6%)
Rest of Alberta			2,294 (71.4%)
Rest of Canada			383(11.9%)

a- Producers' benefits are the sum of direct net benefits of irrigated crops amounting $476 million (Section 6.1.1) and direct net benefits of livestock production amounting $58 million (Section 6.1.2).

Alberta's irrigated agriculture industry (including infrastructure) generated $3.2 billion to the national GDP--17% of the benefits accrued to producers, 71% to the province (excluding

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[44] See Section 4.7.

producers) and the remaining 12% to the rest of Canada. The benefits that accrued to producers are the sum of direct net benefits of crop production and direct net benefits of livestock production. The net benefits for irrigated crop production were estimated to be $476 million (Section 6.1.1) and the net benefits of livestock production were approximated to be $58 million (Section 6.1.2). Hence, the net benefits of irrigation to producers were estimated to be $534 million (Table 6-10).

6.1.7 Discussion of Results

The economic impact of Alberta’s irrigated agriculture has been studied since the 1960s. The ultimate purpose of the studies was to derive an appropriate cost-sharing arrangement between irrigation producers and the government of Alberta (McAndrews et al 1967; Russell et al 1984; Kulshreshtha et al 1985). These studies assessed the economic impacts in terms of GDP.

By using the same indicator, GDP, the current study addressed an important question of “Who benefits from Alberta’s irrigation and who should pay for it?”. The study estimated that Alberta's irrigation-related activities, directly or indirectly, produced around $3.2 billion to the national GDP in 2011. To put the results into perspective, this represents about one per cent of the province's total GDP.[45] The distribution of the benefits was 17% for producers and 83% for the province and the rest of Canada. The estimates of the current study suggest that the magnitude of the benefits of irrigation has almost tripled from what had been estimated back in the 1980s but the share of producers did not significantly change.[46]

Other similar studies have also recently estimated the relative distribution of benefits of irrigated agriculture in Alberta (e.g., Paterson Earth & Water Consulting Ltd 2015),

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[45] In 2011 Alberta’s GDP was about $300 billion (Statistics Canada 2016b).

[46] See the findings of Russell et al (1984) in Section 2.4.2.

Saskatchewan (e.g., Clifton Associates Ltd 2008) and the United States (Pacific Northwest Project 2013). Paterson estimated that irrigation-related activities contributed around $3.6 billion to Alberta's GDP. The study indicated that 10% of the GDP accrued to irrigation producers and 90% to the province.[47] The estimate was made based on the average value for the period of 2000-2011. Clifton Associates Ltd (2008) estimated that irrigation expansion in Saskatchewan over the period of 40 years would increase household income by $12 billion. The study indicated that 20% of the income accrued to producers, and 80% accrued to the province and the rest of Canada. Pacific Northwest Project (2013) estimated that irrigated agriculture industry generated US $156 billion of household income in the Western United States in 2011.[48] The study did not estimate the distribution of the income but looking at the findings it appeared that 23% of the total income accrued to producers.

The share to producers in the current study tends to be higher than in Paterson's study. This is because of three reasons. First, the economic analysis in the current study was undertaken in 2011, whereas, the economic analysis in Paterson study was undertaken based on the average of 2000-2011.The current study was undertaken in 2011 to be consistent with the input-output multipliers for crop production, which had a 2011 base year (Section 4.4). The benefits of crop production and livestock production were relatively higher in 2011 than in the preceding years mainly due to higher relative prices for agricultural products. Second, the secondary benefits were lower in the current study mainly because the GDP of food processing sector estimated by Paterson study was relatively higher than the official estimate of Statistics Canada, which was

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[47] The study assessed the direct and secondary impacts generated by irrigation related activities such as crop production, livestock production, agri-food processing, irrigation infrastructure rehabilitation and operation, irrigation machinery and equipment, and other benefits of non-irrigation activities such as drought mitigation, water use, recreation, hydropower generation and commercial fishing.

[48] This includes the direct impact of US $64 billion and the secondary impact of $92 billion (Pacific Northwest Project 2013).

used in the current study. Third, the current study did not consider the non-irrigation benefits which were included in Paterson's study.

6.2 Economic Viability of Irrigation Expansion

This section provides the financial CBA results for further expanding the irrigated land by 10% over a 16 year period. The financial CBA was undertaken from the producers' perspective by considering the financial costs and benefits, which were discounted using the financial discount rate. The results are structured into four subsections. The first section presents estimated net present values under different discount rates. The second section presents the sensitivity analysis of the results for key variables. The third section presents the estimated minimum subsidy requirements for pipeline replacements. The final section provides a discussion of findings of the current study by comparing with previous studies.

6.2.1 Net Present Values

Table 6-11 below shows the estimated financial net present values of irrigation expansion for the two policy scenarios (with 75% subsidy and without subsidy) under the baseline discount rate of 10% as well as for the other two discount rates of 7.5% and 12.5%. The internal rates of return are also provided for the two scenarios.

Table 6-11: Net present values of irrigation expansion in southern Alberta under different discount rates

Discount rate (%)	Net present values (Million Dollars)[b]	
	With 75% subsidy[a]	Without subsidy
7.5	154	-34
10.0 (base)	78	-83
12.5	39	-101
Internal rate of return (%)	18.9	6.6

a-Considering government contribution of 75% for irrigation pipelines construction.
b-See Appendix G for more details about the calculation of net present values.

As shown in Table 6-11, at the baseline discount rate, 10%, the NPV of expansion with the current subsidy of 75% on IRP is positive ($78 million). However, without the subsidy scenario, the NPV is negative (-$83 million). This implies that investments in irrigation expansion will be sufficiently profitable for producers if the government continues providing the 75% subsidy on the irrigation rehabilitation program. However, without this effective subsidy, expansion is unlikely to be sufficiently profitable.

The profitability can also be seen for discount rates of 7.5% and 12.5% in Table 6-11. It appears that without the subsidy, expansion will remain to be unattractive at the 7.5% rate but with the subsidy it will be attractive even at the 12.5% rate. As expected, the NPV is highly influenced by the discount rate. Given that irrigation is a capital-intensive project, the benefits that occur towards the end of the time horizon have relatively less weight at a higher discount rate. Hence, the discounted benefits hardly compensate the investment costs in the absence of subsidy.

The internal rate of return shown in the bottom of Table 6-11 provides clear information of the rates of return that producers would gain from their investment. With the current 75% subsidy, the internal rate of return of expansion is estimated to be as high as 19%. However, without the subsidy scenario, it would be only 7%. This implies that with the continuation of government subsidy, producers would gain up to 19% rate of return from their investment on irrigation expansion, which is significantly higher than the assumed opportunity cost of their investment (10%). However, in the absence of the subsidy, the rate of return from expansion would be below the opportunity costs of their money--meaning investing in expansion would not be a rational choice for them.

6.2.2 Sensitivity Analysis of the Results

Sensitivity analysis was undertaken to further examine the effects of key variables on the net present values at the 10% discount rate. Table 6-12 below presents results of the sensitivity analysis.

Table 6-12: Sensitivity analysis of net present values

	Net present values at 10% discount rate (Million Dollars)	
Factors	With 75% subsidy[a]	Without subsidy
Baseline estimate	78	-83
1. Shorter Life of pipeline (60 years)	78	-84
2. Higher Energy cost (+10%)	77	-85
3. Higher Pivot cost (+10%)	73	-89
4. Higher Pipeline cost (+10%)	73	-104
5. Higher Crop Production costs (+10%)	64	-97
6. Lower Crop prices	9	-153
All conservative[b]	-17	-195
Lower Pipeline cost (-10%)	84	-61
Higher Crop prices	170	8

a-Considering government contribution of 75% for irrigation pipelines construction.
b-"Conservative" represents the first six combined negative changes, with the exception of higher energy costs, that reduce net present values against the baseline assumption. The energy costs were not included as they are already included within crop production costs.

The results of the sensitivity analysis in Table 6-12 have three parts. The first part shows the effects of negative changes (i.e., changes that decrease net present values) individually for six variables on net present values. The effect for each of the variables was examined individually and can be compared with baseline estimate. The second part shows the combined negative effects of all of the variables on the net present values. The combined negative effect is considered as a conservative estimate relative to the baseline. The third part presents the effects of positive changes (i.e., changes that increase the net present values against the baseline estimate). Specifically, the effects of higher level of crop prices and lower level of costs of pipelines were examined.

The sensitivity analysis of crop prices indicates that the net present values could be highly influenced when considering the variability of relative crop prices below and above the average real crop prices[49] over the period of 2000-2011. The net present value for the subsidy scenario using minimum crop prices was estimated to be \$9 million, versus the value of approximately \$80 million when using average crop prices (Table 6-12). That means expansion would be still sufficiently profitable to producers with the existing government subsidy. Without the subsidy, the net present value at the minimum crop prices would become as low as negative \$150 million (Table 6-12). But at the maximum crop prices, the net present value would be positive \$8 million.

The sensitivity analysis for the other variables in Table 6-12 indicates that each of the variables would not have a significant effect on the net present value individually (i.e., the sign of the NPV would not change) but when they are considered simultaneously, their impacts would be significant. For instance, lowering the life span of pipeline from 80 to 60 years or increasing the costs of irrigation fuels by 10% from baseline (2011 prices) would decrease the net present value for the subsidy scenario by \$1 million. The conservative cost estimation for pipelines or pivots (i.e., 10% increase from the baseline) would decrease the net present value for the subsidy scenarios by \$5 million. The conservative scenario for costs of crop production (i.e., 10% increase from baseline) would decrease the net present value by \$14 million (i.e., decrease from \$78 million to \$64 million). However, when all conservative estimates, including the effect of minimum crop prices, are considered simultaneously, the net present value for the subsidy scenario would fall to negative \$17 million. This suggests that irrigation expansion would not anymore be profitable with the existing government subsidy at the 10% discount rate.

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[49] The historical minimum and maximum real crop prices were estimated for the period of 2000-2011.

It is also important to see the sensitivity analysis of the variables by examining the effects on internal rate of return by directly comparing the changed internal rate of return with the baseline discount rate. Table 6-13 shows the results.

Table 6-13: Sensitivity analysis of internal rate of return of irrigation expansion

	Internal rate of return (%)[c]	
Factor	With 75% subsidy[a]	Without subsidy
Baseline estimate	18.9	6.6
1. Shorter Life of pipeline (60 years)	18.9	6.4
2. Higher Energy cost (+10%)	18.7	6.5
3. Higher Pivot cost (+10%)	17.9	6.4
4. Higher Pipeline cost (+10%)	17.8	6.0
5. Higher Crop Production costs (+10%)	17.3	6.0
6. Lower Crop prices	11.0	3.5
All conservative[b]	8.2	1.6
Lower Pipeline cost (-10%)	20.1	7.2
Higher Crop prices	29.5	10.3

a-Considering government contribution of 75% for irrigation pipelines construction.
b-"Conservative" represents the first six combined negative changes, with the exception of higher energy costs, that reduce net present values against the baseline assumption. The energy costs were not included as they are already included within crop production costs.
c- Internal rate of return is the rate at which the net present value equals zero.

The results of the sensitivity analysis of internal rate of returns in Table 6-13 have a similar interpretation as the results of the sensitivity analysis of net present value presented earlier. The variability of crop prices has a strong effect on internal rate of return. The internal rate of return for the subsidy scenario would be in the range of 11-30% considering the minimum and maximum crop prices. At the maximum crop prices, even without government subsidy the internal rate of return of expansion would be marginally higher than the opportunity costs of capital. The assumed negative effect of each of the other variables is not strong enough to decrease the internal rate of return below the baseline discount rate. When the negative effects of all the variables are combined, however, the internal rate of the return for subsidy scenario would fall to 8%, suggesting that investment in irrigation expansion would be unattractive in the exiting government subsidy.

6.2.3 Subsidy for Irrigation Pipeline Replacement

The minimum subsidy required for pipeline replacement was estimated for the baseline condition and conservative condition under different discount rates ranging from 7 to 13%. The conservative condition represents a scenario of higher lifespan of pipelines, higher costs of pipelines, costs of pivots, costs of crop production, and lower crop prices than what was assumed to be the case in the baseline condition (Table 6-12). The minimum subsidy is a percentage of subsidy that equates the NPV for the subsidy scenario to zero. The results are provided in Figure 6-1 below.

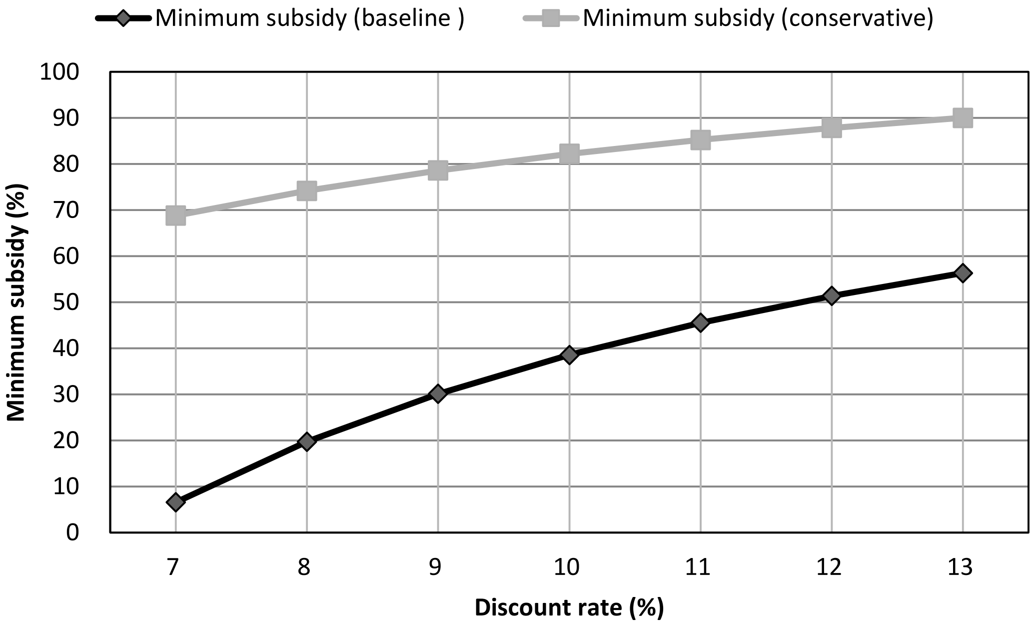

Figure 6-1: Minimum subsidy required for irrigation pipeline construction for the baseline and conservative scenarios under different discount rates
The baseline scenario is based on the baseline assumption that reflects a more realistic situation; and the conservative scenario is based on a “pessimistic” scenario that assumes a historical lower crop prices, a 10% higher in costs of crop production, costs of pipelines and costs of pivots, and a more conservative lifespan of pipeline (60 years) than the baseline scenario (Table 6-13).

As Figure 6-1 above shows, subsidy requirement increases with higher discount rates. At a 7% discount rate, producers would require at least 7% government subsidization for pipeline construction. However, at a 13% discount rate, a minimum subsidy of 56% would be needed.

The figure also shows how the subsidy requirement varies between the baseline condition and conservative condition at a given discount rate. For example, at the baseline discount rate, 10%, producers in the baseline condition would require a minimum subsidy of 40% while in the conservative condition they would require 82%. The current 75% subsidy seems sufficient enough to make producers profitable in the baseline condition but not in the conservative condition.

6.2.4 Discussion of Results

CBA was undertaken to evaluate the financial profitability of expanding irrigated crop land by 10% (59,225 hectares) over the next 16 years. The results revealed that the profitability of irrigation expansion for crop producers is subject to the government subsidy provided for the investment in pipeline replacement. With the governments' contribution of 75% to irrigation rehabilitation program, the investment for irrigation expansion would be profitable for producers. It would generate a NPV of $78 million or $1,324 per hectare at the baseline discount rate, 10%, (Table 6-11). However, in the absence of this effective subsidy, expansion would be economically unattractive for producers. This is because the net benefits obtained from converting the dryland crops into irrigated crops are hardly enough to cover the full investment costs required for irrigation expansion. Without the subsidy, expansion would be economically viable to producers for discount rate of 6.6% and lower. However, this is far below the assumed opportunity cost of investment (Table 6-11).

Furthermore, the results of the conservative scenario suggested that even with the 75% subsidy, the expansion of irrigation would be unlikely to be profitable to producers (Table 6-12). If producers experience the conservative scenario in the future, the question is then what will be the minimum level of government subsidization required in order to make the planned expansion economically viable? The results suggested that in the conservative scenario, producers would require a minimum subsidy of 82% at the baseline discount rate (see Figure 6-1).

In general, the main findings of the current study are consistent with previous studies and also reflect the reality condition. For instance, the CBA study undertaken by Rescan (2012) indicated that investment in improvements of irrigation conveyance works would not be economically viable to producers in Saskatchewan even at a 2% discount rate. The study emphasized the need for government subsidization in order to make expansion economically viable to producers. Similarly, Rudenko et al (2015) showed that the investment costs for canal lining in Uzbekistan (in Asia) are higher than the financial net benefits. The study underlined the need for government subsidy to secure financial profitability from irrigation water-saving conveyance technologies. Other studies in Australia too emphasized the need for government subsidy for the investment in water-saving irrigation conveyance works (Connell 2011).

Chapter 7 Conclusions, Limitations, and Further Research

There are two major issues facing Alberta's irrigation. The first issue is related to the cost-sharing arrangement between the provincial government and producers. Irrigation capital costs for rehabilitation of conveyances are shared between the provincial government and producers. The cost-sharing arrangement is based on the relative distribution of irrigation benefits, with the split currently being set at 75%-25% between the provincial government and producers. This cost-sharing formula dates back to the 1990s and it may not represent the current relative distribution of irrigation benefits. Irrigation impact analysis was undertaken to test whether the 75-25% cost-sharing arrangement is still appropriate.

The second issue is related to the economic viability of expanding irrigated crop land in southern Alberta. The government of Alberta, along with the 13 irrigation districts in southern Alberta, have set an objective to increase irrigated cropped land by 10% in the coming two decades. This is to be done by investing in rehabilitation of irrigation conveyances and improvement of on-farm irrigation systems. Producers have a concern whether expansion would be profitable with the existing government subsidization. Financial cost-benefit analysis was undertaken to address two questions: (1) Will the direct incremental benefits of irrigated crops compensate the investment costs for irrigation expansion?; and (2) Is government subsidization required for expansion to be economically viable and, if so, what is the minimum required level of government subsidy?

The current study assessed the economic impacts of Alberta's irrigated agriculture as of 2011. The economic impacts of major irrigation activities on the provincial and national economies were estimated using input-output multipliers. Four major irrigation activities were considered: crop production, livestock production, agricultural food processing, and irrigation infrastructure rehabilitation and maintenance. The direct and secondary economic impacts generated by each of the four activities were estimated in terms of value-added. Finally, the aggregate value-added impact of irrigation was estimated and the distribution of the aggregate benefits of irrigation among the producers, the province and the nation was determined.

A financial cost-benefit analysis was undertaken to examine the profitability of expanding the irrigated land in southern Alberta. The analysis was undertaken from producers' perspective. The direct costs and benefits of irrigation expansion were calculated in constant 2011 Canadian dollars. The costs include capital costs for replacing the existing old canals with pipelines and the purchase of new low pressure pivots required for expansion. The costs for pipelines were calculated assuming two scenarios. The business-as-usual scenario assumed that the government will continue to provide 75% subsidy for water delivery pipelines that will be required for expanding the irrigated land. The alternative scenario assumed the absence of subsidy. The benefits include the incremental net benefits of irrigated crops. The incremental net benefits were calculated as the difference between the gross margin of irrigated crops and gross margin of dryland crops. The benefits and costs were then discounted assuming the baseline financial discount rate of 10% and life span of 80 years for pipelines. The profitability was examined by calculating the net present values. In addition, the level of government subsidization required for pipelines construction was calculated from the net present value model. Finally, sensitivity analysis was undertaken for some of the uncertain variables.

7.1 Conclusions and Policy Implications

The objective of the current study was to assess the magnitude and distribution of the economic benefits of Alberta's irrigation on the provincial and national economies, and to evaluate the economic viability of further expanding the irrigated crop land from a producers' perspective. The study clearly indicates that the current 75% contribution of the provincial government to the irrigation rehabilitation program is less than what irrigation actually contributes to the provincial and national economies. It appears that the investment in irrigation expansion is not viable if funded by producers alone. Irrigation expansion is clearly a capital-intensive project as such its economic viability for producers is contingent upon the levels of subsidy and opportunity costs of producers' money.

In general, the results of the current study clearly imply that the benefits of irrigation by far go beyond the farm gate and irrigation producers are unable to recover the full capital costs for further expansion. This has important policy implications for the provision of economic incentives for producers investing in water saving irrigation technologies.

7.2 Temporal Variability of Direct Economic Impacts

Derivation of the share of irrigation producers is subject to the temporal variability of primary production. The share in the current study was estimated based on 2011. This was done to be consistent with the input-output multiplier model for crop production, which had a 2011 base year (Section 4.4). The net crop return in this year was relatively higher than the preceding years (see Figure 7-1). This is mainly due to higher crop prices in 2011.[50] The net livestock

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[50] The net return of irrigated crops fell down in 2005/06 as a result of low crop prices (Section 5.4.3). The net return was also declined in 2009/10 as a result of reduction in irrigated land (see Section 3.5).

return in 2011 was also higher than the preceding years (Statistics Canada 2016b). Therefore, it should be noted that the share of producers in 2011 could be higher than in other years.

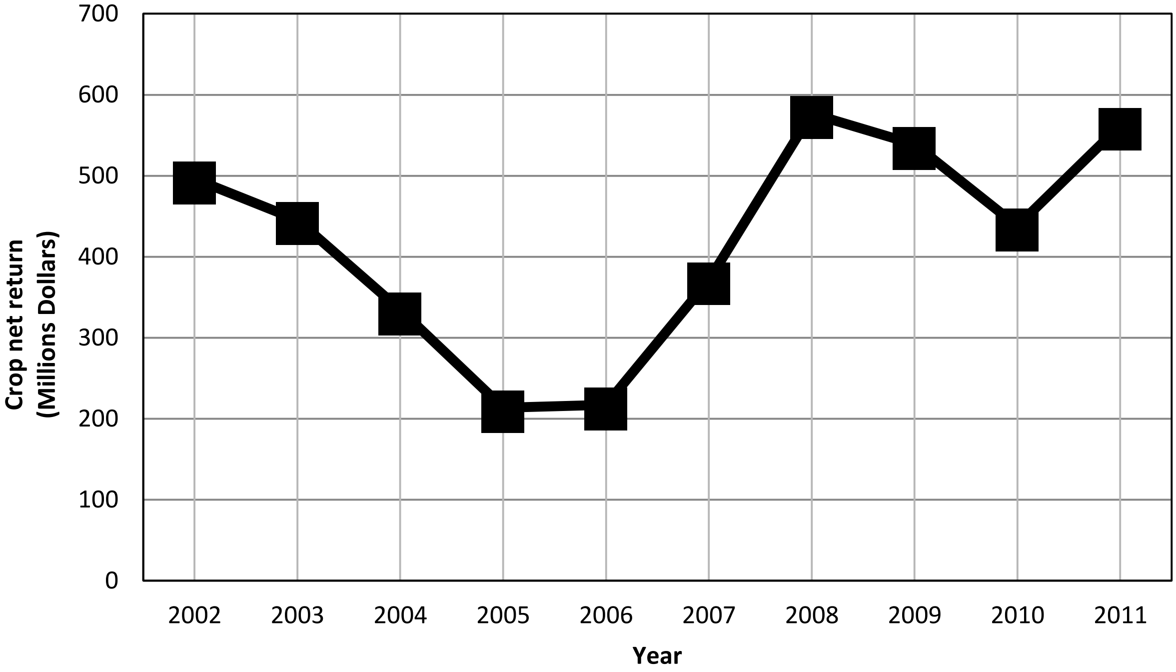

Figure 7-1: Historical net returns for irrigated crop in Alberta (in nominal crop prices)

7.3 Limitations on Secondary Economic Impacts Assessment

The secondary benefits represent an additional consideration in estimating the relative distribution of irrigation benefits. The estimation of the secondary economic impacts is not as straightforward as the estimation of direct impacts of irrigation. The secondary impacts are estimated using I-O analysis, which requires complex macroeconomic database (Section 2.3).

The current study assessed the secondary economic impacts of three irrigation activities: crop production, livestock production, and irrigation infrastructure rehabilitation and maintenance. The study attempted to estimate the secondary impacts of these activities on the Alberta's economy as well as on the national economy. In addition, the study applied the economic impacts of food processing sector estimated by previous study. To be conservative and to avoid double-counting, the secondary impacts for food processing were considered only for the provincial economy. The current study has major two strengths. First, the base values or the direct impacts used to estimate the secondary impacts were based on accurate figures obtained from Statistics Canada (Section 4.4-4.6). Second, the multipliers used in the current study were based on reliable sources, and were conservative as the double-counting effect was taken into account. Despite these strengths of the study, there are some caveats that need to be taken into account. What follows discusses the major caveats.

7.3.1 Temporal Variability of Input-Output Multipliers

Like direct effects, the multiplier effects used to assess the secondary effects also vary over time. Table 7-2 below shows the relationship between the direct GDP impact and GDP multiplier effect for the provincial primary production over the period of 2008-2011.

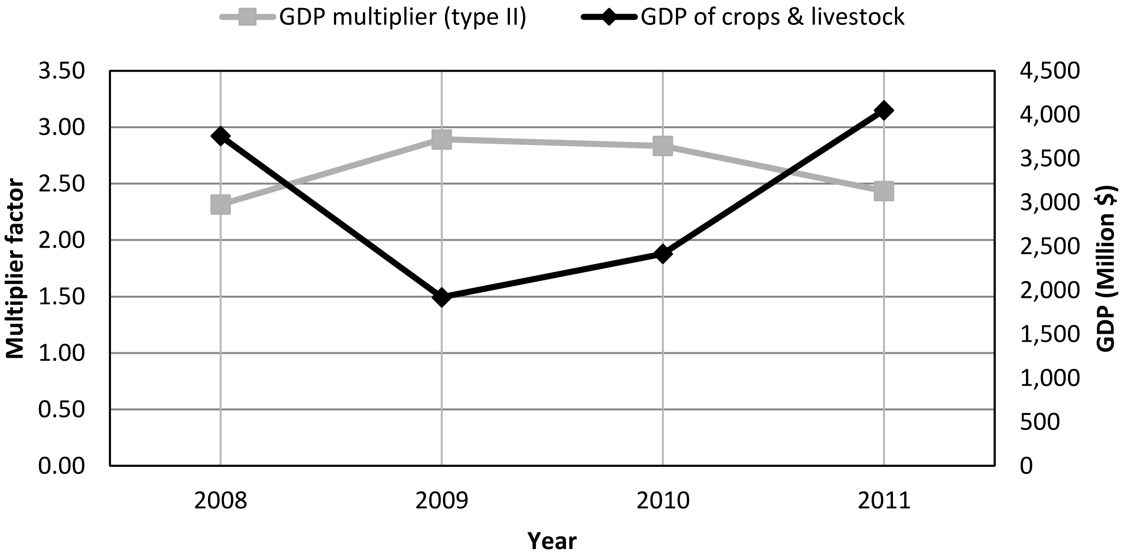

Figure 7-2: Relationship between direct GDP and Type II GDP multiplier for primary production in Alberta
Source: Adapted from GOA (2016) and Statistics Canada (2016c)

Clearly, the Type II GDP multiplier effect appears to be inversely related with the direct GDP impact of primary production. This is because the Type II multiplier effect measures the ratio of the total economy wide effects to the direct effect. If the value of the agricultural sector increases (e.g., due to higher relative prices of agricultural products) the multiplier effect for this sector declines, and vice versa.

In the current study, for crop production, both the base value and multipliers had a base year of 2011. However, for livestock production, the multiplier for 2010 was applied as the best proxy for the 2011 base value. This is because 2010 was the most recent release of Statistics Canada I-O Multiplier Table by industry, where the multiplier for livestock production is separated from crop production. The actual multiplier for livestock production in 2011 might be slightly lower than in 2010 as the above figure suggests. However, the multiplier for Alberta's cattle production derived by Kulshreshtha (2012) for year 2011 was exactly the same as the multiplier for Alberta's livestock production for year 2010 obtained from Statistics Canada.

7.3.2 Secondary Impacts of Food Processing

Double-counting is a major problem in estimating the secondary impacts for primary production industry and the forward agri-processing industry. Paterson Earth & Water Consulting Ltd (2015) estimated the secondary GDP impacts of the food-processing by excluding the double-counting effect of the secondary GDP impact of the primary production which was already counted in the primary production. Like Paterson, Clifton Associates Ltd (2008) estimated the secondary impacts of the food processing sector for an irrigation expansion project in Saskatchewan and avoided the double-counting effect.

The multiplier effect for the food processing sector published by Statistics Canada or Alberta Treasury Board and Finance did not exclude this double-counting effect and hence the multipliers are overstated. The current study estimated the economic impacts of food processing based on the conservative GDP multiplier effect obtained from Paterson Earth & Water Consulting Ltd (2015) and the actual direct GDP impact obtained from Statistics Canada (2016c). Therefore, the estimated economic impacts for food processing in the current study can be considered as realistic since it was based on the actual provincial figure, and since the double counting effect was excluded by following Paterson Earth & Water Consulting Ltd (2015).

7.3.3 Non-irrigation Benefits

In addition to the agri-food benefits generated by irrigation, Alberta's irrigation infrastructure generates external benefits to other non-irrigation beneficiaries through drought mitigation, water use, recreation, hydropower generation and commercial fishing. Paterson Earth & Water Consulting Ltd (2015) estimated the total non-irrigation benefits to be about $85 million. However, these benefits were not beyond the scope of the current study as the estimation of these benefits requires further economic valuation methods.

7.4 Limitations of the Financial Cost-Benefit Analysis Model

It should be noted that the results of a CBA of irrigation expansion like the one provided here hinge on underlying assumptions. The current study attempted to provide the estimates based on a baseline scenario that was meant to reflect the reality condition, as well as a conservative scenario, which meant to reflect a set of "pessimistic" assumptions. Yet, there are several factors and assumptions that need to be realized when interpreting and applying the results. The major ones are highlighted below.

Expected increase in irrigated land. The irrigated crop land was assumed to be increased by 10% (about 60,000 hectares) through extensification (i.e., by converting from non-irrigated or dryland crops). This is expected to happen within the irrigation districts boundary.

The study did not consider the irrigated land that could be increased outside of the districts' boundaries. This was because of a lack of data to estimate the costs for expansion beyond these boundaries. Also, the study did not consider the irrigated land that could be increased by switching from surface irrigation system into pivot system as the analysis require partial budgeting, which is beyond the scope of the current study. If these lands were included, the total expected increased land would be much higher than the current study (Phillips 2015) and the CBA results would also be changed depending on the costs and benefits for the included areas. Moreover, the study assumed that the counterfactual scenario to be dryland crop production. Practically, however, expansion may happen on dryland pasture land, which may in turn reduce the pasture land that supports livestock production. The incremental benefit might be changed depending on the value of the pasture land. The current study did not account for this effect.

Costs for pipeline and low-pressure pivot system. The capital cost for pipeline was based on the average of Eastern and Western Irrigation Districts for which there was a complete set of cost information. It should be realized that the pipelines in the two districts represent 35% of the total pipelines in the 13 districts (AAF 2015a). Similarly, the capital cost for low pressure pivot system varies across different data sources and hence an average estimate was used in the current study.

Benefits of irrigation expansion. Given the current study is interested in the financial CBA, only direct crop benefits of irrigation were considered. No attempt was made to incorporate the benefits obtained from livestock production.

Saved maintenance costs. The current study did not account for the advantage of pipelines over open canals in terms of reducing maintenance costs. This was because of lack of data. Hohm (2016) said that the irrigation districts do not have a numerical value for saved maintenance costs (personal com.). FAO indicated that replacing open canals with closed pipelines would reduce the maintenance costs from one-tenth to one-quarter (Phocaides 2000).

Variation across districts. The results represent the average condition for the 13 irrigation districts. However, there are certain variations among the districts in terms of crop-mixes, irrigation methods, production costs, infrastructure, expansion potential, and so on (AAF 2015a). For instance, Klein et al (2012b) indicated that the crop margin for irrigated crops and dryland crops varies across sub-basins (Oldman, Bow, Red-Deer and South Saskatchewan) in southern Alberta. Moreover, it should be noted that the results cannot represent the private irrigation projects as there is also a significant difference between the district and private irrigators (Nicol et al 2010).

Future policies and uncertainties. No attempt was made in the current study to estimate the potential impacts of future changes in the agri-food processing industry, and trade policies (e.g., Trans Pacific Trade Agreement), climate, or other socio-economic conditions.

7.5 Further Research

Social cost-benefit analysis of irrigation expansion is recommended to evaluate the welfare economic values of water used for irrigation from the provincial perspective. This will be important to understand the economic tradeoffs between the irrigation sector and other competing sectors (i.e., urban and environmental uses) as the government of Alberta envisioned achieving a sustainable water management in Water for Life Strategy. A rigorous social cost-benefit analysis involves estimating the external benefits and costs besides the direct benefits and costs of irrigation projects.

The current study relied on the fact that the water required for expansion comes from water conserved as a result of replacing the open-canals with buried pipelines and using additional low-pressure pivots. The two technologies have different water-use efficiency and economic efficiency. Further research is required to evaluate the economic efficiency of different water-saving alternatives in Alberta and thereby identify the least-cost option. In China, for instance, the cost-effectiveness of on-farm and conveyance water-saving irrigation technologies was evaluated to understand the economic feasibility of water-saving irrigation technologies as an approach to coping with climate change (Zou et al 2013). Similarly, in Australia, the cost-effectiveness of several water saving options was investigated, and it was concluded that public policies to subsidize investments for improvements in irrigation efficiency are not cost-effective compared to alternatives, such as buying water through markets (Qureshi et al 2010).

The current study is mainly based on secondary data sources. A first-hand survey is required particularly to understand producers' decision making behaviour regarding future irrigation expansion, crop-mix, crop-livestock interaction, and also to get a numerical value for the advantage of pipelines over open canals in term of reducing the maintenance costs.

Moreover, further research is required at a district level to investigate the variation of NPVs across districts. Finally, a systematic sensitivity analysis is recommended using Monte Carlo simulation to understand the effects of several factors in a continuous scale.

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Appendix A Variable Costs of Irrigated Crops and Dryland Crops

Table A: Variable costs for irrigated crops in southern Alberta (in 2011, dollars per hectare)

Crops	Seed	Fertilizer	Chemicals	Crop Insurance	Trucking & Marketing	Fuel, Oil & Lube	Irrigation Fuel and Electricity	Repair-Machinery & Building	Utilities & Misc.	Custom Work & Specialized Labour	Labour & Benefits	Storage	Total Variable Costs
Durum	74	202	69	52	42	64	41	48	32	35	24	0	682
Hard Wheat	84	202	69	37	38	63	38	47	32	35	24	0	669
CPS	80	202	58	39	42	64	41	48	32	35	24	0	665
Soft Wheat	71	216	69	41	46	65	38	49	32	35	24	0	686
Barley	56	202	69	31	37	65	41	49	32	35	24	0	642
Canola	98	248	100	21	21	65	63	46	32	27	24	0	744
Beans	124	191	164	106	32	95	51	84	43	80	112	0	1,081
Potatoes	845	649	804	0	371	262	139	257	256	321	497	330	4,732
Sugar Beets	291	221	69	21	283	203	76	131	57	60	124	41	1,578
Alfalfa Hay	29	54	5	0	41	98	65	56	68	15	37	0	469
Barley Silage	56	196	23	0	124	87	84	42	43	80	50	0	783
Corn Silage	56	196	23	0	124	87	84	42	43	80	50	0	783
Grass Hay	37	54	5	0	41	98	65	56	68	15	37	0	477

Source: AAF (2015b)

Table B: Variable costs for dryland crops in southern Alberta (in 2011, dollars per hectare)

Crop	Seed	Fertilizer	Chemicals	Crop Insurance	Trucking & Marketing	Fuel, Oil & Lube	Irrigation Fuel and Electricity	Repair-Machinery & Building	Utilities & Misc.	Custom Work & Specialized Labour	Labour & Benefits	Storage	Total Variable Costs
Soil Zone: Brown (Stubble)													
Durum	64	104	52	34	17	29	0	21	18	4	15	0	358
Hard Wheat	66	104	52	28	17	29	0	21	18	4	15	0	354
CPS	62	104	52	35	19	29	0	21	18	4	15	0	361
Soft Wheat	0	0	0	0	0	0	0	0	0	0	0	0	0
Barley	39	125	47	28	20	32	0	21	18	4	15	0	348
Oat	27	98	18	27	16	32	0	16	13	8	15	0	270
Canola	78	148	54	53	9	34	0	20	18	8	15	0	436
Field Peas	97	46	46	34	17	29	0	20	18	8	15	0	330
Alfalfa Hay	21	27	3	0	39	35	0	17	13	8	12	0	175
Cereal Silage	45	112	23	0	51	32	0	17	17	120	12	0	430
Soil Zone: Dark Brown (Stubble)													
Durum	64	125	62	34	17	29	0	21	21	11	15	0	399
Hard Wheat	66	125	62	28	17	29	0	21	21	11	15	0	395
CPS	62	125	52	35	21	30	0	21	21	11	15	0	394
Soft Wheat	0	0	0	0	0	0	0	0	0	0	0	0	0
Barley	45	139	47	25	20	32	0	21	21	11	15	0	375
Oat	30	106	23	23	16	28	0	17	15	7	15	0	279
Canola	98	173	60	46	11	35	0	21	21	11	15	0	491
Field Peas	97	46	57	34	19	34	0	21	21	11	15	0	355
Alfalfa Hay	21	33	3	0	39	35	0	17	15	8	12	0	183
Cereal Silage	45	112	23	0	51	32	0	17	17	120	12	0	430

Appendix B Economic Impacts of Crop Production

Table C: Calculation of economic impacts of crop production (in 2011)

	Particulars	Crops	Irrigated (I)	Dryland (D)	Alberta(A)	Methods/description
A	Major crops (ha)	Cereals	186,284	4,190,939		Major crops selected in the crop budget model include a total of 13 types of irrigated crops, and 9 types of dryland crops (see Section 5.4)
A1		Oil seeds	80,502	2,376,598		
A2		Speciality	55,737	278,960		
A3		Forages	160,785	1,978,658		
A4		Total	483,307	8,825,156		
B	All crops (ha)	Cereals	204,204	4,457,696		All cropped land including miscellaneous crops not selected in A
B1		Oil seeds	91,474	2,419,226		
B2		Speciality	106,528	368,266		
B3		Forages	172,112	1,989,488		
B4		Total	574,317	9,234,676		
C	Net returns (NR) for major crops ($)	Cereals	85,569,062	930,936,661		Net return for selected crops was calculated as a difference between gross return and cash costs of production (see Section 4.4)
C1		Oil seeds	60,195,747	1,111,410,922		
C2		Speciality	191,099,428	65,288,569		
C3		Forages	32,518,768	282,046,648		
C4		Total	369,383,005	2,389,682,800		
D	Net returns for all crops ($)	Cereals	93,800,581	990,191,583		Net returns for all crops calculated by multiplying C by the ratio of B to A
D1		Oil seeds	68,400,338	1,131,345,694		
D2		Speciality	365,239,006	86,189,765		
D3		Forages	34,809,657	283,590,459		
D4		Total	562,249,581	2,491,317,501		
E	Value-added (VA) for major ($)	Cereals	142,798,928	1,479,412,965		Value-added or GDP for selected crops calculated as the difference between gross return and costs for intermediate inputs (see Section 6.1.1)
E1		Oil seeds	85,503,483	1,424,490,553		
E2		Speciality	227,097,374	101,488,999		
E3		Forages	80,855,869	439,790,983		
E4		Total	536,255,654	3,445,183,500		
F	VA for all ($)	Cereals	156,535,808	1,573,578,879	1,730,114,687	VA for all crops calculated by multiplying E by the ratio of B to A
F1		Oil seeds	97,157,481	1,450,040,863	1,547,198,344	
F2		Speciality	434,040,122	133,979,242	568,019,365	
F3		Forages	86,552,021	442,198,223	528,750,244	
F4		Total	774,285,432	3,599,797,207	4,374,082,639	
F5		Share	18%	82%	100%	Share to Alberta (F4)
G	VA actual provincial ($)				3,701,100,000	Statics Canada (2016c)
H	VA calculated/VA actual				85%	G/F4
I	VA adjusted for actual ($)		655,156,304	3,045,943,696		H*F4
J	NR adjusted for actual ($)		475,743,624	2,108,011,202		H*D4
			Irrigated		**Dryland**	
			Alberta	**Canada**	**Alberta**	**Canada**
K	Type II GDP multiplier		1.38	1.58	1.52	1.82
L	Total GDP impact (K*I)		905,470,154	1,033,814,250	4,624,552,154	5,542,373,907
M	Total GDP (per irrigated ha)		905,470,154	1,033,814,250	287,607,300	344,687,905

Appendix C Economic Impacts of Livestock Production

Table D: Calculation of economic impacts of livestock production (in 2011)

Particulars		Items	Irrigated (I)	Dry (D)	Alberta (A)	Description
A	Cropped land (ha)		612,447	9,141,401	9,753,848	Statistics Canada (2016a)
B	Farms (%)	Cattle and calves	18.3	81.7		IWMSC (2002)
B1		Dairy	15	85		
B2		Hog	13.7	86.3		
B3		Sheep and lamb	19.6	80.4		
B4		Poultry and eggs	9.3	90.7		
B5		Honey	10	90		
B6		Others	16.5	83.5		
C	Cash sales ($)	Cattle and calves	554,009,754	2,471,712,246	3,025,722,000	Alberta livestock sales Statistics Canada 2016c) For irrigated and dryalnd calculated as B*C (A)
C1		Dairy	75,419,035	428,722,965	504,142,000	
C2		Hog	57,289,114	359,359,886	416,649,000	
C3		Sheep and lamb	4,224,623	17,337,377	21,562,000	
C4		Poultry and eggs	27,849,626	272,587,374	300,437,000	
C5		Honey	5,796,829	52,166,171	57,963,000	
C6		Others	15,316,307	77,282,693	92,599,000	
C7		Total	739,905,289	3,679,168,711	4,419,074,000	
C8		Share	17%	83%	100%	
D	VA actual provincial				347,900,000	Statistics Canada (2016c)
E	VA irrigated vs dryland		58,250,450	289,649,550		C8*D
			Irrigated		**Dryland**	
			Alberta	**Canada**	**Alberta**	**Canada**
F	Total GDP multiplier		0.72	1.04	0.72	1.04
G	Total GDP impact (C7*F)		532,731,808	769,501,500	2,649,001,472	3,826,335,460
H	Total GDP (Irrigated land equivalence based on A)				177,475,356	256,353,292

Appendix D Economic Impacts of Food Processing

Table E: Economic impacts of Alberta's irrigation-related food-processing activities (in 2011)

	Alberta Direct GDP 2011 (Million $)			Irrigation GDP Impact (Paterson 2015)			
Food Processing Industry	Paterson (2015)	Statistics Canada (2015)	Ratio	Share of Irrigation (%)	Direct Impact (Million $)	Total GDP Multiplier	Total Impact (Million $)
	A	B	C=A/B	D	E=A*D	F	G=E*F
Meat Processing	1,416	820	1.73	16.3	231	3.24	748
Grain Milling	717	267	2.68	18.3	131	2.53	332
Animal Food	115	119	0.96	18.3	21	3.59	75
Fruits & Vegetables	102	x		61.5	63	2.75	173
Other Food	598	x		13.4	80	4.56	365
Total	2,948	2,264	1.30	17.8	525	3.23	1,693
Total (Scaled down by 23%)[a]							1,301

a-The ratio of $2.264 billion to $2.948 billion.

x- means not available due to confidentiality

Appendix E Annual Cash Flows

Table F: Summary of costs and benefits [Constant 2011 Canadian dollars]

Items	Description (units)	Values	Method
Expansion	Total expansion (ha)	59,225	Phillips (2015); AAF(2015)
	Annual (ha/year)	3,623	Average 1999-2014 (AAF 2015A)
	Implementation period (years)	16	Total divided by annual
Crop benefit	Incremental gross margin, IGM ($/ha)	660	Irrigated minus dryland crops
	Total IGM ($ per 16 years)	39,117,161	$/ha of IGM times total expansion
	Annual IGM ($/yr)	2,393,158	Total divided by 16 years
Pipeline	Total increase (km)	1,677	Philips (2015); AAF(2015)
	Annual increase (km/yr)	106	Average 1999-2014 (AAF 2015A)
	Implementation period (years)	16	Total divided by annual
	Capital costs ($/km)	260,052	WID & EID average of 2002-14
	Total capital costs ($ per 16 years)	436,107,978	$/km costs times total pipelines
	Annual capital costs ($/yr)	27,691,872	Total divided by 16 years
Low Pressure Pivot	Total increase (ha)	59,225	Philips (2015); AAF(2015)
	Annual (ha/yr)	3,623	Average 1999-2014
	Implementation period (years)	16	Total divided by annual
	Capital costs ($/ha)	2,010	AAF (2010); Hohm (2016)
	Total capital costs ($ per 16 years)	119,042,223	$/ha cost times total pivots
	Annual capital costs of ($/yr)	7,282,912	Total divided by 16 years

Appendix F Annual Cashflow Development

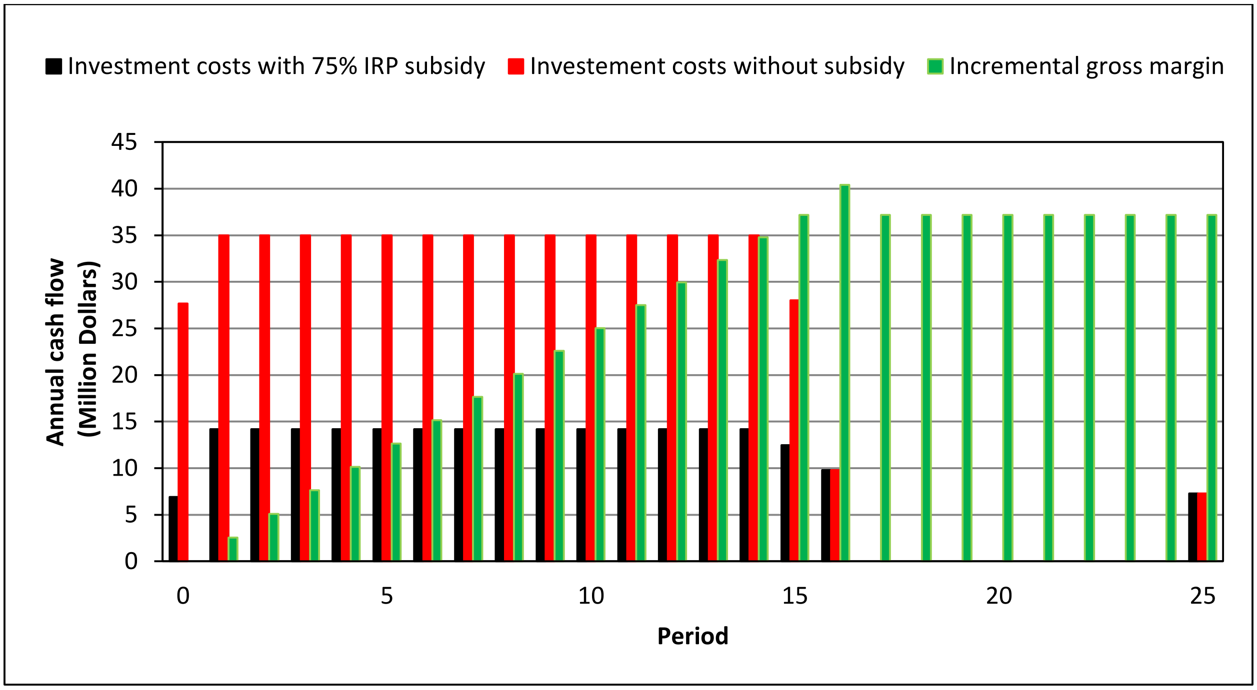

Figure A: Annual cash flows for the first 25 years

Note: the implementation period is 16 years; low pivots are replaced every 25 years; investment costs include for pipelines and low pressure pivots but subsidy is considered only for pipelines or irrigation rehabilitation program (IRP).

Appendix G Net Present Value Calculation

Table G: Net present values of irrigation expansion (values are in million dollars and net present value is computed at discount rate of 10%)

Period	Pipeline costs without Subsidy	Pipeline costs with Subsiy	Pivot costs	Net crop return	Net crop return accumulated	Net present value without subsidy	Net present value with subsidy
1	27.69	6.92	0.00	0.00	0.00	-25.17	-6.29
2	27.69	6.92	7.28	2.55	2.55	-26.80	-9.63
3	27.69	6.92	7.28	2.54	5.09	-22.45	-6.85
4	27.69	6.92	7.28	2.53	7.63	-18.68	-4.49
5	27.69	6.92	7.28	2.52	10.15	-15.42	-2.52
6	27.69	6.92	7.28	2.51	12.66	-12.60	-0.87
7	27.69	6.92	7.28	2.50	15.16	-10.17	0.49
8	27.69	6.92	7.28	2.49	17.64	-8.08	1.60
9	27.69	6.92	7.28	2.48	20.12	-6.30	2.51
10	27.69	6.92	7.28	2.47	22.59	-4.77	3.23
11	27.69	6.92	7.28	2.46	25.05	-3.48	3.80
12	27.69	6.92	7.28	2.45	27.49	-2.38	4.23
13	27.69	6.92	7.28	2.44	29.93	-1.46	4.55
14	27.69	6.92	7.28	2.43	32.35	-0.69	4.78
15	27.69	6.92	7.28	2.41	34.77	-0.05	4.92
16	20.73	5.18	7.28	2.40	37.17	1.99	5.38
17			9.80	3.23	40.41	6.06	6.06
18			0.00		37.17	6.69	6.69
19			0.00		37.17	6.08	6.08
20			0.00		37.17	5.53	5.53
21			0.00		37.17	5.02	5.02
22			0.00		37.17	4.57	4.57
23			0.00		37.17	4.15	4.15
24			0.00		37.17	3.77	3.77
25			0.00		37.17	3.43	3.43
26			7.28		37.17	2.51	2.51
27			7.28		37.17	2.28	2.28
28			7.28		37.17	2.07	2.07
29			7.28		37.17	1.88	1.88
30			7.28		37.17	1.71	1.71
31			7.28		37.17	1.56	1.56
32			7.28		37.17	1.42	1.42
33			7.28		37.17	1.29	1.29
34			7.28		37.17	1.17	1.17
35			7.28		37.17	1.06	1.06
36			7.28		37.17	0.97	0.97
37			7.28		37.17	0.88	0.88
38			7.28		37.17	0.80	0.80

39			7.28		37.17	0.73	0.73
40			7.28		37.17	0.66	0.66
41			9.80		37.17	0.55	0.55
42			0.00		37.17	0.68	0.68
43			0.00		37.17	0.62	0.62
44			0.00		37.17	0.56	0.56
45			0.00		37.17	0.51	0.51
46			0.00		37.17	0.46	0.46
47			0.00		37.17	0.42	0.42
48			0.00		37.17	0.38	0.38
49			0.00		37.17	0.35	0.35
50			7.28		37.17	0.25	0.25
51			7.28		37.17	0.23	0.23
52			7.28		37.17	0.21	0.21
53			7.28		37.17	0.19	0.19
54			7.28		37.17	0.17	0.17
55			7.28		37.17	0.16	0.16
56			7.28		37.17	0.14	0.14
57			7.28		37.17	0.13	0.13
58			7.28		37.17	0.12	0.12
59			7.28		37.17	0.11	0.11
60			7.28		37.17	0.10	0.10
61			7.28		37.17	0.09	0.09
62			7.28		37.17	0.08	0.08
63			7.28		37.17	0.07	0.07
64			7.28		37.17	0.07	0.07
65			9.80		37.17	0.06	0.06
66			0.00		37.17	0.07	0.07
67			0.00		37.17	0.06	0.06
68			0.00		37.17	0.06	0.06
69			0.00		37.17	0.05	0.05
70			0.00		37.17	0.05	0.05
71			0.00		37.17	0.04	0.04
72			0.00		37.17	0.04	0.04
73			0.00		37.17	0.04	0.04
74			7.28		37.17	0.03	0.03
75			7.28		37.17	0.02	0.02
76			7.28		37.17	0.02	0.02
77			7.28		37.17	0.02	0.02
78			7.28		37.17	0.02	0.02
79			7.28		37.17	0.02	0.02
80			7.28		37.17	0.01	0.01
	Net present values					***-83***	***78***

Appendix H International Irrigation Management Experiences

The irrigation experiences of five countries (the United States, Australia, Mexico, Ethiopia and Canada) are discussed below.

United States of America

Although the United States (US) has abundant water resources, more than 50% of its territory is vulnerable to drought to some extent (OECD 1999). Particularly, the Western portion of the country does not get enough rainfall to support the desired agricultural production (Keleta et al 1982). Irrigation is the major water consuming sector representing 75-90% of the developed water supplies (Gollehon and Quinby 2000; Schoengold et al 2004). The irrigated crop land accounts for 11% of total arable land (OECD 1999). Majority of the irrigation occurs in the western part of the country (Schoengold et al 2004).

Historically, the irrigation water management is the US had faced several problems. These include: (i) the need to comply with increasingly stringent environmental and natural habitat restoration regulations; (ii) the need to increase urban water supply to meet urban growth needs; (iii) the need to improve the economic efficiency of water used in the agricultural sector; and (iv) the need to raise more revenue from users in order to recover a larger proportion of water supply costs from irrigators (Wahl 1989, cited by Wichelns 2010, 34).

A number of irrigation water pricing policy reforms were undertaken to address these problems since the establishment of the US Bureau of Reclamation (USBR) in 1902 (Keleta et al 1982). What follows briefs the major reforms.

In 1902, the USBR established the initial policy for constructing and managing irrigation projects (Gollehon and Quinby 2000). The policy designed a full cost recovery principle, where irrigators were required to pay the annual O & M costs, and capital costs of construction through ten years of repayment. However, this principle was not successful since repayments of cost to the government were not satisfactory. This was mainly due to lack of enough farm income (Gollehon and Quinby 2000).

Realizing the problem of full cost recovery principle, the new policy of cost recovery was proposed by the Reclamation Act in 1939. The new policy required farmers to repay the capital costs free of interests within 40 years besides the annual O & M costs. However, the new policy recognized farmers' ability to pay, where irrigation costs beyond their ability were supposed to be recovered from surplus of hydroelectric power and other beneficiaries of the irrigation projects (Keleta et al 1982; Teerink and Nakashim 1993). However, this cost-sharing policy was eventually became questionable in recovering irrigation as the O & M costs increased over time[51].

As a result, the Reclamation Reform Act of 1982 was passed in California's Central Valley Projects (CVP) reinstating the full cost recovery principle (GAO 1991, cited in Wichelns 2010, 15). Since then, irrigation water price has dramatically increased to recover the full costs of irrigation (Wichelns 2010).

In 1992, the California’s Central Valley Project Improvement Act (CVPIA) was established seeking to motivate further improvements in water management, facilitate water trading, raise water pricing through increasing blocking-rate structure[52], and reallocate a portion of the CVP’s agricultural water supply to environmental uses (Fischhendler and Zilberman 2005

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[51] In 1984, the US General Accounting Office reported that irrigation, municipal and industrial customers had repaid only 5.5% of the capital investment of US$1.38 billion. Also, the irrigation fees collected have been insufficient to cover annual O & M costs (cited by Teerink and Nakashima 1993, 37).

[52] Increasing blocking-rate was applied in such a way that water consumed above the 90 percentile of the specified volume of water contract to be charged up to UD$ 0.5 per cubic of meter. The ultimate purpose of this scheme was to generate sufficient revenue for the environmental restoration fund (GAO 1991, cited in Wichelns 2010).

cited in Wichelns 2010, 15). Moreover, an Emergency Drought Water Bank was established to facilitate the transfer of water from willing sellers to willing buyers (Teerink and Nakashim 1993; Wichelns 2010).

Two key lessons can be learned from the US policy reforms.

First, full cost recovery principle resolved financial problems. Cost recovery principle below the full cost principle (e.g., ability to pay) caused not only unsustainable financial problem but also inefficient water use problem (Schoengold et al 2004; Wichelns 2010). Consequently, both the United States Congress and state governments enforce the full cost recovery principle until 2030 (Wichelns 2010).

Second, the combination of full cost recovery with appropriate water markets, legal frameworks, and active famers participation are important to achieve successful outcomes in meeting the growing demand for urban, environmental, and agricultural uses (Wichelns 2010).

Australia

Australia is the driest continent. The water shortage problem has led the continent to reform its water policy so as to optimize the water uses. The irrigated crop land in Australia accounts for 4% of the total arable land (OECD 1999).

Until the late 1980s, irrigation water pricing was determined by social and developmental considerations (Industry Commission 1992). This pricing policy caused a number of fundamental problems, such as low cost-recovery, negative rate of returns, strong dependence on government funding, severe degradation of environment, lack of transparency in water fee collection (OECD 1999; Parker and Speed 2010).

As a result, in 1990s, the Council of Australian Governments (COAG) established a milestone national water pricing framework by emphasizing full cost recovery principle (Grieg 1997)[53]. This policy was a result of a "National competition economic" policy reform that set forth a framework for re-engineering the Australian economy. The policy emphasized market-oriented economic solution, privatization, and low government subsidy (Young 2010). The water reforms and the full cost recovery principles had several objectives, such as promoting water trading, improving institutional arrangements, separation of land and water use rights, increasing involvement of farmers, and promoting sound environmental management of water ecosystems (OECD 1999).

The water reform implemented irrigation management transfer (IMT), where the irrigation managements and ownerships transferred from the state to the local irrigation companies and water user associations (Grieg 1997; Poddar et al 2011).

The implementation of IMT and full costs recovery have improved irrigation management systems with volumetric water supply, reliable water delivery, effective cost recovery, financial autonomy, effective maintenance, and efficient water reallocation to more efficient users via trading (Mapson and Poulton 2001). The reform has resulted in an increase in water charge by 35 - 50% (Grieg 1997).

The key lesson learned from Australia is that water pricing reform need to be implemented in conjunction with other water policy strategies, such as water trading, environmental policy reforms, institutional reforms (Grieg 1997; OECD 1999; Parker and Speed 2010).

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[53] Full costs as defined by the COAG, include the following five elements:(1) operating and maintenance expenses; (2) administrative expenses; (3) environmental externalities (e.g., salinity impacts) (4) depreciation on a "replacement cost" basis; and (5) the opportunity costs of capital (Grieg, 1997).

Mexico

Majority of Mexico's land area is classified as arid and semiarid (Sam and Johnson 1997). The irrigated crop land accounts for 25% of the cultivated land (OECD 1999).

Until the late 1980s, the irrigation system was owned, funded and managed by the state. Mexico's economic crises in 1982 caused several adverse impacts on the irrigation sector. As a result of the crises, the government was not be able to provide funding for irrigation infrastructure maintenance and rehabilitation. This led to the disclosure of water delivery services for about 1.5 million hectares of irrigated land (Meinzen-Dick 1997). The O & M costs paid by farmers declined by 60 % (Sam and Johnson 1997).

To solve these problems, in 1990, the government established a national "irrigation module" that aimed to transfer irrigation management responsibilities from the government to the water users associations (WUAs) (Svendsen et al 1997). The IMT reform has achieved a significant level of financial self-sufficiency very quickly. After four years of the reform, the IMT and the associated increases in water charges have significantly increased recovery of O & M costs (Sam and Johnson 1997)[54]. This increased revenue has in turn supported rehabilitation and maintenance activities. The reform has also improved water use efficiency (Sam and Johnson 1997).

Despite the successful achievements of water reforms in Mexico, the following three major problems were emerged (Sam and Johnson 1997).

- Farmers were unable to pay irrigation costs at the time of drought and lack of sufficient government funding failed to handle drought problem.

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[54] Water prices increased by 45–180% from 1990 to 1996 (Garrido and Calatrava 2010).

- Use of volumetric water pricing suffered from low (or zero) fee collection during drought condition in some irrigation districts.
- Lack of clearly defined water property rights caused conflicts between water users. As a result, some of the water users turned out to be reluctant to pay for irrigation water services.

Ethiopia

Ethiopia has abundant water resources that could be used for wide range of irrigation developments. However, the developed water is by far below the available potential due to lack of adequate infrastructure (Awulachew et al 2007). In 2005, about 250,000 hectares (5% of the arable land) was irrigated while the irrigation potential has been estimated to be about 4.25 million hectares (Awulachew et al 2005). The irrigated land doubled in 2010 according to the estimate of International Commission on Irrigation and Drainage (ICID) (2014). Yet, majority of the irrigation projects are small-scale[55] and traditional schemes (Awulachew et al 2005)

Since 1990s, Ethiopia's economic development strategy established on the basis of Agriculture Development Led Industrialization (ADLI)[56]. The government has prioritized irrigation development strategy to support ADLI with principal objectives to achieve food self sufficiency and satisfy the raw material demand of local industries (Cherre 2006).

Historically, irrigation was owned and managed by the government. This management system faced several challenges, such as low rate of cost recovery, poor irrigation efficiency,

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[55] Irrigation projects in Ethiopia are identified as large-scale irrigation if the size of command area is greater than 3,000 hectares, medium-scale if it falls in the range of 200 to 3,000 hectares and small-scale if it is covering less than 200 hectares (MoWR 2001; Awulachew et al 2005).

[56] Agriculture is central to the Ethiopian economy, employing about 86% of the population, contributing around 52% of the gross domestic product and generating 90% of export earnings (Castalia Strategic Advisors 2008).

lack of government funding, and poor rehabilitation and maintenance (Castalia Strategic Advisors 2008).

Recently, the government designed a new strategy of irrigation development to accomplish Government's Plan for Accelerated and Sustained Development to End Poverty (PASDEP) and the Government's strategy for meeting the Millennium Development Goals. In 2008, the government of Ethiopia and World Bank established an agreement to implement the Ethiopian Nile Irrigation and Drainage Project (ENIDP) using the principles of public-private partnership (PPP). The project is expected to double the existing irrigated land by 2016. The major objectives of implementing PPP approach were: to improve the reliability of irrigation to smallholders; to improve water management practices; to involve the private sector in the development and operation of irrigation schemes; to attract investors in commercial farming; to provide farmers with access to inputs, post-harvest services, infrastructure and other services (Castalia Strategic Advisors 2008).

The PPP contract involves a number of guiding principles that include: (1) the private operator finances 5-10% of the capital costs of construction and the government finances the remaining; (2) farmers pay initially portion of the O & M costs and gradually the full O & M costs; (3) the government collect water changes through WUAs; (4) WUAs assists farmers in purchasing agricultural inputs, marketing crops, and so on; (5) the private operator is responsible for building, operating, maintaining, and delivering water to farmers; and (6) financial autonomy institution is formed (Castalia Strategic Advisors 2008).

Trier (2014) highlighted several lessons of PPP learned from the experiences of three countries (Ethiopia, Brazil and Morocco). The major lessons are described below.

- The PPP models are more appropriate for new development than for the exiting irrigation schemes because of more resistance and additional complexity involved.
- The PPP models are more appropriate for modern irrigation, which require huge investments.
- The development of PPP initiative requires a sound and efficient marketing campaign.
- PPP in the irrigation sector is recommended only in countries with successful previous experience with PPP in other sectors and with a solid legal PPP framework.

Canada

Canada is considered as a water-rich country, which accounts for 20% of the World's fresh water stored in the lakes. However, this water abundance is "more myth than reality" due to two major reasons (Sprague 2007, cited in Corkal and Adkins 2008). Firstly, there is a spatial disparity between the supply of and demand for water. While the majority of the water supplies (67%) flow northward, about 90% of Canada's population resides in the south where most of the arable land exists. Secondly, it should be noted that Canada has only 6.5% of the world's renewable water supply. The availability of water is a challenging problem in the semi-arid western provinces, such as Alberta, British Columbia and Saskatchewan (Corkal and Adkins 2008).

The irrigated land accounts for two per cent of the total arable land in Canada (OECD 1999). About two third of the irrigated land occurs in Alberta (Statistics Canada 2011). While there is a potential for expansion of irrigation, limitations exist in terms of infrastructure and access to suitable water supplies (Corkal and Adkins 2008). Agriculture is a major consumer (70-80%) of Canada's water resources (Corkal and Adkins 2008).

Historically, water pricing policies in Canada has focused on managing water supply (Horbulyk 1997). Water demand was allocated using established water licenses, rights and other sharing rules. Irrigators are charged for irrigation services on a flat rate basis. Canada is one of the OECD countries with the lowest cost-recovery for irrigation water supply (Cornish et al 2004). Low cost-recovery coupled with tighter federal budgets has prompted irrigation water pricing reforms in 1980s (Corkal and Adkins 2008). Water management policy transformed from a supply development focus to a sustainable development focus[57] (Corkal and Adkins 2008).

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[57] An integrated water resource management (IWRM) approach was applied in the management of water, land and agricultural resources (Roy et al 2009).