THE VALUE-ADDED OF ENVIRONMENTAL MONITORING FOR CUMULATIVE EFFECTS MANAGEMENTAND DECISION-MAKING IN THE LOWER ATHABASCA PLANNING REGION OF ALBERTA, CANADA

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ABSTRACT

There has emerged in recent years a general consensus that anthropogenic development, including energy resource extraction, agriculture, and urban expansion, pose significant threats to water security and the health of watersheds in Canada. A component of identifying and managing the cumulative effects (CE) of this development is data from short and long-term monitoring programs to support decisions about water use and development. However, attention to CE management is often short-lived, and is exacerbated by the fragmented nature of monitoring data and programs. It is therefore important to understand unsuccessful CE efforts of the past to help determine features of future CE monitoring. In addition, it is often argued that CE management is ineffective due to challenges associated with institutional and organizational arrangements for mobilizing CE monitoring with decision-making. This thesis explores whether and how current environmental monitoring programs and organizations support CE management for land-use decision-making. The research is conducted in the Lower Athabasca planning region of Alberta, Canada, where a variety of industrial activities, a CE approach to decision-making, and a variety of monitoring efforts are ongoing. First, this thesis presents a review of the past and present monitoring programs, identifying reoccurring themes in the failure of monitoring programs, and deriving lessons for other jurisdictions. It then explores the task of integrating environmental monitoring with CE management and decision-making based on semi-structured interviews with CE monitoring professionals, to understand perspectives on the current state-of-practice while considering other options. Results show that three approaches exist for this integration: a distributed monitoring system, a one-window system, and an independent exploratory system. Each system has its own strengths and weaknesses, and the decision to implement any one system depends on the purpose of existing monitoring; the credibility and depth of understanding of region-specific scientific underpinnings; and the needs of CE decision-making. Instead of being susceptible to shorter-term institutional change, monitoring expectations should be guided by the immediate and longer-term needs of decision-making, and supported, implemented, and maintained by credible science. Monitoring to advance CE practice should therefore be the ongoing product of cohesive CE visioning, with oversight from independent scientific efforts.

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ABMI – Alberta Biodiversity Monitoring Program

AEMERA – Alberta Environmental Monitoring, Evaluation and Reporting Agency

AOSERP – Athabasca Oil Sands Environmental Research Program

ARWQI – Alberta River Water Quality Index

CE – Cumulative Effects

CEMA – Cumulative Environmental Management Association

EIA – Environmental Impact Assessment

EMSD – Environmental Monitoring and Science Division

JOSM – Joint Oil Sands Monitoring

LARP - Lower Athabasca Regional Plan

LICA – Lakeland Industry & Community Association

LTRN – Long Term River Network

LUF – Land-Use Framework

LUF CE – Land-Use Framework Cumulative Effects

NRBS – Northern River Basins Study

NREI – Northern Rivers Ecosystem Initiative

RAMP – Regional Aquatics Monitoring Program

RGMN – Regional Groundwater Monitoring Network

WBEA – Wood Buffalo Environmental Association

WSC – Water Survey of Canada

CHAPTER 1

INTRODUCTION

1.1 Introduction

Water security is broadly defined as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems" (UNU 2013). However, there has emerged in recent years a general consensus that anthropogenic development, including energy resource extraction, agriculture, and urban expansion, pose significant threats to water security and the health of watersheds (Vörösmarty et al., 2010; WWAP, 2015), particularly in western Canada (Schindler & Donahue, 2006; Ball et al., 2013b; Noble & Basnet, 2015). Project-based environmental impact assessment (EIA) is the primary regulatory instrument in Canada for assessing and managing the potential impacts of development on the environment (Noble, 2015a), including impacts to Canada's freshwater systems (Munkittrick et al. 2000; Dubé, 2015). Broadly speaking, EIA is a "look before you leap" approach to environmental decision-making, where information is gathered and analyzed in order to influence land-use decisions in favour of development (Noble, 2015a). However, project-based EIA, due to its project-by-project approach to development planning and decision making, has long been recognized as insufficient to address the cumulative effects (CE) caused by human development actions (Odum, 1982; Kennedy, 1995; Dubé, 2003; Duinker & Greig, 2006; Harriman & Noble, 2008; Noble 2015b).

Understanding the true significance of the impacts of any single project on the environment requires at least some consideration of the impacts of all other disturbances in the project's regional environment (Kennedy, 1995; Noble, 2015a). The temporal and spatial boundaries associated with project-based EIA, however, and its focus on single-project decisions, are insufficient to address the array of developments and impacts acting upon a region or watershed (Noble et al., 2011; Canter et al., 2014). The challenges to CE are often associated with the lack of information available to project proponents regarding the impacts of other land uses in the project's regional environment (Therivel et al., 1992; Ball et al., 2013a); but more often associated with the complexity of CE – that CE may emerge long after (Hegmann et al., 1999) or far downstream of where the development has taken place (Dubé, 2003; Canter et al., 2014). In response, scholars have argued for the development and implementation of more watershed-based approaches to assessing and managing cumulative effects to Canada's river systems, operating beyond the project scale and influencing not only project-decisions but also broader land use policy and planning actions (Hubbard, 1990; Duinker & Greig, 2006; Harriman & Noble, 2008; Seitz et al., 2011; Sheelanere et al., 2013; Canter et al., 2014; Noble & Basnet 2015).

1.2 Watershed Cumulative Effects Assessment and Management

Water security risks and uncertainties are arising from the CE of human activities (Schindler & Donahue 2006, Vörösmarty et al. 2010), sparking interest in watershed-scale CE assessment and management. The watershed is a useful scale for determining environmental baseline information, indicators and thresholds (Burt, 2003; Seitz et al., 2011), orchestrating regulatory activities (Falkenmark, 2004) and facilitating monitoring programs to understand, and appropriately manage, the CE of land use and development (Burt, 2003; Dubé, 2006; Dubé et al., 2013). In Canada, several watershed-based CE programs have emerged, such as the Cumulative Impact Monitoring Program in the Northwest Territories, the Northern Rivers Ecosystem Initiative (Gummer et al., 2006), and the Land-Use Framework (LUF) adopted by the Government of Alberta (GOA) in 2008 as an approach to environmental management. Initiatives such as these have advanced CE practice; Dubé (2003) indicates that "…studies in Canadian waters have provided a solid practice for environmental effects monitoring design, environmental indicator selection, and for setting threshold levels to evaluate the significance of a change." The challenge, however, is that although the literature and recent short-term CE studies have provided a robust set of requisites for the implementation of watershed-based approaches for assessing and managing cumulative effects, including monitoring requirements (Westbrook & Noble, 2013; Dubé et al., 2013; Sheelanere et al., 2013), it also recognizes the inadequacy of existing monitoring efforts to contribute to CE management (Schindler, 2013; Dube et al., 2013), particularly their influence on policies, planning and decision making processes (Hegmann & Yarranton, 2011; Duinker et al., 2012; Noble, 2015).

Monitoring is a key component of understanding CE to watersheds, yet Dubé et al. (2013) argue that it is "the most deficient aspect of [CE] studies worldwide." Needed are coordinated, integrated, consistent and standardized monitoring activities for understanding CE to watersheds in Canada (Dubé, 2003; Ball et al., 2013a; 2013b); however, the absence, or fragmented nature, of monitoring programs and datasets continue to be a major obstacle to effective CE management (Timoney & Lee, 2001; Dubé et al., 2006; Seitz et al., 2011; Ball et al., 2013; Westbrook & Noble, 2013; Dubé & Wilson, 2013; Noble et al., 2014). Arguably, the biggest challenges to CE management are not technical or scientific (Jones, 2016), but overcoming institutional and organizational challenges (Chilima et al., 2013).

1.3 Environmental Monitoring for Cumulative Effects

The act of monitoring itself is not a result, but a process concerned with detecting change in the environment (Hellawell, 1991); there is no shortage of technical documentation to guide a successful monitoring system (see Noss, 1990; Chapman, 1996; Dubé, 2003; Kilgour et al., 2006; Reynolds et al., 2011; Dubé et al., 2013). However, the need for a monitoring program, based often on the nature, duration and magnitude of environmental change, may be identified by a variety of scientific or community-based questions or concerns (Hutto & Belote, 2013). This results in a number of motivations for, and approaches to, environmental monitoring. An underlying challenge, then, is that in any given region (e.g. a watershed), environmental monitoring may be understood to encompass different activities and different objectives by the different actors or sectors involved (Munkittrick et al., 2000; Hutto & Belote, 2013).

For example, site-specific environmental monitoring, which usually includes compliance, inspection and follow-up monitoring, is a legislated activity which acts as a tool to measure compliance in project-specific EIA (Noble, 2015). It approaches monitoring from a “stressor-based” perspective (Dubé, 2003), where monitoring focusses upon a constituent of a valued ecosystem component (see Beanlands & Duinker, 1984) that is known or perceived to be a measurable receptor of environmental stress. At the same time, monitoring programs may be designed to identify cause-effect relationships, which may be initiated by stakeholders or interested parties such as scientific researchers and research organizations (McDonald-Madden et al., 2010) or industry (Hewitt et al., 2010). Many cause-effect monitoring programs are designed for the purpose of scientific inquiry, typically led by academic researchers, environmental groups or government scientists, and may be ongoing in a region parallel to other monitoring initiatives (Hutto & Belote, 2013).

In contrast, regional ambient monitoring activities, which often collect baseline information at large spatial and temporal scales, are more likely to be "effects-based" (Dubé, 2003). Often referred to as "omnibus" or "surveillance" programs, they are intended to monitor environmental components based on the known effects of impacts from human activities (Dubé, 2003). Regional ambient monitoring is often identified as the responsibility of government to implement (Griffiths et al., 1999; Lovett et al., 2007; Biber, 2011), but is increasingly becoming an activity which is executed by communities (Whitelaw et al., 2003; Johnson et al., 2015). Such regional, long-term monitoring data is crucial for establishing baseline conditions (Burt, 2003), validating models (Summers & Tonnessen, 1998), detecting environmental change (Harremoes et al., 2001; Millennium Ecosystem Assessment, 2005), as well as influencing environmental policy (Parr et al., 2003) and laws (Biber, 2011).

Each of these monitoring approaches has a place in CE management and, despite their differences, they are not mutually exclusive (Burt, 2003). This is consistent with the monitoring needs for detecting and managing watershed CE, where a multi-scaled system using both stressor- and effects-based approaches to monitoring are required (Dubé et al., 2013; Ball et al., 2013; Sheelanere et al., 2013). Environmental processes in watersheds occur at different temporal and spatial scales (Holling & Meffe, 1996), and CEs can occur quickly or gradually (Hegmann et al., 1999) or even far downstream of original land use and development activities (Dubé, 2003). Coordinated watershed-scale monitoring, which captures the accumulation of land-use activities through time at multiple scales, is thus crucial to CE management (Hegmann et al., 1999; Ball et al., 2013a; Dube et al., 2013). This is contrary to the current fragmented state of most Canadian environmental monitoring systems (Seitz et al., 2011; Dubé & Wilson, 2013; Noble et al., 2014), in which CE management experiences only episodic attention (Parkins, 2011; Noble, 2015b).

1.4 Purpose and Objectives

Understanding and managing the impacts of the current pace and extent of development requires abundant information about environmental change (Parr et al., 2003; Lindenmayer, 2010). However, simply collecting and accumulating data without regular assessment or uptake in decision-making adds little value to understanding and managing impacts (Lovett et al., 2007), and can result in criticisms to, and the overall failure of, monitoring programs in general (Reid, 2001; Biber 2011). The utility of monitoring programs for making decisions about land use and development depends, in part, on those monitoring programs being technically sound and consistently administered (Elzinga et al., 2001; Lindenmayer & Likens, 2009). Describing the technical and conceptual features of good CE monitoring design is rich in the scholarly literature (Dubé, 2003; Dubé et al., 2013; Westbrook & Noble, 2013); however, research focused on the institutional or administrative characteristics of CE monitoring is less common (Parkins, 2011; Chilima et al., 2013; Noble 2015b) but equally important to the failure or success of monitoring programs and organizations (Reid, 2002).

Whether and how existing monitoring programs and organizations support the understanding and management of CE for land-use planning and regulatory decision-making has received limited attention; but there is a recognized need to strengthen the integration of monitoring programs and organizations, CE management, and decision-making processes (Parkins, 2011; Hegmann & Yarranton, 2011; Westbrook & Noble, 2013; Noble, 2015; Jones, 2016). The complexity and fragmentation of data collection and delivery of monitoring information to CE management may be a major challenge to advancing CE assessment (Hegmann & Yarranton, 2011; Seitz et al., 2011; Noble, 2015).

The **purpose** of this research is to explore whether and how current environmental monitoring programs and organizations support CE management for land-use planning and decision-making. The research is situated in the Lower Athabasca planning region of Alberta, Canada – a region subject to multiple land use and development pressures, a provincially-adopted CE approach to land-use decision-making (GOA, 2008), and a wealth of continuous and intermittent monitoring programs (Lott & Jones, 2010; Miall, 2011) from the mid-1900s to present. The specific objectives of this research are to:

i. Identify and characterize the nature, types and fate of programs and organizations that exist in the Lower Athabasca region to monitor or assess the state of, or trends in, the environment.
ii. Examine whether and how those programs and organizations contribute, or have contributed, to CE management and/or influence land-use plans and regulatory decisions.

iii. Explore options to better link monitoring programs to CE management, planning and decision making processes.

1.5 Study Area Overview

The Mackenzie River Basin, which covers 1.8 million square kilometres, flows into the Beaufort Sea and spans three provinces and two territories (MRBB, 2010). One reach of this immense river basin is the Athabasca watershed of Alberta, Canada. This watershed originates from the Athabasca glacier in the Rocky Mountains and flows northwest into Lake Athabasca which straddles the northern border between Alberta and Saskatchewan. In Canada, natural resources are largely the responsibility of the provincial government to manage, while fish and inter-provincial waterbodies are under the purview of the federal government to oversee (Noble, 2015a). As such, regulation and monitoring of the environment is often completed by a mixture of either or both levels of government. For the purposes of land-use planning at the provincial level, the Athabasca watershed is split into two separate land-use planning units, the Lower Athabasca and Upper Athabasca, under the land-use framework of 2008 (GOA, 2008) (Figure 1.1). In this thesis, the term "government" refers to the provincial government, unless stated otherwise.

Industrial activity has expanded rapidly in the Lower Athabasca region in recent years, including forestry operations, metal mining and agriculture. Perhaps none more controversial, however, than oil sands extraction and its subsequent production and distribution. Northern Alberta is home to the third largest oil reserve in the world (CAPP, 2014), with the Lower Athabasca being home to a large portion of the Athabasca and Cold Lake oil sands harbouring both surface and in-situ mining activities.

The region is also home to, or a contributing factor for, several initiatives aimed at understanding the cumulative environmental effects of these activities, such as the Northern River Basins Study and the Northern Rivers Ecosystem Initiative. A number of organizations have also evolved in the Lower Athabasca that aim to monitor components of the environment for regulatory or scientific purposes (Lott & Jones, 2010), such as the Wood Buffalo Environmental Association, the Alberta Biodiversity Monitoring Institute, and the Joint Oil Sands Monitoring program. These programs and organizations are returned to in Chapter 2.

Figure 1.1 Lower Athabasca planning region, Alberta, Canada

1.6 Thesis Format

This thesis adopts a thesis-by-manuscript format, consisting of two manuscripts and a concluding chapter. The first manuscript, Chapter 2, addresses the first objective of the thesis, to identify the nature and types of programs that exist to monitor or assess the state of, or trends within, the environment in the Athabasca region. The history of monitoring activity and associated institutions in the region are described and analyzed to examine the conditions which have influenced their endurance or demise over time. In doing this, it begins to address the second objective by introducing the monitoring programs which inform the CE management system.

Attention is focused on influential institutional and administrative conditions for monitoring and key learning opportunities for other jurisdictions.

The second manuscript, Chapter 3, addresses more robustly the second objective by examining how the monitoring programs inform the CE management system. It then analyzes this approach in comparison to others in order to address the final objective, which is to explore options to better link monitoring to a CE management system and to decision-making processes. Advancements in understanding different approaches to the organizational arrangements for CE monitoring provides learning opportunities and recommendations for other jurisdictions while advancing the CE literature.

The thesis concludes with Chapter 4, which integrates the findings of the two manuscripts and suggests a number of recommendations for improved CE monitoring in the study area, and recommendations for further research.

CHAPTER 2

ADVANCING CUMULATIVE EFFECTS MONITORING: CONSIDERATIONS FROM THE LOWER ATHABASCA REGION OF ALBERTA, CANADA

2.1 Abstract

Canadian watersheds are under pressure from the cumulative effects (CE) of human activities. Although there has been some research addressing the institutional arrangements of CE monitoring and management initiatives, as well as the technical and scientific requisites for CE monitoring, much less attention has been given to understanding the complex challenges associated with implementing and sustaining long-term commitments to CE monitoring and management. Understanding unsuccessful CE efforts of the past can help determine successful features of CE management for the future. This research explores the shortcomings and failures of regional environmental monitoring programs to better characterize the challenges of supporting long-term CE management. A literature review was conducted to construct a timeline for regional monitoring to illustrate the extent of efforts through time; to identify reoccurring themes in the failure of monitoring programs; and to derive lessons for other jurisdictions. Key themes emerging from this review included: monitoring should not be the responsibility of multi-stakeholder groups due to the potential for conflicts of interests; a degree of scientific autonomy is important but attention should be paid to the relevance of scientific endeavours to CE decision-making arenas; costly administrative transitions in efforts to rebrand or redistribute monitoring should be avoided; and, finally, institutional memory should be valued when considering ways to improve a monitoring system. The research concludes that adding value to CE decision-making through effective monitoring should be facilitated by innovative and integrative frameworks and supported by a shared vision for CE management.

2.2 Introduction

Scholars and agencies have invested significant resources in the basic science requisites to understand cumulative effects (CE) in support of better decisions about land use and resource development (e.g. Culp et al., 2001; Gummer et al., 2006; Squires et al., 2010; Westbrook & Noble, 2013; Dubé et al. 2013; WWF Canada, 2014), particularly the development and testing of new methods and tools for CE monitoring and evaluation (e.g. Hegmann et al., 1999; Dubé & Munkittrick, 2001; Dubé, 2003; Quiñonez-Piñón et al., 2007; Canter et al., 2014). Large scale and long-term monitoring plays a crucial role in detecting CE, alongside other finer scale monitoring efforts such as those carried out for individual project developments (Hegmann et al., 1999; Ball et al., 2012a; Dubé, 2015). Effectively managing CE relies, in part, on the availability and sustainability of long-term monitoring data to support both short- and longer-term decisions about land and water use and development (Dubé, 2003; Squires et al., 2011; Hegmann & Yarranton, 2011; Ball et al., 2012a; Dubé, 2015).

The Lower Athabasca region of northern Alberta, Canada, is home to a variety of land use activities including municipalities, tourism, forestry operations, pulp and paper production, natural gas extraction, as well as development of the third largest oil reserves in the world – the Athabasca oil sands (Attanasi & Meyer, 2010; LARP, 2012; Kurek et al., 2013; GOA, 2015). Each of these activities, individually, has the potential to generate adverse impacts on the environment (Kelly et al., 2009; Squires et al., 2010; Seitz et al., 2011; Korosi et al., 2016), and collectively they may be contributing to potentially significant cumulative environmental effects to both terrestrial and aquatic systems (Timoney & Lee, 2001; OSAP, 2011; Schindler & Donahue, 2011; JOSMP, 2012; Latifovic & Pouliot, 2014; Sauchyn et al., 2015). The Lower Athabasca has also been the center of several initiatives and organizations that aim to monitor the environment for regulatory or scientific purposes (Lott & Jones, 2010; Miall, 2011), which have contributed significantly to advancing current practice and knowledge of CE monitoring and management (Kennedy, 1995; Johnson et al., 2011; Noble, et al., 2014). The wealth of industrial and scientific activity in the Lower Athabasca have propelled it into the international environmental management spotlight (Culp et al. 2001; GOA, 2008; Gosselin et al., 2011; Olszynski, 2014).

A major challenge to CE programs in the Lower Athabasca, however, and a characteristic of CE initiatives across Canada and internationally (Noble, 2015b), is that they are often "short-term bursts of activity" and "short-lived organizational commitments" (Parkins, 2011). The absence or fragmented nature of long-term monitoring is a cause for concern in supporting CE management and decision making (Schindler, 2010; Squires et al., 2010; Ball et al., 2012a; Dube et al., 2013), since understanding CE is a long-term endeavour requiring consistent and continuous datasets (Ball et al., 2012a; Kristensen et al., 2013; Sheelanere et al., 2013). The main constraints to CE assessment and management appear to be institutional in nature more so than scientific or technical (Noble, 2010; Chilima et al., 2013; Sheelanere et al., 2013; Jones, 2016); many programs designed to support CE assessment and management fail at the point of implementation (Noble 2008), or lose the long-term support and uptake to influence decisions (Lawe et al., 2008; Noble, 2015b). There has been some research addressing institutional capacity for CE initiatives, particularly within the context of watershed-based CE assessment (e.g. Kristensen et al., 2013; Sheelanere et al., 2013), but much less attention has been given to understanding the complex challenges associated with long-term commitments to CE monitoring and management (Noble, 2015b).

This paper examines the history and evolution of environmental monitoring in the Lower Athabasca, specifically the conditions that have led to program success, transformation and, in some cases, failure. There have been other reviews and commentaries about the state of monitoring in the Lower Athabasca (e.g., Lott & Jones, 2010; Miall, 2011; Schindler, 2013; Wallace, 2013) – many of which are referred to in this manuscript. None of these reviews, however, consider the origins and fate of the full range of programs and initiatives; they often focus on individual programs, and not on the collective lessons that have emerged to better support long-term monitoring for CE management. Without stepping back to assess the evolution and fate of organizations "…important opportunities for improvement [are likely] missed, and the chances are surely higher that similar failures will happen again" (Walshe & Shortell, 2004).

In the sections that follow is, firstly, an overview of the Lower Athabasca region and the approach adopted in this review. A chronology of the evolution of monitoring programs and organizations is then presented, along with a brief assessment of their origins and fates. Major themes or lessons emerging from the history and evolution of monitoring in the Lower

Athabasca are then discussed, followed by recommendations for monitoring programs moving forward. Although this study is focused on the Lower Athabasca, the lessons emerging are likely of importance to other jurisdictions in the planning and management of CE monitoring frameworks and initiatives.

2.3 Study Area and Methods

The Lower Athabasca region covers approximately 93,260 square kilometres of northeast Alberta, encompassing the Regional Municipality of Wood Buffalo, Lac La Biche County, and the Municipal District of Bonnyville. The region is home to a variety of human land use and industrial activities (see Fig. 2.1), which have developed rapidly over the past two decades, including natural gas development and associated infrastructure (e.g. well sites, seismic lines, pipelines and right-of-ways); forestry, including pulp and paper mills; agriculture; tourism; thermal electric generating stations; and aggregate mining (GOA, 2009). The cumulative impacts of these activities are a growing concern (Squires et al., 2009; Johnson et al., 2011). For example, there are currently 66 mega projects (valued at over $5 million) in the regional municipality of Wood Buffalo; 7 of which are major pipelines, another 7 are water or wastewater facilities, and 30 are oil and gas facilities (GOA, 2017). Annual water withdrawal by oil sands mines was 121 million cubic metres in 2015 (AEP, 2015) for approximately 39 oil sands projects - with another 44 projects approved or recently announced (Alberta Energy, 2016). Approximately 40% of the Lower Athabasca land base is also managed under a forestry tenure system, and another 5% is used for agriculture (LARP, 2012).

Oil sands represent by far the largest share of economic activity in the Lower Athabasca, accessible by both surface and in-situ mining. Oil sands development began in the region in the 1960s; increases in oil prices in the early 2000s triggered large scale expansion of oil sands development (CAPP, 2015). Between 2000 and 2011, oil sands production doubled to 1.7 million barrels per day of crude bitumen (LARP, 2012); the population of the Regional Municipality of Wood Buffalo more than doubled during that same time period (GOA, 2012). Despite recent drops in world oil prices, oil sands production injected an estimated $23 billion into the Canadian economy in 2015 (CAPP, 2016), and generated $8.4 billion in royalty revenue to the Alberta government in the 2014-2015 fiscal year (CAPP, 2015).

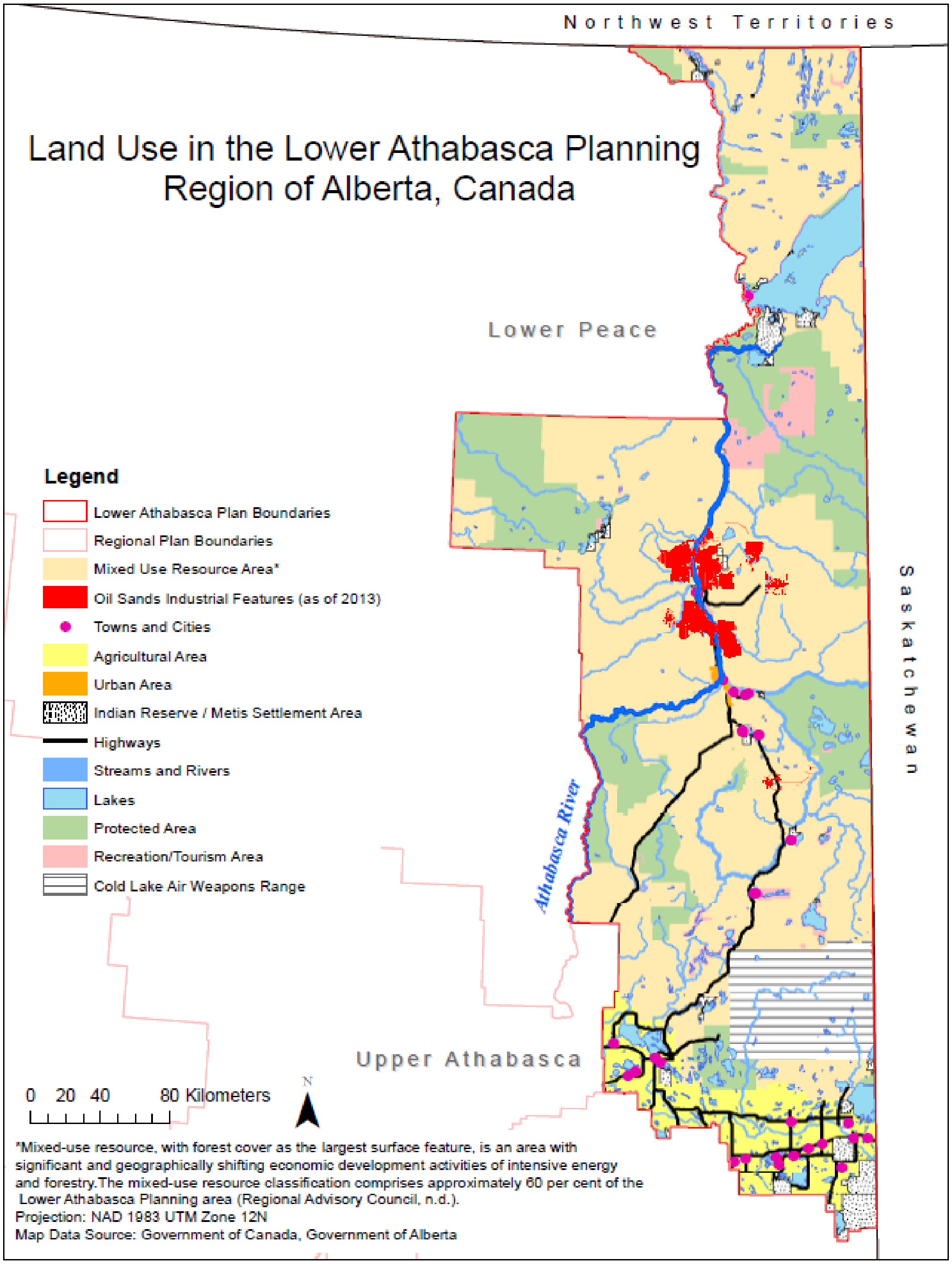

Figure 2.1 Land-use in the Lower Athabasca Planning Region.

During this period of unprecedented growth, and in response to a recognized need to better manage the CE of development in the region, the Alberta government established the province's Land-Use Framework (LUF) in 2008, under the authority of the *Alberta Land Stewardship Act*. The LUF established seven land-use planning regions in the province based on watershed boundaries. Regional plans for each watershed establish the desired future state of the region over the next 50 years. The province describes its LUF as adopting an integrated approach to land use management, which examines the relationship between all land use activities, and sets the stage "for robust growth, vibrant communities and a healthy environment" (GOA, 2014). Amongst the tasks set out under the LUF are to identify key environmental issues, understand the current state of environmental components through regional assessments, and work collaboratively to identify environmental targets and thresholds through the development of management frameworks (GOA, 2016). Management frameworks are intended to operate within the regional plans, and are described as a "key approach to manage the long term cumulative effects of development on the environment" (GOA, 2010). For each regional plan, including the Lower Athabasca, management frameworks are created for surface water quality, surface water quantity, air, biodiversity and groundwater.

In addition to the LUF, both the Alberta and federal governments are mandated with various responsibilities for implementing or overseeing environmental protection measures and monitoring efforts in the Lower Athabasca – such as habitat protection under the federal *Fisheries Act*, and site-specific monitoring for environmental assessment processes and water withdrawal licences occurs under the province's *Environmental Protection and Enhancement Act* and *Alberta Water Act*. Multiple other regional-scale programs have also emerged in the Lower Athabasca region to fulfill environmental objectives, supported by government and/or industry, including the Regional Aquatics Monitoring Program, Wood Buffalo Environmental Association, and the Alberta Biodiversity Monitoring Institute. Several of these programs are intended to support CE management initiatives, thus contributing to a wealth of different environmental monitoring programs and organizations operating in the Lower Athabasca region.

2.3.1 Research methods

The extent of environmental monitoring activity in the Lower Athabasca region is vast. For the purpose of this study, attention was focused on regional-scale, long-term monitoring efforts – those, arguably, with the most potential to support CE management (Hegmann et al., 1999; Dubé, 2003; Lindenmayer & Likens, 2009; Dubé et al., 2013). The scope of the review was limited to regional environmental monitoring *programs* which focus on the priority environmental components identified in the province's LARP – namely air, biodiversity, water quality, water quantity, and groundwater management (GOA, 2010). Understanding the evolution of monitoring conducted for these components, however, required also the inclusion of the range of monitoring *organizations* responsible for administering funds to support monitoring, for providing scientific oversight, or for making use of these programs and their data.

The review of monitoring programs and organizations was based on a document analysis – identifying, evaluating and synthesizing the existing body of completed and reported work (Fink, 2005) – and focused on the sequence of environmental monitoring in the Lower Athabasca. To do this, firstly, an inventory of monitoring programs and organizations associated with the environmental components identified in the LARP was created. These programs and organizations were organized chronologically, based on their date of implementation or establishment, and a review was conducted to describe pertinent events and characteristics of their inception and development. The documents reviewed included monitoring program and organization descriptions, such as policy documents, reports and white papers released by the program or organization, government reports; and also literature written about the programs and organizations – such as peer reviewed assessments or criticisms, regional planning documents, and news articles. All of the documents analyzed were either publically accessible via the internet or accessed through the University of Saskatchewan library. Due to the nature of regional monitoring in the Lower Athabasca, programs and organizations that have helped shape the current monitoring landscape outside of the LARP were also included. Without this information, an accurate depiction of the state of affairs, and how monitoring has shifted over time, could not have been established. After reviews for each program and organization were complete, it was clear that the sequence of monitoring initiatives followed loose patterns that could be characterized as monitoring "episodes".

The aim here was not to determine whether each individual monitoring program or organization in the Lower Athabasca has been a success or failure, since organizational success or failure can be interpreted in a variety of ways (Mellahi & Wilkinson, 2004). Rather, the review set out to accomplish two things: First, to establish the primary rationale for the inception of each monitoring program or organization, which set the context for understanding the rationale for each and how it was structured. One of the most important initial characteristics of an enduring and effective monitoring program is that it relies on "carefully designing and implementing appropriate studies to answer [scientific questions that are] relevant to policy options for the management of ecosystems" (Lindenmayer & Likens, 2010). As such, particular attention was given to the original motivation(s) for the monitoring program, which could then be compared to how the monitoring program was implemented or evolved over time. Second, the review set out to identify the conditions or factors that resulted in either the continued success of each monitoring program or organization, or its criticisms and demise.

2.4 Regional Environmental Monitoring Programs and Organizations in the Lower Athabasca

The chronology of regional monitoring initiatives in the Lower Athabasca is synthesized in Figure 2.2. The timeline begins in 1919, with the establishment of the Water Survey of Canada (WSC) – a program that still operates today. The WSC collects nationwide baseline water quantity data and is funded jointly by federal and provincial governments. Similarly, the ongoing Long-Term River Network (LTRN) was established as a province-wide water quality monitoring program with 30 monitoring locations. These two programs provide publically available water quantity and quality information to inform land-use decisions; however, these programs are not entirely immune to data discontinuities as a result of budget cuts (OSAP, 2011). For example, a reduction in hydrometric monitoring in the mid 1990's, as a result of fiscal pressures on the federal government, resulted in increased analytical error and uncertainty (see Spence et al., 2007).

The first comprehensive, regional monitoring effort in the Lower Athabasca was not established until 1975, under the Alberta Oil Sands Environmental Research Program (AOSERP). The program ended in 1980, after a conclusion that no new baseline studies would be required (Lindeman et al., 2011), despite none of the program's original objectives being fully satisfied (Smith, 1981). From 1991 – 1996, more explicit studies for understanding cumulative effects emerged from the Northern River Basins Study (NRBS), which provided a set of recommendations to guide new research studies and improve monitoring (NRBS, 1996a). The following year, in an effort to eliminate redundancy in monitoring associated with site-specific environmental assessment approvals, the Regional Aquatic Monitoring Program (RAMP) was established by several oil sands developers. RAMP was dismantled in 2012, after several critical reviews of its scientific integrity concluded that the program was incapable of detecting regional trends and cumulative effects (RAMP Review, 2011). The Wood Buffalo Environmental Association (WBEA) was also established in 1997, in response to concerns from several First Nations regarding air quality. The program still operates today, monitoring air quality associated with increasing industrial emissions in the Wood Buffalo region.

The Northern Rivers Ecosystem Initiative (NREI) ran from 1998 to 2003, in response to recommendations emerging from the earlier NRBS, to provide a comprehensive and authoritative body of knowledge to guide decision-making (Gummer et al., 2006). One year following the establishment of NREI, the multi-stakeholder organization Cumulative Environmental Management Association (CEMA), consisting of representatives from all levels of government, industry, non-governmental organizations and First Nations, was created to study and communicate to governments and regulators the CE of regional development through policy recommendations and management frameworks. CEMA was disbanded in 2016, after funding from the provincial government and industry was discontinued.

Several other programs were also established in the 2000s, and continue to operate today – including the Lakeland Industry and Community Association (LICA), a non-profit air, water and soil monitoring and educational program; the Alberta Biodiversity Monitoring Institute (ABMI), an independent ecological monitoring program; and the Regional Groundwater Monitoring Network (RGMN). The Joint Oil Sands Monitoring (JOSM) organization emerged in 2012 in response to critical evaluations of the scientific rigour of RAMP, and the general need for scientific integration between monitoring programs in the Lower Athabasca (JOSMP, 2012). Two years later, in 2014, the independent Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA) was established, which shifted the implementation and oversight of all monitoring programs outside of the provincial government. AEMERA was dismantled in 2016 in order to return the responsibilities back into the provincial government under the province’s newly formed Environmental Monitoring and Science Division (EMSD).

In the sections that follow, the history and evolution of these monitoring programs and organizations in the Lower Athabasca are presented as five “episodes” (Fig. 2.2) based loosely on the time of inception, the conditions which resulted in the need for the monitoring entity, and characteristics of the program or organization through time. For each program or organization, a review of its inception and evolution is presented, including its current status.

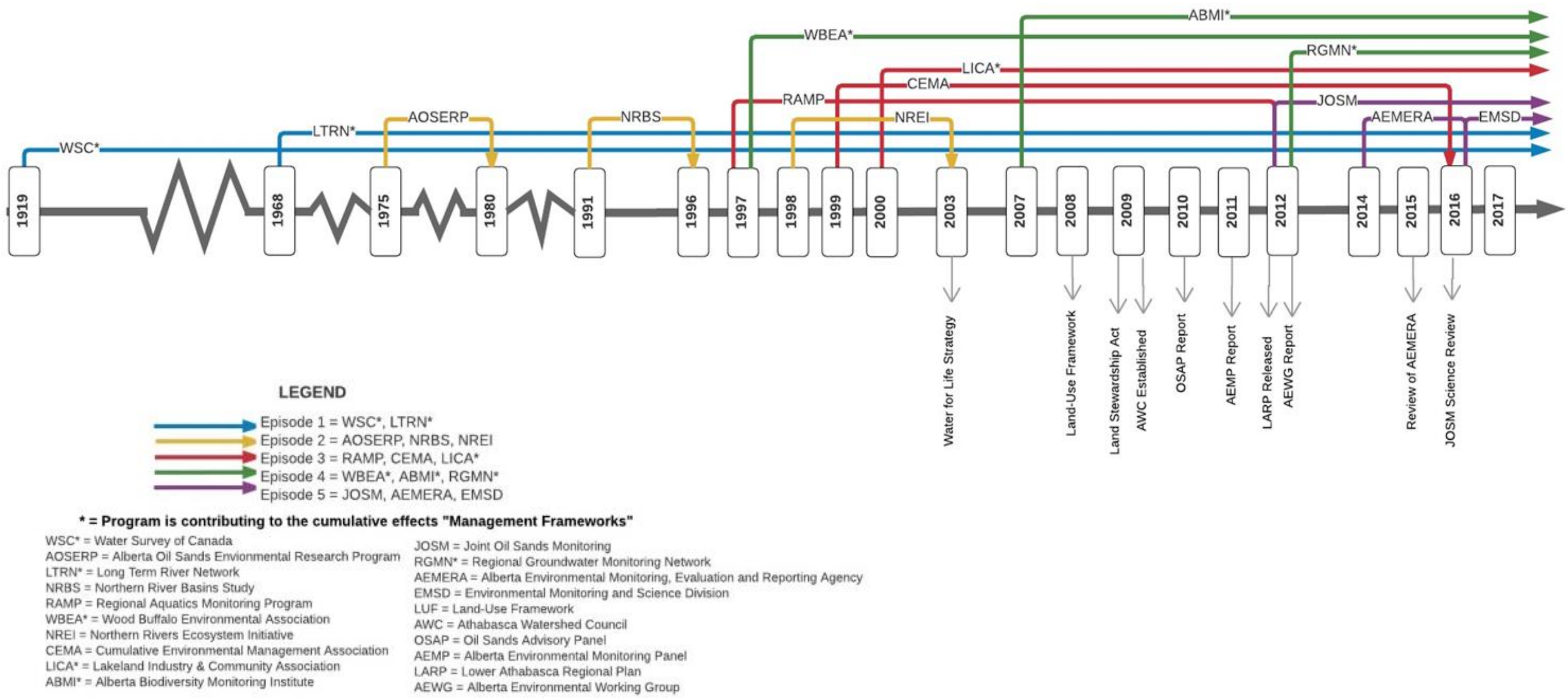

Figure 2.2 Regional environmental monitoring timeline for the Lower Athabasca region of Alberta, Canada.

2.4.1 Episode 1 – WSC, LTRN

The first episode captures long-term water quantity and quality monitoring programs, namely the WSC and LTRN, operated and funded jointly by the federal and provincial government, and that have been in place from the early to mid-1900s to present day.

2.4.1.1 Water Survey of Canada (WSC), 1919 - present

The WSC is the primary agency for providing water quantity data for the Athabasca River. Beginning in the late 1800s under the Department of the Interior and then the Water Resources Branch, the WSC is currently operated by the federal government - though it is not wholly a federal program (Lindeman et al. 2011; EC, 2013). Funding agreements between federal and provincial governments were established in 1975. Hydrometric (water level and streamflow) monitoring stations of federal interest are funded by the general government; stations of provincial interest are funded by the province of Alberta; those of joint interest are jointly funded. Over 2,500 active hydrometric stations are in operation nationwide, of which about 1,600 have data transmitted in real time (EC, 2014) and made available through a portal on the Environment and Climate Change Canada website (wateroffice.ec.gc.ca as of March, 2017). Currently, 11 WSC hydrometric stations are in operation in the Lower Athabasca planning region of Alberta for the purposes of the Water Quantity Management Framework (See Appendix 1). Of these, only one station is used for developing and monitoring triggers and thresholds for the Lower Athabasca region (GOA, 2015). All stations include measurements related to stream flow and water level, with five also including sediment transport information. Only two monitoring stations in the Lower Athabasca are operating continuously; others collect data only during summer. All stations but two are funded by the federal government (GOA, 2015).

WSC procedures are compliant with the International Standards Organization ISO 9001:2000 (Matrix Solutions Inc., 2012; Auditor General of Canada, 2010); however, a 2010 report by the Auditor General of Canada concluded: “Environment Canada has not located its monitoring stations based on an assessment of risks to water quality and quantity. As a result, it may not be focussing its monitoring efforts on the activities and substances that pose the greatest risks. The Department has not established many of the essential management practices needed to plan, implement, assess, and improve its long-term monitoring programs. It has not taken the initial steps to clearly establish the extent of each program's monitoring responsibilities, risk-based priorities, and client needs" (Auditor General of Canada, 2010). Apart from the 11 stations mentioned above, many other WSC stations do exist. Of these, many have been discontinued; Lindeman et al. (2011) reports that historically there had been 165 flow monitoring stations in the entire Athabasca watershed, compared to 95 by 2011. Some of these remaining have changed operational ownership (i.e. to the Regional Aquatics Monitoring Program), or are visited only seasonally. Federal staff has requested procedural audits from RAMP for WSC data validation, but none were administered and thus those data are not published in the WSC data portal (Lindeman et al. 2011).

2.4.1.2 Long Term River Network (LTRN), 1968 - present

The LTRN is a series of monitoring stations now operated by the provincial government which monitors water quality. Water quality data for the Athabasca River dates back to 1955, when Environment Canada began sampling at a station at the town of Athabasca – just outside the Lower Athabasca region. Data also became available in 1978 at another station, which was added at the town of Old Fort, approximately 200 km north of Fort McMurray (AEP, 2016). In 1987, data collection at these sites became the responsibility of Alberta Environment. In 2002, another station was added in the region upstream of Fort McMurray (WMDRC, 2011). These monthly LTRN data have been useful in determining trends in provincial river systems (i.e. Hebben, 2009), as well as contributing to the provincial water quality index - the Alberta River Water Quality Index (ARWQI), which is calculated for each river basin and reported annually (AEP, 2016). The LRTN and ARWQI report data for 62 different variables, of which 36 are included in the LUF CE Water Quality Framework (see Appendix 2). The limits and triggers associated with the LUF CE Water Quality framework, however, only apply to data which is collected at a single LTRN monitoring station.

2.4.2 Episode 2 – AOSERP, NRBS, NREI

The second episode involves three programs – AOSERP, NRBS, and NREI. These shorter-term programs were developed to collect, analyze, and report data aimed at better characterizing baseline environmental conditions. Also including cause-effect studies, these programs were early efforts to investigate the regional CE of human activities.

2.4.2.1 Alberta Oil Sands Environmental Research Program (AOSERP), 1975 – 1985

In 1975, the Alberta provincial government and the federal government came together in an effort to address the potential environmental impacts of expanding oil sands operations (Wallace, 2013). The AOSERP agreement was signed in 1975, which developed a program using a systems approach; describing air, land, water and human systems separately in order to consider future research options as well as lend results to computer simulation modelling for predicting environmental effects (Smith, 1981). An amended agreement in 1977 described the purpose of the AOSERP as "…to provide timely information about factors that will aid the parties in establishing guidelines for socially acceptable limits of damage to present and potential uses of biotic and abiotic resources" (AOSERP, 1978), and includes 10 broad program objectives – including to "establish monitoring networks in order to obtain baseline data on variables in the environmental systems and review the monitoring requirements annually" and "identify environmental and social problems that can be expected to result from presented and proposed oil sands development" (Smith et al., 1979). The 17-million-dollar budget for AOSERP resulted in a substantial accumulation of baseline data for the region; reviewed by Smith (1981), who identified 200 different research reports generated under AOSERP.

The program was completed in 1985, based on an assumption that no further expansion of oil sands development in the region was likely, thus leading to the conclusion that no new baseline studies would be required (Smith, 1981; Lindeman et al. 2011). However, Wallace (2013) and Schindler (2013) suggest that a reorganization of the program just two years after its inception, along with "other administrative and fiscal tensions" (Wallace, 2013), including the withdrawal of the federal government's involvement, signal alternative reasons for the program's demise. Smith (1981) also concluded that despite the amount of information generated, there was still much room for improvement in data integration between systems generally. That said, AOSERP did gain international recognition for its co-operative approach to environmental research between the provincial and federal governments (Wallace, 2013).

2.4.2.2 Northern River Basins Study (NRBS), 1991 – 1996

In 1991, the NRBS brought the governments of Alberta, the Northwest Territories and Canada together in an attempt to address the impacts of development in the Peace, Slave and Athabasca

River basins. The NRBS, and its ecosystems approach, grew out of the need for a better understanding of environmental conditions threatened by the individual and cumulative effects of current and future land uses (NRBS, 1996a). The program's need was triggered largely by an increase in forestry operations and a proposal for the Alberta Pacific Pulp Mill at Athabasca, Alberta (Schindler, 2013). The NRBS was managed by a multi-stakeholder board of 25 members with a 12.3-million-dollar budget. Its primary objectives were to: provide a scientifically sound information base for planning and management of the water and aquatic environment so as to ensure its long-term protection, improvement and wise use; collect and interpret data and develop appropriate models related to hydrology, water quality, fish and fish habitat; and ensure that technical studies undertaken in the basin are conducted in an open and cooperative manner and that their purpose, progress and results are reported regularly to the public.

The program was established as a 5-year effort and was completed in 1996, with a final study report released that consisted of a compilation of 161 research papers (NRBS, 1996a). Wallace (2011) describes the NRBS as an impressive research endeavour by way of involvement of renowned scientists on its advisory committee, and the engagement of Aboriginal groups and the public. Several recommendations emerged from NRBS, mostly suggesting that further research is needed to understand the effects of climate, flow regulation and land-use on hydro-ecological changes in the Peace-Athabasca system (Prowse et al., 2006); but also that an integrated ecosystem monitoring program, coordinated by scientific experts, should be established (NRBS, 1996b). The NRBS also advocated for the Mackenzie River Transboundary Waters Master Agreement, in order to better manage and protect the river basins. Recommendations for improved monitoring and other actions largely went unaddressed (Schindler, 2013), but the Mackenzie River agreement was signed in 1997, and the Mackenzie River Basin Board was established under the *Canada Water Act* (1972) to implement the Agreement.

2.4.2.3 Northern Rivers Ecosystem Initiative (NREI), 1998-2003

In response to recommendations generated by the NRBS, and in part owing to the collaborations it established, the NREI was another five-year program that emerged jointly between the governments of Canada, Alberta and the Northwest Territories. The program was focused on identifying water management issues, with follow-up actions emerging that involved both policy initiatives and further scientific research (NREI, 2004a). Included amongst the priorities of the

NREI were pollution prevention and risks to drinking water; understanding long range transport of air contaminants; integrated environmental monitoring; integrated planning of land and water; and communications and public outreach.

Results emerging from the NREI included responses to some of the recommendations set out by the previous NRBS. New insights into pollution prevention, contaminants, dissolved oxygen and nutrients, human health, hydrology and climate, basin management and wildlife and biodiversity were included amongst the NREI's key outputs (NREI, 2004b). Combined, the NRBS and NREI was said to have provided a set of scientific studies on which to base further assessment and scientific work (Dubé, 2003; Dubé et al. 2006). Gummer et al. (2006) concluded that completion of the NREI, in some respects, brought to conclusion the previous work of the NRBS and, "in a broader sense, with the escalating development pressures in the basins, such as the multibillion investments in the oil sands area, these studies together provide a comprehensive authoritative body of knowledge which will guide decision-making for decades to come."

2.4.3 Episode 3 – RAMP, CEMA, LICA

Episode 3 is characterized as several multi-stakeholder, consensus-driven monitoring programs and organizations including RAMP, CEMA and LICA. These monitoring programs and organizations emerged to facilitate stakeholder communication and collect or make use of monitoring data – including data collected by themselves and/or others.

2.4.3.1 Regional Aquatics Monitoring Program (RAMP), 1997 - 2012

RAMP was established with a mandate to determine, evaluate and communicate the state of the aquatic environment and changes that may result from cumulative resource development within the Regional Municipality of Wood Buffalo (RAMP, 2009). The multi-stakeholder, consensus-based program was funded by the Oil Sands Development Group, which is driven largely by industry partners (Lott & Jones, 2010). Included amongst RAMP's objectives were to: monitor aquatic environments in the Athabasca oil sands region to detect cumulative effects and regional trends; collect baseline data to characterize natural variability in the aquatic environment; assess the accuracy of predictions contained in regulatory environmental assessments; satisfy the monitoring required by regulatory approvals and company-specific community agreements of oil sands operators and other developers; incorporate traditional environmental knowledge into monitoring; and communicate monitoring results. RAMP grew out of the realization that duplication was occurring by early oil sands operators in terms of their required environmental effects monitoring programs (Lott & Jones, 2010).

Several technical, community and joint-community (alongside CEMA) reports were generated under RAMP. The program helped contribute to improved integration of aquatic monitoring efforts across the region; better understanding of the cumulative state of the aquatic environment; identification of long-term trends; and improved knowledge about the effects of oil sands activity on the aquatic environment (Lott & Jones, 2010). However, significant growth in oil sands activity (CAPP, 2015), coupled with studies by Kelly et al., (2009, 2010) that showed there were impacts from oil sands development that RAMP was not capable of detecting, specifically contaminant loading in snowpack and the Athabasca River, meant that the region and the credibility of RAMP were placed in the international spotlight (see Schindler, 2010; Miall, 2013). Reports from RAMP and CEMA, in contrast, concluded that the environmental impacts of oil sands development were negligible; and a report commissioned by the provincial government questioned the findings of Kelly et al. (2009, 2010), arguing that baseline levels of contaminants are variable through space and time and thus comparisons before and after oil sands development were difficult to make (Conly et al., 2002; Headley et al., 2005; WMDRC, 2011). The conflicting evidence led to a series of government and independent reviews (Ayles et al., 2004; RSC, 2010; OSAP, 2010; Donahue, 2011; RAMP Review Panel, 2011), consequently revealing a series of shortcomings regarding RAMP's monitoring design, methodologies and transparency. The shortcomings of RAMP were highly publicized, leading it to bear the brunt of national and international accusations of disregard for environmental protection by government (Donahue, 2011).

Many studies have alluded to RAMP's origins and operations under the umbrella of industry as the main reason for its shortcomings (Kelly et al., 2009; 2010; RAMP Review Panel, 2011; Donahue, 2011; Schindler, 2013; Wallace, 2013; Miall, 2013; Hodson, 2013; Kurek et al., 2013). As a multi-stakeholder and consensus-driven program, there was enduring concern that it was being appropriated by industry, which was disproportionately represented (Donahue 2011), leading some stakeholders to eventually remove themselves from the program (Schindler, 2013). Inconsistent administration as new stakeholders came on board without clear roles or direction, inconsistent financing, the absence of a lead agency, a general lack of coordination of RAMP's multi-stakeholder environment, and a lack of monitoring data access, resulted in fragmented studies of varying quality (OSAP, 2010; Wallace, 2013) and a suspicion amongst the scientific community about program's credibility (Schindler, 2013; Wallace 2013). In 2012, RAMP was absorbed in the Joint Oil Sands Monitoring Plan (see below), which assumed the monitoring endeavours operated by RAMP (RAMP Review Panel, 2011; JOSMP, 2012).

2.4.3.2 Cumulative Environmental Management Association (CEMA) 2000 – 2016

CEMA emerged in the late 1990s to address recommendations made in a 1998 Regional Development Strategy of the oil sands region, which was completed in response to a forecasted increase in development (CEMA, n.d.). A multi-stakeholder advisory group, CEMA was "committed to respectful, inclusive dialogue to make recommendations to manage the cumulative environmental effects of regional development on air, land, water and biodiversity." (CEMAb, n.d.). Included amongst its main goals was to: recommend management frameworks, best practices and implementation strategies that address cumulative effects on air, land, water and biodiversity; and actively promote inclusive dialogue and information exchange (CEMAc, n.d.). CEMA did not execute its own environmental monitoring, but it played an important role in the use and development of regional monitoring programs. Lott & Jones (2010), for example, report that information products generated under CEMA have been adopted and implemented widely by government and have helped to achieve meaningful change - current water management frameworks under the LARP are based largely on the work of CEMA. One of CEMAs last products, prior to the organization's end in 2016, was an Indigenous Traditional Knowledge Framework, described as "… a sound and defensible approach for addressing the necessity of including Indigenous Traditional Knowledge in all facets of environment stewardship, as outlined in the United Nations Declaration on the Rights of Indigenous Peoples" (CEMA, 2015).

CEMA included representation of over 50 stakeholders, making it a hub for information exchange in the oil sands region. However, the quantity and diversity of representatives eventually impeded its ability to define clear goals and make swift decisions (Hegmann & Yarranton, 2011; Noble et al., 2014). A report commissioned by the province concluded that the consensus approach "can result in decisions being watered down to the extent that they do not meet the best interests of any party or the environment [and] an incentive to delay the decision making process as long as possible" (Radke, 2007). CEMA was plagued by inconsistent governance structures, a perception of favouritism towards industrial interests, power inequalities and conflicts, and the eventual withdrawal of some First Nations participants from the association (AMMSA, 2011; Schindler, 2013). There was also concern amongst some CEMA members that the province was not implementing recommendations, reporting that although the province "takes a go-slow approach to environmental management, oil sands lease sales are not delayed, despite a formal request from CEMA" to take time to set environmental limits and thresholds for the region (Severson-Baker et al., 2008). Because of these concerns, several environmental interest groups (Pembina Institute, Toxics Watch Society of Alberta, Fort McMurray Environmental Society) also withdrew their involvement in CEMA. A subsequent review by The Human Environment Group (THDG, 2014) recommended that CEMA should not begin any new projects, and its duties should be absorbed into another organization such as the Canadian Oil Sands Information Alliance. Statements from the Canadian Association of Petroleum Producers labelled the activities of CEMA as redundant (ESAA, 2015), as recommendations had already begun to emerge to form a new environmental monitoring and CE management system. Funding for CEMA was suspended in April, 2016.

2.4.3.3 Lakeland Industry and Community Association (LICA) 2000 - present

LICA is a community-based organization which executes both water quality and airshed monitoring programs (LICA, 2008). Its mission is to "support the community by gathering and sharing information relevant to the environment and development" using a consensus-approach to decision making. Formed in 2000, LICA is a partnership between industry, government and the community of Bonnyville, to implement studies relating to the environmental health of the region (OSM, 2017a). The first phase of its airshed monitoring became operational in 2003 (LICA, 2004); the monitoring network has expanded to include both passive and continuous long-term data collection, along with soil acidification sample plots. LICA data supports one of the eight airsheds of Alberta by reporting on the Air Quality Health Index, but is also used in other applications such as in oil sands monitoring to characterize patterns of natural and anthropogenic airborne contaminants (OSM, 2017b).

Amongst the strengths of the LICA are its efforts to keep stakeholders informed by disseminating monitoring data and providing information sessions and presentations to towns and municipalities throughout the Lakeland region (Urban System Ltd., 2011). However, an external review of LICA's monitoring network found discrepancies between continuous and passive monitoring data and concluded that the network generally suffered from large measurement uncertainties, insufficient spatial and temporal resolution, and short time series (RWDI AIR Inc., 2008). The report made nine recommendations to improve the LICA monitoring system. LICA continues to generate and disseminate near real-time airshed monitoring data, which is used to inform provincial state of the environment reporting and supports the current LARP air quality management framework.

2.4.4 Episode 4 – WBEA, ABMI, RGMN

Episode four includes WBEA, RGMN and ABMI, which began largely with funding from industry and/or government to implement monitoring programs for specific environmental components.

2.4.4.1 Wood Buffalo Environmental Association (WBEA) 1997 - present

In the mid-1980s, in response to First Nations' concerns in the Wood Buffalo region over air quality, the provincial government and oil sands industry formed an air quality task force. The task force explored air quality issues, established monitoring priorities and made several recommendations for better dialogue and a consensus based approach to addressing air quality concerns which, in 1997, led to the establishment of the WBEA (WBEA, 2016). Initially, WBEA operated compliance air monitoring under provincial regulatory requirements as well as community air monitoring stations for the provincial government. This transitioned to a fully independent monitoring network in 1998, with air monitoring stations dedicated to compliance monitoring, community health monitoring and baseline data collection, as well as source attribution of compounds (Percy et al., 2012a). WBEA currently informs one of the eight air sheds in Alberta that report hourly air monitoring data for provincial (Alberta Ambient Air Quality Objectives) and federal (Air Quality Health Index) health advisories, and is a member of the Clean Air Strategic Alliance, providing strategies to assess and improve air quality in Alberta (CASA 2016). WBEA also operates a human exposure monitoring program, using odour analyzers to characterize odours as a result of concerns raised by the public, and a terrestrial environmental effects monitoring program, to determine if anthropogenic emissions of compounds from oil sands operations are having a long-term adverse effect on the terrestrial environment (Percy et al. 2012b).

WBEA has been subject to several scientific peer reviews since its inception, and in 2008 underwent a shift towards an "air pollutant pathway-driven, emission source to ecosystem receptor sink program… carried out by a team of 35 respected international scientists" (Percy, 2013), expanding its mandate beyond compliance-based monitoring. Federal and provincial reviews of WBEA, including a Royal Society report, have been largely supportive of its monitoring programs (OSAP, 2010; GOC, 2011; RSC, 2012); and Lott and Jones (2010) report that WBEA has maintained an effective relationship with local stakeholders and community members. Currently, WBEA monitoring activities are part of the Joint Oil Sands Monitoring plan (see below), and used alongside the LICA in the air quality management framework for the LARP.

2.4.4.2 Alberta Biodiversity Monitoring Institute (ABMI) 1997 - present

The ABMI is an independent monitoring organization, jointly established by Alberta Innovates, the Royal Alberta Museum, the University of Alberta and the University of Calgary. It is responsible for monitoring Alberta's biodiversity by collecting and identifying species and measuring habitat characteristics at 1,656 site locations across the province, revisiting sites every five years (ABMI, 2016a). Initiated in 1997 with funding support largely from industry, ABMI focussed initially on monitoring forest biodiversity but has since expanded to include aquatic and wetland monitoring activities. ABMI data is available online, but site locations are not made public. Trends detection in biodiversity indicators established from site-resampling is core to ABMI's mandate; but it wasn't until 2015, 18 years after ABMI's establishment, that sites began being revisited (ABMI, 2015). ABMI often operates in partnership with academic researchers, governments, First Nations and industry to developing projects to address ecological issues and help inform land use planning – such as its ecosystem services assessment initiatives, designed to "better understand how planning and management decisions affect the landscape and increase benefits to Albertans" (ABMI, 2016b). The ABMI was also instrumental in laying the groundwork for the Ecological Monitoring Committee for the Lower Athabasca (EMCLA), which was initially established to oversee terrestrial monitoring activities under the

Environmental Protection and Enhancement Act (EMCLA, 2016), and ABMI has been a key behind-the-scenes contributor to developing the biodiversity management framework under the LARP.

Since its establishment, ABMI has successfully been able to maintain its operations as an independent, arms-length organization. However, being the largest project of its kind in Canada (AITF, 2016), and requiring approximately $12 million to deliver the program in its entirety (ABMI, 2008), ABMI has yet to be rolled out in full. A major constraint to ABMI is its lack of secure funding (Huot & Grant, 2011). To date, the program is approximately two-thirds funded and secure funding for data collection remains a long-term priority (ABMI, 2015).

2.4.4.3 Regional Groundwater Monitoring Network, 2012 – present

The RGMN was created in 2012 to implement monitoring related to the groundwater management framework under the Alberta LUF. Previous groundwater monitoring information was derived from various historic sources, including site-specific monitoring and the groundwater observation well network, which operated through the 1970s to 1990s (CAPP, 2013). The groundwater management framework consists of three areas: north Athabasca oil sands, south Athabasca oil sands, and the Cold Lake – Beaver River area. The monitoring network for each area consists of a sub-set of industry and government monitoring sites for wells and aquifers. The objectives of the RGMN are to: understand the natural variability of groundwater conditions in the region; provide baseline coverage in areas of no anthropogenic effects in each of the key regional aquifers; understand aquifer interactions, and how and where the groundwater system is connected to surface environments; and assess long-term water quality and water level trends, and the potential cumulative effects from current and future development activities (from GOA, 2012c). The RGMN currently contributes to regional decision-making under the Alberta LUF (GOA, 2012c).

2.4.5 Episode 5 – JOSM, AEMERA, EMSD

The final episode, episode five, includes JOSM, AEMERA and EMSD, which have come online only recently and in response to critical reviews of the regional monitoring system.

2.4.5.1 Joint Oil Sands Monitoring (JOSM). 2012 – present

In 2011, in response to a series of critical reviews of the state of environmental monitoring in the oil sands (Kelly et al. 2009, 2010), an integrated oil sands environmental monitoring plan was introduced, which provided technical details on what should be monitored in the oil sands region as well as when, where and how monitoring should be executed. This monitoring plan provided technical guidance for oil sands monitoring, and in early 2012 the Canada-Alberta JOSM implementation plan was released for administering monitoring activity. The JOSM plan described how the governments of Alberta and Canada would "put in place a world class monitoring program for the oil sands to provide assurance of environmentally responsible development of the resource" (JOSMP, 2012). It also set out funding arrangements, by way of an amendment to the *Alberta Environmental Protection and Enhancement Act*, to allow the collection of funds for JOSM from oil sands operators (Auditor General of Alberta, 2014). The intent of the JOSM was "…to enhance monitoring activities and work to integrate environmental monitoring across all environmental components, which were historically monitored independently through separate organizations or programs" (Hatfield Consultants, 2015). Included amongst the programs objectives are to support sound decision-making by governments as well as stakeholders; ensure transparency through accessible, comparable and quality-assured data; enhance science-based monitoring for improved characterization of the state of the environment and collect the information necessary to understand cumulative effects; and develop a better understanding of historical baselines and changes.

Implementation of the JOSM plan introduced a three year (2012-2015) "…rationalization and integration of current monitoring activities into a single, government-led program" (JOSMP, 2012), co-led by the Assistant Deputy Minister of Science and Technology, Environment Canada and the Assistant Deputy Minister of Science and Monitoring, Alberta Environment and Water. In early 2015, however, with no formal agreement signed between the two governments, JOSM fell solely into the hands of a new provincial monitoring agency – the Alberta Environmental Monitoring, Evaluation and Reporting Agency. A program review by Stratos Inc. (2015) found that the monitoring program's scope was unclear in the context of ambient monitoring needs for Alberta's LARP; it lacked an overall strategic approach that included key monitoring questions; the program's relationship with interested parties was strained due to the lack of a meaningful and transparent approach for considering and addressing their interests; and the program's budgeting process lacked transparency. The program has made some progress toward implementing scientifically defendable monitoring efforts, but issues remain surrounding "limited evidence of efforts to evaluate and use the data collected before 2012" and the JOSM has "made limited progress on harmonizing and rationalizing pre-existing disparate monitoring approaches and activities" in the oil sands region (Hopke et al., 2016).

2.4.5.2 Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA), 2013 - 2016

AMERA was formed in 2013, based on the findings of a provincial government review of environmental monitoring regimes in Alberta recommending that "…the amount and quality of environmental monitoring, evaluation and reporting in Alberta requires substantial improvement" (AEMP, 2011) and that "only an independent, science-based monitoring authority, at arms-length from government and industry" (Miall, 2013) could carry this out. The agency was created through the proclamation of section 3(1) of the *Protecting Alberta's Environment Act* (2013): to obtain credible and relevant scientific data and other information regarding the condition of the environment in Alberta; and to ensure the data and other information are available and reported to the public in an open and transparent manner. AEMERA was mandated "…to provide open and transparent access to scientific data and information on the condition of Alberta's environment, including specific indicators as well as cumulative effects, both provincially and in specific locations" (AEMERA 2015). One of its unique characteristics was its science advisory panel, which provided scientific oversight to the monitoring responsibilities of the organizations under its authority, as well as its traditional environmental knowledge panel.

AEMERA became administratively independent, as a science-based monitoring authority, in 2015. That same year, however, a provincial election put a new political party in power. A report was subsequently commissioned to review AEMERA's operations, which concluded that an independent monitoring body was unnecessary; the implications of transferring science capacity from the province to AEMERA had not been fully considered; the program's governance costs are duplications of less expensive existing provincial monitoring arrangements; and that AMERA was "a failed experiment in outsourcing core responsibility of government to an arms-length body" (Boothe, 2015). In April 2016, the Minister of Environment and Parks announced that AEMERA would be folded back into the provincial government "to strengthen our scientific capacity and be more transparent and credible in our reporting" and that "the private model diverted overhead costs away from monitoring, led to confusion around roles and responsibilities, and limited resources" (GOA, 2016b). This sparked criticism from the scientific community (Weber, 2016), arguing that "…the Alberta government is making a huge mistake by eliminating AEMERA just when it is beginning to show an accurate picture of the state of the Athabasca River and gain public support" (Schindler et al., 2016).

2.4.5.3 Alberta Environmental Monitoring and Science Division (EMSD), 2016 - present

With the announcement that AEMERA would be folded back into the provincial government, a new division within the Ministry of Environment and Parks was formed to house it – the EMSD. With a mandate to "provide open and transparent access to scientific data and information on the condition of Alberta's environment, including specific indicators as well as cumulative effects" (EMSD, 2016), EMSD was established to provide data on the condition of Alberta's environment including: baseline environmental monitoring; cumulative effects monitoring; data evaluation and management; on-going condition of environment reporting; and data, evaluation, knowledge and reporting to inform policy and regulatory decision-making.

2.5 Discussion

The Lower Athabasca region of Alberta, Canada, has a rich and diverse history of environmental monitoring programs and organizations. The WSC and LTRN have been long-term monitoring systems operating in the region, administered by governments, which have been consistent since 1919 and 1968, respectively. These types of programs, which monitor ambient environmental conditions, provide baseline data for characterizing the state of the environment and evaluating long-term change and are often attributed to be a responsibility of the public sector (Biber, 2011; GOC, 2013; Olszynski, 2014). With increasing pressures mounting from oil sands development, and concerns over potential CEs, several new monitoring programs were introduced, including AOSERP, NRBS and NREI, to provide better calibrated baseline information, more detail concerning cause-effect relationships, and to provide recommendations to governments for improving the knowledge and management of regional environmental change. Monitoring programs such as RAMP, WBEA and ABMI followed, with motivations to encapsulate monitoring for specific environmental components and, similar to their predecessors, were made possible through substantial financial injection from industry. Two multi-stakeholder monitoring organizations, CEMA and LICA, were also introduced to the Lower Athabasca to build consensus and facilitate venues for stakeholder communication, as well as to provide recommendations for CE policy and land use planning. More recently, new monitoring organizations, such as JOSM, AEMERA and EMSD, have become the new face of monitoring and CE support in the region - emerging in response to internal and external criticisms of the state of the Lower Athabasca and challenges to the disjointed nature of previous monitoring initiatives.

Despite the original mandates of these programs, the stopping and starting of some of them, combined with the evolution of others, has resulted in an episodic history of regional monitoring programs and organizations for CE support. This history has, by many accounts, eroded public trust in government commitments to long-term monitoring (Wallace, 2013) and in industry's ability to detect and appropriately manage the impacts of development activities. More ominously, the growth, decline and evolution of monitoring in the Lower Athabasca has contributed to a culture of uncertainty surrounding the stability of governance arrangements and support for long-term environmental monitoring systems to address CE, despite consistent calls to do so (Smith, 1981; NRBS, 1996b; Ayles et al., 2004; Gummer et al., 2006; OSAP, 2010; Schindler, 2010; AEMWG, 2012; Wallace, 2013; Noble et al., 2014). In the sections that follow, several observations are ventured based on themes emerging from the review. These themes are likely of value in advancing the administration and organizational arrangements for CE monitoring in Alberta and in other jurisdictions.

2.5.1 Coordinating multi-stakeholder interests

Multi-stakeholder initiatives play an important role in environmental planning and decision-making (Smith, 2008; Canter & Ross, 2010; Chilima et al., 2013; Thaler & Levin-Keitel, 2016). Both multi-stakeholder environmental monitoring initiatives established in the Lower Athabasca, however, namely RAMP and CEMA, achieved limited success and were ultimately disbanded due to outside intervention. RAMP was created and led by industry, which allegedly resulted in poorly planned scientific studies and a reputation tarnished to the point of disbandment after several critical scientific reviews (OSAP, 2010; RAMP review Panel, 2011; Donahue, 2011).

CEMA, although at times was well supported by its members and generated important policy recommendations, was a complex environment for producing results due, in part, to the size and diversity of its membership which often impeded its ability to define clear goals and make timely recommendations (Severson-Baker et al., 2008; Hegmann & Yarranton, 2011). Both of these organizations suffered from suspicions of corruption, among other conflicts, leading to rifts within their ranks and causing some members, including First Nations, to abandon ship.

RAMP and CEMA suffered also from more ominous issues, which are somewhat typical of multi-stakeholder initiatives in environmentally and administratively complex regions (see Truex & Soreide, 2010; Thaler & Levin-Keitel, 2016). RAMP, for example, experienced constant re-examination of its mandate and governance structure, an inconsistent budget, as well as year-to-year personnel changes, all while focused on assessment and monitoring of ecosystems rife with significant natural variation. This lack of consistency and strategy "severely limited the ability of RAMP to monitor the environment relative to existing and future development pressures" (Ayles et al., 2004). CEMA was responsible for tackling some of the most controversial environmental issues in Canada and arguably in the world (Takach, 2014) at that time, specifically the impacts of oil sands development. Like RAMP, it too experienced consistent re-evaluation of its mandate, but also suffered from the misuse of the information it generated and provincial government delaying responses to CEMA's recommendations months or even years after they were tabled and relevant (Radke, 2007; Severson-Baker et al., 2008). These issues resulted in a confusing and tired state of affairs for monitoring and collaborative decision making that was in sharp contrast to the provincial vision for the pace of oil sands development (Schindler, 2013).

Resource sectors and regions with a high degree of administrative and scientific complexity are prone to conflicts of interest, imbalance of power and capacity, and prolonged periods of consensus building (Truex & Soreide, 2010; Bakker & Cook, 2011). The lessons learned from RAMP and CEMA suggest that multi-stakeholder groups may not always be the appropriate venue for designing and implementing science-based monitoring systems for CE, due in part to the participation and influence of a range of actors, often with competing agendas, and not always familiar with the science-based requirements for monitoring change (Donahue, 2008; Biber, 2011; Hegmann & Yarranton, 2011). However, administrative inconsistencies and challenges also undoubtedly contributed to RAMP's and CEMA's failure, in part by harbouring uncertainty relating to each program's goals and continuity. The Lower Athabasca experience suggests that effective multi-stakeholder initiatives for monitoring require consistent administration with proper guidance and long-term support from a lead agency (see also Chilima et al., 2013; Sheelanere et al., 2013). Perhaps, more importantly, this administration should be designed independent of economic or political interests, aligned instead with the basic science requirements for the long-term monitoring of cumulative change (Greig & Duinker, 2011; Westbrook & Noble, 2013), and operate within a broader governance system that is publically accountable and can act upon recommendations (Thaler & Levin-Keitel, 2016).

2.5.2 Scientific autonomy that supports decision making

There are independent monitoring programs in Alberta have emerged as reputable, science-based organizations. Functioning largely independent of industry and government, WBEA and ABMI both are recognized for the accessibility of their data and credibility as science-based programs (OSAP, 2010; Lott & Jones, 2010; RSC, 2012). ABMI's focus on defensible data collection methodologies for answering a range of scientific questions (Nielsen et al., 2009; Haughland et al., 2009), and WBEA's frequent reviews and science-based leadership (Percy, 2013), have allowed these programs to grow and gain trust and credibility amongst data users – including industry, government and the public. Many authors suggest that the independence of an organization, or at the very least a degree of independent oversight, is important to the trust and credibility of its monitoring and management programs for addressing often complex, multi-sctor CE problems (Therivel & Ross, 2007; Sheelanere et al., 2013; Noble et al., 2014; Cole Burton et al., 2014).

Scientific autonomy from government and industry is important, but whether monitoring activities are pursuing the correct CE questions is equally important and is an enduring criticism of monitoring programs in the Lower Athabasca (Stratos Inc., 2015; Hopke et al., 2016). Despite its independence and credibility, the ABMI, for example, has been accused of being a "…poorly planned and unfocused monitoring program… [and has] been planned backwards on the collect [data] now, think-later principle" (Lindenmayer & Likens, 2010a). ABMI is proposed to be the key data contributor for the forthcoming biodiversity management framework under the province's LARP, and its principles likely to be transferred to other CE systems in the province (e.g. Haughland et al., 2009; Cole Burton et al., 2014). However, Lindenmayer & Likens (2010b) describe the ABMI monitoring approach as problematic "…because it confounds assigning causality to observed trends… [while more effective] monitoring programs will be those that are statistically well-designed with relevant management interventions." Criticisms of ABMI suggest that caution is needed, particularly for autonomous organizations, to ensure that the monitoring pursued to support CE understanding is not only science-based, but also relevant for answering the questions of most importance for management and decision making (Noble, 2015b). Monitoring should not occur completely independent of decision making processes about the management of CE (Hegmann and Yarranton, 2011), and greater attention is needed on designing monitoring programs to ensure that the results can be used to support informed, evidence-based regulatory decisions. Collecting and accumulating data without clear relevance to regulatory decisions can be seen as adding little value to CE management (Lovett et al., 2007), and may result in criticism about, and ultimate failure of, monitoring programs (Reid, 2001; Biber 2011).

2.5.3 Administrative complexity

The evolution of monitoring programs and organizations in the Lower Athabasca is illustrative of the cross-agency and jurisdictional challenges than can impede integrative efforts to support CE efforts. Schindler (2013) and Wallace (2013) point to tensions between provincial and federal governments over research and monitoring in the oil sands as early as the 1970s, under the AOSERP. The perception also that RAMP's inadequacies were the result of it being industry-funded (Schindler, 2010; Donahue, 2011), and stakeholder power struggles in CEMA (THDG, 2015), contributed to administrative tensions and conflicts over what constituted credible results and responses that ultimately led to their demise. The result was widespread perception that the provincial and federal governments had failed to execute scientifically sound environmental monitoring amidst continued industrial development. Donahue (2011), for example, argued that "current environmental monitoring … [is] neither adequate nor scientifically defensible... [and] neither level of government can adequately measure impacts that have been caused by existing oil sands developments nor predict what the effects of approved or planned projects will be".

The new monitoring programs that emerged, JOSM and AEMERA, were characterized by administrative transitions which occurred largely without a shared vision for the organizational outcome of either. Jurisdictional claims by both the federal and provincial governments

(Donahue, 2011; Miall, 2013), as well as monitoring undertaken by a confusing array of programs and organizations (Lott & Jones, 2010), brought a number of challenges to the organizational arrangements for a new and integrative monitoring system. For example, funding for previously independent monitoring programs, such as WBEA and ABMI, was suddenly funnelled through the new monitoring organization AEMERA, which appeared to add another layer of administrative complexity to existing programs.

The most notable challenge, however, was which government, federal or provincial, would lead a new "world-class" government monitoring system. Deliberations resulted in the system initially to be jointly administered (JOSMP, 2012), contrary to the need for a single lead agency for CE management (Seitz et al., 2011; Sheelanere et al., 2013), in an effort to renew trust in the science capacity of both governments, but also satisfy competing jurisdictional claims by co-governing the system. However, both governments had different ideas of what an integrative monitoring program needed to accomplish – specifically, the scientific questions that the monitoring program needed to answer: long-term ambient monitoring versus or shorter-term efforts to determine cause-effect relationships. Stratos Inc. (2015) reports that governance arrangements between the interested parties were strained due to an absence of an overall strategic approach. The rise and fall of AMERA, the province's independent monitoring agency, was similarly characterized by "bureaucratic infighting." Integrative monitoring programs across large regions require a degree of coordination that is much greater than what is need to support more localized, sector-specific monitoring initiatives. Establishing clear communication and accountability roles between the parties involved in monitoring, and the coordination of existing administrative structures or agencies responsible for monitoring (Boothe, 2015), are important pre-requisites for any integrative monitoring program designed to support CE management and decisions.

2.5.4 Institutional memory

The long list of reviews and critiques of monitoring programs and initiatives in Lower Athabasca, many of which were commissioned by governments, has generated a wealth of recommendations to make monitoring more effective, more credible, and more relevant to decision making. There are some signs of progress. For example, increased efforts to ensure that monitoring data are transparent and accessible (Dowdeswell, 2011) – a fundamental requirement for ensuring credible and accountable CE decision making (OSAP, 2010; Sheelanere et al., 2013; Noble et al., 2014); and increased, independent scientific oversight such as that granted to AEMERA and maintained when AEMERA's responsibilities were transferred into the provincially-led EMSD program (GOA, 2016c). Regular peer-reviews about the state of monitoring, and tacking action to respond to recommendations emerging from those reviews, has played an important role in the Lower Athabasca in building credibility and ensuring the validity of monitoring programs and initiatives.

Other recommendations, however, seem unable to garner the same amount of attention and these repeatedly dismissed recommendations suggest either a lack of institutional memory, or a deliberate unwillingness to improve the current system. One of the most enduring challenges to monitoring programs in the Lower Athabasca, and evidenced also in other regions and jurisdictions (Dubé & Munkittrick, 2001; Dubé 2003; Ball et al., 2013b), is the coordination and integration among monitoring components and monitoring programs (Squires et al., 2009; Dubé & Wilson, 2013; Westbrook & Noble, 2013). In 1996, for example, the NRBS recommended that "current and future monitoring activities within the basins be integrated… to identify priorities, avoid duplication, redirect efforts and allow for monitoring at a basin scale" (NRBS, 1996b). The years following saw the contradictory inception of monitoring programs independent of one another, such as RAMP, WBEA and ABMI – each with their own mandate and monitoring protocols.

Other important recommendations have similarly been persistently dismissed as new monitoring programs came on scene – including determination of the correct scientific questions to guide regional monitoring and to support decision making. For example, in 1996, the NRBS (1996a) recommended that the first step in developing a monitoring framework for the region must be deciding "…what needs to be monitored and for what reason." Subsequent reviews of monitoring programs across the region, however, have indicated that clear questions are still not being formulated or addressed to guide monitoring programs in a way that supports decision needs (Ayles et al., 2004; OSAP, 2011). In a 2016 science review of the joint oil sands monitoring programs, for example, only 15% of parties interested in regional monitoring surveyed agreed that clear objectives and questions had been articulated for the monitoring committees to address. It is also unclear in the academic literature *who*, explicitly, is or should be responsible for developing the scientific questions to guide monitoring for CE. This research shows that going beyond generic references to "scientists", "practitioners" and "government" (Kilgour et al., 2007; Duinker et al., 2012; Sheelanere et al., 2013) may be required in scientifically complex jurisdictions.. As the science of monitoring has continued to advance (Duinker et al., 2012; Dube et al., 2013; Noble, 2015a), recommendations about the institutional improvements needed to support it, specifically, addressing the challenges associated with more integrative monitoring for watershed-based understanding, who should be responsible, and the alignment of monitoring priorities across agencies and institutions, require much more policy and research attention.

2.6 Conclusions

This paper shows that environmental monitoring in the Lower Athabasca region of Alberta has experienced an episodic history that has posed both challenges to, and opportunities for, CE management. The first episode, the WSC and the LTRN, are both government programs that have operated over many decades to inform regulations and decision-making. In episode two, shorter-term programs such as AOSERP, NRBS and NREI were developed and aimed to collect, analyze, and report data to better characterize baseline environmental conditions as well as to begin to investigate the CE of human activities. Several multi-stakeholder, consensus-driven monitoring programs and organizations then emerged in episode three, including RAMP, CEMA and LICA, to facilitate stakeholder communication and implement or make use of monitoring data – including data collected by others. Episode four includes WBEA, RGMN and ABMI, which began largely with funding from industry to implement independent monitoring programs for specific environmental components. The final episode, episode five, includes JOSM, AEMERA and EMSD, which have come online only recently and in response to critical reviews of the regional monitoring system.

The availability and sustainability of long-term monitoring data to support both short- and longer-term decisions about land and water use and development is needed for managing CE (Dubé, 2003; Squires et al., 2011; Hegmann & Yarranton, 2011; Ball et al., 2013b; Dubé, 2015). Much attention to the scientific aspects of CE monitoring has resulted in a variety of tools and aspirations for its technical implementation (Hegmann et al., 1999; Dubé, 2003; Quiñonez-Piñón et al., 2007; Canter & Atkinson, 2011; Seitz et al., 2011). Some literature suggests the role science plays in CE assessment is one of collaboration, meaning that the assemblage of results from cause-effect studies as well as from regional-scale and long-term monitoring programs are important for guiding predictive CE models and identifying environmental thresholds (Greig & Duinker, 2011; Duinker et al. 2012). However, the institutional arrangements to support these assemblages or linkages for regional CE monitoring and management is largely uncertain, with only a few case studies providing positive experiences (see Dubé et al., 2006; Noble, 2008; Johnson et al., 2011). Ironically, two of these success stories are the NRBS and NREI programs of the Lower Athabasca, which supply valuable evidence that effective CE monitoring is not impossible.

The Lower Athabasca has been subject to a variety of land uses, monitoring programs and organizations, and scientific studies, thus making it an interesting case study for exploring arrangements for cumulative environmental effects monitoring. This study organizes this history and highlights valuable lessons for Alberta and other jurisdictions. For example, multi-stakeholder groups are not likely an appropriate venue for monitoring because of their susceptibility to changes by stakeholders with biased opinions (see also Donahue, 2011 and Biber, 2011). In addition, multi-stakeholder groups can only function within a system which takes their recommendations seriously (Severson-Baker et al., 2008), and implements them over temporal scales which correspond to the state of CE knowledge instead of economic and political cycles. Scientifically autonomous groups, such as ABMI and WBEA, can provide credible information, but close attention needs to be paid to the core mandate and questions being asked of such programs and organizations to avoid costly initiatives which pursue questions irrelevant to CE management and decision making (see also Duinker et al., 2012; Noble 2015a). Creating a core, cost-effective monitoring system which is scientifically defendable with clear pathways to decision-making may be particularly important in times of critical evaluation when funding agencies experience economic stress or public scrutiny (Lovett et al., 2007; Lindenmayer & Likens, 2009).

Further, ongoing administrative tensions associated with overlapping mandates and jurisdictional claims can result in a segregated vision for what monitoring needs to accomplish (Donahue, 2011); this is contradictory to what is needed for effective CE assessment (Gunn & Noble, 2009; Johnson et al., 2011). This segregation can lead to the unnecessary establishment or dismantling of monitoring programs with similar but different scientific approaches, which result in time and monetary costs for rebranding or transitioning to a new system. Finally, institutional memory should be valued. Recommendations from past environmental projects, whether commissioned by government or not, require some degree of follow-up examination and action in order to avoid potentially significant knowledge gaps in the future.

Fragmentation and the absence of monitoring data is a challenge for addressing CE in the Lower Athabasca (Squires et al., 2011; Schindler, 2013; Noble et al., 2014), as well as in many other Canadian jurisdictions and internationally (Chilima et al., 2013; Kristensen et al., 2013; Noble & Basnet, 2014). Administrative and organizational complications leading to the failure or dismantling of programs or organizations is not uncharacteristic of land use planning and cumulative effects management (Parkins, 2011), or environmental monitoring generally (Reid 2001; Biber, 2011). In the case of monitoring, this is perhaps partly due to its scientific and technical complexity, making it seem "opaque" to actors without scientific expertise. This, in addition to difficulties associated with determining whether monitoring is effective (Irvine et al., 2015), and to whose standards (Biber, 2011; Schindler, 2013),make monitoring particularly susceptible to budget cuts such as those experienced during times of economic and political change (Lovett et al., 2007; Olszynski, 2014). There is also a tendency for political parties to make shorter-term scientific investments with more immediate payoffs at the expense of longer-term monitoring (Lindenmayer & Likens, 2009; Biber, 2011; Olsynski, 2012).

In conclusion, this review illustrates that, in addition to scientific struggles (RAMP review, 2010; Donahue, 2011), the episodic administrative and organizational environment of regional monitoring in the Lower Athabasca has further troubled the CE data, management and decision making challenges experienced. Recent consensus on how monitoring should be implemented has largely eluded the Lower Athabasca context; "…there is ongoing tension between the scope and nature of monitoring required for oil sands industry impacts, and for the management frameworks of LARP and other land use plans" (Stratos Inc., 2015). This is a problem exacerbated by reoccurring disagreements between governments (Schindler, 2013; Boothe, 2015), leading to a problematic co-governance approach to regional monitoring. Along the lines of other regional CE capacity studies, which suggest creativity and innovation for institutional arrangements to be necessary for effective watershed-based CE (Chilima et al., 2013), a main challenge is likely that the types of monitoring needed for a robust CE system requires support from region-specific organizations with a shared vision to address and manage CE.

CHAPTER 3

INTEGRATING ENVIRONMENTAL MONITORING WITH CUMULATIVE EFFECTS MANAGEMENT AND DECISION-MAKING

3.1 Abstract

It is often argued that CE assessment and management is ineffective due to the challenges associated with institutional and organizational arrangements for mobilizing monitoring with CE management and decision-making. This paper explores the challenging task of integrating environmental monitoring with CE management and decision-making. The research is situated in the Lower Athabasca planning region of Alberta, Canada, a region which has adopted a CE approach to land use decision-making and harbours several monitoring programs. Semi-structured interviews were conducted with 27 CE monitoring and management professionals to understand perspectives on the current state-of-practice while considering other options. Results show that three basic options or approaches exist for integrating monitoring for CE management and decision-making: a distributed system, which makes use of existing independent monitoring programs and funnels data through a government agency; a one-window system, which absorbs independent monitoring programs into a single monitoring agency; and an independent exploratory system, which invests in an iterative series of independent science-based studies to better characterize natural variability and understand regional CE issues. Each framework has its own strengths and weaknesses and the decision to implement any one system depends on the perceived purpose of existing monitoring; the credibility and depth of understanding of region-specific scientific underpinnings; and the needs of decision-making for managing CE. Enhanced by better integration between environmental disciplines, a shared CE vision must be a priority for choosing or designing an effective monitoring system which will depend on the key scientific questions that most adequately address the needs of CE decisions.

3.2 Introduction

Exploring ways to improve land-use decision making has become a priority for researchers and governments as the cumulative effects (CE) of human development become more apparent and better understood (Schindler & Donahue, 2006; Vörösmarty et al., 2010; Seitz et al., 2011; WWAP, 2015; Mantyka-Pringle et al., 2017). Integrating environmental monitoring, assessment and management through regional or watershed-scale CE frameworks is providing important direction for understanding cumulative change in many Canadian jurisdictions (CEARC, 1988; Kennedy, 1995; GOA, 2008; CCME, 2009; Greig & Duinker, 2011; Noble et al., 2014; Dubé, 2014; Jones, 2016), and research has recently emerged to explore the capacity requirements to implement watershed CE initiatives (Kristensen et al., 2013; Chilima et al., 2013). However, it is also evident that many programs designed to support CE assessment at the regional or watershed scale lose the long-term support needed to ensure their sustainability, or even fail at the point of implementation (Lawe et al., 2005; Noble, 2008). In part, this is because many CE initiatives receive only episodic attention (Parkins, 2011) and CE science, including monitoring, is often developed in isolation of land-use planning, public policy, and decision-making (Schindler & Donahue, 2006; Hegmann & Yarranton, 2011; Noble, 2015b). Arguably, the biggest challenges to CE management are not technical or scientific (Jones, 2016), but overcoming institutional and organizational challenges to implementation (Chilima et al., 2013).

Data generated through long-term environmental monitoring programs provide the foundation for informing CE frameworks and land-use decisions. Several studies have focussed on advancing the scientific design of CE monitoring programs to better detect, observe and determine the significance of the effects of human development activities (Dubé & Munkittrick, 2001; Westbrook & Noble, 2013; Ball et al., 2013a; Dubé et al., 2013). Many monitoring standards and better practices have emerged as a result (Canter & Atkinson, 2011); for example, using both effects and stressor-based approaches (Dubé, 2003), and implementing consistent and comparable monitoring at local and regional scales (Ball et al., 2013a). Efforts have also focused on the generation of region- and industry-specific monitoring data for identifying cause-effect relationships based on anthropogenic disturbances and natural processes unique to each region (Schindler & Donahue, 2008; Westbrook & Noble, 2013). These data are used for a variety of CE purposes including “state of the environment” reporting (Culp et al., 2000; Dubé & Wilson, 2013), establishing reference conditions (Squires et al., 2009; Seitz et al., 2011), identifying environmental thresholds (Kilgour et al., 2007), building predictive models (Francis & Hamm 2011; Duinker et al., 2012), and designing better management responses (Therivel & Ross, 2007; Cole Burton et al., 2014).

Despite these advances, knowledge about environmental stressors and effects remains elementary (Seitz et al., 2011; Schindler, 2013; Jones, 2016) and researchers agree that "…monitoring is the most deficient aspect of [CE] studies worldwide" (Dubé et al., 2013). Environmental monitoring may be ineffective for a variety of scientific, political or administrative reasons (see Strayer et al., 1986; Caughlin & Oakly 2001; Reid, 2002; Lindenmayer & Likens, 2010a; Donahue, 2011; Biber, 2011). For example, some studies suggest that the structure of monitoring organizations often does not accommodate the administration and maintenance of long-term monitoring programs (O'Neill, 2008; Lovett et al., 2007; Lindenmayer & Likens, 2010a; Noble & Birk, 2011), which can sometimes lead to their disassembly or failure (Reid, 2002; Biber, 2011; Schindler, 2013). This is complicated by the fact that environmental monitoring may be occurring on a given land base by a variety of actors and for a variety of different purposes (Lott & Jones, 2010; Lindeman et al., 2011; Hutto & Belote, 2013), which can lead to fragmented or disparate sources of data and information for understanding CE (Vörösmarty et al., 2010; Seitz et al., 2011; Dubé & Wilson, 2013). Further, effective CE assessment and management requires a variety of tools and predictive components (Canter & Atkinson, 2011; Dubé et al., 2013), all of which require different approaches to environmental monitoring.

Calls for improved integration of CE monitoring with management and decision making are not new (Gillingham et al., 2016). However, the monitoring structures and organizational arrangements best suited for effective long-term monitoring that supports CE decision making remains unclear, with only a few case studies providing short-term examples (see Culp et al., 2001; Gummer et al., 2006). The purpose of this paper is to examine opportunities for improved integration of environmental monitoring with CE management and decision-making needs. It does so within the context of the Lower Athabasca watershed, Alberta, Canada. The Lower Athabasca has adopted a CE approach to land-use decision making with the establishment of a provincial land-use framework. Being one of the only Canadian jurisdictions to implement watershed-scale CE management, it provides an opportunity to examine how monitoring programs can be organized such that they meaningfully contribute to government-led CE management and decision-making (Johnson et al., 2011; Seitz et al., 2011; Noble et al., 2014). In the sections that follow, the Lower Athabasca regional context is presented followed by the research methods. Frameworks for monitoring to support CE management and decision-making are then presented and discussed, followed by the implications and emerging considerations for other jurisdictions.

3.3 Study Area and Methods

3.3.1 Lower Athabasca Planning Region

The Athabasca watershed originates from the Athabasca glacier in the Canadian Rocky Mountains and flows northwest into Lake Athabasca, which straddles the northern border between the provinces of Alberta and Saskatchewan (MRBB, 2011; LARP, 2012). For the purposes of land-use planning, the Athabasca watershed is split into two separate land-use planning units in Alberta, the Lower Athabasca and Upper Athabasca (Figure 3.1). The Lower Athabasca also contains parts of three other river basins including the Peace/Slave River, the North Saskatchewan River and the Beaver River. Covering approximately 93,260 square kilometres, the Lower Athabasca boasts an impressive amount of development including aggregate mining, municipalities, forestry operations and agriculture (GOA, 2009; Squires et al., 2009; LARP, 2012). Also present is development associated with controversial surface and in situ mining of the Athabasca and Cold Lake oil sands, the third largest oil reserve in the world (CAPP, 2014). The amount and pace of development has thrust the region, indeed the entire province, into the international spotlight for environmental monitoring and management (RSC, 2010; Donahue, 2011; Miall, 2013; Olszynski, 2014).

In the early 2000s, economic justifications for land-use decisions, unprecedented population growth, and an absence of appropriate regional planning activities (Timoney & Lee, 2001; Kennett & Schneider, 2008) bolstered the need for a landscape approach to provincial environmental management (GOA, 2008). In response, in 2008, the Government of Alberta established a provincial Land-Use Framework (LUF), dividing the province into seven land-use planning regions delineated by watershed boundaries. The *Alberta Land Stewardship Act* (2009) supports the LUF by establishing the legal requirements for developing regional plans (LARP, 2012). While the LUF describes the provincial vision, objectives and outcomes for the overall approach to land use planning and management; regional plans establish the desired future qualitative state of each region over the next 50 years.

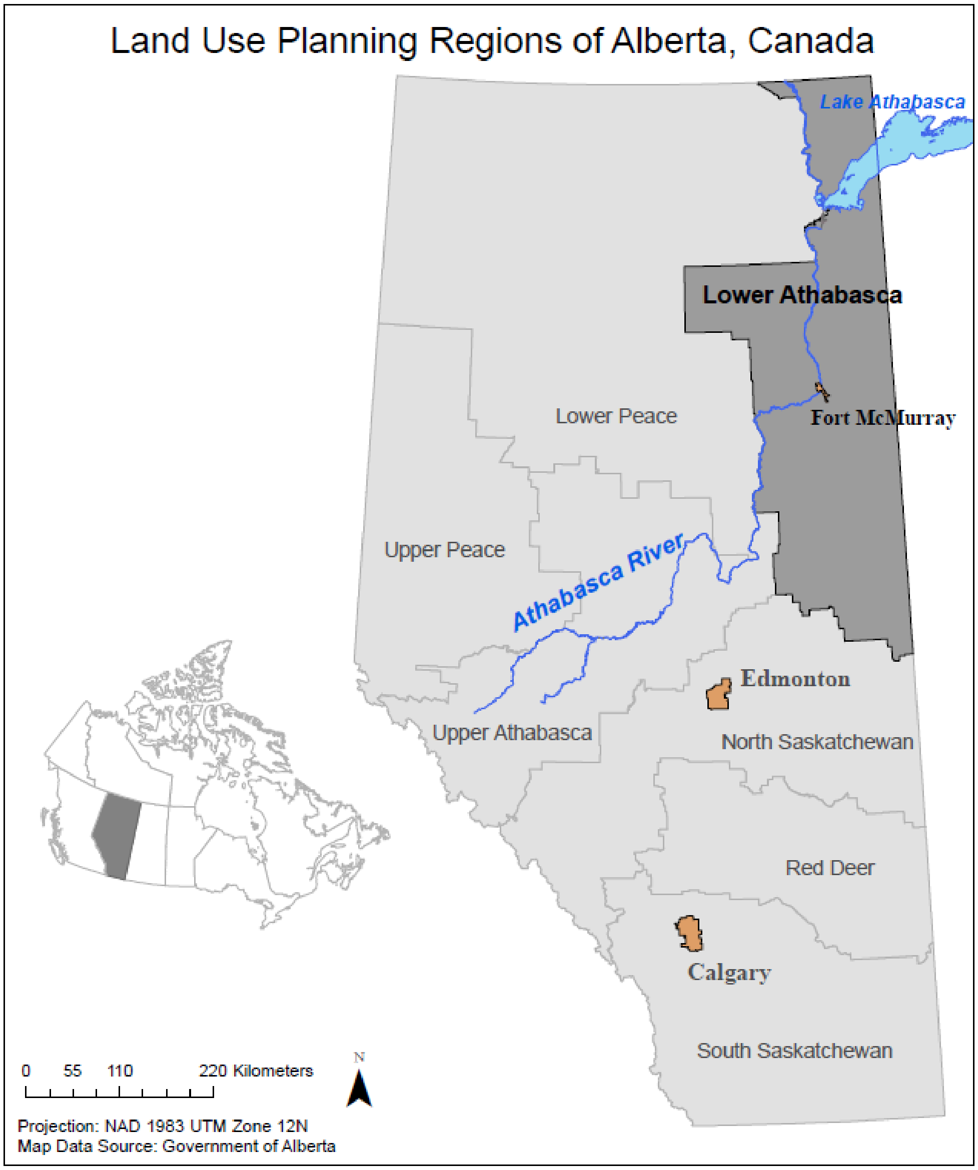

Figure 3.1. Map illustrating the land use planning regions from the land-use framework.

The province promotes an integrated approach to resource management in the regional plans, which "looks at the relationship between all … activities, along with natural events, and the challenges facing the region, and sets the stage for robust growth, vibrant communities and a healthy environment" (GOA, 2014). The plans are subject to review every 10 years and, so far, regional plans have been completed for the Lower Athabasca Planning Region (LARP, 2012) and the South Saskatchewan Planning Region (SSRP, 2014). Some of the tasks for regional plans are to: identify key environmental issues, understand the current state of environmental components through regional assessments and work with others to identify environmental targets and thresholds through the development of management frameworks (GOA, 2016a) – further referred to here as LUF CE frameworks.

LUF CE frameworks operate under the guidance of regional plans, and are a "key approach to manage the long term cumulative effects of development on the environment" (GOA, 2010). For each regional plan, LUF CE frameworks are intended to be created for five environmental components, namely; surface water quality, surface water quantity, air, biodiversity and groundwater. A sixth framework for fluid tailings management has also been developed due to oil sands mining operations in the Lower Athabasca. LUF CE frameworks establish environmental indicators, thresholds (including triggers and limits) and management actions if thresholds are exceeded (LARP, 2012) (Figure 3.2). This approach utilizes the concept of "valued ecosystem components" (VECs), which are environmental attributes that represent, reduce or quantify important features of the environment, effectively narrowing the scope of what needs to be monitored (Beanlands & Duinker, 1983; Canter & Ross, 2010). VECs are often chosen based on their social, cultural, economic, scientific or aesthetic value, and are measured using selected indicators (Duinker & Greig, 2007; Canter & Ross, 2010). The principles for indicator selection, as well as their associated triggers, limits and management actions, are consistent between environmental components; however, the nature of environmental components and their indicators requires various tools and methods of measurement, and so the administrative structure between LUF CE frameworks varies.

The LUF CE frameworks and, by extension, the monitoring which informs them, carry legal weight. LUF CE frameworks operate within the regional plans which are considered regulations under Part 2 section 13(2) of the *Alberta Land Stewardship Act* (2009) and are also able to supersede any other Act and regulations under Part 2 section 17(1) of the same Act. This gives power to decision-makers to approve or reject developments according to indicator measurements based on monitoring data.

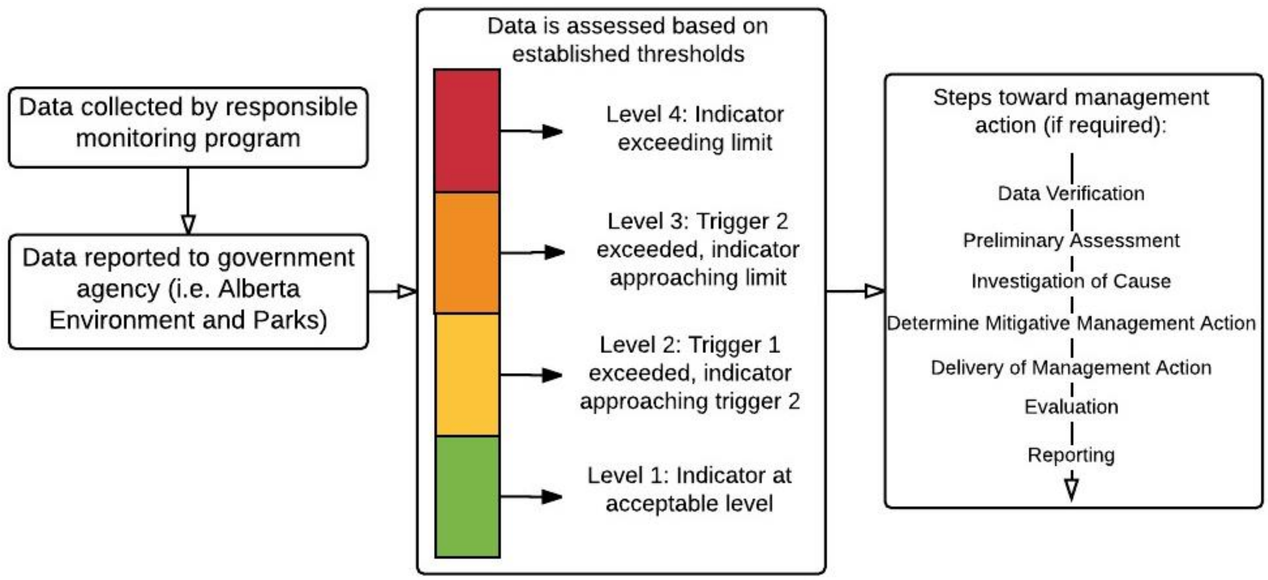

Figure 3.2. Author's conceptualization of the cumulative effects approach to land-use decision making in Alberta, based on GOA, 2012d.

To inform the LUF CE frameworks, monitoring systems have been arranged in collaboration with existing ambient environmental monitoring programs, such as the Long-Term River Network, Wood Buffalo Environmental Association and Alberta Biodiversity Monitoring Institute to name a few. Each LUF CE framework is thus informed by a different monitoring program (Figure 3.3). The history and diversity of monitoring programs in the Lower Athabasca (Lott & Jones, 2010; Miall, 2013), and the CE approach to land-use decision making (GOA, 2008), provides a rich environment for exploring their integration and deriving lessons for practice.

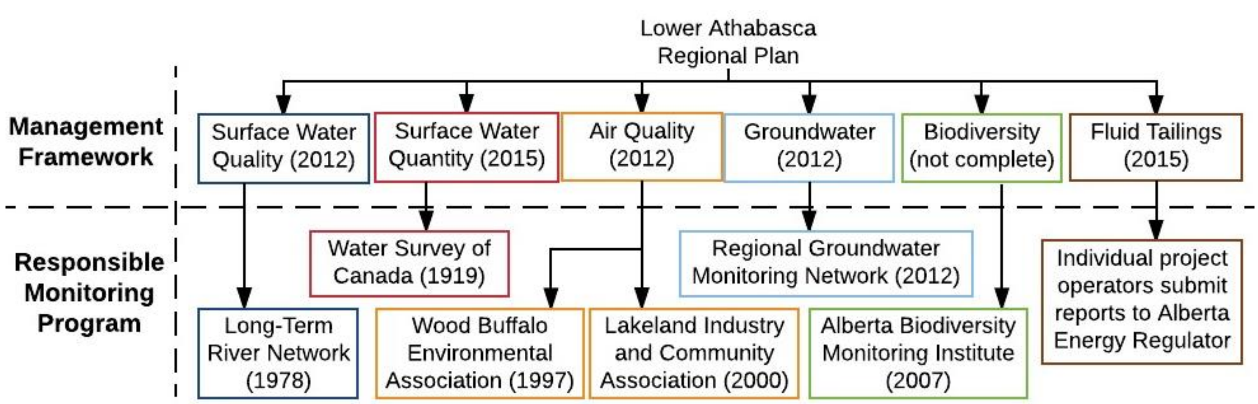

Figure 3.3. Responsible monitoring program(s) for each of the LUF CE management frameworks, and their year of inception, under the Lower Athabasca Regional Plan.

3.3.2 Methods

The primary method used in this research was semi-structured interviews (see Rowley, 2012). The focus of the interviews was to: examine how monitoring is integrated into the existing CE management system; explore perspectives about the nature and efficacy of this integration from environmental monitoring and CE practitioners, including strengths and weaknesses; and identify options to better link monitoring initiatives to CE management and decision-making. Participants were asked a series of questions relating to their experience with regional monitoring within the Lower Athabasca, characteristics of past and present monitoring programs, and the nature and efficacy of information exchange between monitoring programs and the CE management system under the LUF. A list of interview questions is included in Appendix 3.

Interviews were carried out between June and September, 2016. Initial interviewees were identified with the help of a few key informants. Other potential interviewees were identified from relevant government documents pertaining to CE management and regional monitoring in the Lower Athabasca, and using a snowball sampling technique (Babbie, 2001) where interviewees were asked for recommendations for potential future participants based on interview questions. E-mail communication was initiated with all potential participants providing a brief description of the research, and was followed up with a confirmation e-mail a short time later to schedule an interview. In total, 55 individuals were contacted of which 27 agreed to participate in an interview. Because implementing environmental monitoring for CE management requires a collection of experts, an array of professionals were interviewed including project managers, environmental scientists, water resource engineers, land-use planners and policy analysts (Table 3.1).

Interviews lasted approximately one hour and were recorded and later transcribed. Transcripts were then thematically analyzed (Patton, 2002; Ryan & Bernard, 2003) with the help of NVivo 11© software. A first round of thematic coding was used to build a primary list of categories, such as the monitoring systems described below, which were used to summarize, organize and manage data. A second round of coding was then used to highlight the reoccurring positive and negative aspects (i.e. sub-themes) of the systems.

Table 3.1. Number of interview participants by professional affiliation.

	Affiliation	No. of Participants
Research and Monitoring Organizations	Alberta Biodiversity Monitoring Institute	5
	Alberta Innovates	1
	Alberta Environmnetal Monitoring, Evaluation and Reporting Agency	2
	Candian Oil Sands Innovation Alliance	1
Industry	Stantec	2
Provincial Government	Alberta Energy Regulator	2
	Alberta Environment and Parks	8
	Agriculture and Forestry	1
Federal Government	Department of Fisheries and Oceans	1
	Environment Canada	1
	Natural Resources Canada	2
Academia	University of Alberta	1
	Total	27

3.4 Results

Monitoring programs are important contributors to CE management strategies, and how they are organized, administered, and interact to inform land-use decisions was identified by all interviewees to be of significant importance. There was also agreement among participants regarding the current structure of regional monitoring programs in the Lower Athabasca for informing a CE approach to land-use decision making under the LUF (see Figure 3.3). Interviews thus largely focused on the strengths and weaknesses of the current approach, and that of alternative approaches to structuring environmental monitoring for CE management. Overall, emerging from the interview results were three distinct approaches to how, conceptually, CE monitoring and decision-making interact (Figure 3.4).

The first approach, conceptualized as a *distributed monitoring system*, reflects the current state of practice in the Lower Athabasca. A distributed monitoring system delegates monitoring of specific environmental components to different monitoring programs. In the case of the Lower Athabasca, some programs operate independently or at "arms-length" from government (though they often receive funding from government), such as biodiversity monitoring under the Alberta

Biodiversity Monitoring Institute (ABMI), or air monitoring conducted by the Wood Buffalo Environmental Association and Lakeland Industry and Community Association; while others are operated and maintained by the provincial and/or federal government, such as monitoring for provincial Long Term River Network program for surface water quality or the federal Water Survey of Canada for surface water quantity. Though not all are independent from governments, they all are independent of each other.

The second approach identified by participants, and an alternative to the current approach in the Lower Athabasca, was a *one window monitoring system*, which was described as a system where all monitoring is conducted by a single organization and, according to most participants, best implemented by a government agency. In this approach, monitoring networks for each component are absorbed into a responsible organization or government agency. The third approach, and also an alternative to the current approach, an *independent exploratory monitoring system*, was described as a system which conducts a series of exploratory studies to better characterize the pertinent CE issues of the region. Some interviewees agreed that investing more heavily in an iterative series of independent scientific studies would contribute to producing a more robust CE ambient monitoring system which could then, more credibly, inform decisions. Each of these approaches is explored in the sections that follow.

3.4.1 Distributed monitoring system

Interviewees agreed that the current monitoring system in the Lower Athabasca closely resembles a distributed organizational structure. *Distributed monitoring systems* delegate data collection for each environmental component to a different monitoring program. Development of a land use or CE management framework is then completed in consultation with the programs themselves to address requirements of monitoring networks and work towards a common vision for implementing a defendable CE monitoring strategy. The data, and in some cases analyses of the data, is then funnelled through a government agency where it is assessed against thresholds established in each LUF CE framework. This information is then used to inform land-use decisions. Interviewees identified several positive and negative attributes of this approach.

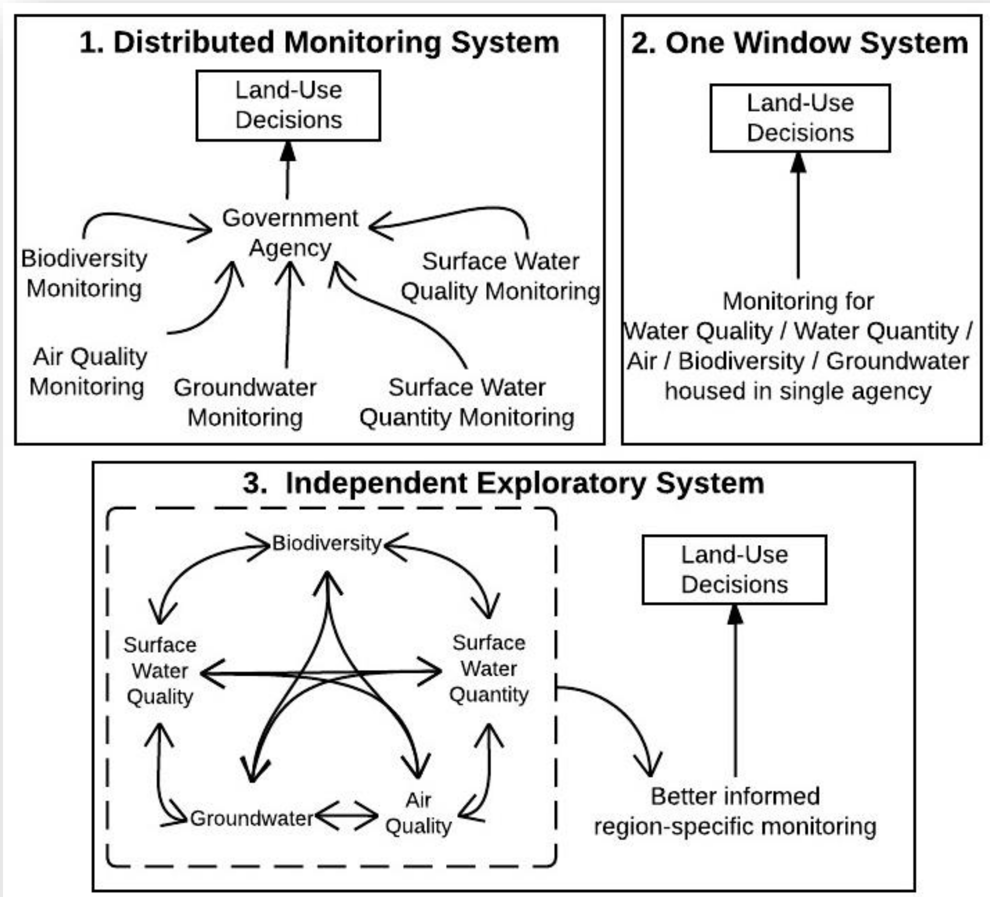

Figure 3.4. Three types of CE monitoring systems for decision making that emerged from interviews.

About half of interviewees explained that environmental monitoring and science is more defendable when implemented and overseen by independent organizations without intimate ties to industry or, in some cases, government. As one interviewee from a monitoring program stated: *"the basis of thresholds for water and air are somewhat more defensible if they are coming from independent programs."* And, another from the same program indicated that *"…[an] issue with monitoring systems sometimes [is] being linked to government who tend to flip around when new people are elected… we are somewhat independent from government… I think that's why it's been successful so far."* These perspectives are consistent with previous analyses of the state of CE monitoring in the study area (e.g. Donahue, 2011; Biber, 2011, Schindler, 2013). For example, several reviews of the government-led regional Lower Athabasca monitoring system before 2008 concluded that the system was incapable of adequately detecting environmental change (Kelly et al., 2009; 2010; RSC, 2010), and called for the establishment of a scientifically independent monitoring and science agency (Schindler, 2010; Dowdeswell et al., 2010).

It was also noted that different environmental components require different methods and techniques to monitor them. Thus, delegating monitoring to organizations or programs with a relatively high degree of specialized scientific and technical knowledge is important to capitalizing on existing expertise and addressing many of the scientific and technical challenges of regional environmental monitoring programs. The consistent administration of some programs, operating independently from government or industry, further provides valuable monitoring infrastructure such as logistical support, trained personnel, equipment and, often, capacity for analysis. As one interviewee from a monitoring program commented: *"…right now there are very few monitoring programs that monitor peatlands for example… it's very much incomplete, and in the north there is very little happening aside from what ABMI is doing."*

Long-term datasets, such as those housed by distributed monitoring programs and organizations, were identified as crucial for understanding the CE of development. To build defendable CE management frameworks, including robust monitoring networks, triggers, limits and management actions, a wealth of analysis using long-term data is thus required. Several interviewees indicated that making use of established monitoring programs is an efficient solution to fulfilling the needs of a CE monitoring system. For example, one interviewee reflected on their experience with the development of the Water Quantity LUF CE framework, explaining that Water Survey of Canada monitoring stations have been in operation since the 1970s. Data from these stations have provided valuable evidence for which to build the CE management system and, by comparison to other environmental components, water quantity data is plentiful and reliable.

However, participants also identified several challenges to, or limitations of, distributed monitoring systems for CE management and decision making. Most of the monitoring programs in the Lower Athabasca emerged to answer scientific questions that are not necessarily aligned with CE management objectives. A common critique noted by participants is that the monitoring network for which each LUF CE framework is built upon has been designed for addressing environmental concerns which pre-date the watershed CE approach established under the regional LUF. For example, when asked "Are existing monitoring efforts calibrated to detect and assess cumulative effects in the watershed?" one interviewee from a research organization explained: *"They're not built for it. Can they do it, maybe? But they weren't built for it. This is a relatively new concept for the government to link its decisions to activities relating to regional thresholds. It's a big process to make sure the local stuff is worked out, the science and citations are correct, and then pass that on and say well what does this mean regionally."*

Further, most all interviewees agreed that if a monitoring program is to be relied upon for CE data, and the CE approach to land-use decision making is a permanent one in the Lower Athabasca, an important requisite is that the government funding base for that program is sustainable for the foreseeable future. One interviewee from a research organization explained that government may not be entirely aware of what the implications are of making commitments to some of these large CE programs, stating: *"Does the government understand the implications of the… management frameworks in terms of the monitoring effort that's required? Do they have the money, resources to support implementation of these beautiful, well intentioned (LUF CE) frameworks? [Independent monitoring programs] may be capable of change and adapting methods to the frameworks, but it's not what they were initially designed to do. So, is the government capable of all of this given new budgets?"*

Interviewees also expressed concern that the episodic nature of monitoring programs and organizations in the region has created a culture of uncertainty surrounding long-term funding commitments and allocations to environmental monitoring. Questions surrounding the efficiency and effectiveness of monitoring used in management frameworks are therefore critical. Related to this, because monitoring programs need to be cognizant of sustainable sources of funding, conflicts of interest arise if monitoring networks are developed by, or in close consultation with, the program ultimately responsible for its implementation. This can lead to commitments to expensive monitoring programs, or limit decision-making to one set of data. For example, several interviewees identified a potentially worrisome relationship between one independent monitoring program and the current biodiversity LUF CE framework. A policy specialist from the provincial government cautioned that hinging the LUF biodiversity management framework on one, independently-led monitoring program is restrictive in that the monitoring program is *"self-serving"*, meaning that there is no opportunity for *"thinking outside the box"* – beyond the scope of the mandate and interests of the monitoring program itself.

Another critique raised by interviewees was that the current distributed monitoring system does not promote integration between environmental components. Integration of environmental information is an important part of understanding and managing CE, and a system that delegates monitoring to separate programs was perceived as risking isolation and perpetuating competition for resources. Interviewee concerns are confirmed by previous studies in the Lower Athabasca (e.g. Lott & Jones 2010), which found that many professionals working in monitoring programs are unaware of other program's operations and data. Two provincial policy specialists similarly commented *"…it really doesn't induce integration. They have been left to their own planning – the original intent of the [monitoring] organizations comes from themselves or industry."* And: *"I think there's a lot of monitoring going on and it basically needs to be rethought. With the same amount of effort… you could do a much better job of monitoring. There are these fractured people and corporate people doing different things and divisions of government, trying to answer the same question."*

Some programs have taken it upon themselves to explore integration studies with some success, such as the Terrestrial Environmental Effects Monitoring program from the Wood Buffalo Environmental Association, which is designed to detect, characterize, quantify and report on impacts that air emissions have had, or may have in the long term, on terrestrial ecosystems (WBEA, n.d.[b]). One provincial scientist, however, commented that the task of integration between disciplines and components is a challenge inherent to the science of and approaches to environmental monitoring in general, and not necessarily a function of distributed monitoring systems.

3.4.2 One window system

The second approach, a *one window system*, envisions a new monitoring regime for the Lower Athabasca that is implemented and maintained by a government agency. Monitoring for each environmental component would be administered and implemented by government, since government is often seen as an appropriate institution for carrying out CE assessment and management (Harriman & Noble, 2008; Noble et al., 2013). This approach absorbs elements of existing monitoring programs in a region to develop a "one-stop-shop" for providing environmental information to decision-making. Interviewees had a variety of perspectives on this approach.

A shared vision for how regional CEs are defined, measured and assessed is important for effective CE management, but almost all interviewees agreed that allocating monitoring to different programs contradicts this principle; for example, a land-use planner from the provincial government commented: *"The benefit of all of them is that they have moved us forward; the weakness is that there is no consistent leadership and vision, it's always slightly changing so you lose staff and time trying to get everyone on the same page."* Although a degree of scientific autonomy is important, participants noted that multiple separate and independent monitoring programs risk them pursuing scientific questions that are outside the scope of, or irrelevant to, decision-making. A representative of the provincial government, who is involved in monitoring integration, indicated that *"…there are opportunities for us all to come under a more broad umbrella in terms of the key questions that we need to be asking and prioritizing them. Making sure we are doing the right thing at the right time. Because maybe the scope of all those endeavours [isn't] adequate."*

The one window system was also described as combating the implications of competition for funding, as well as possibly eliminating the need for promoting individual programs, which can be confusing to stakeholders and the public. About one quarter of interviewees suggested that having a single agency to implement monitoring would not only be less expensive administratively, but facilitate integration between environmental components. In this approach, scientists from different disciplines would be working in closer proximity to one another, promoting partnerships and collaboration. One provincial policy specialist explained their concern with a distributed monitoring system, which constrains this type of integration: *"…the biggest concern was for me the segregation of the monitoring. With the [biodiversity] people doing this, air people doing that etc. there [isn't] a lot of integration and you really need to do that for CE."*

More than half of interviewees also noted, however, that if monitoring was housed in a single government agency, political changes and shifting priorities would inevitably influence the scientific direction monitoring takes. As one provincial scientist explained: *"Within government there are all kinds of other interests and influences; you can have the best intentions in terms of science, reporting to the public, etc. and politics can affect that."* Data and scientific oversight should also be supplemented from elsewhere to prevent the single agency from becoming self-governing and susceptible to corruption – a notion supported by many interviewees, with one provincial policy specialist explaining: *"…you can't just rely on one source of data and if you do you need to be clear why you are using only that one. I don't think that government has done the best job in identifying what the best sources of data are to everyone."*

A provincial scientist involved in developing the LUF CE frameworks added that internalizing all monitoring to a single agency would be fraught with challenges, both administratively and scientifically. This interviewee explained that even within government monitoring programs for a single environmental component there is difficulty in prioritizing monitoring efforts. The same interviewee commented: *"Should we aspire to [a one-window system]? Absolutely. But it adds overhead and clunkiness – we even have a difficult way of prioritizing within our department."* Another provincial policy specialist similarly mentioned that *"…at some point, with CE, it takes collective effort; what I have found is that reluctance isn't just external, it's also internal, so every jurisdiction of government has to overcome the traditional roles and responsibilities of monitoring."*

Two interviewees cautioned that a one window system may mistakenly lead people to assume that because all monitoring data is housed inside a single agency that there is better integration between components. As one provincial policy expert explained, *"The land-use framework people just want to pull it all in and sit on it and expect magical things will happen… [independent monitoring programs] do collaborate with different institutions, academics whatever but that's because we know where to go in our network of people that are willing to work on [projects]."* Due to the nature of integration, a major challenge to a one-window system is pursuing the most relevant and defendable questions for monitoring to answer that support CE management, but *"…a big barrier is that everyone has their own questions to answer."*

3.4.3 Independent exploratory system

Discussions about a third possible approach to monitoring, an *independent exploratory system*, was often based on the concern about monitoring programs that are "data-rich but information-poor" (see also Ward et al., 1986). Several participants noted the current inability to define or come to consensus on ambient monitoring questions and whether current ambient monitoring is able to adequately address the scientific needs of managing CE. In 2012, for example, due to a series of reports from the governments of Alberta and Canada (triggered by Kelly et al. 2009 and 2010, showing inadequacy in the monitoring system), a new Joint Oil Sands Monitoring (JOSM) plan was launched by the Alberta and federal governments to "improve characterization of the state of the environment in the oil sands area and an enhanced understanding of cumulative effects and environmental change" (JOSMP, 2012). The JOSM was largely external from monitoring for informing the provincial LUF CE frameworks. The JOSM plan was raised often during interviews, with some describing existing ambient monitoring activities (see Figure 3.3) used in the LUF CE frameworks as inadequate for identifying and managing CE. The independent exploratory approach to monitoring calls for heavier investment in industry and regional-specific studies, embodied as a program such as JOSM. Participants suggested that a structured approach to these "cause-effect" studies would provide important information such as the origin and fate of contaminants in a watershed, and could be used to inform a more robust CE ambient monitoring system. Several arguments for and against heavier investments in an exploratory system were raised by interviewees.

An argument made in support of an independent exploratory system was that the LUF CE frameworks themselves are not entirely scientifically defendable. Some interviewees felt that, in essence, the LUF CE management frameworks are an interesting concept in pursuing a CE approach to decision-making. They disagree, however, that they provide enough scientific evidence to support land-use decisions. Criticisms extended to ambient monitoring in general, and hinged on the idea that simply collecting data without a clear, question-driven impetus, offers little value to the pursuit of decision-making based on strong scientific evidence. As one provincial scientist explained, indicator limits and thresholds don't necessarily fit the exploratory approach: *"So for example the water quality framework, there are a handful of parameters from a single [monitoring] site. That's it for the entire lower Athabasca. That says, if we have a little bit of info at [one monitoring site, that] allows us to make all land use decisions for the lower*

Athabasca. There is a fiction to the framework…" Another policy specialist similarly explained: *"We have parameters for a bunch of media, but are they the right ones I'm not sure. The science just isn't there yet. You have to set up a planning process which you can first understand the industry then ultimately plan a monitoring network."* Some interviewees also cast doubt upon whether the scientific evidence used to build the LUF CE frameworks, in absence of adequate cause-effect understanding, will be able to withstand challenge from developers whose project's result in indicator exceedances. As a representative of one monitoring program commented: *"The thresholds aren't finalized yet – they don't have a strong scientific basis… So when development is redirected or approvals are denied based on cumulative development on an indicator based on a threshold with weak science, there will be push back."*

Many criticisms about the existing LUF CE frameworks stem from the uncertainty surrounding the chosen thresholds and what they truly signify for the health of an indicator and/or may require in terms of proper management intervention. Many participants reported that disentangling cause and effect of trends over such a vast region requires more data and hypothesis testing than what is currently accrued. For example, one provincial scientist explained that exploratory studies "*…really answer the question of what actual effects does this land use have on the environment; …if these studies are designed properly we can more definitively say this type of industry/activity has this effect on this specific ecosystem, results in this type of disturbance, this time scale for recovery which is all transferable [and] I think that's the approach we need for monitoring.."* About one quarter of interviewees also commented that the natural variability of some environmental components is simply not well enough understood to make informed land-use decisions, and that investing in an independent exploratory system would begin to answer some of the underlying scientific questions about the effects of human activities, and thus strengthen future decisions based on more credible indicators and thresholds.

However, interviewees also acknowledged several challenges of a CE monitoring system built entirely on exploratory scientific questions. Though the value of science in decision-making is high, a main concern identified was that the types of questions asked by exploratory studies do not necessarily supply the CE system with the answers needed for land-use decision making. As one representative from the provincial government mentioned: *"…we have these frameworks, we need answers and [advocates for exploratory studies] would say, well, we have other questions* *we want to ask. We have these frameworks; we need these answers, we don't need theories on other things you want to look at."*

Other interviewees, including a provincial policy specialist, similarly commented that there are *"lots of different scientific questions you can ask, especially somewhere with as many pressures as the oil sands"* but it's "*really important to focus the monitoring to a regional CE perspective to give decision making the best idea of desirable future outcomes."* Some interviewees also suggested that an independent exploratory system does a poor job of prioritizing monitoring efforts, and overlooks the importance of ambient monitoring data. Referring to the JOSM program, for example, an interviewee from a research organization reported that the program "*is using a lot of scientific research that isn't necessary – or isn't as high a priority"* and that there is a broader need for discussion about *"where the priority should lie; if the CE approach is taken, [ambient monitoring] should probably be priority."*

Data management issues were also identified as potential challenges of an independent exploratory system, due in part to the motivation to publish scientific findings. The time and effort needed to perform analyses and prepare manuscripts for publication was noted as an obstacle for a system whose goal should, ideally, be to ultimately inform land-use decisions. As one provincial scientist mentioned, under this approach data are often not made available for use until results are published and, even then, the raw data can be hard to access. Another provincial policy expert similarly commented on their experience with JOSM, reporting that *"we brought in researchers and their objectives were publications and research. I don't know if that's what was needed that early…analytical capabilities were getting into a back log."* Interviewees also noted that generating data through scientifically-led exploratory monitoring systems doesn't necessarily mean that those data are useful for decision making, in that "*data isn't the same as information."*

3.5 Discussion

Experiences with regional monitoring in the Lower Athabasca watershed provides useful insights on the sometimes-competing nature of monitoring and how it could, or perhaps should, be better integrated for CE management and decision-making. The results show three perspectives for integrating environmental monitoring with CE management and decision-making, each of which has its own strengths and weaknesses.

First, a *distributed monitoring system* arranges existing independent monitoring programs, gathers and recalibrates their data, and mobilizes them for use in decision-making. Being free of control from industry and government was believed to make this system more scientifically credible, and remove barriers to accessing long-term datasets. Biber (2011) and Donahue (2011), for example, suggest that monitoring programs influenced directly by industry or government have greater potential to be steered towards unnecessary or ineffective monitoring efforts, because of their potential for adverse effects on "business as usual" economic development. The concern however, is that independent monitoring programs are often designed for a purpose, and/or to achieve objectives, that do not necessarily align with CE and decision making needs, and therefore less influential. In a review of watershed-scale CE monitoring practices, Dubé et al. (2013) state that monitoring programs are "…designed with a specific purpose and often to meet a specific regulatory need. [And that] monitoring has not been conducted or designed specifically for the purposes of cumulative effects assessment…" Independence also contributes to missed opportunities for knowledge integration due, in part, to fragmented data management practices (Noble et al., 2014). It is no secret that disparate sources of monitoring in Alberta have resulted in fragmented sources of environmental information (Squires et al., 2009; Seitz et al., 2011), likely because of different monitoring objectives and sources of funding (Lott & Jones, 2010). Finally, independent monitoring programs are often accused of being needlessly expensive and time consuming (Caughlan & Oakley, 2001; Legg & Nagy, 2006; McDonald-Madden et al., 2010), which begs the need for more efficient monitoring systems. As such, more attention needs to be given to not only ensuring that independent monitoring programs are scientifically adequate (Lindenmayer & Likens, 2010a; Schindler, 2013), but that they are also useful to land use and regulatory decision making (Ball et al., 2013b) and economically efficient (Legg & Nagy, 2006; Wintle et al., 2010).

A *one-window system* amalgamates existing monitoring programs into a single monitoring agency, housed within government. This type of system may generate greater efficiencies by removing layers of administration needed to coordinate multiple, external monitoring initiatives and may help reduce the physical and administrative barriers to knowledge integration by creating a single multi-disciplinary organization. More importantly, with greater monitoring oversight it is more likely that this approach will better support a shared vision for what monitoring needs to accomplish and respond more directly to CE decision making needs (Canter & Ross, 2010; Noble & Basnet, 2015). However, even if housed within and coordinated by government, setting priorities for data collection and subsequent analyses can be a challenge due to the competing needs of monitoring information and government's role to fulfill obligations to a variety of scientific endeavours expected of the public service. Biber (2011) explains the reasons why such challenges exist, for example, decisions to invest in shorter-term scientific studies with more immediate, issue-specific payoffs at the expense of long-term monitoring. This is not surprising, considering that policymakers are often "…bombarded with information of varying uncertainty and bias… on a multitude of potential policy topics" resulting in "attention allocated to some problems rather than others" (Jones & Baumgartner, 2005). Further, although encouraging integration between environmental components, a one window system does not necessarily achieve it. This is due to the fact that integration of environmental systems is incredibly complex (Liu et al., 2015), and simply housing all monitoring in the same organization does not address those intricacies.

The third system, an *independent exploratory system* invests much more heavily in independent scientific studies which, iteratively, over time, provide information for informing a more robust CE monitoring program – including the scientific evidence needed to support thresholds, management actions, and disentangling long-term ecological and environmental processes. An independent exploratory system provides scientific confidence to future decisions based on cumulative effects. However, a variety of challenges exist with this approach from the perspective of management and decision-based CE frameworks, including risks associated with the pursuit of scientific questions outside the scope of, or that do not coincide with, the needs of decision-making. Other studies similarly warn of the risks of investing in monitoring systems which address scientific questions that do not answer management questions (Lovett et al., 2007; Lindenmayer & Likens, 2010a). Also, the technical detail of data and analyses often generated through exploratory studies makes metadata and applications to regulatory decisions a significant challenge. These types of concerns are consistent with Hegmann & Yarranton (2011), who similarly caution that a CE system must produce results relevant to decisions and do so in a timeframe which suits the needs of all parties, including decision-makers.

Several broader observations also emerged from the study results concerning the support for CE decision-making provided by monitoring programs. First, despite agreeing that it is important to understand how monitoring is administered and implemented, about half of interviewees believe that it does not matter *who* is responsible for conducting environmental monitoring. With proper oversight, auditing, and openly available data, it may not matter if an organization is independent, nor if monitoring responsibilities are allocated to one versus many organizations. This finding was surprising, since organizational issues are often credited as being a key factor attributing to the failure of monitoring programs. For example, studies show that monitoring programs are prone to failure based on organizational issues, including the inability to retain key personnel, poor data management procedures, and abrupt changes to data collection protocols (Reid, 2001; Caughlan & Oakly, 2001; Lindenmayer & Likens, 2010a). These weaknesses are in addition to the realities of modern political and economic whims, which neither monitoring programs nor watershed planning initiatives are entirely immune to (Timoney & Lee, 2001; Blomquist & Schlager, 2005; Biber, 2011). Careful planning and attention to the agents responsible for monitoring is thus critical to developing reliable and accountable monitoring organizations.

Second, a theme which was frequently raised during interviews was the operational challenges of the three monitoring approaches given the reality of constrained government budgets. Although comparative studies focussed on the costs of specific components of a monitoring system are relatively common (for example, Wintle et al., 2010; McCarthy et al., 2010; Braun & Reynolds, 2011), considerably less work has been done to explore the costs associated with one organizational structure for monitoring versus another. In this research, it became clear that some felt that the administrative overhead costs associated with having a variety of separate monitoring programs, such as those within the current distributed monitoring system, introduces opportunities for unnecessary spending. Interviewees also suggested that a distributed monitoring system may be needlessly expensive due to its development being independent of government fiscal oversight; therefore, commitments to support such programs may be misguided. Others felt that a one-window system, with its internalized approach to monitoring under a single administrative umbrella, may at least partly rid a system of some of those same overhead costs. Importantly, however, a one-window approach does not make a monitoring system, as a whole, immune to future funding cuts as a result of economic shifts or new political strategies. The independent exploratory monitoring system, despite its scientific defensibility, was frequently identified to be of fiscal concern. This is likely due, in part, to the potential for a series of cause-effect studies to become increasingly expensive due to the effort needed to confidently explore the fate of all contaminants and their cumulative impact. This has the potential to quickly exceed budgetary constraints, resulting in unrealistic financial demands. Financial weaknesses permeate each of these monitoring approaches; most of which are based on problems that question the sustainability of stable funding in the long-term. The issue of stable funding is not a new problem for environmental programming generally (Mulder et al., 1999; Caughlan & Oakly. 2001; Reid, 2002; Lovett et al., 2007; Ball et al., 2013a) which may be explained by a variety of conditions (see Reid, 2002; Biber, 2011). Generally, however, regional environmental monitoring programs reveal symptoms of 'wicked' problems such as climate change (McCann, 2013); which often suffer from inadequate funding and a lack of committed and persistent attention through time (Head, 2008).

Third, echoing an array of literature (see OSAP, 2010; RSC, 2010; Donahue, 2011; WMDRC; 2011), experiences from the Lower Athabasca reflect the difficulties in determining the most appropriate questions for monitoring to pursue. The first two conceptual monitoring systems, distributed and one -window, suggest that ambient environmental data collection, as it currently exists, is sufficient to provide land-use decision making with the appropriate level of scientific detail. The third approach, however, is based on the premise that a more scientifically-driven monitoring approach is needed for sound decision making, focused on understanding causal relationships through independent science. Interviewees were aware of this dichotomy, and often had opinions seated either on one side of the argument or the other - i.e. in favour of either continuous but perhaps redesigned ambient monitoring, or greater investment in exploratory studies. This debate in environmental monitoring is not new (see Nichols & Williams, 2006; Lindenmayer & Likens, 2010a; Wintle et al., 2010), with both approaches offering significant scientific benefits (see Nichols & Williams, 2006; Lovett et al., 2007; Nielsen et al., 2009; Bunn et al., 2010; Haughland et al., 2010; Courchamp et al. 2014). Wintle et al. (2010) go so far as to design an economic model for deciding on whether to invest in an ambient (surveillance) or exploratory (targeted) monitoring efforts, and McDonald-Madden et al. (2010) similarly provide a decision-tree to determine when and what type of monitoring to undertake. Not surprisingly, both examples are dictated largely by what type of scientific question needs to be answered, working under the premise of "…what we strive to know should be driven by what we need to know" (McDonald-Madden et al., 2010). This is a key limitation in most CE monitoring systems – the questions are not only many and varied, but in some instances monitoring is not targeted to answer any specific question.

Arguably, information from both ambient and exploratory studies is needed for assessing and managing natural and anthropogenic CE (Prowse et al., 2006; Westbrook & Noble, 2013). The debate then transitions from deciding on either an ambient *or* exploratory approach, to finding an appropriate balance between the two in terms of resource allocation. Importantly, this balance needs to be sought while reinforcing a shared vision for what a CE management system should strive to accomplish and the types of questions it needs to answer - a significant challenge considering the pre-conceived notions that accompany each of the two monitoring approaches (Lindenmayer & Likes, 2010a). In other relatively successful Canadian CE assessment experiences, such as the 5-year Northern River Basins Study, scientific principles from earlier CE monitoring technical frameworks (i.e. Munkittrick et al., 2000; Dubé & Munkittrick, 2001) were used to guide *both* ambient and exploratory monitoring. A 1996 report from the NRBS foreshadowed this need to balance monitoring efforts: "[Ambient] monitoring data are essential to the documentation of trends within the environment... However, only properly designed experiments are capable of determining causal mechanisms with statistical rigour… In addition to the testing of specific hypotheses, research should be directed toward specific needs (e.g., improvements in data collection techniques, enhancement of predictive models) identified by routine monitoring" (NRBS, 1996b).

3.6 Conclusion

Significant improvements are being made towards a CE approach to decision-making (Kennedy, 1995; GOA, 2008; CCME, 2009; Greig & Duinker, 2011; Noble et al., 2014; Dubé, 2014), including in the Lower Athabasca region of Alberta (Johnson et al., 2010; Noble et al., 2014). However, an enduring challenge has been to inform decision and policy makers of the types of monitoring ongoing on the land base and assessing whether and how they can contribute to CE management. An important first step in determining the best appropriate approach to monitoring is understanding the underlying purpose(s) and rationale(s) of different monitoring- and science-based activities (Bunn et al., 2010; Lott & Jones, 2010), and whether and how they support CE management and decision needs (Duinker & Greig, 2006; Hegmann & Yarranton, 2011; Noble, 2015b).

Dubé et al. (2013) argue that "…watershed cumulative effects assessment, to be useful, require[s]… Assessment of accumulated state and prediction of alternate development trajectories supported by regional monitoring and directed by a watershed plan…" and "all [of these] components are dependent on monitoring." Despite the clear importance of monitoring, rarely are conceptual frameworks for integrating monitoring with CE management and decision-making explored in the literature. The three approaches discussed in this research provide insight into the array of ideas and perspectives which underlie conceptual frameworks for integrating monitoring with CE management and decision-making. Deciding which of these frameworks is the most useful or appropriate will likely depend on the nature of available data, predictive tools and monitoring effort in a given region (Wintle et al., 2010; Canter & Atkinson, 2011), but also communicating the needs of CE monitoring by decision-makers.

At the heart of these decisions is the establishment of clear scientific questions for monitoring to answer, which must align with a shared vision for how to identify and manage CE and also broader strategic land use and planning goals (Harriman & Noble, 2008; Gunn & Noble, 2009). A single organizational approach to monitoring for cumulative effects is needed, while recognizing that both consistent, ambient monitoring as well as more exploratory scientific studies are likely required. The importance of this decision should not be understated, the outcome being either an enduring, credible and trustworthy source of CE information, or another short-lived monitoring episode (such as those described in manuscript #1) or failed monitoring experiment (Boothe, 2015). It is no secret that monitoring data is a critical component of CE frameworks (Dubé & Munkittrick, 2001; Duinker et al., 2012; Westbrook & Noble, 2013; Ball et al., 2013a) and decision-making (Field et al., 2007; Lovett et al., 2007; Lindenmayer & Likens, 2010a). However, monitoring does not provide all of the necessary information for effectively managing CE or making land-use decisions (Biber, 2011; Hegmann & Yarranton, 2011). Instead, it plays the role of just one very necessary cog in a CE management wheel that drives larger, more nuanced policy, planning and decision-making processes.

CHAPTER 4

CONCLUSION

The Lower Athabasca experience has advanced CE management in both practice and theory, yet it has still fallen short of a robust CE management system which lives up to the expectations of all stakeholders. In short, regional environmental monitoring has been "…largely embraced – [but] poorly implemented" (Olszynski, 2013). These and other criticisms of the efforts the government of Alberta has implemented under the ambitious 2008 Land-Use Framework (for example Adkin et al., 2017), however, should not cast a long or dark shadow over the original and current motivations to do so. Acknowledging the (somewhat unprecedented) initiative taken by the provincial government to implement such a framework is warranted. The Lower Athabasca planning region hosts (and has hosted) a variety of environmental management activities related to addressing the CE of human activities and can provide valuable lessons for the pursuit on CE monitoring programs and land use planning and decision frameworks for other jurisdictions.

This thesis set out to explore whether and how current environmental monitoring programs and organizations support CE management for land-use planning and decision-making. Chapter 2 (manuscript # 1) explored the shortcomings and failures of regional environmental monitoring programs, based on the Lower Athabasca experience, to better characterize the challenges of supporting long-term CE management. It identified and characterized the nature, types and fates of programs and organizations to monitor or assess trends in the environment. An important step in determining features of effective CE management in the future is learning from CE monitoring programs and organizations that have failed in the past. A set of considerations for CE monitoring efforts were discussed, namely that: i) monitoring should not be the responsibility of multi-stakeholder groups, due to the potential for conflicts of interests; ii) costly administrative transitions in efforts to rebrand or redistribute monitoring should be avoided; iii) institutional memory should be valued when considering ways to improve a monitoring system; and iii) a degree of scientific autonomy is important, but more attention should be paid to the relevance of scientific endeavours to CE decision-making arenas. The results showed that the episodic nature of regional CE monitoring, as well as lack of consensus towards monitoring goals, has resulted in a culture of uncertainty towards sustained resources and effort towards CE monitoring and management generally. This uncertainty threatens the value-added of monitoring for CE since consistency and credibility are important characteristics of sources of environmental information (Reid, 2002; Ayles et al., 2004; Lindenmayer & Likens, 2009; Noble & Birk, 2011).

To examine whether and how monitoring programs and organizations contribute to CE management and influence land-use decisions, Chapter 3 (manuscript # 2) explored the challenging task of, and options for, integrating environmental monitoring with CE management and decision-making. Results of 27 semi-structured interviews from the Lower Athabasca showed that different perspectives exist for this integration, with three monitoring systems emerging as possibilities - each with their own set of strengths and weaknesses. In particular, a distributed monitoring system which makes use of existing infrastructure but does not promote integration between disciplines; a one window system which likely rids some administrative costs but makes monitoring more susceptible to political and economic change; and finally an independent exploratory system which may produce a more scientifically defendable monitoring system however may potentially pursue scientific questions irrelevant to land use decision-making. Further, the results suggest that regardless of the monitoring system there is a need to ensure that the rationale and purpose of monitoring efforts are clear, to identify whether they align with CE objectives, and, since CE management requires different types of monitoring (i.e. ambient and exploratory studies), determining which scientific questions to pursue requires a shared vision for how CE information is to be used to inform land-use decisions. Building consensus towards solutions to these context-specific problems will enhance public, scientific and political trust in monitoring, enhancing its credibility and ultimately adding more value to its role in CE management generally.

Combined, the results of both manuscripts support research findings from both inside (Noble, 2008; Hegmann & Yarranton, 2011; Parkins, 2011; Dubé et al., 2013; Sheelanere et al., 2013; Noble et al., 2014) and outside (Lovett et al., 2007; Schindler, 2010; Lindenmayer & Likens, 2010a; Wintle et al., 2010; Biber, 2011; Donahue, 2011; Olszynski, 2014) the CE literature, and identify opportunities and lessons to advance CE monitoring in theory and practice. Arguably, monitoring data provides the most important piece of CE management and assessment frameworks for understanding cumulative impacts, as well as for making defendable land-use decisions. The main findings of this thesis are that the true value of environmental monitoring for CE assessment and management often suffers due to the lack of a shared vision for what scientific priorities need to be fulfilled. The thesis shows that building trust for and deciding upon which organization(s) to execute consistent monitoring are challenges because of the variety of scientific expectations of monitoring at a given time, and understanding which, if any, regulatory or jurisdictional requirements they are fulfilling. The findings of this research advocate for building consensus towards determining what level of confidence has been acquired for environmental baseline and trends. A better understanding of what the expectations are of present and future monitoring programs, particularly when they are funded by either provincial or federal government, or whether they fit the purview of CE management, can then be assessed. Instead of being susceptible to political or economic whims, these expectations should likely be guided by the needs of decision-making which is based on the region-specific CE of human activities, and implemented and maintained by mobilizing credible science. Monitoring which is used to advance CE practice should therefore be the ongoing product of cohesive CE leadership and visioning, with oversight from independent scientific efforts.

Two important opportunities for further research became apparent during this research. The first deals with the issue and confusion surrounding what CE assessment and management needs in terms of integration. On the one hand, scientific integration is required to better align environmental disciplines in understanding the impacts of development as well as ongoing natural processes since the impacts of human activities are poorly understood (Schindler & Donahue, 2006; Squires et al., 2010; Dube & Wilson, 2013). On the other hand, there is much opportunity to study integration of monitoring and CE assessment with decision-making. In tune with recent calls for "…embracing its inclusion within the halls of public decision making" (Hegmann & Yarranton, 2011; Noble, 2015b), much more analysis is required to understand how integrating CE assessment might fit into the public policy and decision making discourse.
A second research opportunity relates to how CE management is conceptualized by those who make use of it. Arguments for a watershed-scale approach to CE assessment and management are well made (Duinker & Greig, 2006; Harriman & Noble, 2008; Seitz et al., 2011). Thus, consensus on the spatial scale at which CE assessment and management is most adequately carried out is being built. But much less is explicitly discussed in the literature about an adequate temporal scale for CE assessment and management. Parkins (2011) and other scholars argue that

CE management should move beyond short-term commitments; however, there is little understanding of what role, through time, CE initiatives of any sort should play in decision-making. For example, should CE initiatives be a permanent approach to land-use decision making (such as the LUF CE frameworks in Alberta), or should they simply be a tool that identifies accumulated environmental state and uses this to predict future scenarios to guide targeted decision-making. Each of these approaches require significant, yet different, needs in terms of environmental data, and institutional support. A much better grasp on how CE assessment and management should be implemented, though admittedly difficult to describe, has significant implications for making blanket recommendations for the effectiveness and value-added of environmental monitoring.

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APPENDICES

Appendix 1

Station	Station Name	Hyd Status	Latitude	Longitude	Drainage Area (km2)	From	To	Flow	Level	Sediment	Operating Schedule	Real Time	RHBN	Agency
07DA001	ATHABASCA RIVER BELOW MCMURRAY	Active	56.78035	-111.4022	132585	1957	2011	Yes		Yes	Continuous	Yes		WSC
07CE002	CHRISTINA RIVER NEAR CHARD	Active	55.83717	-110.869	4862.9	1982	2010	Yes			Seasonal	Yes		WSC
07CD001	CLEARWATER RIVER AT DRAPER	Active	56.68528	-111.2554	30791.6	1930	2010	Yes		Yes	Continuous	Yes	Yes	WSC
07DD003	EMBARRAS RIVER BELOW DIVERGENCE	Active	58.42222	-111.5514	N/A	1971	2010	Yes		Yes	Seasonal			AEP
07KF015	EMBARRAS RIVER BREAKTHROUGH TO MAMAWI LAKE	Active	58.48	-111.4444	N/A	1987	2010	Yes			Seasonal			AEP
07DC001	FIREBAG RIVER NEAR MOUTH	Active	57.65109	-111.2026	5987.6	1971	2011	Yes		Yes	Seasonal	Yes		WSC
07CD004	HANGINGSTONE RIVER AT FORT MCMURRAY	Active	56.70897	-111.3564	962	1965	2010	Yes		Yes	Seasonal	Yes		WSC
07CB002	HOUSE RIVER AT HIGHWAY NO. 63	Active	55.64251	-111.1527	780.6	1982	2010	Yes			Seasonal	Yes		WSC
07CA012	LOGAN RIVER NEAR MOUTH	Active	55.17239	-111.7248	425	1984	2011	Yes			Seasonal	Yes		WSC
07CA013	OWL RIVER BELOW PICHE RIVER	Active	55.0109	-111.8563	3078.3	1984	2011	Yes			Seasonal	Yes	Yes	WSC
07DD002	RICHARDSON RIVER NEAR MOUTH	Active	58.36036	-111.2404	2730.9	1970	2011	Yes			Seasonal	Yes		WSC

WSC monitoring stations in operation which are used in the water quantity LUF CE framework.

Appendix 2

List of variabes which are included in the LTRN, ARWQI and water quality LUF CE water quality framework.

Long-Term River Network		Alberta River Water Quality Index		Water Quality Management Framework
Dissolved Kjeldahl Nitrogen	Particulate Nitrogen	pH	Dicamba	Calcium
Ammonia Nitrogen	Silver	Dissolved Oxygen	Triallate	Chloride
Total Kjeldahl Nitrogen	Aluminum	Total Phosphorus	Atrazine	Magnesium
Nitrite + Nitrate Nitrogen	Arsenic	Total Nitorgen	Bromoxynil	Potassium
Total Nitrogen	Barium	Nitrite Nitrogen	Cyanazine	Sodium
Nitrate Nitrogen	Boron	Ammonia Nitrogen	Malathium	Suphate
Nitrite Nitrogen	Beryllium	Fecal Coliform Bacteria	Methoxychlor	Total Dissolved Phospohorus
Total Phosphorus	Cadmium	Escherichia coli	Chlorpyrifos	Nitrate Nitrogen
Total Dissolved Phosphorus	Cobalt	Aluminum	Imazamthabenz	Total Ammonia
Chlorophyll a	Chromium	Arsenic	Diuron	Aluminum
Total Coliform Bacteria	Hexvalent Chromium	Beryllium	Dichlorprop	Antimony
Escherichia coli	Copper	Boron	From Govt of Alberta website http://aep.alberta.ca/water/reports-data/alberta-river-water-quality-index.aspx	Arsenic
Flow	Iron	Cadmium		Barium
Temperature	Lithium	Cobalt		Beryllium
pH	Manganese	Copper		Bismuth
Conductivity	Molybdenum	Iron		Boron
Alkalinity	Nickel	Lead		Cadmium
Hardness	Lead	Lithium		Chromium
Dissolved Oxygen	Selenium	Manganese		Cobalt
Turbidity	Antimony	Mercury		Copper
Non-Filterable Residue	Stronitum	Molybdenum		Iron
Total Dissolved Solids	Titanium	Nickel		Lead
Filterable Residue	Thallium	Selenium		Lithium
Dissolved Potassium	Vanadium	Silver		Manganese
Dissolved Sodium	Zinc	Thallium		Mercury
Dissolved Calcium	Uranium	Uranium		Molybdenum
Dissolved Magnesium	List of LTRN variables collected at Old Fort and Fort McMurray stations from 1957 - 2007 from Hebben (2009)	Vanadium		Nickel
Bicarbonate		Zinc		Selenium
Carbonate		Cyanide		Silver
Chloride		Fluoride		Strontium
Fluoride		2,4-D		Thallium
Sulphate		MCPP		Thorium
Silica		MCPA		Titanium
Total Organic Carbon		Diazinon		Uranium
Particulate Organic Carbon		Lindane		Vanadium
Dissolved Organic Carbon		Picloram		Zinc

Appendix 3

List of semi-structured interview questions.

TOPIC	Questions
	Does the amount of current monitoring mirror the amount of development in the region? (i.e. Does the amount of development necessitate more, less or the same amount of monitoring?)
	Are the recent changes* to institutional and government arrangements for environmental monitoring preventing or stimulating progress? *Creation of JOSM or the creation and destruction of AEMERA, for example
Program-Specific	Where does the need for this monitoring program originate?
	Are detecting cumulative effects an official or unofficial objective to this program?
	Has the approach of this program changed to adopt the planning objectives of understanding cumulative effects? How?
	Where and by whom does the majority of data analysis and reporting occur for this program?
	How does this program effectively "fit" into existing resource management and/or land-use planning activities? For instance, at what stage of land-use planning / regulatory decision-making is this program consulted?
	Are there examples where the results of this program had an effect on land-use decision making?
	Is there collaboration with other monitoring programs in the region?
	Is the amount of collaboration sufficient for the effort necessary for detecting watershed-scale cumulative effects?
Athabasca Monitoring	Has monitoring data/information been used to establish baseline conditions of the Athabasca River at adequate spatial and temporal scales?
	Has monitoring data/information been utilized to establish targets, thresholds and limits for effects on air, water, land and biodiversity?
	Are the roles of programs defined to construct a monitoring network capable of detecting cumulative effects?
	How has the accessibility of data changed in recent years?
Info Exchange	Where do land-use planners, regional decision-makers and resource managers look for monitoring information? (In general OR which specific program / documents / source of expertise)
	What facilitates this exchange of information? (i.e. state of the environment reports / annual reports / meetings with government officials)
	Are decision-makers being provided with the most relevant and timely information for understanding the cumulative effects of human activity?
	Which monitoring efforts (past or present) provided the most useful information for cumulative effects and decision-making?
	What makes some monitoring efforts more or less useful than others?
	Are existing monitoring efforts calibrated to detect and assess cumulative effects in the watershed?
	Is the monitoring system, as a whole, integrated enough to fulfill provincial cumulative effects objectives?
	What are the most significant barriers and opportunities for mobilizing monitoring information for assessing cumulative effects?