Wetland Conservation & Stewardship Pilot Project in the Beaver Hills Biosphere:

State of Science Review

FINAL REPORT

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List of Terms

Acronyms

BHB: Beaver Hill Biosphere

BHI: Beaver Hills Initiative

CICES: Common International Classification of Ecosystem Services

ES: Ecosystem Services

GIS: Geographic Information System

MEA: Millennium Ecosystem Assessment

TEEB: The Economics of Ecosystems and Biodiversity

Glossary

Ecosystem services: contributions of ecosystem structure and function—in combination with other inputs—to human well- being

Ecosystem processes: changes or reactions occurring in ecosystems; either physical, chemical or biological; including decomposition, production, nutrient cycling and fluxes of nutrients and energy.

Ecosystem structures: biophysical architecture of ecosystems; species composition making up the architecture may vary.

Ecosystem functions: intermediate between ecosystem processes and services and can be defined as the capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly.

Intermediate ecosystem services: biological, chemical, and physical interactions between ecosystem components. E.g., ecosystem functions and processes are not end-products; they are intermediate to the production of final ecosystem services.

Final ecosystem services: Direct contributions to human well-being. Depending on their degree of connection to human welfare, ecosystem services can be considered as intermediate or as final services.

Ecosystem service supply: refers to the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period. Depends on different sets of landscape proper ties that influence the level of service supply.

Ecosystem service demand: is the sum of all ecosystem goods and services currently consumed or used in a particular area over a given time period.

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1.0 Introduction

The Beaver Hills Biosphere Reserve Association is initiating a wetland conservation and stewardship pilot project in the Beaver Hills Biosphere that aims to explore alternative approaches to wetland conservation and stewardship in a way that supports both traditional and current cultural attributes of the Biosphere. Through this approach, the BHB will be a living laboratory in which knowledge can be co-created and explored by a wide range of stakeholders, and potential solutions and approaches to land management can be tested and refined in an applied context. A key goal of the BHB wetland pilot is to test and evaluate a diverse set of policy and market approaches for incentivizing wetland stewardship within the Biosphere, such that the multiple benefits associated with wetland conservation and restoration can be maintained or enhanced. Developing new and innovative tools to retain, enhance, and restore wetlands in the Biosphere is particularly important in the context of a changing climate, where increased temperatures and shifting precipitation patterns are expected to reduce surface water quality and quantity, thereby placing increased stress on aquatic ecosystems in the region (All One Sky Foundation 2019).

In order to effectively design and implement a wetland conservation and stewardship pilot project in the Beaver Hills Biosphere, an important first step is to review and synthesize the type and scope of existing wetland policies and regulations that apply to wetlands in the Biosphere, as well as reviewing the state of science as it relates to the assessment and management of wetland function and associated ecosystem services. To this end, this report is focused on summarizing and synthesizing the state of wetland science and ecosystem service assessments in the Biosphere and elsewhere, in addition to providing a summary and critique of the existing spatial data that may be leveraged as part of the pilot program. This report is the second "state of" assessment for the BHB, the first of which provided a review of existing wetland policies and regulations, and outlined considerations and recommendations for the design of the pilot project (Fiera Biological 2019).

2.0 Ecosystem Service Assessments

2.1. Link Between Ecosystem Function & Services

The concept of natural capital and ecosystem services first began to emerge in the 1990s (e.g., Costanza & Daly 1992; Costanza et al. 1997), and over the last two decades, the terms, definitions, and frameworks for classifying and assessing ecosystem services have changed and evolved through time. Early definitions described ecosystem services (ES) as the direct and indirect benefits or contributions to human well-being derived or obtained from natural habitats (Millennium Ecosystem Assessment 2005; TEEB 2010; de Groot et al. 2010). More recently, definitions of ES have become more specific with respect to recognizing and describing how ecosystem structure and function contributes to human well-being (Burkhard et al. 2012; Burkhard & Maes 2017).

In terms of understanding what ecosystem services are, and how they relate to ecosystem function and benefits, the “cascade model” has become a commonly used heuristic for communicating the linkage between the biophysical structure and function of ecosystems, and how these ecosystem features produce services that directly or indirectly benefit society (Figure 1)(Potschin & Haines-Young 2017). Within this model, ecosystem services are at the interface between the environment (i.e., biophysical structure/process and ecological function) and people (i.e., social and economic systems). The “environment” is typically represented by a habitat type (e.g., wetland), and the ecosystem functions are the characteristics or properties of that habitat that are potentially useful to individuals or communities (e.g., water storage, filtration). In turn, ecosystem services are derived from ecosystem functions, and represent the realized flow of services for which there is a demand (e.g., flood protection, water treatment) (de Groot et al. 2010; Maes et al. 2016; Potschin & Haines-Young 2017). Importantly, an ecosystem service only exists if there is a “good” or “product” that creates a benefit that is experienced by an individual or a community; thus, clearly understanding the beneficiary of an ecosystem service is an important consideration in any ecosystem service assessment. In many cases, there is a desire or interest in quantifying the value of ecosystem benefits, and because people benefit from ecosystem goods and services across a range of different dimensions (Summers et al. 2012), valuation can be determined using monetary or non-monetary valuation approaches. Finally, the cascade model acknowledges that the supply of ecosystem services can be impacted or regulated by external pressure or policy action, and that land management decisions can positively or negatively impact ecosystem structure and function, thereby affecting the amount and quality of the final service, as well as the benefits and values derived from that service.

While the cascade model is a simplification of the complexity of ecosystems, it serves to help conceptualize the linkages between ecosystem functions and the benefits that people derive from nature, and has given rise to other models that serve as the foundation for ecosystem service assessments (e.g., Maes et al. 2016; Figure 2). Specifically, these models communicate the need to map and measure indicators across the entire ecosystem service pathway in order to understand the supply and demand of services, and how human activities and land management interventions impact the quality and supply of these services (Potschin & Haines-Young 2017).

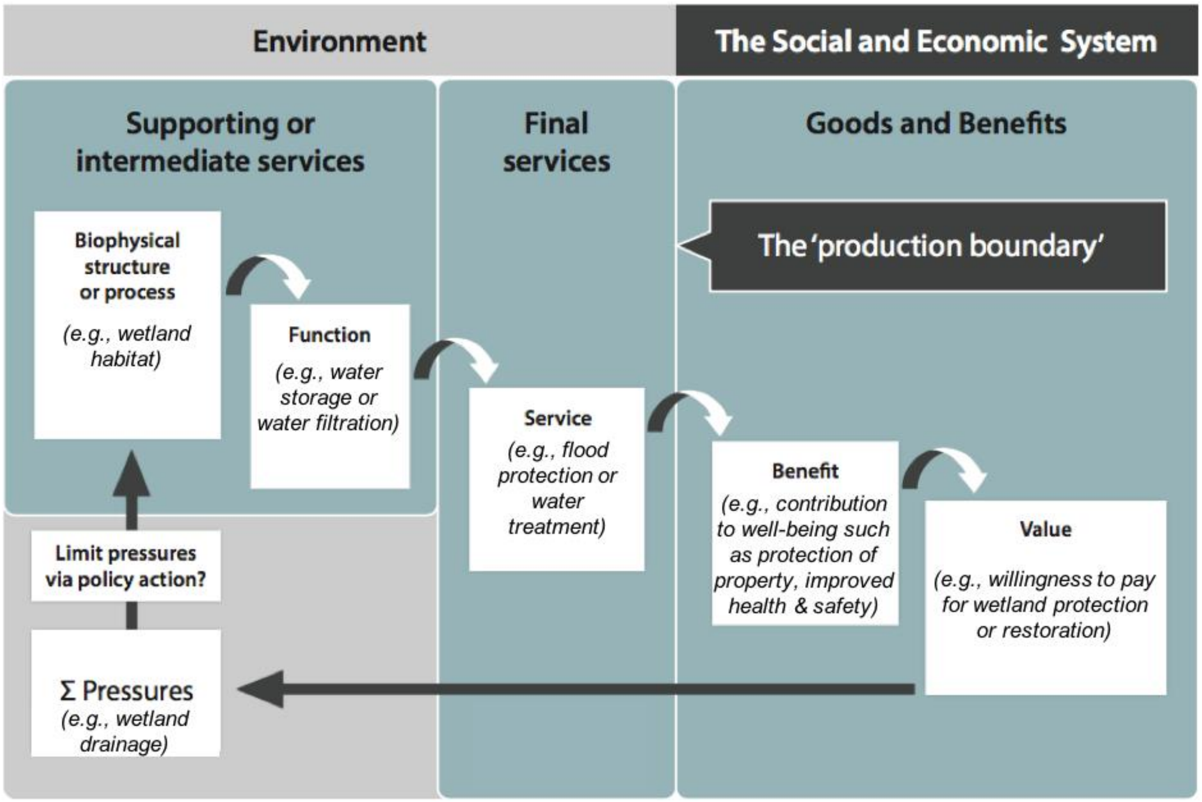


Figure 1. The cascade model. Adapted from Potschin and Haines-Young 2017.

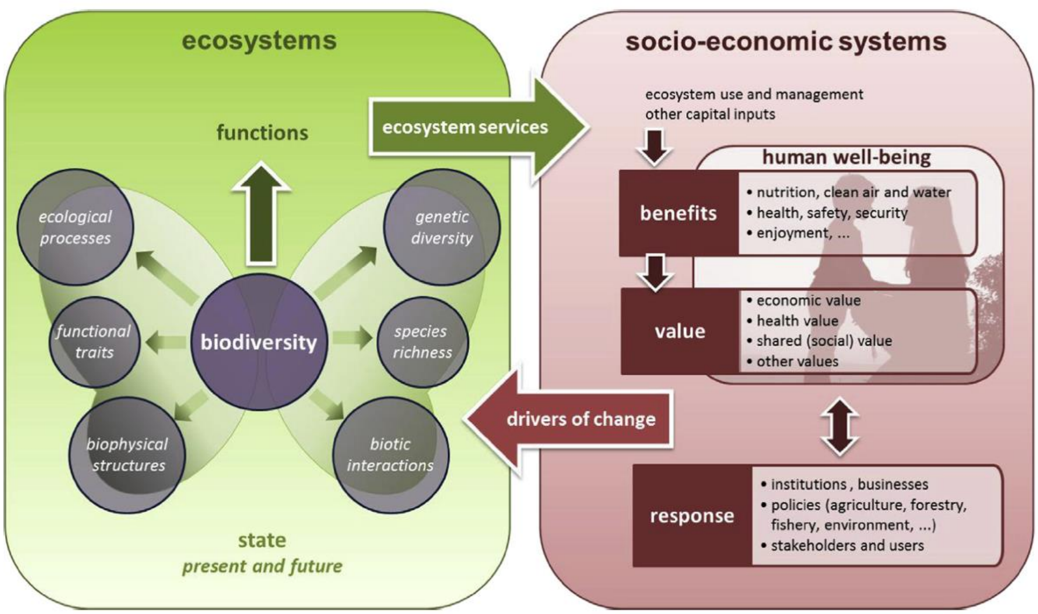


Figure 2. Conceptual framework for assessing ecosystem services adopted by the European Union (Source: Maes et al. 2016).

2.2. Ecosystem Service Assessment Frameworks

There are a number of different frameworks that describe how to undertake an ecosystem service assessment (e.g., Millennium Ecosystem Assessment 2003; Government of Alberta 2011a; Everard & Waters 2013; Crossman et al. 2013; European Environment Agency 2016; Value of Nature to Canadians Study Taskforce 2017; Maes et al. 2018; Burkhard et al. 2018; von Haaren et al. 2019). Generally, each framework includes a number of steps, and these frameworks typically include some or all of the following:

1) Identifying the management issue and/or purpose of the assessment, including the identification of the habitat(s) that are the focus of the assessment
2) Mapping the extent and location of the target habitat(s)
3) Assessing and mapping the condition of the target habitat(s)
    a. Selecting condition indicators
    b. Quantifying condition
    c. Mapping condition
4) Identifying the ecosystem services that are associated with the target habitat(s)
    a. Selecting indicators for assessing each ecosystem service
    b. Quantifying the condition and supply of each ecosystem service
    c. Mapping the current and future supply of ecosystem services
5) Assessing the value and/or benefits of the ecosystem services
6) Disseminating results and formulating a management and/or policy response
7) Monitoring and assessment of outcomes

In the context of the Beaver Hills Biosphere Wetland Conservation and Stewardship Pilot Project, the first step of identifying the management issue (the loss and degradation of wetland habitat) and the ecosystem of interest (wetlands) has been completed. Consequently, we discuss each of the steps outlined above in relation to the Beaver Hills Biosphere Wetland Conservation and Stewardship Pilot Project, and specifically, we outline relevant considerations for the planning, design, and implementation of the assessment of wetland ecosystem services in the biosphere.

2.2.1. Mapping the Extent and Location of Ecosystems

Central to any assessment of ecosystem services is to understand the extent and location of the ecosystems of interest. Importantly, this step requires consideration of the typology (classification) that will be used to identify ecosystems, which should be informed by the purpose and the required scale of the mapping, and will be constrained by the type of data that is available to create the inventory. Generally, this step includes the use of existing, or the creation of new, land cover or habitat data. Primary considerations for the use or creation of land cover or habitat data for the purpose of an ecosystem service assessment includes the following:

- Thematic resolution: What land cover or habitat types are of interest? In the case of wetlands, does the assessment simply require differentiation of wetlands from uplands, or is the mapping of class (e.g., bog, fen, marsh, swamp), form (graminoid fen, shrubby swamp), or type (seasonal graminoid marsh) required?
- Spatial resolution and coverage: What is the smallest habitat feature that is of interest to the assessment? If there is existing land cover or inventory data, what is the minimum mapping unit of the data? If new spatial data is created, what are the cost implications of selecting the desired minimum mapping unit? Does existing data cover the area of interest?

- Vintage: For most assessments, an up to date (or reasonably so) land cover or habitat inventory should be used if an assessment of the "current" condition is desired. For some assessments, change in the amount of habitat may be of interest, and in this case, having access to or creating a historic inventory will be required.

Once land cover or habitat data that shows the location and extent of habitats has been developed, this data can be analyzed in a geographic information system (GIS) to assess and measure a number of important attributes, including the extent to which existing habitats (and their associated ecosystem services) have been conserved within existing protected areas networks, and which ones are at risk of loss or further degradation. If historic data are also available, GIS can be used to understand patterns of loss as well as the amount of loss through time. The habitats identified as part of this step will also become the spatial units of analysis for the ecosystem condition and service assessment.

2.2.2. Assessing & Mapping of Ecosystem Condition

As illustrated in the cascade diagram (Figure 1), ecosystem services arise when ecosystem structures and processes contribute to the well-being of individuals, either directly or indirectly. Thus, an ecosystem service assessment includes first measuring the distribution and condition of habitats (supporting or intermediate services), then evaluating the potential supply or the flow of services from that habitat (the final services), and finally, assessing the goods and benefits those services (Potschin & Haines-Young 2016).

An important step in the assessment of supporting services to evaluate the state or condition of the habitat(s) of interest, in order to evaluate the extent to which those habitats can supply ecosystem services (Figure 3). The capacity of a habitat to supply ecosystem services depends on its physical, chemical, and biological condition at a particular point in time, which is influenced by both its natural condition (e.g., soils, aspect) and the anthropogenic pressures to which it is exposed (e.g., disruption of hydrology, vegetation clearing, pollution, etc.). Often, this step includes some measure of habitat quality or a direct or indirect measure of biodiversity for the ecosystem(s) of interest.

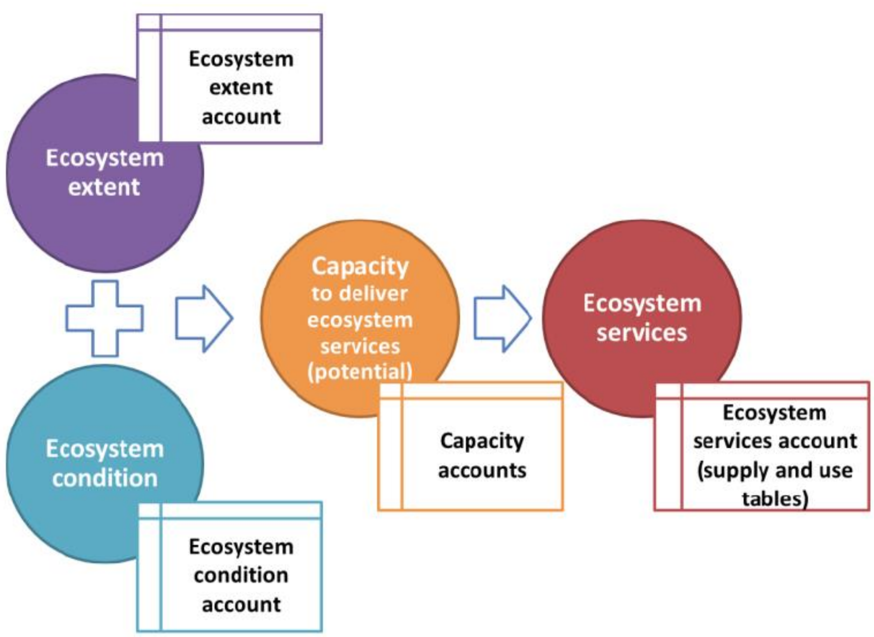


Figure 3. Information on the extent and condition of an ecosystem is essential to understanding the capacity of that ecosystem to deliver ecosystem services (Source: Maes et al. 2018).

Generally, habitats need to be in good condition to provide ecosystem services, and drivers of change can have both positive (e.g. restoration) and negative (land use pressure) impacts on condition (Maes et al. 2018; Vihervaara et al. 2019). Thus, pressure, condition, and the supply of ecosystem services are linked, as condition is likely to be good (with correspondingly high function and supply of services) if pressures are absent (Figure 4). Consequently, pressures can be used as a proxy for assessing condition in absence of information or data that allows for the direct measurement of habitat condition, quality, or biodiversity (European Environment Agency 2016). While direct measures are often preferred, the existence of data that is of sufficient quantity or coverage is often lacking, and the collection of such data is typically cost-prohibitive (Maes et al. 2018; Vihervaara et al. 2019). As a result, indictors or proxies of condition are often used, and these can be measured indirectly (e.g., through remote sensing) or through modelling (European Environment Agency 2016; Maes et al. 2018). In the context of an ecosystem service assessment, indicators of condition should in some way be linked back to the ecosystem service(s) of interest, as this will help to determine the capacity of the habitat to supply the service. Further, having indicators of condition that are in some way related to environmental legislation or policy is useful, as policy and legislation are potential drivers of change, and the impact of these drivers can be tracked as part of a given project as ecosystem condition is assessed through time.

In selecting indicators for assessing habitat condition, there are a number of important considerations. First, the question of what reference or baseline condition is being used to assess change must be addressed. In particular, a decision must be made regarding whether a historic or natural reference condition is being used, or whether the purpose of the assessment is to inform policy and improve condition over the existing baseline (Burkhard et al. 2018). Second, where possible and feasible, a balance of pressure and condition indicators should be selected. This is because condition indictors are more reliable at signaling that something may be wrong, whereas with pressure indicators, the relationship between pressure and condition may not be predictable, or there may be a lag between a change in pressure and a change in condition.

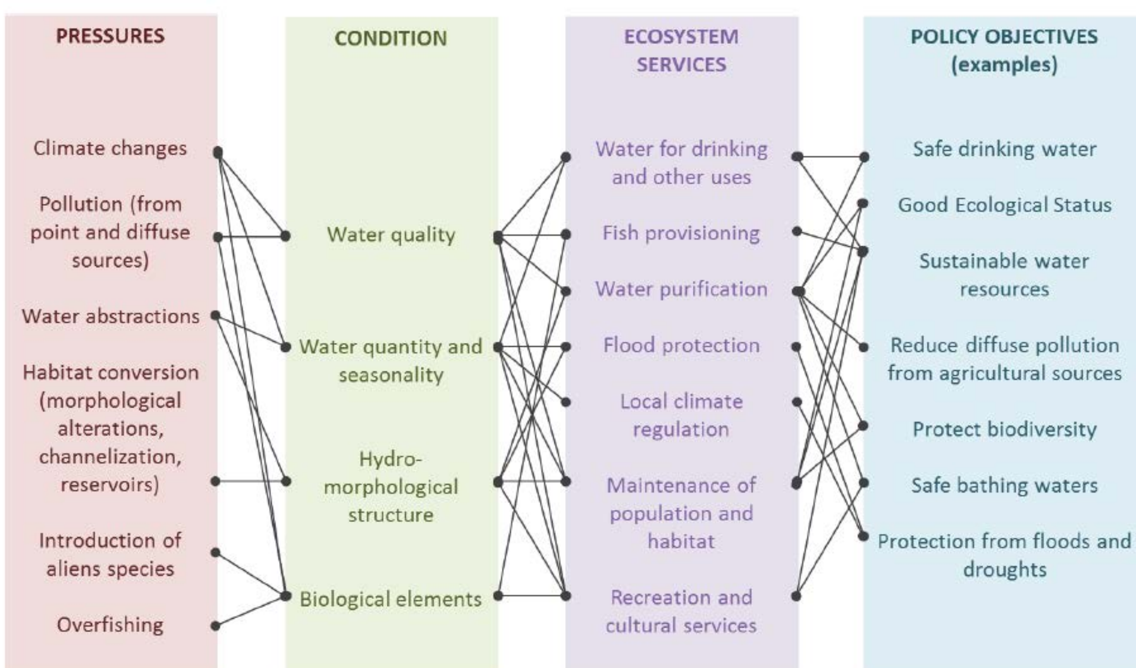


Figure 4. An example of the linkage between pressures, ecosystem condition, and ecosystem services in freshwater systems. (Source: Maes et al. 2018).

2.2.3. Assessing and Mapping Ecosystem Service Delivery

The first step in the assessment of ecosystem service delivery is to define what services are being produced. Because ecosystem services have become a significant component of many government programs and policies over the last two decades, there has been a proliferation of frameworks for defining ecosystem services (Haines-Young and Potschin 2017a). This includes some of the most well-known classifications systems, such as those created by the Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystems and Biodiversity (TEEB), as well national frameworks such as those created by the United Kingdom, Germany, Spain, and the United States (see US EPA 2015 for a review of varioius ES classification frameworks). This has resulted in classification systems that define ecosystem services in slightly different ways, thereby resulting in assessments that are not standardized or comparable (Rendon et al. 2019).

In an effort to address the need for a standardized ecosystem service classification system, the Common International Classification of Ecosystem Services (CICES) was developed and is increasingly being used by the ecosystem services community (e.g., European Environment Agency 2016). Originally developed by the United Nations Statistical Division as part of their System of Environmental and Economic Accounting (Haines-Young & Potschin 2017; Kasparinskis et al. 2018), CICES is a hierarchical classification system that is split into sections, divisions, groups, and classes (Figure 5). The sections generally apply to the major services (i.e., provisioning, regulating, cultural) defined by the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005a), but CICES has been refined to focus on “final” ecosystem services (the middle box depicted in the cascade diagram in Figure 1) (Potschin & Haines-Young 2016; Haines-Young & Potschin 2017). Regardless of what classification system is used to classify ecosystem services, it should be noted that these classification frameworks are not static, and that each can (and should) be adapted to suit project- and location-specific needs. Further, as these frameworks are used to measure, map, and manage ecosystem services, the understanding of how to practically apply the information evolves, along with the frameworks themselves (Haines-Young & Potschin 2017).

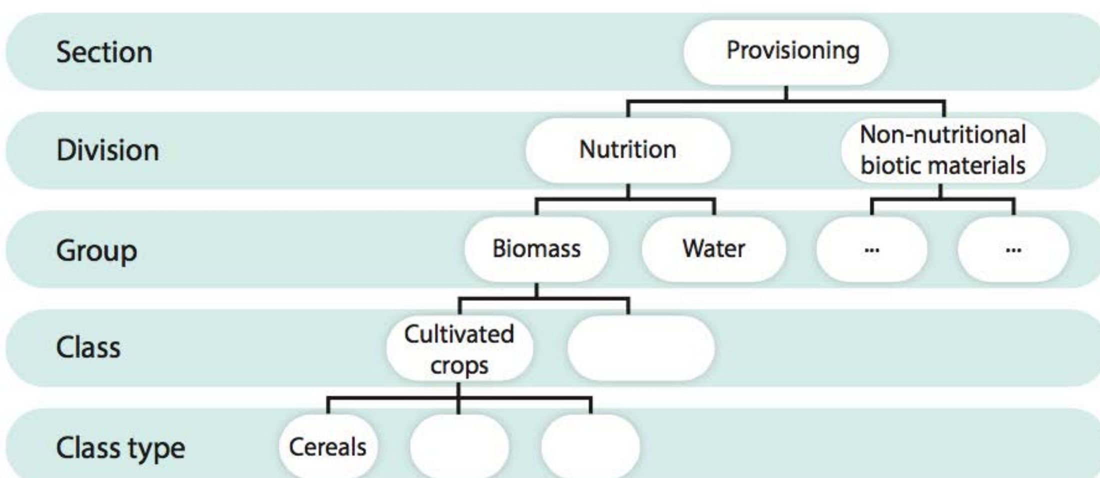


Figure 5. The hierarchical structure of the Common International Classification of Ecosystem Services (CICES), with reference to a provisioning service (cultivated cereal crop) (Source: Haines-Young & Potschin 2017).

Once the ecosystem services of interest have been identified, the supply of each service must be measured (Kasparinskis et al. 2018; Burkhard et al. 2018; Vihervaara et al. 2019). As with ecosystem condition, indicators of ecosystem service supply are typically measured in biophysical units either directly, indirectly, or through modelling, with the complexity of measurement ranging from very simplistic (e.g., percent cover of a land cover type) to more complex (e.g., process-based or probabilistic statistical models) (Burkhard & Maes 2017; Vihervaara et al. 2019) (Figure 6). Direct measures of ecosystem service indicators use primary data and are actual measurements of a state, quantity, or process (e.g., a count of the number of people who visited a park), whereas indirect measures typically need further interpretation or modelling to derive an ecosystem service value (e.g., modelling potential park use based on travel distance). Notably, ecosystem service indicators can be measured using a range of different methods, including surveys or interviews with stakeholders. Socio-cultural methods such as these can be essential sources of local information and knowledge about the location, distribution, condition, availability, and demand for an ecosystem service (Burkhard & Maes 2017; McInnes & Everard 2017; Kasparinskis et al. 2018).

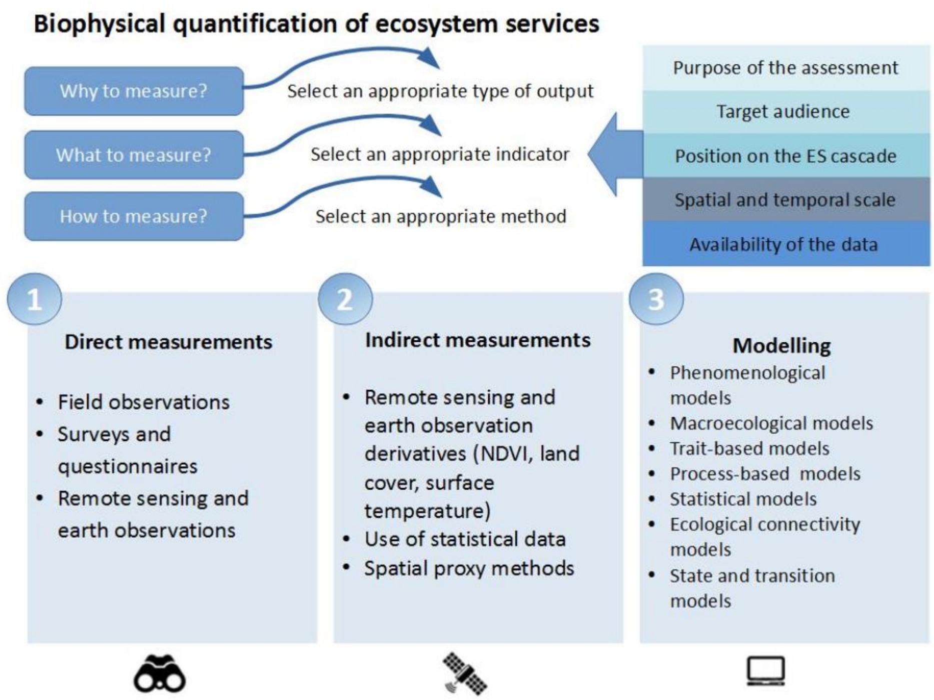


Figure 6. General approaches for measuring the supply of ecosystem services (Source: Vihervaara et al. 2019).

Given the proliferation of ecosystem service and wide range of studies and assessments worldwide, there are many examples of ecosystem service indicators that have been used; however, the choice of indicators is particular to a given assessment, and must be informed by the purpose of the study, the audience and users of the information, the spatial and temporal scale of the assessment, and the availability and quality of existing data (Burkhard & Maes 2017). An additional consideration when assessing the supply of ecosystem services is whether to assess the stock of the ecological asset, or the flow of services from that asset (Burkhard & Maes 2017) (Figure 7). A stock refers to the capacity of an ecosystem to deliver an ecosystem service benefit (e.g., lake productivity, as measured by kg of fish), whereas a flow is a measure of the actual use of an ecosystem service for which a benefit is derived, and is expressed in a per unit time measurement (e.g., kg/ha/year of fish harvested). For some indicators, it may not be possible to measure the flow of ecosystem services, or the stock and flow of a service may be measured differently and/or may have different units of measurement. Thus, determining whether a stock or flow is being measured is an important consideration in this step of the assessment.

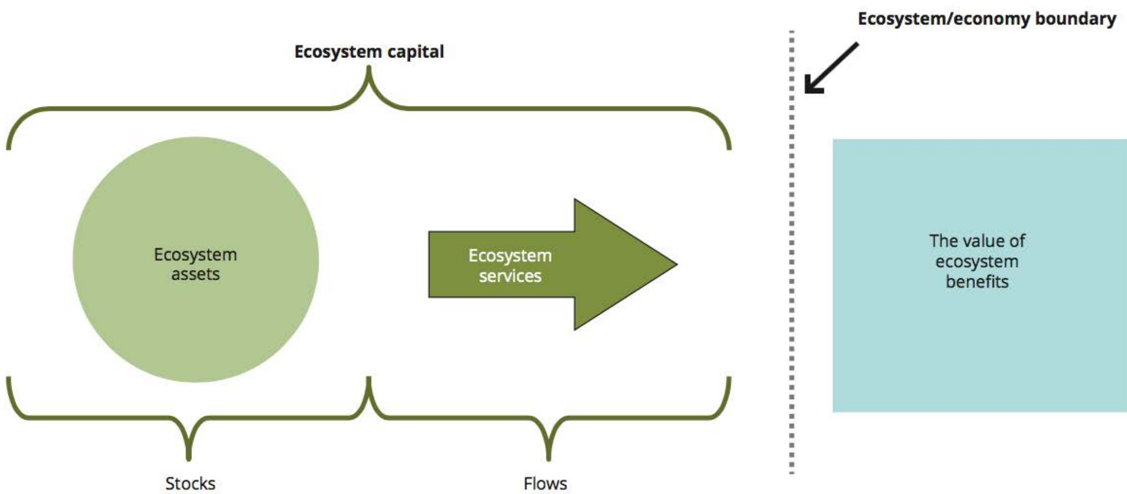


Figure 7. An illustration of the distinction between stocks (ecosystem assets) and flows (ecosystem services), and the relationship between stocks and flows, and ecosystem values (Source: European Environment Agency 2016).

2.2.4. Valuing Ecosystem Services

The final step in an ecosystem service assessment is the identification of the goods and benefits of the ecosystem service, and the associated value of the benefits derived from the service (Burkhard & Maes 2017). There are three value domains associated with ecosystem services: ecological, economic, and socio-cultural (Millennium Ecosystem Assessment 2005a), with economic and socio-cultural values reflecting the relative importance (i.e., the demand-side) of ecosystems services to people (Martín-López et al. 2014; Scholte et al. 2015) (Figure 8). Socio-cultural values are generally considered to be the principles, importance, or preferences expressed by people towards nature (Pascual et al. 2017), while economic values include direct and indirect contribution to an individual's welfare and well-being as measured through utility or preference satisfaction (Wegner & Pascual 2011). Importantly, socio-cultural values are not limited to cultural ecosystem services alone, but are connected to the full spectrum of provisioning, regulating, and cultural services (Scholte et al. 2015).

While much of the past work on ecosystem service valuation has been focused within the economic domain, there has been increasing recognition of the importance of value pluralism and the integration of multiple knowledge-systems into ecosystem service assessments (Walz et al. 2019). As a result, socio-cultural valuation is receiving much greater attention, and theoretical frameworks and methods for evaluating these much less tangible values are actively being developed (Díaz et al. 2015; Scholte et al. 2015; Pascual et al. 2017). Socio-cultural valuation is used to capture the values and perceptions that people assign to ecosystem services (Figure 9), thereby conveying the relative importance of ecosystem services, as well as how perception or preference between individuals and groups or across geographies may influence values now and into the future (Walz et al. 2019). Understanding socio-cultural values of ecosystem services is essential to the management of natural resources, because while people may be *aware* of the ecosystem services that are provided by a particular ecosystem, they may not *assign* importance or value to those services (Scholte et al. 2016). Thus, understanding the environmental value orientations that individuals and groups have with respect to the ecosystem services supplied by specific ecosystems or habitats (e.g., wetlands) is an important component of designing effective conservation or management programs.

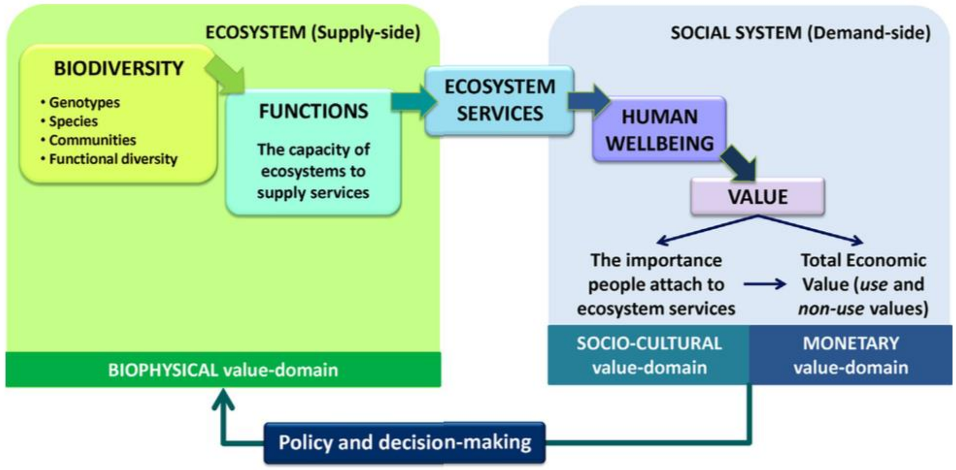


Figure 8. Illustration of the three major value domains of ecosystem services, with the ecosystem value-domain (supply) on the left and the socio-cultural and economic (monetary) value-domain (demand-side) on the right. (Source: Martín-López et al. 2014).

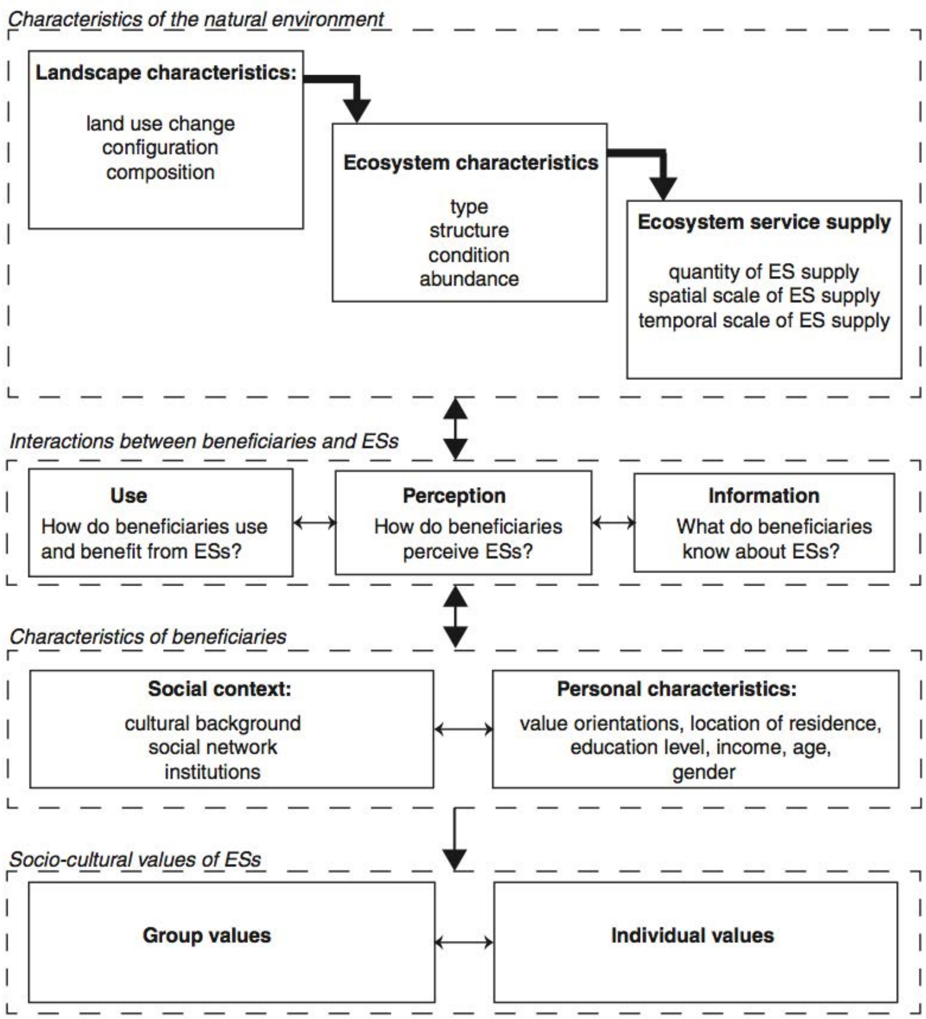


Figure 9. The determinants of socio-cultural values of ecosystem services (Source: Scholte et al. 2015).

Economic valuation attempts to measure the welfare derived from the use and consumption of ecosystem services, and is typically expressed in monetary units. Specifically, economic assessments quantify and characterize some or all of the use and non-use values that make up the "total economic value" of an ecosystem (Figure 10). Total economic value includes good and services derived from ecosystems that may be traded directly in well-functioning markets, and thus, have readily observable economic values (e.g., wood used for construction). In contrast, there are many other goods and services that do not have a market value (e.g., reduction in downstream flood risk); consequently, assigning an economic value is much more difficult, and this has given rise to a range of different non-market valuation methods that attempt to capture the monetary value of these services (de Groot et al. 2016).

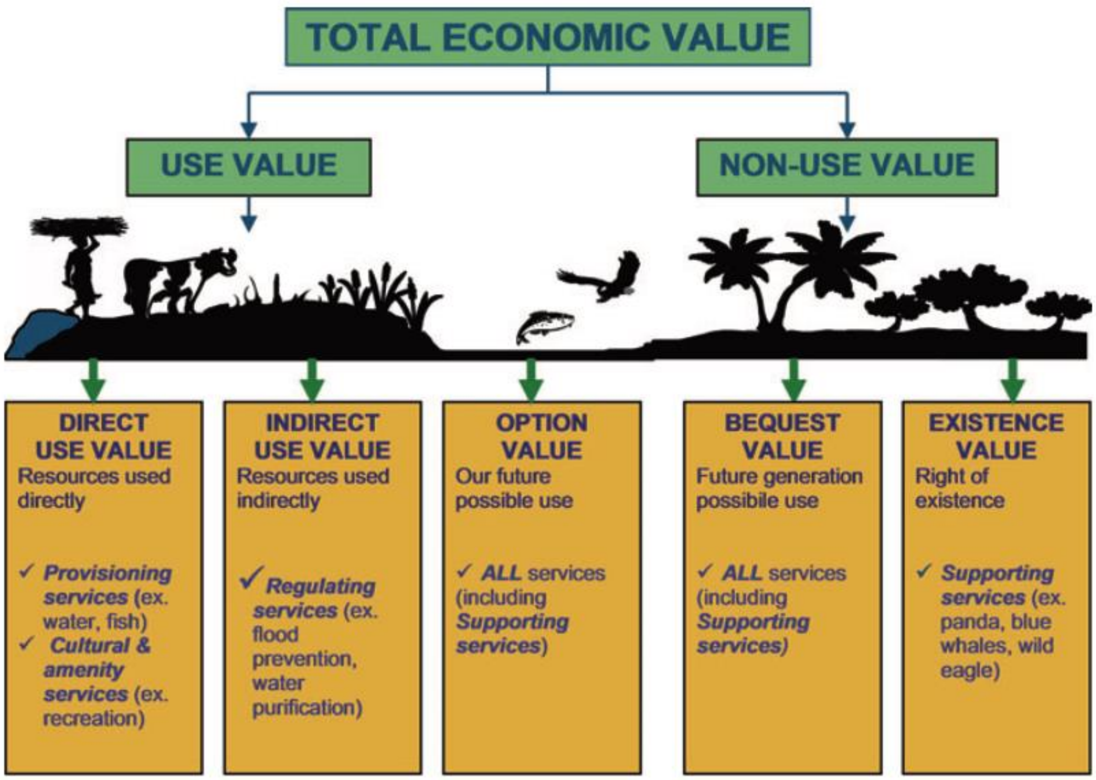


Figure 10. Use and Non-use values that make up the total economic value of an ecosystem (Source: de Groot et al. 2016)

With respect to assigning monetary values to ecosystem services, there are two main approaches: primary valuation methods and value transfer methods (Brander & Crossman 2017; Brander et al. 2018). Primary valuation methods use new or original information derived from primary data to derive estimates, whereas value transfer methods use existing primary information from one site, and apply it to another site or context. Primary valuation methods include three main approaches: 1) cost-based approaches, where some measure of the cost associated with a service is used as a proxy for value; 2) methods that use production inputs as an estimate of value, and; 3) methods that use consumer behaviour (reveal and stated preferences) to measure value (Figure 11) (Brander et al. 2018). Because primary valuation approaches can be expensive and/or primary data may be lacking, the value transfer method is often used to leverage existing information from elsewhere, or to extrapolate or "scale up" local data to derive regional estimates. Once valuation has been completed, any number of further analyses or assessments can be explored, from understanding which ecosystem services are providing the greatest monetary benefit, to scenario analysis that determines the economic impact of loss of habitat.

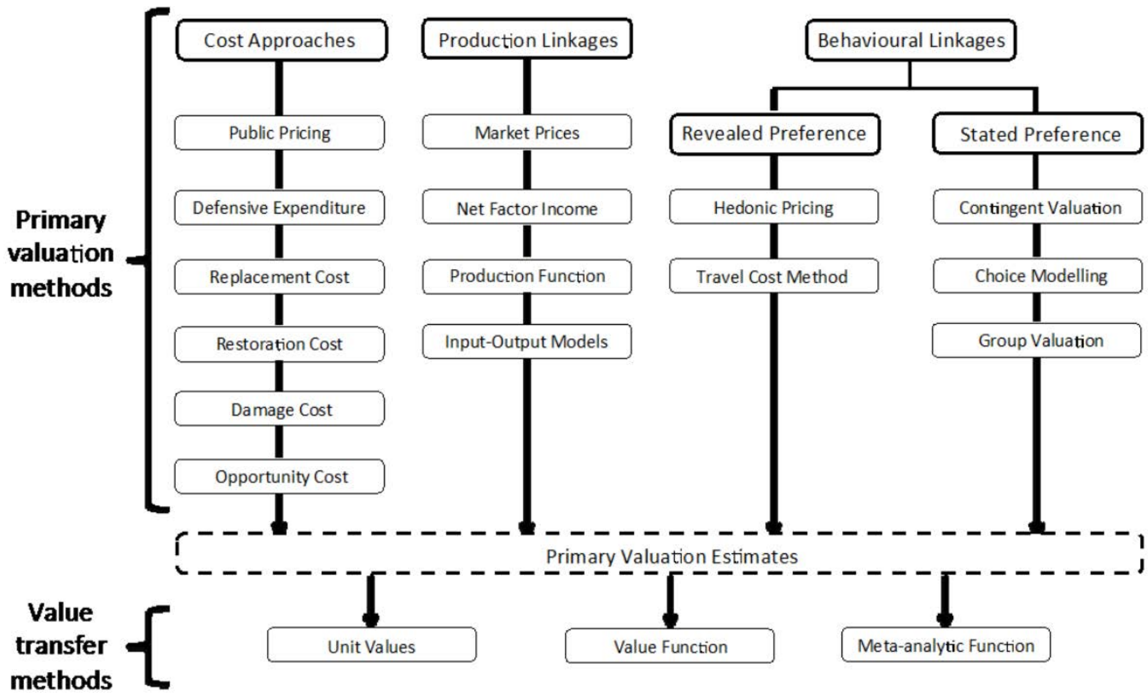


Figure 11. Overview of the primary valuation and value transfer methods used in the economic valuation of ecosystem services (Brander et al. 2018).

3.0 Wetland Ecosystem Service Assessments

Wetlands are complex and diverse aquatic ecosystems that support a wide range of plant and animal species and communities and are important components of larger hydrologic systems. Wetland structure (i.e., types and distribution of organisms and physical features) and processes (i.e., photosynthesis, carbon flux, decomposition, primary production, nutrient cycling) give rise to a wide range of different functions (hydrologic, biogeochemical, habitat) that provide benefits to human communities. Importantly, the type and extent of ecological function varies considerably by wetland class (e.g., peatlands versus marshes; seasonal marsh versus permanent marsh), and a single wetland can provide multiple services and benefits. Consequently, wetland ES assessments must consider the types of wetlands that will be included in the assessment to ensure that the list of ecosystem services and the data used to evaluate the wetlands is appropriate.

Notably, the list of ecosystem services that are produced by a single wetland can be extensive (e.g., Table 1), and assessing all of the potential services is generally not possible due to time, cost, and data limitations. Thus, most wetland ecosystem service assessments evaluate only a handful of ecosystem services, and the choice of which services to select is typically driven by the purpose of the assessment, the interests of the stakeholders involved in the project, the end users of the information, and the type and quality of data that are available.

In this section, we review a number of wetland ecosystem service assessments that have been completed in Alberta and elsewhere, to provide examples of the types of condition and ecosystem service indicators that have been previously used. These summaries also include an overview of key insights or lessons learned from each project, if available and applicable to the Beaver Hill Biosphere pilot project.

Table 1. General list of ecosystem services generated by wetlands, organized using the CICES classification framework. Not all types of wetlands in all geographies may produce the full suite of services listed.

Section	**Division**	**Group**	**Class**
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown for nutritional purposes
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown as an energy source
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture as an energy source
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used as a source of energy
Provisioning (Biotic)	Genetic material from all biota	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population
Provisioning (Biotic)	Genetic material from all biota	Genetic material from plants, algae or fungi	Higher and lower plants (whole organisms) used to breed new strains or varieties
Provisioning (Biotic)	Genetic material from all biota	Genetic material from plants, algae or fungi	Individual genes extracted from higher and lower plants for the design and construction of new biological entities
Provisioning (Biotic)	Genetic material from all biota	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population
Provisioning (Biotic)	Genetic material from all biota	Genetic material from animals	Wild animals (whole organisms) used to breed new strains or varieties
Provisioning (Biotic)	Genetic material from all biota	Genetic material from organisms	Individual genes extracted from organisms for the design and construction of new biological entities
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water for drinking
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as a material (non-drinking purposes)
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as an energy source

Table 1. Continued

Section	Division	Group	Class
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Weathering processes and their effect on soil quality
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of freshwaters by living processes
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive/observational interaction
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training

Table 1. Continued

Section	Division	Group	Class
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value

3.1. GOA Ecosystem Services Approach Pilot on Wetlands

3.1.1. Purpose and Objective

This study covered an area of 274 km^2 that included the Town of Chestermere and a portion of The City of Calgary and Rocky View County, and the goal of this pilot was “the development and operationalization of an ES Approach to provide a tool to enhance decision making” (Government of Alberta 2011b p. 5). Specifically, decision-makers wanted information that was credible, defensible and relevant to the decisions they faced regarding and development and wetland retention, and emphasized a need for economic values in addition to biophysical information about the distribution, quantity, and quality of ecosystem services. Additionally, this pilot was designed to inform the wetland approval process and to address three critical gaps in the approval process that were identified by stakeholders:

1) There is insufficient evidence to support avoidance, minimization, and compensation decisions on wetlands.
2) There is insufficient consideration of cumulative effects and long-term consequences of decision-making.
3) There is limited ability to communicate the ‘values’ of wetlands.

Therefore, the pilot aimed to provide a framework and an approach to help identify and qualitatively, quantitatively, and monetarily assess the benefits provided by wetland ecosystems.

The first step in the pilot was to identify the priority ecosystem services to be assessed. This included identifying the ecosystem services that were produced by wetlands in the pilot study area, and prioritizing the services that would be further assessed using criteria provided by decision-makers and information related to the dependencies and impacts of wetland ecosystem service provision on multiple stakeholders.

3.1.2. Identification of the Relevant Ecosystem Services

To identify the priority ecosystem services for assessment, the pilot used the Millennium Ecosystem Assessment framework and identified all of the wetland ecosystem services that were present in the study area. For each of the services, a definition specific to the pilot was developed, and the beneficiary groups associated with each service were assigned. Through a series of working sessions involving decision-makers and experts, the comprehensive list of services was narrowed down to four core ecosystem services that were considered to be the most relevant to decision-makers within the pilot study area. The four core ES included:

- **Water Supply and Storage**: Storage and retention of water in wetlands for domestic, industrial, and municipal water use.
- **Flood Control**: The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in wetlands.
- **Water Filtration/Purification**: Role that wetlands play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through soil and subsoil.
- **Carbon Storage**: The stock of organic carbon stored in soils for Class III, IV, and V wetlands.

In order to reflect the multitude of ES that wetlands provide and to increase awareness and improve management decisions by decision-makers, an expanded list of services was also developed, which included the core services, as well as: food/crops, pollination, soil formation, erosion control, aesthetic, heritage, recreation and tourism, and science and educational value. The core ES were given priority for assessment resources, and the additional ES were to be assessed as resources allowed. A dependencies and impacts assessment was used to help rank and determine the ES relevance. Notably, the pilot did not consider biodiversity as a stand-alone ecosystem service; rather, it was measured and reported on as it relates to the provision of other related ecosystem services.

In order to better understand and communicate the ecosystem services concept, Cascade Diagrams were developed for each ES in order to identify the ecosystem service indicators to be used in the assessment (Figure 12). In this pilot, the Cascade Diagram became the conceptual framework for how wetlands lead to the benefits that decision-makers can consider in their work, and helped to order the assessment work. The Cascade Diagram applied in this pilot is a static figure that explains how ecosystem services are produced and lead to human well-being, but does not incorporate the dynamic feedbacks from humans to the ecosystem. For example, it does not capture how drivers of change, such as population growth and development, impact the supply of ecosystem services.

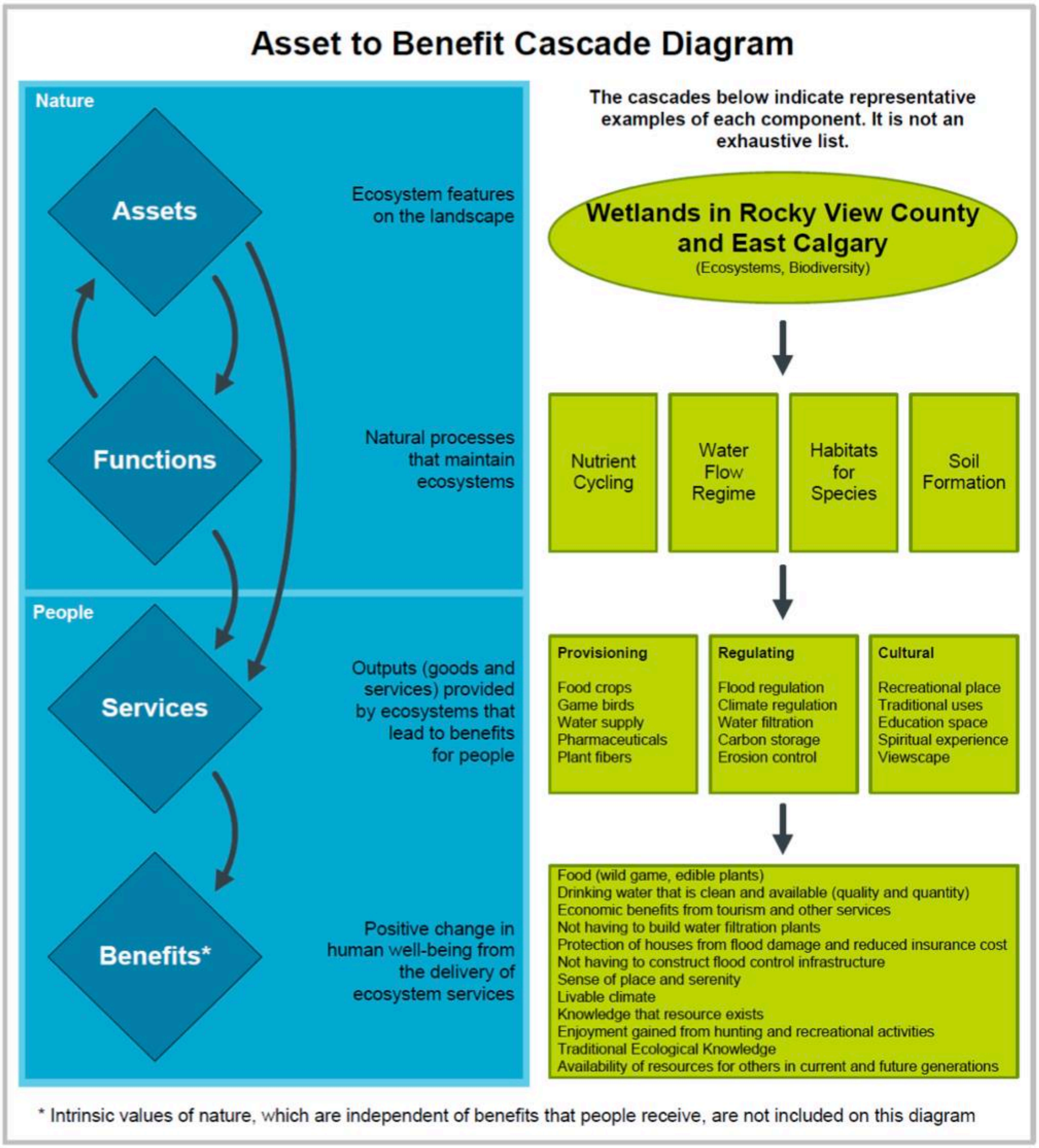


Figure 12. Cascade diagram that was used in the pilot study to illustrate the links between natural assets, ecological functions, ecosystem services, and benefits to humans (Source: Government of Alberta 2011b).

3.1.3. Indicators

For the core priority ES, indicators were chosen that were linked to the production and/or consumption of the service and were relevant to decision-makers and other stakeholders. The initial goal was to develop and implement methods for assessing the current condition of each service (in relation to a baseline or threshold) and recent trends in the service (rate of change, positive or negative); however, drivers of change or pressures on ES were assessed superficially and not in a systematic or consistent way in this pilot, which limited the capacity of the pilot to uncover the underlying factors that are leading to changes in the supply of the core ecosystem services.

The indicators used to quantity ecosystem services in the pilot included the following:

- **Water Storage:** The water storage function of wetlands was assessed in two steps that determined the total water storage capacity of each wetland: 1) existing water volume in wetlands was calculated using the equation Volume (m^3) – 2850 x Area^1.22; and 2) the additional wetland water storage was calculated (mean elevation of the wetland boundary minus the maximum water level). While fairly simple to calculate, the method provided a limited assessment of water storage because connectivity between wetlands was not considered.
- **Flood Control**: Flood control was assessed using a modified version of the modelling developed by Cobbaert et al. (2011). Flood control estimation calculated for each wetland required values for water storage capacity, area of impervious surfaces, wetland catchment size to wetland ratio, amount of upslope wetlands, wetland position in watersheds and subwatersheds, connections to surface waters through natural or artificial drainage systems (presence/absence of outflow), and subsurface storage potential (based on vulnerability maps). The modelling approach provided some indication of the potential of each wetland to provide flood control; however, it was limited in that it doesn't provide an indication of where there are impacts to human well-being (e.g., where is flood control lacking, or what areas are particularly important for flood control).
- **Water Purification:** This service was assessed by focusing on the potential of wetlands to remove sediments and nutrients (i.e., N and P) from a water supply. A Wetland Purification Score was calculated for all wetland complexes in the study area, and was based on metrics of wetland area (total area of wetlands within a wetland complex), pollutant sources (percentage of wetland contributing area that is under urban land use), pollutant removal opportunity (an index of wetland area to wetland contributing area ratio, percentage disturbed land, and wetlands upslope of wetland complex), pollutant transport potential (mean slope of wetland's contributing area), potential significance of purification (distance from wetland complex to stream/river), and recharge potential (position of wetland complex in catchment). This approach was limited in that it used fairly basic parameters, and therefore, only assessed potential, and not whether and in what ways wetlands are actually contributing to water purification.
- **Carbon Storage:** Was assessed for Steward and Kantrud Class III, IV, and V wetlands (Class I and II were omitted due to project limitations and costs). The current carbon stock contained in existing wetlands was first estimated using a current wetland inventory, and then the amount of carbon dioxide re-emitted to the atmosphere as a result of wetland loss since 1962 was calculated using a historic inventory. Carbon stores were estimated based on a conservative estimate of soil organic carbon loss based on observed concentrations in reference wetlands. This method required accurate current and historic wetland inventories and was limited in that Class I and II wetlands were not considered.

All other ES were investigated using a desktop literature review.

3.1.4. Ecosystem Service Valuation

Importantly, the pilot recognized that until ES are linked to some aspect of development, human health or general well-being, an assessment is not truly about ecosystem services, but rather, is about resources or natural assets. It is the explicit identification of beneficiaries that creates an ecosystem service value, whether that value is assessed using sociocultural or monetary metrics. Thus, the ES Pilot investigated the links between wetland ecosystem services and human well-being using scientific literature, a socio-cultural survey, a stakeholder workshop, and economic valuation studies (Government of Alberta 2011c). They found that linking ES to human well-being is not straightforward and also requires a biophysical assessment of where on a landscape changes to ecosystem service supply might impact human well-being. For example, an assessment of flood control should include an assessment of where flood risk is the greatest for humans. Therefore, the valuation that occurred as part of the pilot was somewhat limited, but was based on the following methods:

- **Valuation of Water Storage** was based on use of water in the study area, and was calculated as the total potential withdrawal of water by the current number of cattle in the study area.
- **Valuation of Flood Control** was evaluated in several ways: i) calculated replacement cost based on known flood control values and the historic rate of wetland loss; ii) calculated restoration cost based on average restoration cost and historic rate of wetland loss; and iii) cost incurred from flood damage (e.g., agricultural insurance payouts).
- **Valuation of Water Purification** was calculated using the replacement cost of constructed or modified wetlands and water treatment plants and estimates of treatment costs for P and N, and incorporating the historic rate of wetland loss.
- **Valuation of Carbon Storage** was estimated using the stock of carbon stored in the case study area with different values of carbon supplied by the Canadian Council of Parks. Annual value loss was based on the historic rate of wetland loss.
- **Valuation of Crops/Food** was calculated using estimated total water requirement for cattle in the study area and the total water capacity of wetlands in the study area.
- **Valuation of Cultural ES** was based on data collected from on-site surveys of visitors, which was used to estimate annual value of recreation; used school visits to estimate perceived value to education and science; to assess value of proximity to wetlands used values of adjacency and proximity to estimate effect on aggregate house value.

A literature review was conducted to determine links between human well-being and all other ES that were assessed in the project.

3.1.5. Lessons Learned

The ES pilot was a first at the time, and accordingly, revealed a number of key learnings and points of consideration for other similar projects (Government of Alberta 2011a):

- Choosing the ecosystem service(s) that will be the focus of assessment is a critical first step that should be completed before other work begins.
- Selecting the ecosystem services to focus the assessment on needs to be completed quickly, using the best available information at the time. Comprehensiveness must be balanced with the real limitations of available resources.
- Act even without complete data. Complete data for ES assessment is rarely available. Data available to understand the condition and trends of ecosystem services might refer to natural assets on the landscape, ecological functions, the actual services provided to humans, or the benefits that people get from ES. Indicators for any of these system components may be useful for understanding ecosystem services in an area.
- Understand the link between drivers and impacts first (compiling necessary supporting material for changes in ecosystem services), and then tailor the assessment. A scientific assessment of drivers of change (i.e. factors such as demographic or political change that

are responsible for changes in land use or land management) is important for understanding the most pressing issues that may affect ES and human well-being.

- Economic valuation is just one tool to establish the link between ecosystems and well-being, and results of economic valuation studies should be reported with caution, as results are often more illustrative than precise.
- The organization of a full assessment process may not always be necessary to provide relevant and credible information about ecosystem services to decision-makers or other end users of the information.
- Social science approaches are useful in establishing how people in a certain area value ecosystem services.
- Biophysical assessments should be designed to also be relevant to establishing the link between ES and human well-being. For example, a biophysical assessment can determine where on the landscape people are most at risk from flooding and how large the risk is.
- Create project specific definitions for ES. The categorization and definitions need to be context specific; in addition, shared understanding among project stakeholders can be built if they participate in exercises to develop project-specific language and definitions.
- Multi-disciplinary teams, working together, are best suited to developing a plan for how to assess each ES. For example, a hydrologist and economist will come up with the most suitable and complementary methods for answering specific questions about flood control than would each of these experts working alone. This process will also identify limitations in knowledge, data and methods that will help determine the most strategic way forward for different members of the team.
- Data compilation should be strategic to avoid collecting and storing data that will not be used. A team responsible for data management might be useful for this purpose. Bring together data owners to discuss the availability, relationships between data, and potential limitations associated with the data.
- ES assessment should complete a systematic, scientific assessment of current trends in important drivers in order to understand the underlying factors that are leading to changes in ecosystem services and identify issues that need to be addressed through management interventions.

3.2. Mapping & Assessment of Ecosystem Services (MAES)

As part of their commitment under the 2011 Convention of Biological Diversity (CBD), the European Union proposed a European Biodiversity Strategy to 2020 (European Commission 2011). Under Action 5 of the strategy, the Member States of the EU have committed to map and assess ecosystems and their services, where "mapping" includes the spatial delineation of ecosystems as well as the quantification of their condition and the services they supply, and "assessing" refers to the translation of predominately scientific evidence into information that can be used to inform policy and decision making (Maes et al. 2016). This initiative has resulted in the creation of an expert working group, which has developed an indicator framework for executing the mapping and assessment of ecosystems and their services (MAES) in Europe. The MAES framework draws heavily from and builds upon the outcomes of both the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005a) and The Economics of Ecosystems and Biodiversity (TEEB 2010) framework.

MAES has developed a set of indicators that can be used to assess pressure and condition of wetlands (Figure 13), and indicators for assessing wetland ecosystem services specifically are still under development (Schröder et al. 2017); however, jurisdictions within the European Union are already applying the MAES framework to evaluate ES for wetlands. The following case study from Romania is one example of how the framework has been applied.

Pressures (Wetlands)	
Habitat conversion and degradation (Land conversion)	**Change of area due to conversion (%/year) (SEBI 004)**
Climate change	Climate impact & sensitivity (CI)
Pollution and nutrient enrichment	Exposure to eutrophication (mol nitrogen eq/ha/y)
Over-exploitation	Agriculture intensity pressure on wetlands (CI)
Introductions of invasive alien species	Number of annual introductions of invasive alien species* (number/year)
Other	Soil erosion (tonne/ha/year) (AEI21)
	Soil sealing (ha/year)
	Loss of organic matter (%SOC/year)
Ecosystem condition (Wetlands)	
Environmental quality	n.a.
Ecosystem attributes	
Structural ecosystem attributes (general)	**Landscape fragmentation (CI)**
	Wetland connectivity indicator (< 10 km from other wetland / > 10 km from other wetland)
	Threatened wetlands related habitats (%, number, area)
Structural ecosystem attributes based on species diversity	Living Planet Index for Mediterranean wetlands (CI)
	Number & abundance of wetland bird species (number/ha)
	Community Specialisation Index (CI)
	Status of globally-threatened wetland-dependent birds/amphibians
Structural ecosystem attributes monitored under the EU Nature directives	**Conservation status & trends of habitats of Community interest associated to wetlands (%)**
	Conservation status & trends of species of Community interest associated to wetlands (%)
	EU Population status & trends of bird species associated to wetlands (%)
	Percentage of wetlands covered by Natura 2000 (%)
	Percentage of wetlands covered by Nationally Designated Areas (%)
Structural soil attributes	Soil biodiversity (DNA-based richness and abundance)
	Soil organic carbon (SOC) (% or g/kg)
	Bulk density (kg/m3)
	Soil moisture (%)
Functional ecosystem attributes (general)	n.a.
Functional soil attributes	Available water capacity (index)

Table notes: Indicators in printed in bold are key indicators; n.a.: not available or not applicable; SEBI: Indicator of Streamlining European Biodiversity Indicators; AEI: Agri-Environment Indicator; *This indicator can only be assessed at level 1 of the MAES ecosystem typology (for all terrestrial ecosystems combined).

Figure 13. List of indicators that are used to assess pressure on and condition of wetlands in the European Union, as part of the Mapping and Assessment of Ecosystems and their Services project (Source: Maes et al. 2018)

Case Study – Mapping and Assessment of the Ecosystem Services in Romania

3.2.1. Purpose and Objective

The objective of this project was to adapt the MAES framework for mapping and assessment of wetland ecosystems in Romania (Matei et al. 2017). Specifically, the methodology was applied in a local context as a case study to assess the Divici-Pojejena wetland, which is a large (440 ha) wetland of international importance located in Iron Gates Natural Park, a Ramsar site. In following the MAES framework, the wetland was mapped and a land cover defining classes of interest was developed, and the analysis of ecosystem services applied the cascade model.

3.2.2. Identification of Relevant Ecosystem Services & Associated Indicators

Using the CICES typology, all of the possible classes of ecosystem services provided by the Divici-Pojejena wetland were identified, and then assessed if possible. A brief overview of the various ES indicators associated with the Provisioning Services is provided here (Table 2); full details and methods for all of the ES indicators assessed are available in the study report (Matei et al. 2017).

Table 2. Overview of provisioning services evaluated for the Divici-Pojejena wetland. Full details and methods are available in the study report.

Class of Ecosystem Services	Specific Indicator (Wetland)	Data/Information (Brief Description)	Source
Provisioning Services – Nutrition Division – Biomass Group			
Reared animals and their outputs	Domestic animals	Number of specimens/village or household which are feeding from the wetland	City Hall, local people, in-situ observations
Wild plants, algae and their outputs	Wild plants used in cooking, cosmetics, pharmaceutical	Amounts of plants collected from the wetland (t/ha)	Local people, economic operators
Wild animals and their outputs	Fish production	Catches in tons from commercial and recreational fishing	Locals, City Hall, ANPA
	Number of fishermen and hunters	Number of fishing permits	ANPA, fishing associations
	Condition of fish populations	The composition of species, age structure and biomass (kg/ha)	ANPA, field observations
Plants and algae from in-situ aquaculture	Production of plants and algae from aquaculture	Amounts collected from wetland	Economic operators, INS
Animals from in-situ aquaculture	Livestock production in aquaculture	Quantities produced in the wetland	Economic operators, ANPA
Provisioning Services – Nutrition Division – Water Group			
Surface water for drinking	Water exploitation index	The quantity trapped relative to available resources for a certain period of time	ANAR, water companies
	Water extraction	Amounts of extracted water (m^3)	ANAR, water companies, INS
	Drinkable water consumption	Amounts of consumed water (m^3)	Water companies, INS
	Surface water availability	Quantities of available water (m^3)	ANAR, water companies
Groundwater for drinking	Availability groundwater	Quantities of available water (m^3)	ANAR, water companies
Provisioning Services – Materials Division – Biomass Group			
Fibres and other materials from plants, algae and animals for direct use or processing	Wood production (ton or volume) from Riparian forest and reed	Amount in tons	Romsilva, documentary studies, mapping
	Exploited area of riparian forests (e.g., poplar) and reed	Area in ha	Romsilva, documentary studies, mapping
Plant materials, algae and animals used in agriculture	Vegetable and animal waste	Amount in tons	Local authorities, locals
The genetic material derived from biota	The genetic material for pharmaceutic use	Amount in tons	Local authorities, locals

3.2.3. Identification of Pressure and Condition Indicators

In applying the MAES framework, two complementary approaches determine ecosystem condition: the mapping and evaluation of pressures and the mapping and assessment of habitat condition, biodiversity, and environmental quality. Therefore, to evaluate the Divici-Pojejena wetland, the project defined the pressures, conditions, and the ecosystem services that were possible to asses based on the availability of data and logistical considerations. These components are shown at the highest level in Table 3and are described in further detail below.

Table 3. Pressures, Conditions, and Ecosystem Services schema applied to assess wetland ecosystem services of the Devici-Pojejena wetland in Romania.

Category	Group
Pressures	Habitat change Climatic changes Invasive species Pollution and nutrient enrichment (Over)exploitation
State/Condition	Water quality Water quantity Soil quality Biodiversity
Ecosystem Services	Provisioning Regulation and maintenance Cultural

Pressure Indicators

Pressure indicators were developed for each group as follows:

- **Habitat change:** Two indicators, a fragmentation indicator and a land cover indicator were calculated. For both of these indicators, change in average values for natural and semi-natural areas over the period of 2000 to 2006 were evaluated using land cover data, which provided an indirect indication of habitat change and wetland loss.
- **Climate change:** Climate change was evaluated indirectly using three indicators, change in average air temperature, change in average rainfall, and number of extreme precipitation events. These indicators were calculated using information from climatological and weather databases.
- **Invasive species:** Pressure caused by invasive species was evaluated by calculating the number of invasive species in Romania, which was calculated using a number of different databases. The indicator was unable to be calculated at a scale specific to the study area, as databases only report invasive species at a national level. Field studies were used to determine invasive species specific to the wetland to improve the indicator.
- **Pollution and nutrient enrichment:** Ten different indicators representing factors that affect the air, water, and soil of the study wetland were calculated. These indicators relied heavily on field sampling in order to calculate values for all of the indicators.
- **Land overexploitation:** Exploitation was based on a number of indicators, such agricultural use and practices, use of water resources, intensive fishing, and tourism, which were evaluated using available information in databases, and by surveying stakeholders in the study area. This provided an indication of the trends in these pressures over time and which were most severe.

Condition Indicators

Condition indicators were developed for each condition group as follows:

- **Water Quality:** Assessment of water quality was evaluated directly by collecting field samples from the study area and evaluating a number of water quality indicators (e.g., nitrogen, iron, oxygen, salinity).
- **Water quantity:** Water quantity was assessed in the field using monitoring stations and data on water levels. This field information was used alongside available remote sensing data provided by the Global Surface Water application, which provides an indication change in and dynamics of the water surface cover since 1984.
- **Soil quality:** Soil quality was assessed in the field by collecting soil samples throughout the study area. This provided information on chemical indicators including pH and heavy metals.
- **Biodiversity:** Biodiversity was assessed by assessing indicators based on land cover data and known species associations with the natural land cover classes in the land cover. This provided information on cover and distribution of natural habitat, structure and function of specific habitats, and species richness of the study area.

3.2.4. Ecosystem Service Valuation

Two methods were applied to value the ecosystem services quantified for the Divici-Pojejena wetland:

- A qualitative method, which used interviews, observations, and surveys to assess the value of the wetland to both stakeholders and the general local population, and;
- A quantitative method, based on the Benefit Transfer method, which applied econometric modelling based on variables defined by Woodward and Wui (2001). The project derived mean values for the study area wetland for all the variables (e.g., flood protection, water quality), and then calculated the total economic value of the wetland. This type of valuation provided an indication of the relative contribution of each ecosystem service for the Divici-Pojejena wetland.

3.2.5. Lessons Learned

The case study was successful in applying the MAES framework and CICES typology to evaluate ecosystem services for a single wetland of interest. While the study successfully assessed pressures, conditions, and services, a number of the indicators had to be dropped throughout the process due to insufficient or unavailable data, and in some cases, indicators were evaluated using subpar data. As well, a number of the indicators relied on field sampling, which may be appropriate for small case studies, but is not practical for assessments that cover larger areas or that include a large number of wetlands. In these cases, proxies or generalizations would need to be made to evaluate indicators such as water quality, water quantity, and soil quality. Importantly, this case study did incorporate cultural services, and used indicators such as the available areas for conversion to protected areas, number of tourist visitors/income from tourism, number of cultural activities, and number of sacred/religious sites and archaeological sites to provide an assessment of cultural ecosystem services.

3.3. Delaware Wetland Ecosystem Service Assessment

3.3.1. Purpose and Objective

Delaware has experienced declines in wetland area due to population growth and associated land development. As a result, the objective of this project was to assess the change in the supply and value of wetland ecosystem services based upon future projected loss of wetland area (Industrial Economics 2011). The spatially-explicit modeling tool InVEST was used to quantify tradeoffs in the delivery, geographic distribution, and economic values of ecosystem services resulting from the projected losses.

3.3.2. Identification of the Relevant Ecosystem Services

Ecosystem functions associated with wetland ecosystems were first identified, and these functions were used to identify the following wetland ecosystem services for inclusion in the assessment:

- Carbon Storage
- Water Purification
- Flood Protection
- Wildlife Protection

The project acknowledges the importance of other wetland-related services (recreation, food provision, fishing), but did not incorporate these into this analysis because of significant uncertainty regarding effects of the study's wetland loss scenario on species populations, and therefore, on the level or quality of associated recreational and commercial activity. Instead, they provided economic information on the value of economic activities that rely on healthy wetland habitats as context for the analysis and to demonstrate the economic contribution of wetland habitats.

3.3.3. Condition Indicators

The project acknowledged that the level at which particular wetlands perform ecosystem functions depends on the type, condition, and situation of the wetland within the broader landscape; however, condition of wetland ecosystems was not considered explicitly as part of this analysis.

3.3.4. Ecosystem Service Indicators (Biophysical Models)

As part of the InVEST modelling process, mapped outputs of the geographic distribution of services provided across a landscape are created. Because it is a spatial model, a resolution must be set for the analysis (e.g., 30 m pixel size). The creation of the mapped outputs is based on models, which each require a variety of data sources, both spatial and non-spatial. The indicators for each of the ES of interest were as follows:

- **Carbon Storage**: Tons of C Stored – used literature review to identify carbon storage per hectare for each land cover type for aboveground biomass and below ground biomass. As well, incorporated soil organic carbon (SOC) from USGS mapping by calculating average SOC estimates for each land cover type. The three carbon pools were aggregated at 30m resolution and used to calculate change in carbon storage with wetland loss.
- **Water Purification**: N and P Loading and Sediment Loading – linked models in InVEST combine water yield, nutrient loading, and filtration information, to calculate the amount of nutrients and sediment retained and exported across a given landscape. First, a water yield model that requires data on precipitation, evapotranspiration, soil depth, plant available water content, root depth, and land use specific evapotranspiration coefficients calculates average runoff from each pixel. Next, nutrient retention is modelled using the water yield model, a DEM, land use-specific nutrient loading rates (N and P), and vegetation filtering capacities. Ultimately, the InVEST model sums nutrient outflows from all cells to determine total pollutant loading to streams. Sediment retention is modelled by using a DEM, rainfall erosivity, soil erodibility, and a crop or vegetation management factor. The output reflects sediment

retention efficiencies by land cover type. The value is the fraction of the sediment retained by the vegetation as the runoff travels downslope.

- **Flood Control**: Storm Peak (m) and Coastal Storm Surge (m) – calculated using the InVEST storm peak model, which estimates the relative contribution of particular areas to flood potential following a storm. The model only considers flooding within floodplains of streams and rivers, and outputs a map of flooded area with water height. Inputs required are a land cover, DEM, wetland inventory, wetland depth, storm depth, land use specific runoff curve numbers, and land use specific roughness values.
- **Wildlife Protection**: Level of Habitat Threat (habitat loss and degradation) – modelled in InVEST by combining data describing habitat distribution with data on the presence of various land use threats (e.g., fire, development) to map relative degradation. Required data includes spatial distribution of important habitats and the threats particular to each habitat type, maximum distance at which a threat degrades habitat, and relative sensitivity of habitats to the various threats.

3.3.5. Ecosystem Service Valuation

Valuation in the project was based on applying the quantified values from the biophysical models developed in InVEST to economic valuation models. Valuation for each ES of interest were as follows:

- **Carbon Storage**: Social Cost of C – economic value is expressed in terms of the social cost of carbon in the atmosphere (i.e., damages associated with climate change)
- **Water Purification**: Avoided Treatment Costs – economic value is expressed in terms of the costs of municipal water treatment to filter nutrients and sediment that would have otherwise been filtered by wetlands
- **Flood Control**: Avoided Damages to Residential Development – economic value is expressed in terms of damages of flooding on residential infrastructure
- **Wildlife Protection**: Not Calculated due to difficulty in establishing quantitative relationships between the projected wetland decline and species populations

3.3.6. Lessons Learned

The Delaware evaluation of wetland ecosystem services provides similar findings and lessons learned, as the GOA wetland pilot, as well as some additional points that are important to consider:

- Choose ecosystem services that are relevant to the questions being asked.
- Be prepared for the eventuality that the valuation of some wetland ES may not be possible; in these instances, providing more general information about the economic value of services can still be helpful in decision-making.
- Relying on model tools, such as InVEST, requires the use of many detailed, and sometimes hard to acquire, datasets. Without access to all the data inputs, the models cannot be run.
- A substantial benefit of spatially-explicit models is the output of mapped data and the ability to prioritize management actions spatially.
- Being transparent regarding the limitations and uncertainties associated with both the input data sources and results is very useful to information users.

3.4. Summary & Relevance to BHB Pilot

As highlighted in this section, wetlands provide a multitude of ecosystem services across the full range of provisioning, regulating, and cultural services (Table 1), with some of the most well-recognized services being water filtration and treatment, stabilization of water supplies through the amelioration of floods and droughts, nutrient cycling modulation, erosion control, and recreation.

The fact that wetlands supply such a large range of services makes them critically important ecosystems to manage, but also highly complex to assess within the context of an ecosystem service assessment. As highlighted in the cases studies presented above, fully assessing the entire range of services is very difficult from a scientific and technical perspective. As a result, prioritizing a smaller number of ecosystem services, and focusing an assessment on these services, is generally the approach taken in most wetland ecosystem service assessments. This prioritization should be one of the first steps taken in any assessment, as this allows for subsequent efforts to be focused accordingly. Given that prioritizing ecosystem services is a critical first step in any assessment, an important consideration is how to derive the list or priority services, and who is involved in the prioritization. There are different approaches to determining which services to focus attention on, including selecting the services that explain the greatest variance in the total value of services, or alternatively, selecting the ecosystem services that have the greatest economic and/or sociocultural values within the local context (Whiteoak & Binney 2012). Additionally, a major constraint in selecting ecosystem services is likely to be the availability of information and/or data that can be used to quantify those services, as well as practical constraints associated with time and resources.

Within Alberta, there has already been some work done to generally prioritize wetland ecosystem services (Native Plant Solutions & Ducks Unlimited Canada 2017). The priority list was created by members of four organizations: Native Plant Solutions, Ducks Unlimited Canada, Alberta Biodiversity Monitoring Institute, and the Alberta North American Waterfowl Management Plan (ABNAWMP) Partnership, and was informed by the services identified by the Government of Alberta ecosystem services pilot project (Government of Alberta 2011b), the Millennium Ecosystem Assessment wetland synthesis report (Millennium Ecosystem Assessment 2005b), well as a literature review. In addition to identifying ecosystem services that are priority for wetland management in Alberta, this report also provides a review of tools and models that can be used to quantify the priority services. The services were identified using the MEA classification framework and includes four regulating and three cultural services (Figure 14). Notably, biodiversity was identified as a priority ecosystem service; however, there has been much debate as to whether biodiversity is a stand-alone service, or whether it is foundational to the proper functioning of ecosystems (see Figure 2), and therefore, underpins the supply of a wide range of services, rather than being an ecosystem service on its own (Mace et al. 2012; Quijas & Balvanera 2013). Whether biodiversity should be considered as a standalone service in an ecosystem assessment is certainly an issue that should be further explored, as many classification frameworks, including TEEB and CICES do not recognize biodiversity as an ecosystem service on its own. In the Case of the MAES assessment approach, biodiversity is specifically considered and measured as part of the condition assessment, rather than it being included as a “final” ecosystem service.

Wetland Ecosystem Service	Ecosystem Function
Flood control	Water storage, flow moderation, stabilization of hydrological flows and regimes
Water purification	Nutrient transformation and retention, sediment retention
Water supply and storage	Surface water detention, flow moderation, stabilization of hydrological flows and regimes, groundwater recharge/discharge
Climate regulation	Carbon storage, greenhouse gas production
Recreation and tourism	Provision of wildlife and plant habitat
Science and education	Provision of wildlife and plant habitat
Aesthetic	Provision of wildlife and plant habitat
Biodiversity	Maintenance/support of hydrological, biological, physical and ecological characteristics, provision of wildlife and plant habitat

Figure 14. List of priority wetland ecosystem services identified by Native Pant Solutions, Ducks Unlimited Canada, Alberta Biodiversity Monitoring Institute, and the Alberta North American Waterfowl Management Plan (ABNAWMP) Partnership (Source: Native Plant Solutions & Ducks Unlimited Canada 2017).

4.0 Review of Relevant Scientific Literature

There has been an immense amount of work that has been completed in the Beaver Hills region over the past 20 years, both by academics and by the Beaver Hills Initiative (BHI). This section includes a summary of some of the most recent and relevant scientific work that has been conducted in the BHB; however, it is not intended to be an exhaustive review of all of the scientific work that has been completed to-date. Rather, the review below has been limited to describing more recent work (i.e., completed in the last 7 years) that is relevant to the wetland pilot project, particularly as it relates to scientific methods and/or datasets that may be useful for mapping wetlands, assessing condition/pressure on wetland ecosystems, and/or assessing wetland ecosystem services and values. In some cases, we have also included a review of recent scientific work that has occurred outside of the BHB, which was chosen because we felt the results could be generalized to wetlands in the BHB, and/or the work was highly relevant. This section is organized by work associated with land management, habitat and biodiversity, quality of life, and hydrology.

4.1. Land Management

State of the Beaver Hills Report (AMEC 2015)

This assessment identifies and measures 23 indicators across five categories (Land, Air, Water, Biodiversity, Quality of Life) that were selected with the intention of tracking changes in ecological, social, and economic conditions in the region through time. The spatial data that was used to quantify the indicators included coarse-scale (30 m) land cover, Alberta Base Features (e.g., hydrology, roads, etc.), and compiled municipal datasets (e.g., land use zoning). The Alberta merged wetland inventory was used for wetland mapping. Within the Land category, there were nine different indicators assessed (Table 4), and several of these could be adopted as condition or pressure indicators for the wetland pilot project; however, the indicators vary in quality with respect to the methods and data that were used. As a result, we caution that each indicator should be considered and critiqued individually to determine whether it would be appropriate for use in the pilot project. Further, the land cover that was used to derive many of the land metrics is coarse (30 m resolution) and was created in 2013; consequently, if a newer land cover is created as part of the wetland pilot project, the indicators would be out of date and should not be used.

Table 4. Land indicators used in the State of the Beaver Hills report.

State of the Beaver Hills Land Indicators
Shorelines and streambanks with development
Streambanks and shorelines protected by permanent vegetation
Areal extent of land use sectors
Intact quarter sections and linear development
Wetland distribution
Habitat extent
Habitat fragmentation
Soil cover
Soil capability related to land cover and land use

4.2. Habitat & Biodiversity

There have been many wildlife research projects that have been conducted in the BHB over the last two decades, but most of these projects are site specific, or have been largely limited to parks and protected areas with the Biosphere. Consequently, the results and data from these projects are limited in their usefulness with respect to assessing habitat condition or biodiversity status in the BHB. More recent scholarly work on community assemblages within prairie pothole wetlands has been completed outside the BHB, but within the Parkland and Grassland regions of Alberta. Given the relevance of this work, and that the results are likely generalizable to wetlands in the BHB, we provide a review of some of this work below.

Concordance in Wetland Physicochemical Conditions, Vegetation, and Surrounding Land Cover is Robust to Data Extraction Approach (Kraft et al. 2019)

This study measured concordance between land cover, wetland vegetation, and physicochemical conditions in 48 prairie pothole wetlands in central Alberta. Land-cover data was extracted using multiple approaches including topographically-delineated catchments and nested 30 m to 5,000 m radius buffers. Results indicated that physiochemical conditions were significantly concordant with land cover. Vegetation was not significantly concordant with land cover, but was strongly and significantly concordant with physicochemical conditions. Concordance was as strong when land cover was extracted from buffers <500 m in radius as from catchments, indicating the mechanism responsible is not topographically constrained. This suggests that local landscape structure does not directly influence wetland vegetation composition, but rather that vegetation depends on 1) physicochemical conditions in the wetland that are affected by surrounding land cover and on 2) regional factors such as the vegetation species pool and geographic gradients in climate, soil type, and land use. This study suggests that surrounding land cover can be a good predictor of wetland physiochemical condition, which in turn drives vegetation community composition. Thus, land cover within 500 m may be a suitable proxy for wetland condition.

Stochastic and Deterministic Processes Drive Wetland Community Assembly Across a Gradient of Environmental Filtering (Daniel et al. 2019)

This study examined the influence of hydroperiod on bird, vegetation, and macroinvertebrate diversity in marsh wetlands in central Alberta. The study found that species richness for birds and macroinvertebrates increased along the gradient of hydroperiod from temporary to permanently ponded wetlands. Gleanson and Rooney (2018) found a similar association between hydroperiod and macroinvertebrate abundance and diversity. These results suggest that wetland permanence should be considered in assessing and evaluating biodiversity in marsh wetlands.

State of the Beaver Hills Report (AMEC 2015)

This assessment identifies and measures 23 indicators across five categories (Land, Air, Water, Biodiversity, Quality of Life) that were selected with the intention of tracking changes in ecological, social, and economic conditions in the region through time. Within the Biodiversity category, there were four different indicators assessed (Table 5), and several of these could be adopted as condition or pressure indicators for the wetland pilot project; however, the indicators vary in quality with respect to the methods and data that were used. For example, the Invasive Species and Species of Conservation Concern indicators are aspatial (i.e., not mapped or related to a location within the Biosphere), and so are of limited use with respect to assessing the condition of ecosystem services of wetlands. Further, the land cover that was used to derive the Protected Areas and Natural and Human Created Edges is coarse (30 m resolution) and was created in 2013; consequently, if a newer land cover is created as part of the wetland pilot project, these indicators would be out of date and should not be used.

Table 5. Biodiversity indicators used in the State of the Beaver Hills report.

State of the Beaver Hills Biodiversity Indicators
Protected habitats
Natural and human created edges
Invasive species
Species of conservation concern

2014: BHI Land Management Framework Update (BHI Planners Group 2014)

This report was a review and update to the 2007 Land Management Framework, and provides an overview of environmental policies in use by each of the five BHI municipalities, a list of key environmental features in the moraine, and maps identifying areas of High, Moderate, and Low environmental sensitivity. Models were also used to map Landscape Connectivity, Core Areas, and other habitat attributes (e.g., patch size). A mix of NRCAN, Alberta base features, municipal data, and other private data sources were used to develop secondary data products, and LiDAR data and SPOT imagery were used to develop new datasets (1:5,000 scale) for hydrology, wetlands, and vegetation heights and native vegetation. One or more of these datasets could be used to assess condition and/or pressure as part of the wetland ecosystem service pilot; however, they would have limited use with respect to assessing ecosystem services related to habitat or biodiversity. A potential limiting factor in using this data is the vintage and accuracy of the land cover and wetland inventory (See Section 5.2 for a discussion about data quality). These data sets would be out of date if a more up to date land cover and/or wetland inventory is created.

The Moraine Mesocarnivore Project - Principle Investigator: Jason Fisher, University of Victoria

This project, which extended between 2013 and 2018, aimed to assess the degree to which the network of protected areas, private woodlots, and developed lands within the Beaver Hills Biosphere maintained mammalian diversity (Stewart & Fisher 2018). The project utilized camera traps, non-invasive genetic tagging (using hair samples), and GPS collars on fisher to measure mammal diversity and statistically relate this to landscape structure, as well as to test for connectivity within and amongst protected areas. The project resulted in numerous scientific publications (e.g., Burgar et al. 2018; Stewart et al. 2019a, 2019b). While this work was not specific to wetlands, this research provides information about mammalian diversity and movement in the Biosphere, which could serve in some way as a pressure indicator for the wetland pilot study; however, access to data would have to be negotiated with the owners, and the usability of the data with respect to deriving a pressure indicator is unknown.

The Accuracy of Land Cover-based Wetland Assessments is Influenced by Landscape Extent (Rooney et al. 2012)

This study examined the efficacy of using land cover data at different spatial scales as a predictor of wetland condition, as measured in the field using plant- and bird-based indices of biotic integrity (IBIs). Land cover data were extracted from seven nested landscape extents (100–3,000 m radii) and used to model IBI scores. Strong, significant predictions of IBI scores were achieved using land cover data from every spatial extent, even after factoring out the influence of location to address the spatial autocorrelation of land cover classes. Plant-based IBI scores were best predicted using data from 100 m buffers and bird-based IBI scores were best predicted using data extracted from 500 m buffers. Road cover or density and measures of the proportion of disturbed land were consistent predictors of IBI score, suggesting their universal importance to plant and bird communities. This study utilized the land cover data from 2009 that is currently in the BHB data repository (see Section 5.2 for a discussion about data). This study is relevant to the wetland pilot project in that it provides information that could be used to develop a biodiversity indicator for the wetland pilot.

4.3. Quality of Life

State of the Beaver Hills Report (AMEC 2015)

This assessment identifies and measures 23 indicators across five categories (Land, Air, Water, Biodiversity, Quality of Life) that were selected with the intention of tracking changes in ecological, social, and economic conditions in the region through time. Within the Quality of Life category, there were six different indicators assessed (Table 6). One or more of these indicators may be useful in assessing ecosystem service demand and/or ecosystem service values. For example, access to natural areas and recreation was assessed based on the proportion or parks and protected areas within the moraine, as well as calculating average distance from an area zoned as residential to a park or protected area. If the area location of parks, protected areas, or areas zoned as residential has not changed substantially, then these data may be applicable. Further, visitation numbers for several of the major parks and recreational areas are reported, which may be useful; however, these numbers are mostly from 2014, so more recent numbers may be desired.

Table 6. Biodiversity indicators used in the State of the Beaver Hills report.

State of the Beaver Hills Quality of Life Indicators
Community/Stewardship groups
Population
Employment
Access to natural areas and recreation facilities
Tourism
Regional Planning

4.4. Hydrology

Does Wetland Location Matter When Managing Wetlands for Watershed-Scale Flood and Drought Resilience? (Ameli & Creed 2019a)

This study examined how wetland location influenced wetland hydrologic function (flood and drought mitigation) using a watershed-scale, surface–subsurface, fully distributed, physically based hydrologic model with historical, existing, and lost (drained) wetland maps. The results indicate that wetlands closer to the main stream network played a disproportionately important role in attenuating peakflow, while wetland location was not important for regulating baseflow. Specifically, model results showed that there was a greater increase in stream peakflow and cumulative flow with the loss of wetlands located within 100 m of the main stream network than when wetlands located farther than 100 m of the main stream network were lost. While this study was done in the Nose Creek watershed in southern Alberta, the results suggest that riparian wetlands and wetlands located in close proximity (<100 m) to main stream network should be prioritized for restoration or protection in watersheds if flood control is a priority.

Groundwaters at Risk: Wetland Loss Changes Sources, Lengthens Pathways, and Decelerates Rejuvenation of Groundwater Resources – (Ameli & Creed 2019b)

A physically based hydrologic model that simulates the timing and pathways of subsurface hydrologic connections was coupled with wetland inventories derived from 1962, 1993, 2009, and a “future” scenario for the Beaverhill watershed to quantify the effects of wetland loss on subsurface hydrology. The grid-free nature of the model allows for the explicit incorporation of the geometry of wetlands of different sizes, and thus facilitates the assessment of the hydrologic influences of each individual wetland on the subsurface hydrology of the watershed. The study showed that wetland loss has led to a contraction of catchment contributing areas to local surface waters, while expanding contributing areas to the regional surface water body. The model also showed regions with thick permeable aquifers were particularly sensitive to the loss of wetlands. The high-resolution watershed-scale flow and transport models that were developed in this study are highly relevant to assessing ecosystem services in the BHB.

Estimating Rates of Wetland Loss Using Power-law Functions – (Serran et al. 2018)

This study used wetland- area vs. wetland-frequency power-law functions to assess wetland loss through time in the Beaverhill watershed; however, the study did not include the full extent of the watershed or the moraine. Wetland inventories from 1962, 1992/93, and 2011 were used to estimate rates of wetland loss. In addition, wetland loss was characterized as “restorable”, “temporary”, and “permanent”. The datasets that were used in this study could potentially have wetland condition information (e.g., “restorable” and “temporary” loss) that would be useful in assigning and assessing wetland impacts and condition.

Quantifying Hydrologic Connectivity of Wetlands to Surface Water Systems – (Ameli & Creed 2017)

This study developed a physically based subsurface–surface hydrologic model to characterize both the subsurface and surface hydrologic connectivity of geographically isolated wetlands in the Beaverhill watershed to explore the time and length variations in these connections to the North Saskatchewan River. This 3-D grid free model is different from process-based (e.g., SWAT) and gridded (discrete) models, in that it can explicitly consider individual wetlands and characterize their links to other waterbodies. LiDAR data from 2009 was used to create a probability of depression layer that was segmented into objects using the multi-resolution segmentation algorithm. Average depression probability values were used to classify objects as wetland or non-wetland, and this layer was used as the input into the model. The study generated a 3-D Groundwater-surface water interaction model identifying recharge and discharge wetlands that allowed for the creation of a subsurface connectivity map. The total groundwater contribution of recharge wetland was calculated on a per month basis. In addition, a surface fill-and-spill overland flow model was generated to determine surface connections. Finally, for all wetlands in the watershed, the surface and subsurface flow contribution of each wetland to the North Saskatchewan River was calculated. Data from this study could be used to understand how wetlands regulate base flow and peak flows within the watershed, and could be useful in assessing wetland ecosystem services related to flood protection and water availability.

New Mapping Techniques to Estimate the Preferential Loss of Small Wetland on Prairie Landscapes – (Serran & Creed 2016)

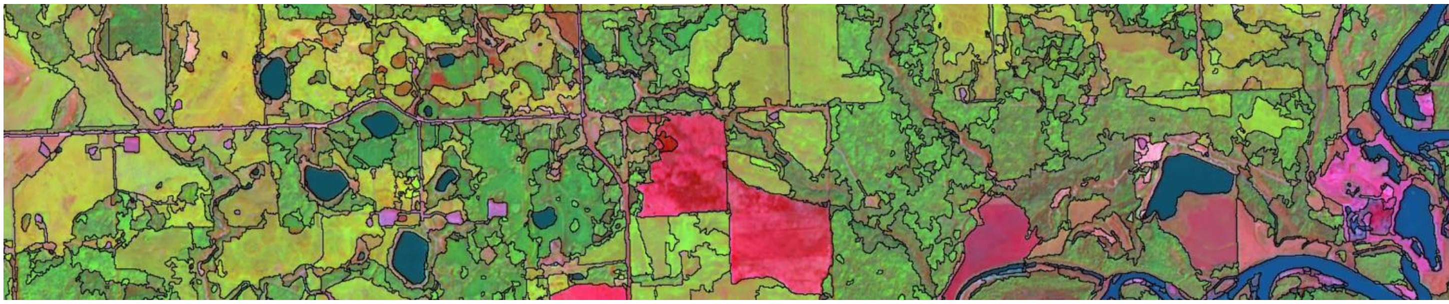
The aim of this study was to improve upon current wetland inventories by developing a method for mapping wetlands using an automated object-based approach that was applied in the Beaverhill watershed. The method improves upon existing wetland mapping methods by effectively mapping small wetlands and better capturing the convolution of wetland edges. A wetland inventory was created using LiDAR and airphoto imagery. Imagery from 1962, 1970, 1982, 1993, 1999, and 2009 was used to create an open water permanence map, allowing for the attribution of permanent open water wetlands within the inventory. The stated minimum mapping unit for the inventory is 0.02 ha. The wetland inventory from this study may be useful with regards to updating or creating a more up to date inventory for the wetland pilot project.

BHI Land Management Framework 2014 Update (BHI Planners Group 2014)

This report was a review and update to the 2007 Land Management Framework and includes models that identify risk to surface and groundwater. These models were created using a combination of land cover, soils, and while these data may be useful in the assessment of condition and/or pressure indicators, or in the assessment of ecosystem services, it is possible that there is more recent or relevant data that has been produced by Irena Creed that would be more appropriate for use in the pilot project.

Environmental Reserve Mapping Project (Creed et al. 2013)

The goal of this project was to define the size and distribution of potential Environmental Reserves and provide an assessment of the flood and pollution control function of individual wetlands to allow for prioritization of areas. As part of this project, a digital database was created that included climatic, geological, topographical, land use/land cover data, and high-resolution aerial photography. The land cover is based on SPOT imagery (circa 2009, 5 m resolution), and wetlands and their contributing areas were mapped using LiDAR and aerial photography. Metrics were developed to assess flood and pollution control scores for wetlands, and Marxan was used to assess priority areas for conservation. The wetland inventory that was delivered as part of this project (derived from 2009 imagery) includes flood protection and pollution control scores for each wetland in the inventory. The report also details the methods used to derive these scores. This data could be used in the wetland pilot to assess ecosystem services related to these services; however, the wetland inventory that was used to derive the scores is over 10 years old and likely does not accurately reflect current conditions with respect to wetland distribution in the BHB.



5.0 Recommendations for BHB Pilot Project

Based on the synthesis of the literature describing wetland ecosystem service assessments that have been completed in Alberta and elsewhere, as well as the previous scientific work that has been completed in the Beaver Hills Biosphere reserve, this section outlines recommendations for the types of condition and ecosystem service indicators that could be adopted for the BHB wetland pilot project. Based on this recommended list of indicators, we provide a summary of the data needs associated with quantifying these indicators in Section 5.2.

5.1. Ecosystem Service Assessment Indicators

5.1.1. Ecosystem Services and Associated Indicators

As has been highlighted elsewhere in this report, one of the first steps in any ecosystem service assessment should be the selection of the services that will be the focus of the assessment. Based on what we understand the goals and objective of the pilot project to be, along with past work that has been done assessing wetland ecosystem services and the data that is currently availability for the BHB, we have provided a list of nine ecosystem services that could feasibly be assessed as part of the pilot.

It is important to note that the list of ecosystem services and associated indicators provided in this section is a recommendation only, and we suggest that the final list of services and indicators be developed in consultation with stakeholders and end users of the information. This is important because recent scholarly work examining public support for wetland restoration in Bulgaria suggests that an increased awareness that wetlands produce ecosystem services does not necessarily lead to a higher appreciation of those services (Scholte et al. 2016). Further, people inherently place a higher value on some services over others, and these preferences vary across individuals and groups based on their contact or experience with wetlands. In particular, Scholte et al. (2016) found that across their sample of farmers, fishermen, and local residents, there was a lower appreciation for regulating services, and higher appreciation for cultural and provisioning ES. This result is important because regulating services (e.g., flood control, water quality treatment) are often the focus of ecosystem service assessments (Rendon et al. 2019), as these services are typically easier to quantify and value; however, these services may not resonant with people in the same way as other services (Scholte et al. 2016).

Table 7. List of ecosystem services, organized using the CICES framework, that could be adopted as part of the BHB wetland pilot project. An example of the types of indicator that could be used to quantify each service is also provided, along with a general statement on the feasibility of assessing each indicator in the context of the BHB pilot.

Section	Division	Group	Class	Indicator Example	Feasibility
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	Carbon storage or sequestration	High
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	Water storage capacity of wetland basin OR Surface/groundwater flow models	High
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of freshwaters by living processes	Nutrient (P/N) storage	Medium
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials, or energy	Surface water used as a material (non-drinking purposes)	Water supply for agriculture	Medium
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials, or energy	Surface water for drinking	Water supply for human consumption	Medium
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	Visitation numbers to parks and recreation sites OR Acres of wetland habitat supporting recreationally important bird or fish species	Medium
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials, or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	Number of waterfowl hunting licenses issued per year	Low
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	Visitation to wetland sites by school groups OR Research funding directed towards the study of wetland ecosystems	Low

5.1.2. Condition & Pressure Indicators

As described in Section 2.2.2, an important step in any ecosystem service assessment is to evaluate the state or condition of the habitat(s) of interest. This type of analysis helps to understand drivers of change and threats to the supply of ecosystem services. Because collecting site-specific information about the condition of every wetland in the BHB is not practical, other indirect measures or proxies of condition will have to be used. Below is a list of condition and/or pressure indicators that have been used in other ecosystem service assessments, or are indicators that we feel are highly relevant to the specific goals of the BHB wetland pilot study:

- **Change in wetland area (%/yr)**: Assessing change in wetland area through time will provide a clear picture of where wetland losses have been the highest, which can help to illuminate what some of the drivers of the loss may be. Further, if the goal of the pilot program is to increase wetland area, this indicator is relevant for assessing progress and success moving forward.
- **Loss of wetland area due to drainage**: Drained wetlands present one of the greatest opportunities for wetland restoration in the BHB, and wetlands that have been drained via a drainage ditch are also eligible for replacement funds through the Government of Alberta Wetland Replacement Program. Identifying the number and location of drained wetlands not only provides important information about the scale of impact to wetlands in the BHB, but also provides critical information for targeting wetland replacement activities as part of the pilot project.
- **Conservation status and trends (% conserved/protected)**: The amount of wetland area that has been set aside for conservation or protection in parks, protected areas, conservation easements, or municipal environmental reserves is a useful metric for measuring success, particularly if targets for conservation or protection are set within the BHB.
- **Wetland connectivity**: Wetland connectivity is critical to wetland function and drives the quality and condition of wetlands, both hydrologically and from the perspective of biodiversity; thus, connectivity is a reasonable proxy for assessing condition. Connectivity of wetlands can be measured using a wide range of metrics, and the choice of which metric should be used should be informed by the availability of data, and what component of connectivity is of most interest or relevance to the project.
- **Land use pressure**: Various scientific studies have shown a strong association between wetland condition and surrounding land use (see Section 4.2 for discussion); thus, the type and intensity of surrounding land use can be a good proxy for wetland condition.

5.2. Data Requirements

Below, we discuss the types of data that are required to map the location and extent of wetlands, as well as to quantify the condition and ecosystem service indicators outlined above. A summary of the data required to quantify each of the suggested indicators is provided in Table 8. We have also included more detailed summaries of the spatial datasets currently held in the BHB data repository in Appendix A.

Table 8. Data requirements to quantify each of the suggested condition or ecosystem service indicators.

Indicator	**Type of Data Required for Quantification**								
	Wetland Inventory		**Wetland Condition/Impact**	**Land Cover**	**Topographic Data**	**Hydrologic data or models**	**Wildlife and/or habitat data**	**Geo Admin & Population**	**Other**
	Current	Historic							
Change in wetland area	√	√		√					
Loss of wetland area due to drainage			√		√				
Conservation status and trends	√							√	√
Wetland connectivity	√			√					√
Land use pressure	√			√				√	
Carbon storage	√								√
Waters storage capacity	√				√	√			
Nutrient storage	√				√	√			√
Water supply for agriculture	√				√	√			√
Water supply for humans	√				√	√			
Visitation numbers to parks and recreation sites	√								
Acres of wetland habitat supporting recreationally important bird or fish species	√						√		
Number of waterfowl hunting licenses issued per year	√								√
Visitation to wetland sites by school groups	√								√

5.2.1. Current & Historic Wetland Inventory

A current wetland inventory is foundational to this project, as this dataset is required for all analysis associated with the assessment (Table 8). Ideally, the current inventory should include wetland class as per the Alberta Wetland classification system (Bog, Fen, Swamp, Marsh, Open Water), with classification to the form level, if feasible. This inventory should also differentiate between natural and man-made (i.e., dugouts) waterbodies, and between wetlands and lakes. In addition to a current inventory, historical inventories would also be useful for evaluating the rate of wetland loss in the BHB through time, as well as highlighting the location of those losses. A historic inventory is also useful in evaluating the extent to which particular ecosystem services have been lost over time, and can help to inform future scenarios for analysis, if this is something that is of interest within the context of the pilot.

Existing Spatial Data

The current BHI spatial data collection contains an abundance of wetland datasets. At least 24 distinct wetland inventories of varying extent, resolution, attribute detail, date, and quality were located in the existing data collection. Among these, some inventories appear to be duplicate versions with different names, while others are wholly unique (Table A- 1). The most recent wetland inventory was developed as part of the BHI Land Management Framework 2014 Update (BHI Planners Group 2014), and was created using SPOT imagery from 2013 and LiDAR data from 2009; thus, the “current” inventory is already seven years out of date. A number of historical inventories from 1962/63, 1970, 1982, 1992/93, 1999, and 2009. have also been created for the BHB, and were derived from black and white air photos. For many of the inventories in the repository, the accuracy and/or minimum mapping units are unknown. Further, when comparing the inventories, there are large differences and discrepancies in the number and extent of wetlands that have been mapped (Figure 15). The inventory created for use in the 2014 Land Management Framework appears to be the most comprehensive and is attributed to Class and Type; however, there are no reported class overall or class accuracies reported for this dataset.

Recommendation

In general, the existing wetland datasets tend to be non-comprehensive and are lacking the proper attributes to allow for their use in the pilot. Because a current wetland inventory is foundational to the assessment, we recommend creating an inventory that is up-to-date and includes the information that is the most relevant and meaningful in the context of the ecosystem service assessment. Existing inventories can be used as supplementary information in the creation of the new inventory (e.g., as training data, or a starting dataset).

If a new wetland inventory is created specifically for the pilot project, we recommend using high resolution (3 m or better) multi-spectral satellite imagery to derive the inventory, as this imagery would provide appropriate spatial and spectral information to create a high quality and accurate inventory. While the initial investment in terms of image purchase may be relatively high (ranging between \$17.50/km^2 and \$29.00/km^2 or ~\$21,000 to ~\$47,000), there will be savings associated with the creation of the inventory. Manual clean-up of the existing inventories using high resolution air photos would be time consuming and thus, costly, and unless high resolution air photos could be secured free of charge through municipal partners, there would also be a cost associated with image acquisition. As an alternative to the purchase of the high resolution satellite imagery, the BHB could investigate the possibility of a partnership with the Government of Alberta in order to secure access to SPOT satellite data (6 m resolution) free of charge. While this imagery is coarser, this imagery still produces good wetland inventory results, although very small wetlands (<0.02 ha) are difficult to resolve using this imagery. Notably, the North Saskatchewan Watershed Alliance is currently commissioning the development of a 6 m land cover for the North Saskatchewan River basin, and so there may be opportunities to partner with the NSWA to gain access to this data.

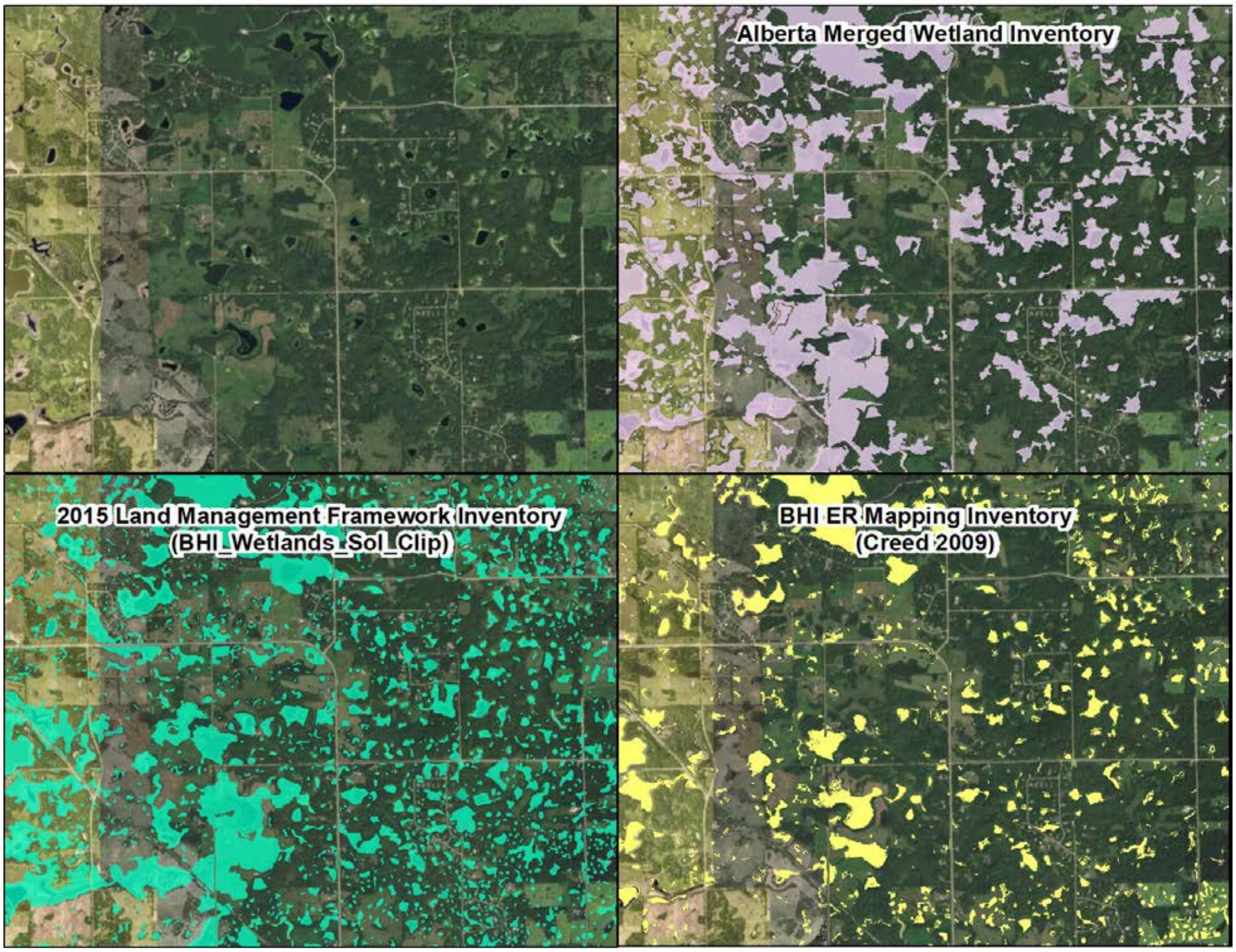


Figure 15. Comparison of three wetland inventories that are in the BHB spatial data collection. All three are out-of-date, and do not have all the recommended attributes outlined in this report for an ecosystem services assessment. As well, there are noticeable differences in the inventories, and the accuracy of the datasets is largely unknown.

5.2.2. Wetland Condition/Impact Data or Inventory

The primary historic and current anthropogenic impacts to wetlands in the BHB include drainage and/or habitat loss due to agricultural activities such as cultivation. Consequently, a critical dataset for the pilot project will be information about the location and extent of impacts related to drainage, cultivation, and other anthropogenic activates that have caused hydrologic or ecological disruption.

Existing Spatial Data

There is no current or historic drained or impacted inventory for the BHB, nor is there any existing inventories that include condition as an attribute in the inventory.

Recommendation

Identifying and mapping impacted wetlands is essential for the pilot project, as these impacted wetlands represent the “market” that is available for restoration or enhancement, as well as providing information about the condition and potential supply of ecosystem services in the BHB. Impacted wetland basins can be identified and included along with intact basins in the development of a current wetland inventory (as described in Section 5.2.1.), with specific condition attribute data included in this inventory to differentiate impacted and intact basins. Alternatively, a separate inventory could be created that includes drained and cultivated wetlands, with information that clearly attributes condition. High resolution satellite or air photos are required to identify drained wetlands, and the creation of this inventory will require some manual interpretation of the imagery to ensure good results.

5.2.3. Land Use/Cover Inventory

Land use/land cover inventories classify the landscape into discrete classes (e.g., water, forest, cultivated land) and provide important information on both context, configuration, and pressure/impacts to wetlands. Consequently, an accurate, up-to-date, and high resolution land cover with appropriate thematic resolution (e.g., relevant and meaningful land cover classes) should be used in an ecosystem service assessment.

Existing Spatial Data

The current BHI spatial data collection contains six land cover datasets with various extents, resolutions, attribute detail, date, and quality (Table A- 2). These datasets are associated with specific projects that have occurred in the Beaver Hills, and are either based on existing, freely available land cover datasets (e.g., Agri-food and Agriculture Canada (AAFC) 30 m land cover), or are newly derived land cover datasets. As such, each dataset has a distinct thematic resolution (i.e., class names); however, the classes across datasets tend to be somewhat comparable. For many of the land cover inventories, we could not find any information stating the overall or within class accuracies or the minimum mapping unit.

Recommendation

In general, the existing land cover datasets tend to be out of date, and based upon a review against recent air photos, appear to lack sufficient accuracy and/or resolution. The 2014 LMF land cover developed by Solstice appears to have the highest degree of boundary detail and an appropriate level of spatial resolution; however, the class accuracy would need to be improved substantially, and the thematic classes may also need to be adapted to suit the needs of the pilot project. Alternatively, a new land cover could be created from scratch using up-to-date imagery and LiDAR data, and could use the existing land covers as supplementary information (e.g., as training data, or a starting dataset). The existing datasets could also provide rough historic context for the area; however, accuracy and spatial resolution of the datasets would need to be considered carefully. Note that if new imagery is purchased for the purpose of creating a wetland inventory (e.g., Worldview-2 2 m satellite imagery), or SPOT imagery is obtained from the GOA, the same imagery can be used to create new land cover data for the BHB.

5.2.4. Imagery and Orthophotos

Air photos and satellite imagery are the primary data source for wetland inventories and land covers because they provide the spectral information required to classify the pixels into classes. Air photos and satellite imagery have different benefits and trade-offs; air photos are available further back in time, and are often available at much higher resolution and show more detail than satellite imagery, but imagery can often be acquired to better reflect dates of interest and has more spectral information (more image bands). Because the date, spatial resolution, and number of bands for an image all impact the quality of a wetland or land cover inventory, choosing images must be done thoughtfully with the needs of the project in mind.

Existing Spatial Data

The BHI spatial data collection contains both historic air photos and satellite imagery that range from 1990 to 2009, and that include a range in spectral and spatial resolution (Table A- 3).

Recommendation

While the BHB data repository has a large collection of images, there is no recent imagery, which would be required to create a current wetland inventory and land cover classification. We recommend the acquisition of either high resolution 4-band (RGB-NIR) air photos or the purchase of high resolution satellite imagery such as Worldview or GeoEye. Either of these choices would provide images suitable for creating a high resolution wetland inventory and land cover. The historic air photos and imagery could be useful in creating historic data products; however, many of the older collections do not cover the entire BHB, and therefore may be of limited use. One alternative option for historic imagery of the area includes the ABMI historic orthophotos, which are available for free from the ABMI, and provide a snapshot from the 1950s-60s. Alternatively, Dr. Irena Creed has a number of historical orthomosaics for the BHB, and these data may be available through a data sharing agreement.

5.2.5. Topographic Data

Topographic data describe the vertical position or profile of the landscape with respect to sea level and typically comes in the form of digital elevation models (DEMs) or contours. Topographic data, especially LiDAR data, is essential for creating an accurate wetland inventory and land cover layer, and these data can also be used to derive other data products that are required for assessing wetland condition and/or supply of ecosystem services, such as catchment or watershed boundaries and hydrologic flow models.

Existing Spatial Data

The current BHI spatial data collection contains a number of elevation datasets that range in spatial resolution (Table A- 4). Coarser resolution datasets can be useful in understanding broad scale landscape-level patterns; however, the lack of topographic detail limits the usefulness of these data for creating secondary products. Thus, high resolution elevation data is necessary to derive wetlands and to accurately model drainage and wetland connectivity. The BHB repository includes an AltaLIS 1:20,000 DEM and 3 m resolution LiDAR terrain products (bare earth elevation, full feature elevation) that were acquired in 2009. A 5 m resolution DEM is also present in the data collection; however, the origin of the data is unknown. The 3 m resolution data was used in the Creed ER Mapping project and the 2014 Land Management Framework project. Each of these projects used the raw data to create secondary files and to inform the development of wetland inventories and land covers. The BHB data collection also contains several other elevation datasets; however, the resolution of these datasets is too coarse to be of use in the pilot project.

Recommendation

The 3 m LiDAR data has sufficient spatial resolution to map wetlands in detail, but this data was collected in 2009 and may not capture current conditions in some locations where development has occurred. While the cost of acquiring new LiDAR data may be cost prohibitive, there may also be opportunities to partner with Parks Canada and Natural Resources Canada to acquire LiDAR data as part of the federal government’s National Elevation Data Strategy. A number of secondary products have been derived as part of various other projects over the years (e.g., slope, aspect, terrain complexity); however, because there is limited information on the methods used to derive these products, it may be more appropriate to process the terrain data to create layers specifically for use in the pilot project.

5.2.6. Hydrologic Data

Hydrologic data comes in many forms, from simply delineating the location of features, to more complex modelled data that predicts the location and flow of surface and groundwater, as well as locations of groundwater discharge or recharge.

Existing Spatial Data

The BHB data repository contains a variety of hydrological data that includes Alberta and NRCAN base features (e.g., lake and river polygons, streams and river polylines) and watershed boundaries, as well as ancillary or derived products from projects such as the 2014 Land Management Framework project (e.g., ground water mapping) and the 2013 ER Mapping project (e.g., flow accumulation).

Recommendation

Because the base features hydrology data and watershed boundaries are updated on a regular basis, and the datasets for these features in the database are likely out-of-date or are older versions, we recommend that the newest versions be acquired for the pilot project, especially since they are freely available. With regards to the products derived in other projects, we suggest these products be used with caution because they were derived using older datasets, and in some cases, the methods and metadata are lacking in detail, making it difficult to fully evaluate the data. The nature of the hydrologic data needs for this project is somewhat unknown until the final list of ecosystem services and indicators is selected; therefore, it is difficult to make specific recommendations with respect to whether the existing data meets the needs of the pilot study. Generally, however, we can say that if a new wetland inventory is derived for the pilot, then any hydrologic modelling related to individual wetlands should likely be redone. Further, the BHB should consider engaging with Dr. Creed (currently at the University of Saskatchewan) to discuss the availability of the hydrologic models that have been recently developed for the Beaver Hills watershed (Ameli & Creed 2017, 2019b and further described in Section 4.4). Preliminary discussions with Dr. Creed suggested that she is open to the possibility of sharing these data. A list of the datasets currently held by Dr. Creed that may be useful in the assessment of wetland ecosystem services in the BHB are listed in Table A- 5.

5.2.7. Wildlife/Biodiversity Data

Wildlife and biodiversity data exist in many forms – from individual-level point data to general maps of species ranges. These data probably represent the most diverse and complex information to incorporate into the pilot project since there have been so many different research projects over the years that have collected species-level information.

Existing Spatial Data

The data collection has both species point data files and species ranges; however, the acquisition date and data sources are mostly unknown, and these data should be used with caution or updated with the most recent versions where possible. Specific to wetlands, presence, absence, and/or diversity of species may provide an indication of a wetland's ecosystem services and value; however, data specific to each wetland is unlikely to be available. Provincial databases, such as ACIMS and FWMIS provide one source of presence data for many plant and animal species; however, these data are only recorded incidences, and therefore, may underestimate true presences of species. Ultimately, for the purposes of this pilot, a balance will need to be found between the type of data that is available for the area and the wetland ecosystem services that are wanting to be calculated.

Recommendation

The nature of the wildlife or habitat data needs for this project is somewhat unknown until the final list of ecosystem services and indicators is selected; therefore, it is difficult to make specific recommendations with respect to whether the existing data meets the needs of the pilot study. Given the general lack of site-specific data, and the expense involved in collecting such data, we expect that any measures of biodiversity or habitat quality within the pilot project will have to rely on proxy metrics, which will have to be developed specifically for each indicator to ensure relevance.

5.2.8. Soils Data

Soils data are typically used to inform the development of other important layers, such as drainage, flow models, agricultural capability, and surface and groundwater risk.

Existing Spatial Data

Several projects in the BHB have used soils data to create models or derive secondary data products. Soils data is freely available from the provincial and federal governments (e.g., Agrasid, Soil Landscapes of Canada); however, soils data are disseminated at a relatively coarse spatial resolution that only allows for a general perspective on soil types and soil profiles across the BHB.

Recommendation

If soils data are required for the pilot project, the most recent version of the freely available datasets should be obtained and used in any analysis or modelling.

5.2.9. Climate Data

Climate data are available as raw point data collected from weather stations, or as grid data that has been modelled independently using point data. Grid data vary in type of data, resolution, and the method that was used to model the point data into a continuous surface. Predictions of future climatic conditions can also be acquired from various sources.

Existing Spatial Data

The BHI database has some climate data from previous projects; however, we recommend climate data be acquired on an as need basis to complement the indicator and analysis that is taking place. For example, if an indicator of wetland permanence or dynamics is required, long term historic climate data alongside historic air photos could be used to understand how a particular wetland contributes to flood mitigation or acts as a source of water during droughts.

Recommendation

Because climate data is collected on an ongoing basis, data for any time period of interest can be retrieved as needed.

5.2.10. Geo Administration Data

Geo administration data include mapped features such as, linear features (e.g., roads, rail), boundaries (e.g., settlements, parks, management areas), land ownership, and population data. Most types of geo administration data are freely available as part of the Provincial Base Features datasets.

Existing Spatial Data

Many geo-administration datasets exist within the BHB repository; however, since these datasets are updated regularly by the province, the datasets currently housed in the repository should be updated with the newest versions. Some data, such as land ownership or specific municipal-level data are not freely available, and must be purchased or acquired from municipalities or through other data partnerships. In past projects, some geo administration data have been acquired from NRCAN or federal data portals. In general, federal data sources of geo administration data are much coarser than provincial datasets and are not updated as regularly. Thus, we suggest limiting the use of federal-level data wherever possible.

Recommendation

We recommend that geo administration data be acquired on an as-needed basis to satisfy the requirements to assess the ecosystem services of interest in the pilot project.

5.2.11. Derived Data Products

As noted in the overview of each of the types of spatial data, as part of many of the projects performed in the Beaver Hills, numerous secondary data layers have been derived to assess various biophysical or other factors of interest. These include layers such as, groundwater risk, surface water risk, agricultural capability, connected habitats, core areas, environmental sensitivity, and many others. Importantly, these layers were developed as part of specific projects over the years, each with its own unique context and goals, and therefore, they are likely to be of limited use to this pilot project. These layers may help to inform the development of other layers; however, given the availability of the raw data layers used to create many of these secondary products, we reiterate that it would be ideal to generate new versions that incorporate the most up-to-date and best quality wetland inventory and land cover available.

6.0 Conclusions

Ecosystem service assessments are increasingly being used by a wide range of organizations to inform policy development and implementation, as well as to focus conservation or management planning to improve outcomes. This report provides a general overview of the ecosystem service assessment process, and specifically, provides examples of ES assessments that have been completed for wetlands in Alberta and elsewhere. Further, this report provides recommendations for the types of condition and ecosystem service indicators that could be adopted by the BHB, and provides a review of existing spatial data in the context of these recommendations.

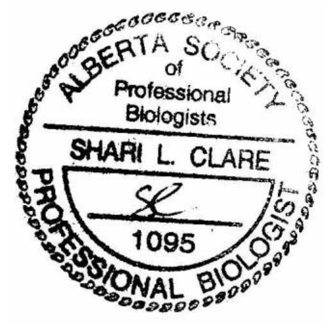
While the BHB data repository currently contains a large range and amount of spatial data, much of it is dated or does not have a sufficient level of detail or information to be useful in this project. In particular, the wetland inventories that have been developed for the BHB area are over 5 years old, and as a result, may not reflect current conditions in the BHB, particularly in areas where there have been major changes in land use. In addition, there is no existing spatial data that provides information on the location of drained or cultivated wetlands, and this information is essential to the success of this project. Thus, there will need to be work done to either update the most recent inventory, or to create new wetland datasets for use in the pilot. Deriving a new wetland inventory will require the acquisition of imagery and/or LiDAR data to support the creation of the new data products, and while the purchase of such data can be expensive, there may be opportunities for partnerships with municipalities, the provincial government, and/or the federal government to share the cost of acquiring these data. Certainly, the value of acquiring new satellite or LiDAR datasets extends well beyond their use on this single project, and the secondary data products that can be derived from these data have wide application for land use planning and management in the Biosphere

The data requirements related to assessing ecosystem services are at this point, largely unknown, because the list of ES that will be assessed in the pilot have not yet been selected; however, given the focus of previous wetland ecosystem service assessments, it is likely that hydrologic data will be required. Fortunately, there has been much academic work done in the Beaverhills watershed over the last decade that focused on the assessment of various hydrological processes, and the data and/or the methods developed as part of these studies can be used to support and inform the pilot project.

Critically, the next step in the BHB wetland pilot project will be the selection of the priority ecosystem services that will be assessed. Choosing the list of priority ecosystem services will serve to focus the subsequent data acquisition and processing steps, which will be essential for efficiently moving the pilot forward. Importantly, if the information is to have a positive impact on wetland conservation in the Biosphere, then the list of ES selected need not be exhaustive, but should in some way be related back to the goals and objectives of the pilot, and should also be reflective of what stakeholders and end users value.

6.1. Closure

This report was written by:



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Appendix A: Spatial Data Summaries

Table A- 1. Wetland inventory datasets in the Beaver Hills Biosphere spatial data repository.

File Name	File Location	Description	Assessment
Wetlands	X:\BHI Compiled Data July 2019\GIS_Library\012_inlandWaters\Altalis\Wetlands.shp	Unknown date and source. Appears to be modified version of base features that has been edited.	Missing majority of wetland features. No attributes. Could be used as supporting information for new inventory.
wetlands	X:\BHI Compiled Data July 2019\GIS_Library\007_environment\BHI_LandManagementFramework\Archive\SpencerEnvironmental_OriginalData\GIS Files\wetlands.shp	Developed for 2007 LMF (Spencer Environmental). Appears to be edit and merge of base features and old Alberta Wetland Inventory.	More comprehensive than Wetlands, but missing most small wetlands and some boundary issues. No attributes. Could be used as supporting information for new inventory.
L_WETLAND_Clip	X:\BHI Compiled Data July 2019\GIS_Projects\BHI_DataMaps_2006\bhi\shapes\L_WETLAND_Clip.shp	Unknown source from ~2006. Appears to be manual delineation.	Boundaries and coverage are questionable. Not likely to be useful.
Wetlands_new	X:\BHI Compiled Data July 2019\GIS_Projects\BHI_DataMaps_2006\data\Hydrology\Wetlands_new.shp	Unknown source from ~2006. Some overlap with other files based on base features, but has some unique features.	Missing majority of wetland features. No attributes. Could be used as supporting information for new inventory.
Canvec_Wetland_merge	X:\BHI Compiled Data July 2019\GIS_Projects\BHI_DataMaps_2006\data\Hydrology\Wetlands_new.shp	From CanVec datasets of unknown year.	Coarse scale (1:50,000) and missing majority of features; however, does have some features not in other datasets. No attributes. Could be used as supporting information for new inventory.
Geobase_NHN_Waterbody	X:\BHI Compiled Data July 2019\GIS_Projects\BHI_LMF_Coverage Extention_2010_notCompleted\data\LMF UpdateData\geobase_NHN_Waterbody.shp	Geobase National Hydro Network of unknown year.	Coarse scale (1:50,000) and missing majority of features. Boundaries are approximate, and attributes are very general. Could be used as supporting information for new inventory.
BHI_Wetlands_20K	X:\BHI Compiled Data July 2019\GIS_Projects\EINP\Hydrography\Altalis\BHI_Hydrology_Altalis_3TM.gdb\Hydrology\BHI_Wetlands_20K	Unknown source and date. Appears to be selected version of base features.	Not comprehensive, and overlaps exactly with Wetlands dataset.
BHI_WETLAND_INVENTORY_WORKING_0222011	X:\BHI Compiled Data July 2019\GIS_Library\012_inlandWaters\AENV_BHI_WETLANDS\BHI_WETLAND_INV.gdb\FEATURE_DATASET_STANDARD\BHI_WETLAND_INVENTORY_WORKING_0222011	Dated 2011. Appears to be slightly edited version of most recent Alberta Merged Wetland Inventory which was created in 2007.	Areas where manually delineated are good, but areas from remote sensing not great. Features are classed based on source (e.g., some are CWCS, others are DUC, others are GVI). Could be used as supporting information for new inventory.

Table A- 1. Continued.

File Name	File Location	Description	Assessment
Wetland_CWCS_2009_clipped	X:\BHI Compiled Data July 2019\GIS_Projects\State of the Beaver Hills AMEC\State of the Beaver Hills AMEC Rev3.gdb\Hyd\Wetland_CWCS_2009_clipped	Clipped version of CWCS 2009 wetland inventory.	Similar to BHI_WETLAND_INVENTORY_WORKING_0222011, but with less spatial feature detail. Features classed based on CWCS. Could be used as supporting information for new inventory.
BHI_Wetlands_Sol	X:\BHI Compiled Data July 2019\GIS_Projects\LMF2015\Vector Data\ConnectedHabitats\BHI_Wetlands_Sol.shp	From 2014 LMF. No data on derivation, but appears to be remote sensing derived primarily from LiDAR.	Fairly comprehensive. Includes Class and Type, but many features without attributes. May be preliminary wetlands layer for the LMF project. Could be used as supporting information for new inventory.
BHI_Wetlands_Sol_clip	X:\BHI Compiled Data July 2019\GIS_Projects\LMF2015\Vector Data\Wetlands\BHI_Wetlands_Sol_clip.shp; X:\2019\1922_Land_Stewardship_Centre_Beaverhills_ES_Project\4_Imagery_LiDAR\BHI Compiled Data July 2019\GIS_Projects\LMF2015\LandManagementFramework_2015.gdb\Wetlands\BHI_Wetlands_Sol_clip	From 2014 LMF. No data on derivation, but appears to be remote sensing derived primarily from LiDAR.	Fairly comprehensive. Some different boundaries and features from BHI_Wetlands_Sol. All features have attributes. May be cleaned up or final version of BHI_Wetlands_Sol. Could be used as supporting information for new inventory.
Wetlands_Nolakes_05	X:\BHI Compiled Data July 2019\GIS_Projects\LMF2015\Vector Data\ConnectedHabitats\Wetlands_Nolakes_05.shp	From 2014 LMF. No data on derivation, but appears to be remote sensing derived primarily from LiDAR.	Another version of Solstice wetlands, but not exactly clear how different or why file was derived.
2009_wetland_inventory_with_fc_and_pc_values	X:\BHI Compiled Data July 2019\GIS_Projects\Creed_BHI ER Mapping Project\Creed Data Transfer_260914\Wetland Inventory\2009_wetland_inventory_with_fc_and_pc_values.shp	Derived as part of Creed ER Mapping project. Based on object based classification of 3m LiDAR and 1m airphotos from 2009.	Not as comprehensive or as accurate boundary wise as CWCS or Solstice inventories, but may identify some smaller or lost agricultural wetlands. Missing obvious wetlands that are in Creed historic inventories and vice-versa. No class attribute.
Creed Historic Inventories (1962, 1970, 1982, 1992-1993, 1999)	X:\BHI Compiled Data July 2019\GIS_Projects\Creed_BHI ER Mapping Project\Creed Data Transfer_260914\BHI Database\Historic Wetland Inventories	Derived as part of Creed ER Mapping project. Segmented historic air photo.	Not as comprehensive or as accurate boundary wise as CWCS or Solstice inventories. Missing obvious wetlands that are in other Creed inventories and vice-versa. No attributes.

Table A- 2. Land cover datasets in the Beaver Hills Biosphere spatial data repository.

File Name	File Location	Description	Assessment
2009_BHI_SPOT Landuse_Complete.tif	X:\ BHI Compiled Data July 2019\GIS_Projects\Creed_BHI ER Mapping Project\Creed Data Transfer_260914\BHI Database\SPOT Land Cover\2009_BHI_SPOT Landuse_Complete.tif	2009 land cover developed from SPOT 4 multispectral (10 m) and panchromatic (2.5 m) imagery provided as part of Creed ER Mapping Project.	Reported overall accuracy of 89%, but no details or within class accuracies provided. Visual inspection against air photo indicates poor to moderate class accuracy and substantial mixing of classes. Out of date. Not recommended for use without substantial clean up and editing.
lulc.tif	X:\ BHI Compiled Data July 2019\GIS_Projects\Creed_BHI ER Mapping Project\Creed Data Transfer_260914\BHI Database\Provincial Land Cover\lulc.tif	Circa 2000 land cover clipped from the AAFC Land Cover for Agricultural Regions of Canada as part of Cree ER Mapping Project. Federal product originally derived from Landsat imagery (30 m).	No accuracy information provided. Severely out of date and coarse resolution. Original classes have been aggregated into fewer classes. Visual inspection against air photo indicates poor to moderate class accuracy and substantial mixing of classes. Not recommended for use. Original data could be used as rough reference.
LCV_AAFC_AB_2000_30m_NAD83	X:\ BHI Compiled Data July 2019\GIS_Projects\State of the Beaver Hills AMEC\State of the Beaver Hills AMEC Rev3.gdb\LCV\LCV_AAFC_AB_2000_30m_NAD83	Circa 2000 land cover clipped from the AAFC Land Cover for Agricultural Regions of Canada and converted to polygons. Federal product originally derived from Landsat imagery (30 m).	No accuracy information provided. Severely out of date and coarse resolution. Original boundaries have been distorted by raster to polygon conversion. Visual inspection against air photo indicates moderate class accuracy but coarse resolution misses many features. Not recommended for use. Original data could be used as rough historical reference.
STB_EOS_2013_CI_BHIclipped	X:\ BHI Compiled Data July 2019\GIS_Projects\State of the Beaver Hills AMEC\State of the Beaver Hills AMEC Rev3.gdb\STB_EOS_2013_CI_BHIclipped	Clipped land cover from the AAFC 2013 Annual Crop Inventory. Federal product originally derived from Landsat and Radar imagery (30 m)	Metadata of original suggests an overall accuracy of at least 85%, but no details or within class accuracies provided. Out of date, and current versions can be acquired freely online. Visual inspection against air photo indicates moderate class mixing and missing many features. Original data could be used as rough historic or current references.
Central_Parkland_Nat_Veg_Inv_clip2_acra_munis7	X:\ BHI Compiled Data July 2019\GIS_Projects\State of the Beaver Hills AMEC\State of the Beaver Hills AMEC Rev3.gdb\LCV\Central_Parkland_Nat_Veg_Inv_clip2_acra_munis7	Clipped from the Alberta Central Parkland Vegetation Inventory (CPVI) Polygons, circa 2001. Originally derived from Landsat and aerial photography.	No accuracy information. Somewhat coarse thematic and spatial resolution, but captures general landscape patterns (disturbed vs intact). Severely out of date. Can be acquired freely on line. Could provide coarse historic reference.
Landcover_Sol	X: \BHI Compiled Data July 2019\GIS_Projects\LMF2015\LandManagementFramework_2015.gdb\LandCover\Landcover_Sol; X:\ BHI Compiled Data July 2019\GIS_Projects\LMF2015\Vector Data\LandCover\Landcover_Sol.shp; X \BHI Compiled Data July 2019\GIS_Library\007_environment\Solstice Generated LCV\Landcover_Sol.shp	Solstice derived as part of LMF 2014 project from 3m LiDAR, 1.5m 2013 SPOT data, and AAFC 2012. Reported scale of 1:5000.	No formal accuracy assessment provided. Project report states: *Overlays with aerial photographs confirmed that this method had generally identified these lands correctly.* Visual inspection against air photo indicates good detail, but only moderate accuracy and moderate to high class mixing in some areas. Somewhat out of date. Could be used as starting point or supporting information for new land cover, but not recommended for use in current state.

Table A- 3. Imagery and orthophotos in the Beaver Hills Biosphere spatial data repository.

Folder/File Name	Location	Description	Assessment
canada_mosaic_white_25_ bhi.tif	X: \BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\1990_GeoGratis_CanadaMosaic	3-band (unknown bands) 28.5 m resolution Landsat orthoimage dated circa 1990	Historic orthoimage from GeoGratis. Coarse resolution and does not include all the original bands from the Landsat imagery. Likely resampled to get 28.5 m resolution. If required, would be better to acquire original imagery for this time period.
046, 047, 048, 049, 050, 051, 052	X:\ BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\1998	Black and white (single band) 2 meter resolution air photos dated circa 1998.	Black and white air photos at good spatial resolution. Only partial coverage of Beaver Hills.
2001_ERJOI	X:\ BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\2001_ERJOI	Black and white (single band) 0.25 meter resolution air photos dated circa 2001.	Black and white air photos a high spatial resolution. Only partial coverage of Beaver Hills.
PFRA Color Orthos 2002	X:\ BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\PFRA Color Orthos 2002	3-band (RGB) 1 meter resolution colour air photos data circa 2002.	Colour air photos at high spatial resolution.
046, 047, 048, 049, 050, 051, 052, 053	X:\ BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\2004	Black and white (single band) 1 meter resolution air photos dated circa 2004.	Black and white air photos at high spatial resolution. Only partial coverage of Beaver Hills
3TODE1243_Imagery_UTM12_NAD83; 4TODE1243_Imagery_3TM_NAD83; MrSID	X:\ BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\2006_SPOT	Black and white (single band) 2.5 m resolution panchromatic image from SPOT4 dated circa 2006.	Black and white imagery mosaic at good spatial resolution.
2007_ERJOI	X: \BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\2007_ERJOI	Black and white (single band) 0.25 meter resolution air photos dated April/May 2007.	Black and white air photos at high spatial resolution.
2009_ERJOI	X: \BHI Compiled Data July 2019\GIS_Library\010_imgeryBaseMapsEarthCover\imagery\2009_ERJOI	Black and white (single band) 0.25 meter resolution air photos dated May 2009.	Black and white air photos at high spatial resolution.

Table A- 3. Continued

Folder/File Name	Location	Description	Assessment
SPOT Multispectral	X: \BHI Compiled Data July 2019\GIS_Projects\Creed_BHI ER Mapping Project\Creed Data Transfer_260914\BHI Database\SPOT\	4-band (RGB-NIR) 10 m resolution imagery from SPOT4 data July/Aug 2009	4-band satellite imagery at moderate resolution. Used in the Creed ER Mapping Project.
SPOT Panchromatic	X: \BHI Compiled Data July 2019\GIS_Projects\Creed_BHI ER Mapping Project\Creed Data Transfer_260914\BHI Database\SPOT\	Black and white (single band) 2.5 m resolution panchromatic image from SPOT4 dated circa 2009.	Black and white imagery at good spatial resolution. Used in the Creed ER Mapping Project.
Spot_All.img	X: \BHI Compiled Data July 2019\GIS_Projects\LMF2015\Raster\Spot	3-band (unknown bands) 3 m resolution mosaicked SPOT imagery of unknown source and date.	Resampled imagery at good resolution, but unknown bands. Used in the Solstice 2014 LMF.
Col_BW_Z12.jp2	X: \BHI Compiled Data July 2019\GIS_Projects\LMF2015\Raster\Ortho	3-band (RGB) 1 m resolution mosaicked air photos of unknown source and date.	Colour imagery from multiple unknown sources at high spatial resolution. Used in the Solstice 2014 LMF.

Table A- 4. Topographic datasets in the Beaver Hills Biosphere spatial data repository.

Folder/File Name	Location	Description	Assessment
BHI_LiDAR_2009	X: \BHI Compiled Data July 2019\GIS_Library\006_elevation\BHI_LiDAR_2009	Contains raw point clouds and processed versions of 3 m LiDAR data. Includes Bare Earth and Full Feature terrain layers.	No information on processing of raw files or reports on data accuracy. Spatial resolution is likely sufficient for wetland and land cover mapping. Versions of the elevation data also exist within the Creed and Solstice 2014 LMF project folders.
AltaLIS_DEM_20K	X: \BHI Compiled Data July 2019\GIS_Library\006_elevation\AltaLIS_DEM_20K	Contains 10 m DEM and contour lines for Beaver Hills area. Raw files from AltaLIS are in zipped folders.	Processing information performed by AltaLIS available in metadata documents. Spatial resolution is coarser than 3 m data, but still could be used to derive secondary products if using 3 m data is too computationally intensive.
EINP_unknownSource	X: \BHI Compiled Data July 2019\GIS_Library\006_elevation\EINP_unknownSource	Contains a TIN, 5 m DEM, and derived secondary products. Raw files include a point dataset, which was probably used to create a TIN and the DEM.	Source of original data and processing methods are unknown, so data should be carefully QA/QC'd before considering use. If the data meet quality standards, then the dataset offers a potentially useful alternative to the other two elevation datasets.

Table A- 5. Spatial datasets that have been created by Dr. Irena Creed that may be useful in the assessment of wetland ecosystem services in the BHB.

Dataset	Reference
Orthomosaics from 1962/63, 1970, 1982, 1993, 1999, 2009, 2011	Serran and Creed 2016 Serran et al 2018
Wetland inventories from 1962/63, 1992/93, 2011, including the identification of temporarily and permanently lost wetlands	Serran and Creed 2016 Serran et al 2018
Open water permanence maps from 1962/63, 1970, 1982, 1993, 1999, 2009	Serran and Creed 2016
Groundwater and surface water models and associated information identifying recharge/discharge wetlands and the flow contribution of individual wetlands to the North Saskatchewan River	Ameli and Creed 2017
3D groundwater-surface water interaction flow and transport model for 1962/63, 1993, 2009 and a "future" scenario	Ameli and Creed 2019