Resilience in river basin management:

A comparative analysis of approaches toward resilience in the Columbia River Basin and Murray-Darling Basin

by

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ABSTRACT

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Marinda Graham

Given the increasing scarcity of freshwater availability from river basins, the traditional command-and-control approach toward basin management is becoming obsolete. Viewing river basins as social-ecological systems and managing for social-ecological resilience is a novel approach that is starting to gain credibility and momentum, leading to the research question: *Are principles of resilience theory being utilized in the management of river basins and if so, which principles are most prevalent?* A secondary question was also posed: *Where resilience theory is being utilized, how is it being applied?* Using qualitative content analysis, management plans for the Columbia River Basin in the US and the Murray-Darling Basin in Australia were coded using seven principles of resilience and an ecosystem service model. Two levels of documents were examined: documents at the basin-wide level and documents at the catchment or subbasin level. At the basin-wide level, the Murray-Darling Basin Plan was evaluated against the Northwest Power and Conservation Council's Columbia River Basin Fish and Wildlife Program. Overall the Columbia River Basin Fish and Wildlife Program exhibited more resilience thinking than the Murray-Darling Basin Plan. At the catchment or subbasin level, Catchment Action Plans from the state of New South Wales were evaluated against Subbasin Plans from the state of Washington. The Catchment Action Plans exhibited a high degree of resilience thinking whereas the Subbasin Plans exhibited only a marginal degree of resilience thinking. When combined as overarching plans, the lack of cohesion and continuity between the Murray-Darling Basin Plan and the New South Wales Catchment Action Plans weakened the overall result for the Murray-Darling Basin. Strong connectivity between the Columbia River Basin Fish and Wildlife Program and the Washington State Subbasin Plans strengthened the overall result for the Columbia River Basin. The additional evaluation of ecosystem services did not contribute much insight.

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List of Acronyms

ACT	Australian Capital Territory
BPA	Bonneville Power Association
CAP	Catchment Action Plan
CAS	Complex Adaptive Systems
CRB	Columbia River Basin
CRBFWP	Columbia River Basin Fish and Wildlife Program
MA	Millennium Assessment
MDB	Murray-Darling Basin
MDBA	Murray-Darling Basin Authority
MDBP	Murray-Darling Basin Plan
NPCC	Northwest Power and Conservation Council
NSW	New South Wales
PNW	Pacific Northwest
SDL	Sustainable Diversion Limit
SES	Social-Ecological System
WA	Washington

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Chapter 1: Introduction

Freshwater is one of the earth's most vital resources and is a critical component of human well-being (Miller et al., 2016). Ensuring sustainable use and continued availability of freshwater is critical for all living species on the planet, however this is being challenged by the rapid rise of global water consumption (World Water Council, 2000). Human-created climate change and loss of biodiversity are impacting the availability of freshwater yet increasing social and economic demands continue to persist (Rockström et al., 2014). Issues that result from water scarcity are not about the water itself but about how people interact with the water (Connell, 2011). Since the 1960s, withdrawals from rivers have doubled and the amount of water in reservoirs has quadrupled (Millennium Assessment, 2005; Rockström et al., 2014). River basins are one of the most important sources of freshwater on the planet, however for most major rivers systems, the rate of extraction is exceeding the capacity, putting the resilience of the systems in jeopardy (Millennium Assessment, 2005; World Water Council, 2000).

River management is, in essence, conflict management (Wolf, 2007). In response to rapid development and stressors such as climate change, management approaches for river systems must be able to address current conflicts in freshwater usage as well as anticipate and adapt to future conflicts (Kenney, 2006). When water reform is viewed as a social process, the current command-and-control approach towards river management becomes obsolete (Connell, 2011). Balancing the many competing uses of river systems is the key towards resolution and reform. However, understanding the multiple conflicting uses of rivers and the impacts on the overall system is complex because river systems do not exhibit simple, linear behavior (Cosens & Williams, 2012). Therefore, a relevant framework for evaluating the functions and health of the river as a social system must be applied (Rockström et al., 2014).

Because river basins provide essential services not just for ecosystems but for humans as well, one novel but increasingly popular approach is viewing river basins as social-ecological systems (SESs), allowing for humans to be part of the river basin as opposed to separate from it when considering management options (Cosens et al., 2014; Huitema et al., 2009; Ostrom, 2009). When managing a river basin as an SES, resilience emerges as a central part of river management (Green et al., 2013; Parsons et al., 2016; Parsons & Thoms, 2017). Defined as the ability of a system to respond to disturbances and absorb change while preserving its core structure and functions (Cosens et al, 2014; Walker & Salt, 2006), resilience can be a powerful mechanism for managing and adapting to the changes we are encountering and will continue to encounter in our river basins (Folke, 2016). The notion of a self-repairing river basin is no longer valid and management approaches must actively address enhancing and strengthening a basin's capacity to provide for social systems as well as ecosystems (Folke, 2003).

Research Question

This leads to my research question: are principles of resilience theory being utilized in the management of river basins and if so, which principles are most prevalent? A secondary question is: where resilience theory is being utilized, how is it being applied? In an attempt to answer these questions, I evaluated and compared how concepts from resilience theory were being applied in management approaches for the Columbia River Basin (CRB) in the Pacific Northwest (PNW) in the United States and for the Murray-Darling Basin (MDB) in Australia. Few studies exist that explore the application of resilience theory to real-world situations (Baird et al., 2016; Sellberg et al., 2018), so my research could contribute to building knowledge in this area. In addition, understanding the similarities and differences of how resilience is being integrated in the recently developed Murray-Darling Basin Plan and the Columbia River Basin plans may potentially lead to valuable insights that can be leveraged by management personnel on both sides. This cross-case comparison may be of practical value for managers of other river basins and of academic value for researchers interested in exploring different approaches (Kenney, 2006). Comparative perspectives also facilitate exchanges of best practices and lessons learned for management reform (Garrick & Bark, 2011), yet very few comparative studies have focused specifically on resilience as a management approach for river basins (Parsons & Thoms, 2017).

Thesis organization:

I have divided this thesis into six chapters. The first chapter introduced my thesis topic and the research questions I will be addressing. The remainder of the first chapter provides background information on the two river basins that are the research subjects of this thesis: the Columbia River Basin in the Pacific Northwest and the Murray-Darling Basin in Australia. Chapter 2 consists of a review of literature starting with ecosystem services and SESs. I then review resilience theory broadly, then narrow focus on resilience as a management approach, followed by resilience as a framework for evaluating river management. I finish with a brief review of comparative analyses that exist for river basins in an attempt to demonstrate the contribution of my research. In chapter 3, I detail the methods I used for my research, including the software, the specific documents used as data, and the building and trialing of the coding frame. I present the results in chapter 4, followed by a discussion of the results in chapter 5. I conclude with chapter 6, which will include suggestions for additional areas of research.

Background

Columbia River Basin

Described as an organic machine (White, 1995), a river lost (Harden, 1996), and a river captured (Pearkes, 2016), the Columbia River and its many tributaries have long been ingrained in Pacific Northwest economy, livelihood, and culture. As the largest river system in the PNW, the CRB covers an area over 670,000 square kilometers (Bonneville Power Administration et al., 2001). Approximately 15% of the CRB is located in interior British Columbia in Canada with the remaining 85% located across seven states of the United States (Figure 1) (National Research Council, 2004). Numerous subbasins produced by the tributaries of the mainstem river exist within the drainage area (Bonneville Power Administration et al., 2001), each with individual goals, objectives, and needs. In addition, there are 14 affiliated tribes in the United States portion of the CRB and three First Nations groups in the Canadian portion of the CRB (National Research Council, 2004) (Table 1). The multiple agencies and laws, as well as state, local, and tribal governments contribute to a complex jurisdictional structure that provides immense challenges for basin management (Cosens, 2010).

Figure 1. The Columbia River Basin in the PNW of the United States and British Columbia in Canada. Locations of dams on the river are also depicted. Reprinted from Northwest Power and Conservation Council, 2014.

Table 1: First Nations and Tribal Nations in the CRB. Adapted from Columbia River Inter-Tribal Fish Commission, 2014.

Tribe (US) or First Nation (CA)	Country	State (US) or Province (CA)
Ktunaxa Nation	CA	British Columbia
Okanagan Nation	CA	British Columbia
Secwepemc Nation	CA	British Columbia
Confederated Tribes of the Colville Reservation	US	Washington
Kalispel Tribe of Indians	US	Washington
Spokane Tribe of Indians	US	Washington
Confederated Tribes and Bands of the Yakama Nation	US	Washington
Kootenai Tribe of Idaho	US	Idaho
Coeur d'Alene Tribe	US	Idaho
Nez Perce Tribe	US	Idaho
Shoshone-Bannock Tribes of the Fort Hall Reservation	US	Idaho
Shoshone Paiute Tribes of the Duck Valley Indian Reservation	US	Idaho
Confederated Salish and Kootenai Tribes of the Flathead Nation	US	Montana
Confederated Tribes of the Grande Ronde Community of Oregon	US	Oregon
Confederated Tribes of the Warms Springs Reservation of Oregon	US	Oregon
Confederated Tribes of the Umatilla Reservation	US	Oregon
Burns Paiute Tribe	US	Oregon

In addition to the complexity of basin management, the basin itself has been plagued by over-allocation of existing water supply, uncoordinated efforts between the various managing entities, and conflicting objectives among stakeholders (Cosens, 2010; Mote et al., 2014). Alterations such as dams, reservoirs, irrigation systems, and navigation channels have impacted the stability of the once wild river (Harden, 1996). Potential shocks such as climate change, changes in policy, and land use changes can destabilize and even transform critical basin attributes that currently contribute to economic, social, and environmental wellbeing within and beyond the basin (Cosens & Williams, 2012; Hand et al., 2018). Adaptation to these projected changes is critical to ensure the overall health of the economy, ecology, and culture in the Pacific Northwest (Hand et al., 2018).

Governance and management of the CRB is one of North America's most jurisdictionally complex (National Research Council, 2004). The legal and institutional framework for decision-making is comprised of a mosaic of treaties, executive directives, court rulings, and legislative enactments (National Research Council, 2004). Table 2 lists a few of the programs and agencies involved in the United States to illustrate the many sources that can affect decisions regarding basin management.

Table 2: Programs and agencies involved in CRB. Adapted from National Resource Council, 2004.

Columbia River Basin Programs, Administrations, Councils
· Northwest Power and Conservation Council (NPCC)
· Bonneville Power Administration (BPA)
· Columbia River Basin Fish and Wildlife Program
Federal Government
· US Army Corps of Engineers
· US Environmental Protection Agency
· US Forest Service
· US Fish and Wildlife Service
· US Geological Survey
· US Bureau of Indian Affairs
· US National Marine Fisheries Service
· US National Park Service
· US Bureau of Reclamation
· US Department of the Interior
Native American Tribes
· Columbia River Inter-Tribal Fish Commission
· Tribes from Table 1
State & Local Government
· Washington
· Oregon
· Idaho
· Montana
Stakeholders
· Power interests
· Irrigation interests
· Navigation interests
· Environmental interests
· Recreation interests

There is no integrated management plan for the CRB. The closest to a basin-wide integrated plan is a program under the Northwest Power and Conservation Council (NPCC), formed as a result of the 1980 Pacific Northwest Electric Power Planning and Conservation Act (also known as the Northwest Power Act) (Connell, 2011). The intention behind the creation of the NPCC was to consider the multiple contending interests from the various groups involved (see Table 2) and broker solutions that best meet overall needs (National Research Council, 2004). As such, one of the key responsibilities of the NPCC is to mitigate the impacts of hydropower generation on CRB fish and wildlife, including and especially endangered species.

The key program to achieve these responsibilities is the Columbia River Basin Fish and Wildlife Program (CRBFWP), which is implemented primarily by four states (Washington, Oregon, Idaho, Montana), the Columbia Basin tribes, and federal fish and wildlife agencies (Northwest Power and Conservation Council, 2014). The CRBFWP addresses the entire 670,000 square kilometers of the CRB as well as the Columbia River mainstem and subbasins, of which there are 62 (Figure 2). Out of the 62 subbasins, 59 have subbasin plans consisting of objectives, goals, and measures that are a significant part of the Program and are core elements of the Program. The subbasin plans provide a critical component of the project review process for Bonneville Power Administration (BPA) funding and also serve as inputs to projects and programs outside of the BPA, including projects and programs in the transboundary areas of Canada (Northwest Power and Conservation Council, 2014).

Figure 2. Map of subbasins under the NPCC Columbia River Fish and Wildlife Program. Retrieved from Northwest Power and Conservation Council, 2014.

The primary document produced that provides overall guidance and governance for the NPCC was evaluated as part of this thesis. In addition, subbasin plans were also evaluated, however due to the large number of subbasin plans as well as the differences between state agencies, laws, permitting processes, and so on, 27 subbasin plans for Washington State were the focal point for my research. Because 69% of the land in Washington State is in the CRB (roughly 184,827 km^2), the management approaches in Washington are important to understand due to the downstream impacts to the surrounding states (Muckleston, 2003). It should be noted that the subbasin plans near the state border do partially encompass areas from neighboring states since state boundaries do not often coincide with subbasin boundaries.

Murray-Darling Basin

The challenges outlined for the CRB are not confined to river basin management in the Pacific Northwest but apply to basin management in general. The Murray-Darling Basin (MDB) in Australia, described as the 'mighty' Murray (Hammer et al., 2011), shares many of the same challenges with the Columbia River Basin, the most significant including over-allocation of resources, highly variable streamflow, and difficulty coordinating management across multiple jurisdictions (Connell, 2011). Spanning four states and the Australian Capital Territory (ACT), the MDB drainage area covers slightly over one million square kilometers and is considered the most important river system in Australia due to the amount of agriculture in the basin (Hart, 2016b; Hammer et al., 2011) (Figure 3). In addition to existing ecological degradation from over-allocation, the Millennium Drought (1997-2009) brought to light the need for more oversight and coordination between the various uses of water from the system (Miller et al., 2016; Neave et al., 2015). Increasing severity and occurrence of droughts is anticipated due to climate change, which further highlighted the need for water reform in the basin (CSIRO, 2008; Colloff et al., 2015; Grafton et al., 2013; Neave et al., 2015).

Figure 3. Map of Murray-Darling Basin in Australia. Retrieved from the Murray-Darling Basin Authority, https://www.mdba.gov.au/discover-basin.

To address the existing and future challenges facing the MDB, the Murray-Darling Basin Authority (MDBA) was formed in 2008 and tasked with creating and implementing a centralized basin management plan focused on sustainable water reform (MDBA, 2012). One of the key aspects of the plan was the establishment of Sustainable Diversion Limits (SDLs), which sets limits on how much water can be taken from the basin. Each state has unique SDLs and the MDBA will monitor the amount of water each state takes in order to ensure compliance. The Murray-Darling Basin Plan (referred to as the Plan) was approved in 2012 and implementation of the plan was targeted for completion in 2019 (MDBA, 2012). However, due to feedback from the states and pending changes to some of the parameters, some components of the Plan are now expected to take until 2024 to reach completion (Hart, 2016a). Compliance to the SDLs is still required beginning in July 2019 (MDBA, 2012).

With the adoption of the Plan, responsibility for basin management is under the leadership of the Australian government. Similar to management of the CRB, successful management of the MDB is interconnected with many other agencies, including 46 aboriginal nations (Tables 3 & 4) (Hart, 2016b). Key governing bodies exist for resource management specific to each of the states. In the state of New South Wales (NSW), Catchment Management Authorities (CMAs) are key governing bodies that facilitate resource management strategy and investment for the specific catchment area of the MDB (New South Wales, 2005). Catchment level action plans (CAPs) for each of the seven defined areas of NSW that lie within the MDB were evaluated as part of this thesis to allow for comparison with the Washington State subbasin plans. Seventy-five percent of the land in NSW is in the MDB, compared to 69% of the land in Washington State in the CRB, drawing parallels between the importance of the river basins to both of these states (Geography, 2015).

Table 3: Programs and agencies involved in MDB. Adapted from MDBA, 2012.

Murray-Darling Basin Program Leads
· Murray-Darling Basin Authority (MDBA)
Federal Government and National Programs
· Office of Environment and Heritage
· Australian Bureau of Statistics
· Livestock Health and Pest Authority
· Research and Development Agencies
· National Parks
· Greening Australia
· Department of Agriculture and Water Resources
· Commonwealth Environmental Water Office
Traditional Owners
· Northern Basin Aboriginal Nations (NBAN)
· Murray Lower Darling Rivers Indigenous Nations (MLDRIN)
State, Territory, & Local Government
· New South Wales
· Victoria
· South Australia
· Queensland
· Australian Capital Territory
Stakeholders
· Power interests
· Irrigation interests
· Environmental interests
· Recreation interests

Table 4: Traditional Owner Member Nations for the Murray Lower Darling Rivers Indigenous Nations (MLDRIN) and the Northern Basin Aboriginal Nations (NBAN). Adapted from http://www.mldrin.org.au/membership/nations/ and http://nban.org.au/.

Murray Lower Darling Rivers Indigenous Nations (MLDRIN)	**Northern Basin Aboriginal Nations (NBAN)**
Barapa Barapa	Barkindji (Paakintji)
Barkindji	Barunggam
Dhudhuroa	Bidjara
Dja Dja Wurrung	Bigambul
Latji Latji	Budjiti
Maraura	Euahlayi
Mutti Mutti	Gamilaroi
Nari Nari	Githabul
Ngarrindjeri	Gunggari
Ngintait	Gwamu (Kooma)
Nyeri Nyeri	Jarowair
Tatti Tatti	Kambuwal
Taungurung	Kunja
Wadi Wadi	Kwiambul
Wamba Wamba	Maljangapa
Waywurru	Mandandanji
Wegi Wegi	Mardigan
Wergaia	Murrawarri
Wiradjuri	Ngemba
Wolgalu	Ngiyampaa
Wotjobaluk	Wailwan
Yaitmathang	Wakka Wakka
Yita Yita	
Yorta Yorta	

Conclusion

In this chapter, I established the critical importance of freshwater to humans and to ecosystems. I also highlighted how global water consumption is continuing to rise, leading to overallocation of freshwater resources. I established that rivers are one of the most important sources of freshwater and that river basin management needs to evolve from the widely-used command-and-control approach to one focused on resilience. I introduced the concept of rivers as SESs and how resilience theory has recently emerged as a framework for management of SESs. I then introduced my research question of whether resilience theory is being integrated into water management plans, and if so, how is it being applied. To address the question, I stated my research would focus on two prominent river basins: the Columbia River Basin in the PNW of the US and the Murray-Darling Basin in the southwest section of Australia. I briefly described both river basins and presented a few of the current challenges with river basin management they experience. In the next chapter I conduct a literature review on SESs, resilience, and their contexts within river basin management.

Chapter 2: Literature Review

Introduction

Support for resilience thinking has progressively increased in subsequent years and gained momentum in across multiple disciplines and fields (Folke, 2016). The establishment of the Resilience Alliance (RA), a multi-disciplinary international research organization, in 1999 helped to establish resilience as a viable theory and approach (RA, https://www.resalliance.org). From 2004 to 2014, Google searches for "resilience" increased by 124% (Baggio et al, 2015) and the number of scientific publications on resilience theory increased from five in 2001 to over 300 in 2016 (Sterk et al., 2017). While these figures demonstrate the growing popularity in resilience theory, they also represent growing confusion over the definition and meaning (Chapin et al., 2009; Folke, 2006; Martin-Breen & Anderies, 2011; Sterk et al., 2017; Walker et al., 2004).

In the following chapter I attempt to address the confusion surrounding the meaning of resilience by narrowing down the specific purpose for which I am using resilience. To start, because I use resilience theory to evaluate management approaches for a specific type of SES – a watershed – I provide an overview of social-ecological systems and how these relate to ecosystem services. I then follow with resilience theory, including background of how it originated as well as evolved to the multiple definitions and meanings that exist today. From there I will narrow down the definition of resilience to SESs. Finally, I will narrow down the definition of resilience even further by focusing on resilience as a tool for management of SESs. I finish with a discussion on how these concepts have been applied to river basins.

Social-Ecological Systems and Ecosystem Services

For millennia, humans have been altering the earth and its ecosystems to meet their physical, social, and spiritual needs (Berkes et al., 2008; Folke et al., 2011). As a result, nearly every ecosystem on the planet has been impacted by humans, either directly through intentional action or indirectly as a consequence of human actions (Folke, 2006; Rockström et al., 2014), particularly during the last 50 years, where the ecosystems have been changing more rapidly and extensively than ever before (Millennium Assessment, 2005). Because humans have altered nearly every ecosystem on the planet, the concept of a pristine ecosystem untouched by humans is no longer valid (Berkes et al., 2008).

Despite the overwhelming evidence that humans influence ecosystems and the services they provide, the overlap between social science and ecological science was limited until late in the 21st century, when the separation of social systems and ecosystems began to be recognized as “artificial and arbitrary” (Berkes et al., 2008; Folke, 2006, p. 262). The term social-ecological systems (SESs) was coined not only to describe the linkage between these two systems but also represent their integrated nature (Berkes & Folke, 1998; Folke et al., 2007), i.e. an SES is a cohesive system whose overall dynamics are characterized by the interactions and feedbacks between components in the ecological system and the social system (Folke et al., 2010). In this context, humans, communities, societies, cultures, and economies are all a part of the system and not merely acting on the system (Cumming et al., 2017; Folke, 2016).

Foundational to SESs is the assumption that they behave as complex adaptive systems (CAS) (Folke et al., 2006; Levin et al., 2013), characterized by the ability to self-organize and adapt, withstand uncertainties, and interact in unpredictable ways (Gros, 2008; Norberg & Cumming, 2008). SESs are also characterized by non-linear dynamics, strong reciprocal feedbacks between the social and ecological components, and multiple basins of attraction (Berkes et al., 2008; Levin et al., 2013). The cumulative impact of these characteristics implies change and continual evolution, which are inherent in SESs (Gunderson & Holling, 2002). Therefore, disturbance and change are viewed as an integral part of an SES rather than unusual or rare (Cumming et al., 2017).

Changes in an SES can occur slowly or more quickly as in the case of a sudden shock or disturbance (Biggs et al., 2015). When a critical threshold is crossed, the SES can undergo a regime shift and evolve into something new and different (Walker et al., 2006). This change in regime is caused by the transcendence of a critical threshold and reversing back to the original or desired configuration is difficult if not impossible (Biggs et al., 2015). Understanding critical interactions in an SES and how these interactions impact thresholds and the system's ability to adapt or transform is highly complex and difficult to articulate. In order to better understand, describe, and predict possible outcomes due to change in an SES, researchers have increasingly turned to resilience as a lens for evaluation (Biggs et al., 2015; Rockström et al., 2014). Resilience theory, reviewed below, facilitates the understanding of complexity within an SES by providing a framework for evaluation (Cosens, 2010).

Another aspect of social-ecological interactions are ecosystem services, defined as the benefits humans obtain from ecosystems. Ecosystem services connect and integrate SESs (Biggs et al., 2015; MA, 2005). In the past 60 years however, the use of ecosystem services has come at the cost of social and ecological degradation because humans typically manage ecosystems to maximize the ecosystem services most valued by the society (Spangenberg et al., 2014), often at the expense of ecosystem services not being as highly valued (Berkes & Folke, 1998; Biggs et al., 2015). Ecosystems need to be healthy to adequately and sustainably provide ecosystem services critical for society's physical, social, and spiritual needs, (Millennium Assessment, 2005).

The challenge of ensuring ecosystems can continue to sustainably provide ecosystem services, both now and in the future, has resulted in a variety of new approaches, one of which is the resilience approach (Folke et al., 2010; Walker & Salt, 2006). Foundational to the resilience approach is that social systems and ecosystems cannot be decoupled and humans are embedded in the biosphere (Berkes et al., 2003). Resilience theory therefore has a strong focus on SESs (Biggs et al., 2015).

Resilience theory

Resilience is a relatively new way of thinking about an ecosystem and has been described as the "science of surprise" (Folke, 2016, p. 5). Resilience first emerged as an ecological perspective in the 1960s and early 1970s as a result of research on interacting populations, such as predator and prey, and their response to ecological stability theory (Holling, 1961; Lewontin, 1969; May, 1972). In 1973, C.S. Holling formally introduced the widely accepted definition of ecological resilience, defining it as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (p. 14). While the ability to absorb shocks is a critical component of resilience, the definition of resilience has expanded in recent years to include the ability of a system to reorganize, renew, and even transform to a new state (Berkes et al., 2003; Folke, 2006; Gunderson & Holling, 2002).

Although the concept of resilience was originally defined in the context of ecosystems, resilience has been applied to social systems as well (Adger, 2000; Holling, 2001). Social resilience as defined by Adger is the ability of the social structure of human communities to withstand external shocks (2000). Social resilience can also be viewed as the ability to achieve well-being even if significant modifications of behavior or changes to the structure of social frameworks need to occur (Hall & Lamont, 2013). In other words, social resilience refers to an outcome in which a group of people retain their well-being when faced with challenges to it by adapting or transforming their behavior or the structure of their social framework (Holling, 2001).

Extending the concept of resilience from ecological systems and social systems to SESs was a logical progression in the application of resilience theory. Using a purely social resilience lens, humans have demonstrated abundant skill at dealing with change and adapting, however the adaptation is often at the expense of the related ecosystems (Smit & Wandel, 2006). Correspondingly, focusing only on ecological resilience often leads to tunnel vision in decision making and consequently wrong conclusions (Folke, 2006). Biggs et al. define resilience of an SES as the capacity of an SES to retain its ability to maintain ecosystem services and human well-being when faced with disturbance, by buffering shocks as well as adapting or transforming as a consequence of change (2015). Cosens et al. further elaborate that resilience "describes the ability of a complex system to continue to provide the full range of ecosystem services in the face of change" (2014, p. 7). In social-ecological resilience, the focus is on concepts of reorganization and renewal as opposed to recovery (Bellwood et al., 2004).

The more resilient an SES is, the more it is able to withstand larger shocks and disturbances without going through a regime shift (Walker et al., 2006). In other words, the resilience of an SES is the capacity to handle variations and changes but still continue to develop (Sterk et al., 2017). Loss of resilience in a SES indicates loss of adaptability, leaving the SES vulnerable (Folke, 2006). Human action can erode resilience and shift an ecosystem into a less desirable state that could lead to impacts on the development and livelihood of society (Gunderson, 2000; Folke et al., 2005). When humans manage ecosystem services for only a few resources, such as managing a watershed only for hydropower or irrigation, resilience can be eroded making the social-ecological system vulnerable.

Resilience as a management approach

Flexibility and emergence are core attributes of SES management and governance (Folke, 2016). Resilience in an SES is characterized by an emphasis on change, unpredictability, and persistence (Holling, 1973), the latter of which is addressed most often by more progressive adaptive management styles (Sterk et al., 2017). To that end, resilience should be considered a critical component of adaptive management, not a substitute for it (Rockström et al., 2014). Rather than trying to control change, as is the management approach when ecosystems are viewed as stable systems with equilibrium points, the resilience perspective promotes management approaches that focus on building or enhancing the capacity of an ecosystem to adapt to change (Berkes et al., 2003; Smit & Wandel, 2006). Resilience is distinctly different from stability, the core lens of traditional command-and-control management (Sterk et al, 2017), which is characterized by an emphasis on constancy, predictability, and efficiency (Holling, 1973). When viewing disturbance through a traditional lens, SESs are thought to self-repair and return to a state of stability and equilibrium via predictable mechanisms (Folke, 2006). However, when viewing disturbance through a resilience lens, SESs learn, self-organize, and continue to develop in the way they respond to disturbance (Norberg & Cumming, 2008).

By viewing disturbance in an SES through the lens of resilience, there is great potential for new management approaches using innovation and development (Folke, 2006). Because the resilience perspective views the future as unpredictable and surprise as inevitable, enhancing ecosystems capacity to adapt to change increases the chances of sustaining desirable pathways (Adger et al., 2005). Desirable, as defined by Daily, refers to the ability of an ecosystem to provide ecosystem services that enable the development of human society (1997). The focus is on change instead of stability because surprise and uncertainty are inevitable (Berkes et al., 2003). This approach is a marked departure from the historically dominant command-and-control management approach with goals of controlling variability (Folke, 2006). A resilience approach to SES management integrates concepts of self-organization, adaptation, and learning, thus enhancing variability (Folke, 2006).

The proponents for the SES resilience approach recommend adaptive management to deal with uncertainties. However, in practice a gap exists between the theory of adaptive management and the actual implementation (Cosens & Williams, 2012; Huitema et al., 2009). The largest gap lies with resolving conflicts and agreeing to trade-offs, which is a function of governance, not management (Cosens et al., 2014). Adaptive governance can address these gaps by providing direction and oversight for conflict resolution and trade-offs, allowing management to operationalize the decisions (Cosens, 2011). Adaptability in the context of SES refers to the "capacity of people to build resilience through collective action" whereas transformability is the "capacity of people to create a fundamentally new SES when ecological, political, social, or economic conditions make the existing system untenable" (Folke, 2006, p.262). The collaboration of a diverse set of stakeholders is critical to adaptive governance as is the ability for the stakeholders to operate at different social and ecological scales (Olsson et al., 2004).

Management of SESs in a way that supports societal needs and development now and in the future is a major challenge (Lambin, 2005). Some resource managers are coming to the realization that the social system and the ecological system need to be managed as one integrated entity (Sterk et al., 2017). However, the linkages in SESs require an extensive transdisciplinary framework that employs the concepts and approaches of many of the natural and social sciences (Chapin, 2009; Walker et al., 2006).

Viewing an ecosystem through the lens of resilience shifts the management lens from the traditional command-and-control approach, which addresses change through an emphasis on the return to stability (Folke, 2006). By contrast, the resilience approach offers a fresher management lens which highlights coping with and adapting to, rather than controlling, change, perhaps even using the change to transform the system to a new state and function (Carpenter & Gunderson, 2001; Rockström et al., 2014; Walker et al. 2006). In this context, surprise and uncertainty are built into the management thinking and therefore are better addressed and dealt with (Walker at al., 2006). Instead, in the command-and-control philosophy, the goal is to remove the disturbance and instead enhance the growth of usually one ecosystem service (Folke, 2006). The consequence of this approach is that the economic health of a region can become reliant on this one ecosystem service, making it vulnerable when changes or disturbances occur that alter the ability to continue to deliver the ecosystem service (Folke, 2006). Additionally, it is typically less advantaged people and regions that suffer when this occurs (Gunderson & Holling, 2002).

Resilience as a framework for evaluating river basin management

Managing river basins for resilience is still a relatively unexplored area (Walker et al., 2006). There are very few precedents for assessment of river ecosystem resilience (Parsons et al., 2016). While several resilience frameworks proposed in the literature (Cosens, 2010; Folke et al., 2010; Marshall, 2010; Nelson et al., 2007; Ostrom, 2009; Tschakert & Dietrich, 2010), none of these frameworks have been validated by empirical results (Biggs et al., 2015) or have been used for evaluation of river basin management. A resilience framework published by Biggs et al. in 2012 has been identified as being suitable for evaluation of river policy and management (Gilvear et al., 2016; Parsons & Thoms, 2016). The framework resulted from a rigorous review of resilience-based literature and an equally rigorous vetting process by the authors and consists of seven principles (Biggs et al., 2012). This framework serves as the basis of my thesis analysis.

Seven Principles of Resilience

The seven principles of resilience identified by Biggs et al. are grouped into two areas, those that relate to enhancing resilience through management practices and those that relate to enhancing resilience through governance (2015). Three principles are related to enhancing resilience through management: 1) maintain diversity and redundancy, 2) manage connectivity, and 3) manage slow variables and feedbacks. The remaining four principles are related to enhancing resilience through governance by creating key attributes of governance that: 4) foster complex systems thinking, 5) encourage learning and experimentation, 6) broaden participation, and 7) promote polycentricity.

Management principles

Maintain diversity and redundancy

It is widely accepted that both diversity and redundancy are vital to the resilience of an SES (Chapin et al., 2009; Elmqvist et al., 2003; Ostrom, 2005). When an SES encounters change or disturbance, diversity increases the number of ways in which the different SES elements can respond (Biggs et al., 2012). Redundancy serves as a safety net against disturbance or unexpected change by providing similar elements that can either partially or completely substitute for each other (Rosenfeld, 2002).

Manage connectivity

Connectivity is defined by the extent to which parts of the SES interact and the ease with which species, resources, or social actors can disperse or migrate across landscapes such as habitats, patches, or social groupings (Bodin & Prell, 2011). The structure of the SES is dependent on the linkages between different elements, therefore the degree of connectivity in an SES impacts overall resilience (Nystrom & Folke, 2001). These linkages can also enhance resilience by connecting elements vital to ecosystem recovery after a disturbance occurs (Biggs et al., 2015).

Manage slow variables and feedbacks

Variables impacting an SES operate on a range of timescales (Gunderson & Holling, 2002). “Slow” and “fast” variables do not have fixed timescales and are instead slow or fast relative to the other variables in a particular SES (Biggs et al., 2012). Slow variables change more gradually than the other variables in the SES and typically determine the overall structure and processes of the SES whereas feedbacks from fast variables impact the dynamics of a system (Biggs et al., 2015). In an ecological system, examples of slow variables include erosion control or long-term changes in rainfall (MA, 2005). In a social system, examples include changes in legal systems or societal values (Abel et al., 2006). Changes in the slow variables and feedbacks of an SES can lead to regime shifts if certain thresholds are crossed, therefore clearly defining and managing for critical thresholds is a way to increase resilience (Scheffer et al., 2009). Monitoring changes in the slow variables and feedbacks of an SES can help identify when system resilience is degrading and in danger of experiencing a regime shift (Biggs et al., 2012).

Governance principles

Foster CAS thinking

CAS thinking involves accepting that uncertainty is pervasive in an SES and viewing SESs as continually evolving systems as opposed to steady state systems (Pahl-Wostl, 2007). Fostering CAS thinking in resource management emphasizes holistic management approaches versus reductionist management approaches where individual system components are managed separately (Holling & Meffe, 1996).

Encourage learning

Learning has been accepted as foundational to addressing uncertainty in an SES and fundamental for building resilience (Gunderson & Holling, 2002; Walters, 1990). Because knowledge is never complete and uncertainty and change are inevitable in an SES, learning must be continually adapted based on the best available information (Chapin et al., 2009; Walker & Salt, 2006).

Broaden participation

Participation is defined as having relevant stakeholders actively engaged in both the management and governance processes (Biggs, et al., 2012). Better management plans result from a broader participation of stakeholders due to the representation of multiple perspectives (Colfer, 2005). Not limited to planning only, participation can occur in all stages of the management process, from developing goals to monitoring outcomes. In governance, individuals directly affected by potential changes in policy should be able to participate in order to share knowledge and help shape solutions. The more inclusive a process is, the more community resilience is bolstered (Elster, 2006).

Promote polycentricity

A polycentric governance system consists of multiple levels of governing bodies operating at different scales (Ostrom, 2005). Each level has autonomy within a defined geographic area and is usually matched to the magnitude of the problem being solved (Folke et al., 2007). A polycentric approach facilitates the implementation of other resilience principles, notably learning and experimentation, participation, and redundancy, therefore, polycentricity has an indirect impact on resilience (Biggs et al., 2015). It should also be noted that operationalizing polycentricity in SESs is not well understood (Biggs et al., 2015).

The seven principles are briefly summarized in Table 5 below.

Table 5: Summary of seven principles of resilience. Adapted from Biggs et al., 2012.

Management attributes	**Description**
Maintain diversity and redundancy	Diversity increases the number of ways in which the different SES elements can respond (Biggs et al., 2012). In addition, redundancy provides similar elements that can substitute for each other either partially or completely (Rosenfeld, 2002).
Manage connectivity	Linkages in an SES can enhance resilience by connecting elements vital to ecosystem recovery after a disturbance occurs (Biggs et al., 2015).
Manage slow variables and feedbacks	Monitoring changes in the slow variables and feedbacks of an SES can help identify when system resilience is degrading and in danger of experiencing a regime shift (Biggs et al., 2012).
Governance attributes	**Description**
Foster CAS thinking	Encourages holistic management approaches and accepting that uncertainty is an inherent property of the SES (Holling & Meffe, 1996).
Encourage learning and experimentation	Learning is foundational to addressing uncertainty in an SES and fundamental for building resilience (Gunderson & Holling, 2002; Walters & Holling, 1990).
Broaden participation	Participation means that relevant stakeholders actively engaged in both the management and governance processes. The more inclusive a process is, the more community resilience is bolstered (Elster, 2006).
Promote polycentricity	Polycentricity consists of multiple levels of governing bodies operating at different scales (Ostrom, 2005). Each level has autonomy within a defined geographic area and is usually matched to the magnitude of the problem being solved (Folke et al., 2007).

Comparative Analyses of River Systems

Until recently there has not been much cross-fertilization among the various disciplines involved in river management (Barrett & Constas, 2014), making comparative analysis challenging (Sterks et al., 2017). Additionally, given the diversity of geographic, socio-economic, and political conditions of river basins, comparing complex river basins is difficult in and of itself. That is not to imply comparisons should not be undertaken, only that the boundaries and parameters of the comparative analysis should be carefully chosen so that inherent differences are minimized and also recognized. One issue is the lack of a common framework to compare river basins, making any such analysis that much more difficult. By applying social-ecological systems theory using a resilience framework, I aim to provide a solid baseline for sound comparison.

At a global level, there is a lack of literature focused on systematic analysis and comparison of river basin plan content (Kazbekov et al., 2016). Although comparative studies of basin plans exist that focus on public discourse and perspectives, water problems, and governance structure (e.g. Garrick & Bark, 2011; Eberhard et al., 2017), comparative studies that focus on basin plan content, logic, and function are not common (Wescoat, 2005). Furthermore, comparative studies attempting to identify transferable best practices between other regions of the world and the western United States are rare (Wescoat, 2005). No comparative analysis of the existence of resilience theory in management approaches exists between the Columbia River Basin and the Murray-Darling Basin.

Conclusion

This chapter has examined the literature on social-ecological systems, ecosystem services, and resilience theory to provide insight on the overlap and interdependence between them. I started with an overview of social-ecological systems (SESs), describing how the term social-ecological system was first coined, the definition of SESs, and the main characteristics of SESs. I followed by describing ecosystem services and their role in connecting and integrating the social system with the ecosystem in an SES. I also described how resilience theory has emerged as a management approach to ensure the continued sustainability of ecosystem services.

I then provided a comprehensive overview of resilience theory, including how it originated and evolved to an approach for managing SESs. I followed by describing resilience-based management, including its relationship to adaptive management and the key differences between resilience-based management and command-and-control-based management. I also outlined the benefits of resilience-based management. I described the challenges of applying resilience as a framework for evaluating river basin management and described a novel study published by Biggs et al. in 2012 that identified seven principles of resilience. I used these seven principles as the foundation of my methodology, which is described in the next chapter. I finished the literature review with a review of studies focused on comparative analyses of rivers, of which there are few, to demonstrate the potential contribution of my research.

Chapter 3: Methods

Overview

The overall goal of this research is to identify patterns of resilience and to understand how resilience theory was being applied in river basin management. To do this, I conducted document analysis utilizing qualitative content analysis (QCA), assisted by MAXQDA software for analysis. QCA was used to detect the presence and patterns of the resilience principles outlined by Biggs et al. (see Table 5) in planning documents for two river basins. For the Columbia River Basin, I analyzed the 2014 Columbia River

Basin Fish and Wildlife Program document as well as 27 associated subbasin management plans within Washington State. For the Murray-Darling Basin, I analyzed the 2012 Murray-Darling Basin Plan as well as catchment action plans for the basin's seven subregions in the state of New South Wales. In each of these documents, I coded whether or not (and which) resilience principles were present.

Additionally, when resilience principles were present, I examined whether and how consideration of ecosystem services was integrated. The ecosystem services I considered were those identified in the Fresh Water chapter in "Ecosystems and Human Well-being: Current State and Trends," a document created over the span of 4 years by the Millennium Assessment (MA), an international group of over 1,360 experts (MA, 2005). The ecosystem services for freshwater as defined by the MA fall under four general categories: provisioning, regulating, supporting, and cultural.

Provisioning ecosystem services consist of material or energy outputs from an ecosystem. For freshwater, the MA outlined six provisioning ecosystem services: 1) fishery/food, which consists of fish and other aquatic organisms consumed for food or medicinal purposes; 2) navigation, meaning water used for transportation for barges and other water vessels; 3) hydropower, water for generating electricity; 4) industrial, meaning water used for manufacturing; 5) irrigation, water for agricultural purposes; and 6) consumption/municipal, which consists of water used for drinking and other household purposes (2005).

Regulating ecosystem services regulate quality of the ecosystem, and for freshwater the MA outlined three regulating ecosystem services: 1) erosion control, which buffers the erosion of soil from land, river banks, and river beds; 2) flood control, which buffers excess flooding through of flood control infrastructure such as flood plains; and 3) water quality, which consists of natural filtration as well as water treatment (2005).

Supporting ecosystem services provide services that support habitat for critical species interactions as well as nutrient cycling. For freshwater, the MA defined three: 1) ecosystem habitat/predator-prey, which consists of those ecosystem services that provide vital habitat; 2) primary production, which includes carbon storage and release; and 3) nutrient cycling such as nitrogen and phosphorus (2005).

Finally, cultural ecosystem services provide spiritual enrichment as well as recreation. The three ecosystem services defined for freshwater are 1) existence and well-being; 2) tourism, which includes sport fishing; and 3) recreation, which includes river rafting, and wind surfing (2005). The results are summarized in Table 6 below.

Table 6: Summary of the ecosystem service categories and freshwater services as defined by the Millennium Assessment, 2005.

Ecosystmem Service Category	Description	Freshwater Ecosystem Services
Provisioning	Material or energy outputs from an ecosystem	Fsihery/food Navigation Hydropower Industrial Irrigation Consumption/municipal
Regulating	Regulates the quality of the ecosystem	Erosion control Flood control Water quality
Supporting	Provide services that support habitat for critical species interactions as well as nutrient cycling.	Ecosystem habitat/predator-prey Primary production Nutrient cycling
Cultural	Provides spiritual enrichment as well as recreation	Existence and well-being Tourism Recreation

My analysis is qualitative. I did not attempt to quantify the results because in many instances, paragraphs were repeated in the management plan which skewed any quantitative results. Also, because the nature of the purpose of the documents, large parts of the management plans are focused on targets and implementation details, which serve a critical purpose in the plans but when taken proportionally skew results as well. Thus, quantitative analysis would not have made sense.

In the following sections I will describe the three steps in my methods: 1) Data selection, 2) Building the coding frame, and 3) Trialing the coding frame.

Data Collection

The document evaluated for the CRB at the basin level was the Columbia River Basin Fish and Wildlife Program 2014 (CRBFWP). Because the Columbia River Basin spans seven states and parts of British Columbia, at the subbasin level I evaluated Subbasin Plans for Washington State (WA) to reduce complexity. All documents were publicly available online and links to the documents are provided in Appendix A. These documents are listed in Table 7.

Table 7: Documents evaluated for the CRB

Document name
Columbia River Basin Fish and Wildlife Program 2014
Asotin Subbasin Plan
Crab Creek Subbasin Plan
Elochoman & Skamakowa Subbasin Plan
Entiat Subbasin Plan
Estuary Tributaries Subbasin Plan
Grays Subbasin Plan
Klickitat Subbasin Plan
Lake Chelan Subbasin Plan
Little White Subbasin Plan
Lower Columbia Mainstem and Estuary Subbasin Plan
Lower Cowlitz Subbasin Plan
Methow Subbasin Plan
Palouse Subbasin Plan
Pend Oreille Subbasin Plan
Salmon Subbasin Plan
San Poil Subbasin Plan
Spokane Subbasin Plan
The Okanogan Subbasin Plan
Tucannon Subbasin Plan
Upper Columbia Subbasin Plan
Upper Cowlitz Subbasin Plan
Upper Mid-Columbia Subbasin Plan
Walla Walla Subbasin Plan
Wenatchee Subbasin Plan
White Salmon Subbasin Plan
Wind Subbasin Plan
Yakima Subbasin Plan

The document evaluated for the MDB at the basin level was the Murray-Darling Basin Plan (MDBP). Because the MDB spans four states and the Australian Capital Territory (ACT), I evaluated Catchment Action Plans (CAPs) from the state of New South Wales (NSW). All documents were publicly available online and links to the documents are provided in Appendix B. These documents are listed in Table 8.

Table 8: Documents evaluated for the MDB

Document name
Murray-Darling Basin Plan
Border Rivers-Gwydir Catchment Action Plan
Central West Catchment Action Plan
Lachlan Catchment Action Plan
Murray Catchment Action Plan
Murrumbidgee Catchment Action Plan
Namoi Catchment Action Plan
Western Catchment Action Plan

Coding Frames

The first step in creating my coding frames was to create a set of concept-driven categories and sub-categories based on the seven principles described by Biggs et al. (2012). The primary coding frame consisted of the seven principles of resilience outlined by Biggs et al. (see Table 5). Subcategories of management and governance were created as well.

The first dimension of the coding frame, *Principles of resilience*, contains two subcategories: *present* and *not present*. A *present* code was applied when a sentence was related to the principles of resilience. Sentences not related to resilience or that were unclear given the context (or lack of context) were not coded and were excluded from the analysis. For example, sentences referencing "adaptive management" would not necessarily be coded as *present* unless the context of the sentence specifically applied to resilience. While adaptive management can be indicative of resilience, it is also widely practiced in non-resilient management styles such as command-and-control. It should be reiterated that sentences coded as *not present* were no longer considered at this point as they were not relevant to my research question.

The *present* code is further subdivided into *governance* and *management*, depending on whether the type of resilience being supported is related to the management of the river basin or the governance of the river basin. *Management* and *governance* are further subdivided into subcategories in order to capture more specific data if present. *Management* is subdivided into *diversity and redundancy*, *connectivity*, and *slow variables and feedback*. *Governance* is subdivided into *CAS thinking*, *learning and experimentation*, *participation*, and *polycentricity*.

As part of the trial phase, I also added two subcategories to the coding frame to determine the frequency with which they were arising and whether these additional codes would add the pertinent information to my analysis. The first subcategory is *climate change,* which was added to *slow variables and feedback*. Climate change was mentioned in several places in the document used for the coding trial, and due to the global concern regarding climate change, I thought it would be of interest to know where and in which documents this concern was being addressed.

The second subcategory I added was *monitoring,* which was added to *learning and experimentation*. Monitoring is a key aspect of *learning and experimentation* in resilience thinking, but it is also a key aspect on non-resilience thinking such as command-and-control. Adding monitoring as a second dimension served two purposes. First, it helped during the analysis phase to understand how much of *learning and experimentation* was due to monitoring versus experimentation or other types of learning that contribute to resilience thinking. Monitoring, while valuable, is a form of passive adaptive management, while experimentation and other types of learning are forms of active adaptive management (Biggs et al., 2015), so having a mechanism to separate monitoring better represents the entire subcategory of *learning and experimentation*. Second, monitoring was mentioned throughout the document used in the coding trial and was in fact the most prevalent of all of the codes. As such, separating *monitoring* from other approaches provided more information to analyze *learning and experimentation*. The first dimension of the coding frame is shown in Figure 4 below.

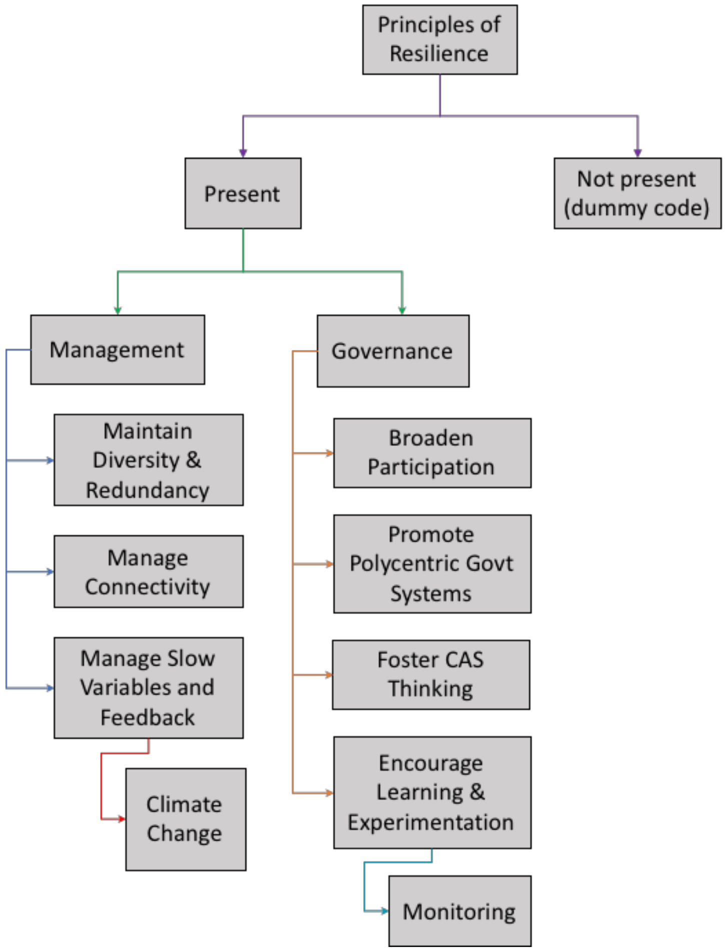

Figure 4: First dimension of coding frame, *principles of resilience*, showing hierarchy of subcategories. Only one code (the common denominator) from this figure was assigned to each sentence.

Subcategories were only coded if the sentence is exclusively related to that category or subcategory, otherwise the sentence gets coded as the parent code, i.e. the common denominator. For example, in the Lower Columbia mainstem subbasin plan, the sentence "there is a continual need to connect ourselves as individual, corporate, and community citizens to our river," (p. 199, 2010) shows that resilience is present and specifically tied to connectivity; as such, it would be coded as *connectivity*. In contrast, the sentence "integrated, resilient, and diverse biological communities are restored and maintained in the lower Columbia River and estuary" is not tied specifically to a single management practice since "integrated" represents *connectivity* and "diverse" represents *diversity and redundancy*. Therefore, the sentence is coded as *management.*

In addition to the first dimension, *Principles of resilience*, a second dimension, *Related to ecosystem services*, was added to the coding frame in order to capture whether the presence or partial presence of resilience is tied to an ecosystem service or not (see Figure 5).

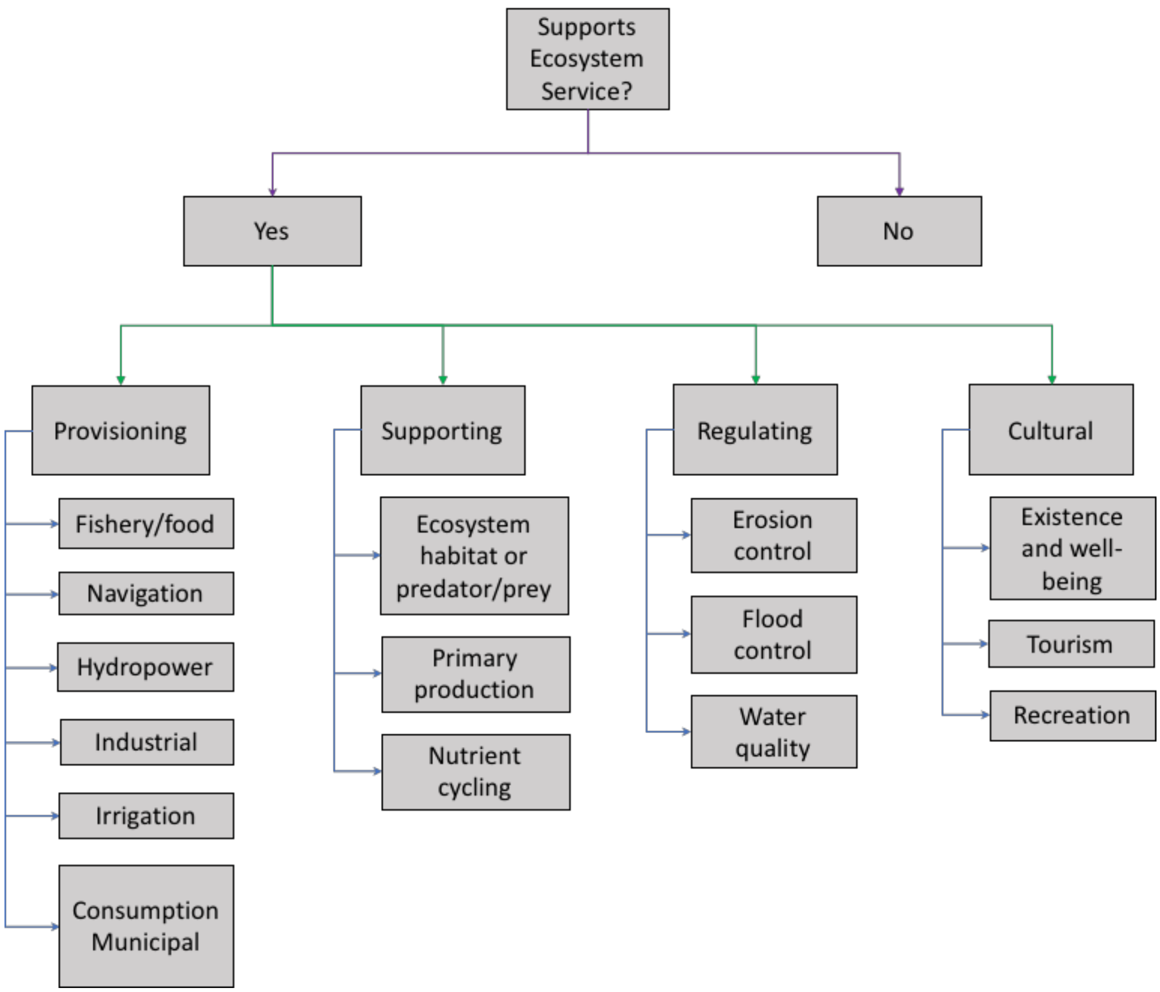

Figure 5: Second dimension of coding frame, *supports ecosystem services*, showing hierarchy of subcategories. Only one code from this figure gets assigned (the common denominator).

The subcategories of *Related to ecosystem services* are *yes* and *no*, and both of these are further subdivided into *provisioning, supporting, regulating, and cultural*. Each of these are further subdivided into subcategories of specific ecosystem services based on the Millennium Assessment for freshwater ecosystem services (2005), described above and summarize in Table 6. The freshwater ecosystems services are then further divided: Provisioning is subdivided into *fishery/food*, *navigation*, *hydropower*, *industrial*, *irrigation*, and *consumption/municipal*. Supporting is subdivided into *ecosystem habitat*, *primary production*, and *nutrient cycling*. Regulating is subdivided into *erosion control*, *flood control*, and *water quality*. Cultural is subdivided into *existence and well-being*, *tourism*, and *recreation*.

Trialing the coding frame

After building the initial coding frames, I trialed the frame on one of the documents being analyzed for the CRB and one being analyzed for the MDB. I chose the documents randomly. The trialing phase served two purposes: first, to ensure I was coding consistently and second, to make sure the categories and subcategories in the coding frame could be logically applied to the material I was analyzing. The trialing phase consisted of two steps: 1) Double Code and 2) Evaluate and Modify.

Double code

In order to ensure I was applying the categories and subcategories consistently, I performed a double-coding process on the documents I was trialing. Double coding consisted of coding the trial documents twice, ten days apart, to ensure consistency.

The results of the double coding were consistent, with only seven out of 178 codes not matching. The inconsistencies were due to visual errors that resulted in mistakenly assigning the wrong codes. I corrected this by assigning different colors to the codes so I could more easily detect a wrong code assigned.

Evaluate and Modify: Results of Trial

For the first dimension of the coding frame, of the two subcategories that I added to the coding frame, *climate change* and *monitoring*, only *monitoring* added any value to the analysis. Climate change was only mentioned once, in the introduction, and not tied to resilience. As such, it was not coded, adding no value to the analysis. Monitoring, however, was coded 9 times between the two documents, so did contribute to the analysis. Therefore, *climate change* was deleted from the coding frame and *monitoring* remained in the coding frame. No changes were required for the second dimension of the coding frame, which focuses on ecosystem services. The final coding frames are depicted in Figure 5 above and Figure 6 below.

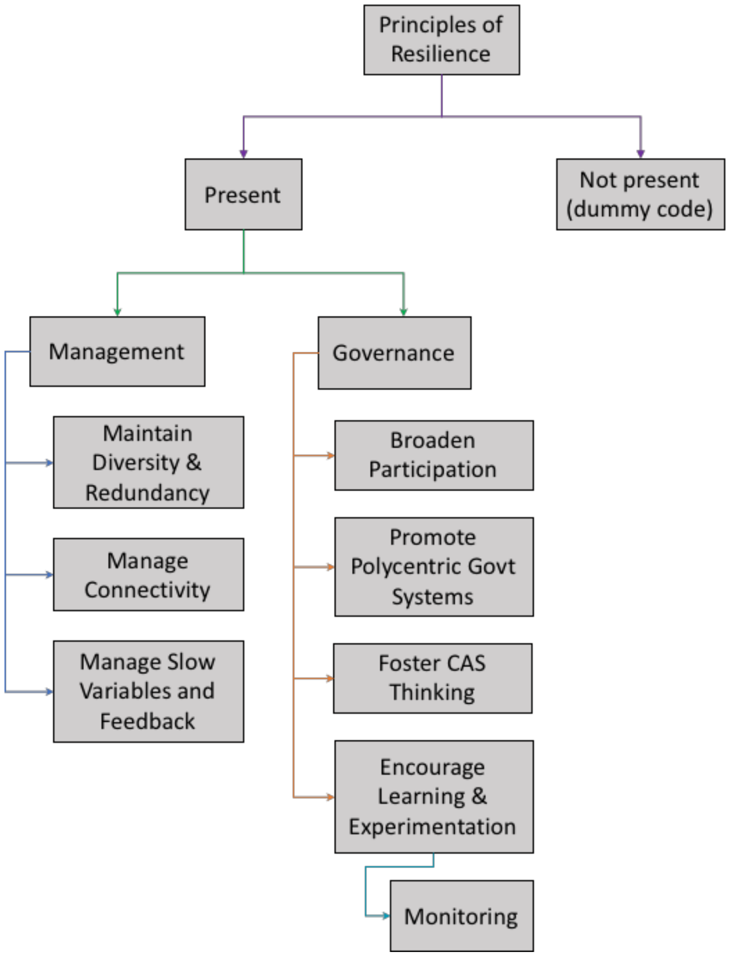

Figure 6: First dimension of coding frame finalized

Code remaining documents

With the updated coding frame, I coded 36 documents in total. Two documents were at the basin level and 34 were at the subbasin or catchment level.

Conclusion

In this chapter, I provided a detailed explanation of the research methodology used to answer my research questions: *Are principles of resilience theory being utilized in* *the management of river basins and if so, which principles are most prevalent* and *where resilience theory is being utilized, how is it being applied?* I started with the type of research methodology used, which was Qualitative Content Analysis. I followed with an overview of the frameworks used to design the coding frames for my analysis, specifically the seven principles proposed by Biggs et al. (2012) and freshwater ecosystem services as defined by the Millennium Assessment (2005). Next, I described my approach for data collection and the listed the documents that were analyzed in Tables 7 and 8. Then I detailed specifically how my coding frames were built and then applied to the data and followed with my methods for trialing, evaluating, and modifying the frames in order to finalize them for the coding of the documents (Figures 5 and 6). In the following section I present the results from the coding.

Chapter 4: Results

This results section is divided into two main sections, results from the MDBP and CRBFWP comparative analysis, followed by results of the CAPs and Subbasin Plans comparative analysis. Within each of these sections, a summary of how each document or set of documents integrated resilience is given along with the comparative analysis to each other. Following the general summaries are the results of each of the seven principles along with any observations concerning the relationship of the specific principle to ecosystem services. A summary table for each of the comparative analyses is also provided.

Results: MDBP and CRBFWP

While neither the MDBP or the CRBFWP were resilience-based, elements of some of the resilience principles were present in both. Table 9 presents a summary of the comparative analysis. Overall, the MDBP lists resilient ecosystems as an objective, but it does so in a generic sense that is not actionable. Furthermore, the concept of the MDB as an SES is nowhere in the document. Management approaches outlined in the MDBP focus heavily on water quality and quantity and overall are not reflective of resilience thinking, with the exception of mentioning the desire for productive and resilient industries and confident communities.

In contrast, the CRBFWP explicitly mentions enhancing ecosystem resilience. Furthermore, the CRB plan acknowledges that humans are integral parts of the ecosystem, indicating that the CRB should be viewed as an SES and stating that an understanding of what is important to people is key to successful ecosystem management. As far as management principles, the CRBFWP discusses the need to understand and manage to the natural limitations of a system and that change is inevitable and healthy, both of which are indicative of resilience thinking. The need for river and dam operations to be adaptive and flexible enough to mitigate impacts from climate change is highlighted, as well as the need to identify and evaluate different management options under various climate-change scenarios.

Table 9: Comparative analyses of resilience principles in the MDBP and the CRBFWP. '0' represents the absence of Resilience Thinking or the Specific Principle, '+' represents the presence of Resilience Thinking or the Specific Principle, '-' represents a conflict with Resilience Thinking or the Specific Principle. A double figure such as ‘0/+’ indicates that some aspects of Resilience Thinking or the Specific Principle were mentioned but not substantively discussed. Refer to Figures 5 and 6 in the methods section for visual representation of the parent/child relationships in the coding hierarchy.

Principles of Resilience	Resilience thinking (RT) or specific principle (SP)	MBDP	CRBFWP	Comments
Present	RT	0	0/+	General concept of resilience not well represented in the MDBP. The CRBFWP had some elements of resilience, in particular in the guiding scientific principles
Management of SESs	RT, child to Present	0/+	0/+	Some aspects of managing for resilience represented in both the MDBP and the CRBFWP but not consistently
Diversity and Redundancy	SP, child to management	0	+	Diversity present in MDBP but only in the context of ecological diversity. Diversity in the CRBFWP includes both ecosystem diversity and social diversity
Connectivity	SP, child to management	0	+	Connectivity present in MDBP but only in the context of ecological connectivity. Connectivity in the CRBFWP includes both ecosystem connectivity and social connectivity
Slow Variables and Feedbacks	SP, child to management	-	0/+	SDLs were calculated using historic data in the MDBP instead of taking future projections into account. The CRBFWP states possible effects of climate change need to be considered.
Governance of SESs	RT, child to Present	0	0/+	Governance of SES not present in MDBP but the CRBFWP had some elements and emphasized the CRB needs to be managed as an SES
Learning and Experimentation	SP, child to Governance	+/0	+	The MDBP emphasized learning but not experimentation. The CRBFWP emphasized learning and emphasized experimentation
Monitoring	SP, child to Learning and Exp.	0	+	The MDBP includes some aspects of monitoring but in the context of compliance to SDLs. The CRBFWP represented monitoring
Participation	SP, child to Governance	+	+	Both the MDBP and the CRBFWP emphasized participation and inclusion
CAS thinking	SP, child to Governance	0	0/+	CAS thinking not present in MDBP but was marginally represented the CRBFWP
Polycentricity	SP, child to Governance	0	0	CAS thinking net present in MDBP but was marginally represented the CRBFWP

Principles of resilience

Diversity and Redundancy

Diversity and redundancy were marginally present in both the MDBP and the CRB. In both documents, ecological diversity was the primary focus, however the importance of cultural diversity and community diversity was identified in the CRBFWP as an important element for societies being able to deal effectively with change. Because ecological diversity was the focus in the MDBP, this principle was tied to ecosystem services, either generally to diversity of the entire ecosystem or specifically to diversity of ecosystem habitat (Figure 7). Ecosystem services were not as strongly related to diversity in the CRBFWP, with roughly half of the instances of diversity not related to an ecosystem service and the other half generally related to diversity of the entire system or to floodplains (Figure 8). It is important to note that Figures 7 and 8 do not represent quantitative results, they only describe the relative occurrence of codes from the ecosystem coding frame (Figure 5 from the Methods chapter). If a code from the ecosystem service coding frame is not present on the chart, then it was not coded for any of the seven principles.

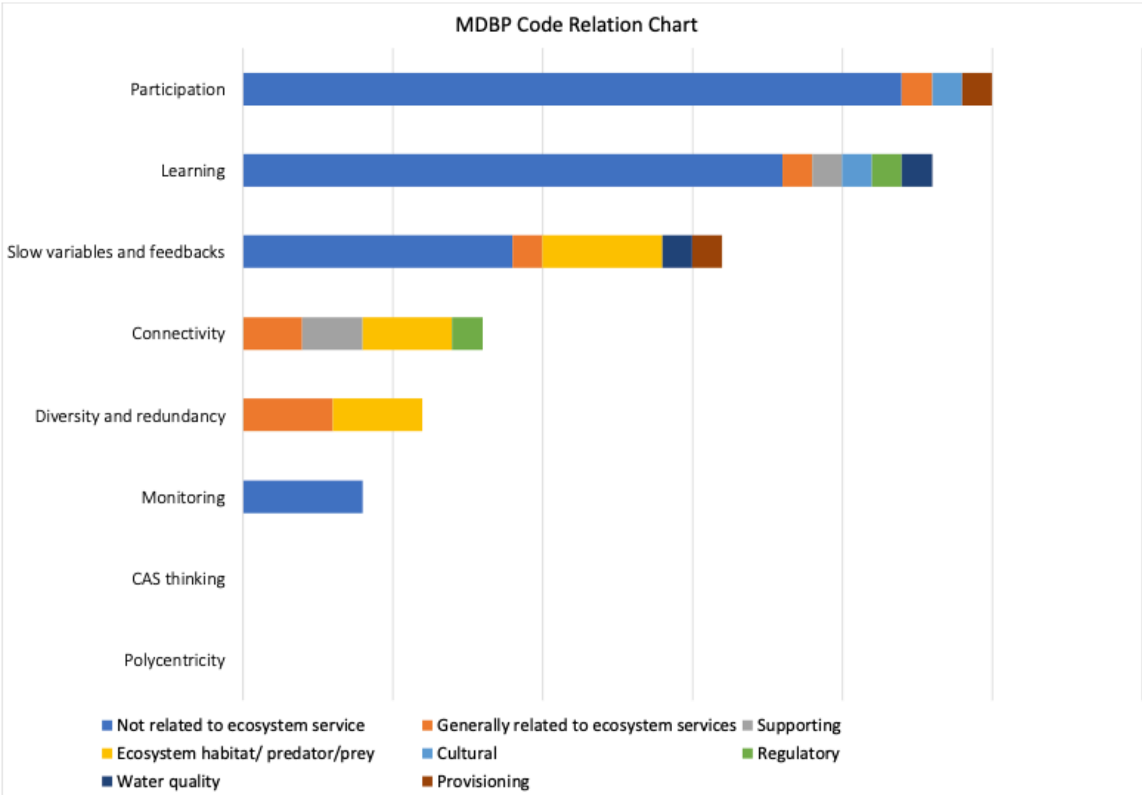

Figure 7: Relationship between principles of resilience and ecosystem services for the MDBP

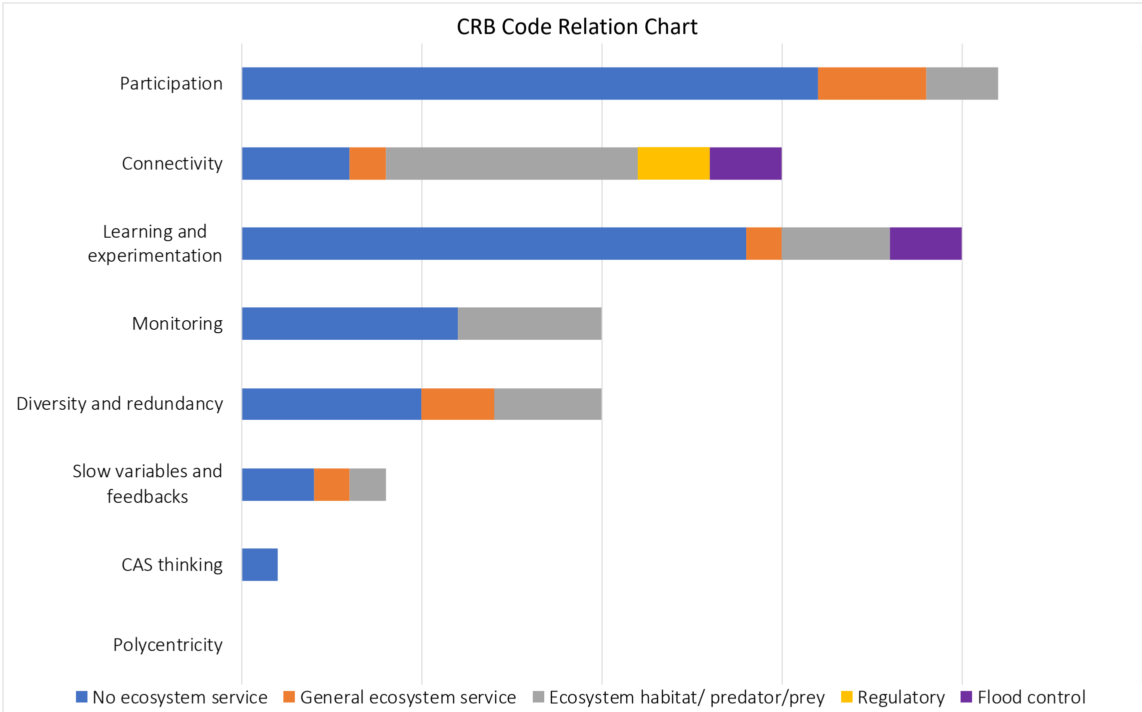

Figure 8: Relationship between principles of resilience and ecosystem services for the CRBFWP

Connectivity

Connectivity was present in both the MDBP and the CRBFWP. The instances of connectivity in the MDBP all related to an ecosystem service based solely on ecological connectivity because there is no concept of the basin as an SES (Figure 7). Instances of connectivity in the CRBFWP are also strongly tied to ecosystem services and ecological connectivity (Figure 8).

Slow variables and feedbacks

The MDBP scored poorly in this area. With the great deal of emphasis on the SDLs and a large portion of the document dedicated to the calculations, the calculations themselves were based on historical climate data and did not take future climate changes into account, which is the antithesis of resilience thinking. Historical records are not sufficient for planning future scenarios in resilience thinking (Miller et al., 2016). Climate change projections were omitted due to uncertainty around the potential effects, which is also in direct conflict with resilience theory, as uncertainty is accepted and expected. The CRBFWP was fairly neutral in this area, however climate change and change in general was highlighted as expected and inevitable. Ecosystem services were related to about half of the instances where slow variables and feedbacks was coded in both the CRBFWP and the MDBP (Figure 7 and Figure 8).

Learning and experimentation

Learning and experimentation were well represented in the CRBFWP. However, in the MDBP only learning was emphasized. Because of the heavy emphasis on Sustainable Diversion Limits SDLs in the MDBP, the focus was primarily placed on learning by providing open access to data and information related to monitoring and evaluation in order to improve knowledge of water requirements and causes of water degradation. In contrast, the CRBFWP explicitly encouraged experimentation as an approach to learning and dealing with uncertainty. Rather than outlining the mechanism for learning (i.e. open access to data), the focus of the CRBFWP was on the application of learning in an adaptive management approach. Learning and experimentation were not tied to ecosystem services in general for the MDBP (Figure 7) and were tied to ecosystem habitat or flood control in roughly one third of the instances in the CRBFWP (Figure 8).

Monitoring

For the MDBP, monitoring was primarily mentioned in the context of measuring compliance against the SDLs, but not in the context of resilience. Furthermore, the mentions of monitoring were not related to any ecosystem services (Figure 7). For the

CRB, monitoring was mentioned in the context of collecting data to better understand and respond to climate change and for long-term monitoring of habitat for endangered species, which is indicative of resilience thinking. When monitoring was present in combination with ecosystems services, it was tied to ecosystem habitat and the need for monitoring to understand the impacts of change on habitats (Figure 8).

Participation

Of all the principles of resilience, the principle of participation was the most prominent and well represented in both documents. For the MDBP, a prominent theme in the plan was publishing information on public websites to make this information easily available. The information that would be available includes the results of research, proposed strategies, and proposed adjustments to the MDBP. Requirements for a minimum timeframe of four weeks for the public to review submissions and provide feedback were specified to ensure adequate time to participate. Consultation requirements were also outlined specifying who must be involved in long term planning of water resources and who from local communities should be included. Finally, participation from Indigenous people was required so that Indigenous values and uses of water resources be identified and incorporated into water resource plans. The required inclusion of Indigenous people in the water resource planning is particularly significant. Less than 1% of the water and land in the basin is owned by Indigenous people, therefore they have historically been excluded from water management (Hart, 2016a). Participation was not tied to ecosystem services in general; this is highlighted in Figure 7.

Like the MDBP, the CRBFWP also requires participation from the public in the form of comments on any recommendations and proposed amendments to the program. Expectations exist for an "extensive" period of time for the public to comment on proposed amendments and public hearings. Unlike the MDBP, no specific mechanisms were identified to ensure the public understands how to participate, such as where draft documents could be obtained. Expectations of participation and collaboration with federal and state agencies, scientists, and non-traditional organizations were outlined but without any specific details on who these groups are. The rights of the Native American tribes in the CRB were recognized although participation was mentioned in the context of existing treaties as opposed to any new way to encourage and solicit input. Participation was not tied to ecosystem services in general; this is highlighted in Figure 8.

CAS Thinking and Polycentricity

Neither the principle of CAS thinking nor polycentricity were present in the MDBP. Only CAS thinking was present in the CRBFWP, but not to any significant extent. CAS thinking was present in a scientific principle regarding ecosystem management, whereby ecosystems were recognized as complex, constantly changing, and largely unknown. This principle co-occurred with Learning and Experimentation as it was related to the need for ecosystem management to be adaptive and experimental. No ecosystem service was related to the instance of CAS thinking in the CRBFWP (Figure 8).

Conclusion for MDBP and CRBFWP Results

This comparative analysis revealed that neither document was based on resilience thinking. However, results indicate that the CRBFWP had a larger number of the principles represented than the MDBP. The CRBFWP had five out of the seven principles present (connectivity, slow variables and feedbacks, learning and experimentation, monitoring, and participation) whereas the MDBP had only one (participation) and was in fact in conflict with one of the principles (slow variables and feedbacks). The CRBFWS provides a better example of how resilience can be integrated into planning, especially when a full integration of the resilience principles is not practical or desired. The results from the secondary coding of ecosystem services did not lead to any additional insight.

Results: NSW CAPs and WA subbasin plans

In contrast to the comparative analysis of the MDBP and the CRBFWP, there were plans based on resilience thinking for this part of the evaluation. The CAPs from NSW were all written based on resilience thinking, and the subbasin plans from WA were not, although they did have instances of resilience principles. While some of the WA subbasin plans had a stronger representation of resilience than others, for the purposes of my research I evaluated them at the aggregate level. See Table 10 for a summary of the comparison.

Table 10: Comparative analysis of resilience principles in the NSW CAPs and the WA subbasin plans. '0' represents the absence of Resilience Thinking or the Specific Principle, '+' represents the presence of Resilience Thinking or the Specific Principle, '-' represents a conflict with Resilience Thinking or the Specific Principle. A double figure such as '0/+' indicates that some aspects of Resilience Thinking or the Specific Principle were represented but not fully. Refer to Figures 5 and 6 in the methods section for visual representation of the parent/child relationships in the coding hierarchy.

Principles of Resilience	Resilience thinking (RT) or specific principle (SP)	NSW CAPs	WA subbasin plans	Comments
Present	RT	+	0/+	Resilience thinking is foundational to all of the CAPs but is not for the subbasin plans, although the subbasin plans do have instances of resilience.
Management of SESs	RT, child to Present	+	0	Managing for resilience is key to the CAPs. The management in the subbasin plans is not based on resilience.
Diversity and Redundancy	SP, child to management	+	0/+	Diversity present in CAPs in the context of social and ecological diversity. Diversity in the subbasin plans focuses on ecology with only a few social references
Connectivity	SP, child to management	+	0/+	Connectivity present in the CAPs both in the context of social and ecological connectivity. A few of the subbasin plans include both ecosystem connectivity and social connectivity
Slow Variables and Feedbacks	SP, child to management	+	0	SDLs were calculated using historic data in the MDBP instead of taking future projections into account. The CRBFWP states possible effects of climate change need to be considered.
Governance of SESs	RT, child to Present	+	0	Governance of SES not present in the subbasin plans. Well represented in the CAPs
Learning and Experimentation	SP, child to Governance	+	0	The CAPs emphasized learning but not experimentation. The subbasin plans had instances of learning but not compared to the CAPs
Monitoring	SP, child to Learning and Exp.	+	0/+	Monitoring is well represented in the CAPs. The subbasin plans had instances of monitoring but not compared to the CAPs
Participation	SP, child to Governance	+	+	Both the CAPs and the subbasin plans emphasized participation and inclusion
CAS thinking	SP, child to Governance	+	0	CAS thinking not present in subbasin plans but represented in the CAPs
Polycentricity	SP, child to Governance	0/+	0	Polycentricity was present in CAPs but not as prevalent as other principles. Not present in subbasin plans

Principles of resilience

Diversity and Redundancy

Diversity and redundancy was the most prominent resilient principle in the WA subbasin plans and was strongly tied to ecosystem services, in particular ecosystem habitat (Figure 9). Diversity, however, referred exclusively to ecological diversity.

In the NSW CAPs, diversity and redundancy were strongly represented, and both social and ecological diversity were addressed. Examples of social diversity included targets to have more Aboriginal people in resource management, emphasizing knowledge diversity as well as age, gender, and cultural diversity amongst resource managers, increasing the diversity of industries in a community to build community resilience, and increasing the diversity of lifestyle options for people. Roughly 25% of diversity in the CAPs was tied to ecosystem habitats (Figure 10). It is important to note that Figures 9 and 10 do not represent quantitative results, they only describe the relative occurrence of codes from the ecosystem coding frame (Figure 5 from the Methods chapter). If a code from the ecosystem service coding frame is not present on the chart, then it was not coded for any of the seven principles.

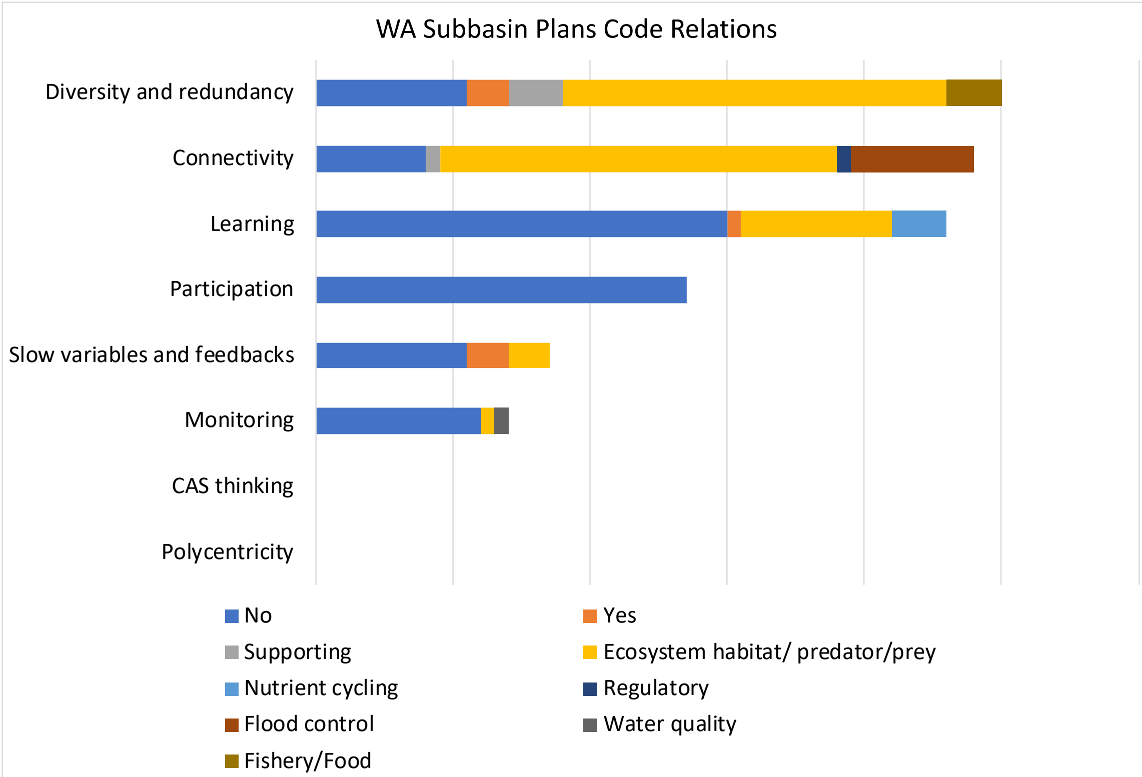

Figure 9: Relationship between principles of resilience and ecosystem services for the WA subbasin plans

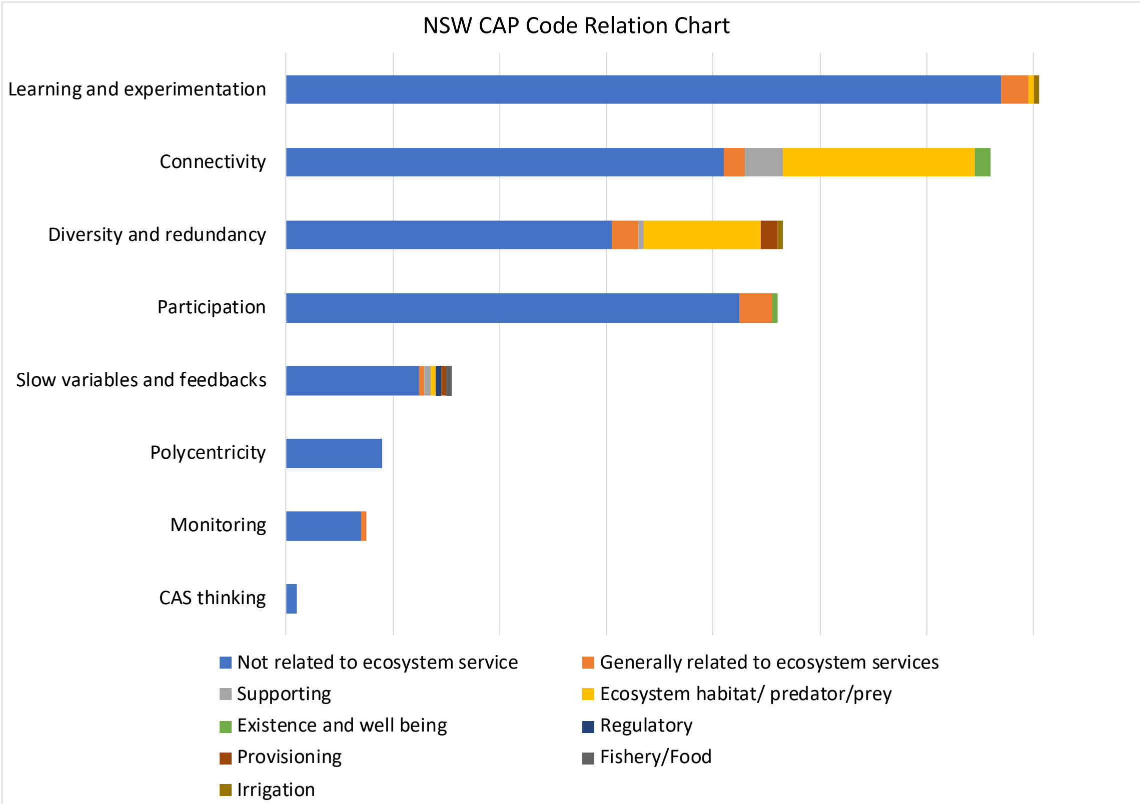

Figure 10: Relationship between principles of resilience and ecosystem services for the NSW CAPs

Connectivity

Connectivity was present in both the WA subbasin plans and the NSW CAPs. The instances of connectivity in the WA subbasin plans nearly all related to connectivity of ecosystem habitat, though there were a few instances of connectivity between community well-being and watershed conditions (Figure 9). The CAPs were more expansive in their mention of connectivity. In addition to ecological connectivity, examples of social connectivity included connecting Aboriginal people to the land through participation in resource management, the connectivity between community health and mental well-being to the health of river systems, and connectivity between government agencies and local communities. Loss of connectivity was noted as well, in particular between the

Aboriginal elders and youth and between loss of connectivity between Aboriginal people and the land, leading to the inability to carry out traditional ecological practices. Roughly one third of the instances of connectivity in the CAPs were tied to ecosystem services, primarily to ecosystem habitats (Figure 10).

Slow variables and feedbacks

Slow variables and feedbacks were present in both the NSW CAPs and the WA subbasin plans. In the CAPs, slow variables and feedbacks are mentioned in relation to taking the Aboriginal 'long view' approach to management, meaning that management should be viewed in the long term and across generations as well as managing to long-term thresholds and tipping points, instead of to individual metrics. The subbasin plans are fairly neutral in this area, however climate change and change in general is highlighted as expected and inevitable. Ecosystem services were not strongly related for either the CAPs or the subbasin plans (Figure 9 and Figure 10).

Learning and experimentation

Learning and experimentation was the most prominent resilient principle in the NSW CAPs and was well represented in the WA subbasin plans. Like the CRBFWP, the focus on learning in the WA subbasin plans is on the application of learning in an adaptive management approach. Experimentation was not present in the subbasin plans. In the NSW CAPs, learning was tied to management actions and was more specific and actionable than in the WA subbasin plans. Like the subbasin plans, experimentation was prominent although 'learning by doing' was emphasized in a few instances. A desire to better understand and incorporate Traditional Ecological Knowledge (TEK) into learning was present in both the CAPs and the subbasin plans, however the CAPs were more specific in regard to how to achieve this, for example by better supporting TEK projects by providing cultural access licenses to cultural water for Aboriginal communities and helping to connect the younger Aboriginal generations to the elders for better transfer of TEK. Learning was not tied to ecosystem services in general for the CAPs (Figure 10) and was tied to ecosystem habitat or nutrient cycling in roughly one third of the instances in the Subbasin Plans (Figure 9).

Monitoring

Monitoring is present in both the CAPs and the subbasin plans, although a more consistent approach is taken across the CAPs. The CAPs describe a Monitoring, Evaluation, Reporting and Improvement (MERI) system, which provides a strategy and framework for monitoring. Interestingly, the CAPs also contain targets to measure social wellbeing through surveys and participation levels. For the subbasin plans, monitoring is in the context of collecting data to monitor progress of projects that have been implemented to ensure that targets are being met. The instances of monitoring were not related to any ecosystem services for either set of documents (Figures 9 and 10).

Participation

Unlike the MDBP and the CRBFWP, participation is not the most prominent principle of resilience for the WA subbasin plans or for the NSW CAPs. Instances of participation in the WA subbasin plans are similar to those in the CRBFWP, emphasizing the importance of participation from the public, local communities, individual land owners, state and local governments, and Native American tribes. Similarly, instances of participation in the CAPs emphasized the importance of participation from the public, local communities, individual land owners, state and local governments, and Indigenous people. Within the CAPs, goals and targets were specified for participation, as well as measures to ensure the targets were being met. Participation was not tied to ecosystem services in general for either the CAPs or the subbasin plans (see Figures 9 and 10).

CAS Thinking and Polycentricity

Neither CAS thinking nor polycentricity were present in the WA subbasin plans. CAS thinking was present in the NSW CAPs but was the least represented of all of the principles and was not tied to any management action. Rather, the CAPs simply acknowledged that ecosystems function as CAS. Polycentricity was present in the context of proposed models, the desire for shared decision making across multiple levels, and empowering local groups to make decisions. There is no indication that true polycentricity actually exists in any of the CAPs. No ecosystem services were related to the instances of CAS thinking or polycentricity (see Figures 9 and 10).

Conclusion for NSW CAPs and WA subbasin plans

The NSW CAPs were clearly more representative of resilience thinking than the WA Subbasin Plans. The NSW CAPs had six out of the seven principles of resilience and only lacked the principle of polycentricity, whereas the WA Subbasin Plans only had one principle present, participation. It should be noted that a few of the Subbasin Plans are more representative of resilience thinking than others, for example the Lower Columbia Mainstem Subbasin Plan and the Estuaries Tributary Subbasin Plan, however as an aggregate they did not represent resilience thinking. As with the analysis for the CRBFWP and the MDBP, the results of the secondary coding for ecosystem services did not lead to any additional insights.

Chapter 5: Discussion

Resilience in the management of the MDB vs. the CRB

The purpose of my research was to understand how resilience thinking and resilience principles were being integrated into basin management plans. Building resilience into water management plans is a potential mechanism not only to mitigate unforeseen changes due to climate change, overallocation of water resources, and competing demands for ecosystem services, but also to adapt or even transform in response to them (Rockström et al., 2014). For my research I focused on the Columbia River Basin in the Pacific Northwest region of the United States and the Murray-Darling Basin in the southeastern region of Australia and analyzed both basin-wide plans and subbasin or catchment plans. My analytical approach consisted of Qualitative Content Analysis (QCA) of the Columbia River Basin Fish and Wildlife Program document at the basin level and 27 Subbasin Plans from Washington State. Similarly, I conducted QCA on the Murray-Darling Basin Plan document at the basin level and seven Catchment Action Plans from New South Wales. I first coded each document for the presence of seven resilience principles (see Figure 6 in the Methods chapter) and then applied a secondary code for ecosystem services (see Figure 5 in the Methods chapter). I then conducted a comparative analysis to better understand the similarities and differences of the approaches taken.

In the following section I first address three key findings from my research: 1) the treatment of slow variables and feedbacks is a differentiating factor between the management plans; 2) incorporating resilience into water management does not have to be an all-or-nothing endeavor; and 3) cohesion and continuity between basin-wide documents and subbasin-level or catchment-level plans could be improved . Following the key findings, I discuss my experience using the seven principles as a tool for evaluating resilience, which may help inform researchers interested in conducting a similar analysis in the future. I follow with my experience using ecosystem services as a second level of coding. I conclude by discussing the limitations of my study and propose recommendations for future research.

Key Findings

Treatment of slow variables and feedbacks

Although the principles of resilience that were the most prevalent across all of the documents were principles involving participation and learning, the key differentiator between the plans based on resilience theory, namely the Catchment Action Plans from New South Wales, and the rest of the plans was the treatment of slow variables and feedbacks. While the existence of slow variables and feedbacks was acknowledged in the plans that were not based on resilience theory, no actionable goals or objectives were set. In the Catchment Action Plans, slow variables and feedbacks were central to the planning approaches and were used to identify critical thresholds. After the set of critical thresholds was identified, the Catchment Action Plans centralized management goals, objectives, targets, and actions around these thresholds. In contrast, the Murray-Darling Basin Plan directly conflicted with slow variables and feedbacks by using historical climate data in the calculation of the Sustainable Diversion Limits (SDLs) and ignoring future climate projections due to uncertainty. Changes in the slow variables and feedbacks can lead to regime shifts if certain thresholds are crossed, therefore clearly defining and managing for critical thresholds is a way to increase resilience (Scheffer et al., 2001).

In addition, in the plans that were resilience-based, monitoring was focused on the both key slow and fast variables that impact the identified thresholds. Monitoring changes in the slow variables and feedbacks of an SES can help identify when system resilience is degrading and in danger of experiencing a regime shift (Biggs et al., 2012). In contrast, the plans that were not based on resilience focused only on managing and monitoring fast variables.

Another distinction between the plans built on resilience theory is that the slow variables were not limited to ecological variables. Social-based slow variables such as age structure of the communities and cultural attitudes toward the environment, both considered slow variables, were also included in defining the goals, objectives, targets, and actions of the plans. The planning approach included long-term goals for social-based slow variables that help build communities with resilience not just to ecological changes such as climate change but also to changing demographics, enterprises, and policies. Changes in social-based slow variables can affect ecosystem services, for example in gradual changes of preferences in ecosystem services (Abel et al., 2006).

Integrating principles of resilience is not all or nothing

Although the New South Wales Catchment Action Plans were built on resilience principles, integrating resilience into existing water management plans does not have to be an all-or-nothing endeavor and can instead be done incrementally. The Columbia River Basin Fish and Wildlife Program serves as an example. While not built on resilience, the Columbia River Basin Fish and Wildlife Program considers the river basin as a social-ecological system, which leads to the assertion that the condition of the basin ecosystem affects not just species such as salmon but affects humans as well. By establishing that human health and well-being are reliant on the health of the basin ecosystem, people may feel more strongly connected to the basin and feel more vested in protecting the health of the basin, which may enhance resilience (Biggs et al., 2015; Postel & Richter, 2012).

Cohesion and continuity of plans is critical

While the New South Wales Catchment Action Plans represented resilience thinking, the lack of cohesion and continuity between the Murray-Darling Basin Plan and the New South Wales Catchment Action Plans becomes apparent when comparing the results from each in Tables 9 and 10. The lack of agreement on management vision will likely erode trust between communities and higher levels of government. This could likely lead to problems in implementation of the Sustainable Diversion Limits established by the Murray-Darling Basin Plan. Several of the Catchment Action Plans explicitly identified the Sustainable Diversion Limits from the Murray-Darling Basin Plan as a potential shock to the ecosystem. A shock is defined as a sudden event or change that impacts stability of a system (Biggs et al., 2015). Resilient systems can buffer shocks but there is still a limit to how much of a shock can be absorbed before a regime shift occurs (Walker & Salt, 2006).

Conversely, although not as representative of resilience thinking as the New South Wales Catchment Action Plans, there is a much stronger connection between the Columbia River Basin Fish and Wildlife Program and the Washington Subbasin Plans. The goals and objectives are consistent and there is an acknowledgement between the Columbia River Basin Fish and Wildlife Program and the Washington Subbasin Plans of the value that each contributes, representing a sound collaboration between governance and management. There is no such mutual acknowledgement or collaboration between the MDBP and the CAPs.

Using principles of resilience as a tool to evaluate river basin management plans

Overall, the seven principles of resilience were useful for evaluating how resilience thinking was incorporated into river basin planning. Of the seven principles, the two least useful principles were Complex Adaptive System (CAS) thinking and polycentricity. For CAS thinking, there is a knowledge gap in how to apply CAS thinking to actionable goals, objectives, and targets (Biggs et al., 2015), and this was apparent in my analysis. When CAS thinking was coded, it was in a generic context and did not lead to any insights into how it would be applied. Similarly. the challenge with polycentricity is the lack of understanding of how to operationalize it in SESs (Biggs et al., 2015).

The principle of participation was strongly represented across all of the documents and the context in which it appeared was similar across all documents, so evaluating it did not lead to much insight. Perhaps a useful next step would be to evaluate the documents by looking for the lack of participation in particular areas, where one group or governing body has much more input than others and analyze for potential conflicts.

Coding for the principle of learning and experimentation was useful particularly when looking for support for experimentation. Encouraging experimentation indicates a willingness to try new approaches and to incorporate new learnings into future planning (Yevgeny, 2014). Learning is also foundational to adaptive management (Holling, 1978), which all of the plans were based on. Evaluating monitoring as a separate code from learning and experimentation was also useful. It highlighted how and what information was being gathered and whether the information was tied to the goals and objectives being set. By evaluating monitoring separately, it was easier to discern short-term versus long-term monitoring, which in turn provided clarification for which slow term variables were being tracked and how. The resilience-based plans contained metrics based on what is important to monitor versus what is easy or convenient to monitor and did not use metrics just because the mechanisms for monitoring were already in place.

Slow variables and feedbacks shed light on how long-term planning and management is incorporated. Although instances of this principle were present in all of the documents, how it was operationalized was different in each document. For example, in the Murray-Darling Basin Plan, the slow variable climate change was ignored, leading to a direct conflict with this principle. In the Columbia River Basin Fish and Wildlife Program, the uncertainty around climate change was embraced and attempts to better understand the potential impacts and incorporate new learnings was explicitly encouraged. In the Washington Subbasin Plans, climate change was merely acknowledged and in the New South Wales Catchment Action Plans, slow variables and feedbacks were foundational. The four different treatments of the same principle indicate that it is a key differentiator.

The principle of diversity and redundancy was useful for evaluation, however coding for it highlighted that diversity was much more prevalent than redundancy. Redundancy has a bad connotation because people associate it with inefficiency in making decisions, increased costs, and duplication of efforts (Jentoft & Chuenpagdee, 2009). Recommendations of redundancy are not often included in management planning. Ecological redundancy was not present either, for some of the same reasons as cost but also because of complexity around how effectively redundant ecosystems can be utilized in the event that one transforms to another state due to an unexpected shock (Nyström, 2006). Although redundancy was not present, evaluating diversity alone was valuable in that it highlighted how diversity is viewed, as purely ecological or in a social-ecological context. The more resilience-forward plans emphasized social diversity as equally important as ecological diversity.

Similarly, connectivity also highlighted the divide been purely ecological approaches and social-ecological approaches. The more resilience-forward plans emphasized social connectivity as equally important as ecological connectivity with respect to enhancing the resilience. An interesting follow up would be to analyze areas where connectivity is over used, particularly in a social context. For example, a high degree of connectivity within a certain group may limit diversity of ideas (Biggs et al. 2015). In an ecosystem, connectivity can enhance the spread of fire or invasive pests. I considered all instances of connectivity as positive, however a deeper analysis might uncover some negative consequences as well.

Evaluating how ecosystem services are tied to resilience principles

Overall, not much new knowledge was gained from this part of my analysis. Instead, it confirmed what the literature suggests, that even with a strong focus on managing a basin for both its ecological *and* social system components, there remains a heavy emphasis on ecological ecosystem services (Folke, 2006). This is highlighted in the absence of cultural ecosystem services in Figures 7, 8, and 9, which represent the relationship between the principles of resilience and ecosystem services for the Murray-Darling Basin Plan, the Columbia River Basin Fish and Wildlife Program, and the Washington Subbasin Plans respectively. Only Figure 10 for the New South Wales Catchment Action Plans features a cultural ecosystem service, “existence and well-being”. Even so, relative to the other ecosystem services, the co-occurrence of “existence and well-being" is small. The emphasis on ecological ecosystem services perhaps occurred because cultural ecosystem services are characterized by intangibility (Milcu, 2013; Sukhdev, 2010).

Study limitations and recommendations for future research

There are several limitations to this study. First, because of the volume of data, I had over 1,500 coded segments. With the large number of coded segments, it is likely that interesting insights were overlooked. As an example, resilience in the New South Wales Catchment Action Plans and the Washington Subbasin Plans was evaluated at the aggregate level. The Catchment Action Plans were all based on resilience-thinking so the aggregate was representative of all of the plans, however the individual Subbasin Plans were more varied and some, like the Lower Columbia Mainstem Subbasin Plan, exhibited more resilience thinking than others. Due to the large volume of coded segments, evaluating resilience on a per document basis was not feasible, therefore it is highly possible that some insights were lost by evaluating the Subbasin Plans at the aggregate level, particularly those insights related to partial integration of resilience principles in plans not based on resilience thinking.

Second, while the principles proposed by Biggs et al. 2012 were central to my methods, this is only one way of thinking about resilience in river basin management. The work by Biggs et al. represents the first attempt at synthesizing the vast array of literature on resilience and distilling it down to the most common elements. As such, the proposed set of principles will almost certainly be refined and modified over time as more and more studies use these principles for research.

Third, this study only covers two river basins and therefore it is unclear how generalizable my results are to other basin management approaches around the world. Comparative research on river basins is limited (Wescoat, 2005), and as such other researchers could select other regions of the world to apply the principles from Biggs et al. and compare the results with those discussed in this thesis.

One interesting follow on to this thesis would be to use the ecosystem services coding frame (Figure 5) as the primary coding frame to evaluate the differences between how ecosystem services are managed in plans based on resilience versus plans not based on resilience. Through my research, I established that the Washington Subbasin Plans were not based on the resilience thinking and that the New South Wales Catchment Action Plans were, making this an ideal document set for comparison. In addition, all of the plans I evaluated for my research mention partnering with indigenous communities in the creation of the plans, so another area for further research could be to assess indigenous viewpoints on the plans as well as how inclusive the process of creating the plans was from their perspective.

Chapter 6: Conclusion

The quality of freshwater resources is crucial for human and ecosystem health (Miller et al., 2016), yet continued availability and sustainable use is being challenged by outdated command-and-control approaches toward river basin management (Folke, 2016; Holling & Meffe, 1996; Rockström et al., 2014). To address this, resilience theory is emerging as an increasingly popular approach to basin management (Cosens et al., 2014; Green et al., 2013; Parsons & Thoms, 2017). Very few studies exist that explore the application of resilience theory to real-world situations, so additional research is vital to the continued adoption of resilience as a viable management option (Baird et al., 2016; Biggs et al., 2015; Sellberg et al., 2018). Given the lack of studies in this area, the primary purpose of this thesis was to contribute to the literature by comparing the similarities and differences of the application of resilience theory to water management in the Columbia River Basin and the Murray-Darling Basin.

To address the lack of literature exploring the application of resilience theory in real-world situations, my research focused on the application of resilience theory in the management of Columbia River Basin and the Murray-Darling Basin. I evaluated the Columbia River Basin Fish and Wildlife Program and Subbasin Plans from Washington State as well as the Murray-Darling Basin Plan document and Catchment Action Plans from New South Wales for the presence of seven resilience principles as well as how the resilience principles related to ecosystem services. The result was a comparative analysis to better understand the similarities and differences of how the principles of resilience were applied in the management of the two basins.

The results of my research indicated that the treatment of slow variables and feedbacks is a key differentiator between plans based on resilience theory and plans that are not. In plans based on resilience theory, slow variables and feedbacks were central to the planning approaches and used to identify critical thresholds. Management objectives, targets, and actions were then centralized around these critical thresholds. My results also showed that integrating resilience principles into management plans is not an all-or-nothing endeavor. The Northwest Power and Conservation Council's Columbia River Basin Fish and Wildlife Program serves as an example of how principles of resilience can be incorporated into a plan that is not based on resilience. Finally, my results suggested that cohesion and continuity between management planning at the basin-wide level and the subbasin or catchment level is critical in order to establish and maintain connections between multiple levels of governance.

Incorporating resilience thinking into basin management is complex but the Catchment Action Plans from New South Wales serve as excellent examples of how resilience theory and principles of resilience can be integrated into water management plans. In cases where budget, knowledge, and/or personnel limitations prevent the complete adoption of resilience into water management planning, the Northwest Power and Conservation Council's Columbia River Basin Fish and Wildlife Program serves as a solid example of how principles of resilience can be built into a plan that is not based on resilience thinking. Overarching goals and objectives, skill and capacity of management personnel, and tolerance for uncertainty are all important factors to consider when incorporating resilience thinking into existing plans based on more traditional approaches.

While my research focused on management of the Columbia River Basin and the Murray-Darling Basin, the methodology I outlined could be used to evaluate resilience not only in other water management plans but also in management plans for other areas of resource management as well. Further research using the seven principles will build upon the work of Biggs et al. and highlight how the principles can be further refined and modified. Although incorporating resilience thinking into basin management is complex, resilience-based management can be a powerful mechanism for adapting to the challenges the world's river basins are facing today and will continue to face in the future (Folke, 2016). Through additional studies focused on the application of resilience theory, we can continue to improve our knowledge on how to enhance resilience and consequently how to more wisely manage one of the world's most precious resources, our river basins.

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Appendices

Appendix A: NPCC Columbia River Basin Fish and Wildlife Program and Washington Subbasin Plan documents with associated URLs.

Document name	URL
Columbia River Basin Fish and Wildlife Program 2014	https://www.nwcouncil.org/sites/default/files/2014-12_1.pdf
Asotin Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/asotin-subbasin-plan
Crab Creek Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/crab-subbasin-plan
Elochoman & Skamakowa Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Entiat Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/entiat-subbasin-plan
Estuary Tributaries Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Grays Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Klickitat Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/klickitat-subbasin-plan
Lake Chelan Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lake-chelan-subbasin-plan
Little White Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Lower Columbia Mainstem and Estuary Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Lower Cowlitz Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Methow Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/methow-subbasin-plan
Palouse Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/palouse-subbasin-plan
Pend Oreille Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/intermountain-province-plan
Salmon Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/salmon-subbasin-plan
San Poil Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/intermountain-province-plan
Spokane Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/intermountain-province-plan
The Okanogan Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/okanogan-subbasin-plan
Tucannon Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/tucannon-subbasin-plan
Upper Columbia Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/intermountain-province-plan
Upper Cowlitz Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Upper Mid-Columbia Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/upper-mid-columbia-subbasin-plan
Walla Walla Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/walla-walla-subbasin-plan
Wenatchee Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/wenatchee-subbasin-plan
White Salmon Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Wind Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/lower-columbia-province-plan
Yakima Subbasin Plan	https://www.nwcouncil.org/subbasin-plans/yakima-subbasin-plan

Appendix B: Murray-Darling Basin Plan and New South Wales Catchment Action Plan documents with associated URLs.

Document name	URL
Murray-Darling Basin Plan	https://www.legislation.gov.au/Details/F2018C00114
Border Rivers-Gwydir Catchment Action Plan	http://archive.lls.nsw.gov.au/__data/assets/pdf_file/0009/495810/archive_border-rivers-gwydir-catchment-action-plan.pdf
Central West Catchment Action Plan	https://centralwest.lls.nsw.gov.au/__data/assets/pdf_file/0019/511093/Central-West-CMA-LLS-Transition-CAP.pdf
Lachlan Catchment Action Plan	https://archive.lls.nsw.gov.au/__data/assets/pdf_file/0009/495486/archive-lachlan-catchment-action-plan-2013-2023.pdf
Murray Catchment Action Plan	http://murray.lls.nsw.gov.au/__data/assets/pdf_file/0004/475753/MurrayCAP.pdf
Murrumbidgee Catchment Action Plan	https://archive.lls.nsw.gov.au/__data/assets/pdf_file/0010/495352/archive_murrumbidgee-catchment-action-plan2013.pdf
Namoi Catchment Action Plan	https://archive.lls.nsw.gov.au/__data/assets/pdf_file/0005/496364/archive-namoi-catchment-action-plan-2010-2020-2013-update.pdf
Western Catchment Action Plan	http://archive.lls.nsw.gov.au/__data/assets/pdf_file/0012/496668/archive-western-catchment-action-plan-2013-2023_part-a.pdf