FREEING THE DESCHUTES: ASSESSING THE IMPLICATIONS OF SEDIMENT TRANSPORT IN DAM REMOVAL: A CASE STUDY OF THE 5TH AVENUE DAM, OLYMPIA, WASHINGTON

by

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ABSTRACT

Freeing the Deschutes. Assessing the Implications
of Sediment Transport in Dam Removal Projects:
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Olympia, Washington

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Dam removal is an emerging restoration measure to return river systems back to their natural states. Managing the sediment that is released when a dam is removed requires extensive planning to determine the volume and magnitude of sediment that will be released once the structure is removed. In the case of the 5^{th} Avenue Dam in Olympia, Washington, the removal of this concrete earthen dam will restore 260 acres of urban estuary habitat. In 2006, the Deschutes Estuary Hydrodynamic and Sedimentation Report used the Delft 3D model to predict where sediment erosion and deposition will occur. Since the completion of this study, the number of dam removal has increased, and various models have been developed to assess and predict how to manage the release of sediment. Results from the research completed highlight that estuary restoration is feasible based upon predictions determined in the 2009 Deschutes Estuary Feasibility Study. The methods used to manage the sediment release are featured in this thesis, based on three different management methods.

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Acknowledgements

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CHAPTER 1

INTRODUCTION

On September 17, 2011, a barge carrying earth-moving equipment started the four-year process of the removal of the Glines Canyon Dam on the Elwha River in Washington State. Citizens, environmental organizations, tribal members, and state and federal agency officials watched a live broadcast of the demolition of this structure (Olympia National Park Service, 2011). That day is considered groundbreaking in river restoration management: The removal of the Glines Canyon and the Elwha Dams, two hydroelectric facilities located in Olympic National Park, set the groundwork for future dam removal projects. People involved with the removal of the Elwha River Dams incorporated numerous management strategies in deciding on how these two structures (and others like them) should be removed (Gowan, Stephenson, Shabman, 2006). Those choices rest on years of data collection to establish a baseline of the river's current status as well as projections about what the river would look like once free of its impediments. Field crews collected an array of pre-removal data to compare to after the dams were removed. Information gathered included fish and wildlife populations, vegetation patterns and dynamics, sediment transport and storage in reservoirs, river channel and coastal evolution downstream of the dam site, the hydrological processes, near shore bathymetry, coastal habitats, and beach erosion (Duda, Warrick, Magirl, 2011).

The removal of a dam from any river system can create a number of positive and negative feedback loops that scientists must factor in when developing their restoration strategy. Dam removal changes the river's physical, chemical, and biological processes. Parameters such as flow, discharge, sediment grain size, sediment load, level of cohesion, deposition, channel morphology, and erosion are a few of the physical properties that researchers record in order to determine how the river might respond to removal. In the case of the Elwha River dams, natural resource managers determined that pre-and post-monitoring measurements were needed in order to assess the river's response to the removal. Since the fall of 2011, scientists have been recording the restoration progress of the Elwha River. Field technicians continue to monitor the effects of the dams' removal. The data collected illustrates how the ecosystem is restoring itself (Gowan, Stephenson, Shabman, 2006). To date, the ecological response to the dam removal has been highly significant in terms of the return of salmon runs and restoration of the river's hydrologic flow regime (Gowan, Stephenson, Shabman, 2006). In a one-day field survey in the fall of 2013, biologists surveyed 1,741 adult Chinook salmon (*Oncorhynchus tshawytscha*) and mapped 763 reds (salmon eggs) in the newly created river habitat (*The Seattle Times*, 2013). The biologists emphasized that 75 percent of the salmon were spotted upstream from the dam's site (*The Seattle Time*, 2013). The increase in salmon habitat is just one of the many positive ecological feedback loops that occur when a dam is removed.

Even though National Park Service, and The United State Geological Survey consider the Elwha River restoration project a groundbreaking case in river restoration history, the idea of dams being removed from our river systems is not a new concept. The removal of dams from the United States river systems has been occurring since the early 1900s: One of the first documented dams to be removed was the Russell Dam in California back in 1922 (Pohl, 2002). The number of dams removed has increased since the early 1920s and has been one of the top river restoration strategies implemented. Historical data shows that during the 1960s and 1970s, fewer than 20 dams were removed

(Stanley & Doyle, 2003). This number increased during the 1980s to the decommissioning of approximately 100 dams, and continued to rise in the 1990s to 160 dams removed (Stanley & Doyle, 2003). In 2002 alone, reports show that 63 dams were removed from river systems in the United States (Stanley & Doyle, 2003). More recently in 2014, 72 dams were removed, which restored approximately 730 miles of river habitat, according to a report released by American Rivers, a national nonprofit based in Washington, D.C. In total, over 500 dams have been removed in the past two decades (Stanley & Doyle, 2003). Figure 1.1 is a map of dams removed from the United States River Systems. A brief evaluation of these numbers demonstrates that dam removal is increasing as a management tool to restore river systems.

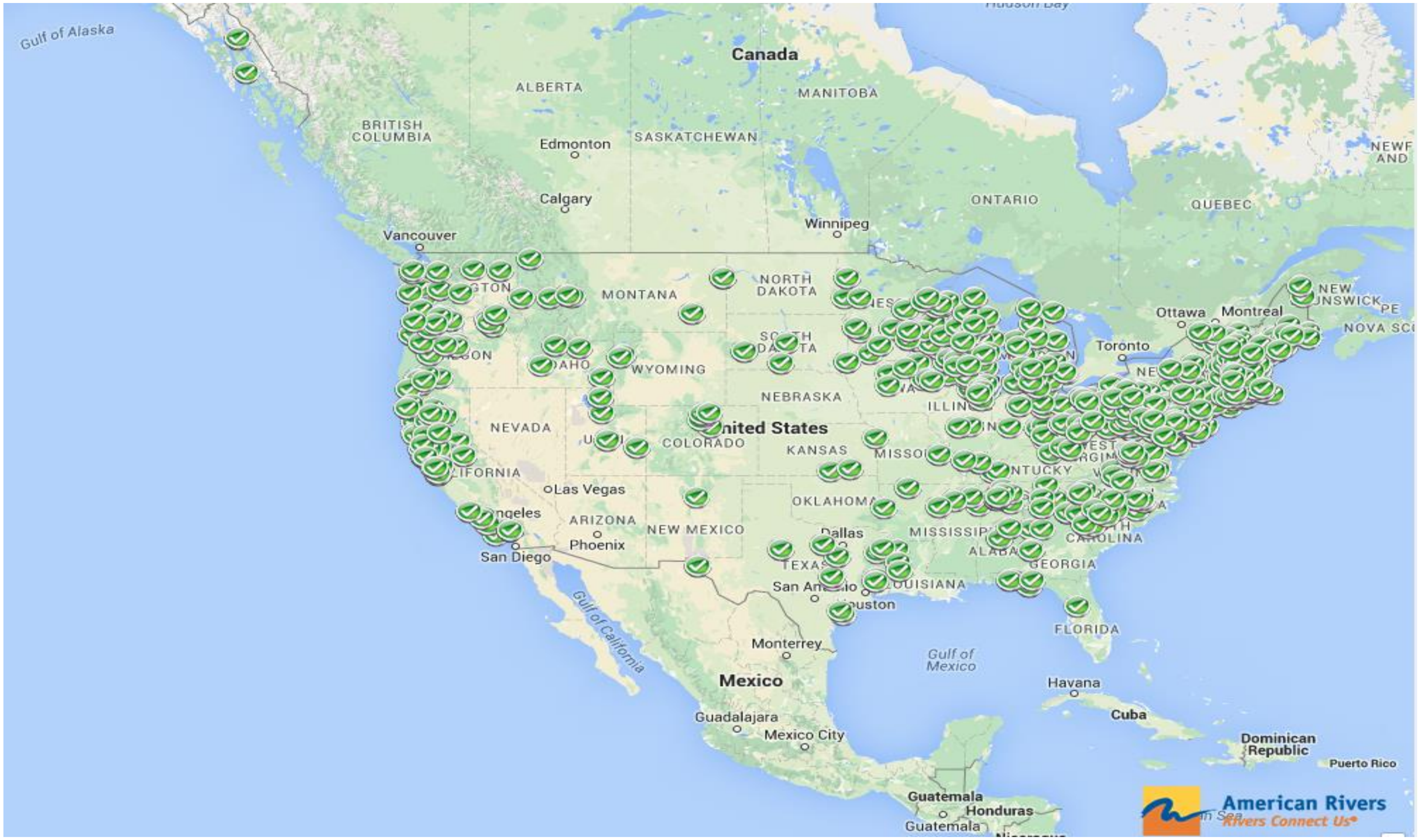

Figure 1.1 A map of all dam removal projects in the United States. (American Rivers)

In this thesis I am using the removal of the 5^{th} Avenue Dam, located in Olympia, Washington, as a case study for assessing the implications of sediment transport in small-scale dam removal projects. The 5^{th} Avenue Dam, built in 1951, creates Capitol Lake, an iconic public recreation site reflecting the Washington State Capital building in downtown Olympia. Figure 1.2 is a map of the 5^{th} Avenue Dam and the Deschutes Estuary.

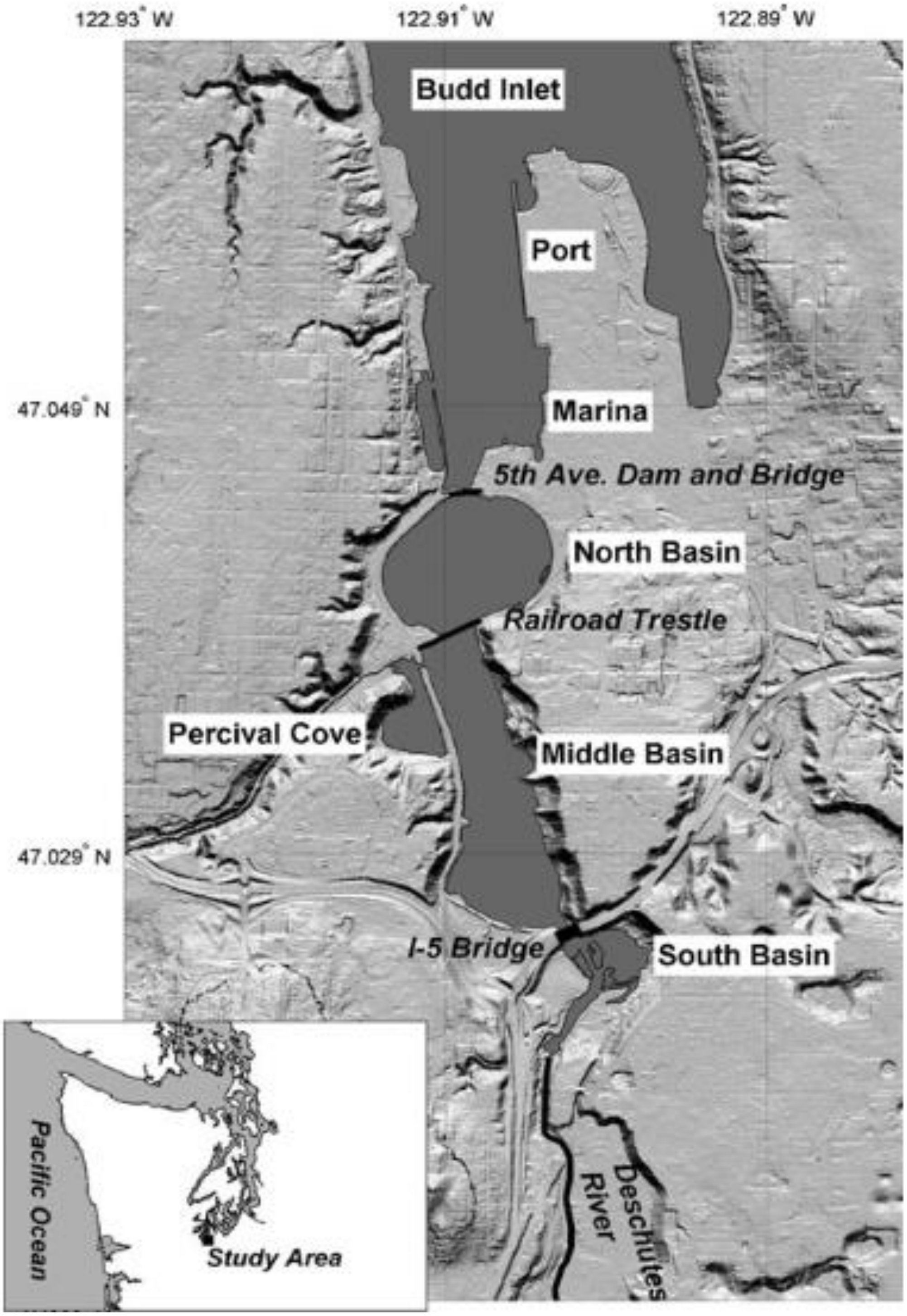

Figure 1.2. Map showing Capitol Lake in 2004. The four distinct sub-basins are South Basin, Middle Basin, Percival Cove, and North Basin and are connected through the labeled features. The Deschutes River enters South Basin from the southwest. The Port of Olympia and municipal marina reside north of the 5th Avenue Dam and Bridge in Budd Inlet. (George, Gelfenbaum, & Stevens, 2012).

Over the years, sediment deposition has decreased the lake's volume by 25 percent, thus creating some negative environmental impacts to the reservoir (Washington Department of Enterprise Services, 2006). The Washington Department of Enterprise Services has closed Capitol Lake to water recreation activities for two primary reasons. First, the New Zealand Mud Snail (*Potamopyrgus antipodarum*), an invasive freshwater mud snail that spreads rapidly due to its lack of predators, has populated the lakebed, causing state officials to close the reservoir to prevent spread of the species to surrounding water bodies. Additionally, Capitol Lake's dissolved oxygen levels are producing harmful algae blooms. The appearance of algae shows the negative feedback loop created by the dam. Poor circulation and the decomposition of the algae blooms depletes the reservoir's oxygen content. If the levels continue to drop, the water body can become hypoxic, a very low oxygen condition that can kill aquatic species. These two negative consequences of having the 5th Ave Dam have spurred state officials to look at new ways to manage the reservoir.

In 1999, the Washington State Department of Ecology, the Washington State Department of Fish and Wildlife, and the Washington State Department of Enterprise Services jointly decided to explore various restoration options to manage the sediment in Capitol Lake. The "Deschutes Estuary Feasibility Study" (referred to as the Study) was completed in 2009, and four restoration scenarios, listed below, were examined:

1) Lake/River/Wetland,
2) Lake,
3) Estuary, and
4) Lake/Estuary.

The Study determined the estuary restoration was feasible and could be restored through the removal of the 5th Avenue Dam. In order to predict how to manage the sediment released under that scenario, state officials developed a technical committee to focus on restoration efforts. The technical committee dedicated a portion of the study to examining the Deschutes River flow and tidal processes. The interaction between these two processes ultimately determines how sediment gets deposited and transported into the estuary and river system. The subsequent "Deschutes Estuary Hydrodynamic and Sedimentation Report" used the Delft3D model (explained below on page 9) to predict how the mixing of freshwater and tidal waves will distribute sediment through the estuary and river habitat.

However, even the most sophisticated modeling has some limitations, creating a level of uncertainty that researchers must take into account when analyzing the results. "There are a lot of natural processes that are occurring at once. For example, where the channel forms, where the sediment deposits, you are trying to predict what this might look like," Guy Gelfenbaum, Researcher with U.S. Geological Survey, Pacific Coastal and Marine Science Center said (Personal Communications, January 27, 2015). "Modeling is very useful in predicting how these natural processes might occur, but there are some limitations. It's like if you blur your eyes [while looking at the model], you will see what the general behavior is going to be- that is what our prediction is from the model," he explained.

According to Downs et al (2009), resource managers have little guidance on how to manage the sediment after dam removal. The researchers claim that data input is one of the most critical elements for a model to predict sediment transport scenarios. Although the ultimate goal in dam removal is to restore the natural pulses of flow and sediment into the downstream reaches, reconstructing a river channel's morphology can be difficult and the outcomes can be hard to predict. In order to project how sediment could be transported and deposited into a river, researchers rely upon numerical simulations to predict the channel response to the removal (Downs et al, 2009). Suspended sediment load, stream flow or sediment load characteristics are measurements scientists use in the various models to help predict the river channel's evolution.

The 2009 Deschutes Estuary Feasibility Study utilized numerical modeling to predict how the sediment would move throughout the Capitol Lake region and into the estuary, Gelfenbaum explained (Personal Communication, Jan. 27, 2015). By using this type of model, the report authors could determine how and where the sediment might deposit throughout the lake's system, and estimate the amount of time it will take to return the estuary back to pre-dam conditions. Based on the model simulations, the researchers developed a timeframe of ten years for the estuary to reach pre-dam conditions. Figure 1.3 shows one of the many numerical simulations created from the Delft3D model used in the 2009 Deschutes Estuary Feasibility Study.

Fig. 3 **a** Numerical model grid, **b** bathymetry for the model domain, and **c** in the modern Capitol Lake region. Grid resolution is higher in the estuary, port region, and ship channel, while other areas have lower resolution. The axes are in Washington State Plane South (km) and bathymetry contours are in 1 m increments

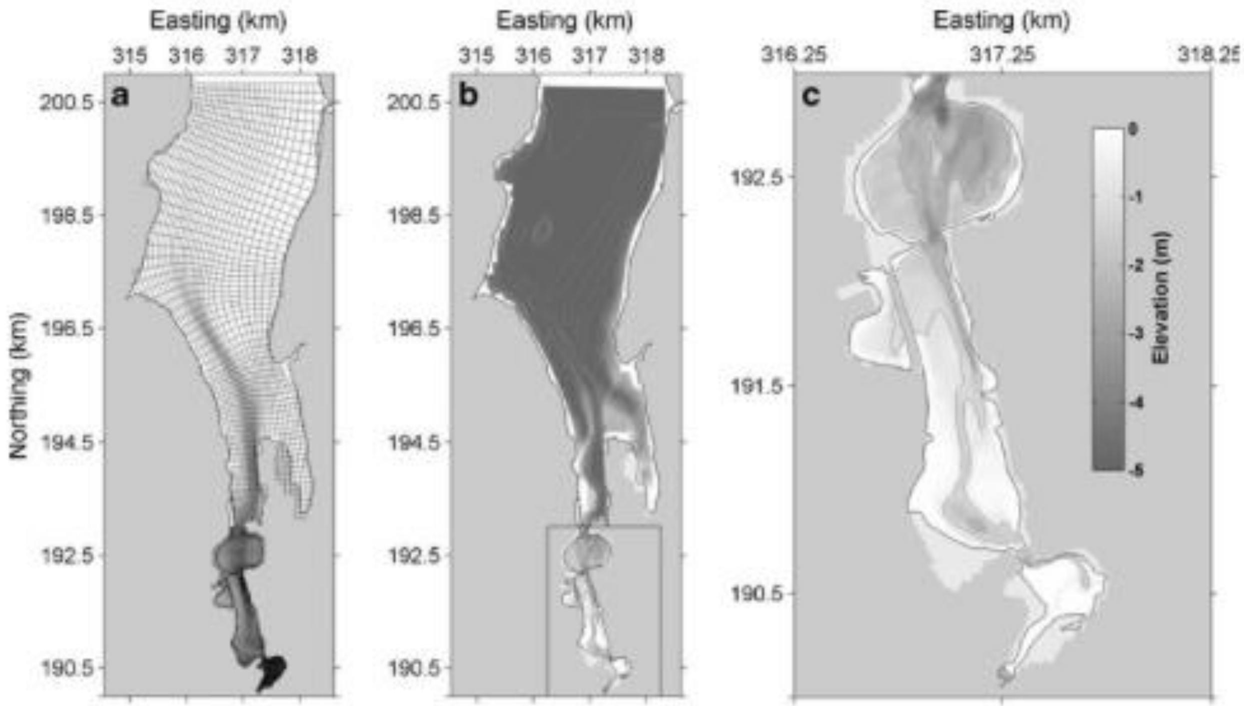

Figure 1.3. An example of a numerical model simulation created by the Delft3D model used in the 2009 Deschutes Estuary Feasibility Study. (2006 Deschutes Estuary Hydrodynamic and Sedimentation Report)

Once field samples have been collected, researchers enter the data into a numerical model that predicts how the river channel might change after the demolition of the dam. For example, a one-dimensional sediment transport model can be used in watersheds to predict large-scale spatial and temporal movements of sediment (Downs et al, 2009). The model can provide insight on how the rapid release of sediment might be deposited or suspended in the river's channel during high and low flow events. A sediment core is a method of analysis that allows researches to examine the composition of river and lakebed. Core samples can help researchers determine the interaction between sediment grain size, volume, and transport. This information is important part in the process of removing a dam because the models provide a roadmap of where the reservoir sediment could be deposited and offers predictions to the potential changes in the river's channel morphology (Downs et al, 2009). These can then be used to support restoration efforts and policy formulation.

When the "Deschutes Estuary Feasibility Study" was completed in 2009, a lack of peer-reviewed studies on dam removal, thus highlighting a weakness in the literature and illustrates the information gap in dam removal projects to date. Scientists have noted this gap in the literature and are developing new sediment transport scenarios **(**Konrad, C. P. (2009); Mussman, E. K., Zabowski, D., & Acker, S. A. (2008); Pizzuto, J. (2002); Poff, N. L., & Hart, D. D. (2002); Sawaske, S. R., & Freyberg, D. L. (2012)). For example, the 2006 "Deschutes Estuary Sedimentation Transport Report" used the Delft3D computer program, a numerical hydrodynamic and morphological model developed by Delft Hydraulics, the Netherlands. This software was developed in the 1980s and is still considered to be one of the premier models for sediment transport and morphology investigations, according to the Deschutes Estuary Feasibility Report. The Delft3D model factors in sediment grain size, deposition, flow, and discharge, but fails to include parameters for the dam removal timeline or sediment cohesion, or to explain how all of these variables can create various negative ecosystem responses. A negative feedback loop created from dam removal is the deposition of fine-grained sediment on flood plains. The influx of non-cohesive material could bury plants and influence the establishment of invasive vegetation, such as Reed Canarygrass (*Phalaris arundinacea*). The report's primary focus was not on the broader ecosystem but on determining which restoration alternative was the best scenario. The report determined that estuary restoration was feasible and would occur after the 5th Avenue Dam removal.

The Deschutes Estuary Feasibility Study used the Delft3D model to assess the four restoration scenarios (listed on page 7) to predict the volume of sediment transported into the estuary based on high and low erosion levels that could occur during four different flow events. Each scenario provided an estimated amount of sediment that would accumulate at the mouth of the Deschutes River and could be transported into Budd Inlet. However, this model relied on a limited amount of empirical data available for the modeling program, thus creating a level of uncertainty about the impacts of stored sediment upon the estuary's ecosystem. The inconsistency in sampling methods used also created a high level of variability in the Sedimentation Transport Report; the results might not have provided an accurate portrayal of sediment conditions of the lake or river channel. Finally, the Deschutes model failed to incorporate any best management techniques for the future management of Budd Inlet.

In 2005, various state and federal agencies collected baseline data for the "Deschutes Estuary Feasibility Study." They broke the monitoring of the lake and river into several sections. Monitoring sites were located through the North, Middle and South Basins of the river and estuary (see Figure 1.2 on page 6). The Department of Ecology surveyed the South Basin and Percival Cove. The Department of Fish and Wildlife surveyed the area under the Interstate 5 Bridge. The United States Geological Survey completed a bathymetric survey between the 5th Avenue Dam and the Port of Olympia. The United State Army Corps of Engineers surveyed the Port of Olympia and sections of Budd Inlet. The Thurston County Regional Planning Department provided the topographic information of the area. The information collected by field staff provided five quantitative data sets used in the Delft3D model to determine sedimentation and hydrodynamics scenarios for the proposed four restoration strategies. The field data collected included surface sediment samples, flow, and cross-section profiles. Unfortunately, the data used in the report were lacking in several areas, such as the various levels of soil erosion. According to the report, the authors decided to determine the level of erosion that could occur in the watershed by looking at two levels of erodibility[1]: a low level and high level. The authors then analyzed how these two parameters would react when critical sheer stress from events, such as floods and the rate of erosion, occurred.

After researching "Deschutes Estuary Feasibility Study" and "Deschutes Estuary Hydrodynamic and Sedimentation Report" and scrutinizing the data supporting their

[1] The level of erosion in the Deschutes Estuary Sedimentation Report is based on two parameters: a high and low level of erosion. These two parameters can impact how sediment is transported and accumulated at the mouth of the river.

conclusions for the 5th Avenue Dam, I decided to focus my thesis research on supplementing the work completed in the sediment transport report. More generally, I am researching the implications of sediment transport in small-scale dam removal projects. This research will answer the following questions: 1) What variables should be considered in the development of a comprehensive sediment transport model when removing a small dam? and 2) What restoration methods should be considered for long-term maintenance of the area?

Research gathered for my thesis will assess how natural resource managers address sediment transport in dam removal projects. The thesis will be organized as follows. Chapter 2 features the methodology used to complete my research and documents my research process and how I selected candidates to interview to gain background information on the Deschutes River and Estuary. Chapter 3 is an overview of dam removal projects, including the influences on river restoration, regulations and management in dam removal projects, inventory of dams, and the size of dams. In Chapter 4, I highlight the issues surrounding the restoration of the Deschutes River and Estuary and the management methods used to address sediment transport in the removal of the 5th Avenue Dam. This chapter also has background information on the Delft3D model, which was used to determine sedimentation scenarios for the removal of the dam. Chapter 5 contains my research analysis. Finally, Chapters 6 and 7 feature a discussion section and a conclusion for this project.

CHAPTER 2

METHODOLOGY

The research completed for my thesis was based primarily on the "Future Areas of Study" section of the 2009 "*Deschutes Estuary Feasibility Study*." That section listed four areas of study that required future research: 1) contamination and pollution dispersion; 2) examination of water quality and seasonal river flows; 3) sea level rise; and 4) improved modeling techniques. After reading the report, I chose to focus on improved modeling techniques and water quality impairments that occurs when a dam is removed. Once I narrowed down my topic I contacted Sue Patnude, Executive Director of the Deschutes Estuary Restoration Team, to discuss my research and develop a list of technical experts who participated in the feasibility study. Ms. Patnude provided me with a list of potential contacts who could provide the history of the study might provide technical advice on the restoration effort. I contacted and interviewed the following people during the months of January and February 2015:

1) Curtis Tanner, Division Manager of the Environmental Assessment and Restoration Division of The U.S. Fish and Wildlife Service, Washington Fish and Wildlife Office;

2) Lance Whitica, Executive Director of the South Sound Salmon Enhancement Group;

3) Guy Gelfenbaum, Researcher with U.S. Geological Survey, Pacific Coastal and Marine Science Center;

4) Carrie Martin, Assets Manager, Washington State Department of Enterprise Services;

5) Elizabeth Grossman, Author, *Watershed, The Undamming of America*;

6) Padraic Smith, Environmental Engineer, Restoration Division, WashingtonDepartment of Fish and Wildlife.

In addition to the interviews, I read journal articles that pertained to the topics of sediment transport, modeling, dam removal, and river restoration practices from the following publications: *BioScience*, *Geomorphology*, *Water Resources Research*, *Nature*, *Journal of Hydraulic Engineering*, *Journal of the American Water Resources Association*, *Ecological Engineering* and *BioOne*.

While writing my literature review, I realized that my research topic required sections that highlighted the historical information of how downtown Olympia converted its estuary habitat to a managed lake. Furthermore, as I began conducting my interviews, I soon realized that I needed to incorporate the evolution of dam removal as a restoration practice, and the way in which researchers are implementing this new strategy to restore rivers and estuary systems.

After reviewing the data and comparing the information provided to methods used in various case studies, and after a site visit to the 5th Avenue Dam, I decided to focus on results on two parameters: volume of sediment released and the timing of how the sediment can be transported and deposited into the system.

CHAPTER 3

DAM REMOVAL

3.1 DAM REMOVAL

Dam removal is a viable restoration practice that returns river systems back to their free-flowing state. Dams can create economic opportunities when installed into a river's system. Rivers provided a seemingly endless supply of water and energy for purposes such as irrigation or hydropower, and create reservoirs for recreation use and water storage. According to the National Dam Inventory Database, 75,000 dams exist in the United States today. The majority of these structures were built during 1900-1949, when our nation's decision makers viewed natural resources as a fuel to support the war effort and for industrialization (Shuman, 1995). Engineers and architects viewed the dams as self-sustaining structures that would only require periodic maintenance and would serve society through their infinitely long lifespan (Shuman, 1995).

However, architects, engineers, and builders failed to factor in how a run-of-a-river dam or the construction of large dams with reservoirs would interact with or impact the rivers' physical, chemical, and biological characteristics and processes (Hart, Johnson, Bushaw-newton, et al., 2002). A river's system changes immediately with dam construction; the impoundment directly effects alterations to the river's floodplain, channel development, and sediment supply (Pizzuto, 2002). (An impoundment is a body of water, a reservoir or lake, created when a dam is constructed in a river system.) Dams also prevent flooding and stop sediment from flushing down into the lower reaches of the stream channel. Weather events, such as snowmelt and heavy rainstorms, can produce high flows, causing rivers to exceed their banks and flood. A dam can help reduce flooding in the downstream reaches of a river system (Shuman, 1995) when its impoundment captures the excess runoff during high flow events. Also, the stored water can be released during scheduled times and used during periods of droughts for irrigation purposes.

Nonetheless, flooding is important in the development of a river's ecological processes. The movement of sediment and periodic high water flows in a river's system help create and form a stream's hydrologic regime (Pizzuto, 2002). River systems benefit from flooding because these natural events transport silt into the floodplains. A flood event helps replenish the soil along a river's riparian area. The soil deposited after a flood has nutrients that aid in crop production. When a dam is constructed in a river, it prevents flooding from occurring and can starve the riverbanks from soil deposition. Over time, the decline in these natural processes can lead to water quality impairment and the loss of aquatic habitat (Gottgens & Evans, 2007).

Stanley and Doyle (2002) argue that the effects of nutrient dynamics, such as the movement of nitrogen and phosphorous in a river system, must be a priority in research and restoration plans. The retention of nutrients in a reservoir or lake is a concern for natural resource managers because the imbalance of nutrients can cause negative effects on the downstream reach. Impairments to the stream's water quality and sediment deposition can be harmful to migratory taxa, such as salmon and other aquatic species. Unfortunately, the ability to predict how stored nutrients move throughout the river channel after dam removal is a complex problem. Some scientists, Stanley and Doyle (2002) and Poff and Hart (2002), for example, claim that restoration efforts should be examined from a watershed scale perspective so that factors, such as land use change, can be incorporated into restoration plans. Furthermore, Stanley and Doyle (2002) advocate for dam removal to be used as an experiment to test predictions and to gain insight in how nutrients can be transported and retained in a river's reach.

The Deschutes Estuary Sedimentation Model did not include a comprehensive set of sediment samples but instead focused on bathymetry, boundary conditions, and time-varying processes, such as river discharge. In recent dam removals, such as the Elwha and Glines Canyon Dam Removal projects, scientists used a landscape evolution model to determine the delta's erosion by integrating field monitoring data and modeling software. A river's delta, located at the mouth of a river system, is at a low elevation and its formation results from the transport of sediment carried from the river's source, commonly found at higher elevations. Hydrologic and hydrodynamic processes influence the particular morphology adopted by a river's delta (Gelfenbaum, et al, 2015). Field studies of river delta morphology have allowed researchers to classify river deltas based on tidal processes, waves, and river discharge (Gelfenbaum, et al 2015). In addition to these processes, the formation of the delta is dependent up the effect of the sediment grain size and how this will interact with the delta's morphology (Gelfenbaum, et al, 2015). The type of sediment deposited in a delta can be transferred from erosion or through the transport processes that can vary with different flow events (Gelfenbaum, et al, 2015.). In addition, the sediment transferred into the delta can be deposited in adjacent beaches and near shore zones (Gelfenbaum, et al, 2015).

The installation of the 5th Avenue Dam has starved Budd Inlet from receiving sediment from the Deschutes River. Sediment transported from the Deschutes River is accumulated in Capitol Lake because of the 5th Avenue Dam. The dam has disconnected the river and estuary habitats. The 5th Avenue Dam, operated by the Washington Department of Enterprise Services, prevents the Deschutes River from reaching Budd Inlet in a natural fashion. Composed of concrete, the 5th Avenue Dam rises height 45 feet and has an 82-foot wide rectangular spillway. Figure 3.1 shows the design of the 5th Avenue Dam. The dam features a fishway channel and gates driven by water level sensors in the lake and in Budd Inlet (Carrie Martin, Asset Manager, Washington Department of Enterprise Services explained (Personal Communication, March 3, 2015)).

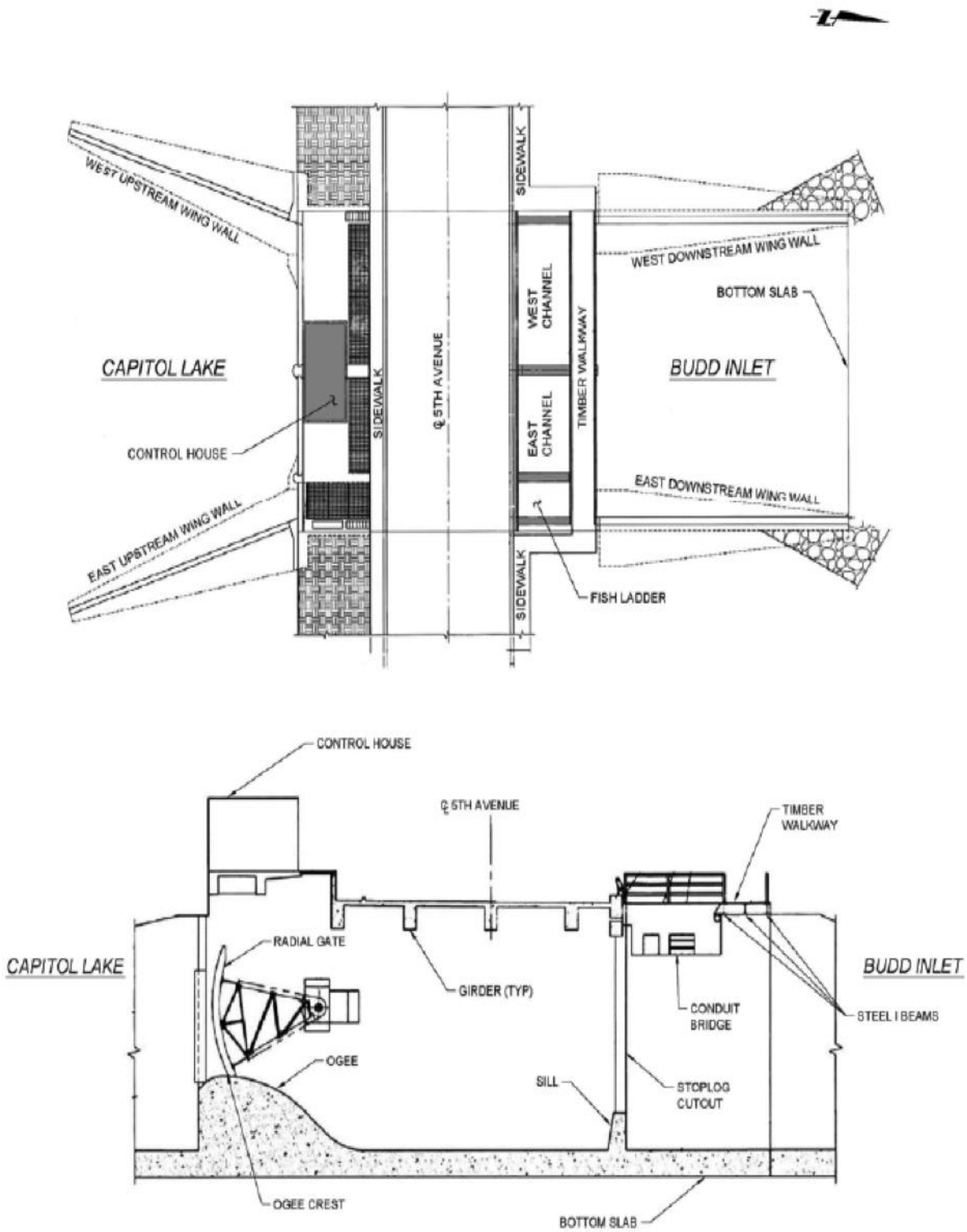

Figure 3.1 A detailed schematic design of the 5th Avenue Dam.
(Washington Department of Enterprise Services)

Dam operators monitor the lake's water level to ensure that when the dam's gates open, tidal water does not enter Capitol Lake. The 5th Avenue Dam's gates are schedule to release water based upon the Deschutes River flow. Capitol Lake's depth is approximately 6.2 feet in the summer and approximately 5.2 feet during the winter season; therefore, water levels fluctuate during the various seasons and weather events. Additionally, the inflow rate from the Deschutes River affects the lake level. When high flow events, such as winter rain storms, occur in the Deschutes River basin, the dam operators will release the additional flow into Budd Inlet (Martin, Personnel Communication).

Dam operators rely upon the tide cycle to determine when they will open and close the gates. For example, there are two high tides and two low tides each day, and the field staff monitoring these cycles will open the gates twice a day. During the scheduled release events, some of the sediment that has been deposited into the lake will enter Budd Inlet. State officials do not have a clear understanding the behavior of how and where the sediment gets deposited because there has not been a completed field survey of how the sediment might be transported. To date, the only research that has been completed on sediment transport was completed during the Study, when officials examined if it was feasible to restore the estuary, Sue Patnude, Executive Director of the Deschutes Estuary Restoration Team said (Personal Communication, February 12, 2015). Even though estuary restoration is feasible, state officials have not made a decision to restore the estuary and Capitol Lake has been just operating at the status quo.

All of the sediment transported from the Deschutes River's source gets deposited in Capitol Lake's three basins. State officials have been debating over various methods to manage the sediment deposited in Capitol Lake. To date, the only method used to manage the accumulated sediment has been the dredging of lake in 1979 and 1986.

When the 5th Avenue Dam is removed, the sediment that has deposited in these regions will become part of the re-formation of the estuary. However, that will require a strategic plan to address how the sediment will be transported into the Budd Inlet, and at what rate. The Study determined that approximately 60 percent of the existing sediment would need to be removed, Curtis Tanner, Division Manager of the Environmental Assessment and Restoration Division of The U.S. Fish and Wildlife Service, Washington Fish and Wildlife Office, explained. The removal of this sediment would be accomplished by dredging the fill material and transporting the debris to an off site location. The remaining material would then be allowed to flow into Budd Inlet. Determining how the sediment and tides will interact in influencing the deposition of the soil will require extensive study, modeling, and planning. One of the methods to predict how these interactions will occur is through the use of models, such as the Delft3D model. In the discussion portion of the Deschutes Estuary Feasibility Study, the authors stated that further research should explore what new modeling techniques have been developed since the publishing of the report to provide a more accurate prediction of erosion and deposition.

In the last decade, scientists have started viewing dam removal as a method to restore river systems back to their pre-disturbed states. Over time, the dam structures and the surrounding environment have begun to deteriorate, causing increases in the dams' operational and maintenance costs. Dam operators must address potential stressors, such as harmful algal blooms and the crumbling or cracking of concrete due to pressure from the collection of silt. Dams severed salmon migration, which is a concern for communities in particular those located in the Pacific Northwest that thrive on fish populations to support the local economy. The installation of fish ladders, dredging of the reservoir, and scheduled water releases are a few best management practices implemented to address these issues.

However, these mitigation strategies are only temporary measures to the long-term operational and maintenance of a structure (Pohl, 2002). According to Babbitt (2002) the old view of dams, the "build now, ask questions later" approach, has been replaced by river restoration efforts, largely due to the high level of uncertainty in the impacts that impoundments have upon environmental and public health. For example, if anyone proposes a dam project today, either building or removing one; they must complete a series of environmental and social impact studies, such as how the installation or removal of a dam might affect area businesses. "The efficacy of dams is being scrutinized in new comprehensive analyses of ecology, economics, energy efficiencies, water conservation and public safety," Elizabeth Grossman wrote in her 2002 book *Watershed: The Undamming of America.* Completing an assessment of the environmental and social impacts before the installation of a new dam or upgrade to an existing dam is important because it allows all parties involved to examine the alterations to the surrounding ecosystem. In some dam construction projects, the structure can impede fish passage, or fragment habitat that is utilized by a variety of terrestrial and aquatic species. By completing these studies, researchers and policymakers are able to gain a better understanding of the impact that removal, installation, or upgrade will have upon the entire ecosystem and what ecosystem services might be lost or altered. Babbitt says local and national governments rely upon the precautionary principle [2] to determine if the benefits of removal outweigh the continued use and benefits of the dam.

Federal and state agencies inspect and monitor dams to ensure that the structures meet federal and state codes. In Washington State, the Washington Department of Ecology (also known as Ecology) regulates dams that capture and store at least 3.2 million gallons of water (Washington Department of Ecology, 2014). Ecology's Dam Safety Office currently oversees 1,019 of 1,141 dams across the state and monitors these structures through inspections (Washington Department of Ecology, 2014). These periodic visits give regulatory staff the ability to assess the structures' integrity. In the case of the 5th Avenue Dam, different types of inspections for the dam occur at different intervals, Martin explained (Personal Communication, March 3, 2015). Because the dam also serves as a bridge, the Washington Department of Transportation checks it for structural soundness. Safety technicians inspect the accessible areas of the structure once every two years and perform an underwater structure inspection every five years. Additionally, the Department of Enterprise Services maintains the mechanical systems, exterior sensors, hydraulic system, and electronic control components. Moffatt and Nichol, an engineering firm based in Seattle, Washington, completed the last full assessment of the dam in 2008.

Pohl (2002) breaks down the rationale behind dam removal into three main categories: economics, safety, and the environment. The economic costs of repairing defects found during an inspection of a dam often drives the removal of these structures (Babbitt, 2002). The economic analysis of the Edwards Dam on the Kennebec River

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[2] Policymakers use the precautionary principle as a decision-making tool to determine if a particular course of action should be made on an issue, in this case the removal of a dam. This principle is used when extensive scientific knowledge is limited on a subject matter

showed that dam removal would cost $2.7 million, compared to $10 million for dam modifications (Doyle, Harbor, Stanley, 2003). Even though the Edwards Dam still produced electricity, it generated only a small amount, an estimated 0.1 percent of Maine's total electric supply (Doyle, Harbor, Stanley, 2003). The cost of upgrades to the structure warranted total dam removal rather than the necessary modifications. The Woolen Mills Dam, located in Wisconsin, was an abandoned structure that was deemed a public safety hazard and required repair (Doyle, Harbor, Stanley, 2003). The modifications to this structure would have cost an estimated at $3.3 million, compared to the $80,000 to remove the structure (Doyle, Harbor, Stanley, 2003). Again, the high costs of upgrades led to the removal of the dam in 1988.

The financial burden to repair or upgrade a dam is prompting dam owners to use dam removal as a tool to return rivers back to their natural states. This change in awareness, and a change in attitude of many from pro-dam to pro-removal, has opened up new avenues in river restoration methods, adding dam removal to the list of potential strategies to restore ecologically degraded rivers (Babbitt, 2002). Additionally, dam removal taps into a social component of environmental stewardship. Downs et al (2009) says that society's shifting ethos toward this new trend allows the public to "feel good" about removing a dam.

Returning to the case of the 5th Avenue Dam in Olympia, state and federal officials have come to a roadblock in the removal of this structure. Tanner, Division Manager of the Environmental Assessment and Restoration Division of The U.S. Fish and Wildlife Service, Washington Fish and Wildlife Office, says that society's opinion on whether or not the dam should be removed plays a critical role in whether or not the river and estuary are restored: “What do you want it to look like?” he asked (Personal Communication, Jan. 23, 2014). One of the biggest hurdles in the removal of the Edwards Dam in Maine was explaining to people what the river system would look like after dam removal, Grossman, author of *Watershed: The Undamming of America,* said (Personal Communication, February 10, 2015). “There were no photographs of what the river was like before the dam went in. They thought the impounded river was the way a river was suppose to be. Some thought that if you removed the dam, it was going to be an empty bathtub.” Gelfenbaum shares a similar opinion about restoration ecology in general: “Restoration is a little about the science and a lot about what people want,” (Personal Communication, Jan. 27, 2014).

The Milltown Dam, located on the Clark Fork River in Montana, illustrates how arduous dam removal can be for a community. The Milltown Reservoir, 7 miles east of Missoula, Montana, was found to be contaminated when Montana Department of Environmental Quality discovered arsenic in the groundwater. This likely resulted from a massive flood in 1908, which washed millions of tons of mine waste into the Clark Fork River (Grossman, 2002). Because of the dam, the pollutants remained trapped in the reservoir. In 1983, United States Department of Environmental Protection added the Milltown Dam to the National Priorities List for removal due to groundwater contamination. Only in 2001 did state and federal agencies start the process of removing more than 2 million cubic yards of sediment; in 2006 the dam was demolished (Grossman, 2002). One of the struggles with the removal of the Milltown Dam, explained Grossman, was the disposal of that contaminated sediment. “The fate of this toxic material was the biggest issue,” she said. State officials decided to haul the sediment upstream to the town of Opportunity to deposit the material. There was some opposition about the removal, but overall, people did understand the need for the dam removal. According to Grossman, this came from the efforts of the Clark Fork Coalition, a local watershed group based in Missoula, which attempted to educate the communities on the problems with the sediment and the importance of its removal.

Now that dam removal is an option, ecologists are engaging in natural experiments with dam removal by documenting the return of ecosystem processes lost or altered by dams. Prior to the removal of the Glines Canyon and Elwha Dams on the Elwha River in Washington, the majority of the research literature primarily focused on how dams alter the river's ecological processes (Gregory, Li, & Li, 2002). Engineers and geomorphologists studied river characteristics such as incision, floodplain formation, and channel development--all functions critical in assessing the health of a river's hydrologic regime. Water temperature, channel morphology, and habitat diversity were considered to be "master variables" in river restoration (Poff & Allan, 1997). These parameters do play an important role in determining the distribution and abundance of riverine species. Yet historically, environmental regulations have been limited in scope, mainly focusing on one aspect of water quality: minimum flow. Poff and Allen (1997) argued that by returning a river back to its natural flow regime, the biodiversity and ecosystem processes of the river would be restored.

The scientific framework for reducing the impact of dam removal upon the upstream and downstream ecosystems is emerging in the field of restoration ecology (Hart, Johnson, Bushaw-newton, et al., 2002). Although dams have been removed from rivers throughout history, restoration ecologists have noted the lack of documentation on the size of the dam, and methodology utilized in past removal projects (Stanley & Doyle, 2002; Pizzuto, 2002). Only a few peer-reviewed articles on the different approaches used to remove dams appear in a handful of scientific journals prior to the 1980s (Gottgens & Evans, 2007). This small number of peer-reviewed studies indicates a significant lack of information on how ecosystems respond to dam removal (Hart, Johnson, Bushaw-newton, et al., 2002).

More recently, ecologists have been filling in this information gap by incorporating the response and recovery process into their restoration plans and publishing this information in journals. After completing an extensive review of literature for this project, I found a trend in the publication of research results. From my research, I have discovered that the majority of articles were published in late-1990s, 2000, and 2002. This number has risen since dam removal projects have increased, in particular with the removal of large-scale hydroelectric facilities. For example, the monitoring of the Elwha and Glines Canyon Dam removals alone has increased the amount of literature on dam removal projects. Researchers are closely monitoring various terrestrial and aquatic parameters, such as vegetation establishment and morphological response time, which were typically not documented before.

For example, in January 2015, the journal *Geomorphology* featured a series of articles about the Elwha River removal project. The United States Geological Survey, the Bureau of Reclamation, the National Park Service, the National Oceanic and Atmospheric Administration, and the University of Washington collaborated on reporting the most recent findings. The group published five separate journal articles on the following topics: sediment budget, erosion of reservoir sediment, fluvial sediment load, river channel and floodplain geomorphic change, and coastal geomorphic changes. The scale of analysis and documentation of the both positive and negative results that are occurring from this specific removal project is changing the scientific community perception on river and coastal restoration efforts. Scientists are evaluating dam removal and river restoration practices in a more holistic method by observing parameters not only occurring on the river, but also occurring in the river's delta and near shore area, connecting the effects that are appearing in the river and coastal zones. The prior methods, used were typically reductionist, where only the parameters of water quality and channel morphology were documented (Bednarek, 2001). In the article featuring the Elwha River delta coastal geomorphic changes, the journal authors wrote the following about the removal project: " The removal project provided an unprecedented opportunity to examine the geomorphic response of a coastal delta to these increases [the sediment released]" (Gelfenbaum et al, 2015).

Furthermore, researchers have been examining different methods of how to remove a variety of dams, from large hydroelectric facilities to a low-head dam on a small stream. In the case of the Elwha River, the project managers determined that a staging was the best option in the removal of these two structures. (Staging is the process of removing the dam in several phases to allow the ecosystem to slowly respond to the increased movement of sediment and flow.) For the removal of the Marmot Dam, located on the Sandy River in Oregon, the researchers decided to use the "blow and go method." (The blow and go method utilizes blasting equipment to remove the dam from the river all at once.) By studying the different removal processes, researchers are monitoring how the ecosystem is changing. In *Coastal Geomorphic Changes,* the researchers spent the first two years after the dam removal observing and documenting the alternations to the Elwha River delta. Weekly observations and repeated beach survey results were combined with digital elevation models to determine the amount of accumulation of sediment in the river's delta (Gelfenbaum et al, 2015). The monitoring efforts provided unprecedented data about the beach and seafloor grain size changes. By documenting these parameters, the researchers could calculate a sediment budget based upon the volume and grain size observed in the delta (Gelfenbaum et al, 2015). Thus, by combining field observations and the use of modeling results, the researchers were able to develop and validate the increases in sediment.

The combination of pre- and post-monitoring of a river's ecosystem represents a shift in the strategies to restore river systems. In the case of the Elwha and Glines Canyon Dam removals, ecologists started gathering data at the site several years before the barriers were slated for removal. Water quality, established channel width, and the presence of aquatic and terrestrial species were a few of the parameters documented in the year prior to the removal. The data collection allowed them to establish a baseline of information to assess the stressor-response relationship that existed between the dams and the river. The monitoring also investigated potential ecological responses that might be manifest when the dams were breached (Hart, Johnson, Bushaw-newton et al., 2002). Researchers measured parameters such as river cross-sections, sediment cores, flow velocity, sediment grain size, color, composition, and structure. The incorporation of temporal and spatial components, such as time and recovery of the river channel, and the correlation of this information to the watershed characteristics, has helped inform the adaptive management and restoration techniques of dam removal (Gregory et al., 2002).

Now, factors such as a river's longitudinal profile, channel position, suspended sediment load, and water levels are collected for several months to a year before a dam is scheduled for demolition. Additionally, the timing of the removal and the estimated volume of sediment distributed once the barrier is removed must also be considered. Most dam removal projects typically occur during the late spring and early fall seasons as a result of concerns about stream flows--the natural resource manager's target for dry temperature and consistent stream flows to transport the material downstream. Researchers now actively document flow and sediment parameters prior to the removal so that models can predict the outcome of such actions and guide which restoration techniques should be applied (Konrad, 2009).

In 2005, Cui et al developed a two-part model called Dam Removal Express Assessment Model (DREAM). The DREAM model simulates non-cohesive sediment transport after dam removal. The DREAM-1 model documents fine sediment transport (sand or finer material), while the DREAM-2 model is able to simulate both coarse and fine sediment. This model was pivotal in the removal of the Marmot Dam because the dam by allowing researchers to predict the scale of the sediment flume that would be transported downstream once the structure was demolished. However, this model also has limitations. Cui et al was unable to provide a detailed channel response at a morphological unit scale (Cui et al, 2006). With extensive monitoring, scientists are using this data to track the river's ecological process, as well as to advance the science of ecology by viewing restoration efforts from a systematic approach (Hart, Johnson, Bushaw-Newton, et al., 2002).

3.2 RETURN OF A RIVER

The term “river restoration” generates controversy because it suggests that a river’s fluvial system can be returned to a pre-disturbed state (Pizzuto, 2002). Returning a river back to anything resembling the previous natural hydrologic regime requires extensive planning. The use of historic aerial photography, paleohydrologic studies of debris left by floods, and studies of historical damage to living trees are several methods used to assess how a river system’s floodplain and riparian vegetation responds during high flow events (Schmitz et al, 2009). For the Deschutes Estuary, historical photographs have provided researchers and me with a glimpse of the conditions existing prior to the installation of the 5th Avenue Dam.

The current scientific knowledge about predicting the ecosystem response to dam removal is relatively limited (Poff & Hart, 2002). A river’s own fluvial processes adds levels of uncertainty to the process (Pizzuto, 2002). As a result, the ability to fully understand the complexity of a river’s hydrologic structure may require extensive monitoring for decades, even centuries. Poff and Hart (2002) argue that in order to have an effective restoration plan, scientists must identify the full range of potential stressors to the river, including the volume and sediment grain size that could be released once the dam is breached. To predict these outcomes, scientists must gather baseline data, often information not available due to the lack of pre-removal monitoring efforts. Since in the past many viewed dams as having infinite lifespans, the idea of removing the structures was not something planners’ or politicians’ considered and they did not contemplate the need to collect data on how the system operated prior to removal. For example, when the state legislature approved the installation of the 5th Avenue Dam in 1938, state officials did not consider in 50 years the state legislature would contemplate the structure's removal.

More recently, scientists have started using spatial distribution models to predict the volume and magnitude of discharge and suspended sediment load once the impoundment is removed (Granata, Cheng, & Nechvatal, 2008). For example, scientists utilize stream channel cross-section surveys to generate a potential sediment discharged rate. Parameters such as channel depth and width provide researchers with data that can be plugged into a Manning's equation[3] to create a probable discharge rate that could occur when the barrier is removed (Granata et al., 2008). Also, researchers can tap archival data, such as maximum daily turbidity, and correlate the turbidity levels to discharge rates by assessing trends seen in a regression model (Granata et al., 2008). The two parameters determine how much total suspended solids exist in the water. Also, evaluating these parameters helps determine how much existing sediment is being transported by the river's system.

Parameters such as dissolved oxygen, total suspended solids, daily stream flows, and so forth, monitored by various state and federal agencies and private companies, give scientists just enough information to predict ecological outcomes. Poff and Hart (2002) claim that monitoring all potential parameters may be labor-intensive and increase removal budgets, but this information is necessary in order to develop a comprehensive restoration plan. Some researchers argue that ecological responses can be predicted based only on the use of existing data (Chang, 2008). This conflict has prompted scientists to

[3] A Manning's equation is one of the most commonly used equations to determine stream channel flows. Robert Manning, an Irish Engineer, first introduced the equation in 1889 as al alternative to the Chezy equation. The Manning's equation is an empirical equation that is applied to uniform stream flow by utilizing the channel's velocity, flow area and channel slope.

develop conceptual models such as the DELF3D to determine which restoration scenario is the most feasible and best suited for the ecosystem (Hart, Johnson, Bushaw-Newton, et al., 2002). Various models provide various outcomes. Spreadsheet-based models calculate sediment yield, accounting for trapping of sediment by upstream reservoirs and changing trap efficiency with time (Cui et al, 2006). The landscape evolution model (LEM) simulates topographic evolution at a wide variety of spatial and temporal scales (Cui et al, 2006). Hydraulic flow and sediment transport models such as SRH-2D produce different results from LEMs because the simulations of the flow range are less detailed (Cui et al, 2006). Each one of these various types of models predict an outcome, but the level of detail of the results can vary based upon its application.

3.3 INFLUENCES ON RIVER RESTORATION

Scientists continue to face controversy over the notion of returning our rivers back to a “natural state” because of impacts historical and current land use practices have upon rivers and river systems. Many of our rivers have been impacted not only by the impoundments themselves but also by various anthropogenic factors such as nonpoint source pollution (Stanley & Doyle, 2002). Oil leaks, garbage, pet waste, and lawn fertilizer are several sources of nonpoint source pollution that impair the Deschutes River and Estuary. On the other hand, environmentalists and some politicians see dam removal as a method to compensate for the negative effects of human activities on river ecosystems. However, dam removal should not be considered as a solution that will automatically return a river back to its natural state. The ability to totally remove the impact of humans from the ecosystem is often impossible (Hart, Johnson, Bushaw-Newton, et al., 2002). Even after impoundment removal and restoration efforts, the river system may not be restored fully due to its proximity to urbanized areas (Roberts, Gottgens, Spongberg, Evans, & Levine, 2007). Stanley and Doyle (2002) and Hart et al (2002) state that restoration plans must examine both the local and regional environment to determine the dynamics between the barrier and the river. By looking at the dam from a variety of perspectives in the restoration planning process, scientists and restoration ecologists can develop a broad understanding of the magnitude and range of physical, chemical and biological responses to dam removal.

Indeed, Hart and Poff (2002) view dam removal as an experimental practice that can provide a better understanding of the intricate relationship between the barrier and the river. Hart and Poff claim that by assessing existing dams, reviewing case studies of previous dam removals, and incorporating current monitoring and historical data, models such as the erosion prediction model can prevent extensive damage from occurring when the dam is removed. Researchers on the Elwha River project, for example, used tools such as the Universal Soil Loss Equation, a formula that helps determine the annual amount of soil loss that occurs in river systems due to erosion. Team gathered sediment core samples from the dam's reservoirs and created an experimental model that examined the application of three different treatment methods to reduce further erosion from occurring in the river's channel post removal (Mussman et al., 2008). By considering the potential outcomes, researchers were able to develop a multi-stage restoration plan that incorporated various best management practices to help reduce runoff and erosion from occurring in the up and downstream reaches.

3.4 REGULATIONS AND MANAGEMENT

The environmental trade-off of changing a river's flow regime from a lotic[4] to a lentic system was rarely considered (Graf, 1999) until the late 1980s, when federal agencies, such as the Federal Energy Regulatory Commission (FERC), began cracking down on deadbeat dams by enforcing environmental regulations. Mandates set forth by the Clean Water Act, the Endangered Species Act, and the Federal Power Act are driving dams to be removed from rivers (Babbitt, 2002), as outlined below. These specific legislative acts require FERC and other federal agencies to examine the environmental, economic and social tradeoffs occurring in the surrounding area since the installation of the barrier.

The Federal Power Act of 1920 created FERC, which oversees the construction and maintenance of dams in the United States. FERC determines the operational uses of a dam by considering the environmental impacts that the structure has upon the ecosystem. In the 1960s, FERC began regulating all non-federal hydro projects across the country (Winter & Cain, 2008). FERC issues permits to dam operators for either 30 or 60 years in order for the dam to generate power; once the permit has expired, the power company must apply for a new permit. During this process, FERC can determine if the dam should be maintained, upgraded, or removed. In the case of the Condit Dam on the White Salmon River in Washington, FERC required the power company to install a fish passage system in order to receive its re-licensing agreement to generate power. However, the power company decided to remove the dam because the demolition costs were significantly lower than the mandated upgrades.

[4] A lotic system describes fast moving water, and an example of this would be a river system. A lentic system is a still body of water, and an example of this would be a lake or reservoir.

The majority of the dams have been removed from United States river systems because of the high costs of upgrading the structure to meet environmental regulations. Because those costs far exceed those of demolishing the structure, dam owners typically decided to remove the barrier. Researchers estimate that by the year 2020, 85 percent of the dams in the United States will be near the end of their operational lives (Doyle, Harbor & Stanley, 2003). This statistic indicates that dam removal most likely will continue to occur and that methods on how to address the ecosystem response to the breaching need to be addressed.

3.5 INVENTORY OF DAMS

State and federal agencies created databases to monitor the number of dams and their potential safety hazards. The Army Corps of Engineers manages the National Inventory of Dams (NID); this system classifies all dams and tracks the age and repair status of the barriers. The National Inventory of Dams records all dams that are potential safety hazards. According to the National Inventory of Dams' website, the dams listed in the database meet at least one of the following criteria:

1) High hazard classification - loss of one human life is likely if the dam fails,
2) Significant hazard classification - possible loss of human life and likely significant property or environmental destruction,
3) Equal or exceed 25 feet in height and exceed 15 acre-feet in storage,
4) Equal or exceed 50 acre-feet storage and exceed 6 feet in height.

However, this database is not an accurate representation of all the dams that have been installed in US river basins. The majority of the dams located throughout the US river systems are categorized as small-scale structures—having a height of 6 feet or less. Many of the small dams constructed in river drainage basins do not meet the criteria and are not listed in the NID database due to the height requirement. This highlights the major drawback of the NID: the list is not comprehensive and lacks a significant portion of barriers impeding river systems. Stanley & Doyle (2003) report that small dams are being removed from river systems but their removal was never well-documented because of their categorization as a small-scale structure. Many researchers have focused on removal of large-scale hydro projects and viewed small dam removal as not having a significant impact upon the ecosystem, but this perspective is changing. Regardless of a dam's size, the structure impacts the stream's physical, chemical, and biological processes.

3.6 SIZE OF DAMS

Small-scale dam removal is not well studied; there is a deficiency in the amount of published literature on their removal (Stanley & Doyle, 2002). However, because there are so many small-scale dams in our river systems, researchers are now looking at various methods to remove these structures. Some river systems may have several small-scale dams in their stream reaches, and removal of one or all of the dams could have a significant ecological impact. Still, we know little about the magnitude of potential positive or negative effects because of the absence of peer-reviewed studies that specifically focus on small-scale dams (Stanley & Doyle, 2002).

The size of the dam in question was ignored by scientists in previous restoration efforts. Scientists now compare the effects of removal of human-made, small-scale dams to that of natural barriers like beaver ponds and waterfalls. Researchers are drawing parallels between the physical or biological impacts of small-scale dams and natural barriers in a stream's channel design. Some parameters, such as the effects on nutrient cycling, habitat and biotic migration, could be monitored to develop a conceptual framework that reveals what ecological effects might be reversible, post-dam removal.

The criteria set forth by the National Inventory of Dams and the state's dam safety office provides a set of guidelines for local, state, and federal agencies to monitor dams. In the case of the 5th Avenue Dam, the Department of Enterprise Services regularly monitors this structure. The 5th Avenue Dam, with a height of 45 feet, falls into the category of a large-scale dam. In addition, the extent of sediment deposition in the lake is severe. To remove the structure, natural resource managers will have to develop a restoration plan that addresses the volume and magnitude of sediment that would be released. This would require an examination of the volume of sediment that will be flowing into Budd Inlet. Padraic Smith, Environmental Engineer, Restoration Division, Habitat Program at Washington Department of Fish and Wildlife, suggested that the restoration of the Deschutes Estuary and the removal of the 5th Avenue Dam should be compared to a natural disaster in terms of how to manage the sediment released. Smith, who works closely with the ArmyCorps of Engineers on managing and upgrading the sediment retention structures on the Toutle River, suggested that some of the methods applied to the Toutle system could be applied to the restoration of the Deschutes Estuary. "You have two perspectives on how you should manage this area. We [engineers/natural resource managers] could trample down the grass three times a year, or should we create a large event (natural disturbance) and let the channel equalize itself," he explained. Additionally, since the Deschutes Estuary has been altered since 1951 when the dam was constructed, the sediment that will be dispersed into the system will provide new habitat for aquatic and terrestrial species. However, some pro-lake supporters don't quite understand the importance of sediment and view it as a nuisance and not as an important resource. "Sediment isn't a bad thing. It's part of the system," Smith said.

Applying these theories and concepts to the 5th Avenue Dam may be difficult because the dam is located at the mouth of the Deschutes River, which creates the Deschutes Estuary. I have spent countless hours researching case studies trying to find a scenario that is similar to the 5th Avenue Dam. I have discovered that the 5th Avenue Dam is a unique situation. The majority of dams installed into a river system are located several miles upstream in the upper estuary or river environments, not directly located in the estuary habitat.

One example with some attributes similar to those at the 5th Avenue Dam is the Chambers Creek Dam, located two miles from Steilacoom in Pierce County, Washington, in the upper estuary environment. The Puget Sound Near Shore Ecosystem Restoration Project has developed a restoration plan for this area, featuring two restoration options: full or partial restoration. Because the Chambers Creek Dam is located in the upper reaches of the estuary and in a former industrial, now urbanized, area, the restoration of this creek and estuary requires extensive modifications to the surrounding infrastructure. For full restoration of the estuary to occur, the plan calls for the removal of the dam, the removal of culverts to daylight two streams, the relocation of a roadway, and the extension of the railroad trestle to increase the width of the inlet to the Puget Sound.

Even though the Deschutes Estuary and the Chambers Bay Estuary feature similar attributes to the restoration of the freshwater and tidal environments, the projects are very different. The restoration of the Deschutes Estuary has been an ongoing topic of conversation by local and state leaders; however, movement to restore this urban habitat has not progressed. Restoration of this area has been halted largely due to the fact that the dam creates Capitol Lake, an iconic public recreation area that is heavily used by the public for recreation purposes.

Additionally, the removal of the 5th Avenue Dam and the restoration of this area is relatively in its infancy. The Deschutes Estuary Feasibility Study's primary goal was to examine the four restoration scenarios and determine, which option was best suited for the area. Beyond this study, there has not been any further development of a restoration plan, such as the one drafted for the restoration of Chambers Bay. Chapter 6 below develops a list of sediment management scenarios for the removal of the 5th Avenue Dam.

CHAPTER 4

THE 5TH AVENUE DAM

4.1 DESCHUTES RIVER AND ESTUARY

The Deschutes Estuary Restoration Team (DERT) aims to remove the 5th Ave Dam at the mouth of the Deschutes River in Olympia, Washington. The dam, built in 1951, creates a reflecting pond, known as Capitol Lake. The lake, maintained by Washington Department of Enterprise Services, violates the Clean Water Act because the dissolved oxygen levels are not meeting federal standards. As outlined above, the dam also traps sediment and keeps it from reaching Budd Inlet to provide the necessary habitat for aquatic species.

An environmental assessment completed by the Capitol Lake Adaptive Management Plan (CLAMP) Steering Committee identified dam removal as the best option for the Deschutes River watershed restoration. CLAMP commissioned a six-year study of four scenarios for the future of the watershed. But progress to move forward in the removal process has stopped. In 2010 the state government disbanded CLAMP and movement to remove the 5th Avenue Dam turned from a state-funded project into a local grassroots campaign.

4.2 CAPITOL LAKE

The Washington Department of Enterprise Services (DES) manages Capitol Lake, and oversees operation and maintenance of the reservoir. Facilities staff monitors flow conditions and conducts schedule water releases to minimize flood risks from high tides and rain events, Carrie Martin, Assets Manager of Washington Department of Enterprise Services, explained (Personal Communication, Feb. 2, 2015).

Additionally, DES manages the trapped sediment in Capitol Lake. To date, Capitol Lake has been dredged twice since the dam's installation. Historical records show that from 1952 to 1974 an estimated 660,000 cubic feet of sediment had accumulated in the lake. DES first dredged the lake in 1979. Approximately 250,000 cubic feet of sediment was removed from the South and Middle Basins and was used to create Tumwater Historical Park (Washington Department of Enterprise Services, 2006). The second dredging event occurred in 1986, when approximately 57,000 cubic feet of material was removed from the Middle Basin. After this dredging event, state officials decided to form a committee to develop a restoration plan for maintenance dredging. During this process the Capitol Lake Management Plan (CLAMP) Steering Committee was formed in 1997. In 1999, CLAMP started to explore four restoration scenarios:

1) Lake/River/Wetland
2) Lake
3) Estuary
4) Lake/Estuary

Based upon the report's findings, the best alternative was complete estuary restoration. However, there has been no progress to move forward with the removal of the 5th Avenue Dam and the restoration of the 260 acres of urban estuary habitat. "One of the main issues with restoring the estuary is that people don't know what the watershed is suppose too look like," Sue Patnude, Executive Director of the Deschutes Estuary Restoration Team said (personal communications, Feb. 2, 2015). Since 2011, the restoration team has been working to educate the public on the importance of restoring this urban watershed. The group has also been creating a bipartisan relationship with the

Capitol Lake Improvement and Protection Association (CLIPA), a pro-lake non-profit group located in downtown Olympia. Both organizations have been meeting on a monthly basis to develop a community forum to present their arguments and help educate the downtown community about various proposed methods on the way in which Capitol Lake should be managed. Even though the estuary scenario was selected as the most economic and effective option, state officials have not moved forward with the development of a restoration plan. "To date, no permits or management alternatives have been selected for Capitol Lake," Martin explained (personal communication, Feb. 4, 2015).

4.3 SEDIMENT

As indicated earlier, dams trap sediment. The sediment stored behind the dam is sculpted by the river's hydrologic regime. The amount of sediment deposited behind the barrier depends on flow of the river and the size of the dam. Large-scale hydropower dams will have a greater amount of sediment deposited due to the large reservoirs created. Small dams or valley dams have a lower amount of sediment deposition because they are smaller in scale (Sawaske & Freyberg, 2012). Ecologists and environmentalists worry about the amount of sediment stored behind the reservoir because the volume of sediment movement could exceed the river's established bankfull width[5] (Gregory et al., 2002). If bankfull width is exceeded, events like flooding or a large wave of sediment can cause extensive damage to the downstream aquatic and terrestrial environments. Researchers are trying to minimize the potential negative impacts by using models to estimate the river and barrier stressor-response relationship. Researchers are starting to

[5] Bankfull width is the point in a stream channel where water reaches a point in elevation on the riverbank before it overflows into the floodplain.

track a reservoir's storage capacity to determine the capacity loss that can occur from upstream sedimentation events.

The development of tools, such as sedimentation models, allows researcher's to predict sedimentation rates and identify reservoirs that might be subject to rapid sedimentation (Minear & Kondolf, 2009). Sedimentation models operate on small temporal and spatial scales and utilize data, such as daily flows, reservoir bathymetry and sediment grain size (Minear & Kondolf, 2009). However, these existing models fail to include two important factors: the effects of trapping by upstream reservoirs, and changes in the rate of sediment retention, which is know as the trap efficiency, every time as a reservoir fills (Minear & Kondolf, 2009). Minear and Kondolf (2009) argue that sedimentation models could benefit natural resource managers if they included a tool that would allow researchers to expand the scope of the model to a regional level so that reservoirs located within a large-scale watershed could be identified based on land disturbances that are occurring throughout the watershed area. For example, if a landslide would occur in the upper reaches of the watershed, releasing massive amounts of sediment into the river, the downstream reservoir could capture this excess material. In an event, utilizing a model to factor in these potential stressors could alert managers to apply best management practices to manage the influx of the sediment. Three possible countermeasures are the installation of upstream sediment traps, scheduling water releases, or dredging of the material. Additionally, by increasing the model's scope based upon influx of regional sediment yields, there is the potential increase for sediment management practices or the dam's removal (Minear & Kondolf, 2009).

A river needs inputs and outputs of sediment into its system. The flux of sediment movement throughout a river system is a natural process that occurs as a result of disturbances, such as landslides or high water events. Natural disasters can recharge a river's system by distributing important nutrients like nitrogen and phosphorus and dispensing fine and coarse substrate that create habitat for aquatic species. The removal of a dam may create an ecological response similar to a natural disaster. Researchers are trying to mimic these natural processes in the dam removal process.

The accumulation of sediment creates a number of issues that ecologists and others must factor into their dam removal and restoration plans. It can be difficult to predicting the rate, volume of erosion, and pattern of sediment transport (Hart, Johnson, Bushaw-newton, et al., 2002). A method of doing so requires monitoring of the river's channel, observing and documenting parameters such as the grain size, level of cohesion, channel slope, and flow. However, a lack of time and funding often prevents an effective monitoring plan from being developed.

Poff and Allen (1997) argue that current management approaches fail to recognize the fundamental scientific principle that the integrity of flowing water systems depend largely on their natural dynamic character. A river's natural flow regime plays a critical role in sustaining native biodiversity and ecosystem integrity in rivers (Poff & Hart, 1997). This argument is the reason that watersheds require managers to develop protocols that can not only incorporate the economic services of the natural environment but also protect the ecosystems functions (Poff & Hart, 1997).

4.4 MONITORING

A comprehensive monitoring plan offers researchers the ability to develop a sediment budget for a river system. According to Minear and Kondolf (2009), reservoir sedimentation is a particularly serious problem in many regions with high sediment yield, particularly in geologically active regions. Some experts, such as Lance Whitica, Executive Director of the South Sound Salmon Enhancement Group, shares a similar opinion about the Deschutes watershed: "The Deschutes is a geologically young river that is trying to reach equilibrium." Whitica and his team of restoration ecologists are implementing several projects to reduce erosion from occurring throughout the river's basin. Installing structures along selected vertical sheer banks to prevent future erosion from occurring, and promoting riparian corridors are two examples of projects that Whitica and his group are implementing.

Sediment budgets for downstream reaches may need to be reconsidered depending on whether incision or floodplain development is expected to occur in the river's channel (Sawaske & Freyberg, 2012). Channel width and depth upstream from the dam will provide researchers with an existing channel form and can allow researchers to predict how the channel may establish itself once the reservoir is removed. Field technicians usually monitor longitudinal profiles and cross-section surveys to determine a river's sediment budget. The monitoring of these variables allows scientists to forecast potential channel development. Even so, the consequences in the downstream reaches can be hard to predict in sediment transport models, because of the high degree of uncertainty of the extent of sediment deposition, erosion, and flooding impacts in the downstream channel. Also, the recovery response in a river's channel is hard to predict and is highly dependent on the purpose the dam served in the ecosystem.

Stream flow gauges measure a river's flow, timing, variability, and natural flow regime. These data should be taken over time to reflect extreme high and low flows, or a range of flows, often expressed as a daily average discharge. The lack of long-term stream flow data can be supplemented statistically from gauged streams in the same geographic area (Poff & Hart, 1997).

4.5 SEDIMENT COMPOSTION

The sediment particulate size is a function in the river system that provides habitat in the downstream reaches. The larger sized gravel and cobbles are stopped by dams, which negatively impacts aquatic habitat that might rely on those sediments, especially in coastal management zones. Dams close to estuary habitats change water flow and temperature, and decrease the flux of fine sediment, which creates a critical habitat for near shore species. The Elwha River Dam Removal project has provided 160,000 m3 in sediment to the mouth of the river, which has provided a vital habitat for clam beds (Gregory et al., 2002). The use of one-dimensional numerical simulations allows researchers to predict a river's reach-averaged channel response, the most practical tool for determining the evolution of non-cohesive reservoir sediment deposits (Downs et al, 2009). One-dimensional sediment transport models are best utilized over large spatial and temporal scales. Field samples featured in the Downs et al (2009) journal article *"Managing Reservoir Sediment Release in Dam Removal Projects: An Approach Informed By Physical and Numerical Modeling of Non-cohesive Sediment"* reveal that subsurface material taken from rivers that have not experienced a large scale influx of fine sediment. The report has shown that gravel-bedded rivers often contain a substantial fraction of fine sediment as a background condition. The journal article also states that in rivers composed of predominately sand-sized sediment, the pulse will only infiltrate immobile gravel deposits to a few gravel diameters in depth. Furthermore, "the rapid release and transporting of fine sediment pulses over a gravel deposit, rather than the transportation of fine sediment over a gravel deposit, rather than transporting the same volume of sediment at a slower rate over an extended period will not result in increased infiltration and may even limit infiltration" (Downs et al, 2009).

Dams capture all but the finest sediments moving down a river (Poff & Hart, 1997). When dam operators decide to conduct scheduled water releases, the sediment-depleted water released can erode finer sediments from the downstream reach. This can leave a coarse downstream streambed, which reduces habitat for many aquatic species. Furthermore, channels may erode, or down-cut and trigger rejuvenation of tributaries, which themselves can become subjected to erosion (Poff & Hart, 1997). The increased release of fine sediment can be problematic in the newly created pilot channels or tributaries because this new material can be re-deposited in between coarse material located throughout the streambed. During high and low flow events; the distribution of fine or coarse sediment can create stresses for aquatic species by reducing habitat creation or function. For species to survive, there is a range of flows that are necessary to scour and revitalize gravel beds, to import woody debris, and to organize matter from the floodplain and provide access to productive riparian wetlands. Additionally, the inter-annual variation in these flow peaks is critical for maintaining channel and riparian dynamics. Poff and Hart (1997) state that virtually all rivers are inherently variable, and that this variability is critical to ecosystem function and native biodiversity. The greatest challenge that faces natural resource managers and the restoration of rivers is that they are also used to satisfying human needs. Paradoxically, for restoration to occur, it will be depend upon the extent of human intervention and flow alteration affecting a particular river.

Another issue the researchers must consider is the presence or absence of heavy metals in the reservoir and stream channel. Toxins can be absorbed physically through sediment particles or through biota attached to the sediment. If a dam is located in an urban watershed, there could be high concentrations of toxins due to anthropogenic influences, such as nonpoint source pollution. The build up of these toxins in the reservoir and behind the dam is a concern because once the impoundment is breached these substances will be dispersed into the downstream channel and can cause adverse impacts in water quality and wildlife habitat standards. Stanley and Doyle (2002) state that there is a lack of studies that examine the removal of contaminated soils from a dam reservoir. The most noted case study seen in literature is that of the removal of the Fort Edwards Dam on the Hudson River in New York. In 1973, a environmental contracting firm demolished this barrier, releasing sediment that contained high levels of oil and polychlorinated biphenyl's (PCBs). The sediment wave left a long legacy of negative feedback loops in the river system and required extensive cleanup efforts and contaminated the food web for several years (Stanley & Doyle, 2003).

4.6 MODELING

In Chapter 3 of this thesis I discuss the evolution of dam removal and highlight how the application of various restoration techniques are evolving since large-scale dam removal projects, such as the Elwha and Glines Canyon Dam on the Elwha River, and the Marmot Dam on the White Salmon River. According to Poff and Hart (2002), there has not been a quantitative geomorphic study that has continued long enough to document the establishment of an equilibrium channel prior to dam removal. Both researchers advocate in favor of the development of a theoretical framework that will help ecologists predict sediment movement after removal. Many researchers are trying to solve this challenge through the use of computer models and statistical analysis (Peck, Mullen, Moore, & Rumschlag, 2007).

Recent attempts to understand river dynamics have ranged from simple analysis of pre-dam channel geometry to data intensive, three-dimensional numerical models (Sawaske & Freyberg, 2012). Sawaske and Freyberg (2012) are pioneering this field by developing a tool to predict the rate and volume of sediment deposited by analyzing sediment, discharge, deposit, removal timeline, channel, and watershed data. Their model examines the evolution of the deposited sediments once the dam is breached and the system begins to restore itself. Both researchers saw a lack in the comparative analysis of post-removal monitoring data, particularly in the evolution of sediment filled reservoirs following dam removal (Sawaske & Freyberg, 2012). Sawaske and Freyberg claim that by comparing amount and quality of post-removal monitoring data, there is a considerable amount of variation in studies. The researchers plan to fill in the gaps by developing this modeling tool to estimate ecological response factors for river systems that span over temporal and spatial scales (Sawaske & Freyberg, 2012).

Models are limited when it comes to being able to describe site-specific aspects of the ecosystem process if a comprehensive set of monitoring data is not available for use. Models cannot predict the full range of potential stressor-responses. To date, there has not been one specific model that is able to incorporate all the elements of dam removal.

CHAPTER 5

RESEARCH ANALYSIS

After reviewing the literature and case studies, and conducting interviews, I concluded that two parameters play an important role in the decision to manage sediment transport in dam removal projects: the volume of sediment that would be released, and the application of methods that are used to manage sediment transport. The recently published literature documenting the habitat modifications that are occurring throughout the Elwha River watershed after dam removal has provided pivotal findings that have supported the claims developed throughout my research process. The Elwha and Glines Canyon Dam Removal project has provided unprecedented information on sediment transport in freshwater and tidal environments. The use of models and field data has allowed the researchers to document the changes occurring throughout the watershed area. Figure 5.1 shows some of the parameters that field crews monitored on the Elwha River Near Shore Zone.

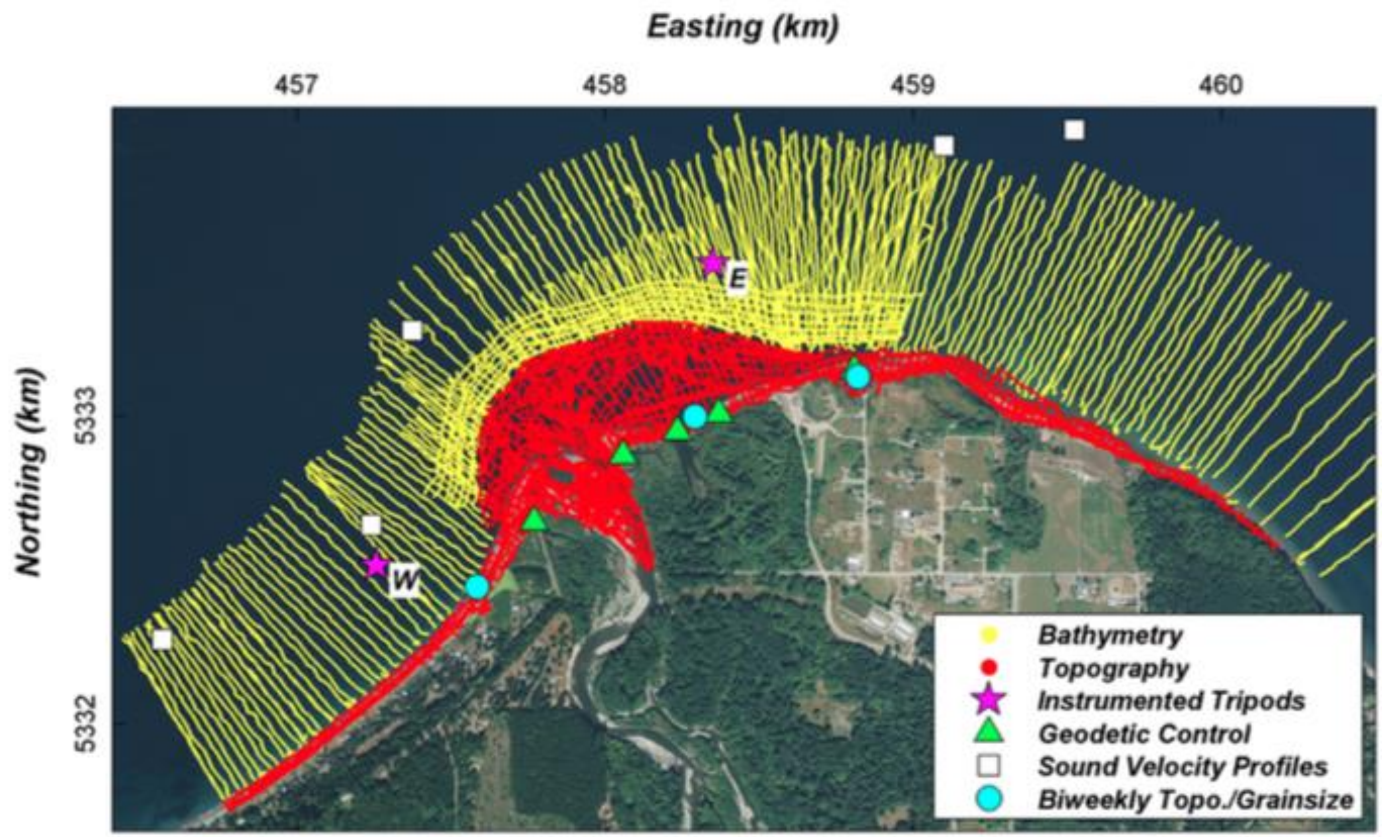

Figure 5.1.Map showing locations of beach topographic and near shore bathymetric data from surveys completed in September 2013. Also shown are locations of instrumented tripods E and W, geodetic control monuments for GPS base stations (green triangles), sound velocity profiles (white squares) used in speed of sound corrections to bathymetric soundings, and biweekly beach topography and grain size profiles (blue circles). (Gelfenbaum et al, 2015).

The Delft3D model simulated the water motion from tides, waves, wind, and buoyancy effects (Gelfenbaum et al, 2015). Additional modeling software could predict the effects of wave motion on the sediment and near shore zone dynamics. The Simulating Waves Nearshore (SWAN) model, for example, which simulates wave propagation in time and space by solving the spectral action balance equation, was used to simulate the interaction of the Pacific Ocean and the near shore zone development. Data was also incorporated into Landscape Evolution Models (LEMs) to determine where sediment was depositing, and to document how the elevation was changing after removal. Figure 5.2 depicts of pre-dam removal morphology and elevation actual changes at the river mouth and near-shore-zones of the Elwha.

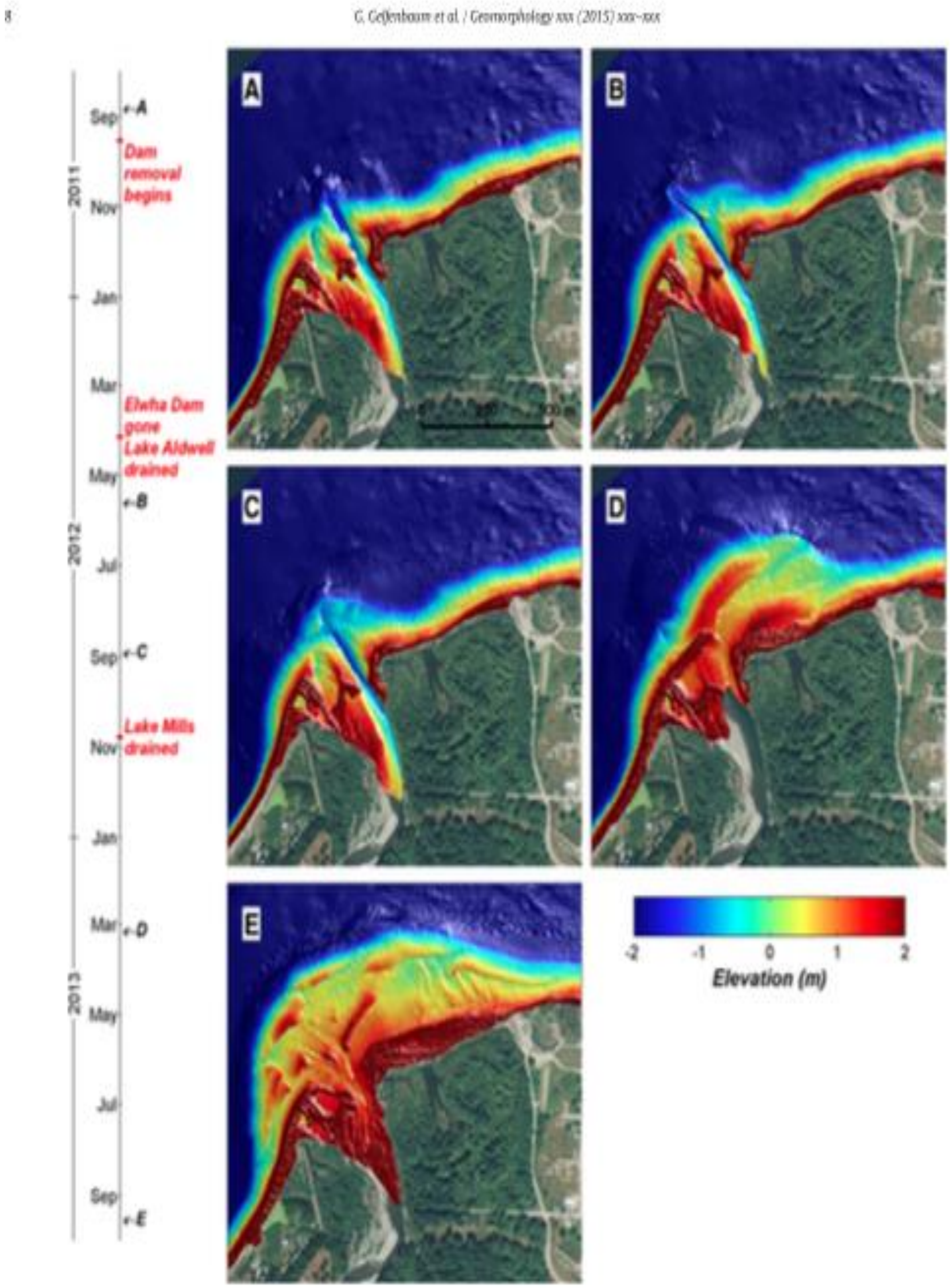

Figure 5.2. Map showing the geomorphic evolution of the active delta before and during the first two years of dam removal. [A] August 2011, [B] May 2012, [C] August 2012, [D] March 2013, [E] September 2013. (Gelfenbaum et al, 2015).

Unlike the Elwha project, the 2009 Deschutes Estuary Feasibility Study used only the Delft3D model to determine how sediment would be distributed throughout Budd Inlet. This model provided results that researchers and policymakers used to determine that estuary restoration could be an option. But based the findings of this thesis research, this model should be coupled with other fluvial and wave models to develop further analysis of the way in which sediment could be transported and the development of sediment deflection design scenarios. Figure 5.3 is a map produced from the 2009 Deschutes Estuary Feasibility Study that predicts where sediment will deposit and what areas might erode.

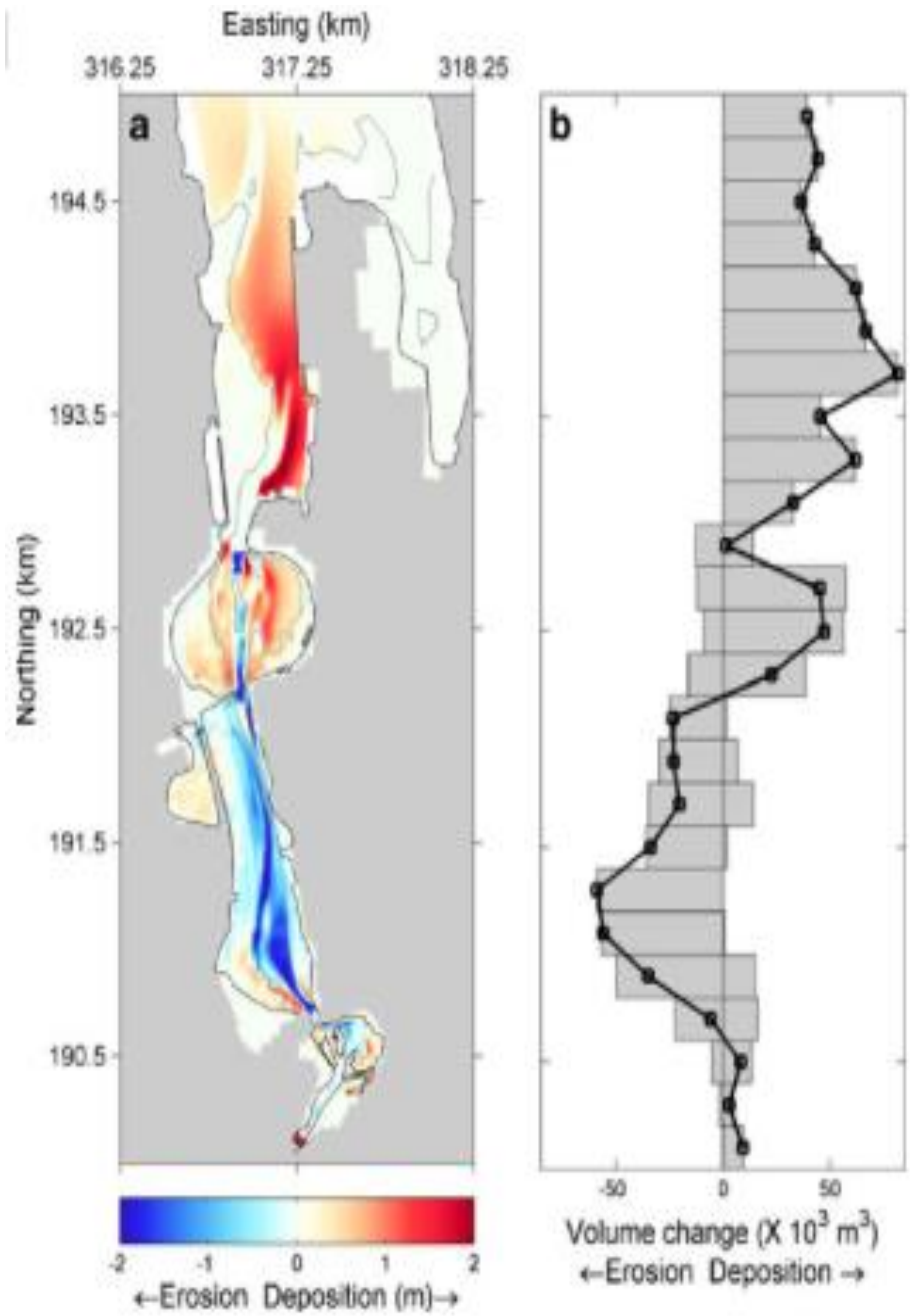

Figure 5.3. a. Erosion and deposition for the restored estuary 10 years after dam removal. Blues indicate erosion, and reds show deposition. Middle Basin experiences the most widespread erosion, while North Basin and the region outside of the estuary accumulate sediment. b Volume change through different segments of the estuary. (George, Gelfenbaum, & Stevens, 2012).

The information compiled on the Deschutes Estuary can be applied to various models to help guide natural resource managers on sediment transport. However, as the restoration efforts move forward, project leaders there should factor in how the volume of sediment released will interact with the tidal and fresheater dyanmics in the watershed area. Figure 5.4 is a map of the potential image of how the sediment might be dispersed in the estuary. However, estuary evolution will be dependent upon the length of time allowed for the natural freshwater and tidal processes to occur to establish equilibrum. Thus, the methods used to remove, manage, and restore the estuary are all interconnected and should be modeled and conceptualized that way.

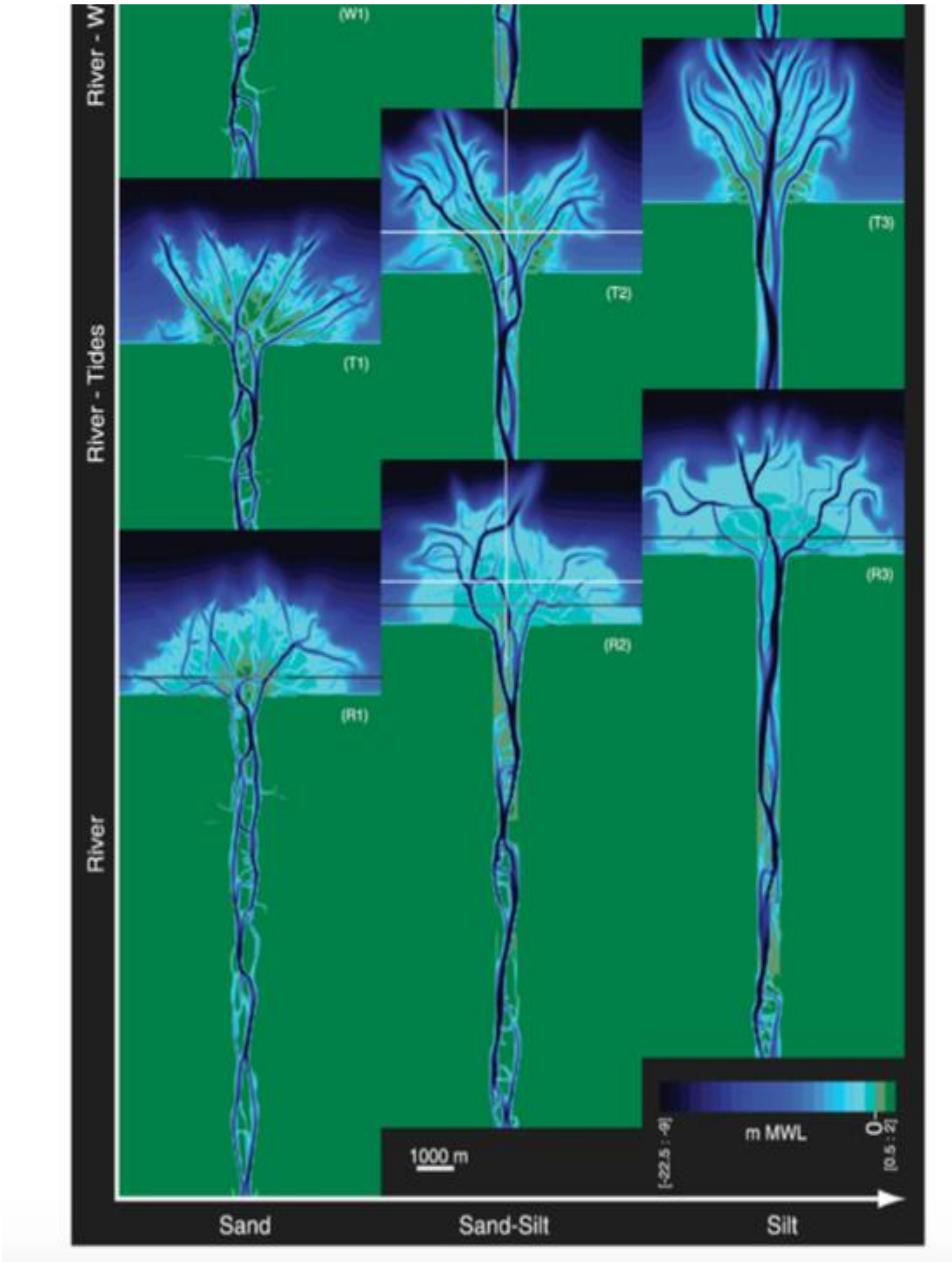

Figure 5.4 is a map of the potential image of how the sediment might be dispersed in the Deshutes Estuary and Budd Inlet. (Geleysnse et al, 2010).

CHAPTER 6

DISCUSSION

I have developed a list of sediment management scenarios that can be used in the removal of the 5th Avenue Dam located in Olympia, Washington. I base my recommendations on the literature I have reviewed and interviews I have conducted with experts in the field. After a site visit to the 5th Avenue Dam with Padraic Smith, Environmental Engineer, Restoration Division, Habitat Program of Washington State Department of Fish and Wildlife, we discussed several sediment management scenarios for the removal of the 5th Avenue Dam.

The sediment management scenarios are grouped into three approaches: direct, indirect, and a hybrid approach. Each of these management scenarios features several different restoration techniques that can be used to mange the sediment. The direct approach would require direct management of the sediment with the use of equipment. These scenarios features two methods:

1) Dredging of the basin, the technique presented in the 2006 Deschutes Estuary Feasibility Study; and
2) Blow and go of the dam, a method used in dam removal cases studies, where the dam is completely removed all at once. This scenario utilizes the river and estuary physical processes to transport the sediment and allow equilibrium to be reached naturally.

The second group employs an indirect approach, which would allow for the application of restoration techniques that guide where the sediment is transported.

1) Install sill basins to allow the tide to use its natural hydrodynamics to capture the sediment in the selected basins

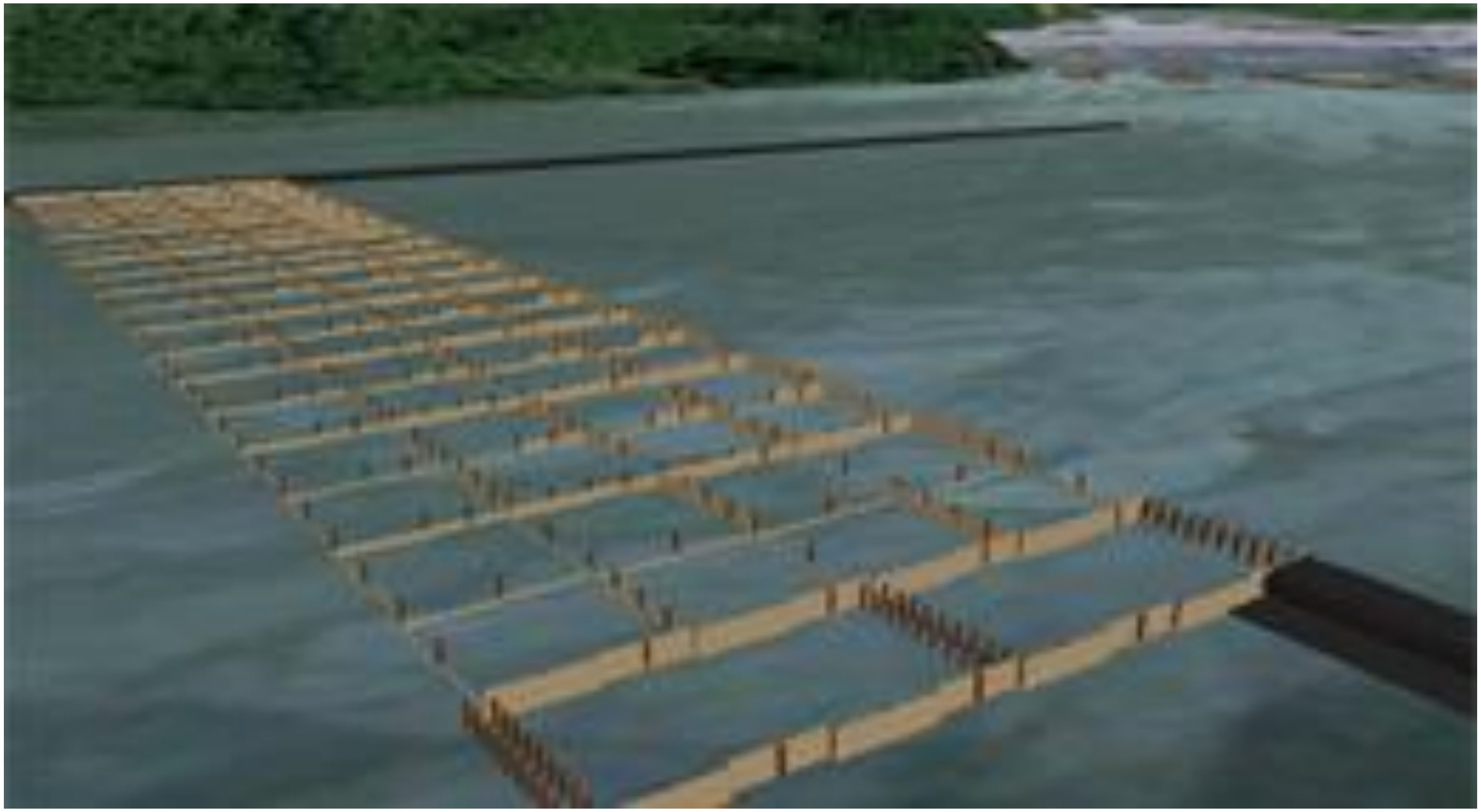

Figure 6.1 Sill basins are a method that can be used to help capture sediment. These structures can be located throughout the Deschutes River and river right behind the railroad tracks to help build up the sediment. (Mount St. Helens National Park)

2) Create low, medium, and high tidal marshes to trap sediment;

Figure 6.2 Tidal marshes can be created from the sediment released in the removal of the 5th Avenue Dam, Olympia, Washington. (Institute of Applied Ecology)

3) Lockdown the sediment in areas to allow erosion to occur in selected sections of the basin as equilibrium is reached; and

Figure 6.3 Matting can prevent erosion from occurring in projected locations predicted from the 2006 Hydrodynamic and Sedimentation Report, part of the 2009 Deschutes Estuary Feasibility Study. (Ridges of Restoration)

4) Install pile dikes to form pilot channels throughout the lower basin to create sinuosity for the sediment to be captured by the dikes.

Figure 6.4 An example of a pile dike that can be placed throughout the Deschutes River to drop out sediment.
(Mount St. Helens National Park)

The final group takes a hybrid approach. This approach can occur in multiple phases to manage the sediment.

1) Make modifications to the ogee structure in the dam and change how the dam is operated. By altering the water level and gate release times, sediment can slowly be introduced into the estuary. Additionally, the dam's existing ogee structure, which is an artificial slope that directs sediment and flow into Budd Inlet, can be modified to redirect the sediment.

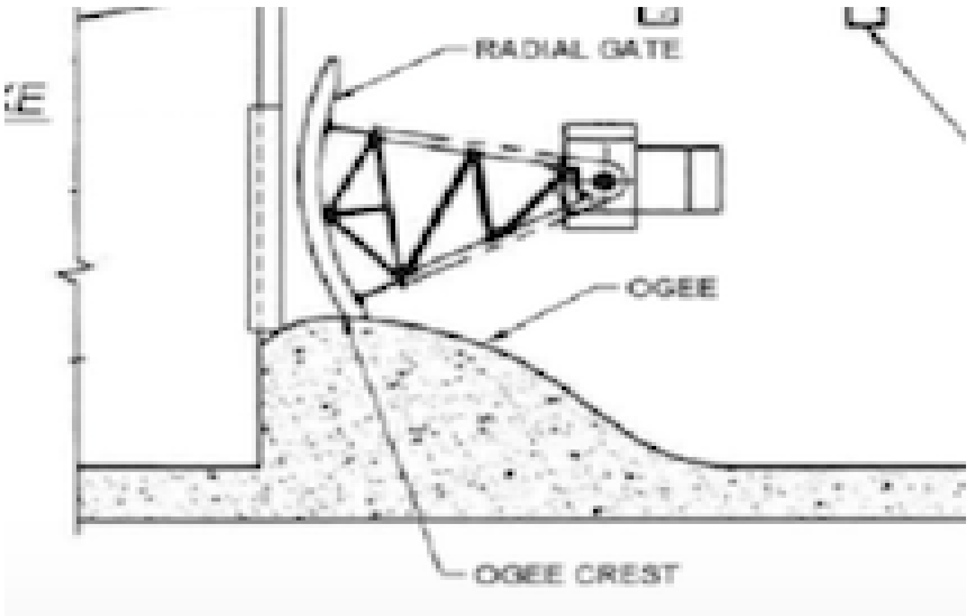

Figure 6.5 Modifying the ogee weir would allow the sediment transport into the estuary by making changes to this structure and dam operations. (Washington Department of Enterprise)

2) Install a structure (i.e. culvert) on river right to divert flow into the basin behind the railroad tracks. (See arrow in Figure 6.6 for further illustration). As the basin fills up and reaches its natural capacity, modifications to the dam and its operations can occur during this time. By using both of these techniques, the sediment will be managed and distributed throughout Budd Inlet, and the estuary.

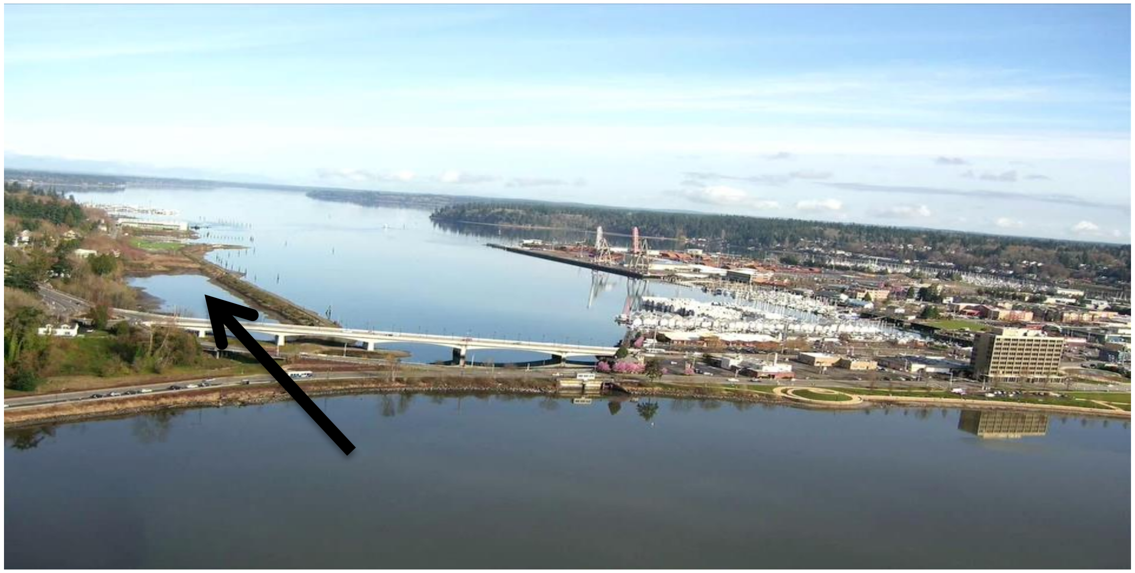

Figure 6.6 Divert sediment by installing a culvert and creating a channel to allow flow to enter basin behind railroad track. Allow the basin to fill and while this process is occurring, modify the dam's operations and the structure so that sediment can be deflected from the Port of Olympia. (Aerial Images NW)

In addition to these sediment management scenarios, I am recommending that state officials develop a project team that focuses solely on sediment transport and an exploration of various restoration efforts that are cost effective for the removal of the 5th Avenue Dam. State officials will have to secure all the proper permits to begin construction on these efforts. Most importantly, the installations of these structures are not an exact science and will require state agencies to have an adaptive management plan that can be implemented when changes occur due to natural processes.

Furthermore, the Washington State Legislature is looking at the long-term maintenance of Capitol Lake during the writing of this thesis. In the proposed state budget for 2015-2017, the state listed the following:

Capitol Lake Long-term Management Planning (30000740)

The appropriation in this section is subject to the following conditions and limitations:

(1) The appropriation is provided solely for the development of a conceptual plan for the future of Capitol Lake and the Deschutes Estuary that is designed to meet multiple objectives, including achieving broad community support and preliminary commitments from state and local funding sources to share costs. The appropriation must be used to develop a financially feasible conceptual plan, including general cost estimates, which incorporate, and achieve compromise between key features of the most widely discussed concepts.

(2) The plan must address these multiple objectives:

(a) Some improvement of estuary functions and fish habitat; (b) Retention of portions of the northern portion of the lake, in accordance with the historic features of the Capitol campus design; (c) Improvement of water quality of the lake sufficient to expand water-related recreation opportunities, which improvement strategies shall take into account information gathered to date through the department of ecology's Deschutes river TMDL study, storm water runoff from Interstate 5 and State Route No. 101, and from Olympia and Tumwater and Thurston county sources; (d) A conceptual plan for shared financing of the plan between state and local agencies, based on both benefits received and liabilities contributed, potentially using the state's lake management district legislation as a model, together with an assessment of whether federal funds might be available; and (e) A conceptual plan for shared governance.

(3) Public input must be sought as the plan is developed.

(4) The plan must be submitted to the state capitol committee and appropriate committees of the legislature by November 1, 2017.

Even though a feasibility study was completed in 2006, there has not been any progress on developing a restoration plan or securing funding. The potential allocation of funds is the first movement towards a long-term management plan. However, the language used in the state budget is vague and their interpretation will be based upon the goals and objectives set forth by the legislature and the public. The sediment management scenarios that I developed are based on improving habitat conditions. By examining the restoration of this area from this perspective there are many ecosystem functions that could be utilized by various aquatic and terrestrial species. Some functions that could be restored include:

- Restore tidal wetlands and estuary habitat
- Improved water flow and quality

- Improved habitat connectivity between the near-shore zone, freshwater environment, and adjacent areas
- Restored natural formation of tidal channels
- Unrestricted flow of freshwater sources
- Accumulation and retention of organic material from plants and aquatic species
- Unrestricted movement and migration of fish and wildlife

CHAPTER 7

CONCLUSION

My research on the removal of the 5th Avenue Dam in Olympia, Washington has led me to conclude that estuary restoration is possible based on the modeling results produced during the 2009 Deschutes Estuary Feasibility Study. Managing the transport of sediment in dam removal is a difficult task, but as research literature has proven, models have provided some insight on how rivers and estuary systems might function after removal. In the case of the Deschutes Estuary, the researchers' main focus was to examine the four possible restoration scenarios. The scope of their work was limited; therefore they did not go into explicit detail in managing the volume of sediment released and what methods should be used in order to manage erosion and deposition.

The research I completed for this project has illustrated the paradigm shift occurring in river restoration and watershed management efforts. The increase in dam removal projects has provided a foundation for natural resource managers to consider dam removal as a restoration measure. However, my research has led me to believe that in order for removal to occur, there are many factors that must be considered beyond the impacts to the physical environment. In the case of the 5th Avenue Dam in Olympia, Washington, the structure is located in the heart of downtown, and much of the city's infrastructure is dependent upon the dam. As I highlighted in Chapter 3, one of the major uncertainties in dam removal is the ability to visualize the restored environment. Managers have started to incorporate technology, such as the use of one- or three-dimensional models to predict the volume of sediment released and the amount of time it will take for the river or estuary system to reach equilibrium. Yet it is still hard for citizens and policymakers to visualize what the final outcome will look like. I believe this is one of the main struggles in dam removal projects. The science behind removing dams is growing, but the public's perspective on restoration efforts can impede the restoration process.

However, the practice of river restoration is changing as efforts to monitor dam removal projects continue to emerge and the changes are documented and published. The Elwha and Glines Canyon Dam removal projects demonstrate how dam removal can achieve full-scale restoration. Efforts to accomplish the removal of these two dams started in 1986, with complete restoration occurring in 2013. Based on the years it took to remove the Elwha River dams, it will most likely take years to complete the restoration of the Deschutes Estuary. The grassroots efforts that the Deschutes Estuary Restoration Team is completing can help guide restoration measures to transpire by educating the community on the positive feedback loops that will occur by having a restored estuary.

Imagine that twenty years after the 5th Avenue Dam has been removed, the estuary reaches equilibrium. Kayakers and stand-up paddle boarders recreate in the newly created habitat. Salmon, seals, and shorebirds can be seen around the estuary while you walk your dog. During low tide, the newly created tidal marshes and mud flats show the pilot channels that have formed since the dam has been removed.

And at high tide, the Capitol Building is reflected in the waters of the restored estuary.

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