USING PROCESS-BASED HYDROLOGIC APPROACHES AND PLACE-BASED EDUCATION TO IMPROVE NONPOINT SOURCE POLLUTION MANAGEMENT

A Dissertation

Presented in Partial Fulfillment of the Requirements for the

Degree of Doctorate of Philosophy

with a

Major in Water Resources

in the

College of Graduate Studies

University of Idaho

by

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May 2015

AUTHORIZATION TO SUBMIT DISSERTATION

This dissertation of Rebecca A. Rittenburg, submitted for the degree of Doctorate of Philosophy with a Major in Water Resources and titled "USING PROCESS-BASED HYDROLOGIC APPROACHES AND PLACE-BASED EDUCATION TO IMPROVE NONPOINT SOURCE POLLUTION MANAGEMENT," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

Despite widespread investment in watershed conservation and outreach efforts to improve water quality in agricultural watersheds through best management practices (BMPs), agricultural nonpoint source (NPS) pollution remains a leading cause of water impairment in the U.S. I theorize the disconnect between conservation efforts and apparent lack of water quality improvements is more accurately a delayed and dynamic feedback from both the ineffective placement of BMPs, physical lag time inherent in the response of water bodies to BMPs, and the social lag time associated with community participation in conservation. The objectives of this research are to advance understanding and develop hydrological and outreach tools to measure and accelerate conservation effectiveness. Chapter 2 is a review paper, which presents a conceptual framework to recommend optimal BMPs that target a watershed's dominant pollutant flow paths to improve conservation effectiveness. Using data in a disturbed, mixed land use watershed with cohesive sediments, Chapter 3 validates the pairing of a hillslope hydrology and erosion model and a fluvial sediment transport model to evaluate spatiotemporal impacts of BMPs on sediment storage and transport in the stream system, and Chapter 4 assesses overall trends in sediment dynamics in the stream system, validating a region-specific channel evolution model to track stream channel recovery from disturbances. These two chapters advance current understanding on how cohesive fluvial systems impact the physical lag time of watershed response to BMPs. Chapter 5 proposes a link between K-12 outreach efforts and increasing BMP implementation through a qualitative inquiry of the effects of youth capital and a place-based learning watershed conservation outreach program on landowner BMP adoption behavior. Investments in youth capital increased interactions between students and community, mobilized conservation resources, and established trusted relationships between landowners and community conservationists to implement BMPs. Chapter 6 concludes by developing a standards-aligned curriculum blueprint for implementing place-based watershed outreach to engage students and community in conservation. This collection of papers provides recommendations to measure and accelerate BMP effectiveness, and provides evidence that K-12 outreach programs can play a role as community catalysts to increase BMP adoption behavior, thus reducing the social lag time in conservation participation.

ACKNOWLEDGEMENTS

I could write enough thank you letters to fill the pages of this dissertation to the army of mentors, collaborators, teachers, students, friends, and family that have inspired and supported the efforts behind this dissertation. Dr. Jan Boll deserves a lifetime supply of dark chocolate for challenging me to think critically about the socio-hydrological landscapes of watersheds. He has taught me about what it means to be a leader, a scientist, and a mentor, as well as someone who gently but persistently pushes forward innovative and integrative ideas. I cannot thank him enough for all of his positive encouragement, and his vision behind many of the unique research and outreach projects that I participated in. Additional gratitude also goes out to my committee: Dr. Erin Brooks, for his creativity, expertise, and endless dedication to watershed hydrology, Dr. J.D. Wulfhorst, for his contagious passion for rural places and his distinctive approach to undergraduate education; and Dr. Brant Miller, for his insight and support in developing The Confluence Project.

Additional thanks go out to Karla and Jan Eitel, Gary Thompson, Greg Fizzell, and Lee Vierling at MOSS for generating bold new ideas for engaging the public in scientific discourse; George Landle, Deirdre Bingaman, Cindy Rust, Jamie Esler, and Rusti Kreider for pushing the boundaries of the traditional classroom; Audrey Squires and Ryan Boylan for our marathon brainstorms in developing The Confluence Project; northern Idaho students that allowed us to pilot the program in their classrooms; past graduate students of the Brooks and Boll lab, particularly Jeremy Newson and Brian Crabtree, and growers in the Palouse region for contributing to the rich dataset of the Paradise Creek Watershed, Dr. E. Langendoen for providing training in CONCEPTS; Anurag Srivastava for his support with WEPP; NSF and USDA funding, support from Avista, and ENVS-WR department; and finally the incredibly adventurous and supportive graduate student community.

DEDICATION

So much love and gratitude goes out to my friends and family for their creative energy, feedback, and constant support over the years. Love and thanks to my brothers, Tom and Angus, who have endlessly inspired me by the innovative solutions and projects that they are constantly creating; Mum, for being there day and night for all the ups and downs, and Dad, for always reminding me that time is the great equalizer; both my parents for teaching me to always seek silver linings; my grandparents Sallie and Tony Good, for stealing me away for unforgettable adventures, and Barbara and Paul Rittenburg for motivating me to leave this world a better place than I found it. Lastly, I am indebted to the love, support, ideas, adventures, coffee breaks and laughs that I have shared with T.S..Magney throughout this journey.

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CHAPTER 1: AN INTRODUCTION

Despite widespread efforts to improve water quality in agricultural watersheds through best management practices (BMPs), agricultural nonpoint source (NPS) pollution remains a leading cause of water impairment in the U.S. (EPA, 2012), contributing to eutrophication in surface waters, unsuitable habitat for aquatic native species and anoxic zones in adjacent oceans (Burkhart and James, 1999). To address this monumentally complex issue, the U.S provides over $1 billion annually in subsidies for river restoration (Bernhardt *et al*., 2005) and has provided over $165 million in 2012 alone on watershed-based NPS pollution reduction (General Accounting Office, 2012). Over the past forty years, there is little evidence to suggest that conservation and restoration efforts improve water quality at the watershed scale (Meals *et al*., 2010; Tomer and Locke, 2011). Over half of the assessed streams in the U.S. are still listed as impaired waterways (EPA, 2012), the majority of which are caused by agricultural sediment and chemicals. We theorize that part of the disconnect between conservation efforts and apparent lack of water quality response is more accurately a delayed and dynamic feedback from both the physical lag time inherent in the response of water bodies to BMPs, ineffective BMP implementation, and the social lag time associated with effective change in watershed management.

A number of well-documented reasons provide insight into this mismatch. In many cases, BMPs are not effective for the landscape conditions in which they are implemented, resulting in minimal to no change in water quality response (Mulla *et al*., 2005). The lag time between when conservation programs are initiated and when a water body responds with pollutant reductions varies based on landscape features, pollutant characteristics, and the way in which a watershed community implements BMPs and measures the effects (Meals *et al*., 2010). Depending on pollutant types, complexity of watershed systems, and BMP maintenance, physical lag times have been estimated to be on the order of decades to centuries, but are not well understood (Gregory *et al*., 2007; Hamilton, 2011). Our current NPS management systems and monitoring protocols do not always provide adequate quantification in order to measure the benefits of implemented BMPs (Tomer and Locke, 2011), and often target upland areas without fully understanding the role of the stream channel in storing and transporting sediment and pollutants.

Because the Clean Water Act does not provide enforceable regulation for NPS pollution, its reductions require voluntary action often on private landholdings (Clean Water Act, 1972). BMPs should be used that correctly target pollution sources and pathways, and for this to occur, community engagement is critical to achieve effectiveness in water quality improvement (Parry, 1998; Sabatier *et al.*, 2005). Multiple barriers to landowner adoption of BMPs are well documented in the literature (Pannell *et al*., 2006; Prokopy *et al*., 2008; Nowak, 2011; Baumgart-Getz *et al*., 2012), yet the link between improved landowner adoption and positive environmental outcomes is less understood (Koontz and Thomas, 2006). Successful water quality improvements require landowners to not only adopt and implement BMPs, but also for managers to collaborate with landowners to prescribe the most effective BMPs given landscape and pollutant characteristics (Nowak, 2011). For these reasons, watershed management is complex, requiring grounding in sound science (Loucks, 2003).

The process of integrating scientific conservation innovations with successful community engagement is not formulaic, particularly in agricultural settings that correlate heavily to private land ownership. A central challenge for effectively combating NPS is how to minimize both the social lag time of community engagement and the physical lag time for water quality responses in the implementation of conservation practices. This multidisciplinary dissertation seeks to address the mismatch between intensive conservation investments and the lack of NPS reductions through three hydrologically-based approaches to better inform successful NPS management (Chapters 2-4), a qualitative inquiry to investigate the role of community outreach and environmental education in overcoming landowner BMP adoption obstacles (Chapter 5), and a project-based K-12 science education outreach solution to overcome barriers to mobilize watershed stakeholders and communities towards watershed conservation (Chapter 6).

CHAPTER 2: EFFECTIVELY TARGETING BEST MANAGEMENT PRACTICES

Many BMPs are simply not effective as a result of poor BMP placement with respect to critical pollutant source areas, timing or flow pathways (Dillaha, 1990; Tim *et al.*, 1995; Mulla *et al*., 2005; Tomer and Locke, 2011). Various groups have suggested “targeting” BMPs for optimal placement and timing for maximum pollution reduction by understanding pollutant transport via hydrologic flow paths (Veith *et al.*, 2004; Mulla *et al.*, 2005; Galzki *et al.*, 2008). Walter *et al.* (2000) suggested limiting potentially polluting activities in hydrologically sensitive areas (HSAs), which occur when runoff is produced in so-called hydrologically active areas (HAAs). I extend the definition of HAAs to include infiltration of pollutants of concern, perched water tables, and subsurface flow. Pannell *et al.* (2006) and Walter *et al.* (2007) indicated that targeting BMPs in HSAs appears more cost effective and can reduce pollutant loading more than indiscriminately implementing BMPs across a watershed.

Through a review of BMP effectiveness literature in Chapter 2, we develop a hydrologically informed method of targeting BMPs within a watershed by matching BMP effectiveness with dominant flow paths in HSAs. A number of BMP review papers have been published. Most, however, do not relate BMP effectiveness to HSAs, and therefore do not necessarily provide translatable recommendations. Therefore, the overall objective is to relate BMP effectiveness to the hydrological characteristics of a particular landscape location that trigger dominant pollutant flow paths in order to understand how to minimize pollutant loading at the watershed scale.

To do this, the objectives of Chapter 2 are to:

i. develop a conceptual framework that relates BMP effectiveness with dominant hydrological flow paths that are a consequence of land and climate characteristics;
ii. determine how BMP effectiveness reported in past plot and field scale studies fit within the framework;
iii. review BMP effectiveness in watershed scale studies and how cumulative effects of BMPs at this scale can be explained within the conceptual framework.

This work provides a reference for watersheds managers to prioritize conservation sites in a watershed and choose the most effective BMP to address NPS hotspots.

CHAPTERS 3 and 4: THE ROLE OF THE STREAM CHANNEL IN POLLUTANT TRANSPORT

Watershed scale reductions often target upland erosion as a key NPS for sediment loading, particularly in Total Daily Maximum Loads (TMDLs) (Shirmohammadi *et al*., 2006). With more widespread soil conservation practices, cleaner runoff has greater capacity to scour stream banks (Mukundan *et al*., 2011). As a result, sediment source erosion may be shifting from agricultural fields to the stream channels and edge of field gullies (Trimble, 1983**;** Simon & Rinaldi, 2006). Stream channels contribute to sediment loading through legacy sediment storage, channel erosion and deposition, and buffering during storm events (Meals *et al*., 2010). We can estimate sediment loading with hydrologic models, and we can monitor sediment loads, but the role of the stream channel is less understood in the overall watershed sediment budget.

Land cover changes cause fundamental shifts in the timing, location, and magnitude of runoff and erosion events. Fluvial systems are complex, constantly changing and evolving, and they respond to the external controls of water and sediment transport by changing morphological form, adjusting from one state of equilibrium to another (Charlton, 2008). Globally, anthropogenic activities such as urbanization, agriculture, and even conservation are increasingly the major regulators of sediment and flow inputs that shape fluvial systems and, thus, are accelerating the rate of change (Leopold, 1973; Harvey and Watson, 1986**;** Gregory, 2006; Knox, 2006; Simon and Rinaldi, 2006).

Agricultural watersheds have been identified as a significant driver of geomorphic change (Hook, 1994, 2000, Urban and Rhoads, 2003). Early to mid-20th century agricultural practices typically resulted in large erosion and runoff events in areas with highly erodible soils, and caused rapid channelization and incision with subsequent widening in stream channels (Simon and Hupp, 1986; Langendoen *et al*., 2009; Shields *et al*., 2010; Bouska and Stoebner, 2014). Large sediment yields from agricultural areas resulted from stream channel erosion. With the widespread adoption of upland conservation practices in agricultural areas, some agricultural fluvial systems have responded to early century disturbances and adjusted to a new equilibrium, and thus, are no longer a significant source or sink for sediments (Bouska and Stoebner, 2014). Urbanization, however, is increasingly a large contributor to the sediment yield due to drastic stream channel modification, short, and high volume peak runoff from increased impervious areas, more frequent flood events, and from increased sediment inputs from anthropogenic activities (Sauer *et al*., 1983; Horner *et al*., 1994; Trimble, 1997).

The stream channel impacts the physical time lag from when a conservation or restoration practice is implemented to when a water quality or biological response is monitored at the watershed scale (Meals *et al*., 2010; Hamilton, 2011). Sediment is stored and remobilized throughout the stream channel over time. The capacity of the stream to transport sediment is limited, and therefore it can take decades to centuries for sediment to move through a fluvial system (Hamilton, 2011). Studies suggest that 90% of the anthropogenic sediment inputs to river systems throughout the US remain in storage (Meade, 1988). Associated pollutants bound to sediments also may remain in stream systems. Therefore, the effects of conservation measures may not be detected until legacy sediments and pollutants are flushed through the system (Walling *et al*., 2003; 2008). As noted by several studies, many BMP assessments are designed so that the effectiveness of a practice cannot be easily quantified due to, among other factors, the inherent physical lag time between implementation and water quality improvements (Gregory *et al.*, 2007; Meals *et al.*, 2010).

Without a complete understanding of stream channel contributions to overall sediment loads, sediment targets set by TMDLs are not always feasible (Mukundan *et al*., 2011). If there is a high degree of stream channel instability, the TMDL should incorporate the role of the stream channel for sediment storage and supply (Simon and Klimetz, 2008; Mukundan *et al*., 2011). Through a better understanding of the temporal and spatial aspects of stream channel scour and sediment storage, conservation practices and stream channel restoration practices can be more effectively targeted to reduce overall sediment loading.

Chapter 3 and Chapter 4 seek to better understand the role of the stream channel in the contribution and storage of sediment in a highly land use watershed. The study area is the Paradise Creek Watershed (PCW), a highly disturbed, mixed land use watershed in northern Idaho with cohesive sediments. We use field observations from benchmarked cross-sections along a channel system, event-based flow, suspended sediment concentration data and sediment transport and channel evolution simulations from an upland hydrology and erosion model (WEPP- UI; Boll *et al*., 2015) and a process-based 1-D open channel sediment transport and channel evolution model, the Conservational Channel Evolution and Pollutant Transport Systems Model (CONCEPTS) (Langendoen, 2000).

The objectives of Chapter 3 are to:

i. Validate WEPP-UI v 2012.8 hillslope hydrology model for study watershed;
ii. Evaluate CONCEPTS’ ability to simulate channel evolution in highly disturbed watershed with cohesive sediments;

iii. Compare hillslope and stream channel sediment contributions to the watershed outlet from 2006-2012;

iv. Assess stream channel response under different upland soil conservation practices.

Pairing WEPP-UI and CONCEPTS models could prove to be a useful management tool for TMDL development and watershed management. In Chapter 4, a localized qualitative channel evolution model is developed for the system to provide a less technical, coarse process-based approach to understanding spatiotemporal sediment dynamics within PCW. The objectives of Chapter 4 are to:

i. Determine if the stream channel is a net sediment source or sink and evaluate the variability of source/sink behavior temporally and spatially by land use;

ii. Characterize current stages of channel evolution.

Chapters 3 and 4 reveal the spatiotemporal dynamics of sediment storage and contribution as well as the effectiveness of upland soil conservation practices to better inform both upland and stream channel NPS management.

CHAPTER 5: ENGAGING THE COMMUNITY TO REDUCE SOCIOPHYSICAL LAG THROUGH PLACE-BASED EDUCATION

Chapters 2, 3, and 4 build upon past work in the field of agricultural watershed management by developing an improved hydrologic understanding of BMP implementation, the role of the stream channel, and physical lag time. Chapters 5 and 6 explore how to engage the community in watershed conservation and overcome landowner barriers to adoption.

Compounding the physical lag, the social system also creates a social lag time based on BMP selection, location, and which community members are willing or able to adopt, implement, and maintain BMPs. While previous physical lag time literature (Gregory *et al.*, 2007; Meals *et al.*, 2010; Hamilton, 2011) acknowledged the need for community engagement in watershed management, detailed strategies have failed to materialize. Any given watershed's social system may have a breadth of public and private land ownership. Diverse interests among stakeholders within a single watershed can contribute to conflicts for NPS management (Bonnell and Baird, 2005), creating a social lag time for reductions. Koontz and Thomas (2006) have recommended that future research focus on how collaborative groups in watersheds can actually improve environmental conditions, rather than just focus on how the group works together.

Elements of collaborative approaches to natural resource management have been explored (Woodard, 1934; Sanchez-Arroyo *et al.*, 2005; Emery and Flora, 2006; Pannell *et al.*, 2006; Duarte *et al.*, 2009; Papworth *et al.*, 2009; Prokopy *et al*., 2011), but without focusing on the specific role of environmental education and youth capital. Environmental education (EE) promotes and fosters awareness and concern for environmental problems and solutions (UNESCO, 1977) and develops an informed and active citizenry to address environmental issues (Fien, 1993). Thus, EE is an essential component of the collaborative approach to conservation, but is often overlooked as an effective method to engage private landowners in adopting BMPs by watershed management groups.

Gruenewald (2003) has proposed a social ecological placed-based education framework, called the critical pedagogy of place. This pedagogical approach links place-based learning (PBL) with the critical pedagogy philosophy, which focuses on helping students to connect knowledge to power and the ability to take constructive action, improving students' sense of agency. The critical pedagogy of place philosophy not only connects students to place, both socially and ecologically through PBL, but also provides students opportunities to take action, as a method to reverse social and environmental degradation through building keen awareness of place. Environmental education pedagogies that not only promote connection to place and understanding of degradation within a watershed, also offer the opportunity to pursue actions to improve the socioecological landscape, can play a key operative role in the conservation movement.

The potential for youth that participate in socioecological place-based environmental education programs to build social capital to drive collective action towards natural resource management in communities has only recently been documented (Krasny *et al.,* 2013). Chapter 5 uses Community Capitals Framework (Flora *et al,* 2004) to assess the role of socioecological place-based learning as a collaborative approach to watershed management. Chapter 5 explores the potential to reduce social and physical lag times for conservation through a qualitative inquiry. The case study suggests that project-based K-12 watershed science education can be a catalyst for leveraging resources, partnerships, and connections to overcome barriers to landowner BMP implementation across a watershed.

CHAPTER 6: IMPLEMENTING EFFECTIVE PROJECT-BASED WATERSHED SCIENCE EDUCATION

From the case study in Chapter 5, we learn that K-12 students and effective socioecological place-based education can help to catalyze a network of partnerships, resources, and grants for both watershed conservation efforts and water quality monitoring, thus reducing the social time lag. Chapter 6 explores and describes methods to implement similar project- and socioecological place-based K-12 watershed science outreach education within the context of the emerging science standards, Next Generation Science Standards (NGSS). NGSS have been developed to generate cross-cutting, process-based, and more relevant science standards in the public school system to ensure that US students are prepared for the expanding employment opportunities in science-based fields (NRC, 2011; NRC, 2013).

Chapter 6 connects back to sociophysical lag in two ways. It first provides practitioners with a blueprint to develop project-based watershed projects into their curricula that can potentially engage communities in NPS management and contribute to intergenerational learning (Ballantyne *et al*. 2001), thus reducing sociophysical lag. Second, it utilizes place-and project-based pedagogies (Marx *et al*., 1997; Gruenewald, 2004; Sobel, 2004) to effectively engage students in meaningful science and engineering practices, which may inspire the next generation of scientists to continue to use innovative scientific practices to manage the environment.

SYNTHESIS

The four components of this dissertation merge the disciplines of hydrology, geomorphology, social science, and science education to investigate ways to engage the community in hydrologically informed watershed management practices. The dissertation begin with a broad overview of how BMPs impact NPS pollution, and how and where to implement BMPs for improved water quality .Then, the following two chapters focus in on one watershed to estimate physical lag time, validate the pairing of a hillslope hydrology and erosion model and a sediment transport model, evaluate conservation measures, and better understand the role of the stream channel in sediment transport and storage. Next, through a

qualitative inquiry, this work investigate how a social ecological place-based learning program and youth catalyze private landowners to implement effective BMPs in an impaired stream system. This suggests that K-12 watershed education can be a key management strategy in resource-limited agricultural watersheds. The dissertation concludes by developing an NGSS-aligned curriculum blueprint for implementing socioecological place-based educational programs at the high school level. Ultimately, this dissertation addresses the current mismatch between science and management through better informing management from a hydrological perspective and exploring the role of K-12 education as a catalyst for effective watershed conservation management.

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CHAPTER 2: AGRICULTURAL BMP EFFECTIVENESS AND DOMINANT HYDROLOGICAL FLOW PATHS: CONCEPTS AND A REVIEW

Rittenburg, R.A., A.L. Squires, J. Boll, E.S. Brooks, Z.Easton, and T.S.Steenhuis. 2015, Agricultural BMP effectiveness and dominant hydrological flow paths: Concepts and a review. Journal of American Water Resources Association. 51(2): 305-329.

ABSTRACT

We present a conceptual framework that relates agricultural Best Management Practice (BMP) effectiveness with dominant hydrological flow paths to improve nonpoint source (NPS) pollution management**.** We use the framework to analyze plot, field and watershed scale published studies on BMP effectiveness to develop transferable recommendations for BMP selection and placement at the watershed scale. The framework is based on the location of the restrictive layer in the soil profile and distinguishes three hydrologic land types. Hydrologic land type *A* has the restrictive layer at the surface and BMPs that increase infiltration are effective. In land type *B1*, the surface soil has an infiltration rate greater than the prevailing precipitation intensity, but there is a shallow restrictive layer causing lateral flow and saturation excess overland flow. Few structural practices are effective for these land types, but pollutant source management plans can significantly reduce pollutant loading. Hydrologic land type *B2* has deep, well-draining soils without restrictive layers that transport pollutants to ground water via percolation. Practices that increased pollutant residence time in the mixing layer or increased plant water uptake were found as the most effective BMPs in *B2* land types. Matching BMPs to the appropriate land type allows for better targeting of hydrologically sensitive areas within a watershed, and potentially more significant reductions of NPS pollutant loading.

INTRODUCTION

As large-scale industrial agriculture became prominent in the 1960s in the American landscape, greater use of chemicals and intensive soil management proved essential to increase food and fiber production. A consequence of this intensive agriculture continues to be nonpoint source (NPS) pollution, which impairs water bodies from addition of sediment, nutrients, or pesticides. In recognition of this threat to aquatic ecosystems, agricultural conservation practices have been developed to manage pollutant sources and to prevent the transport and delivery of pollutants from both overland and subsurface flow to water bodies (Mulla *et al.*, 2005)**.** The Natural Resource Conservation Service (NRCS) has developed many pollution prevention techniques and quantitative standards of best management practices (BMPs) that can be found in the NRCS Field Office Technical Guide (NRCS, 2011).

Despite widespread implementation, the success of BMPs to control nonpoint source pollution has been mixed and the reported effectiveness of a single BMP can vary greatly. For example, Liu *et al.* (2008) showed sediment trapping efficacy from over 80 buffer studies varied from 54 to 100%. Often times these variable BMP efficiencies are a result of poor BMP placement with respect to critical pollutant source areas, timing or flow pathways (Tomer and Locke, 2011), or a poor match of the BMP to the physical characteristics of the landscape. Most published BMP studies have not clearly identified the physical characteristics (e.g., soil type, topography, land cover and treatment, and climate) responsible for BMP effectiveness. In the studies that did, authors found BMP effectiveness to be dependent on local hydrologic and climatic conditions (e.g., Walter *et al.*, 2001; Ghidey *et al.*, 2005; Deasy *et al.*, 2007).

Therefore, achieving BMP effectiveness requires knowledge of the local climate and site characteristics that trigger activation of the hydrologic flow paths (i.e., overland flow, subsurface lateral flow, and percolation and saturated flow in ground water). Various groups have suggested “targeting” BMPs for optimal placement and timing for maximum pollution reduction by understanding pollutant transport via hydrologic flow paths (Veith *et al.*, 2004; Mulla *et al.*, 2005; Galzki *et al.*, 2011). Walter *et al.* (2000) suggested limiting potentially polluting activities in hydrologically sensitive areas (HSAs), which occur when runoff is produced in so-called hydrologically active areas (HAAs). In their case, HSAs linked saturated areas to surface water bodies via overland flow. In this paper, we extend the definition of HAAs to include infiltration, perched water tables, and subsurface flow.

Studies that linked flow paths to the effectiveness of BMPs began with Stewart *et al.* (1975). Stewart *et al.* (1975) developed charts linking climate, topography, soils, and farming practices with effective management practices. Walter *et al.* (1979) extended this further and noted how soil and water conservation practices affect the flow path. More recently, Mulla *et al.* (2005) identified a significant opportunity to optimize BMP type and placement within a landscape through targeting. In addition, Pannell *et al.* (2006) and Walter *et al.* (2007) indicated that targeting BMPs in HSAs appears more cost effective and can reduce pollutant loading more than indiscriminately implementing BMPs across a watershed because the BMP is matched to the local hydrologic and climatic conditions. Gburek *et al.* (2000) identified similar potentials for reducing phosphorus loading if critical source areas are targeted.

Despite efforts over the past four decades, there is still not a clear consensus of the actual effects of BMPs at the watershed scale. Tomer and Locke (2011) reviewed Agricultural Research Service (ARS) benchmark watersheds and corroborated findings by numerous other studies (Dillaha, 1990; Tim *et al*., 1995; Mulla *et al*., 2005) and by researchers in the USDA Conservation Effects Assessment Project (CEAP) watersheds. As noted by several studies, many BMP assessments are designed in such a way where the effectiveness of a practice cannot be easily quantified due to, among other factors, the inherent physical lag time between implementation and water quality improvements (Gregory *et al*., 2007; Meals *et al*., 2010). Other studies find that some BMPs are simply not effective due to structural failure or incorrect implementation of the management practice. However, in this work we will focus on the need for a better method of targeting BMPs within a watershed by both identifying HSAs and matching BMP effectiveness with dominant flow paths. A number of BMP review papers have been published, however most do not relate BMP effectiveness to HSAs, and therefore do not provide translatable recommendations for selecting BMPs for a given HSA based on the pollutant flow path.

Therefore, our objective is to relate BMP effectiveness to the hydrological characteristics of a particular landscape location in order to minimize pollutant loading at the watershed scale. To do this, we 1) develop a conceptual framework that relates BMP effectiveness with dominant hydrological flow paths that are a consequence of land and climate characteristics; 2) determine how BMP effectiveness reported in past plot and field scale studies fits within the framework; and 3) review BMP effectiveness in watershed scale studies and how cumulative effects of BMPs at this scale can be explained within the conceptual framework.

CONCEPTUAL FRAMEWORK FOR TARGETING BMPS

In this framework, we first determine the soil and climate characteristics in landscapes that drive dominant hydrologic flow paths. From there, we define three hydrologic land types that are characterized by these specific flow paths. Next, we simplify the classification of major pollutant types, and relate pollutant transport to probable flow paths and land types. The conceptual framework of hydrological land types, and their respective dominant flow paths, probable pollutant transport, and BMP recommendations can be found in Figure 2.1.

Hydrologic Flow Paths and Land Types

We argue that BMP effectiveness is greatest when placement is fundamentally based on the dominant hydrologic flow path that is associated with the pollutant of concern within a landscape. The hydrology in our conceptual framework is based on how water flows in the landscape. All excess rain (i.e., precipitation that does not evaporate or transpire) eventually flows laterally towards a surface water body or percolates vertically to ground water. The lateral path that the excess rain follows depends very much on soil characteristics such as permeability and where the restrictive layer occurs in the landscape (Figure 2.1).

The restrictive layer is at the soil surface when the precipitation intensity is greater than the infiltration rate of the soil, and surface runoff occurs (sometimes called Hortonian flow). This can occur for soils that have low organic matter, surface crust formation, fine texture, are degraded with decreased macroporosity (Horton, 1933), or are frozen. Hortonian overland flow usually occurs during storms and shortly thereafter. In our conceptual framework we identify areas in a landscape where the precipitation intensity is greater than the infiltration capacity due to a surface restrictive layer as Hydrologic Land Type *A* (Figure 2.1).

When the infiltration rate at the surface is greater than the precipitation intensity, precipitation will infiltrate the soil and percolate downwards either to the groundwater or to a restrictive layer at some depth in the profile (Hornberger, 1998). Subsurface restrictive layers were identified as bedrock, an argillic or fragipan horizon, or an abrupt increase in clay content and/or bulk density which impede percolation to groundwater. If not discussed in the studies reviewed, presence of restrictive layers was determined with the NRCS Soil Survey. When the infiltration rate is greater than the precipitation intensity, locations fall into the broader category of Hydrologic Land Types *B* (Figure 2.1). If there is a restrictive layer in the profile, it can be either at shallow depths or at much greater depths. The surface layer of soils exhibiting a restrictive layer typically has either high organic matter content and is well structured, has a significant portion of sand, is from volcanic origin, has been glaciated, or has intensive impacts from moldboard or large disc plows. In these soil types, due to various processes, restrictive layers can form.

When a restrictive layer is at shallow depth, water will flow laterally over the restrictive layer with a driving force equal to the slope (Hydrologic Land Type *B1* in Figure 2.1). Soils become fully saturated when the lateral transport capacity becomes less than the incoming lateral or vertical flux. This occurs in times of excess rainfall at locations where the slope decreases, or where the conductivity of the soil decreases. In the saturated location, exfiltration occurs, triggering (saturation excess) overland flow. The transport time for water to flow laterally through the soil to the stream channel depends on the hydraulic gradient and hydraulic conductivity, but generally occurs within 5 to 10 days after the rainfall event, after the threshold is exceeded. When installed, tile lines may accelerate the flow path within Hydrologic Land Type *B1*.

When the restrictive layer is deep or altogether not present (deeper than the elevation of the surface of the water body) water will flow predominately downwards via matrix and preferential flow until it reaches the water table and then flows under its own weight (i.e., piston flow) to the stream channel as base flow. This percolation flow path is typically slower than overland flow paths. Percolation occurs within the Hydrologic Land Type *B2* in Figure 2.1**.** For ease of writing we will leave off the word hydrologic and call them simply “Land Types”.

Hydrological Classification of Pollutants

Effectiveness of BMPs also depends on the chemical and biophysical characteristics of a particular pollutant. Although classification and terminology used to describe pollutant types vary throughout the literature, we are mainly interested in how they behave with respect to the flow path they follow. The type of flow path, the time that the pollutant is in the flow path, and the pollutant characteristics determine the dominant form of pollutant transport. Pollutants are transported as either sorbed (e.g., attached to soil particles) or dissolved in water. Therefore, we classify pollutants as either particulate or dissolved at the time of transport. Sediment is a method of transport for sorbed pollutants and is a pollutant itself. It will be discussed with particulate pollutants. When pollutants are weakly or strongly adsorbed, they are "two-phased" and occur in both dissolved and particle-attached states. Nutrients and pesticides can go through transformations and be present in various forms at the time of transport. In this review, we focus on pollutants typically associated with agriculture: phosphorus, nitrogen, pesticides and sediment. For weakly adsorbed pollutants we are more concerned with the dissolved form and for strongly adsorbed pollutants we are more concerned with the particulate form.

Pollutants of concern. Phosphorus (P) can occur in multiple forms (Haygarth and Sharpley, 2000), but in order to determine what flow path P will follow, we classify P as soluble reactive phosphorus (SRP; i.e., dissolved) and as particulate phosphorus (PP). Sediment is transported through overland flow and erosion, and serves as a surrogate for the transport of PP and strongly adsorbed pesticides due to these contaminants' tendency to bind to soil particles.

Nitrogen occurs in many forms, as particulate organic matter, dissolved organic matter and various inorganic forms such as nitrate and nitrite (non-adsorbed), ammonium (strongly adsorbed), and can be rapidly transformed between states. The most common form of nitrogen (N) in water is nitrate (Logan *et al.*, 1980). Under aerobic conditions, other mobile forms of N (e.g. ammonium and nitrite) quickly transform to nitrate in the soil (Wild and Cameron, 1981).

Pesticides are classified as non-adsorbed, weakly adsorbed, or strongly adsorbed (Walter *et al.*, 1979; Smith and Ferreira, 1987; Reichenberger *et al.*, 2007). As stated above, weakly to strongly adsorbed pesticides are two-phased contaminants.

Pollutant transport by hydrologic flow paths. Strongly adsorbed chemicals are predominately associated with the particulate form and move in overland flow with particulates. In the subsurface path, strongly adsorbed chemicals adhere to the soil matrix. As a result, they are generally considered immobile. If adsorbed to very fine colloidal soil particles, small quantities can move significant distances. Non-adsorbed chemicals move at a similar rate as water.

In order to understand the movement of the two-phased (weakly to strongly adsorbed) chemicals, we need to understand what portion of the chemical is in the water phase and acts as dissolved and how much is attached to the sediment. Under equilibrium conditions (i.e. no net change in the balance of chemicals between dissolved and particulate phases), and with a low adsorption coefficient of 1, there is 100 times as much pesticide in the water phase as in the particulate phase. For an adsorption partition coefficient of 100 (intermediately adsorbed), half of the pollutant is transported with the sediment and half in the water. Only for strongly adsorbed chemicals, such as PP and some pesticides, is the transport principally associated with the particulate form. For strongly adsorbed chemicals, reducing erosion is an effective way to prevent pollutants from entering a water body or by increasing deposition before sediment enters the water body.

For subsurface flow, the residence time in the flow path influences contaminant transport (Walter *et al.*, 1979; Logan *et al.*, 1980; Wild and Cameron, 1981; Reichenberger *et al.*, 2007). Subsurface flow can occur through preferential or matrix flow paths. In preferential flow paths, transport is fast and there is not sufficient time for equilibrium conditions to form within the soil matrix, and chemicals are transported rapidly downward, independent of adsorption until the terminus of the preferential path (Wild and Cameron, 1981; Gaynor and Findlay, 1995; Flury, 1996; Sharpley *et al.*, 2000; Gelbrecht *et al.*, 2005; Kim *et al.*, 2005; Reichenberger *et al.*, 2007). Matrix flow is a more gradual transport pathway, slowing contaminant transport. Matrix flow is a more gradual transport pathway, slowing contaminant transport. Given a sufficiently long half-life, small but still significant quantities of pollutants can move down to groundwater (Walter *et al*., 1979).

Tile drainage can cause an artificial preferential, lateral flow path, transporting weakly and non-absorbed pollutants in dissolved form and strongly adsorbed pollutants associated with fine soil colloids (once they arrive at the tile line) to water bodies. In regions with limited infiltration rates, surface inlet tiles are common, transporting pollutants that would otherwise be transported by overland flow.

Transport of agricultural chemicals as a function of hydrological land types

In our framework, we characterized three land types by specific flow paths and we simplified the classification of major pollutant types so that we can understand their transport along the major flow paths in each land type. In this section, we apply the framework to transport of agricultural related chemicals and sediment. We will then compare results of published field and plot scale studies with our conceptual framework to develop BMP recommendations based on how pollutants and sediment are transported.

Land type *A* (Figure 2.1), occurs, for example, in the Midwest in soils under conventional tillage practices where the high intensity summer convective storms are often present (Gassman *et al.*, 2010). To understand how chemicals move in land type *A* soils, we note that rain mixes with the soil solutes in a thin mixing layer of 0.5-2 cm at the soil surface where overland flow can pick up solutes **(**Ahuja *et al.*, 1981; Steenhuis *et al.* 1994, Gao *et al.*, 2004; Sanchez and Boll, 2005**).** Typically, infiltration rates in type *A* soils initially are high and then decrease over time, so there is a delay between the start of the rainfall and the initiation of runoff (Horton, 1933). In this initial period of infiltration, dissolved chemicals will move downward out of the mixing zone and are less available for transport by overland flow. Therefore the loss of nitrate in surface runoff is often less than the amount lost to leaching pathways (Walter *et al.* 1979; Wang and Zhu, 2011). Two-phased pesticides and SRP move downward much more slowly than nitrate resulting in increased availability when runoff occurs and can be more readily mobilized in overland flow (Saia *et al.*, 2013). Overland flow also induces erosion, which can carry strongly adsorbed pesticides, ammonia and PP.

Land type *B1* with shallow restrictive layers are found all over the US and are particularly expansive in the clay pan soils of the Midwestern U.S. (Ghidey *et al.*, 2005; Mudgal *et al.*, 2010a, b), as the dense glacial till layers in New York (Easton *et al.*, 2008), as argillic layers in the Palouse region in the Pacific Northwest (Brooks *et al.*, 2010), and many other locations in the U.S. (McDaniel *et al.*, 2008). These soils increase overland flow and subsurface lateral flow by inhibiting deep vertical infiltration, causing perched water tables. In many areas with such soils, tile drainage has been installed thereby reducing overland flow and the presence of saturated areas but providing a direct pathway for pollutants to surface water bodies (Strock *et al.*, 2010). Lateral flow in type *B1* landscapes occurs when a saturated lens forms atop of the restrictive layer and the hydraulic gradient is greater than the matric potential. Therefore places in the watershed that have steep slopes, conductive soils and small contributing areas (i.e., upslope areas) are usually unsaturated at the surface. In contrast, soils with a large contributing area and relatively flat slopes are saturated during periods in the year when there is more precipitation than evaporation. These periodically saturated soils occur in areas that are concave and in the bottom of long slopes near the stream channel.

Lateral flow primarily carries dissolved contaminants down the slope. The saturated areas producing saturation excess overland flow behave similarly as the runoff areas in land type *A* and can be source areas for SRP, PP (see Sanchez and Boll, 2005), organic N, pesticides and sediment. The main difference with land type *A* soils is that dissolved chemicals can originate from the entire subsurface lateral flow zone above the restrictive layer (Steenhuis and Muck, 1988). In addition, *B1* land types can be saturated for an extended period, and are, therefore, a source of denitrification in the landscape (Kuo, 1998). Subsurface lateral flow that exfiltrates in the saturated areas can mobilize SRP on its way to the stream. Water bodies in *B1* landscapes are therefore characteristically high in SRP and low in nitrate (Sanchez and Boll, 2005; Flores-Lopez *et al*., 2010).

Land type *B2* has deep soils (Figure 2.1) and is common in many parts of the US such as in Michigan, Wisconsin and Minnesota. Leaching of nitrate is the most prominent concern because the subsurface soil structure allows deep infiltration. In these land types, transport of nitrates via the soil matrix and dissolved forms of pesticides via preferential flow paths is most common (Steenhuis and Parlange, 1990). Note that nitrate also moves in preferential flow paths, however the amount is generally substantially less than the fraction moved in matrix flow (e.g., Zhang *et al*., 2011; Parn *et al*., 2012; Spence *et al*., 2012; Ballantine *et al*., 2013). Nitrate in preferential flow is therefore less of a concern in groundwater. However, for pesticides, where even trace concentrations in groundwater are problematic, a small application of 2 kg/ha is sufficient to reach a level of a few parts per billion in ground water. Therefore, pesticide transport via preferential flow is a concern for groundwater quality.

We recognize that this framework is simplified and that there are many borderline cases in which water can follow different flow paths depending on the rainfall intensity, the condition of the soil, and topography. A review of rainfall characteristics can be used to assess the importance of temporal changes in land type characterization (Walter *et al*., 2003, 2005).

Because restrictive layers and soil depths are often not uniformly distributed across the landscape, it is likely that a watershed contains a patchwork of *B1* and *B2* land types. A good example is the Mohantango watershed in Pennsylvania, where the two sites draining in the East Mohantango creek are completely different. One has shallow soils with a restrictive layer and the other has deep soils (Needleman *et al.*, 2004). Similarly, the shallow upland soils and karst geology in the Lincoln Lake CEAP Watershed in Arkansas create spatial diversity in *B1* and *B2* land types (Edwards *et al.*, 1996). A patchwork of land types like this requires different BMPs throughout the watershed.

In many landscapes, regardless of land type, concentrated flow (e.g., rills and gullies) may occur due to topography and tillage/cropping practices (Grissinger, 1996). Effectiveness of BMPs (e.g., grassed waterways and sedimentation basins) that reduce pollutant transport through concentrated flow paths that are already formed is outside the scope of this review. However, BMPs that address overland flow in this review do aid in reducing the formation of concentrated flow paths. In the next section, we define BMP effectiveness based on the land types.

BMP EFFECTIVENESS STUDIES

We divided the literature on BMP effectiveness into plot and field studies, and watershed scale studies. Since hydrological land types and associated flow paths tend to be more uniform at a smaller spatial scale, we first considered the interaction of BMPs and flow paths within a land type from plot and field studies. Only experimental or physically-based model studies that included physical site characteristics were used in this analysis to ensure that results could be related to land types *A, B1* or *B2*. Physical site characteristics that we looked for included soil type, surface infiltration capacity or saturated hydraulic conductivity, soil depth, and climate information such as annual precipitation amount and precipitation intensity. In order to define a land type, we needed information about seasonal precipitation, types of dominant flow paths present, and soil type. We used the flow chart in Figure 2.2 to determine the land type using information contained in the study, and publicly available climate and soil survey data. Specific, quantitative thresholds of climatic and landscape characteristics in each land type cannot be reported here because these characteristics varied too much for each study and in each region.

To determine the dominant flow paths, we sought out studies that had sufficient soil and precipitation data or we further investigated publicly available soil survey and climate data. When we could not infer the dominant flow path, we eliminated the study from our analysis. Of the over 300 BMP effectiveness plot and field studies reviewed, approximately 80 were suitable for our analysis. Because this review presents a conceptual, process-based approach for understanding BMP effectiveness, rather than in depth analyses of individual BMPs, pollutants, or regions, we do not directly address narrowly focused BMP review papers in this analysis. Transferring lessons learned from empirical modeling studies was particularly difficult because models are typically calibrated to a specific area and the physical processes and dominant flow paths are not always discussed with respect to the physical mechanisms controlling losses. We considered only sites with natural, relatively fixed, soil and water characteristics. For this reason, irrigated systems were not considered in this study.

In the watershed scale analysis our conceptual framework was applied to Paradise Creek Watershed, ID, Lincoln Lake Watershed, AR, Cannonsville Watershed, NY, and Little River Experimental Watershed, GA. We made one or two-day site visits to these watersheds in 2009-2011. The information from plot and field studies was included in the analysis of the watershed scale studies, where BMP interactions become more complex. These four watersheds are examples of how the framework can be used as a tool to select an appropriate suite of BMPs for a given watershed.

BMP Effectiveness Analysis: Plot and Field Scale Studies

Plot and field scale BMP effectiveness study locations were grouped by *A*, *B1,* and *B2* land types to synthesize trends of BMP response. Specific findings for each land type and the effective BMPs for the dominant flow path(s) associated with each land type are presented. Effective BMPs for each land type and their effect on the physical processes that target the dominant flow path for each land type are listed in Table 2.2 (e.g. slow overland flow velocity, increase infiltration capacity to reduce overland flow). The BMPs included in Table 2.1 and described in the text are the most commonly cited and demonstrated practices. We understand that there are effective BMPs that have not been evaluated in the published literature. The Conservation Reserve Program (CRP), which encourages farmers to convert highly erodible agricultural land into vegetative cover, and contour farming, for example, are likely effective for all land types, but plot and field scale studies that demonstrate their effectiveness are not readily published for all land types. Contour farming has been cited as effective (Kenimer *et al*., 1997 cited in Reichenberger *et al*., 2007; Gerontidis *et al*., 2001; Deasy *et al*., 2007), but it was difficult to parcel out the effectiveness of the individual practice as it was often combined with other practices (Van Doren *et al*., 1950). While field observations by both producers and researchers suggest that gully plugs reduce overland flow and erosion in *B1* land types, the current literature lacks evidence that they are effective, and thus gully plugs are omitted from this review.

Effective BMPs for A Land Types

In *A* land types, where Hortonian flow dominates, effective BMPs can be generally grouped into three categories: 1) BMPs that increase the soil's ability to infiltrate and store water, reducing overland flow, 2) BMPs that reduce application of the pollutant at the source, and 3) BMPs that reduce the overland flow water velocity, once generated. Of the 30 studies characterized as *A* land types, properly placed buffers, terraces, nutrient management plans (NMPs), Integrated Pest Management (IPM), the Conservation Reserve Program (CRP), cover crops, mulch tillage, and no-till were the most effective BMPs (see Table 2.1 and Table 2.2).

Structural and vegetative BMPs. Buffer strips have been studied in many places, and are widely implemented, but they are not always effective. Examples of successful wetland construction and controlled drainage were also found, but these studies were not as prevalent. We grouped all edge-of-field vegetated filter strips, grassed waterways, and riparian buffer strips into the buffer strip category. Based on a review of buffer strips on Virginia farms in which 36% of buffers were completely ineffective (Hayes and Dillaha, 1992), we created a checklist to determine if a site is suitable for a buffer based on field slope, soil loss rates, site maintenance, and overland flow concentrations. We adapted this to create buffer strip suitability recommendations based on land type (Table 2.3). Buffer strips are effective for targeting overland flow paths if they provide surface roughness to reduce overland flow velocity, and increase time–of-concentration, thereby promoting deposition of sediments and infiltration of dissolved chemicals. Buffers may be more effective for removing PP than SRP from surface flow (Uusi-Kamppa *et al*., 2000). Buffer strips were effective when overland flow was shallow, dispersed, and uniform through the buffer (Dillaha *et al*., 1986a; Dillaha *et al*., 1986b; Robinson *et al.*, 1996; Cole *et al.*, 1997; Clausen *et al.*, 2000). A buffer strip study in northeastern Iowa (Robinson *et al.*, 1996) found that 70% of the sediment was removed in the first 3 meters of the buffer, with little removal observed with increased width. In this study, 67% of the total rainfall observed was during high intensity storms, triggering infiltration excess overland flow. The upland area adjacent to the buffer was an 18 m fallow strip, and was tilled every three weeks to minimize concentrated flow before overland flow entered the buffer strips. The steepest buffer strips in the study (slope gradient of 12%) were the least effective at reducing soil losses and overland flow. A comprehensive review paper of buffers ranging from 3-10 m, suggested that a buffer slope greater than 9.2% does not slow overland flow velocity enough for the buffer to effectively infiltrate overland flow or allow sediment deposition (Dillaha *et al.*, 1986a).

The benefits of terracing for *A* land types was demonstrated in a study in southwestern Iowa, where seasonal discharges of overland flow, nutrients, and sediment were all reduced tenfold in the terraced scenarios (Gassman *et al.*, 2010). Authors cited the terraces as being most effective during critical erosion periods, which is likely when infiltration excess overland flow is generated during extreme rainfall. Terraces were also highly effective on *A* land types with steep slopes (30-60%) (Dano and Siapno, 1992) and moderately steep slopes (Chow *et al.*, 1999). Terraces are likely most successful in *A* land types with moderately steep to steep slopes because they slow overland flow enough to increase water residence time within the terrace, allowing for infiltration and increased soil moisture storage for plant uptake (Chow *et al.*, 1999) as well as possible degradation of pesticides, deposition of sediment, and denitrification. As seen in the Iowa study, however, adding tile lines during construction of terraces can lead to increased nitrate losses (Gassman *et al.*, 2010).

Source management. Nutrient management plans and IPM were highly variable in effectiveness based on the application amount, timing, and strategy (Table 2.1 and Table 2.4). Incorporation of pesticides and herbicides into the mixing zone (A horizon) of soil through mulch tillage or chisel-plowing and the direct injection of manure reduced pollutant loss in overland flow (Withers and Jarvis, 1998; Sharpley *et al.*, 2000). In a manure application management study in Iowa, Coelho *et al.* (2006) optimized the rate and method of side-dressed injection application of liquid swine manure in corn fields to match the nitrogen uptake of the crop and minimize nitrate losses to ground and surface waters. When the application exceeded the crop demand for N, nitrate concentrations increased in both the topsoil and drainage water. Injection application was recommended because it maximized the crop yield while minimizing nitrate loss to soil, groundwater, and surface water.

Ghidey *et al.* (2005) found that incorporating soil-applied pesticides below the upper 2-5 cm of the soil is one of the most effective ways to reduce overland flow of pesticides. They studied the effect of split application of pesticides based on the hypothesis that multiple smaller applications would reduce loss. However, that did not prove true. Since pesticide loss was greatest immediately following application, split application created multiple periods of vulnerability for overland flow particularly during large storm events, despite the smaller quantities of application. They concluded, therefore, that timing of application is far more important than rate of application. However, it is logical that any reduction in application rate will reduce potential pollution by pesticides (Hall *et al.*, 1972, cited in Mickelson *et al.*, 1998).

These NMP and IPM examples provide evidence that even within the *A* land type, there is not a single NMP or IPM strategy. Site specific plans that are well managed may provide greater success, especially when applications do not coincide with large precipitation events, and are applied when crops can uptake the chemicals or there is enough organic matter and residue in the soil to either immobilize or bind them allowing for biodegradation (see Table 2.4).

Tillage and crop management practices. Reduced tillage practices increase soil infiltration capacity, reducing infiltration excess overland flow during high precipitation events. In the examples where no-till was effective in reducing overland flow (Mostaghimi *et al.*, 1991; Forney *et al.*, 2000; Ghidey *et al.*, 2005; Lerch *et al.*, 2011), the topography was flat, and the soil type was primarily silt loam, and in some of the pesticide cases, incorporation of the pesticides coupled with the no-till operations ensured greater reductions in pesticide transport. In the no-till example of Mostaghimi *et al.* (1991), nitrate concentrations in overland flow were reduced by 50% compared to conventional tillage and the nitrate yield in overland flow was comparable to control plots without any fertilizer application. Mickelson *et al.* (1998) also found that incorporation of pesticides into a silty clay loam soil in Knoxville, IA was an effective method for reducing pesticide overland flow.

With the introduction of reduced tillage operations on *A* land types, the dominant flow path can shift from infiltration excess to saturation excess in shallow soils or vertical leaching in land types with deep soils. A study in Maryland (Isensee and Sadeghi, 1993) compared the response of corn plots to no-till and conventional tillage over a 2-year study period. During the summer months, the effectiveness of no-till versus conventional tillage was primarily a factor of soil infiltration rates and antecedent soil moisture conditions. Overland flow rates were greater from no-till plots when the time between rainfall events was less than 7 days, overland flow from conventional tillage was greater when the time between events was more than 7 days. In this particular study, the dominant flow path may have switched from saturation excess during multiple rainfall events that occurred within 7 days to infiltration excess when rainfall occurred on drier soils with lower infiltration capacities. The study also found that slow release pesticide application on both tillage systems resulted in lower pesticide concentrations in overland flow and was a good option for land types that alter between infiltration and saturation excess.

There are multiple cases where no-till reduced overland flow and associated pollutants such as soil loss and/or TP, but as a result, enhanced leaching of other pollutants such as nitrates or soluble pesticides due to the increased infiltration capacity (Flury, 1996; Carter *et al.*, 1998; Forney *et al.*, 2000; Shipitalo *et al.*, 2000). The national movement towards mulch tillage practices in the past century has effectively reduced sediment loss from upland areas across the country (Blevins *et al.*, 1998). Mulch tillage is slightly less effective at reducing pollutant delivery than no-till (Lerch *et al.*, 2011), but there is also less risk of mulch tillage triggering new flow paths, and it is less costly to implement. Before a BMP is implemented to address infiltration excess overland flow and erosion issues, the potential land type transition and dominant flow path change to saturation excess, subsurface lateral flow, or leaching should be examined. This can be done through a modeling approach (Brooks *et al.*, 2015), through soil type analysis, or from observations of producers who have already implemented the BMP in a similar land type and have witnessed how the BMP impacts the dominant flow path. As discussed in the next two sections, soil depth is a key characteristic for the potential to trigger a different flow path.

When cover crops are established prior to major hydrological events, they improve infiltration capacity, uptake, surface roughness, and they slow overland flow velocity, as cited in multiple studies on *A* land types (Wendt and Burwell, 1985; Zhu *et al.*, 1989; Kaspar *et al.*, 2001). The USDA CRP has also been highly successful in removing *A* land types with high erosion rates from agricultural production (Hansen, 2007; Tomer and Locke, 2011). With the reintroduction of perennials in these areas, the hydraulic conductivities of the soils are often enhanced (Jiang *et al.*, 2007), thus reducing overland flow. As well, the added vegetative cover can reduce erodibility.

Effective BMPs for B1 Land Types

In a *B1* land type, saturation excess and subsurface lateral flow are dominant flow paths, and in hilly terrain formation of gullies may occur. After source management through NMPs and IPM, tile drainage best addresses these dominant flow paths (Table 2.1). However, while artificial drainage may decrease the overland flow volume, it may create a subsurface flow path, which does not necessarily reduce the overall pollutant transport. *B1* land types are challenging to manage due to the presence of perched water tables above shallow restrictive layers. The flow path cannot easily be altered. The literature lacks convincing evidence of effective BMPs for land types dominated by saturation excess processes (Table 2.1 and Table 2.2).

Structural and vegetative practices. Tile drainage is a common practice to manage perched water tables because it enhances infiltration thus reducing surface flow path activation. However, it also increases the likelihood of subsurface transport of pollutants, especially in soils of high hydraulic conductivity (Sharpley *et al.*, 2000; Dinnes *et al.*, 2002). An in-depth review of BMP effectiveness in tile-drained landscapes suggests employing multiple management strategies, including NMPs, diversifying crop rotations, cover crops, and conservation tillage to reduce the impact of tile drainage on pollutant export (Dinnes *et al.*, 2002). Removing N once delivered to the stream through wetlands and biofilters is also a recommended practice. In addition to tile drainage, diversion ditches also have been constructed to intercept subsurface lateral flow in perched systems and reduce downslope soil saturation (Frankenberger *et al.*, 1999; Easton *et al.*, 2008; Zhang *et al.*, 2013). Upslope drainage which intercepts clean water above a potential pollutant source area, such as a confined feeding lot or barnyard, is also highly recommended (Scott *et al.*, 1998). Examples of effective buffers for *B1* land types were not found (see Table 2.3). For this review, the transition from cultivated land to permanent vegetation to control pollutant sources in saturated areas was considered a conservation cover BMP, and therefore did not fall within the definition of buffer. In a review, Helmers *et al*. (2008) found that in areas where saturation excess is the dominant flow path, the conversion of cultivated areas to perennial vegetation was an effective method to reduce source areas of NPS pollution. In this review, conservation cover falls under the CRP practice.

Source management. Because perched water tables are so difficult to manage, BMPs that target the source of the pollutant application like NMPs and IPM are generally the most effective practices for overall reductions (Table 2.1). Moving the pollutants out of the periodically saturated areas to the uplands where there is lateral flow through the soil is effective as has been proven in the New York City source watershed in the Catskill Mountains (Bishop *et al.*, 2005; Easton *et al.*, 2009). A study in the Catskills region by Walter *et al.* (2001) illustrated just how beneficial NMPs can be for a *B1* land type where shallow lateral flow and saturation excess overland flow are predominant. This study identified sources of overland flow generation at a hillslope scale, both spatially and temporally, and avoided spreading manure in these areas. Phosphorus levels were reduced at the watershed scale using this spatial and temporal NMP. Table 2.4 illustrates other key “source” BMP findings.

Tillage and crop management practices. Depending on the depth to the restrictive layer, overland flow volume may not decrease with enhanced infiltration capacity due to the saturation excess overland flow mechanism inherent in these systems. The addition of organic matter and surface residue from conservation and no-till practices are beneficial for denitrification, degradation (Fawcett *et al*., 1994), and sorption processes. Increased surface roughness also reduces the risk of soil erosion (Walter *et al*., 1979; Fawcett *et al*., 1994; Mudgal *et al*., 2010a). The study by Ghidey *et al*. (2005) described above in the A land type section showed that reduced tillage can prevent Hortonian overland flow. Because this study was done in an area with restrictive layers, once the reduced tillage improved the infiltration capacity, this *A* land type transitioned to a *B1* land type. In soils prone to overland flow such as the claypan soils with restrictive layers studied by Ghidey *et al.* (2005) in Missouri, no-till was not effective for reducing herbicide loss through overland flow unless pesticides were incorporated into the soil profile. Conservation tillage is more effective for soils with restrictive layers. Soils in Ghidey *et al.* (2005) were characterized as silt loam and silty clay loam, with an argillic layer less than 36 cm deep leading to perched water tables. For this *B1* land type, the dominant flow path was saturation excess overland flow because the field area was flat and there was not enough of a gradient to promote subsurface lateral flow. In a situation like this, buffers and terraces are not effective because there is not enough slope gradient. Both no-till and conservation tillage were found to be effective in this area in plot and field scale studies, but to differing degrees, because these intensively cultivated soils likely had a reduced infiltration rate. In a 1993 to 2001 plot scale study, Lerch *et al.* (2011) found that no-till without pesticide incorporation reduced atrazine by 90 g/ha, which was three times the reduction of mulch tillage with incorporation. Metolachlor was reduced by 31 g/ha; this was double the reduction that mulch tillage had even with herbicide incorporation.

Another plot scale study by Ghidey *et al.* (2005) in the same area from 1997 to 2002 not only found greater pesticide reductions from no-till than mulch till, but also found that no-till management actually had greater overland flow rates than mulch tillage. The authors suspected that the mulch tillage practice broke up the sealed soil surfaces that can occur in silt loam soil, resulting in more micro relief and faster drying of the soil whereas the no-till systems did not significantly develop preferential flow paths, perhaps due to the restrictive layers. No-till increases the infiltration capacity of the soil, but unless water can percolate through the restrictive layer or the soil structure has enhanced its water holding capacity, the soil profile will eventually saturate and create saturation excess overland flow. No till systems should increase surface residue, prevent soil crusting, increase micro relief in the soil, and increase the drying out of the soil (Ghidey *et al.*, 2005). It is possible that in the study period, these soil transformations had not yet occurred.

The plot and field scale studies in Missouri (Ghidey *et al.*, 2005; Lerch *et al.*, 2011) are good examples of situations where mulch tillage and no-till were effective for surface pollutants, but did not reduce vertical leaching of dissolved pollutants because of the restrictive layer, and did not promote subsurface lateral flow because of the flat terrain and shallow soil. The lessons learned in Missouri regarding no-till and mulch tillage can be applied to other locations with flat terrain, restrictive layers, and high rainfall intensity that are transitioning to mulch tillage and no-till practices (Table 2.1).

Effective BMPs for B2 Land Types

Deep percolation is the dominant flow path in *B2* land types due to deep, well-drained soils with high infiltration capacities. To best reduce the leaching of pollutants of concern, application at the source should be reduced and the residence time in the mixing layer (0.2-5cm from soil surface) should be increased to enhance denitrification, degradation, and crop uptake of pollutants (Fielder and Peel, 1992; Flury, 1996; Shepard, 1999; Dinnes *et al.*, 2002; Reichenberger *et al.*, 2007; Kay *et al.*, 2009). BMPs like buffers, controlled drainage, conservation tillage paired with cover crops or source BMPs most effectively enhanced residence time in the mixing zone (Table 2.2).

Structural and vegetative practices. Buffers were effective only if the leaching flow path was to a shallow groundwater source such that the buffer vegetation interacted with the dominant flow path (Lowrance *et al*., 1997: Mendez *et al*., 1999; Borin *et al*., 2004; Miller *et al*., 2010; see Table 2.3). Studies of effective riparian buffers near Tifton, Georgia indicated that when the buffer root zone was deep enough to intercept shallow subsurface flow from upslope contributing areas, nitrates and pesticides could be removed in B2 land types (Hubbard and Lowrance, 1997; Vellidis *et al*., 2002).

Controlled drainage is a commonly used practice in *B2* land types (Table 2.1). Studies showed that by maintaining a saturated root zone, pollutant concentrations and leaching could be reduced by increasing residence time in the mixing zone and increasing plant uptake (Evans *et al.*, 1979; Lalonde *et al.*, 1996; Skaggs *et al.*, 2005; Feset *et al.*, 2010). In a North Carolina study with sandy soil, Dukes *et al.* (2003) tested controlled drainage systems on both *B1* and *B2* land types. In the *B2* land types, controlled drainage led to a 73% reduction in nitrates in shallow groundwater. The authors hypothesized that the reductions were due to enhanced denitrification deeper in the soil profile.

Source management. In a three-year experimental study in Iowa (Blackmer and Sanchez, 1988), 49-64% of fertilizer applied in the fall was lost to leaching rather than plant uptake from corn production. The loss of nitrogen through the top 1.5 m of the soil profile appeared to be due to precipitation events paired with the lack of cover crops to uptake the excess nitrogen. To best manage *B2* land types, source management BMPs like NMPs and IPM should be implemented as shown by Goulding *et al.* (2000) and Vellidis *et al.* (2002). In an event-based nitrogen leaching study at a 157-year-old agricultural experiment site in Rothamsted, UK, Goulding *et al.* (2000) found that NMPs that increase N efficiency decrease N leaching by 74% compared to 120 years ago. They also found that even plots that had not received fertilizer in over 150 years still leached N after rain events during the beginning of the water year. This study highlights that even with increased N uptake and efficiency in agriculture, rainfall events may still release pollutant residue from prior applications. In the study by Isensee *et al.* (1990) in Maryland, pesticide concentration in leachate was greater when application occurred prior to a large rainfall event. Authors stated that during these rainfall events, preferential flow paths may have been triggered, enhancing the leaching rate. Reduction of application and enhancement of crop uptake can help to buffer the overall effects of event-based leaching.

Tillage and crop management practices. Similar to the *B1* land type, addition of organic matter and surface residue from conservation and no-till practices are beneficial for denitrification, degradation, and sorption processes in *B2* land types (See Table 2.1 and Table 2.2). In land areas with deep soils, conservation tillage and no-till can convert *A* land type flow paths to *B2* land type flow paths by increasing the infiltration capacity. Cover crops may be added to *B2* land types to target both when the landscape is a seasonal *A* land type to increase infiltration capacity, and to increase time in the mixing zone when it is a seasonal *B2* land type. Cover crops have increased residence time in the mixing layer in studies by Meisinger *et al.* (1991) and Staver and Brinsfield (1998).

While conservation tillage increases infiltration capacity compared to conventional tillage, Shipitalo *et al.* (2000) found that the difference between leaching rates in conservation tillage and conventional tillage were minimal. Conservation tillage typically transports the greatest amount of solutes during the first precipitation event after chemical application via macropores, followed by reduced solute transport in subsequent events. Therefore, if NMPs and IPM align application of agrichemicals after a major precipitation event in conservation tillage systems, solute leaching may be less if time between events is sufficiently great.

Plot and Field Scale Studies Summary

Patterns observed for effective BMPs by land type, the temporal and spatial variability for land type transitions, and recommendations for future plot and field scale BMP effectiveness studies emerged from the BMP analysis at plot and field scale by land type.

Overall, regardless of scale or land type, site-specific "source" BMPs that included NMPs and IPM, on the basis of this review, were determined to be the most effective way to reduce pollution (Logan, 1990; Edwards *et al.*, 1996; Lord and Mitchell, 1998; Coelho *et al.*, 2006, 2007; Kay *et al.*, 2009). By reducing excess application, and avoiding periods of high precipitation, there were fewer pollutant issues (Edwards *et al.*, 1997a,b; Dinnes *et al.*, 2002). Key findings from source BMP effectiveness studies are illustrated in Table 2.4. Buffer strips were widely implemented, but were most effective when interacting with shallow, diffuse flow in A land types or in B2 land types that have high water tables in which the buffer root zone can interact with subsurface flow (Table 2.3). Management for high intensity rainfall events or for rainfall after soil crusting has occurred may be nearly impossible, as highlighted in Isensee and Sadhegi (1993), Isensee *et al.* (1990), and Goulding (2000), although from author observations, some growers in northern Idaho use a harrow to break up soil crusting after planting. However, as indicated, slow release pesticides, cover crops, or application planning can provide protection against the impact of these rainfall events. Transient restrictive layers, such as tillage pans, are equally difficult to manage for.

Hydrological land types may be variable in space and time. Saturation excess overland flow may be the dominant flow path after spring infiltration excess overland flow. Or, for example, later in the season, an area with deep soils may transition to a *B2* land type with leaching as the primary flow path if high intensity rainfall patterns that cause infiltration excess overland flow dissipate. By implementing a BMP to address infiltration excess overland flow, a grower may inadvertently trigger a leaching pathway. When managing for both surface and subsurface transport of dissolved and particulate pollutants, conservation tillage paired with source BMPs that address timing and quantity of application can effectively reduce surface transport. At the same time, a suite of source and conservation tillage BMPs can prevent subsurface pollutant transport through preferential flow by overall reduction of application (Shipitalo *et al.*, 2000).

BMP EFFECTIVENESS ANALYSIS: WATERSHED SCALE STUDIES

Targeting BMPs within a watershed with limited conservation dollars is a common challenge. When extending beyond the plot and field scales, it can be difficult to determine which BMPs will be most effective in what locations. To aid in this effort, we now examine BMP effectiveness in watershed scale studies and how cumulative effects of BMPs at this scale can be explained within our conceptual framework. We included watersheds in this examination if information about the following four characteristics was available: spatial variability of soils, temporal variability of climate, identification of HSAs, and the type of BMPs installed. If one or more of these characteristics was not included in published studies, it was difficult to determine land types across the watershed or to critique the placement of BMPs. For some watersheds, that information was found in alternate sources (described below). We reviewed studies of BMP implementation in 18 watersheds and found that few provided the necessary information to determine land types present in the watershed or to determine the effectiveness of each type of BMP utilized. The land type conceptual framework could apply to most watersheds if the appropriate soil and climate information can be found (see Figure 2.2). If future watershed scale studies include this information, the land type conceptual framework can be applied more broadly. We focused on four NIFA-CEAP watersheds that some or all of the authors had visited and for which information was available. These include Paradise Creek watershed in Idaho (ID), Lincoln Lake watershed in Arkansas (AR), Cannonsville watershed in New York (NY), and Little River Experimental watershed in Georgia (GA). We used these watersheds as examples of how to apply the conceptual framework to target BMP placement at the watershed scale.

Prior to site visits to these watersheds, a land type classification was prepared based on watershed descriptions in publications and readily available data sources. Preliminary classifications were made by examining the publications and then were confirmed using outside data sources, including the rainfall frequency atlas for the US (Hershfield, 1961) and the NRCS Soil Survey. Monthly maximum 30 min rainfall rates for ID, AR, NY, and GA based on 30-year climate data (Figure 2.3) were used to determine precipitation characteristics for land type classification. In addition, NRCS Soil Survey data on soil depth to a restrictive layer, slope range, and the A-horizon hydraulic conductivity (K_{sat}), adjusted for conventional, mulch tillage and no-till conditions (Table 2.5) were also used. Depth to a restrictive layer was identified as depth to bedrock, an argillic or fragipan horizon, or the depth of an abrupt increase in clay content and/or bulk density. The no-till K_{sat} was the value found in the NRCS Soil Survey. K_{sat} for conventional tillage was determined based on soil texture (Flanagan and Livingston, 1995). For conservation tillage, the K_{sat} value was the average of the no-till and conventional tillage value. During the site visits, the land type classifications were presented and our estimates of dominant flow paths were discussed with local watershed scientists. In Table 2.5, land type classifications were based on soil depth, K_{sat}, and the monthly 30 min rainfall intensity shown in Figure 2.3 for the predominant runoff period of December-March. In each NIFA-CEAP watershed, we presented our land type classification to local scientists and watershed managers who confirmed that these land type classifications were accurate and that we correctly derived the dominant flow paths from the land type classification. Slight differences in hydrological understandings were due to local knowledge, such as presence of karst hydrology in Lincoln Lake watershed.

Paradise Creek Watershed, ID

In the Paradise Creek watershed (4,890 ha) in north central Idaho sediment is the primary pollutant of concern. The watershed is characterized by a patchwork of predominantly *B1* and *B2* land types due to well-drained silt loam soils, often with shallow argillic layers, and low intensity precipitation (see Figure 2.3). HSAs are present in the in the spring when soils are saturated and thus overland flow increases, particularly on toe slopes with shallow restrictive layers. However, when conventionally tilled or frozen, a soil crust forms reducing the infiltration capacity creating *A* land types (Table 2.5). When subjected to freezing, the *A* land type causes very high overland flow and erosion rates resulting from low infiltration capacities of frozen soil. Steep slopes (up to 35%), also characteristic of this region, lead to converging overland flow, which creates gullies (Brooks *et al.*, 2010).

Implementation of conservation tillage and contour farming starting in the mid-1970s and CRP in the 1980s (Carlson *et al.*, 1994; Kok *et al.*, 2009) drastically altered the dominant hydrologic flow path within this watershed to those associated with *B1* and *B2* land types (Table 2.5), (Brooks *et al.*, 2010). That shift on upland fields facilitated increased infiltration and reduced erosion. Long-term monitoring showed significant reductions in watershed sediment loading from the time of conventional tillage practices (Brooks *et al.*, 2010), but with the need for further reductions.

Between 2000 and 2003, various BMPs were installed throughout the rural and urban parts of the watershed including sedimentation basins (also called gully plugs), buffer strips, no-till, stream bank stabilization, riparian and wetland restoration, and bridge crossings. Some functioned well, such as gully plugs that reduced soil loss from upslope contributing areas in converging parts of the landscape. But not all BMPs were placed in HSAs. For example, buffer strips were installed by willing landowners, often times where conditions were not optimal, such as below steep slopes, where concentrated flow paths are present, or in areas continually inundated during the winter (as observed by the authors). Based on recommendations (e.g. Stewart *et al.*, 1975; Veith *et al.*, 2004; Mulla *et al.*, 2005), and from our conceptual framework to improve targeting, we infer that basin-wide reductions would be more significant if land types had been considered when BMPs were placed. For example, placing buffer strips in *A* land types with low to moderate slopes and not in *B1* land types, and converting farming practices on *A* land types to either no-till or CRP, would further reduce sediment loads at the watershed outlet.

Lincoln Lake Watershed, AR

The Lincoln Lake Watershed (3,240 ha) in northwestern Arkansas exhibits a complex land type configuration as well as temporal shifts due to high intensity precipitation particularly during May through September (Figure 2.3). The watershed has shallow soils in the upland areas. Deeper soils with moderately good to excessive drainage comprise 70% of the land area, primarily near Lincoln Lake and in forested areas (Edwards *et al.*, 1996). Deep leaching to a karstic groundwater system is, therefore, dominant in the majority of soil types and thus the watershed is predominantly *B1* and *B2*. The principal HSAs exist where excessive drainage occurs, however, during high intensity precipitation events from May to September, *A* land types can result, creating HSAs related to reduced infiltration capacity and the resulting overland flow paths (Table 2.5). Land use in the watershed is primarily grass/hay and pasture land, and poultry operations (Edwards *et al.*, 1996, 1997; Chaubey *et al.*, 2010; Gitau *et al.*, 2010).

NMPs promoting manure application rates to meet crop N requirements reduced nitrate losses by 35 to 75% in the Lincoln Lake Watershed (Edwards *et al.*, 1996). Furthermore, NMPs were most effective when manure was not applied during wet antecedent conditions, in order to prevent nitrates from moving with subsurface lateral flow, and when manure application was prohibited within 10 m of surface waters (Edwards *et al.*, 1997b). While other BMPs such as waste utilization, pasture and hay land management, dead poultry composting, and waste storage structure construction were also implemented, the authors cited the NMP as the key BMP, which is in line with the results from plot and field scale studies. In a watershed like Lincoln Lake, with the unpredictable and intense nature of the January to April storm events, NMPs that reduce pollutants at the source are highly recommended.

Cannonsville Watershed, NY

While the Cannonsville Watershed (117,900 ha) in New York State (James *et al.*, 2007; Rao *et al.*, 2009; Flores-López *et al.*, 2010) is primarily forested, the agricultural area (17% of the watershed area), which is dominated by dairy operations, has a strong presence. The dairy operations have led to eutrophication problems in respective downstream reservoirs due to phosphorus loading. Low intensity precipitation is predominant in the Cannonsville Watershed except for the occasional thunderstorm during summer (Figure 2.3; Walter *et al.*, 2001; Walter *et al.*, 2003). HSAs which produce the majority of the overland flow via saturation excess overland flow include near stream areas and areas with shallow soil over a slowly permeable glacial till soil or bedrock. Due to mostly low precipitation intensity in the Cannonsville watershed, a patchwork of *B1* and *B2* land types exists with occasional seasonal shifts to the *A* land type during bursts of extremely high intensity precipitation (Table 2.5 and Figure 2.3) and frozen soils at the end of the winter.

SRP loading from dairy cattle manure was primarily mitigated through targeting HSAs. Exclusionary fencing and cattle crossings were placed in the near stream areas, and timing and placement of fertilizer and manure application were considered throughout the watershed (Rao *et al.*, 2009; Flores-Lopez *et al.*, 2010) by preventing manure spreading in HSAs. In order to make this possible, paved paths were constructed upslope and more powerful tractors were cost-shared that could pull the manure up the hill away from the saturated areas at the bottom of the watershed where farms were located because of the availability of drinking water for the cattle.

Using the Variable Source Loading Function model (VSLF) (Schneiderman *et al.*, 2007), Rao *et al.* (2009) analyzed the effectiveness of various BMPs. The authors concluded that total P losses decreased only after installing cattle crossings in the creek, protecting riparian areas, reducing the spreading of manure during hydrologically active periods, and excluding livestock from the stream. This suite of targeted NMPs resulted in the largest SRP reductions (Bishop *et al.*, 2005; Easton *et al.*, 2008) in the *B1* land type, which is the land type in this watershed that typically contributes the most to pollutant loss through surface flow paths.

Little River Experimental Watershed, GA

Because of extensive, long-term research in the Little River Experimental Watershed (LREW) (33,700 ha) in southern Georgia, climate and spatial distribution of soil types and depths are well known (Vellidis *et al.*, 2002) making application of the land-type based BMP recommendations relatively simple. The infiltration capacity of soils in the watershed is generally high but with the presence of shallow restrictive layers (Cho *et al.*, 2010), and thus *B1* land types are most prevalent (Table 2.5). High intensity precipitation during summer thunderstorms also occurs, which may occasionally exceed infiltration capacity (Figure 2.3). Subsurface lateral flow enters stream channels by passing through riparian zones dominated by forested wetlands. If farming were to occur in the riparian zones and toe slopes, controlled drainage, cover crops and crop rotations would need to be considered as that would be the primary location of HSAs. However, because of the hydric properties of those soils, farming is not common and wetlands and forested buffers are highly recommended. Furthermore, the natural buffer strips close to the streams were indeed very effective because in this watershed, nutrient transport was very small (Cho *et al.*, 2010). In the upland areas, NMPs are recommended in order to control for the amount of fertilizers or pesticides that can be lost through surface transport pathways (e.g. runoff, erosion).

Consistency between Land Type Classification and Literature Recommendations at Watershed Scale

Implementation of BMPs at the watershed scale has the potential to achieve larger water quality impacts if the BMPs are targeted at the correct locations based on a thorough understanding of the local physical and climatic characteristics. At the watershed scale, it is especially important to understand the land types present at smaller spatial scales and how to correctly target BMPs within the watershed. With the proper information, land type based recommendations for targeting dominant flow paths within a watershed can be accomplished and lead to substantial improvements in water quality, as observed in the Paradise Creek watershed (Brooks *et al.*, 2010). In watersheds where less is known about the physical characteristics, land type identification, creation of BMP recommendations, and their subsequent implementation based on locally dominant flow paths may require an upfront time investment, but if the BMP implementation is designed correctly, water quality improvements may be achieved.

Temporal shifts in land type characteristics were not often evaluated in watershed studies. Baseline monitoring should occur before BMP implementation, and long-term, event-based monitoring should continue long after installation to determine effectiveness and account for the potential lag time of pollutant response. Our recommendations tie into those by Mulla *et al.* (2005) with regards to the ability of BMP effectiveness studies at the watershed scale to produce clear results. They need: 1) to be long enough to account for weather variability or lag time; 2) the study design to be scientifically rigorous; 3) the BMPs targeted at HSAs; and 4.) modeling efforts representative of actual physical processes.

Lag time of pollutant response when monitoring BMP effectiveness is often mentioned at the watershed scale. Many authors of watershed scale studies discussed the impact of lag time on results (e.g. Boesch *et al.*, 2001; Schilling and Spooner, 2006; Rao *et al.*, 2009; Brooks *et al.*, 2010; Gassman *et al.*, 2010). Study length may not be sufficient to measure the desired response (if any) or there may be too much variability in the results to meaningfully quantify the BMP impact. Studies and monitoring projects may also be abandoned before significant changes appear in monitoring data (Meals *et al.*, 2010; Hamilton, 2011). In order to avoid that problem, study design needs to account for the response period by either lengthening monitoring time, decreasing scale by choosing a nested basin, or improving the statistical design (e.g. paired watersheds). Lag times are not constant across watersheds, varying based on watershed size, hydrology, pollutant type, BMP and stream characteristics (Meals *et al.*, 2010). However, estimations can be made in order to design more effective studies. Gregory *et al.* (2007) described the timing between conservation, restoration actions and ecological responses. They also recommended taking a more synergistic approach to watershed management beyond just the agricultural system, through incorporating ecological restoration and community collaboration to enhance biological responses in addition to improved water quality and decreasing lag time. Meals *et al.* (2010) compiled a list of reported lag times for different watersheds.

CONCLUSIONS AND RECOMMENDATIONS

Our conceptual framework for analysis of NPS pollution in agriculturally dominated watersheds focuses on classification of land types (*A*, *B1*, *B2*) based on climate, soil type, land use, and topography. We sought to 1) develop a conceptual framework that relates BMP effectiveness with dominant hydrological flow paths that are a consequence of land and climate characteristics; 2) determine how BMP effectiveness reported in past plot and field scale studies fit within the framework; and 3) review BMP effectiveness in watershed scale studies and how cumulative effects of BMPs at this scale can be explained within the conceptual framework.

Our conceptual framework is centered on three hydrologic land types. Hydrologic land type *A,* where the restrictive layer is at the surface and land management practices that increase infiltration are effective. Hydrologic land type *B1,* where the surface soil has an infiltration rate greater than the prevailing rainfall intensity, but there is a restrictive layer at some depth causing lateral flow and saturated areas where water storage is limited and the profile cannot carry the flow from upslope. Few structural practices are effective for these soils. Hydrologic land type *B2*, where infiltration rate is greater than rainfall intensity (as with *B1*), but the profile lacks restrictive layers and the dominant flow path is percolation.

For each land type, effective BMPs were selected through a literature review analysis of plot and field scale studies based on the dominant hydrologic and pollutant flow paths, while taking into account the variability of land type characteristics in space and time. The key findings from the plot and field scale analysis showed that source BMPs such as NMPs and IPMs can be very effective at reducing pollutant delivery to surface and groundwater, independent of hydrologic land type. Conservation tillage (Blevins *et al.*, 1998) and CRP have been widely successful across landscapes at minimizing nonpoint source pollution (Hansen, 2007) and in converting *A* land types with sediment loading problems to *B1* and *B2* land types with increased infiltration capacity. Caution must be taken in buffer implementation because they may not be effective, especially in *B1* land types or in areas with concentrated flow.

We demonstrated that the conceptual framework could be applied at the watershed scale through an analysis of four data-rich watershed case studies. The inherent lag times within the social and physical system can disguise the actual effectiveness of a BMP or watershed scale suite of BMPs. Hydrologic land types can shift in space and time, and modifications from BMPs can alter the dominant flow path, triggering a new transport path for pollutants. Optimal NPS reduction at the watershed scale results when suites of BMPs address application of pollutants, transport of those pollutants based on the dominant flow paths, and delivery to the stream through effectively placed buffers or wetlands.

In order to reduce NPS pollution, our conceptual framework and literature review emphasize the need to address both the application of pollutants (i.e. amount and timing) as well as the dominant flow path(s) that transport the pollutants. Our land type framework provides a qualitative understanding of when and where to apply agrichemicals and fertilizers and how BMPs interact with the dominant flow path. Understanding of quantitative effects of BMPs on pollutant transport for the different land types will require a process-based decision-support tool that utilizes readily available data. An example is the hydrologic characterization tool by Brooks *et al.* (2015*),* which has simplified process-based modeling in a web-based environment. Such a tool advances the land type approach to include effects of site-specific spatial and temporal variability, such as slope configuration, seasonal patterns, and comparison of management scenarios, while also modeling adsorption and degradation traits of specific pollutants.

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TABLES

TABLE 2.1 Commonly effective BMPs for *A*, *B1*, *B2* land types and supporting studies.

Best Management Practice	**A**	**B1**	**B2**
Mulch Tillage	Ghidey *et al.* 2005 Deasy *et al.* 2007	Tollner *et al.* 1984 Ghidey *et al.* 2005 Ghidey *et al.* 2010	-
No Tillage	Mostaghimi *et al.*1991 Forney *et al.* 2000 Ghidey *et al.* 2005 Lerch *et al.* 2011	Mostaghimi *et al.* 1991 Forney *et al.* 2000 Ghidey *et al.* 2005 Lerch *et al.* 2011	-
Terraces	Alberts *et al.* 1978 Dano and Siapno 1992 Chow *et al.* 1999	-	-
Conservation Reserve Program (CRP)	Udawatta *et al.* 2006 Jiang *et al.* 2007	*	*
Cover Crops	Wendt and Burwell 1985 Zhu *et al.* 1989 Kaspar *et al.* 2001	Wendt and Burwell 1985 Zhu *et al.* 1989	Meisinger *et al.* 1991 Fielder and Peel 1992 Staver and Brinsfield, 1998 Shepard 1999 Kay *et al.* 2009
Effective buffers**	Robinson *et al.* 1996 Cole *et al.* 1997 Clausen *et al.* 2000 Lee *et al.* 2003	-	Hubbard and Lowrance 1997 Mendez *et al.* 1999 Vellidis *et al.* 2001 Borin *et al.* 2004 Miller *et al.* 2010
NMP/IPM	Coelho *et al.* 2006 Ghidey *et al.* 2005 Mostaghimi *et al.* 1991 Mickelson *et al.* 1998	Mostaghimi *et al.* 1991 Isensee and Sadhegi 1993 Mickelson *et al.* 1998 Walter *et al.* 2001 Ghidey *et al.* 2005 Coelho *et al.* 2006	Isensee *et al.* 1990 Shepard 1996 Goulding *et al.* 2002 Vellidis *et al.* 2002
Tile Drainage	-	Dinnes *et al.* 2002	-
Drainage Ditch	-	Frankenberger *et al.* 1999 Zhang *et al.* 2013	-
Controlled Drainage	-	-	Feset *et al.* 2010 Skaggs *et al.* 2010 Lalonde *et al.* 1996 Evans *et al.* 1979
Crop Rotations	-	-	Randall *et al.* 1997
Wetland construction	**Brix, 1994; Lee *et al.* 2009**	**Dinnes *et al.* 2002**	**Brix, 1994; Helmers *et al.* 2008**

* Specific CRP studies not found, but still assumed effective. See text for further explanation. **Buffers must meet the suitability components described in Table 2.3 to be considered effective for each land type.

TABLE 2.2 Summary of physical processes enhanced by each BMP. CRP refers to the Conservation Reserve Program. NMP refers to nutrient management plans and IPM to integrated pest management plans.

BMP	**Decreases or changes timing of surface application**	**Slows overland flow velocity**	**Increases infiltration capacity**	**Increases surface roughness**	**Increases residence time in the mixing layer**	**Increases plant uptake**
Mulch Tillage	-	Tollner *et al.* 1984 Ghidey *et al.* 2005 Deasy *et al.* 2007 Ghidey *et al.* 2010	Tollner *et al.* 1984 Ghidey *et al.* 2005 Ghidey *et al.* 2010	Ghidey *et al.* 2005 Deasy *et al.* 2007 Ghidey *et al.* 2010	-	-
No Tillage	-	Mostaghimi *et al.*1991	Mostaghimi *et al.*1991 Forney *et al.* 2000	Mostaghimi *et al.*1991 Ghidey *et al.* 2005	-	-
Terraces	-	Alberts *et al.* 1978 Dano and Siapno 1992 Chow *et al.* 1999	-	-	-	-
CRP	-	Udawatta *et al.* 2006 Jiang *et al.* 2007	Udawatta *et al.* 2006 Jiang *et al.* 2007	Udawatta *et al.* 2006 Jiang *et al.* 2007	-	-
Cover Crops	-	Wendt and Burwell 1985 Zhu *et al.* 1989 Kaspar *et al.* 2001	Wendt and Burwell 1985 Zhu *et al.* 1989 Meisinger *et al.* 1991 Fielder and Peel 1992 Staver and Brinsfield 1998 Shepard 1999 Kaspar *et al.* 2001	Wendt and Burwell 1985 Zhu *et al.* 1989 Meisinger *et al.* 1991 Staver and Brinsfield 1998 Shepard 1999 Kaspar *et al.* 2001	Meisinger *et al.* 1991 Fielder and Peel 1992 Staver and Brinsfield 1998 Shepard 1999	Meisinger *et al.* 1991 Fielder and Peel 1992 Staver and Brinsfield 1998 Shepard 1999
Effective buffers*	-	Robinson *et al.* 1996 Cole *et al.* 1997 Clausen *et al.* 2000 Lee *et al.* 2003	Robinson *et al.* 1996 Cole *et al.* 1997 Lee *et al.* 2003	Robinson *et al.* 1996 Miller *et al.* 2010	Hubbard and Lowrance 1997 Vellidis *et al.* 2003	Hubbard and Lowrance, 1997 Mendez *et al.* 1999 Vellidis *et al.* 2003 Borin *et al.* 2004 Miller *et al.* 2010
NMP/IPM	Isensee *et al.* 1990 Mostaghimi *et al.* 1991 Isensee and Sadhegi 1993 Shepard *et al.* 1996 Mickelson *et al.* 1998 Walter *et al.* 2001 Goulding *et al.* 2002 Vellidis *et al.* 2002 Ghidey *et al.* 2005 Coelho *et al.* 2006	-	-	-	-	-

TABLE 2.2 Summary of physical processes enhanced by each BMP. CRP refers to the Conservation Reserve Program. NMP refers to nutrient management plans and IPM to integrated pest management plans.

BMP	**Decreases or changes timing of surface application**	**Slows overland flow velocity**	**Increases infiltration capacity**	**Increases surface roughness**	**Increases residence time in the mixing layer**	**Increases plant uptake**
Tile Drainage		Dinnes *et al.* 2002	Dinnes *et al.* 2002	-	-	-
Drainage Ditch	-	Frankenberger *et al.* 1999 Zhang *et al.* 2013	-	-	-	-
Controlled Drainage	-	-	-	-	Skaggs *et al.* 2010	Lalonde *et al.* 1996 Skaggs *et al.* 2010
Crop Rotations	-	-	-	-	-	Randall *et al.* 1997
Construct-ed Wetlands	-	Brix, 1994; Lee *et al.* 2009	-	-	-	Brix, 1994; Lee *et al.* 2009

*Buffers must meet the suitability components described in Table 2.3 to be considered effective for each land type.

TABLE 2.3 Suitability of a site for buffer strips (modified from Hayes and Dillaha (1992) as cited in Barling and Moore (1994) and appropriate buffer characteristics for land types.

	Landscape Factor	**Suitability component for site and buffer**	**Comments**
For all land types	Upland Characteristics	Slope limitations: e.g. slope of field must be less than 9.2% and greater than 1%[1]; slope range between 3-12%[5]	Sites with greater slopes are not suitable for buffers; runoff velocity will be too high, reducing trapping efficiency to unacceptably low values· Sites with very small slopes are not suitable for buffers because hydraulic gradient is insufficient[1]
		Field cannot have excessive soil loss rates: e.g. soil loss rates must be less than 22.5 Mg/Ha)[1]	If soil loss rates are excessive, other in field conservation practices must be used to reduce soil loss to acceptable levels otherwise rate of deposition in buffer will exceed the buffer trapping efficiency[1]
		The ratio of field area to buffer area must not be too great, preferably less than 50:1[1]	If the ratio is too great, the site is unsuitable unless the soil erosion rates are very low. [1]
		Areas with concentrated flow such as in rills and gullies must be targeted with conservation tillage, or gully plugs before flow enters buffers	Buffers can only effectively filter pollutants if overland flow is dispersed through sheet flow, and is not in the form of concentrated flow.[1]
		Predict and identify overland flow source areas before designing and implementation of buffer using topography, soil characteristics, vegetation, and climate[2]	Buffers must intercept the dominant flow path that transports pollutants to be effective
	Maintenance	Landowner/ operator must be willing and able to maintain buffer	This includes mowing, controlling growth of undesirable weeds; inspection and repair after major storm events, excluding grazing and vehicle disturbance, especially during buffer establishment[1]
A	Infiltration excess overland flow path	Buffer strip must reduce overland flow velocity, increase infiltration capacity, and increase surface roughness	The buffer must allow for deposition of sediment and removal through uptake of N and P, denitrification, or degradation of pesticides
B1	Saturation excess overland flow path	Buffers are rarely effective for B1 land types due to perched water tables and concentrated flow	Forested buffers and constructed wetlands can provide suitable increase in uptake, infiltration capacity, retention and denitrification and degradation of pollutants
B2	Leaching flow path	Deep rooted, forested buffers effective only if leaching flow path is to a shallow ground water source[3]	Pollutants can be reduced only when the soil root zone is deep enough to intercept shallow ground water subsurface flow[4]

1. Hayes and Dillaha, 1992
2. Barling and Moore, 1994
3. Lowrance *et al.* 1997; Mendez *et al.* 1999; Borin *et al.* 2004; Miller *et al.* 2010
4. Hubbard and Lowrance, 1997; Vellidis *et al.* 2002
5. Franti, 1997

TABLE 2.4 Summary of source BMP effectiveness findings by land type: NMPs and IPM.

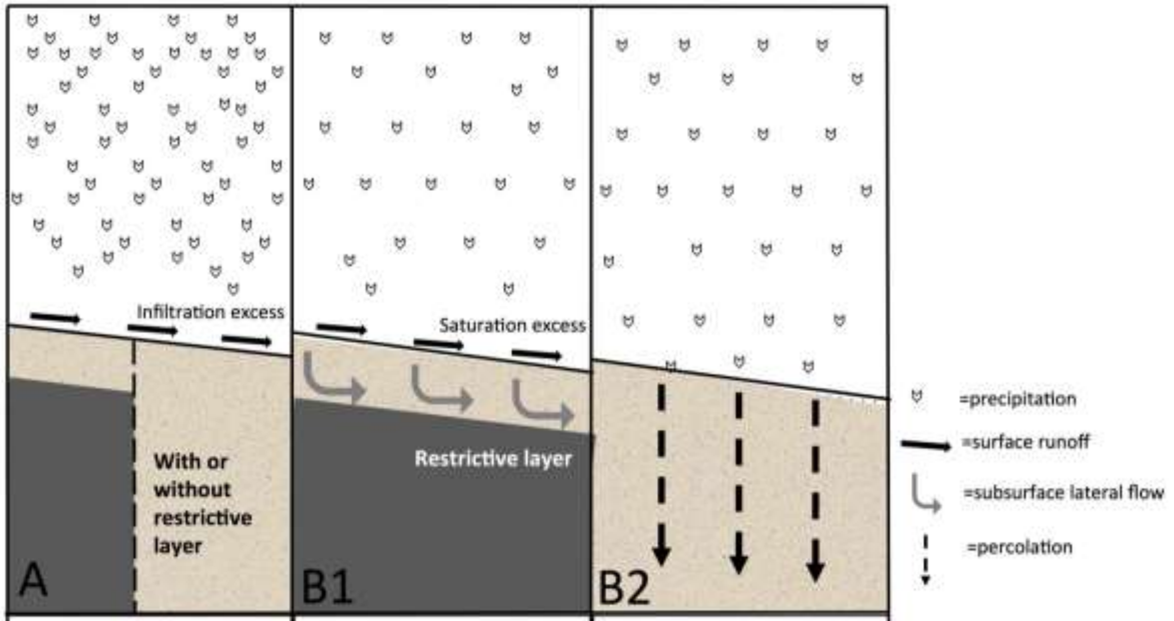
Effectiveness component	**Prioritize for Land Types:**	**Selected Studies**
Alter ratio of N and P in animal feed	*A,B1,B2*	Heathwaite *et al.* 2000. Powell *et al.* 2001; Sharpley *et al.* 2007; Swink *et al.* 2010
Install exclusionary fencing in grazing sites	*A,B1,B2*	Line *et al.* 2000; James *et al.* 2007; Kay *et al.* 2009; Rao *et al.* 2009; Flores-Lopez *et al.* 2010;
Optimize side-dressed manure injection	*A,B1,B2*	Jokela *et al.* 1996; Coelho *et al.* 2006;
Reduce application rate; optimize for crop uptake and denitrification and degradation processes	*A,B1,B2*	Isensee and Sadeghi, 1993; Edwards *et al.* 1996; Forney *et al.* 2000; Coelho *et al.* 2006;
Avoid application on HSAs or Variable Source Areas	*A, B1*	Walter *et al.* 2001; Heathwaite *et al.* 2005
Incorporate fertilizer/ pesticides into the mixing zone	*A and B2*	Mickelson *et al.* 1998; Withers and Jarvis. 1998 Sharpley *et al.* 2000; Ghidey *et al.* 2005; Lerch *et al.* 2011
Avoid application before large precipitation events, minimize time between application and planting	*A, B1, and tile drained land types*	Steenhuis and Walter 1980; Blackmer and Sanchez 1988; Edwards *et al.* 1997 a,b; Randall *et al.* 1997; Withers and Jarvis. 1998; Higgs *et al.* 2000; Dinnes *et al.* 2002; Ghidey *et al.* 2005; Reichenberger *et al.* 2007; Sharpley *et al.* 2007

TABLE 2.5 Typical soil depth to restrictive layer, land slope, and A-horizon hydraulic conductivity for soils in four watersheds, with land type based on monthly mean 30 min rainfall rates during major runoff periods in each watershed region. Data obtained from the NRCS Soil Survey and the rainfall frequency atlas for the US (Hershfield, 1961**).**

Watershed & Soil Type	Soil Depth (cm)	Land Slope (%)	CT A-horizon K_{sat} (mm/hr) - LT[1]	MT A-horizon K_{sat} (mm/hr) - LT[1]	NT A-horizon K_{sat} (mm/hr) - LT[1]
Paradise Creek Watershed, ID (threshold precipitation intensity: 10 mm/hr)					
Palouse silt loam	150	2 - 5	2 - A	18 - B2	32 - B2
Southwick silt loam (Argillic of fragipan)	97	5 - 8	5 - A	18 - B2	32 - B2
Taney silt loam (fragipan)	69	8 - 35	4 - A	18 - B1	32 - B1
Garfield silty clay loam	20	8 - 20	6 – A	8 - A	10 - B1
Lincoln Lake Watershed, AR (threshold precipitation intensity: 20 mm/hr)					
Pembroke silt loam (Argillic)	200	0 - 2	5 - A	18 - A	33 - B2
Linker silt loam (Argillic)	89	3 - 8	9 - A	50 - B1	330 - B1
Johnsburg silt loam (fragipan)	60	0 - 6	5 - A	18 - A	33 - B1
Captina silt loam (fragipan)	51	1 - 8	5 - A	50 - B1	324 - B1
Cannonsville Watershed, NY (threshold precipitation intensity: 10 mm/hr)					
Elka channery silt loam (stony)	180	15 - 35	10 - B2	21 - B2	79 - B2
Lackawanna silt loam (fragipan)	71	0 - 55	10 - B1	21 -B1	32 - B1
Collamer silt loam (lake plain)	53	0 - 25	5 - A	18 - B1	32 - B1
Little River Watershed, GA (threshold precipitation intensity: 30 mm/hr)					
Lakeland sand	216	0 - 12	33 - B2	181 - B2	330 - B2
Tifton loamy sand	99	0 - 8	31 - B2	181 - B2	331 - B2
Cowarts fine sandy loam (perched water)	70	1 - 25	20 - A	61 - B1	100 - B1

[1] CT = Conventional Tillage; MT = Mulch Tillage; NT = No Tillage; LT = Land Type

FIGURES



	Precipitation intensity>infiltration capacity	Precipitation intensity<infiltration capacity	Precipitation intensity<infiltration capacity
Soil depth	Shallow or Deep	Shallow	Deep
Dominant Flow Paths	**Infiltration excess,** regardless of presence of restrictive horizon or slope	**Lateral flow** and/or **saturation excess; tile drainage**	**Percolation** and/or **tile drainage**
Probable Pollutant Transport	Pesticides, phosphorus, soil loss	Pesticides, nitrates, phosphates, soil loss	Pesticides, nitrates, phosphates
Effective BMPs	Mulch tillage, no tillage, terraces, CRP, buffers*, cover crops, NMPs, IPMs, constructed wetlands	Mulch tillage, no tillage, CRP, cover crops, tile drainage, NMPs, IPMs, constructed wetlands	CRP, buffers*, Cover crops, controlled drainage, crop rotations, forested buffers, NMPs, IPMs, constructed wetlands

FIGURE 2.1 Land type conceptual framework (abbreviations: NMP: Nutrient Management Plan; IPM: Integrated Pest Management plan; CRP: Conservation Reserve Program). *Buffers must meet the suitability components described in Table 2.3 to be considered effective for each land type.

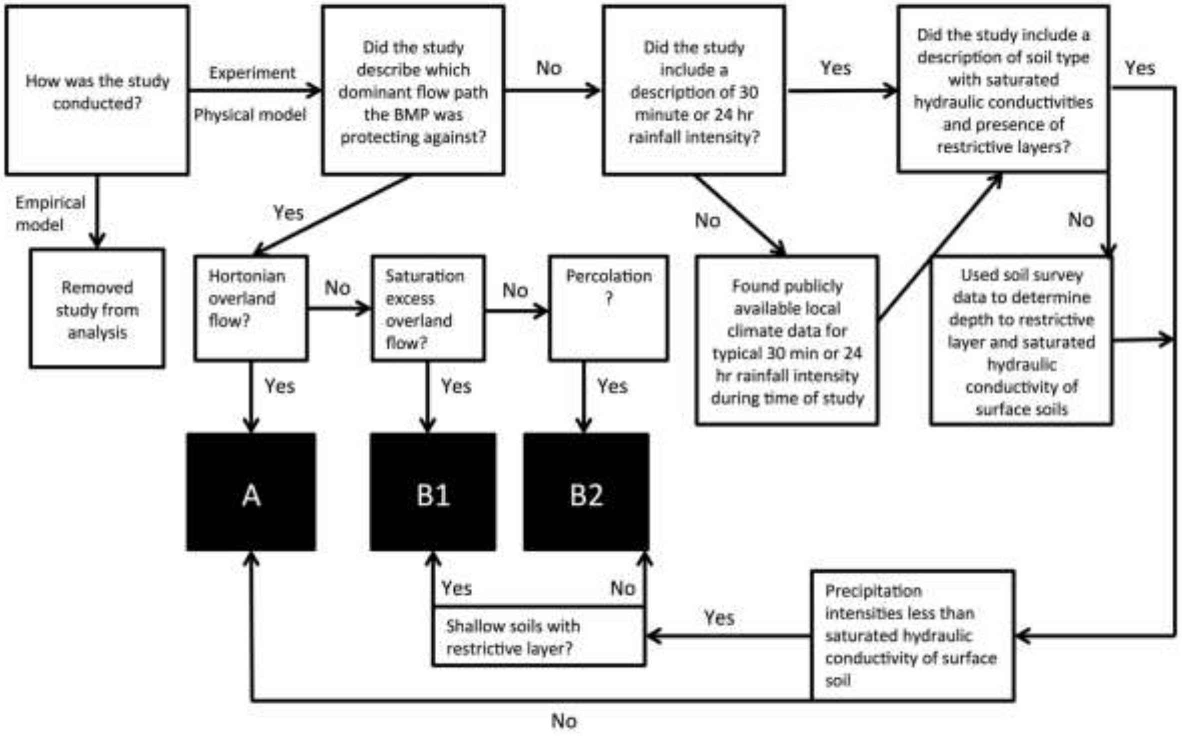


FIGURE 2.2 Land type classification decision flow chart for attaining soil and climate information and determination of A, B1, and B2 land types for BMP effectiveness studies.

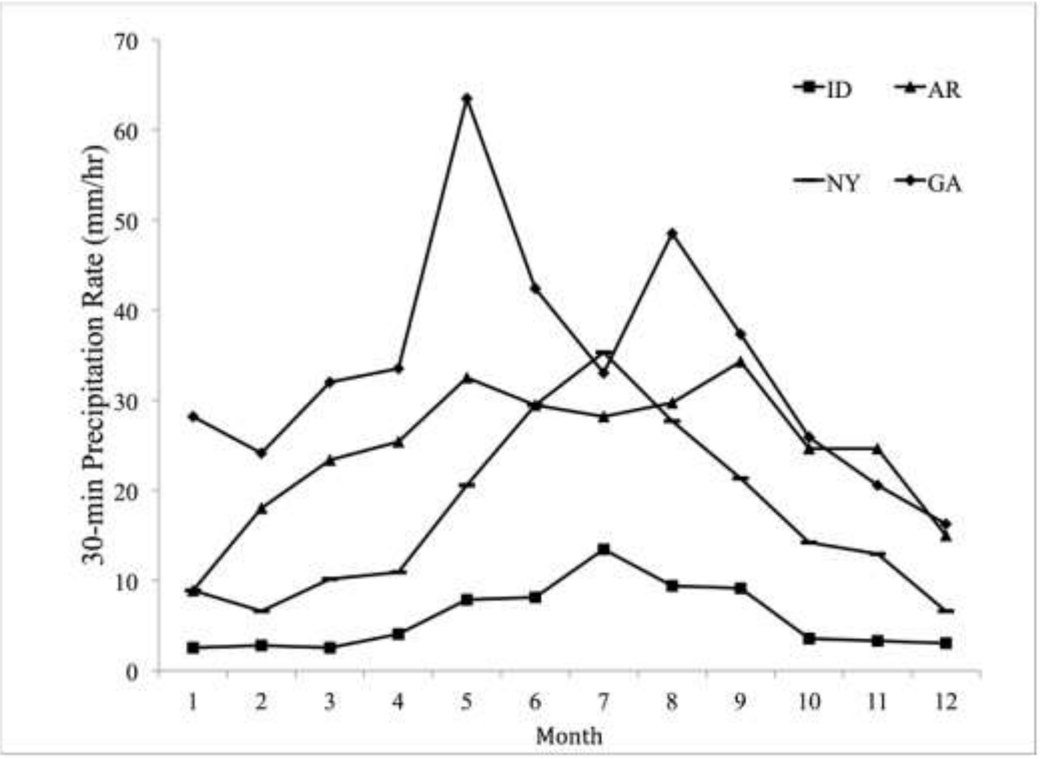


FIGURE 2.3 Mean monthly maximum 30 min rainfall rates for Idaho, Arkansas, New York, and Georgia based on 30 year climate data (source: Hershfield, 1961. Rainfall frequency atlas of the US)

CHAPTER 3: AN INTEGRATED MODELING APPROACH TO EVALUATE EFFECTS OF CONSERVATION PRACTICES IN AN AGRICULTURAL WATERSHED WITH COHESIVE SEDIMENTS

ABSTRACT

Widespread improvements in upland soil conservation practices nationwide have aided in reducing field-sourced sediment delivery to streams. Many soil conservation measures reduce sediment concentrations, but when they do not attenuate hydrologic discharge, cleaner runoff into streams has a greater capacity to erode streambeds and banks. Erosion prediction models estimate upland sediment contributions, while watershed scale sediment loads are monitored at watershed outlets. There is an inherent disconnect between annual loads calculated from upland areas and sediment measured at the outlet of watershed, due to instream storage and transport processes of hillslope, legacy, and stream-sourced sediments. The objectives of the study were to validate the WEPP hillslope hydrologic and erosion model and evaluate CONCEPTS' ability to simulate channel evolution in highly disturbed watershed with cohesive sediments, to compare hillslope and stream channel sediment contributions to the cumulative sediment yield, and to compare the simulated sediment sources under different conservation practices. This study linked the spatiotemporal aspects of upland erosion and runoff events to fluvial processes using a hillslope hydrologic and erosion model (WEPP-UI v2012.8) and a sediment transport and stream bank stability model (CONCEPTS). Both WEPP-UI and CONCEPTS both simulated streamflow well when compared to observed data (NSE=0.50 and 0.48 respectively). Pairing WEPP-UI and CONCEPTS demonstrated good agreement between observed and modeled cumulative sediment yield at the watershed outlet (3350±650 tonnes and 4160 tonnes, respectively). Results indicate that changing conservation practices that resulted in a watershed-scale 25 percent increase or decrease of the current sediment load may not be detectable at the watershed outlet, masking significant conservation efforts. Testing conservation scenarios demonstrated that drastic decreases in upland sediment supply results in increased stream scour. By better understanding how stream systems respond to varying upland managements, conservation practices and stream channel restoration practices can be more effectively targeted to reduce overall sediment loading.

INTRODUCTION

Damage attributed to fluvial sediment in North America has been estimated from $20-50 billion annually for physical, chemical, and biological systems (Pimentel *et al*., 1995; Osterkamp, 2004). Excess fluvial sediment impairs water quality, threatens the ecological integrity of riverine and coastal habitats (Karr, 1999), impacts floodplain elevations, and can reduce reservoir storage capacity (Walling *et al*., 2000; Larsen *et al*., 2010; Kemp *et al*., 2012). Major sources of excessive sediment contributions to watersheds nationwide have been credited to agricultural erosion (EPA, 2015).

In response to impacts from excess sediment, widespread improvements in upland soil conservation practices nationwide have aided in reducing field-sourced sediment delivery to streams. Many soil conservation measures reduce sediment concentrations, but do not attenuate hydrologic discharge, and therefore cleaner runoff into streams has greater capacity to erode streambeds and banks (Mukundan *et al*., 2011). As a result, erosion and sediment sources in cultivated watersheds may be shifting from agricultural fields to stream channels and gullies (Trimble, 1983; Simon and Rinaldi, 2000; Tomer and Locke, 2011). The role of gullies and stream channels in the overall watershed sediment budget, however, are not well understood (Simon and Klimetz, 2008; Mukundan *et al*., 2011; Mukundan *et al*., 2012).

In addition to current instream erosion events, fluvial systems are still responding and evolving from past sediment accretion events from the late 19th and early 20th centuries (Simon and Klimetz, 2008; Hamilton, 2011; Tomer and Locke, 2011). The flushing of legacy sediments contribute to overall sediment yields, and may impact our understanding of the current effects and consequences of soil conservation measures (Gregory *et al*., 2002; Meals *et al*., 2010; Hamilton, 2012). Mitigation of problems associated with excess fluvial sediment requires identifying and quantifying sediment sources. To improve our ability to measure the effects of BMPs and stream restoration and identify critical sources of sediment loading, further research into fluvial sediment dynamics is critical (Tomer and Locke, 2011).

Quantifying sediment sources is challenging due to the spatial and temporal variability of factors such as climate, land use, geomorphic processes, sediment storage in the floodplain, sediment delivery to the stream channel, stream channel erosion, and the storage and conveyance of sediment in the fluvial system (Langendoen *et al*., 2001). Watershed scale reductions often target upland erosion as a key nonpoint source (NPS) for sediment loading, particularly in estimation of Total Daily Maximum Loads (TMDLs) (Shirmohammadi *et al.*, 2006). Erosion prediction models estimate upland sediment contributions, while watershed scale sediment loads are monitored at watershed outlets. There is an inherent disconnect in the sediment delivery ratio, however, between annual loads calculated from upland areas and sediment measured at the outlet of watershed, due to instream sediment storage and transport of hillslope, stream channel, and legacy sediments. As a result, there is often an unknown physical lag time from when a conservation or restoration practice is implemented and when the effectiveness of that practice is measured as reductions in overall sediment loads at the outlet of a watershed (Gregory *et al.*, 2007; Meals *et al.*, 2010; Hamilton *et al.*, 2011), making it challenging to determine conservation practice effectiveness.

One way to address this limitation is to link the spatiotemporal aspects of upland erosion and runoff events to fluvial processes using a hillslope variable source hydrology and erosion model (Boll *et al.*, 2015) and a sediment transport and stream bank stability model. By pairing a hillslope and stream channel model, the response of the stream channel through bed and bank erosion events and streambed sediment storage within fluvial systems can be simulated in response to upland erosion and runoff dynamics.

Understanding upland infiltration excess and saturation excess runoff processes, and the role of variable source hydrology within a watershed is becoming increasingly important for soil conservation and for estimating flow and sediment inputs in fluvial systems (Hewlett and Hibbert, 1967; Dunne and Black, 1967; Walter, 2000; Mulla *et al.*, 2005). When rainfall intensity is greater than a soil's infiltration capacity, infiltration excess runoff occurs. Shallow soils with either restrictive layers characterized by low hydraulic conductivity or bedrock at shallow depths are more sensitive to soil water storage capacity. As a result, when the soil water content in shallow surface soil layers exceed water storage capacity, these areas drive subsurface hydrologic processes that can result in saturation-excess overland flow and perched water tables (Walter *et al.*, 2000; McDaniel *et al.*, 2008). Subsurface flow is controlled largely by gravitational forces, and therefore steep and variable topography largely impacts where subsurface flow converges to create saturation excess. Because soil properties, restrictive layers, and topography can be patchy across a landscape, the mechanisms that drive the two overland flow processes highly vary both spatially and temporally across a watershed.

Correctly identifying when and runoff processes occur is important because overland flow transport sediments to the stream as well as many agricultural chemicals. Many hydrologic models fail to simulate subsurface flow, and therefore do not reliably capture variable sources of runoff. WEPP-UI 2012.8 (Boll *et al*., 2015) has modified the subsurface hydrologic routines of the Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995) to correctly account for variable source hydrology. With improved subsurface hydrology, upland runoff event and erosion processes can be better simulated and applied to fluvial sediment transport models.

Langendoen (2000) developed the Conservational Channel Evolution and Pollutant Transport Systems model (CONCEPTS), a process-based open channel transport model, to simulate a channel's evolutionary response to disturbances that cause incision. The model uses an unsteady 1-D approach to route upland sediment and flow inputs through interpolated cross sections to estimate outflow, while simultaneously simulating bank instability, lateral bank erosion, and sediment entrainment and deposition in the streambeds. CONCEPTS is unique compared to other 1-D models (e.g. HEC-RAS) in that it can simulate both cohesive and non-cohesive soils. As a result, the model can indirectly aid in quantifying bed and bank scour and storage, and ultimately, annual sediment loads. Due to the simplification required in 1-D models, CONCEPTS is best for predicting long time scales for longer stream reaches, and is more computationally efficient than 2 or 3-D models (Kondolf, 2005).

When permanent cross sections are distributed across a watershed to best represent critical areas of scour, aggradation, and stability, hypotheses regarding sediment basin-wide transport and storage can be tested with the addition of modeling efforts. CONCEPTS can predict and quantify channel evolution through time, including change in thalweg elevation, and changes in channel top width (Langendoen *et al*., 2009). Applications of the model include evaluating the total time lag between when sediment enters a stream to when it is flushed through the watershed outlet, or for evaluating restoration plans with a process-based approach. Our study will be the first to apply both WEPP-UI 2012.8 and CONCEPTS to a northwest agricultural watershed with winter hydrology and cohesive sediments to better understand sediment contributions from hillslopes, streambed and bank, and conservation practice effectiveness.

The main goal of this study is to better understand stream system response to upland management practices and stream channel sediment contributions, storage, and transport in an agriculturally-dominated watershed with cohesive sediments. Specific objectives were to:

1) Validate WEPP-UI v 2012.8 hillslope hydrology model in study watershed
2) Compare hillslope and stream channel sediment contributions to the watershed outlet from 2006-2012.
3) Evaluate CONCEPTS' ability to simulate channel evolution in highly disturbed watershed with cohesive sediments.
4) Assess stream channel response under different upland soil conservation practices.

Using a long-term data set in the Paradise Creek watershed in northern Idaho (Brooks *et al*., 2010), a watershed hydrologic model was linked to a stream sediment transport model to evaluate conservation practices.

METHODS

Study Area

The stream system evaluated for this study is located within the agricultural portion of Paradise Creek Watershed (PCW; 2870 ha; HUC 17060108) nested in the Palouse River basin in northern Idaho. PCW is characterized by forested mountains in the headwaters (18% watershed area), intensive dryland agricultural land in the mid portion of the watershed (62% watershed area; Figure 3.1), and an urban area (20% watershed area) in the lower section of the watershed to the state line between Idaho and Washington. Recent sediment loads estimated from the long term, event-based monitoring efforts in Paradise Creek attribute 58% of the sediment load from agricultural areas and 43% from urban contributions (Brooks *et al*., 2010). The watershed is dominated by winter hydrology, enduring snow, rain-on-snow events, and freeze thaw cycles that contribute to spring runoff and gully and rill erosion. Annual precipitation ranges from 650-1000 mm, and 70% of that occurs in the winter months (Brooks *et al*., 2010). Soils are largely composed of silt loam, derived from the Palouse loess, with patchy argillic horizons that impede infiltration and cause saturation excess overland flow. The loess deposits are underlain with Columbia River basalt. Basalt layers are exposed in the lower reaches of the watershed. The forested headwaters flow through Idaho batholith granitic formations. Steep hillslopes in the agricultural areas paired with moderate to flat slopes in the urban areas describe the topography of the area, with elevations ranging from 770 m to 1330 m (Figure 3.1). In the past forty years, conservation tillage practices and riparian buffers have been increasingly implemented in the agricultural areas (Kok *et al*., 2009).

Paradise Creek is a 4th order stream. In the first 8.1 km of the stream, flow is ephemeral, with dry periods from July through September. The gradient of the stream changes from a 1.8% slope for the first 2.1 km, 0.40% for the next 4 km, and 0.02% for the final 2 km of the stream profile (Figure 3.2). Bed and bank material is made up of primarily cohesive sediments. Native riparian vegetation is absent in the majority of the agricultural reaches. Cultivation occurs up to the stream bank tops. Reed canary grass, an invasive species, is abundant within the stream channel in both the agricultural and urban areas.

Model Descriptions

WEPP-UI. The Water Erosion Prediction Project- University of Idaho (WEPP-UI) hillslope model (v2012.8) (Boll et al., 2015), a process-based hydrology and erosion model, was used to simulate the surface and subsurface transport of water and sediment delivery from the upland areas to the stream to develop inflow hydrographs. WEPP is the most suitable hydrologic and erosion model for PCW because it can simulate both infiltration excess and saturation excess overland flow processes to better predict variable source hydrology (Boll et al., 2015). Given the presence of clay plan restrictive layers and the complex topography in PCW, the ability to simulate lateral flow and variable source area hydrology is required. Rill erosion and interill erosion due to raindrop impact and thin sheet-flow are simulated in WEPP to represent the loss of soils from concentrated flow in small channels (Laflen et al., 1997). The governing equations, assumptions, and limitations are discussed at greater depth in Boll et al. (2015) and Laflen and Nearing (1995).

Data inputs required for WEPP included climate data, soil properties, representative hillslopes, and land management files for each hillslope. Climate files were generated using daily observed temperature data and hourly precipitation data from the University of Idaho weather station for the 2002-2012 simulation. The stochastic climate generator, CLIGEN, was used to estimate the daily average wind speed, solar radiation, and dew point temperatures

(Nicks et al., 1995). Soil parameters were populated using the USDA-NRCS SSURGO soils database (2015). Land management files were developed through surveying local growers to attain geospatial information related to historic cropping practices including tillage type, timing of planting, plowing, and harvesting, and implementation of gully plugs. Land use maps were created based on the survey, and have been verified via field inspection. Crop types and rotations were verified for 2006-2012 using the USDA National Agricultural Statistics Service Cropland Data Layer (2015).

Using GeoWEPP and a 10m digital elevation model (DEM) (Renschler, 2003), PCW watershed was broken up into 556 representative hillslopes (Figure 3.1),with each hillslope having a unique combination of associated land management, slope, and soil parameters based on the land use map, SSURGO soils database, and DEM. Each hillslope was represented by up to 19 overland flow elements (OFEs), with the length of each OFE dependent on the natural slope breaks in the topography or hillslope.

WEPP-UI output generated lateral flow, percolation, and sediment loss for each OFE, and accumulated daily water balance and sediment components for each hillslope. Daily streamflow and sediment delivery from the hillslope simulations were summed for each contributing tributary to the main stem of Paradise Creek as boundary conditions and inflows at the representative tributary nodes within the CONCEPTS model (Figure 3.1**)**. Daily runoff volumes for each tributary were converted to discharge (cms) based on tributary area.

While the hydrologic processes in WEPP-UI have been advanced to simulate complex systems, Stream sediment transport algorithms have not yet been developed for large (> 1 sq mile) watersheds and therefore a sediment delivery ratio was used to estimate sediment delivery and deposition within tributary watersheds. We applied a relief-length (R/L) sediment delivery ratio to the WEPP-UI simulated sediment detached from hillslope (Maner and Barnes, 1953; Roehl, 1962). The R/L ratio approach for the sediment delivery ratio was selected for PCW due to the basin's complex topography and was applied by determining the difference in relief (m) between the mean elevation for each hillslope and the elevation of the specific tributary node to which the hillslope drains to. The length was calculated by finding the maximum flow length (km) from each hillslope to corresponding tributary node. The reduction ratios were applied to the daily simulated sediment detached for each hillslope to determine the sediment delivered to the mainstem of Paradise Creek.

WEPP-UI sediment output is divided into five size fractions (clay (<0.002mm), silt (<0.01mm), sand (<0.03), clay-silt aggregates (<0.125mm), and clay-silt-sand aggregates (<2mm). Assuming that the two aggregate size fractions disaggregate once suspended in flow, we divided the aggregates back out into clay, silt, and sand loads based on the percentage composition clay-silt-sand predicted by WEPP-UI. The size fractions were then divided out to meet CONCEPTS sediment size class requirements. Daily sediment load for each size class and for each tributary were converted to loading rates (kg/s) as sediment inputs to WEPP-UI.

CONCEPTS. CONCEPTS is a process-based, open channel 1-D model and simulates unsteady flow and transport of both cohesive and cohesionless sediments, based on particle size class, as well as bank erosion processes (Langendoen, 2000). The model predicts the response of sediment transport and channel geometry to altered flow regimes and disturbances, such as instream hydraulic structures, upland soil conservation practices, or restoration implementation. The governing equations, assumptions, and limitations of the model's hydraulics, sediment transport, and bank instability components are discussed in depth in Langendoen and Alonso (2008), Langendoen and Simon (2008), and Langendoen *et al*. (2009).

Hydraulics. CONCEPTS' basic assumption is that stream flow is one dimensional along the centerline of the channel, and thus is limited to incised stream systems. CONCEPTS requires channel form, channel boundary roughness, and water inflows to simulate stream hydraulics. Using the Saint-Venant equations (Cunge *et al*., 1980), CONCEPTS calculates flow as a function of time simultaneously through a series of cross sections, and varies between diffusion and dynamic wave equations depending on the inertia forces present.

CONCEPTS uses a generalized Priessmann scheme (Abott and Basco, 1989) and the Gaussian elimination with partial pivoting for banded matrices to solve the set of algebraic equation by altering the time step (see Langendoen & Alonso, 2008).

Sediment transport and bed adjustment. To simulate sediment transport, CONCEPTS is governed by a mass conservation law for sediment by size fraction class. Required input data include grain size distribution and stratigraphy of the bed material, critical shear stress, cohesionless soil erodibility, and sediment inflows. Both cohesionless and cohesive bed material are simulated, taking into account the differing processes for the entrainment and deposition of bed material. The bed is divided into a subsurface layer and an active mixing layer, in which suspended sediment in the water column and bed material are continuously exchanged. If the bed scours or fills, particles are exchanged between the active layer and the subsurface layer. An excess shear stress approach is used to calculate the erosion rate of cohesive sediment (Ariathurai and Arulanandan, 1978):

$$E = eB(\frac{\tau}{\tau_c} - 1) \qquad (1)$$

where E=erosion rate, e=erosion rate constant, B=wetted width of streambed, τ=average bed shear stress, and τ_c= critical shear stress to initiate erosion. The deposition rate is calculated using Krone's formulation (1962):

$$D = B\omega c(1 - \frac{\tau_b}{\tau_d}) \qquad (2)$$

where τ_d=shear stress below which sediment particles in transport begin to deposit; τ_b=bed shear stress; ω= fall velocity (m/s); and c=point sediment concentration (ppmw). If $\tau_b > \tau_d$, CONCEPTS sets the deposition rate to 0.

If the material is cohesionless, CONCEPTS assumes that the erosion and deposition is proportional to the difference between the sediment transport rate and sediment transport capacity (Bennett, 1974).

Sediment transport capacity it calculated using a modified version of the sediment transport capacity predictor SEDTRA (Garbrecht *et al.*, 1995). Sediment is divided into 14 predefined size classes, and an appropriate transport equation is used depending on the size class. Total sediment transport is then calculated as the sum of each size class. Wash load without deposition is used for size classes less than 10 μm, the Laursen equation (1958) is used for silts, the Yang equation (1973) is used for sands, and Meyer-Peter and Muller equation (1948) are used for gravels.

Streambank erosion. Bank instability is modeled based on two dominant fluvial erosion processes responsible for bank retreat and channel widening. The first is fluvial erosion and entrainment of bank toe material by flow, and the second is bank mass failure due to gravity in the form of planar and cantilever failure (Langendoen and Simon, 2008). Required data to model bank instability include stratigraphy and grain size distribution of the bank material, the resistance to erosion with both critical shear stress and erodibility, and the shear strength including both effective cohesion and the effective angle of internal friction for each bank soil.

Bank stability is governed by the static equilibrium of forces and moments. Using a factor of safety approach, CONCEPTS performs stability analyses of both planar slip and cantilever failure of overhanging banks. The bank is divided into “slices” and the balances of weight, normal, hydrostatic, and pore pressure forces are evaluated in both vertical and horizontal directions (Langendoen *et al*., 2008). If gravitational forces downslope exceed the resistance to movement, the bank fails, and slides into the channel. Bank geometry, pore-water pressure, confining pressure, and riparian vegetation all impact bank stability.

Cantilever slips occur when an overlying erosion-resistant layer is on top of an erodible layer, causing overhanging banks. Cracks develop in the banks caused by tensile forces, and create instability in the bank. CONCEPTS simulates this process using a ratio of weight of the cantilever block to the shear strength of the bank materials.

CONCEPTS requires a set of assumptions in order to simulate a fluvial system’s hydraulics, sediment transport, and bank stability. In turn, each assumption causes the model to be somewhat limited. Table 3.1 outlines the model’s assumptions and corresponding limitations for the proposed study area.

Despite the limitations of CONCEPTS, it is currently the best available 1-D process-based tool to model channel evolution in cohesive systems (Langendoen and Alonso, 2008), and a better alternative to the empirical models for stream channel evaluation such as natural channel design (Simon *et al*., 2008).

CONCEPTS Model Inputs

Model input parameters, units, data sources, and potential limitations are listed in Table 3.2 and are further discussed in this section.

Upland hydrology and sediment transport: To simulate the hydraulics of the stream system, hydrographs of all runoff events and associated sediment transport were developed for the upstream boundary (MS_3) and at the mouths of major tributaries using WEPP-UI (MS_3.5, MS_4, MS_5, MS_6, MS_7, MS_8, MS_9, MS_9.5, MS_10, and MS_11; Figure 3.1).

Because WEPP only simulated the transport of fine clay, silt, sand, and small and large aggregates, sediment rating curves were developed for CONCEPTS size classes 5 through 8 for each tributary. Bedload transport of larger particle sizes was simulated for each tributary based on observed streambed and bank particle size distribution, bulk density, and sediment transport under steady state staged flows in CONCEPTS.

Stream channel properties: From 2005 to 2012, thirty-six stream reaches from the agricultural region to the Idaho-Washington state line along Paradise Creek and its tributaries were selected for long term monitoring. The reaches were chosen based on accessibility via public land or landowner permission as well as their ability to represent critical areas of erosion or deposition, degree of vegetation density, elevation and slope. The majority of study reaches had three cross sections, spaced 10-30 m apart. Each cross section was marked with a 1m long rebar, capped with a washer or plastic cap for visibility. Geographic positioning systems (GPS) locations were recorded for each cross section so that the sites could be revisited and monitored over time.

At the end of each water year, from 2005 to 2012 (with the exception of 2011), bank and bed scour and aggradation were estimated by surveying the stream channel elevation profile at each cross section. The elevation profiles were measured using a Leica GeoSystems model 500 survey grade differential GPS based station, set up on the roof the Engineering/Physics building on the University of Idaho campus on an established survey marker. At each cross section, a survey rover was used to record elevation measurements perpendicular to flow. Measurements were recorded at each significant change in elevation across the profile. Measurements averaged 40-60 elevation points per cross section. The standard user error of the DGPS was 2.5%. The stream bank and thalwegs were recorded at each location to characterize the channel geometry. Qualitative notes on regarding the presence and type of vegetative cover were also recorded.

Streambed sediment and stream bank soil grain size distribution were collected and calculated for each cross section using the Coulter counter method in 2005 (Pennington and Lewis, 1979). The bed and bank material is composed of primarily cohesive soils and sediments, with an average bulk density of 1185 kg/m calculated based on data collection from 75 reaches on Paradise Creek of both bank and bed material (Newson, 2007).

The 8.1 km stream profile for CONCEPTS was generated by using 21 stream cross sections from the 2005 survey (Figure 3.2). Additional cross sections and their river kilometer

(RKMs) were generated with 0.2 km spacing to fill in any gaps between observed data using an interpolation scheme from observed cross sections to develop defined bed and bank profiles (See Appendix A for input file generation). Streambed sediment and stream bank soil properties were parameterized using observed data from the particle size distribution and bulk density survey and estimated using regional studies (Table 3.1).

Model Testing

Through a long-term water quality monitoring program, 15-min and event-based discharge (cms) and turbidity data (NTU), as well as weekly and event-based suspended sediment concentration (SSC) data (kg/L) have been collected from 2002-2012 at a forested, rural, and urban gauging site. In depth methods of the monitoring study are described in Brooks *et al*. (2010). For this study, daily streamflow (mm/day) and sediment yields (cumulative tonnes) from the rural agricultural gauging station (MS_D) were used from the long term monitoring program. The long term monitoring dataset was used to validate WEPP-UI. Only the 2006-2012 water year hydrographs from WEPP were used as inflows for CONCEPTS. Because the stream survey began in the fall of 2005, the initial stream channel conditions for CONCEPTS also start with the 2006 water year dataset. These data were used to validate hydraulics for WEPP and CONCEPTS.

For WEPP-UI, the subsurface saturated hydraulic conductivity (K_s) and reservoir coefficient parameters were approximated within a reasonable range to find the best fit between simulated and observed streamflow data and annual water balance components. All other properties were populated from publicly available data sources. Hillslope scale K_s is difficult to measure in the field (Brooks *et al*., 2006), but drives subsurface processes. To test model performance, K_s was varied up to 4 orders of magnitude smaller and greater than the estimated value in the USDA-NRCS SSURGO soils database for each soil type. Using a linear reservoir model, baseflow was predicted based on a reservoir coefficient and the daily simulated deep percolation. The reservoir coefficient was varied in increments of 0.005 between 0.02 and 0.1 to find the best fit.

The Nash-Sutcliffe efficiency parameter (NSE; Nash and Sutcliffe, 1970) and the deviation of runoff volume ($D_{v;}$ Martinec and Rango, 1989) were used as statistical indices to rate model performance of both WEPP and CONCEPTS hydrological simulations. NSE indicates the agreement between simulated and observed values, and we adopt the qualitative assessment that below 0.2 is insufficient, 0.2-0.4 is sufficient, 0.4-0.6 is good, 0.6-0.8 is very good, and greater than 0.8 is excellent (Foglia *et al*., 2009). The deviation of runoff volume was calculated annually and was based on daily predictions and observations. Negative values of D_v indicate overprediction by the model and positive values indicate underprediction. We assume D_v within the range of -20% to 20% show acceptable agreement between simulated and observed streamflow values.

Because Manning n, the erosion-rate coefficient, and critical shear stress were not measured in situ, these values were approximated in CONCEPTS by finding the best fit through comparing simulated versus observed annual channel geometry outputs using mean absolute deviation (MAD) and root mean squared deviation (RMSD) as statistical indices to assess the predictive power of CONCEPTS. MAD provides a measure of the average distance of the data set from the mean, and indicates the predictive power of the model. RMSD is also a good measure of accuracy because it aggregates the individual differences between observed and simulated data to create one single measure of predictive power of the model. Simulated and observed cross sectional area, channel bed width, and channel depth changes were compared from 2005 and 2012 using reference cross sections. (Figure 3.2: PCW_10, PCW_13, PCW_16, PCW_17, PCW_19, PCW_26, PCW_33, PCW_36). Reference cross sections were selected based on their ability to represent the three gradient sections along the stream model. The simulation was run from water years 2006-2012, using 2005 channel geometry files. The 2012 simulated channel geometry was compared to the observed 2012 cross sections.

To test the stream channel response to upland management scenarios, previous WEPP-UI scenario testing of conservation practices were used (Boll *et al*., 2008) to apply realistic sediment reductions (+25%, -25, 50, and 75%) to the tributary inflow files. The change in cumulative sediment yield and stream channel storage based on the change of sediment supply was assessed.

RESULTS AND DISCUSSION

Model Validation

Hydrology. The WEPP hydrology simulations showed acceptable water component mass balance values when compared to observed data (Table 3.3). Simulated streamflow was calculated as 18% of the total precipitation over the study period, which matches well to the observed value of 16%. Evapotranspiration processes are the primary loss of water, accounting for 70% of the total precipitation. This is a reasonable value for the study area given the intensive crop cultivation and hot, dry summers and is similar to other water balance studies within the region (Brooks et al., 2006; Dhungel, 2007; Dijksma et al., 2011). The simulation estimated only 1.3% of precipitation percolating through the restrictive layers, which may be low, but reasonable given the localized recharge areas (Dijksma et al. 2011) and is in agreement with other regional models (Dhungel, 2007).

Overall, the combined WEPP and CONCEPTS simulation showed good agreement with the observed streamflow data at the watershed outlet (Figure 3.3, Table 3.4). For WEPP, the overall NSE for water years 2006-2012 was 0.50, with a D_v value of -5%, showing a slight overprediction in streamflow values. Overall, WEPP performed well for each water year except for 2010 (Table 3.4). Water year 2010 was a low flow year and therefore, the NSE statistical index is not the best indicator to show overall agreement because the range of values for streamflow within the water year is much less than other years. Figure 3.3 shows that in 2010, WEPP matches simulated streamflow fairly well, and D_v= 19%, showing an acceptable level of underprediction.

Because the hydrologic inflows from CONCEPTS are generated for only the ten major tributaries to the main channel, some of the runoff and lateral flow from the watershed is absent in the CONCEPTS modeling. As demonstrated in Figure 3.3 and Table 3.4, the tributaries chosen as inflows for CONCEPTS are sufficient to capture the majority of events across the study period ($NSE_{CONCEPTS}$=0.48). While the summer baseflow of 0.002 m^3/s does not accurately reflect the ephemeral nature of Paradise Creek, CONCEPTS slightly underestimates streamflow volumes (D_v=13%), indicating that the continuous baseflow input does not significantly impact total water volumes within the stream system.

Sediment transport. The sediment delivery results from the WEPP simulations are illustrated in Figure 3.4. The majority of the hillslopes (97%) delivered less than 300 tonnes to the representative tributaries. Of the 556 simulated hillslopes, 17 hillslopes contributed greater than 300 tonnes, and 11 of those hillslopes are characterized by Southwick soils and steep slopes. Southwick soils are shallow, silt-loam soils with argillic restrictive layers. During snowmelt and rainfall events, water runs as subsurface lateral flow through the steep and mid sections of the hillslope, converging as saturation excess overland flow along the toe slope (Boll *et al*., 2015). Southwick soils, therefore, generate saturation excess overland flow, and are the most hydrologically sensitive areas in the watershed. One hillslope that is currently in CRP, but is also characterized by shallow soils and steep slopes contributed 528 tonnes over the six year simulation. The two largest hillslope sources of sediment are both in barley-wheat rotations, with mulch tillage and are located on steep, short hillslopes, with shallow soils with close proximity to the main stem of Paradise Creek. Because the relief-length ratio was applied as the sediment delivery ratio, a greater percentage of sediment detached at these hillslopes was simulated as delivered to the stream.

The cumulative sediment delivered to Paradise Creek as hillslope input from WEPP to CONCEPTS for water years 2006 to 2012 was 9,016 tonnes (Figure 3.5). The largest sediment delivery occurred on January 9th, 2009 when 4,960 tonnes were delivered to the creek. Conditions for this event included a snowmelt event, saturated soils and thus saturation excess overland flow, and large erosion events on steep slopes with shallow soils. Spatially, over the six year simulation, 54% of the total sediment delivery came from the MS_5 tributary basin, 23% from the MS_6 tributary basin, and 10% from MS_9 tributary basin. The remaining 13% of total sediment came from the remaining tributaries, with the forested headwater basins (MS_3 and MS_3.5) contributing insignificant loads (< 2 tonnes over six year simulation). Overall, sediment from hillslopes consisted of 19% clay, 60% silt, and 21% sand particles.

Using the runoff and sediment simulated from WEPP as input to CONCEPTS, the cumulative sediment yield at the outlet (MS_D) simulated by CONCEPTS, was 4,160 tonnes. Comparatively, the observed sediment yield at the outlet was 3,350±630 tonnes over the same time period (Figure 3.5). Overall, CONCEPTS simulated similar sediment transport through the stream channel to the trends observed in the measured data. During high hillslope erosion years, transport limited years, the stream channel stored sediment (water years 2006, 2008), and during low hillslope input, transport limited years, more sediment is flushed from the stream channel (water years 2007, 2009). In water year 2007, despite an erosion event that contributed 1,115 tonnes to the stream, very little sediment was transported to the outlet, and most sediment was stored within the stream channel. The same behavior is evident in water year 2009, when of the peak sediment input from WEPP only 570 tonnes (10% of the hillslope contribution) was transported to the outlet and the rest was stored in the streambed. In contrast, during the fall of water year 2010, over 750 tonnes were transported to the outlet despite no additional hillslope inputs, indicating a flush of streambed and bank sediments.

CONCEPTS overpredicted total sediment transport to the outlet in water year 2006 which may be a result of an initial flush of streambed and stream bank sediments a response to the initial conditions of the CONCEPTS simulation. A total of 734 tonnes of sediment was simulated during low flow conditions, prior to any hillslope inputs in the fall of 2005. When CONCEPTS begins a simulation, it assesses all sites for potential bank failures. It is possible that the first pulse of sediment moved through the channel caused release of soil blocks that mass wasted as a result of planar failures. Fine sediments within the streambed mixing layer also may have moved through the stream system as an initial response in the simulation.

Because this study does not incorporate any in situ measurements of the erodibility coefficient, critical shear stress, and estimates Manning’s n values based on observations, a sensitivity analysis was conducted to see to what degree these parameters influenced the total sediment yield (Figure 3.6). Overall, the model results were very sensitive to the erodibility coefficient and roughness coefficient, and less sensitive to critical shear stress, as discussed below.

With increasing critical shear stress, CONCEPTS showed an increase in overall yield (Figure 3.6a). For example, when critical shear stress of the bed materials increased from 4.5 Pa to 6.5 Pa, the total yield increased from 4,120 tonnes to 5,760 tonnes. The linear fit to the data in Figure 3.6a had an r^2 of 0.82. This positive relationship is not intuitive. Because increased critical shear stress of bed materials requires increased shear stress in the mixing layer to entrain particles, it would seem that increased critical shear stress would reduce overall yields, because bed materials would be less erodible. With uniformly increased critical shear stress of the bed materials, however, it is possible that increased shear stress was applied to the banks if the system was supply limited because the bed materials could not be entrained upstream, and bank erosion increased. The relationship between critical shear stress and cumulative sediment yield could be further developed by testing a wider range of critical shear stress values, and by examining the impacts on steam bank erosion when critical shear stress of streambed sediments is increased. Because 5.6 Pa was an observed critical shear stress in a similar cohesive stream system in the region (Papanicolaou *et al.*, 2001), and because the parameter did not vary the results significantly, 5.6 Pa was used in the final model.

By increasing the erodibility coefficient of the streambed within a range of 4E-06 to 7E-06, the cumulative sediment yield increased by an order of magnitude (Figure 3.6b). Initially, CONCEPTS simulated very high scour rates and overall sediment yields. Because the bed and banks of Paradise Creek are cohesive and field observation indicated the low flow banks are resistant to fluvial erosion, we selected 4.0 E-06 m/Pa·s as a the erodibility coefficient to simulate representative low rates of toe and streambed erosion.

The Manning's n roughness coefficient significantly impacted the cumulative sediment yield. With a uniform streambed and bank roughness of 0.04, the cumulative sediment yield was 12,600 tonnes (Figure 3.6c). By increasing the roughness to 0.065, which is more representative of small stream channels with vegetation, the sediment yield decreased to 6,190 tonnes. In the final model, Manning's n was varied between 0.06 and 0.075 to represent the small levels of diversity of vegetative cover and stream channel size observed along the reach. When Manning's n values for the streambeds and banks were raised above 0.075, the model ran into numerical instability which limited the ability to test the full effects of roughness due to excessive vegetation observed for many of the study reaches.

Channel properties. Simulated and observed cross-section geometry were closely matched, over the six year simulation. When simulated and observed cross sectional area, streambed width, and channel depth were compared for the 2005 channel conditions to the 2012 channel characteristics in the reference reaches (Figure 3.2) there was relatively good agreement between simulated and observed data, as shown in Figure 3.7 and 3.8, and discussed below.

Simulated and observed changes in cross sectional area between 2005 and 2012 by river kilometer are shown in Figure 3.7a. Negative values indicate aggradation and positive values indicate scour. The MAD and RMSD values for the change in cross sectional area between the observed and model are 0.31 m^2 and 0.50 m^2, respectively. Given the sensitivity of variables that were parameterized in CONCEPTS, these values show very good agreement. Most of the reference reaches showed close agreement, except for PCW_17 (Figure 3.8d), and PCW_33 (Figure 3.8e). For both of these sites, CONCEPTS over predicted scouring. PCW_17 is a site which typically aggrades due to dense vegetative encroachment. CONCEPTS simulated streambed scour at this site, rather than the inset floodplain deposition that typically occurs. When Manning's n was increased for this site to better represent the vegetative cover, CONCEPTS ran into numerical instability.

PCW_33 typically flushes and fills with sediment, based on the observational surveys. CONCEPTS overpredicted stream scour, but in a given year, it is possible that this site would scour out streambed sediment during a flush event, and store stream sediments during subsequent transport-limited events. In Figure 3.8f, the variability in scour and fill for the six year survey period is evident. The stream flushed sediment on the left side of the bed while storing sediment in the low flow channel on the right side of the bed.

The observed and modeled cross sectional area change for the first site (PCW_10; Figure 3.8a) shows good alignment, but the changes in stream depth and width are quite different. In Figure 3.8a, the site shows little movement between 2005 and 2012 in the observed data. Fluvial toe erosion occurred, widened the streambed and filled in the low flow channel. The net effects of cross sectional area change do not capture this disagreement, and thus stream channel depth and streambed width were also assessed to evaluate CONCEPTS' ability to simulate stream channel erosion and deposition.

Channel bed width change is used as an indicator (see Figure 3.8b) rather than top width of the channel because top width did not change significantly in either the observed or simulated data since bank instability is not a dominant process in the upper reaches of PCW. Bed width change is a better indicator of short term changes in fluvial sediment transport dynamics. The MAD and RMSD values for the bed width change between 2005 and 2012 with surveyed and modeled data are 0.33 m and 0.53 m, respectively. This is a large range of deviation given the typical streambed widths in PCW (0.40 m to 4.1 m, mean=1.7m) and can be explained by PCW_17 and PCW_33, as described above. CONCEPTS simulated streambed widening, which rarely occurred in the observed data for these reaches The rest of the simulated reference reaches aligned well with the observed data, as shown by in Figure 3.7b. In particular, CONCEPTS simulation of streambed lowering and slight widening in PCW_14 (Figure 3.8b), PCW_16 (Figure 3.8c), and PCW_37 (Figure 3.8g) demonstrate the model's ability to maintain cohesive and stable banks while flushing streambed sediments which is representative of this stream system.

Changes in stream channel depth are shown in Figure 3.7c. Incision is represented by negative changes in depth, whereas aggradation is shown by positive values. The MAD value for modeled and observed was 0.10 m and the RMSD value was 0.18 m. Again, PCW_17 and PCW_33 demonstrate the greatest misalignment, as a result of streambed lowering and filling, respectively. CONCEPTS overpredicted scour events, which is further described in the *Model Strengths and Limitations* section below.

Effects of Conservation Practices

Different sediment input scenarios were simulated to assess the net effect on the cumulative sediment yield at the outlet. Actual land use change simulation results based on previous WEPP-UI management scenario modeling and analysis (Boll et al., 2008) informed relative sediment input changes used in this study by 25% increments. In these scenarios, a 25% increase in sediment input is representative of most sensitive hillslopes being converted from the current wheat and barley rotations to a wheat and pea rotations. A 25% decrease represents buffer strips to the hillslopes in the upper portion of the agricultural watershed. A 50% reduction is representative of implementing gully plugs in all hillslopes that currently contribute >300 tonnes over the six year simulation, assuming that those hillslopes currently have gullies present. A 75% reduction is representative of watershed conversion from mulch tillage to no tillage, or a land use conversion from agricultural use to grass for sediment contributing hillslopes.

CONCEPTS simulation results in response to the cumulative sediment yield and cumulative hillslope sediment contributions from these management scenarios showed interesting results (Figure 3.9). When sediment inputs varied by ±25% , the cumulative sediment yield varied only by 300 tonnes, suggesting that the stream channel is not very sensitive to a 4,000 ton range in hillslope sediment inputs over the six year simulation, assuming that streamflow remains the same. When hillslope sediment inputs were reduced by 50%, the cumulative yield decreased from the current management by 40%, but when hillslope inputs were reduced by 75%, the sediment loading was greater than the loading at 50%. The cumulative sediment yield was simulated as greater than the sediment inputs, indicating greater stream channel erosion and bank instability as the flow had greater scouring capacity without having to transport the hillslope sediments. These findings support the hypothesis that with cleaner runoff from increased upland conservation, stream channels may become larger sources of sediment as they respond to drastic changes in hillslope sediment supply inputs. With increased sediment inputs, the stream channel plays a greater role as storage and a buffer for hillslope-sourced sediment.

Model Strengths and Limitations

Results from the pairing of WEPP-UI and CONCEPTS to simulate channel evolution and sediment transport processes in the PCW demonstrate that the two models can simulate the hydrologic processes of a highly variable and complex landscape. Improvements to the sediment transport processes in both models, however, are needed for application in small catchments. The streamflow simulated by WEPP-UI and subsequently routed through the stream channel in CONCEPTS agreed reasonably well with the observed streamflow throughout the six year simulation which covered both high and low flow years ($NSE_{WEPP}=0.50$; $NSE_{CONCEPTS}=0.48$, overall). The sediment detachment and delivery to the stream from WEPP-UI should be modified to include valley floor deposition and tributary storage and transport of sediment to the main channel. Further discussion on WEPP-UI and CONCEPT's strengths, limitations and recommendations for improvement follows below.

The findings from the WEPP-UI simulations show the model's ability to simulate streamflow in a small watershed, using primarily publicly available data with limited calibration. WEPP-UI predicted overall daily runoff volumes that matched well with observed data, and also simulated the variable source hydrology inherent in the Paradise Creek watershed which is characterized by complex topography with patchy restrictive argillic layers and winter-dominated hydrologic regime. Findings from the hydrological verification of WEPP-UI show that the updated physically-based processes that simulate both infiltration-excess and saturation-excess overland flow do accurately simulate spatiotemporal distribution of runoff generation from both seepage in toe slopes during as subsurface flow exfiltrates and generates runoff as well as Hortionion overland flow. The large runoff event in water year 2009 (Figure 3.3) for example, demonstrates WEPP's ability to simulate peak runoff from a snowmelt event**,** whereas the peak runoff event in the spring of 2012 shows the Hortonion overland flow response of the watershed to a large precipitation event.

One limitation of WEPP's hydrologic simulation is that underpredicted peak events. This underprediction may be explained by limitations of the input data. One climate file was used for the entire basin. There are spatially variable precipitation events within the small basin, and some areas are hit by storm events with greater precipitation intensity than others, generating variable runoff that may be missed in the simulation. The precipitation data were at an hourly timestep. By using 15 minute precipitation data, greater variation in precipitation intensity could be incorporated into the simulation, and likely capture more of the peak runoff events.

It is more difficult to validate WEPP-UI's sediment routines because there are no observed hillslope data for comparison. Even with observed data for validation of WEPP-UI erosion processes, it is typical to see low model efficiency in sediment transport models (Yang, 1996). Spatially, most of the erosion events occur in areas with shallow soils and steep terrains which matches field observations of where rills and gullies have developed. When hillslope runoff from WEPP-UI was routed through CONCEPTS, the simulated results are comparable to the observed data, with a cumulative yield of 4160 tonnes and 3310 tonnes respectively, suggesting that the WEPP-UI hillslope sediment inputs into CONCEPTS were reasonable. The overall sediment delivery ratio for Paradise Creek from WEPP-UI hillslope simulation to observed cumulative load is 37±7%, compared to the 46% sediment delivery ratio predicted by CONCEPTS.

As suggested by Boll *et al*. (2015), erosion and deposition routines in WEPP-UI should be updated to incorporate the impacts of erosion from saturated, seepage zones. Currently, the model simulates the highest erosion events in locations with lower runoff volumes, but steep slopes, and not in areas of lesser slope gradients and perched water tables. Further research on how the degree of saturation in the soil profile impacts soil erodibility may improve the spatial variability of erosion events that occur due to saturation excess overland flow. Temporally, sediment detachment and delivery to the stream channel from the simulations occurred primarily during December and January freeze thaw, snowmelt, and precipitation events. The observed data shows pulses in sediment loading later in the spring, typically in March and April. Due to the high levels of soil saturation in the later spring, saturation excess overland flow is typically the dominant hydrologic flowpath. If the soil erodibility parameters and detachment processes in WEPP-UI were adjusted to better represent erosion due to saturation excess, sediment delivery could better reflect the resulting erosion from runoff generation processes in systems with variable source hydrology.

Using the relief-length ratio as a sediment delivery ratio for hillslope-sourced sediment is not a physically based mechanism for simulating sediment transport dynamics. A reduction of the total load of sediment detached from the hillslope on a given day was converted into a loading rate (kg/s) over the course of the day as an inflow to CONCEPTS. Because the stream channels in PCW are fairly small (<3 m^2 on average), they cannot always transport an entire days' worth of sediment, and thus there were occurrences where the stream channel at a tributary node would fill in completely with sediment during an erosion event, limiting the ability to test high sediment load scenarios. Realistically, after a hillslope scale erosion event, the transport of the sediment would include toe slope and valley deposition, and temporary storage along the flow path to the stream, creating a more pulsed release of sediment into the main stem of the channel.

There is a watershed operational mode in WEPP that incorporates sediment transport from hillslopes to the main stream channel through a channel network, but it however, is not appropriate for small catchments (<130 km^2) like PCW due to its simplified flow routing and sediment transport mechanisms that do not capture the physical processes that dictate open channel flow (Conroy *et al*., 2006). A single transport equation is used for sediment transport, regardless of the particle size, and has not been proved to appropriate simulated bedload transport of sediment in channel networks (Bravo-Espinosa *et al*., 2003).

Despite the sediment transport limitations of WEPP-UI, results from the paired WEPP-UI CONCEPTS simulation demonstrated reasonable cumulative sediment yield at the watershed outlet from 2005-2012 as compared to the observed data and simulated similar fluvial sediment transport streambed storage and scour processes as seen in the surveyed data. In the hydraulics simulation of CONCEPTS, we expected that a minimum baseflow that is numerically required throughout the year would significantly impact sediment transport. PCW is an ephemeral stream system, with dry periods throughout the summer. As a result, much of the stored streambed sediment may be flushed during the first runoff events in the fall. With continuous simulated baseflow in CONCEPTS, there was concern that a significant amount of fine sediment may be transported during the summer months when there is typically no flow and sediment transport, and that fall sediment transport events would be buffered by the small amount of flow in the system. Results show that the base flow did not significantly impact the overall agreement between observed and simulated daily streamflow data at the outlet (Figure 3.3, NSE=0.48), likely because the shear stress from this flow is less than the shear stress of the bed. Significant sediment loads were also not transported to the outlet during the summer months, as indicated by the simulated cumulative yield plot in Figure 3.5, indicating that baseflow discharges did not have enough transport capacity to move streambed sediment. This indicates that CONCEPTS is an acceptable model for ephemeral streams, even with the minimum baseflow requirement.

As demonstrated in the 2005 and 2012 reference reach comparisons between observed and modeled data, CONCEPTS simulated many of the instream fluvial processes well. In reaches that show bed adjustment through scouring (Figure 3.8b,c,e,g), CONCEPTS matched both the trends and magnitude of change very closely to observed data. In PCW_16 (Figure 3.8c), where the observed data clear shows bed adjustment, but not incision, CONCEPTS simulated change in depth. When adjusting the elevation of hard, non-erodible layers to prevent scour in sites where incision no longer occurs due to exposed argillic hardpan layers, CONCEPTS would often run into numerical instabilities. Bed rock elevations were set to <20 cm below the thalweg elevations for cross sections that do not incise, as a way to account for legacy sediments stored in the streambed, and to allow the model to run without running into instabilities. As a result, some of the cross sections that are not actually incising over the six year simulation did show patterns of scour (Figure 3.8c,d,f).

The 1-D design of CONCEPTS does not account for inset floodplain deposition of sediments. In many PCW reaches, sediments are deposited along the inset floodplain when flow exceeds the low flow channel due to reduced transport capacity (Figure 3.8d). Because the banks are cohesive, fluvial erosion does not always occur during these flow events, despite increased stream power. Because CONCEPTS sediment transport processes deposit sediment on the floodplain or on the streambed, it cannot simulate the inset floodplain storage processes described above which have been found in PCW and in other regions with incised stream channels and cohesive bed and bank properties (Beechie *et al.*, 2007). To investigate CONCEPTS ability to deposit on the inset floodplain, left and right bank top nodes were defined where the low flow channel meets the inset floodplain, and the streambed was defined as the width of the low flow channel. In doing this, the overall area of the stream channel was too small to convey flow and sediment from the inflow files, and thus the model ran into instabilities. In larger systems, inset floodplain deposition could likely be simulated, but not in smaller order streams where the width of the low flow channel is less than one meter.

The largest limitation in applying CONCEPTS to a small catchment with cohesive sediments is the instability inherent in applying numerical models. The sensitivity analysis performed with a range of critical shear stress, erodibility coefficients, and Manning's n roughness coefficients was limited in that many of the values tested resulted in instabilities at specific sites or during large runoff events, and therefore could not be included in the analysis or in the validation of the model. Various upland management scenarios were tested to see how an increase or decrease in flow and/or hillslope sediment impacted overall sediment yield, however, many of the scenarios resulted in instabilities. This currently limits CONCEPTS usefulness in small catchments for assessing the effectiveness of management practices. When scaled down to the reach length of less than five kilometers, CONCEPTS is not as sensitive and scenario testing can take place.

This study paired a hydrodynamic sediment transport model that can simulate sediment transport processes in smaller watersheds, and it simulated variable source hydrology using physically-based approaches. The integration of WEPP-UI and CONCEPTS is distinct from other coupled upland hillslope and hydrodynamic sediment transport studies that used WEPP with CHHE1D (Conroy *et al.*, 2006), AGNPS with CONCEPTS (Langendoen *et al.*, 2009).

AGNPS uses empirical approaches for runoff generation and cannot simulate saturation excess. CHHE1D is not appropriate for smaller watersheds that are less than 130km^2 like PCW. CONCEPTS simulated channel evolution and fluvial erosion and storage in a cohesive system better than the watershed version of WEPP-UI is capable of due to its use of sediment transport equations suitable for each particle size class, and it is more suitable for cohesive systems than the current versions of HEC-RAS. The process-based integration provided insight for understanding how the stream channel stores and flushes sediment.

CONCLUSIONS

Coupling the variable source hydrology and erosion model WEPP-UI with a hydrodynamic sediment transport and channel evolution model, CONCEPTS, was shown to be a viable and new approach to assess watershed scale sediment transport in a small catchment with cohesive sediments. The pairing of the two models demonstrated good agreement between observed and modeled streamflow, cumulative sediment yield data, and fairly good agreement between stream channel evolution data. In some reaches, CONCEPTS overpredicted scour and streambed widening. Overall the model was limited by its sensitivity to widely adjusted parameters such as the erodibility coefficient, bedrock elevation, and Manning’s n values in small stream channels.

The six year simulation showed that sediment from large erosion events initially is stored in the channel, and slowly flushed out over time. Over the six year simulation, over 9,000 tonnes of sediment were supplied to the main channel, and 4,160 tonnes were released and transported to the outlet. The effects of current upland management practices and erosion events are buffered by the stream, which overall, acts as storage. Changing conservation practices that result in a watershed scale 25 percent increase or decrease of the current sediment load may not be detectable at the watershed outlet, masking significant conservation efforts. Our findings suggest that upland conservation efforts that drastically reduced sediment input, such as no till practices or CRP may increase instream scour and bank erosion due to increased transport capacity. Understanding how the stream channel impacts watershed scale sediment better informs how watershed outlet data truly represent upland and fluvial sediment transport processes.

Future work could investigate the coupling of WEPP-UI and CONCEPTS in larger stream systems to see if the same numerical instability issues are present, even with daily inflow data from WEPP-UI. Simulation results could be improved by using an empirical hydrograph method to develop hourly triangular inflow hydrographs with more representative rising and falling limbs and peak flow rates to investigate if hourly inputs improve the stability of the model. Determining ways to make the numerical approach to CONCEPTS less sensitive to changes in small stream systems would allow this model to be a robust management tool in which upland management and stream restoration practices could be simulated and assessed for effectiveness. In addition, allowing the roughness coefficient in the streambed and bank to change based on vegetation growth and senesce throughout the year may improve results.

Understanding stream channel response to varying sediment and flow inputs from agriculture as well as urbanization will benefit future conservation effort. Potential restoration designs could be added to assess CONCEPTS to see how channel geometry, sediment transport, bed scour and fill, and bank stability may be impacted. In addition, different upland BMPs scenarios can be modeled with WEPP-UI, and the impacts on stream hydraulics, sediment transport, and bank stability can further be evaluated. CONCEPTS' process-based approach allows for a watershed scale understanding of the potential impacts of channel restoration practices as well as upland conservation practices.

ACKNOWLEDGEMENTS

Jeremy Newson and Brian Crabtree, previous graduate students in the Brooks and Boll lab, were key contributors to the data collection and initial WEPP-UI model set up and WEPP-UI and CONCEPTS integration**.**

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TABLES

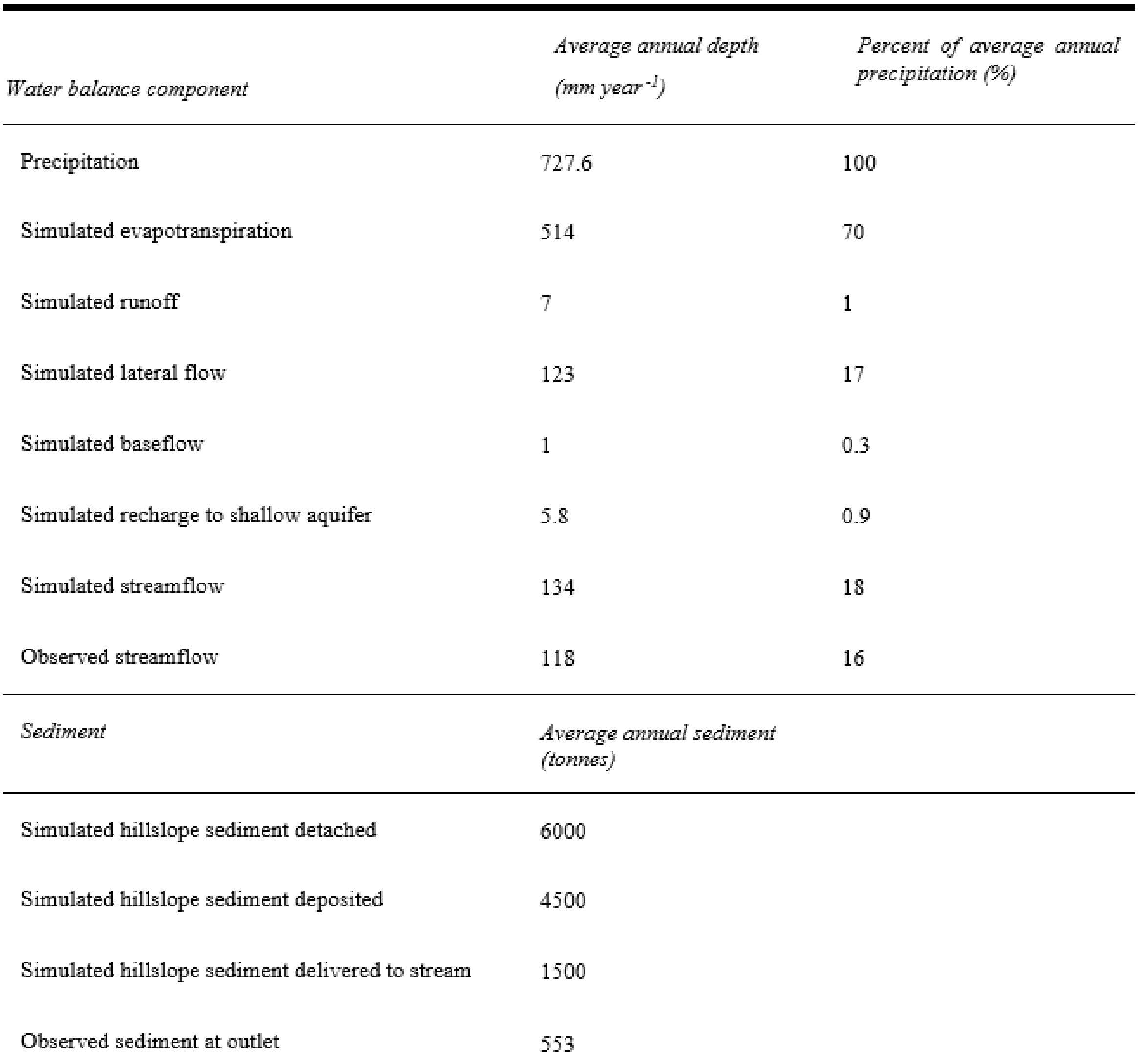
Assumptions	**Limitations**
1-D channel flow along centerline of channel	Cannot simulate processes occurring meander bends or braiding within wider channels at low flow.
Assumes straight channel	Cannot simulate increased boundary shear stresses on meander bends
Simulates total sediment load rather than bed and wash loads	Different size classes of particles behave differently in bed and wash loads
Only models planar and cantilever bank instability	Does not account for rotational or piping/sapping failure; also may not account for impacts of infiltration or evapotranspiration in surface soils of banks
Assumes pore pressure, erodibility coefficients, Manning roughness coefficients, and shear stress to be constant	Vary temporally based on season, presence, and types of vegetation and root structures.

TABLE 3.1 CONCEPTS assumptions and limitations for study area

TABLE 3.2 Model inputs, sources, and limitations for CONCEPTS simulation

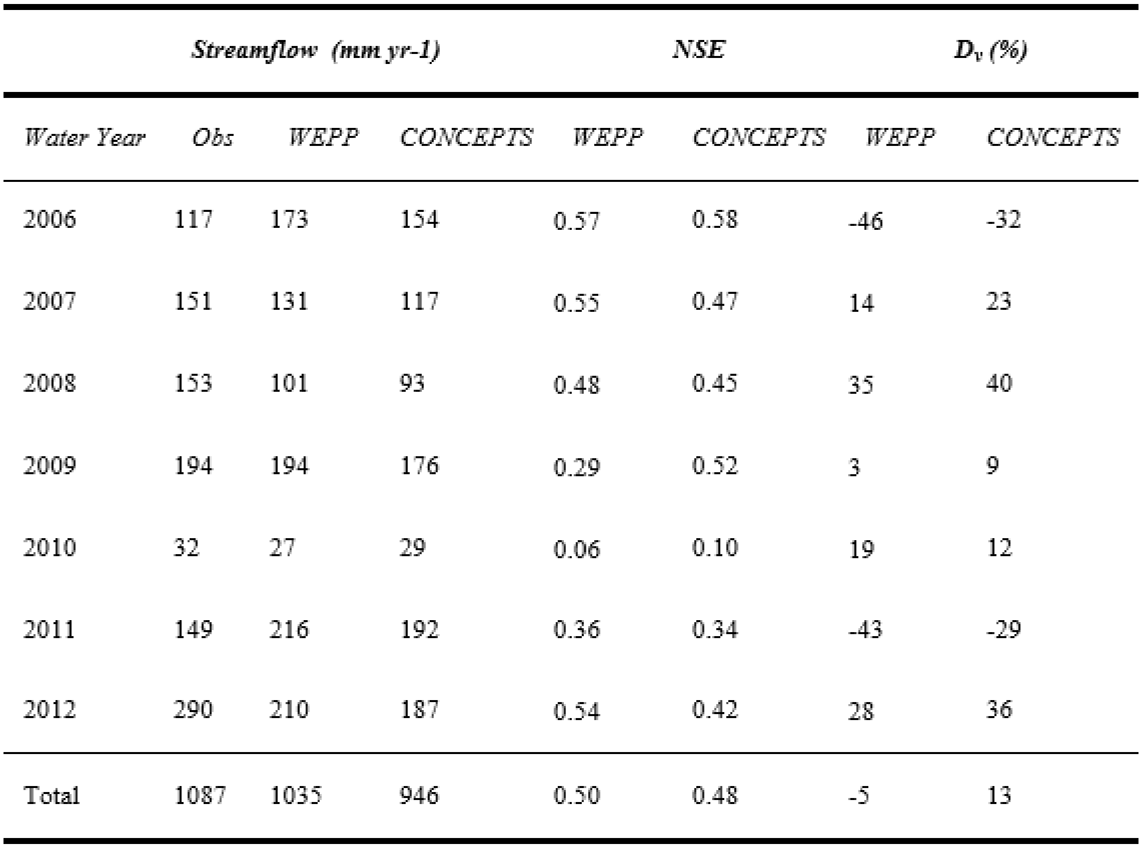
	Variable	Value	Units	Source	Potential Limitations
Channel Form	x,z		m	Annual survey	User accuracy and precision
Channel boundary roughness	n	0.03-0.1	-	Range used to based on field observations of channel roughness and vegetation presence	Seasonally variable based on growth and senesce of riparian vegetation
Water inflows	q		m^3/s	WEPP 2005-2012 simulations; daily hydrographs	Magnitude of peak events not always capture by WEPP simulation
Bed Material grain size distribution	k	14 size classes	m	Coulter counter method (Pennington and Lewis, 1979); established for each cross section	From 2006-2007 survey. Characteristics may have changed with time
Bed material stratigraphy				Limited to one bed material sediment layer	Some reaches have gravel bars, exposed basalt, or claypan layers underlying shallow fine sediment layers
Critical shear stress of bed material	τ_c	5.6	Pa	Papanicalaou, 2001	Variable across space and time
Erodibility of bed material	M	$0.4*10^{-7}$	m/Pa-s	Produced the best fit to prevent instability in results	Calibrated based on reasonable range of values
Sediment inflows	q_{sk}		kg/s	WEPP 2006-2012 sediment delivery output files, with particle size fractions	WEPP accuracy based on input parameters (climate, landuse, soils, hillslope)
Bulk density	ρ_b	1185	kg/m^3	Bulk density measurements from banks and beds	Variable across streambeds (ranged from 660-1515 kg/m^3)
Bank stratigraphy				Field observations. Assumed one soil layer.	Roughness and bulk density change with depth.
Bank material grain size distribution			m	Coulter counter method (Pennington and Lewis, 1979); established for each cross section	From 2006-2007 survey. Characteristics may have changed with time
Critical shear stress	τ_c	5.6	Pa	Papanicalaou, 2001	May be spatiotemporally variable
Erodibility coefficient of bank	M	$0.4*10^{-7}$	m/Pa-s	Produced the best fit to prevent instability in results	Calibration
Effective cohesion	c^i	5000	Pa	-	Calibration
Specific weight of sediment	γ_s	18000	N/m^3	-	Calibration
Effective angle of matric suction	φ_b	15.4	°	-	Calibration
Effective angle of internal friction	φ^i	25	°	-	Calibration

TABLE 3.3 Water balance and sediments components for WEPP-simulation



Water balance component	*Average annual depth (mm year^{-1})*	*Percent of average annual precipitation (%)*
Precipitation	727.6	100
Simulated evapotranspiration	514	70
Simulated runoff	7	1
Simulated lateral flow	123	17
Simulated baseflow	1	0.3
Simulated recharge to shallow aquifer	5.8	0.9
Simulated streamflow	134	18
Observed streamflow	118	16
Sediment	*Average annual sediment (tonnes)*	
Simulated hillslope sediment detached	6000	
Simulated hillslope sediment deposited	4500	
Simulated hillslope sediment delivered to stream	1500	
Observed sediment at outlet	553	

TABLE 3.4 Annual streamflow and model testing statistics for WEPP and CONCEPTS. NSE refers to the Nash Sutcliffe Efficiency and D_v refers to deviation of runoff volume.



	Streamflow (mm yr-1)			***NSE***		***D_v (%)***	
Water Year	*Obs*	*WEPP*	*CONCEPTS*	*WEPP*	*CONCEPTS*	*WEPP*	*CONCEPTS*
2006	117	173	154	0.57	0.58	-46	-32
2007	151	131	117	0.55	0.47	14	23
2008	153	101	93	0.48	0.45	35	40
2009	194	194	176	0.29	0.52	3	9
2010	32	27	29	0.06	0.10	19	12
2011	149	216	192	0.36	0.34	-43	-29
2012	290	210	187	0.54	0.42	28	36
Total	1087	1035	946	0.50	0.48	-5	13

FIGURES

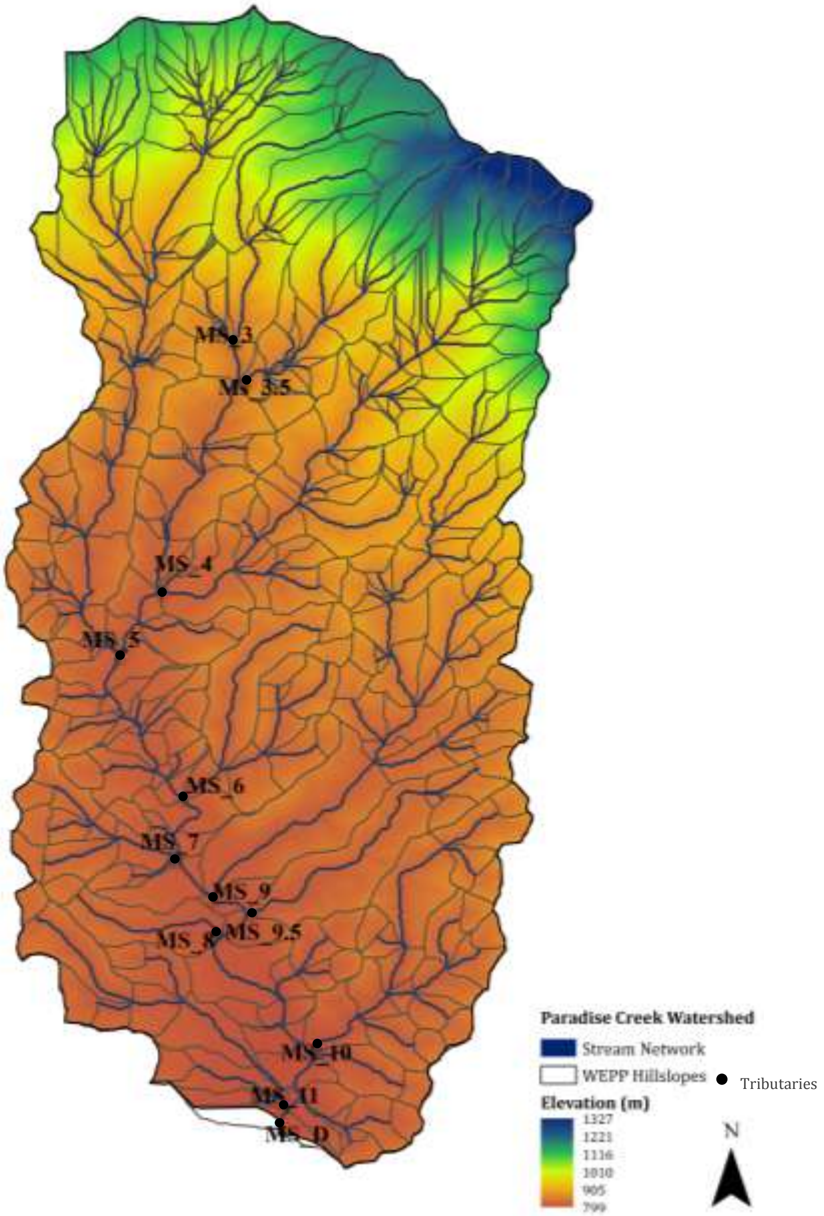


FIGURE 3.1 Map of Paradise Creek Watershed including elevations, distributed hillslopes for WEPP simulation, stream network, and tributaries used as inflow conditions for CONCEPTS. MS_D indicates the location of the gaging station.

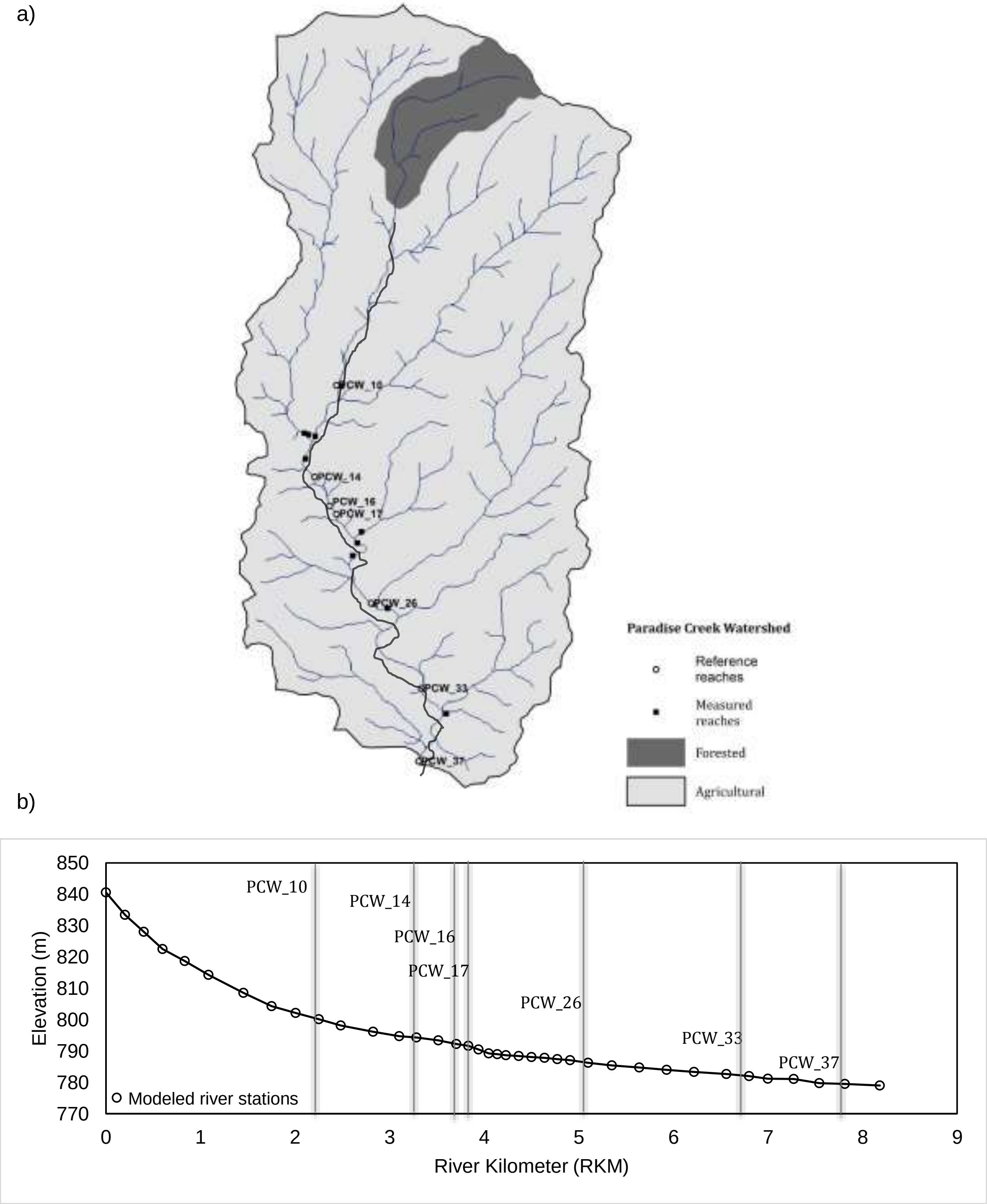


FIGURE 3.2 a) Locations of measured and reference reaches from stream channel survey, used as initial conditions for channel form boundaries in CONCEPTS. The dark line reflects the perennial portion of the stream network that was simulated in CONCEPTS; b) Elevation profile of thalwegs of the main stem of Paradise Creek with locations of reference reaches.

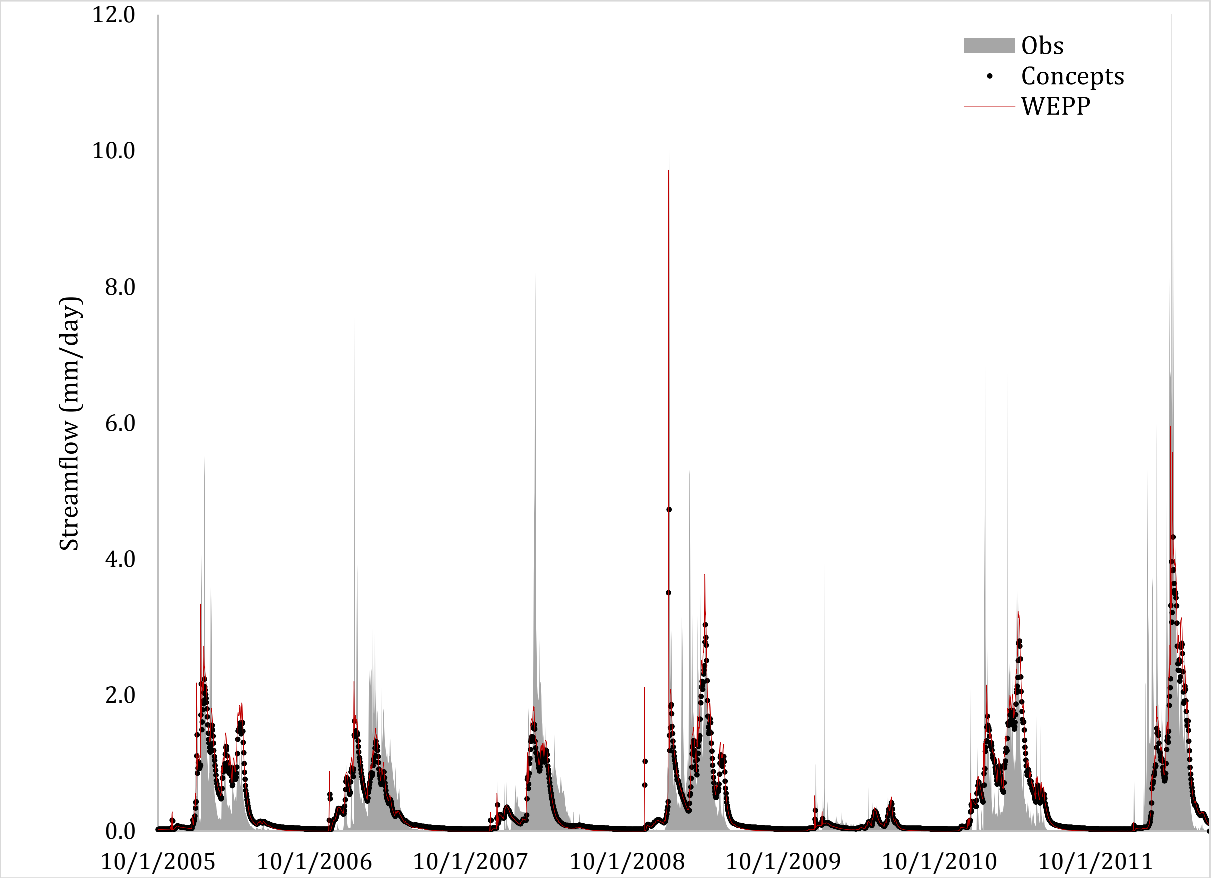


FIGURE 3.3 Paradise Creek streamflow (mm/day) for water years 2006-2012 from gaging station MS_D, WEPP simulation, and CONCEPTS simulation. (NSE_{WEPP}=0.50; $NSE_{CONCEPTS}$=0.48)

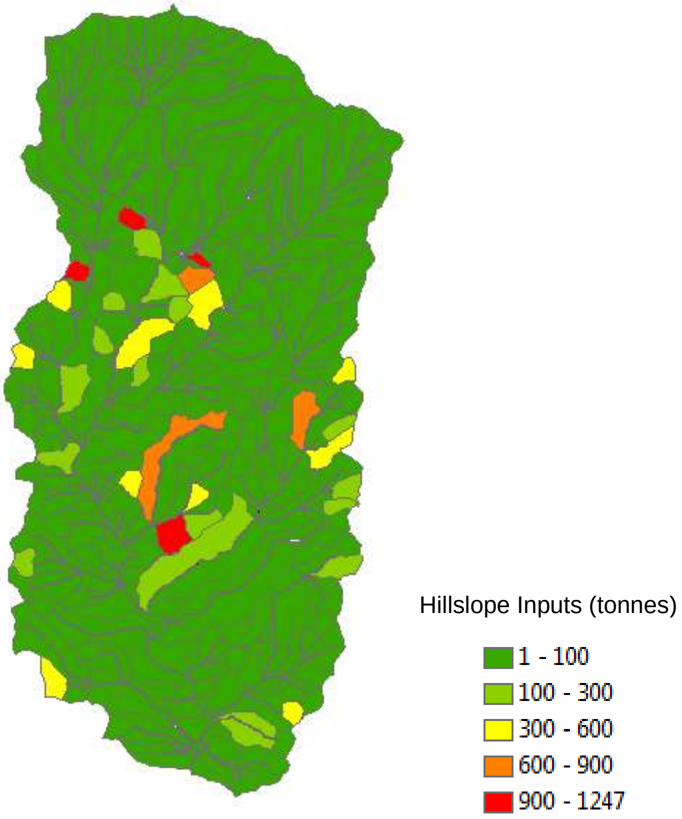


FIGURE 3.4 Sediment delivery map: Total sediment delivery (tonnes) from hillslopes to the main stem of Paradise Creek as simulated by WEPP-UI.

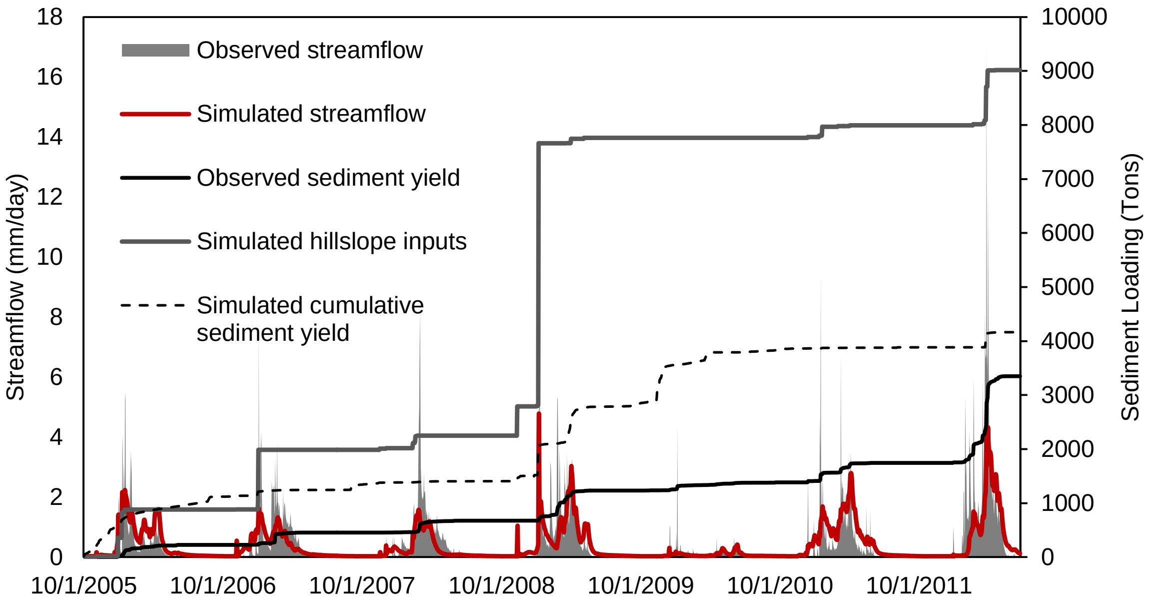


FIGURE 3.5 Cumulative sediment yield (tonnes) at MS_D for water years 2006-2012 from observed data collected at MS_D, CONCEPTS simulation, and cumulative hillslope inputs from WEPP simulation for Paradise Creek.

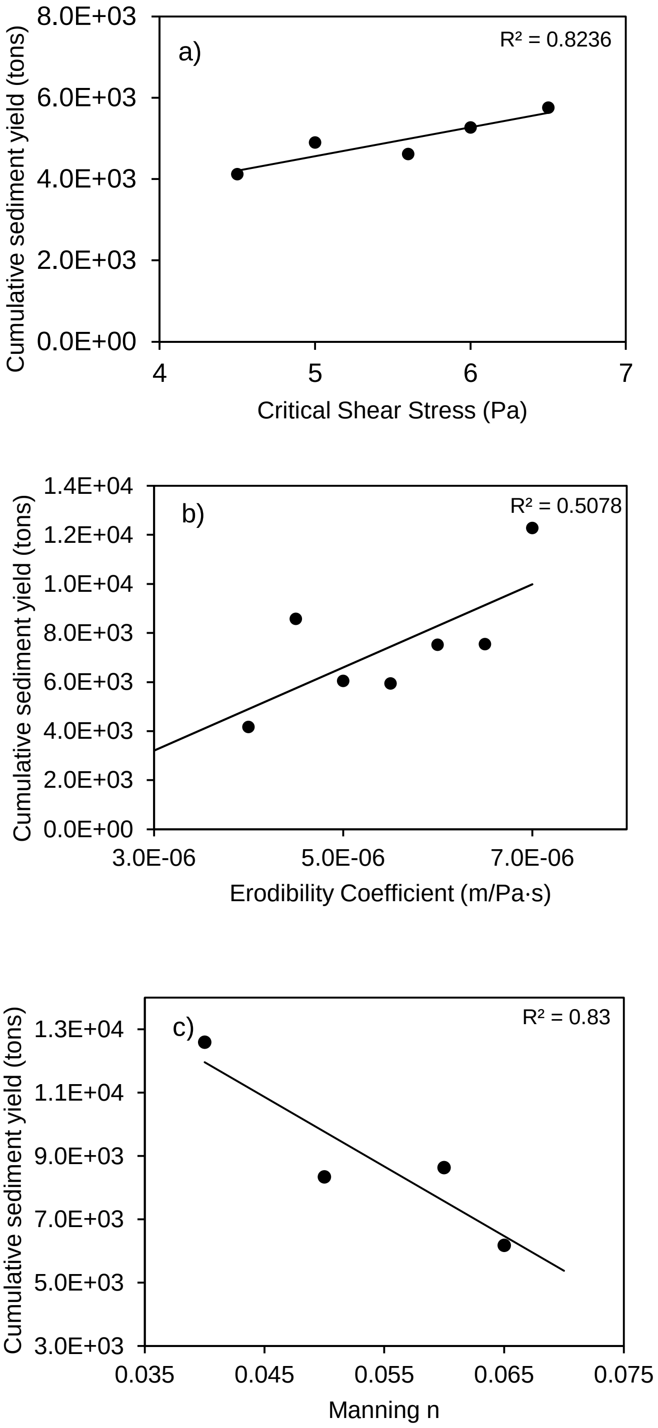


FIGURE 3.6 Sensitivity analysis of impacts of CONCEPTS input parameters on cumulative sediment yield (tonnes) from 2006-2012 Paradise Creek simulation (a) critical shear stress (r^2=0.82); (b) erodibility coefficient (r^2=0.51); (c) Manning n roughness coefficient (r^2=0.83).

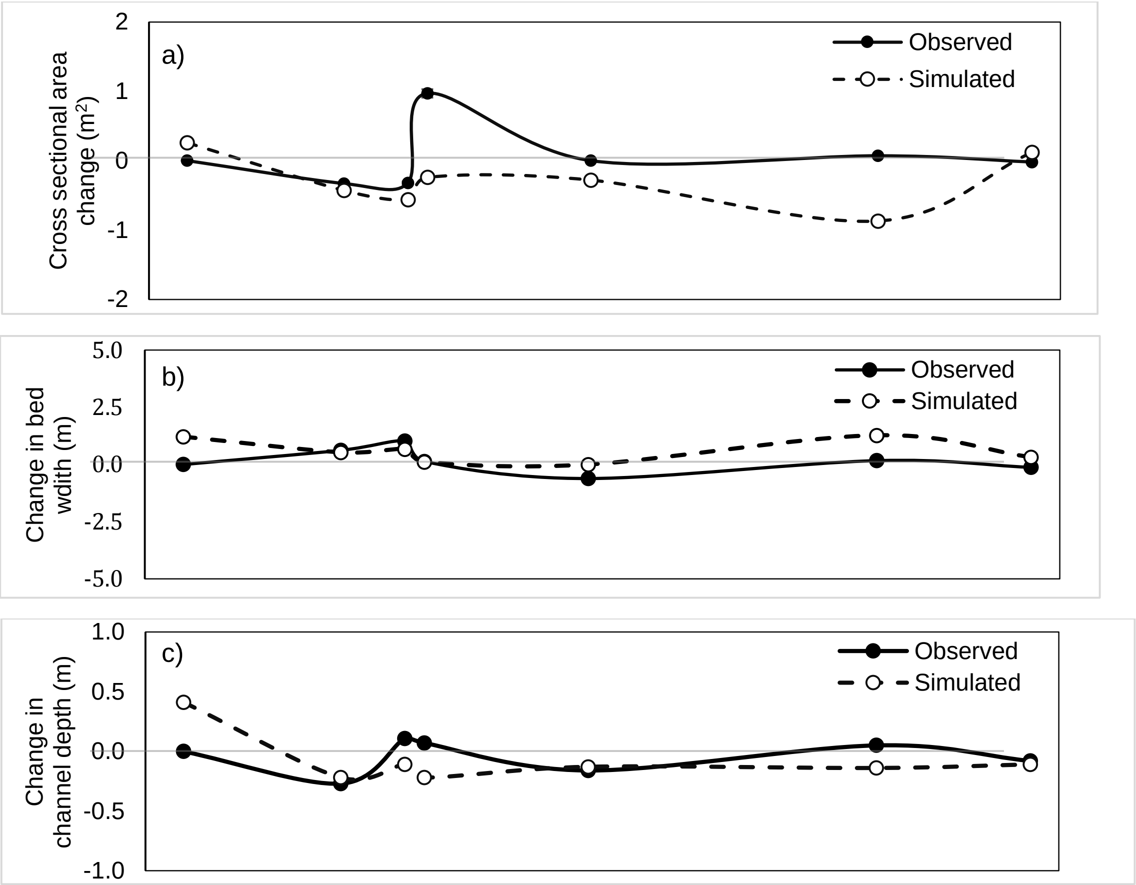


FIGURE 3.7 Comparison of 2005 and 2012 channel geometry properties of Paradise Creek from observed and CONCEPTS simulated data (a) change in cross sectional area; (b) change in channel bed width; (c) change in channel depth; RKM=river kilometer

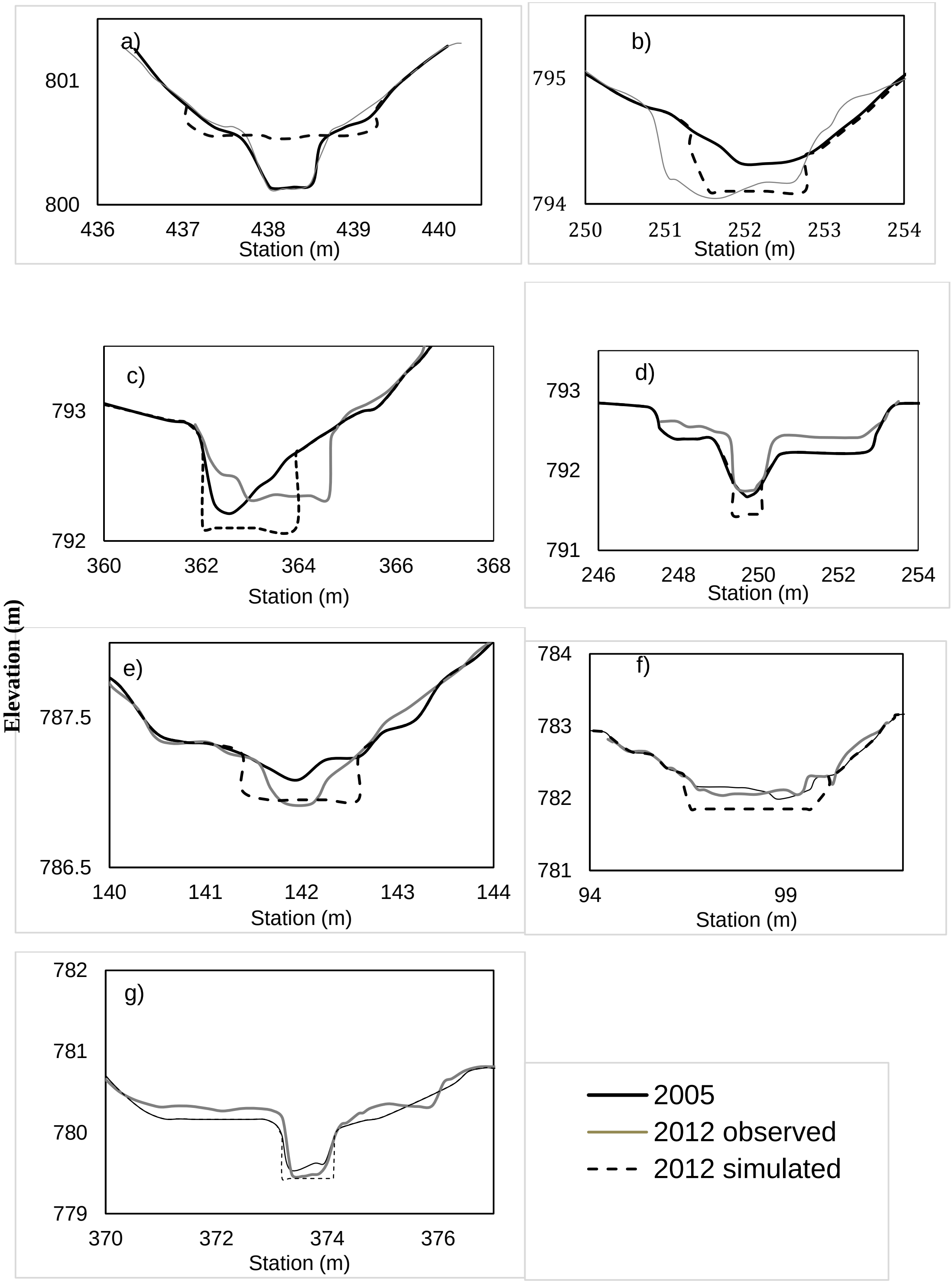


FIGURE 3.8 Comparison of 2012 simulated and observed reference channel cross section profile changes (a) PCW_10 at RKM 2.25; (b) PCW_14 at RKM 3.28; (c) PCW_16 at RKM 3.70; (d) PCW_17 at RKM 3.83; (e) PCW_26 at RKM 4.91; (f) PCW_33 at RKM 6.80; (g) PCW_37 at RKM 7.81

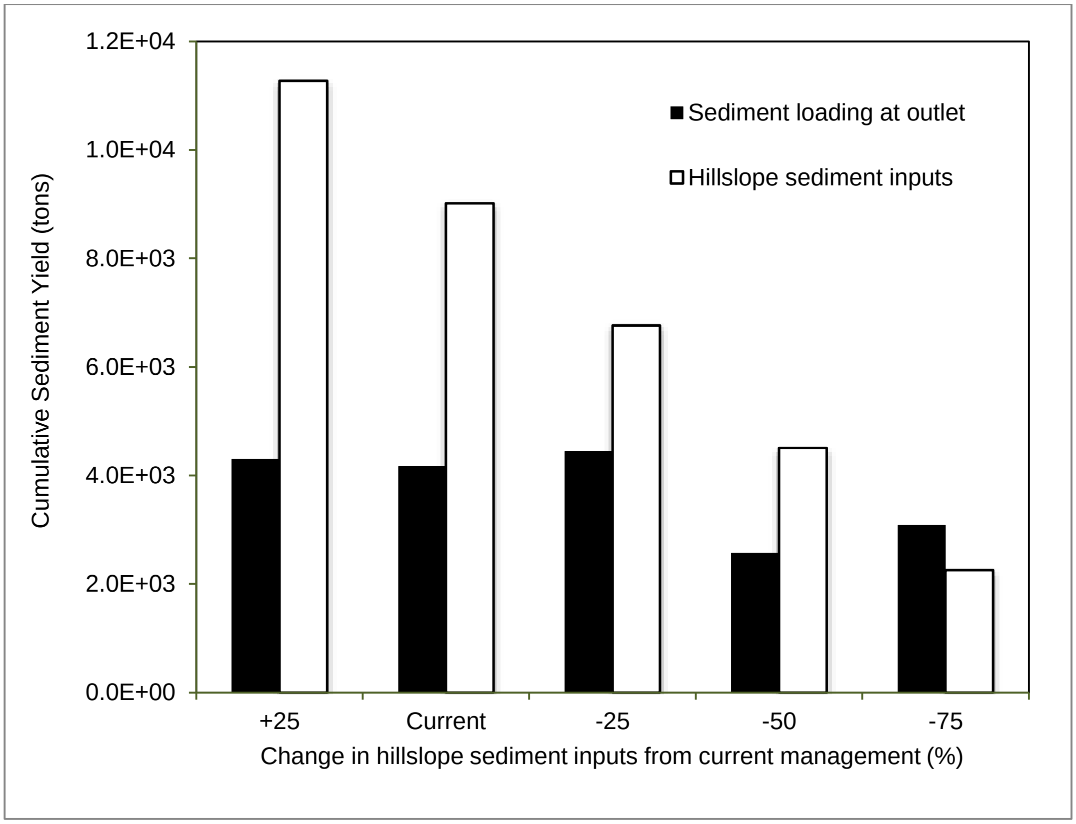


FIGURE 3.9 Bar chart of cumulative sediment yield and hillslope sediment inputs of different management scenarios

CHAPTER 4: EVALUATING STREAM SEDIMENT DYNAMICS AND CHANNEL EVOLUTION IN A HIGHLY DISTURBED MIX LAND USE WATERSHED

ABSTRACT

Fluvial systems are constantly changing and evolving, responding to external controls of water and sediment transport by changing morphological form, adjusting from one state of equilibrium to another. Stream channels contribute to sediment loads in the form of legacy sediments, channel erosion and deposition, and buffering during storm events. Through a better understanding of the temporal and spatial aspects of stream channel scour and sediment storage, conservation practices and stream channel restoration practices in agricultural watersheds can be more effectively targeted to reduce overall sediment loading, The objective of this study is to better understand how the stream channel impacts annual sediment delivery dynamics in a highly disturbed mixed land use watershed. Using field observations from benchmarked cross-sections along a channel system over a 7-year period, we investigated if the stream channel is a net sediment source or sink and how source/sink behavior varies temporally and spatially by land use. The source-sink behavior was used, in turn, to characterize current stages of channel evolution. Results suggest that during the study period of 2006-2012 the stream channel is a net sink for sediment. A region-specific channel evolution model was modified to indicate how the stream channel has adjusted to disturbances, and as a result, how it impacts fluvial sediment dynamics. Rural reaches are in phases of aggradation and are reaching quasi-equilibrium whereas the urban reaches are more dynamic, acting as both sources and sinks for sediment as they continue to degrade and widen. Downstream urban fluvial sediment sources are increasing with urban development while upstream rural fluvial sources are decreasing with increased upland soil conservation efforts. While the rural reaches have largely adjusted to historical disturbances, the urban reaches are still in the process of adjusting to more recent urbanization and stream channel modification disturbances and undergo greater fluvial erosion.

INTRODUCTION

Land cover changes cause fundamental shifts in the timing, location, and magnitude of runoff and erosion events. Fluvial systems are complex, constantly changing and evolving and respond to the external controls of water and sediment transport by changing morphological form, adjusting from one state of equilibrium to another (Charlton, 2008). Globally, anthropogenic activities such as urbanization, agriculture, and even conservation are increasingly the major regulators of sediment and flow inputs that shape fluvial systems and, thus, are accelerating the rate of change (Leopold, 1973; Harvey and Watson, 1986**;** Gregory, 2006; Knox, 2006; Simon and Rinaldi, 2006).

Agricultural watersheds have been identified as a significant driver of geomorphic change (Hook, 1994, 2000, Urban and Rhoads, 2003). Early to mid-20th century agricultural practices typically resulted in large runoff and erosion events in areas with highly erodible soils. These events caused rapid channelization and incision with subsequent widening of stream channels (Simon and Hupp, 1986; Langendoen *et al*., 2009; Shields *et al*., 2010; Bouska and Stoebner, 2014). Historically, therefore, large sediment yields from agricultural areas resulted from stream channel erosion. Watershed scale reductions often target upland erosion as a key nonpoint source (NPS) for sediment loading, particularly in estimation of Total Daily Maximum Loads (TMDLs) (Shirmohammadi *et al*., 2006) paying little regard to the role of the stream channel as a source and sink for sediment.

With the widespread adoption of upland conservation practices in agricultural areas, some agricultural fluvial systems have responded to early century disturbances and adjusted to a new equilibrium, no longer a significant source or sink for sediments (Bouska and Stoebner, 2014). Urbanization, however, is increasingly a large contributor to the sediment yield due to drastic stream channel modification, short, and high volume peak runoff from increased impervious areas, more frequent flood events, and from increased sediment inputs from anthropogenic activities (Sauer *et al*., 1983; Horner *et al*., 1994; Trimble, 1997). Without a complete understanding of stream channel contributions to overall sediment loads, sediment targets set by excess sediment TMDLs are not always attainable (Mukundan *et al*., 2011). Improved understanding of how stream channels respond to upland land use conversions could aid in better identifying to what degree excess sediment loading is a result of hillslope erosion or stream channel responses to upland inputs for watershed management and TMDL sediment targets.

Channel Evolution Models (CEMs) offer a qualitative method for understanding and predicting long-term trends in stream channel morphology. Using qualitative and quantitative data, CEMs classify current stages of the fluvial system to evaluate and predict how the system will likely evolve over time. The CEM concept was developed and introduced by Schumm (1973). After a series of experiments that addressed incision-deposition-incision processes within a fluvial system, Schumm (1986) produced a CEM for alluvial systems that describes the common stages of evolution as a stream transitions from being stable, to disturbed, to a series of degradation, degradation and widening, and aggradation and widening processes until a stream reaches a new quasi-equilibrium. Stability and equilibrium in a fluvial system are indicated by dense vegetation and frequent interaction with a floodplain. Simon and Hupp (1986) and Simon and Rinaldi (2006) expanded upon Schumm's model to develop the CEM displayed in Figure 4.1. CEM models can be used to develop a coarse process-based understanding of how stream channels contribute or store sediment (Lisle *et al*., 2014).

While the classic CEM displayed in Figure 4.1 conceptually depicts the state-transition phases of small, simple physical systems, more complex systems do not always follow the same trajectory (Makaske *et al*., 2002; Leyland and Darby, 2008; Hawley *et al*., 2012; Toone *et al*., 2012). Different combinations of ecological, hydrological, geomorphological, and human alterations create antecedent conditions in a basin that may affect a stream's response to disturbance (Van Dyke, 2013). A case study in the Walla Walla and Tucannon River Basins in the southeastern regions of Washington demonstrates the value of developing localized CEMs to better describe a system's response to a unique disturbance history (Beechie *et al*., 2007). Stream channels within this region are deeply incised due to a history of intense upland erosion from rill and gully erosion and fine silt-dominated material. Beechie *et al*. (2007) found that in this system, there was a cluster of stream channel types that did not undergo a widening phase (IV and V in Simon and Rinaldi's CEM) due to mass wasting that buttressed the base of the banks. As a result, these stream channels could not widen or develop inset floodplains. Through an evaluation of two trajectories of channel evolution in this region, Beechie *et al*. (2007) developed region-specific CEMs (Figure 4.2: Beechie *et al*., 2007).

The use of CEMs qualitatively tracks a fluvial system's rate of recovery, and thus gives a broad overview of stream channel response to conservation and restoration efforts. Characterization of basin-specific channel evolution using CEMs may aid in identifying where sediment is stored and sourced in a fluvial system and may contribute to selection and targeting of best management practices and restoration efforts (Simon, 1995; Hawley *et al.*, 2012). For example, if a stream channel was historically incised, and increased bank heights create bank instability and mass wasting, the stream channel may be in a stage of widening until the banks approach more stable bank height conditions. If a stream restoration plan incorporates instream boulders or log structures to increase aggradation rates to channels that are undergoing widening processes, undercutting and further widening beneath the installed structures may occur, negating the intention of the restoration to restore floodplain connectivity.

Channel evolution can be tracked through permanent benchmarked channel cross sections. Using erosion pins and repeatedly monitoring and observing changes, stream channel form, such as bankfull and incision widths and depths, can be assessed and quantified over time. Tracking the adjustment of stream channel width and depth is a useful method for observing response to altered flow and sediment loads because these geomorphic characteristics are more sensitive over a shorter spatiotemporal scale (Knighton, 1998) than larger scale characteristics such as meander length and sinuosity. Paired with stream channel cross section monitoring, basin-specific CEM development can be used as a fluvial system monitoring, prediction, and management tool. By knowing the evolution and response of a system to disturbances, fluvial sediment transport and bank stability models used for restoration design can be better validated. Channel evolution and geomorphic changes can be used to evaluate pre and post treatment impacts from upland best management practices and stream restorations (Olson-Rutz and Marlow, 1992; Trimble, 1997).

When permanent cross sections are distributed across a watershed to best represent critical areas of scour, aggradation, and stability, hypotheses regarding basin-wide sediment transport and storage can be tested with the addition of modeling efforts (See Chapter 3). The objective of this study is to assess overall trends in sediment dynamics in the stream system, and to validate a region-specific channel evolution model to track stream channel recovery from disturbances. Specific objectives are:

1) To determine if the stream channel is a net sediment source or sink and evaluate the variability of source/sink behavior temporally and spatially by land use, and

2) To characterize current stages of channel evolution.

We used field observations from benchmarked cross-sections along a channel system over a 7-year period in the Paradise Creek watershed in northern Idaho, USA, and demonstrate the insight provided by channel cross section monitoring and a region-specific CEM to reveal the role of stream channel sediment storage and contributions in a long-term sediment monitoring study.

METHODS

Study Area

Paradise Creek Watershed (PCW) in northern Idaho is a sub basin within the Palouse basin, which has a rich agricultural history, beginning in the late 1800s. PCW has an area of 50 km^2 within the state of Idaho, and is characterized by forested mountains in the headwaters, intensive agricultural land in the mid portion of the watershed, and an urban area in the lower section of the watershed to the state line between Idaho and Washington (Figure 4.4). The watershed is dominated by winter hydrology, enduring snow, rain-on-snow events, and freeze thaw cycles that contribute to spring runoff and gully and rill erosion. The soil type is largely composed of silt loam, known as the Palouse loess, with patchy argillic horizons that impede infiltration and cause saturation excess overland flow. Steep hillslopes in the agricultural areas paired with moderate to flat slopes in the urban areas characterize the topography of the area.

The complex topography, and fine loess soils initially created a challenge for the agricultural region. In the 1920s and 1930s, erosion rates of 200,000-450,000 kg ha^{-1} were observed (Brooks *et al*., 2010). In the PCW, basin-wide efforts to improve soil conservation through contour and conservation tillage, along with gully plugs, conservation tillage, and riparian buffers over the past 80 years have drastically improved total sediment loading to the watershed outlet. The legacy effects of this disturbance, however, are still evident in the stream channel morphology today (Figure 4.3).

Paradise Creek is a 4th order stream. In the first 8.1 km of the stream, which flows through the rural area, flow is ephemeral, with dry periods from July through September. In the following 8 km, the stream flows through the urban area, and after the city of Moscow wastewater treatment plant, the flow is perennial. The gradient of the stream changes from a 1.80% slope for the first 2.1 km, 0.40% for the next 4 km, and 0.02% for the final 10 km of the stream profile. In the upper reaches, some areas of the stream have incised to an argillic layer, and in the lower reaches, much of the stream has incised to a basalt bedrock layer. The bed and bank material is composed of primarily cohesive sediments, with an average bulk density of 1185 kg/m^3 calculated based on data collection from 75 reaches from both bank and bed material (Newson, 2007). Native riparian vegetation is absent in the majority of the agricultural reaches. Reed canary grass (*phalanas arundinacea*), an invasive species, is abundant within the stream channel in both the agricultural and rural areas. Multiple channel restoration projects have been implemented in the urban area over the last 20 years, along with conservation tillage, gully plugs, and riparian buffers in the agricultural areas. Recent sediment loads estimated from long term, event-based modeling efforts on Paradise Creek attribute 58% of the sediment load from agricultural areas and 43% from urban contributions (Brooks *et al*., 2010).

Recent sediment loading data indicate that overall, sediment loads attributed to agricultural land use are declining (Brooks *et al.*, 2010)., however, there has been an increasing trend in sediment loads during 2006 to 2012 in the urban reaches of Paradise Creek (Squires, 2014). It has been hypothesized that the increase in sediment loads from the urban section may be a result of legacy sediment that was transported from the rural uplands and stored in the deposition zone through the urban sections, and is slowly getting flushed out over time (Newson, 2007).

Field Methods

Thirty-six stream reaches from the top of the agricultural region to the Idaho-Washington state line along Paradise Creek and its tributaries were selected based on accessibility via public land or landowner permission in 2005 as well as their ability to represent critical areas of erosion or deposition, degree of vegetation density, elevation and slope of the stream profile. The majority of study reaches had three cross sections, spaced 10-30 m apart. Each cross section was marked with a 1 m long rebar, capped with a washer or plastic cap for visibility. The coordinates for the left and right bank top position were recorded with a global positioning system (GPS) so that the sites could be revisited and monitored over time.

At the end of each water year, from 2005 to 2012 (with the exception of 2011), bank and bed scour and aggradation were estimated by surveying the stream channel elevation profile at each cross section. The elevation profiles were measured using a Leica GeoSystems model 500 survey grade differential GPS (DGPS) base station, set up on the roof the Engineering/Physics building on the University of Idaho campus on an established survey marker. At each cross section, a survey rover was used to record elevation measurements perpendicular to flow. Measurements were recorded at each significant change in elevation across the profile. Measurements averaged 40-60 elevation points per cross section, with precision of 3 mm. The standard user error of the DGPS was 2.5%. The stream bank and thalwegs were recorded at each location to characterize the channel geometry. Qualitative notes on vegetation type, and presence of cover were also collected.

Data analysis

Data were post processed using Ski-Pro 2.0 processing software, ArcGIS 9.2, and Microsoft Excel to determine cross sectional area and profile shapes. Cross section area was calculated and compared for each cross section for each survey year using a consistent stream bank elevation reference point. This ensured that the differences in areas calculated each year reliably demonstrated changes in streambed and bank, rather than changes in floodplain elevation. To address Objective 1, differences between aggradation and scour behavior both spatially and temporally were evaluated. Because the entire set of 36 reaches was not surveyed every year, cross sectional area changes for the surveyed channels were compared over a two year time frame from 2006-2012 to ensure a richer data set. Using the cross sectional area change (m^2) over two years, we estimated the total sediment scoured or aggraded per site (kg/m), based on the average bulk density (1185 kg/m^3). Negative sediment movement was interpreted as kg of sediment scoured per meter of stream length across the reach and positive sediment movement was interpreted as kg of sediment aggraded, or sediment stored per meter of stream length across the reach.

The cross sections were divided into “rural” and “urban” land use types. The rural category represented all reaches upstream from the agricultural gauge station (Figure 4.4), and the urban category represented all reaches between the agricultural and urban gauging stations. Statistical paired t-tests were conducted to find significant changes in cross sections (p-value

<0.05), and two and one tailed Welch's t-tests were performed to assess temporal changes and spatial changes based upon the land use (rural or urban) (p-value <0.05).

Beechie's CEM was selected and applied to PCW because similar patterns of recovery from incision without a widening stage were observed in many of the surveyed reaches. The study area in Beechie's model also was situated in complex topography with fine sediment and erosion resistant basalt, experienced winter-based hydrologic events, and had a similar anthropogenic disturbance history as PCW. To perform the CEM analysis for Objective 2, a times series of the cross section profiles for each survey site was analyzed. Using Beechie's CEM diagram (Figure 4.2), cross section profiles from 2005-2012 were evaluated and categorized into Model I or Model II based on channel form, the presence of an inset floodplain, and the incision depth. The trends of aggradation, incision, widening, and scour were noted, and the sites were categorized into evolutionary stages within each model type. Incision depth, as defined by Beechie *et al*. (2007), was estimated as the depth from the historical flood plain to the current channel bed. To estimate bankfull width, the channel width at the elevation of the inset floodplain was measured. We looked at the relationship between incision depth and bankfull widths of all sites to test if there was a similar relationship between deep and narrow incision depth to bankfull width ratios and Model I evolutionary types, and wider and shallower channel form characteristics for Model II evolutionary types, as observed by Beechie *et al*. (2007) (Figure 4.2),

RESULTS

Spatial and Temporal Variability

Stream channel surveys indicate that since 2008 Paradise Creek is aggrading. Temporally, 2006-2008 was a scour period, and 2008-2010 and 2010-2012 were aggradation periods. Spatially, reaches in the urban section show more scour behavior and are more dynamic than the rural sections. Specific details of the spatial and temporal results are described in the following sections.

Spatial variation. Spatially, the two-year changes in the urban section demonstrated a greater variance than the rural sections (p=0.0045; Figure 4.5), indicating that the urban reaches play a role as both a source and sink over the study period, and that reaches within the urban area vary more as sources and sinks within a two-year period than the rural reaches, which have less variation in scour/aggradation behavior within a two-year period. When total sediment movement was compared over the course of the 2006-2012 period, no statistically significant difference in scour or aggradation were observed between urban and rural cross sections. When assessing short term changes, however, the urban reaches scoured significantly more than the rural reaches (p=0.0097) with a mean scour of 629 kg/m (n=7) in the urban reaches compared to 64 kg/m (n=28) aggradation in the rural reaches during the 2006-2008 period. In the subsequent two-year periods, no significant difference was observed between the rural and urban sections. This demonstrates that overall, the net effect of sediment storage of transport of the urban and rural reaches over a longer time period (six years) is similar despite more dynamic behavior in the urban reaches over shorter time periods.

Aggradation outliers in the histogram are from cross sections that were restored prior to the start of the stream reach survey. Scour outliers represent sites that were modified or restored within the study period. These outliers were removed from the statistical analysis. The role of reaches impacted by beaver activity were also not included in this analysis because of their significantly high aggradation rates, but those sites will be further addressed in the discussion section. Another reach that was removed from this analysis is located at the upstream boundary of the urban area, so its impacts are captured in the urban gaging station, but it is in an agricultural field and therefore does not represent typical urban reaches. The effects of this reach are further described in the discussion section.

Temporal variation. In the 2006-2012 study period, the two-year changes in reach behavior showed overall scour in 2006-2008 (median= -179 kg/m, n=38), and aggradation in 2008-2010 (median=43 kg/m, n=66) and 2010-2012 (median=70 kg/m, n=73) for all stream sites (Figure 4.6). Temporally, there was no significant difference between scouring or aggradation behavior by year for the entire surveyed stream channel.

When analyzing cross sectional area changes by the rural and urban land use types, the rural stream reach behavior did not change significantly over the six-year study period (both when comparing the same site’s behavior over time through a paired t-test (n=7), and when all rural sites from each time period are compared through a two-tailed t-test, p-values< 0.05 (n=33). The urban sites did scour significantly more in 2006-2008 than in 2008-2010, with a mean sediment scour of -630 kg/m in 2006-2008 compared to a mean sediment storage of 100 kg/m in 2008-2010 (p=0.0026 in two-tailed Welch's t-test (n=33), and p= 0.043 in paired t-test (n=7). In all other time periods, comparisons for the urban reaches, there were no significant differences.

Overall stream channel. Through analyzing net changes of sediment movement over the two-year periods from 2006-2012 for each site (n=173), we found that overall the stream was aggrading (Figure 4.7). There are greater instances of aggradation than scour (70 aggradation occurrences, 21 scour occurrences), and particularly more instances of aggradation events greater than 500 kg/m (29 occurrences) (Figure 4.7). Over a third, 38%, of the two-year assessments showed little net movement of sediment (no greater than 200 kg/m aggradation and no less than 200 kg/m scour), indicating potential stability.

Channel Evolution Model

The CEM analysis indicates that there are two well defined Model I and Model II evolutionary trajectories present in PCW, and that the differentiation of the two is not tightly connected to the incision depth and bankfull width. Model I is more abundant in the rural reaches whereas Model II is more predominant in the urban section.

Channel evolution characterization. Figure 4.8 displays the diversity of channel forms present in Paradise Creek, moving downstream. The majority of the cross sections are incised, with incision depths ranging from 0.5 to 3 m and incision widths ranging from 4 to 50 m. No typical relationship between downstream hydraulic geometry characteristics such as bankfull width, height, width to depth ratios, or cross sectional area with drainage basin size were found for the surveyed reaches.

Evolutionary models and stage types by land use are shown in Figure 4.9. A frequency analysis shows that the majority of the urban reaches (n=37) were in the Model II trajectory (83%), and the majority of rural reaches (n=36) were in the Model I trajectory (68%) (Figure 4.9).

In the entire stream system, there are just two instances of early evolutionary stages of incision (Ib and IIc), indicating that the stream system is no longer significantly downcutting. More than half of the rural reaches (61%), and 46% of the urban sections are in quasi-equilibrium states of Model Id or IIe. About a third of urban sites are degrading (27%) and 27% of the rural sites are degrading with limited widening, and therefore contribute sediment to the system. More urban sites (27) are in processes of aggrading and widening (Model IId) than the rural sites (18%). Sites in the Model IId trajectory provide both fluvial sources of bed and bank sediment as well as sediment storage. In the rural reaches, 39% of the sites are still providing sediment to the system (Model Ib, Ic, IIc), whereas 54% of the urban sites contribute sediment. These results suggest that the current evolutionary trajectory of the rural reaches results in greater storage of sediment while a greater number of urban reaches are still supplying sediment to the system, which is confirmed by the spatiotemporal variability results discussed above and corroborate loading data by Brooks *et al*. 2010. .

Reaches in Model I trajectories have the capacity to both contribute and store greater loads of sediment than reaches in Model II trajectories. On average, a reach in Model Id stored 2004 kg/m (n=11) compared to a reach in Model IIe which stored on average 935 kg/m (n=9) over the 2008 to 2010 survey period. The Model Ib reach also scoured out greater amounts of sediment (230 kg/m, n=1), than the Model IIc degrading reaches (88 kg/m, n=5).

Incision depth and bankfull width relationship. When incision depth (m) was plotted against bankfull width (m), the evolutionary models do not fall out into obvious w/d clusters, as seen in the Beechie Study (Figure 4.10). Model I sites with large bankfull widths and small incision heights are also prevalent. While, similar to Beechie's study, Model I represents deep and narrow channels (incision depth > bankfull width) and Model II wider, shallower channels (incision depth < bankfull width), Model I trajectories are also present where incision depth is less than bankfull width. In a scatterplot between incision depth and distance upstream from the outlet (Figure 4.11), the number of Model I sites increased and the incision depth decreased with increasing distance upstream. This suggests that Model I sites are more prevalent at smaller incision depths (<2.25m), and in the upstream portion of the watershed.

DISCUSSION

Spatial and Temporal Variability

The limited timeframe for the geomorphic observations, land use, and channel diversity in this study make it challenging to understand all the fluvial processes and mechanisms that drive channel morphology. The dataset, however, reveals insightful trends related to sediment dynamics. Results from this study suggest that currently the stream channel is a net sink for sediment (Figure 4.7). More rural reaches are in phases of aggradation and are reaching quasi-equilibrium whereas more often, the urban reaches are more dynamic, acting as both sources and sinks for sediment (Figures 4.5 and 4.6).

A greater number of rural reaches may be in stages of aggradation or quasi-equilibrium because the fluvial system has had decades to respond to the initial disturbance of land conversion from native prairie to intensive agriculture. Fine sediments facilitated rapid incision and knickpoint development (Daniels 1960; Thomas *et al.*, 2006), As documented in other agricultural stream systems composed of loess and fine sediments (Bouska and Stoeber, 2014), the stream likely rapidly incised following the land conversion from prairie to agriculture disturbance in late 1800s and early 1900s. As a result, in many rural reaches, the streambed already has downcut to a hard argillic layer and the channel is no longer incising.

The combination of fine cohesive sediments, small stream channels, bank failures, and the high sediment trapping capacity of invasive reed canary grass is likely a dominant factor in why the rural area is aggrading over time. Systems with cohesive sediments, like PCW, tend to incise without a consequent widening phase (Schumm, 1999). Cohesive banks more frequently undergo mass wasting events due to changes in pore pressure and weakening from bank toe fluvial erosion (Papanicolaou, 2001). After incision, stream bank height increases, and after flow decreases and banks are saturated, banks are more likely to fail due to reduced pore pressure. Field observations show that the small incised channels in the rural area (Figures 4.8 4.11) tend to retain sediment from mass failures. As suggested by Beechie *et al.* (2007), in these cases, it is likely that in the rural areas, the stream channel itself is too small to export sediment as rapidly as it is delivered. The collapsed banks then armor the walls of the streambed, preventing excessive fluvial erosion, and therefore there is not significant widening.

The collapsed banks in agricultural systems offer ideal habitat for invasive species, such as reed canary grass (Lavergne and Molofsky, 2004). Because of nutrient enrichment from agricultural runoff, lack of competition due to loss of biodiversity from agricultural land conversion, and a hydrologic regime that alternates between wet and dry periods (Madsen *et al.*, 2001), reed canary grass has invaded the majority of the agricultural reaches with dense stands of vegetation (Figure 4.12). Presence of macrophytes has been shown to reduce flow velocities, increase sedimentation rates, and reduce potential for resuspension of fine sediments (James and Barko, 1991; Fonseco and Calahan, 1992; Madsen *et al.*, 2001). Further, Cotton *et* *al.* (2006) found that macrophytes in stream systems trap fine sediments both during growth and die back periods, providing sediment retention year round. A study on the impacts of submerged macrophytes on sediment transport in lowland streams found that even during high flow events, vegetation still added enough roughness and slowed flow velocities to allow both some bed-load and suspended load fine sediments to deposit (Sand-Jenson and Pedersen, 1999). In PCW, dense reed canary grass stands die back and flatten out along the streambeds and banks during the winter, creating dense vegetative mats that provide armoring that may prevent streambed sediments from resuspending during the first flushes of sediment from hydrologic events at the beginning of the water year (Figure 4.12).

Reed canary grass is also prevalent in the urban portion of the watershed, but there is greater variability in disturbances in the urban reaches compared to the rural reaches. The diversity of localized disturbances combined with a low gradient channel profile in the urban reach may explain why the urban reaches provide both storage and contribute sediment from increased bank erosion. The urban reaches experience impacts from recent stream channel modification and restoration, beaver activity, and flashier runoff and stormwater from impervious areas which all likely drive the less predictable sediment dynamics. Stream channel modifications have immediate effects on geomorphic change, which slows over time as the stream channel adjusts to a new equilibrium (Graf, 1977; Simon, 1989). In the urban area, many stream modifications were made in 2010 and 2011. The outliers in Figures 4.5 and 4.6 that exhibit the greatest scour occurred in the urban reaches that have been recently modified from stream restoration practices (Figure 4.13)**.**

Urban reaches in the lower portion of the watershed tend to have larger incision depths than the rural reaches (Figure 4.11). Because flow is perennial throughout the urban reaches, reed canary grass is not as prevalent in the streambeds. As a result of greater incision, the banks heights are relatively high, and thus undergo greater undercutting, mass wasting, and slumping processes (Figure 4.13). Field observations indicate that the failed blocks of sediment either are invaded by vegetation, and thus armor the banks, or are flushed out of the system over time. As the bank heights decrease with time, these widening processes may diminish, allowing for greater aggradation and storage for sediment in the urban section. By raising streambed elevation through aggradation, the system may be better connected with the floodplain, creating a healthier stream system (Cluer and Thorne, 2014), but this may alter floodstage elevations in the urban area, impacting development and flood management.

The aggradation outliers in Figures 4.5 and 4.6 were from stream channels that have been affected by beaver activity (e.g. Figure 4.14). Beaver dams have been used as a method for restoring incised streams because they reduce stream power and flow velocity and allow sediment to accumulate on the streambed and floodplain, while reducing bank erosion (Pollock *et al.*, 2014). While beavers have not been intentionally placed in this watershed for restoration efforts, and actually are often removed from the system by the city and private landowners, they impact sediment storage at the watershed scale**.** For example, between 2008 and 2010, one site that has been impacted by beaver activity stored 3557 kg/m of sediment, which was over ten times greater than the average sediment storage of the rest of the stream sites surveyed in the basin (mean=386kg/m between 2008 and 2010). In addition to the beaver activity in the urban section of the watershed, there is also a sediment storage basin that remains from an area where the stream used to be routed underground before restoration. The role that this basin plays in overall sediment storage was not included in this study.

Below the rural gauging station, the stream channel flows through a low gradient agricultural field before entering the urban area of the town. A riparian buffer was implemented in this particular reach (Figure 4.15). Reed canary grass has invaded the buffer and original stream channel. Consequently, the stream has rerouted high energy flows into areas of lower resistance, and as a result has scoured out a new channel within the field (Figure 4.15). From 2008 to 2010, alone, the reach averaged scour was 4880 kg/m. During flood stage, suspended sediment is likely trapped within the buffer, but the new channel development is also a large source of sediment that is then carried through the downstream urban reaches, outweighing the benefits of the buffer’s trapping capacity. The lateral migration resulting from both increased roughness from the buffer and low gradient is having the opposite effects that the landowner had intended.

In addition to sources from the poorly placed riparian buffer, the expanding urbanization of the city of Moscow is increasing impervious area as well as construction site areas, and thus creates more sources of sediment, and increases the flow and magnitude of peak flow (Wolman, 1967; Trimble, 1997). Urban growth, therefore, is likely increasing the rates of channel erosion in the urban reaches. A recent city survey revealed that there are over 200 stormwater outfalls within the urban area of PCW. The impacts of discrete outfalls of flow and sediment on the streambed and bank erosion should be further examined. From field observations, it is clear that during high stormwater runoff events, these localized outfalls have high scouring capacity, and further weakening banks (Figure 4.16)

While the annual channel geometry measurements do not capture event-based scour and deposition throughout the year, the two-year cross sectional area change (Figure 4.6) does capture overall trends. During the six years of study, the watershed experienced a diverse set of hydrologic regimes, including high flow years (2009, 2012), and low flow years (2005, 2010), and therefore the study period is representative of years that the stream had varied levels of transport capacity and stream power, ultimately impacting sediment transport and fluvial erosion (Squires, 2014).

Loading data from the long-term event-based monitoring study show alternating influences of sediment contributions from the urban and rural areas (Brooks *et al.*, 2010; Squires, 2014). In water years 2007 – 2010, the rural and urban reaches have similar observed annual sediment loads (Figure 4.17). In water years 2011, the loading data suggest almost twice as much sediment sourced from the urban area as from the rural area. In 2011, a section of the urban channel was daylighted and rerouted which may have contributed to the greater sediment loads. Due to an extremely wet spring in 2011, over half of the agricultural area was not planted. As a result, the soil moisture content was greater during the next fall and winter in these fallowed areas due to the absence of evapotranspiration, resulting in greater hillslope erosion events and sediment loading in the spring of 2012 in the rural area. Urban reaches showed greater deposition during the 2012 water year which may have been a result of greater concentrations of suspended sediment traveling and depositing through the urban transport-limited and low gradient reaches as well as the introduction of the sediment storage basin that resulted after the channel was rerouted (Figure 4.17, Squires, 2014).

The sources contributing to annual sediment loads observed at the gauging stations could be sourced from hillslope erosion, construction zones, and storm water outfalls, but the stream channel also plays a role as a source or sink (Brooks *et al.*, 2010). While the trends in the annual sediment loads do not solely reflect the stream channel sediment dynamics, the trends of the urban reaches acting more dynamically as both a source and sink for sediment is also reflected in the geomorphic dataset (Figure 4.6). Downstream urban sediment sources are increasing with development while upstream rural sources are decreasing with improved soil conservation measures. As a result, the stream may have greater transport capacity and stream power after flowing through the rural area, increasing channel erosion in the urban areas. While the rural reaches have largely adjusted to historical disturbances, the urban reaches are still in the process of adjusting to development.

Channel Evolution Analysis

The CEM analysis indicates that there are two evolutionary trajectories present in PCW, with Model I more abundant in the smaller stream channels common in the rural section and Model II more predominant in the urban sections. A greater number of rural reaches have recovered from historical disturbances and are at or nearing quasi-equilibrium (Figure 4.9), whereas there is a greater diversity of stage type in the urban reach, possibly a result of more recent disturbances.

Interestingly, reaches within the quasi-equilibrium stage of Model I tend to store more sediment than reaches in Model II. Because Model II has a widening stage, it would seem that the channels would be wider and shallower and thus have greater trapping capacity for sediment. The CEM analysis differs from the CEM developed for the Tucannon and Walla Walla River Basins (Beechie *et al*., 2007), in that Model I and Model II evolutionary trajectories do not closely correlate with the bankfull width and incision depth ratio (see Figure 4.2). The Tucannon and Walla Walla River basin study covered a much larger area and surveyed cross sections with a greater range of depths and widths than present in PCW. The incision depth does not vary widely among reaches in PCW (0.5 to 3 m) compared to the Walla Walla and Tucannon River basins (1.8 to 8.3m), thus it does not impact the incision depth to bankfull ratio to the same extent as in Beechie's study.

Beechie *et al*. (2007), hypothesized that reaches with small bankfull width to incision depth ratios fell into Model I trajectories because the channel geometry did not allow for enough flow strength to widen the channel, and therefore the stream does not evolve through a widening stage like the traditional CEM (Simon and Hupp, 1986). In PCW, a smaller fluvial system, we revise the Beechie *et al*. (2007) CEM to a PCW region-specific model that shows that even stream channels with high bankfull width to incision depths may not have the flow strength to widen. This may be a result of the cohesive bank failures that armor the toe from fluvial erosion or the reed canary grass at the bank toes that trap sediment, and reduce flow velocities, potentially reducing fluvial erosion and widening.

More rural reaches fall within the Model I trajectory because they do not undergo a widening phase (Figures 4.9 and 4.11). The majority of rural reaches are no longer incising (Figure 4.9). The low flow channels show temporal patterns of fill and scour (e.g. Figure 4.18), but overall show net aggradation. The urban sections do show widening trends which may be a result of greater stream power and shear strength on the stream banks from higher intensity flow events from runoff from impervious areas or stormwater outfalls. In addition, the stream channels in the urban section in the lower portions of the watershed are more incised (Figure 4.11), resulting in greater bank toe erosion, bank instability, and lack of connection to the floodplain to dissipate flow.

Implications of the CEM analysis include targeting restoration based on the stage of evolution (Shields *et al*., 1998; Watson *et al*., 2002). Because Model I reaches do not go through a widening phase, and are predominantly already in or moving towards a stage of quasi-equilibrium, they should not be targeted for restoration (Figure 4.9). Shield *et al*. (1998) argued that stream restoration should not occur until a channel has reached the widening and aggrading stage (Model IId) because it has been shown that once a stream reaches this stage, it is moving towards equilibrium (Schumm *et al*., 1984; Harvey and Watson, 1986, Brooks *et al*., 2003). In targeting sections in Model IId (45% of the total sites surveyed), instream wood or boulder structures for restoration have a lesser chance of failing because the stream is less likely to undergo rapid widening and undercutting.

In addition to the PCW-specific CEM, the relationship between w/d ratio and trends in scour and aggradation may be beneficial in selection of stream restoration designs. Unlike natural systems, this highly disturbed watershed does exhibit any typical trends or relationships between drainage basin area and downstream hydraulic geometry characteristics. The impacts of channel modification, urban development, and beaver disturbances tend to be localized at the reach scale, currently. There is, however, a relationship between the w/d ratio state and whether or not a reach is more likely to scour or aggrade. Width to depth ratios are used to assess departures from stable conditions in a stream, and to better understand how a channel form adjusts to changes in discharge and sediment supply (Charlton, 1998). For this ratio, the bankfull depth is measured, rather than the incision depth used in the channel evolution analysis. Bankfull depth is used because it better addresses the width at which the recent discharge and sediment supply are shaping the current channel form, whereas the incision depth better indicates how a stream has responded to historical disturbances.

Figure 4.19 indicates that in PCW, reaches with a w/d ratio ranging from 4 to 6 exhibit stability in overall sediment movement in that they transport as much sediment as they store over time. Cross sections with small w/d ratios (<4) tend to scour more whereas cross sections with w/d ratios between 6 and 10 tend to aggrade. The smaller w/d ratios likely scour more due to increased unit stream power and shear stress within the channel, or due to bank instability. Many of these sites were located in deep reaches of the urban section. Channels with large w/d ratios can better dissipate the energy of high flow events, and also have greater floodplain connectivity. Interestingly, wide channel systems (w/d ratio >10) in PCW are the greatest contributors to the sediment load. As the stream becomes wider and shallow, instead of depositing sediment across the floodplain, the stream laterally migrates to scour out areas with less roughness and streambed resistance (e.g., Figure 4.12).

While the results of this study are specific to PCW, understanding the physical processes and mechanisms of one system aids in understanding other systems with similar anthropogenic histories (Osborne *et al*., 1993). Like many other mixed land use watersheds, PCW has been highly disturbed. It does not conform to traditional and predictable hydraulic geometry relationships in response to discharge (Wohl, 2004). We found that contrary to normal supply, transition, storage dynamics of a stream profile (Charlton, 2008), PCW stores sediments in the rural areas with higher gradients, and both stores and supplies sediment in the lower gradient reaches of the urban section. Composed of primarily cohesive sediments, development of the PCW CEM was greatly helped by the CEM developed by Beechie for another incised stream system. Understanding the evolutionary trajectories of a fluvial system assists with restoration and conservation targeting goals, and creates reference conditions from which more extensive studies and modeling simulations can be applied.

Our findings could be strengthened with a longer dataset. The field observations from this study and the results can be used to inform and validate process-based channel evolution and sediment transport models. By simulating the long-term responses of stream channel form and sediment transport to disturbances such as the changes in magnitude and timing of flow and sediment loading from urban development, agricultural conservation practices, climate change, and channel modifications, we can better assess potential impacts of conservation and restoration. Greater research into the role of reed canary grass and its sediment trapping capacity could also further inform if the invasive species does provide benefits to the stream channel by accelerating the rate of recovery from historical incision.

CONCLUSIONS

This study sought to determine the spatiotemporal dynamics of sediment scour and storage and characterize stream channel evolution stages in a highly disturbed, mixed land use watershed with cohesive sediments. Results from this case study indicate that overall, Paradise Creek is in a stage of aggradation, and thus storing sediment, but the urban reaches are temporally dynamic, and some years provide more sediment to the system. While a large portion of the surveyed reaches are moving towards stages of quasi-equilibrium, there are still a large number of sections that are widening, particularly in the urban section. The stream has responded to historical disturbances of land conversion from native prairie to intensive agricultural by reaching aggradation and quasi-equilibrium stages in the rural reaches, whereas in the urban area, it is still responding to recent disturbances such as channel modification, increased impervious areas, and beaver activity through widening and scouring processes. This suggests that the stream will continue to contribute sediment through the urban sections until the stream channels have recovered from incision and can connect with the floodplain so that energy can be better dissipated rather than contribute to fluvial erosion.

Results from this work can aid in conservation and restoration efforts in the watershed. Because more of the reaches in the rural reaches are at or are approaching quasi-equilibrium, restoration efforts should continue to target upland hillslope processes that reduce agricultural runoff and erosion, rather than focus on stream channel restoration or modifications. One key finding from the cross section survey is that riparian buffers should not be placed where the stream profile gradient shifts from high to low. The combination of decreased stream power and increased roughness may cause unintentional lateral migration outside of the riparian buffer. Restoration including the installation of rip rap structures, instream logs and boulders should be avoided in areas that are currently in widening and degrading stages of evolution. To accelerate recovery in the urban reaches, beaver analogs (Pollock *et al*., 2015) could be introduced in reaches that are currently aggrading and widening to increase sediment retention, decrease bank erosion, and reconnect the channel with the floodplain.

In the PCW TMDL (IDEQ, 1997), only 5% of the sediment load was allocated to the urban area. An average of 43% of annual loads in Paradise Creek have been attributed to the urban area (Brooks *et al*., 2010), and this study suggests that urban stream bank and bed erosion is more predominant than previously thought. Sediment TMDLs should account for stream channel adjustment to channel modifications and disturbances. Management processes can then identify the geomorphic characteristics that appear to stabilize the stream and aid in meeting restoration goals.

This paired use of stream channel cross section monitoring and the validation of a region-specific CEM illuminate the power of a low cost method for understanding fluvial systems. Using geomorphic observations such as cross section area change, width to depth ratios, and channel evolution models to inform channel response to disturbance can aid in restoration efforts, improving a coarse process-based understanding of underlying geomorphic processes and reference conditions to further inform management and in depth modeling efforts (Clarke *et al*., 2003; Lisle *et al*., 2014). To test stream restoration effectiveness and upland conservation practices, process-based channel evolution and sediment transport models, such as CONCEPTS (Langendoen, 2000), can provide greater insight on the impacts of changing sediment and flow inputs and the long term implications of conservation practice impacts on sediment transport.

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FIGURES

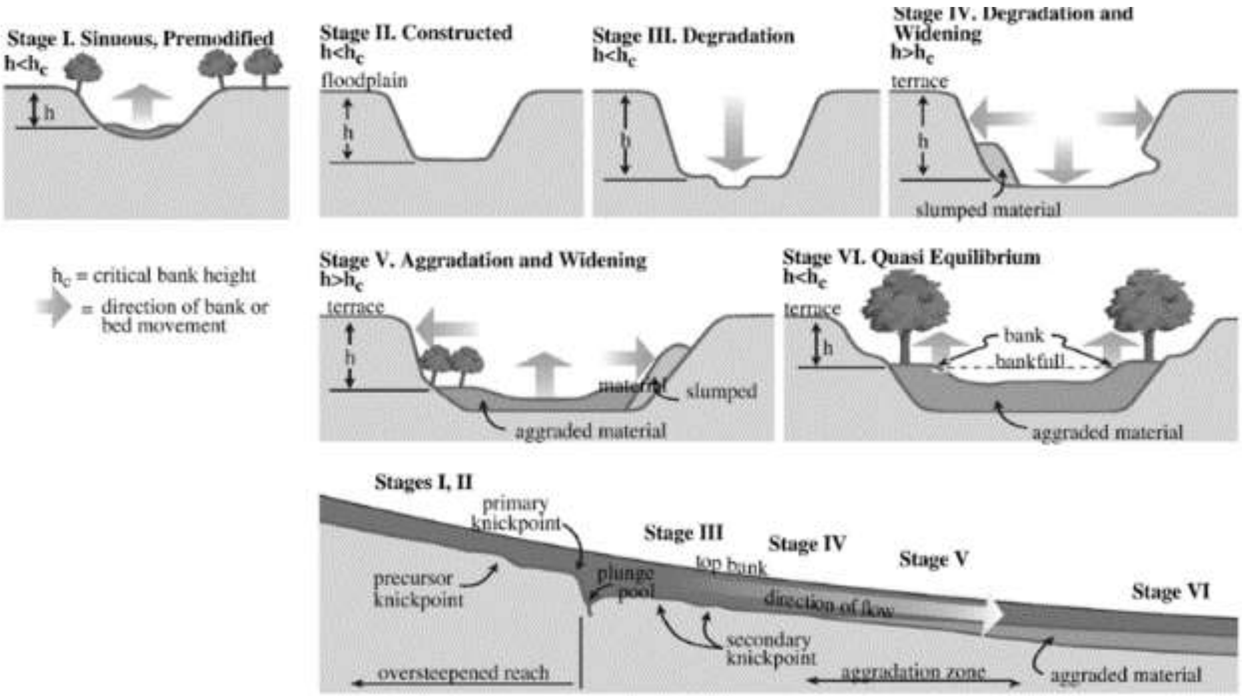

FIGURE 4.1 Channel evolution model stages (Simon and Rinaldi, 2006).

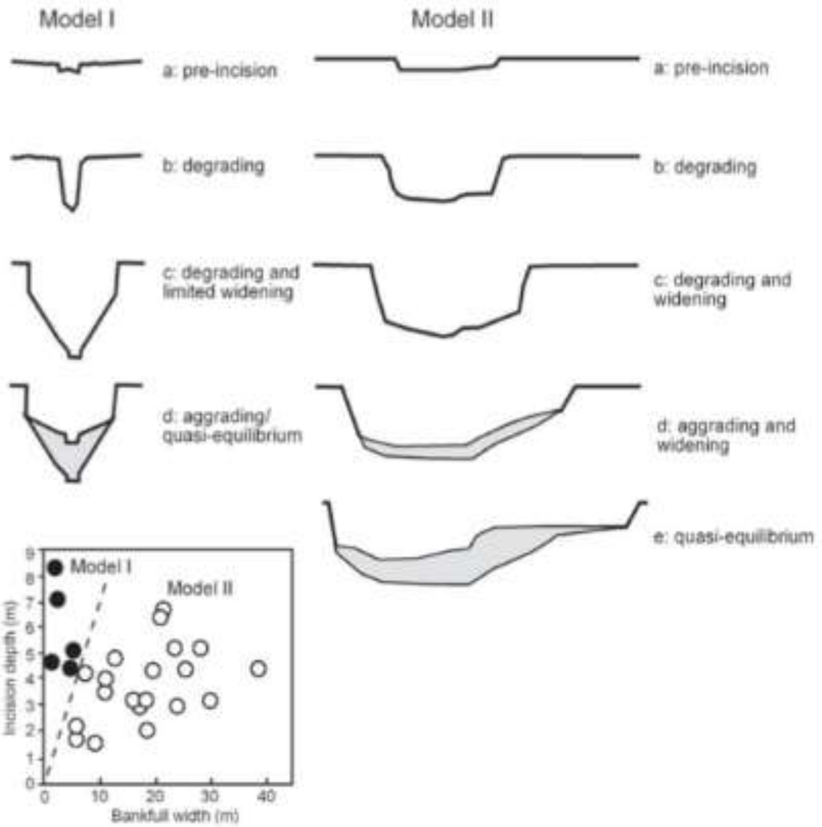

FIGURE 4.2 Alternative channel evolution models developed for the Walla Walla and Tucannon River Basins (Beechie *et al*., 2007).

FIGURE 4.3 Transition in the Paradise Creek Basin from a native Palouse Prairie, to mechanized agriculture in the early 1900s, to the current stage of soil conservation and the legacy effects seen in the stream channel.

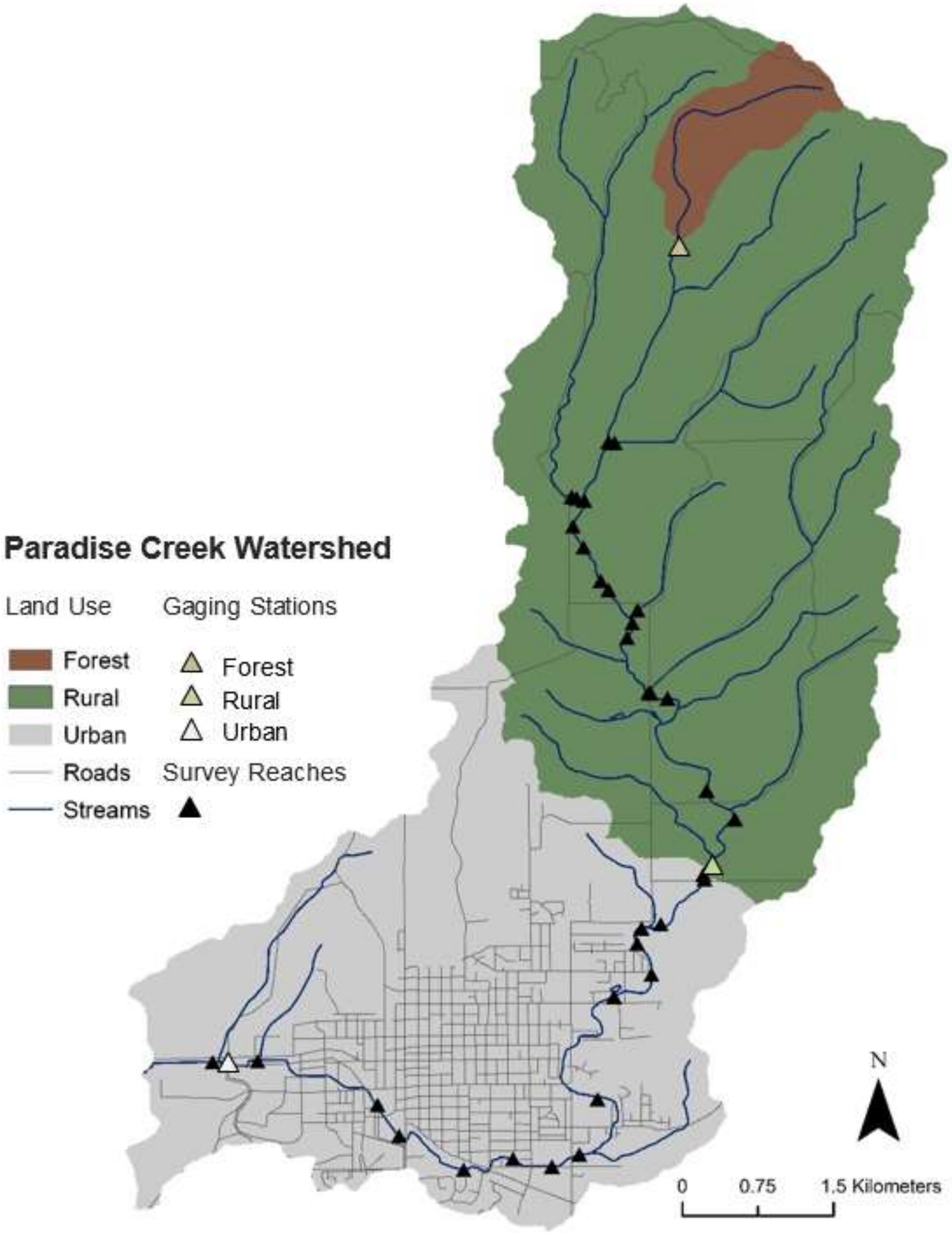

FIGURE 4.4 Map of Paradise Creek Watershed with land uses, locations of forested, rural, and urban gaging stations, and stream reach survey sites.

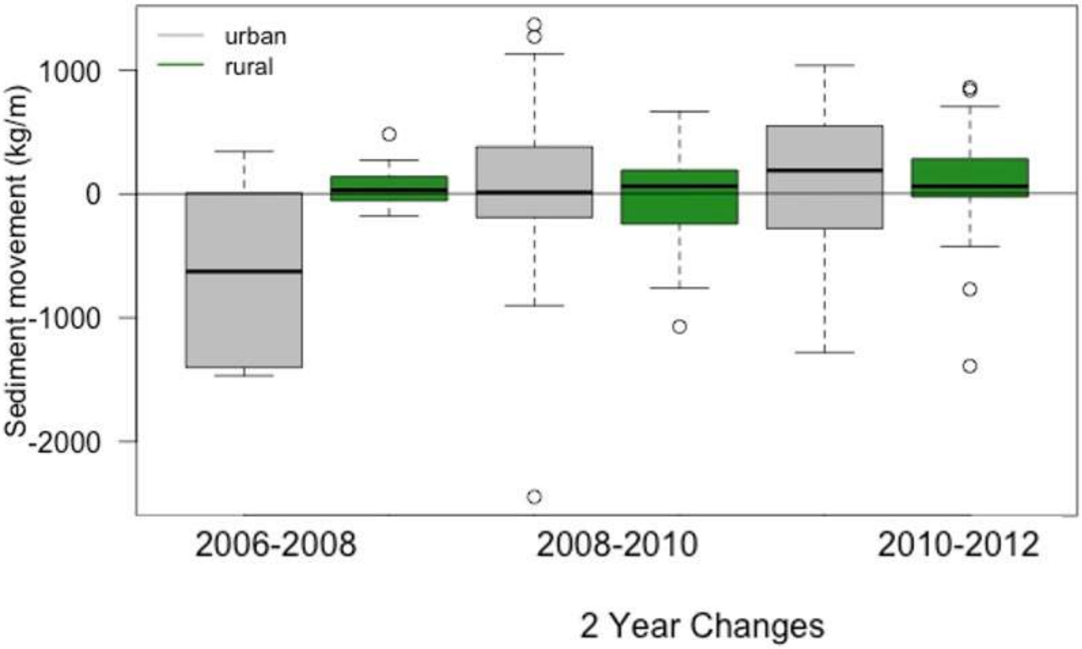

FIGURE 4.5 Spatiotemporal variation in reach behavior displayed through two-year changes in average sediment movement (kg/m) per surveyed cross section. Negative values indicate scouring. Positive values indicate aggradation.

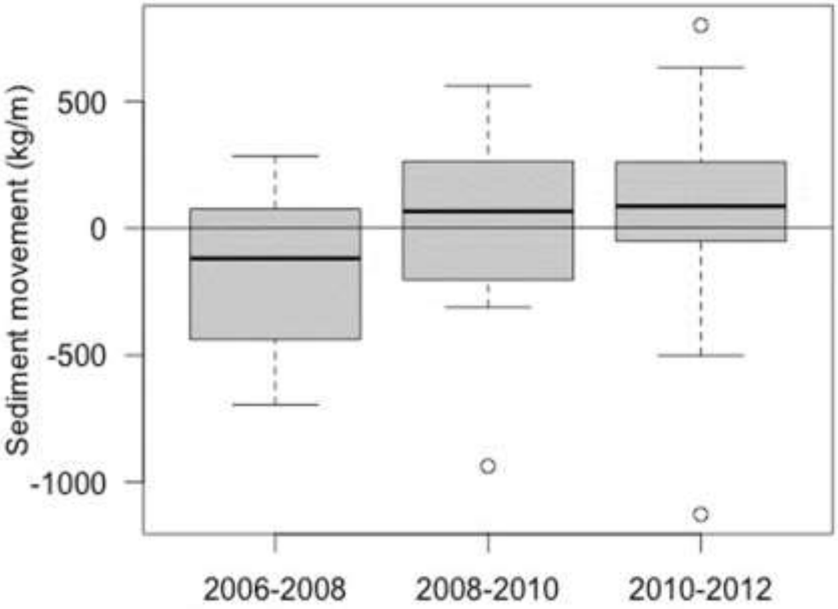

FIGURE 4.6 Temporal variation in reach behavior displayed through two-year changes in average sediment movement (kg/m) per reach. Negative values indicate scouring behavior. Positive values indicate aggradation behavior.

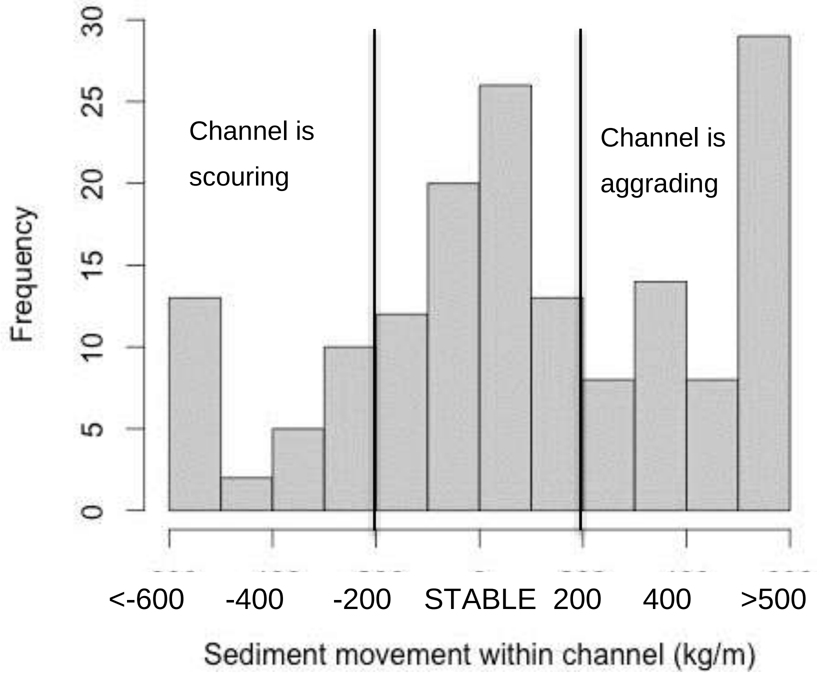

FIGURE 4.7 Histogram of all cross sectional area two-year changes (m^2) between 2006-2012 from all cross section surveys. Positive values indicate channel is aggrading and negative values indicate channel is scouring. Stable cross sections are within the -200 to 200 kg/m range.

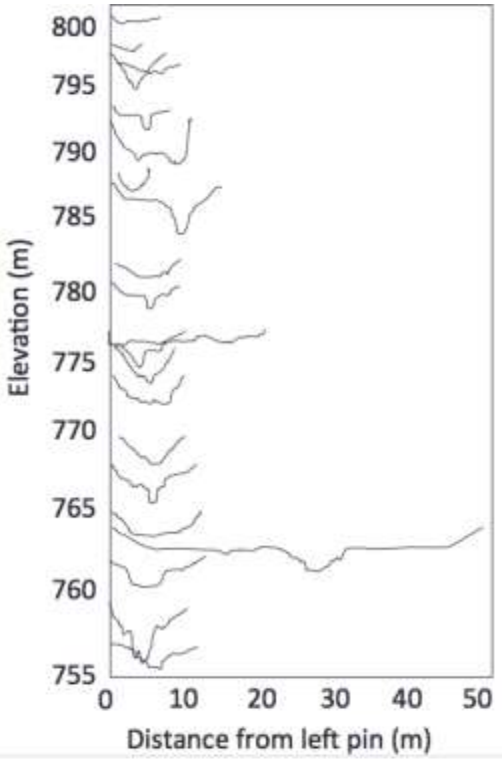

FIGURE 4.8 Subset of cross section geometry from the top of the rural stream section (800 m) and moving downstream through the urban section (755 m) of the main tributary of Paradise Creek.

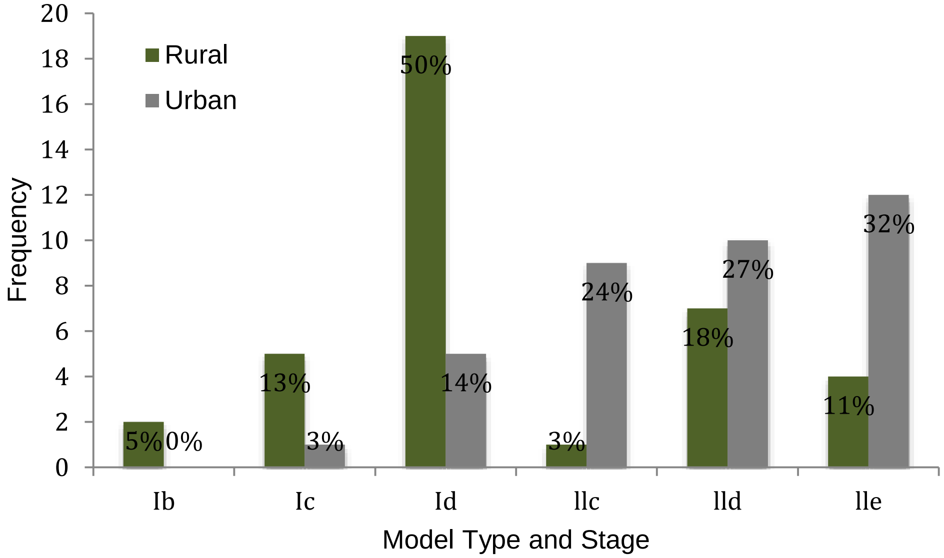

FIGURE 4.9 Frequency of evolutionary model type and stage found in 70 channel surveys in the urban and rural reaches of the Paradise Creek main tributary.

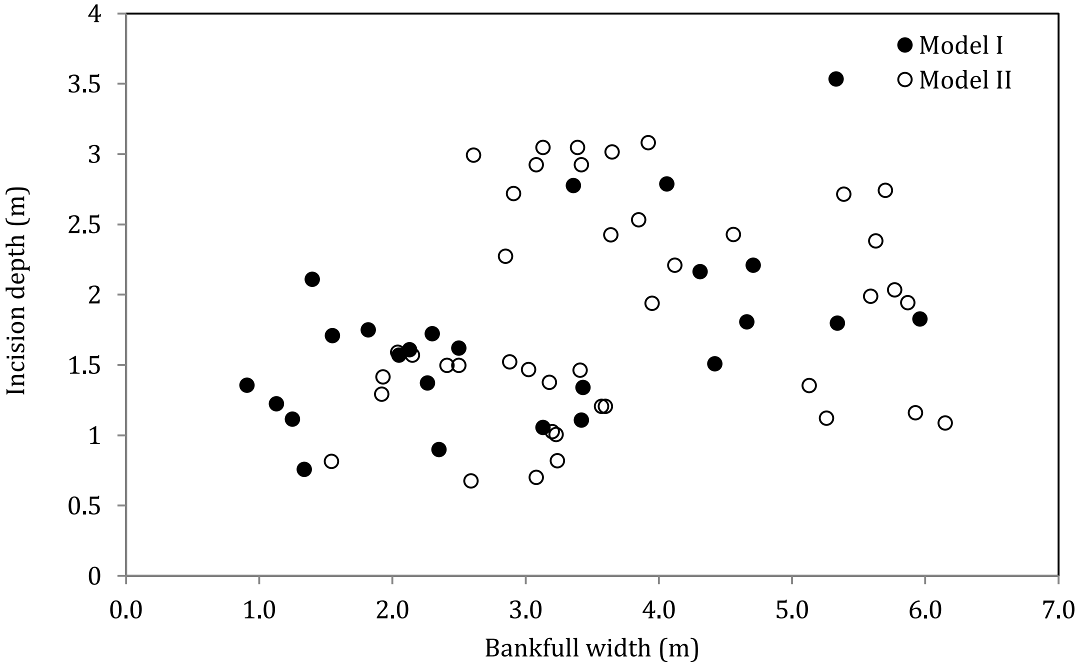

FIGURE 4.10 Relationship between bankfull width (m), incision depth (m), and evolutionary model type.

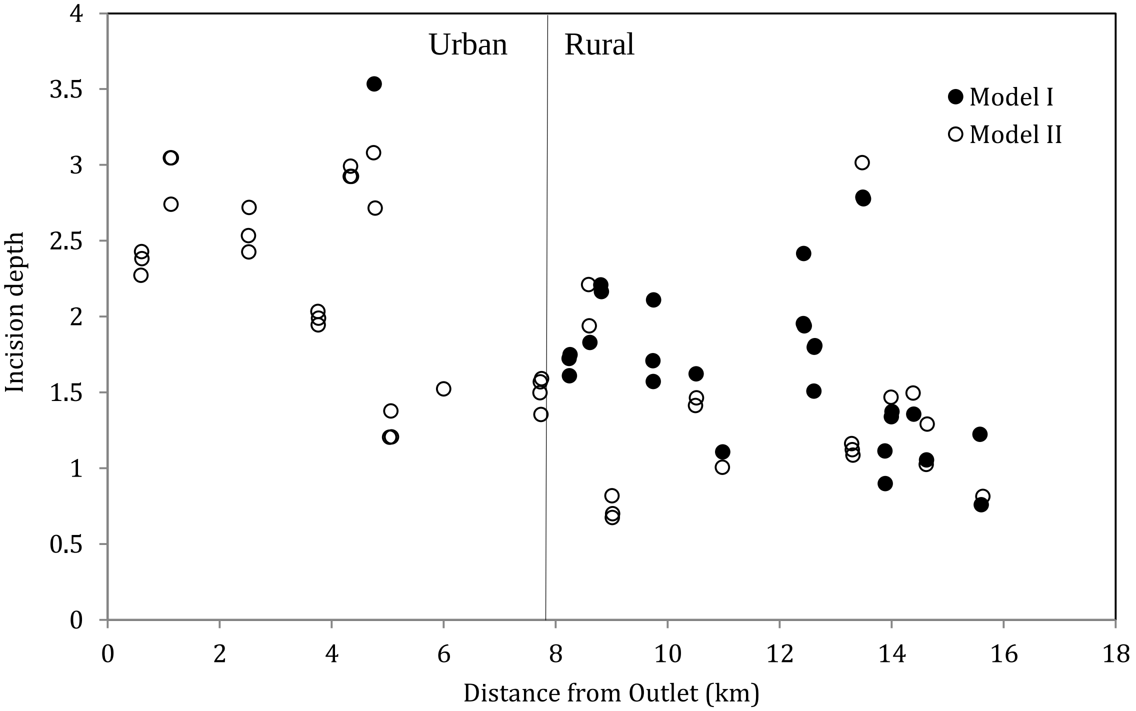

FIGURE 4.11 Incision depth (m) and evolutionary model type of surveyed cross sections moving from downstream to upstream (km).

FIGURE 4.12 Reed canary grass presence in rural reaches of Paradise Creek Watershed.

FIGURE 4.13 Example of widening processes and bank failure in recently restored section of Paradise Creek in the urban area.

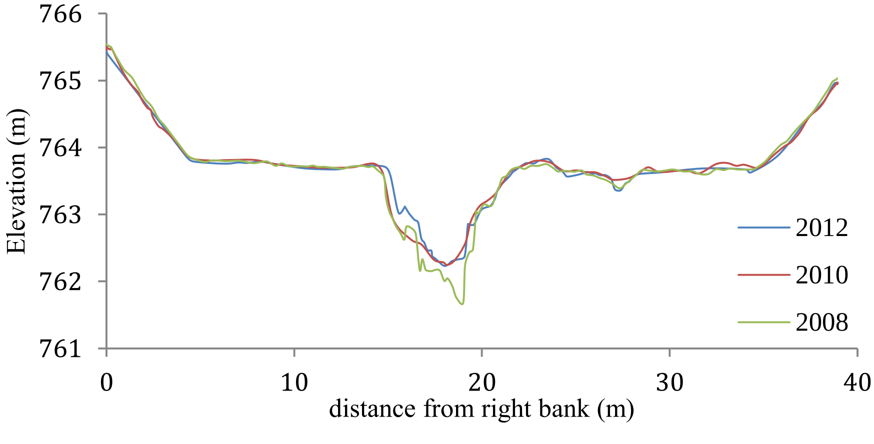

FIGURE 4.14 Cross section measurements from 2008, 2010, and 2012 of urban site with beaver activity present.

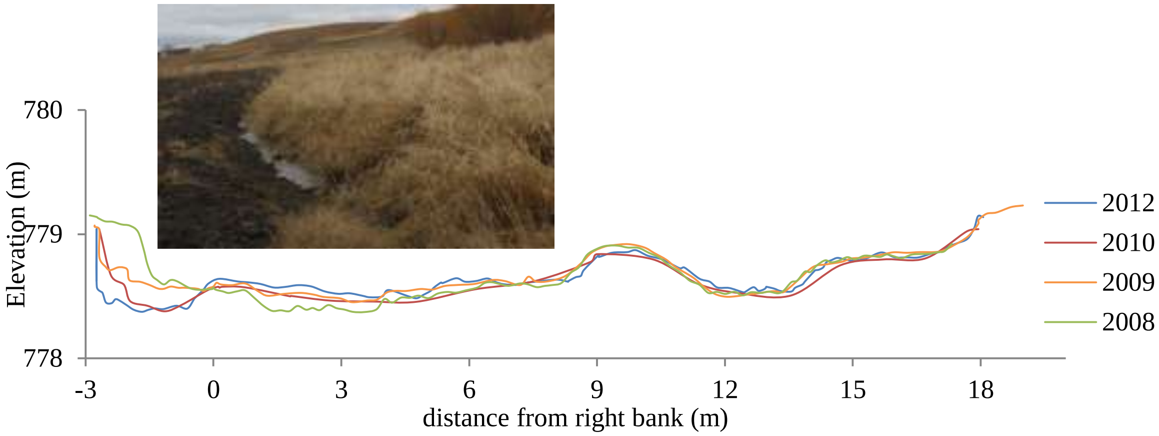

FIGURE 4.15 Cross section with riparian buffer from 2008, 2009, 2010, and 2012 surveys.

FIGURE 4.16 Evidence of localized scour capacity of stormwater outfall in urban reach of Paradise Creek.

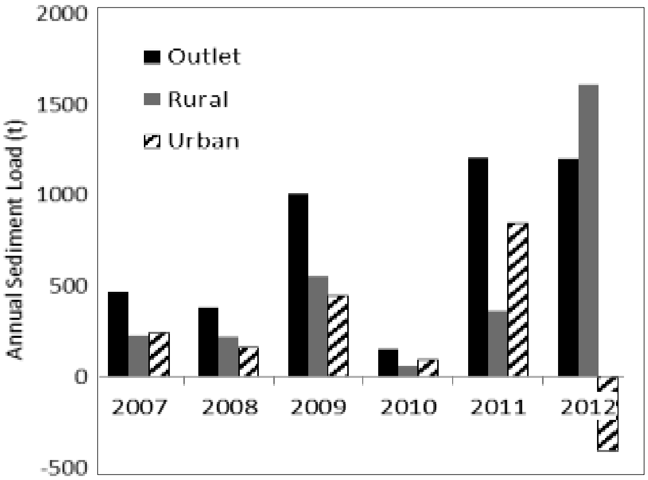

FIGURE 4.17 Annual sediment loads measured in PCW. Black bar is total load measured at the watershed outlet. Gray bar is total load measured at rural station. Diagonally hashed bar is load attributed to urban land use by subtracting rural load from watershed outlet load. Negative value indicates deposition (Squires, 2014).

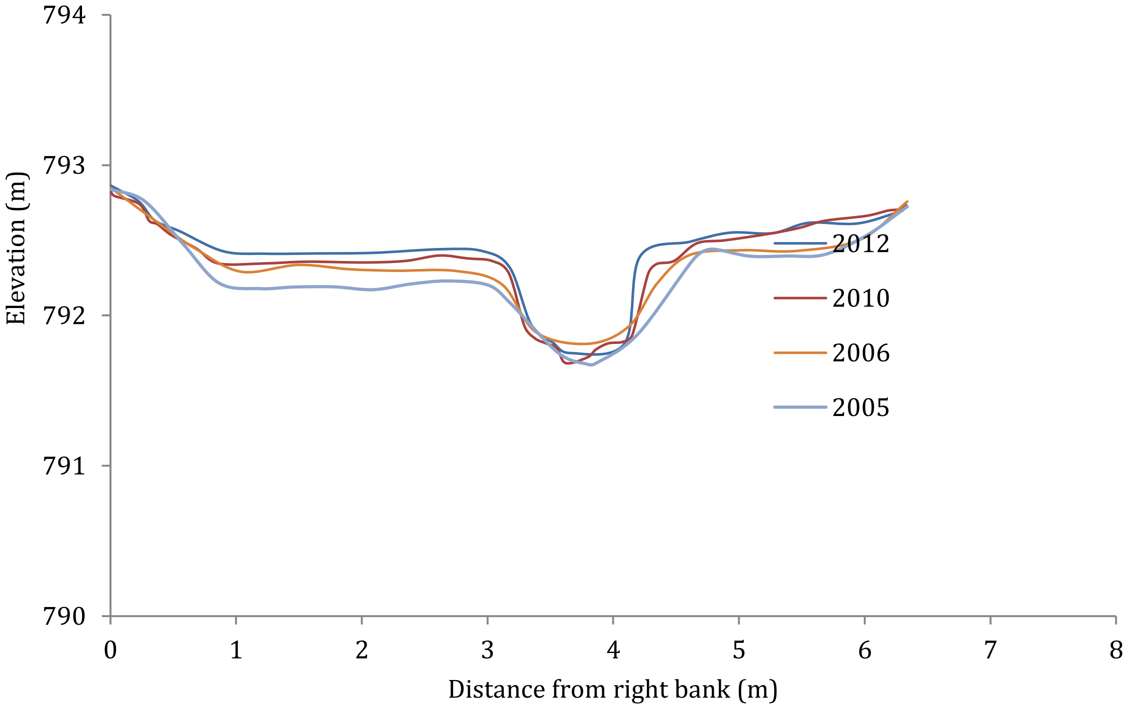

FIGURE 4.18 Example of rural Model Id cross section from 2005-2012.

CHAPTER 5: THE ROLE OF YOUTH CAPITAL AND PLACE-BASED EDUCATION OUTREACH EFFORTS IN MOTIVATING CONSERVATION ACTION IN WATERSHED RESTORATION

ABSTRACT

Environmental education outreach programs are an essential component to effective collaborative approaches to conservation. Environmental education specifically targeted to K-12 audiences and centered in socioecological place-based pedagogies provides students the opportunities to take key messages about conservation issues and actions to their communities, acting as catalysts and agents of attitude and behavior change. The direct link between environmental education efforts and change in conservation behavior in community members is not well documented. In the context of watershed conservation and using the Community Capital framework, we assessed the role of a community-based environmental education program in changing watershed conservation behavior among landowners. We found that investments in socioecological place-based education and youth capital improved intergenerational interactions and learning between students and their community, mobilized resources for conservation, and helped to establish trusted relationships between landowners and community conservationists to implement conservation practices. Through investments in youth and social capital such as K-12 environmental education and community partnerships, resource-limited watersheds can engage in watershed conservation, and create greater community capacity for future conservation projects.

INTRODUCTION

The need for improved water quality and restored aquatic habitats drive multiple scales of local, state, and national research, conservation, and environmental education (EE) outreach programs across the U.S. The U.S provides over $1 billion in subsidies for annual river restoration (Bernhardt *et al.*, 2005) and over $165 million in 2012 alone on watershed-based nonpoint source pollution reductions (General Accounting Office, 2012). Agricultural land use has been cited as the primary contributor to nonpoint source (NPS) pollution loading to surface waters (EPA, 2010). A typical watershed has varying levels and combinations of university extension, governmental organizations, nonprofit conservation groups, and K-12 schools implementing watershed outreach education programs to increase environmental awareness and to promote conservation behavior. An increasingly common critique is why, despite all these subsidies and outreach efforts, over half of the nation's surface waters are still listed as impaired waterways (EPA, 2012).

One response from biophysical scientists is that improvements in water quality, particularly in rural, agricultural watersheds, take decades to achieve because of the physical lag time inherent in a water body's response to best management practices (BMPs) (Koontz and Thomas, 2006; Gregory *et al.*, 2007; Meals *et al.*, 2010; Fremier *et al.*, 2013). Compounding the physical lag, there is also an innate social lag time based on community members' willingness or ability to adopt, implement, and maintain BMPs (Meals *et al.*, 2010). To better link the public to watershed conservation, collaborative approaches to watershed management that involve creative win-win incentives and solutions for stakeholders to engage in conservation actions have emerged (Sabatier *et al.*, 2005). Researching effective collaborative approaches to watershed management includes identifying the contexts and processes that catalyze the formation of collaborative efforts and their success, and determining who participates in collaborative efforts and why (Sabatier *et al*, 2005). Elements of collaborative approaches to natural resource management have been explored (Woodard, 1934; Sanchez-Arroyo *et al.*, 2005; Emery and Flora, 2006; Pannell *et al.*, 2006; Duarte *et al.*, 2009; Papworth *et al.*, 2009; Prokopy *et al.*, 2011), but without a focus on the specific role of innovative EE efforts and youth as critical assets towards community development and conservation.

Environmental education is an essential component of the collaborative approach to conservation. EE promotes and fosters awareness and concern for environmental problems and solutions (UNESCO, 1977) and develops an informed and active citizenry to address environmental issues (Fien, 1993). Awareness and concern for the environment, however, does not necessarily lead to conservation action (Ballantyne *et al*, 2006; Koontz and Thomas, 2006). EE is often targeted at youth. Youth do not necessarily have the immediate power to influence large-scale effective conservation actions (Sutherland and Ham, 1992) and/or may feel overwhelmed by a lack of power to make create positive change in the environment (Uzzell, 1994).

To improve the effectiveness of EE programs, programs that are founded in place-based (Sobel, 1996; Woodhouse and Knapp, 2000), project-based (Marx *et al*, 1997), service-learning, and/or community-based (Villani and Atkins, 2000) learning pedagogies have been suggested to strengthen links between student's learning, awareness of civic responsibility in their communities, and engagement with their environment (Gruenewald, 2002). We place each of these pedagogies under the term of place-based learning (PBL), with the distinctive pedagogical characteristics of being based on particular attributes of place, multidisciplinary, experiential, and connecting place with both self and community (Woodhouse and Knapp, 2000). When education is linked to place and community, the number and diversity of potential community leaders and the capacity to solve community problems increases (Tompkins, 2008).

Many case studies have indicated the successes of PBL in driving economic and community development in rural communities using asset-based frameworks (Barsch, 2008; Tompkins, 2008; Krasny *et al*., 2013). PBL has been shown to expand social capital through building strong networks, growing human capital by increasing knowledge, and strengthening political capital by promoting awareness to impact decision making at the community level. In addition, students play a role as key community members through PBL pedagogies (Tompkins, 2008), becoming assets for implementing community ideas, rather than isolated within schools. As a result, students begin to see themselves as viable citizens (Bartsch, 2008).

PBL initiatives promote deliberate interactions with adults to promote meaningful intergenerational learning in which adults and youth reciprocate learning (Ballantyne, 2006). In one intergenerational learning study, 50% of all students participating in EE projects took influential messages about conservation issues and actions home to their parents, acting as potential catalysts and agents of attitude and behavior change (Ballantyne *et al*., 2001). In developing a framework of researching intergenerational influence through environmental education, Ballantyne *et al* (2006) called for further investigations of the influence of youth on parents' and community conservation actions and the identification of factors that impact the process of intergenerational influences. While research has looked at the role of PBL activities in strengthening economic and community development in rural areas by raising student test scores, cultivating student civic competencies, creating opportunities for intergenerational learning, and improving quality of life, it has not yet been attributed to directly influencing watershed conservation behavior at the community level.

Gruenewald (2003) has proposed a socio-ecological placed-based education framework, the so-called critical pedagogy of place, to link PBL with the critical pedagogy philosophy, which focuses on helping students to connect knowledge to power and the ability to take constructive action, improving students' sense of agency. The critical pedagogy of place philosophy not only connects students to place, both socially and ecologically through PBL, but also provides students opportunities to take action, as a method to reverse social and environmental degradation through building keen awareness of place. The goals of this pedagogical approach are to promote decolonization and reinhabitation in socioecological landscape. Gruenewald defines decolonization as the ability to understand and resist ideas and forces that allow for disruption and injury to socioecological systems. By decolonizing, there is opportunity for reinhabitation, or "learning to live well socially and ecologically in places that have been disrupted and injured" (Gruenewald. 2003 p9). EE pedagogies that not only promote connection to place and understanding of degradation within that place, also offer the opportunity to reframe and reinhabit that place through pursuing actions that improve that place both socially and ecologically and play a key operative role in the conservation movement. In this study, when we refer to PBL, we are referring to Gruenewald's definition of socio-ecological placed-based education that fits within the critical pedagogy of place framework.

The potential for youth that participate in PBL outreach programs to build social capital to drive collective action towards natural resource management in communities has only recently been documented (Krasny *et al*, 2013). In this work, the role of youth in building community capacity is described as youth capital. The context and role of K-12 EE and youth capital in influencing intergenerational conservation has not yet been extensively recognized as an effective process for mobilizing resources and stakeholders within a community to overcome obstacles towards conservation practice adoption. In this study, we use the Community Capitals Framework (Flora *et al.*, 2004) to assess the role of a PBL program that promotes decolonization and reinhabitation as a collaborative approach to promote intergenerational conservation behavior amongst stakeholders.

THEORETICAL FRAMEWORK

The community capitals framework (CCF) is a systems perspective for community analysis. This asset-based development framework identifies critical capacities, skills, and capitals for community building by looking at the investments and interactions between social, human, financial, cultural, political, built, and natural capitals. CCF is a stock and flow framework, which identifies assets within each capital as stocks and the types of capital invested as flows, as well as interactions between stocks and resulting impacts (Flora *et al.*, 2004). Conventionally, CCF analyzes change in rural areas (Emery and Flora, 2006) and community development programs that focus on vital economies, social inclusion, and healthy ecosystems (Emery *et al.*, 2006). We modify the application of the CCF from economic development, as applied in Emery and Flora (2006), to specify how investments and interactions between the community capitals affect community conservation actions, with specific emphasis on the impacts of youth capital and EE on collaborative approaches to watershed management.

The particular role of and investments in students and youth in building social capital is referred to as youth capital. Youth have been noted as a key source of social capital (Putnam, 2000; Putnam, 2003; Krasny *et al.*, 2013). The energy and ideas of youth can be a key connection between schools and communities, which can build strong associations amongst community members (Bartsch, 2008). In rural communities, schools are community centers that hold central cultural, social, economic, and political roles (Tompkins, 2008) so that the role of youth in building social capital is even greater. For this work, the role of youth capital will be described separately from social capital within CCF.

Emery and Flora (2006) suggested that by successfully investing in and leveraging selected community capitals, a community may experience a “spiraling up” effect. For example, Krasny *et al.* (2013) further explored how social capital in the form of intergenerational and community approaches to EE can foster collective action towards natural resource management within communities. We theorize that investing in EE and youth capital will aid in leveraging social, human, and financial assets within the community and will improve cultural, built and political stocks towards conservation, thereby enhancing social learning, and increasing conservation actions amongst stakeholders.

We focus this study on resource-limited, rural agricultural watersheds. Rural agricultural watersheds are key areas contributing to NPS pollution in the U.S. They also have greater average densities of acquaintanceship (Freudenburg, 1986), thus greater capacity for interactions amongst community members. Therefore, we theorize that the impacts of intergenerational and community-based EE are likely to have a greater impact. While access to financial resources may be limited in small rural communities, the number of social interactions between community members is often greater than in larger communities, allowing greater leveraging of existing community capitals. Schools are also central to rural communities, enhancing their potential for impacting community development and conservation behavior (Bartsch, 2008).

Community capital types are defined below. We recognize that there are many methods to measure and define each of the capitals within CCF (see Fey *et al*., 2006), but we define each capital as it applies to assess the role of EE and youth capital in catalyzing conservation action.

Community Capitals

Social capital is described as the community cohesion of the bonded, bridged, and linked connections between organizations, agencies, and people that promote and/or inhibit the social drive to improve water quality (Pretty, 2003). Bonding social capital occurs between people with similar interests (i.e., church groups, schools, sports teams). Bonded relationships can lead to “bridging” to groups with other views, which can eventually be linked to external agencies (Pretty, 2003), and allows interactions and investments to the other community capitals.

Garnering trust usually proves invaluable in the context of natural resource management and relationship development (Gulati, 1995; Leach and Pelkey, 2001; Davenport *et al.*, 2007), and has been highlighted as essential for community-based water resource protection (Gulati, 1995). Water quality improvements, in particular, require agency and private landowner collaboration and trust because of the need to manage change. Initially, relationship building may seem to increase social lag time, but over time, these relationships can shorten social lags by creating partnerships and enhancing the likelihood of adoption behavior (Pannell *et al.*, 2006). Essentially, interactions between agency representatives and communities improve if there is established trust through bridged and linked connections because they lack regulatory authority for NPS management.

Youth capital, as defined previously, fits within social capital and but will be applied to the CCF as a separate capital for the case study.

Human capital is defined as the skills and abilities of people within a community to develop and enhance their resources, and access outside resources and bodies of knowledge to enhance their understanding, identify effective practices, and access data (Emery and Flora, 2006). This includes investment in technical expertise in both agriculture and hydrology, with specific understanding of watershed conservation. It also reflects leadership ability, engagement in civic responsibilities, the ability to access and disseminate information and resources across a network of actors, and the ability to be work with landowners to effectively implement conservation practices. Lastly, human capital includes the knowledge, skills, and abilities for both conservationists and educators to effectively collaborate to develop meaningful PBL outreach programs that work both within the K-12 classroom as well as in the community.

Financial capital reflects public and private financial resources that are available to invest in conservation projects. Within this work’s context, financial capital includes donated materials, volunteer hours, or public and/or private funding for conservation projects and/or other capitals that impact conservation projects. Availability of financial resources within a watershed greatly influences a community’s ability to engage in NPS reductions (Koehler and Koontz, 2008). Limited resources are particularly common in rural areas (Fey *et al.*, 2006).

Built capital is the infrastructure that supports other community capitals, such as roads, water systems, or schools (Flora *et al.*, 2006). We include hydrologic monitoring infrastructure and BMPs (i.e., fencing, controlled drainage, riparian buffers) within the built capital definition.

Cultural capital refers to people's traditions and language and the way that people see the world and how they act within it (Bourdieu, 1973; Flora *et al*., 2004). We include cultural capital because it provides a reference as to what issues community members and leaders view as important within a community (Emery and Flora, 2006) and could pertain to a conservation ethic. Particularly for water quality, if cultural traditions are interconnected with water resource capital (i.e. fishing, ceremonies, lifestyle, sense of place), cultural capital can play an influential role in conservation action for reducing potential pollution inputs.

Political capital is defined as access to power, organizations, connections to resources and power brokers (Flora *et al*., 2004). We also refer to the ability of community members to find their own voice to contribute to their community (Aigner *et al*., 2001), and more specifically, to contribute to improving water quality.

Natural capital is the environmental assets within a particular location, such as climate, natural resources, wildlife, and scenic value (Emery and Flora, 2006). Natural capital shapes and influences cultural capital in terms of natural or scenic value or traditions centered on natural resources (Costanza *et al*., 1997; Pretty, 1998). We narrow natural capital to the water quality asset of water resources.

Conservation action is measured and indicated by accounts of landowner BMP adoption and implementation, recognizing that it takes investments in a suite of community capitals to overcome landowner BMP adoption barriers.

Previous literature on BMP adoption behavior indicates both trends as well as individualistic indicators of what causes an individual landowner to adopt a BMP (Nowak, 2011). Pannell *et al*. (2006) described in depth the social, cultural, and personal influences in adoption decisions. An individual's personal achievement goals, trialability, and the relative advantage of a particular BMP for that individual, impact landowners' decision-making process toward adopting BMPs. Three common key findings from meta-analyses and reviews on landowner adoption indicate that 1) trusting and respectful relationships between landowners, advocates of innovations such as scientists, extension agents, other landholders and private companies; 2) shorter spatial and temporal distances between a landholding and sources of information regarding the practice (i.e., proximity to university or extension agency, access to internet resources); and 3) the relative physical proximity to other adopters are key to conservation action (Baumgart-Getz *et al*., 2011; Prokopy *et al*., 2008; Pannell *et al*., 2006; Nowak, 1983; 1985).

Without adoption and/or maintenance of a BMP, conservation effectiveness may not be achieved (Stewart *et al*., 1975; Barling and Moore, 1993; Mulla, 2008; Meals *et al*., 2010; Tomer and Locke, 2011). By building social capital through partnerships, conservation action may become more likely (Bodin and Crona, 2009). By investing in human capital through increased access to research, tools, and the best available science, landowners and watershed planners may choose more effective conservation practices. And finally, in rural, resource-limited watersheds, leveraging financial capital through partnership building could improve BMP adoption behavior (Baumgart-Getz *et al*., 2012). In the case study below, we assess how PBL can help to mobilize this chain of community capital investments.

CASE STUDY

In this case study of a small, resource-limited watershed in the inland Pacific Northwest, we explore how a PBL environmental education outreach program influenced community capital investments, intergenerational interactions, and conservation actions. The site name and characteristics are kept generic to protect stakeholder confidentiality. We chose this watershed because it has limited financial capital to carry out research and conservation practices – a factor representative of many rural watersheds. In addition, we have observed innovative collaborative approaches to watershed management via local outreach activities supported by a university science outreach program. Given its rural and somewhat isolated geographic location and small population, this watershed is resource-limited in terms of human and financial capital, but has invested in youth capital and environmental education, which we argue, has increased conservation actions among community members with private landholdings.

The case study basin is listed as impaired due to phosphorus loading to a reservoir, high temperature, low dissolved oxygen, and sedimentation, due to surface runoff and stream bank erosion from compacted soils due to continual cattle grazing, summer flood- irrigation practices and loss of riparian vegetation. The city has a population of 152 people (US Census, 2010), and 41.7% of the 60 households have children under the age of 18.

Through a collaborative partnership with a university science education outreach program, the local elementary school 5th grade class has been involved in PBL watershed restoration efforts since 2008. Working with government agencies, the city council, and local nonprofits, the class has started a citizen science water quality monitoring program, raised trout in the classroom, and planned and implemented streambank restoration projects.

Qualitative Approach

We used an interactive, qualitative approach – approved by the University of Idaho Institutional Review Board (Appendix A) – to investigate a range of perspectives from key stakeholder representatives. Following document review and a snowball sampling method, we conducted data collection via in-depth interviews between 2011-2014 with 14 stakeholders and key informants involved in EE, restoration, conservation, and water quality monitoring practices. Rather than a representative sample of the population within the basin, data collection focused on a purposive strategy to gain an informed understanding of the range of perspectives among those actively engaged in and/or affecting EE, local conservation, and BMP implementation (Davenport and Anderson, 2005).

The purpose of the interviews was to understand how the actors are involved in watershed conservation and monitoring, their perceptions of natural capital, and to see what community capitals they contributed to and relied upon in order to participate. We used a semi-structured interview guide with open-ended questions to direct conversation around four major themes (see Appendix B): 1) participation in and connections to watershed conservation/restoration; 2) relationships and partnerships with other actors; 3) sources of and access to human, financial, and built capital with respect to watershed conservation; and 4) perceptions of water quality response. Broad questions related to each theme were posed to the respondents, with follow-up probing questions to attain more detail. This approach allowed us a broad range of themes as well as options for more specific details about individual respondents' observations, perceptions, and attitudes within the data collected (Charmaz, 2001). It also allowed the connections to youth capital and the PBL outreach program to emerge naturally, without introducing bias as the interviewer.

Interviews began in 2011, and in a follow-up phase, participants were revisited in 2014 to improve trustworthiness and credibility in the study through prolonged engagement, and to learn about development of new projects and partnerships. All participants were interviewed by the primary researcher. Average interview length was 45 minutes. When feasible, interviews were conducted in person; several were conducted over the phone due to logistical constraints. All interviews were recorded with consent, and the primary researcher kept field notes for each interview. Recordings were transcribed verbatim. The case study location and respondents' identities are made generic to de-identify individuals and place. Respondents included representatives from the state Department of Fish and Game (FG), the state Department of Environment Quality (DEQ), Trout Unlimited (TU), the local Soil Water Conservation District (SWCD), the county and city council, the regional United States Forest Service office (USFS), an university science education outreach organization, the local elementary school, and four landowners who have all participated in conservation practices for the project since 2008.

We used the grounded theory process (Strauss and Corbin, 1990) to employ iterative analysis on qualitative data from the interviews. Using this approach, we built a systematic coding structure from interview transcripts and secondary documents with continuous refinement (Betts *et al*., 1996). We read and coded all the interview transcripts, city council meeting notes, and local and organizational publications. Community capital sub-coding headings were generated from the data to create axial coding and overall community capital themes from the data. Two independent researchers verified the accuracy of the coding system, and through discussions, some modifications to the coding scheme were developed. With the data generated from these interviews, we each coded each participant's responses using the coding scheme described in Table 5.1.

Adjacency matrices were created to construct community network analysis maps, based on stated relationships between individual actors and relationships between actors and organizations. The network analyses were used to better understand social capital within the community, through examining the relations among actors and how actors are positioned within a network (Wasserman and Faust, 1994; Scott, 2000, Prell *et al*., 2009). The degree of centrality is a key measure that indicates how many ties an individual has with other actors within a network. Betweenness centrality exposes how easily and independently a participant can access other members of the network, and therefore disseminate and access information and resources throughout the network (Freeman, 1979). We use betweenness centrality to identify key leaders and facilitators within the network. Gephi (version 0.8.02), an open source graph visualization platform, was used to analyze network density and degree of centrality within the networks (Bastion *et al*., 2009).

RESULTS

In the resource-limited watershed in our case study, investments in social and human capital through socioecological PBL outreach efforts have proved crucial for mobilizing human, financial and built capitals for watershed management. Non-traditional watershed conservation actors have developed water quality PBL outreach initiatives that, paired with financial incentives, have played a crucial role in overcoming barriers to BMP adoption and implementation.

Social Capital

Water quality based PBL efforts have provided a critical opportunity to build bonded, bridged, and linked social capital between agency members, watershed actors, and landowners. A partnership between a school teacher, an university outreach organization, FG, SWCD, USFS, TU and the DEQ provided opportunities for the 5th grade students from the local elementary school to raise trout in their classroom and collect water quality measurements.

> We posed the question: [This] creek is listed as impaired. We asked the kids, "Do you want to get involved and help DEQ? The kids were overwhelmingly excited that they could do something, so we began brainstorming. We decided we could start by testing the water quality and study the characteristics of the creek… The students then decided that the city should know about their project and the state of the creek. (teacher)

Driven to do something and with the teacher's support, students presented their results at a city council meeting, and wrote an EPA 319 grant with the USFS and TU to develop and manage a stabilization project to help reduce stream bank erosion from the runoff off the school parking lot, with long-term goals of restoring trout habitat. The intergenerational interactions between students and community members affected conservation action. Student research and conservation efforts encouraged a landowner to donate thirty acres of land to the city for restoration and as an educational park with an interpretative trail for the public. Explaining his motivation for the stream restoration, this landowner said, "Clean water, fish in it, and what is it naturally for. That's all you can hope for. [Something] naturally there for my great grand kids to have something to look at."

The 5th grade EE project began in 2008 (see Bingaman and Eitel, 2010; Schon *et al.*, 2014 for more project information). Since the inception of the project, five additional landowners have engaged in riparian restoration practices, through partnerships between K-12 EE organizations and agency conservation groups. The motivated teacher and her 5th grade students have played a pivotal role of key facilitators in this small, rural watershed, which we theorize increased intergenerational conservation actions.

Results from the network analysis illustrate the connectedness of participating actors through bonded, bridged, and linked relationships (Figure 5.1). Actors and organizations were grouped into interest categories based on what they described as their participation in watershed restoration and conservation, including “conservation”, which comprises BMP implementation, “K-12 education”, which includes EE based efforts within the basin, “political”, which includes decision-making organizations and actors, and lastly, “landowners” who have engaged in BMP adoption. The dense network of resources, information, and labor enabled implementation practices.

This analysis suggests that EE actors and organizations, although not traditional players in watershed planning, were vastly important for bonded linkages to conservation actors, but also as bridged social linkages to the landowners. The relative size of the nodes in the network map indicates which actors have the greatest betweenness centrality, or the greatest access to other actors, and therefore information and resources. The largest conservation-based actor was the former DEQ officer, who linked landowners with EE and conservation actors. The former DEQ employee was mentioned as a key partner by every actor interviewed. In the K-12 education groups, the teacher, had the greatest betweenness centrality, again, providing the key facilitator role between landowners, conservation, and other EE groups to gain access to and provide information and resources. These results indicate that agency investment and connectedness to youth capital can play a pivotal role in building community capitals and mobilizing resources for improved watershed conservation.

The high density of acquaintanceship pertinent to these relationships was reflected in the interview responses. One of the landowners remarked, “There’s about a one degree of separation and obviously water is a really big deal up here so it doesn’t take much for people to understand who’s doing what.” He went on to describe the community as “incestuous” –

referring to the ties of “friends, buddies and acquaintances.” “I’m president of the [local foundation], which was the initial funding for the [elementary school’s creek] study, and through that magnitude and personally though kids’ families, and through the teacher, I got involved [in the restoration project]”.

Questions of trust between agency members and landowners can often be a barrier to conservation action (Pannell *et al*., 2006). Employees at FG and DEQ have overcome these barriers through creative approaches to acquire funding to purchase vegetation and fencing materials by collaboration between K-12 EE actors as well as the time of motivated and skilled adult and student volunteers. A large amount of trust was highlighted by all landowners in reference to working with both FG and DEQ, in order to strengthen social capital. In regard to working with the FG biologist, one landowner stated, “I was really impressed with the way she went about it. She did the willow weavings on the offside bends of the creek, which were very successful…. I had great success with [her] and her volunteer crew, I am very happy and I hope they keep going…. [She] always calls up before she comes on my land. She doesn’t need to. She doesn’t hurt anything”.

Youth Capital

Valuing and investing in K-12 education was a key similarity that drew all of the key actors together. When asked about the 5th graders’ role in the restoration project, the former DEQ officer responded, “Without the students, I think we would see little community participation. Those little kids have a tremendous role. The more I think of it…. that's what did it. That is how we got our foot in.” The SWCD implementation director stated, “In a lot of cases the landowners would not be doing this without the students and the volunteers.” The elementary school teacher mentioned one of the ranchers and said, “He was really inspired by the kids’ presentation. He wanted to get involved.”

Similarly, the USFS biologist noted, “I know one of the ranchers in that area; I think in his mind he might be more amiable to working towards restoration kind of due to the fact that the kids are looking at this and it’s important to them. He now has grandkids in the area. It does have a positive impact in that way.” She also said, “I know that in discussions especially with other people who have been looking into grants, or into working for watershed restoration especially in that area, the fact that the kids have been presenting their findings to city council and the public … is helping to change perceptions" in reference to landowner adoption behavior. When asked if there would be as many conservation efforts without the participation of the K-12 education actors and consequent funding, the USFS restoration specialist responded, "The education component was huge. If it wasn't for that, I don't think so. Unless it came through TU. But who would do it, you know? Who is going to go in there? I think it's unlikely that it would happen without the educational component."

The former DEQ employee stated, "It's amazing how many people talk about [the students' bank stabilization] project just because they can see the project from the road. " In addition, according to the teacher and DEQ, local contractors, parents, and landowners donated time, skills, and resources to the students' projects, again increasing community participation in BMP implementation. Fey *et al.* (2006) found that implementation of projects that have the greatest impact on the greatest number of people were more effective than multiple projects with less community wide impact. Because project development was visible to the community, participation was encouraged and led to external funding opportunities. To target conservation in social "hotspots" with high visibility may also increase intergenerational conservation action.

The FG and former officers both value education because they hope that students will get excited about their projects and persuade other community members to participate. The FG began talking about high school students who have been volunteers on some of their projects. "Some may be rancher kids who will tell their dads to pull back their fences off of the stream banks," said the volunteer coordinator.

One teacher indicated, "Whenever you get kids together, it's a catalyst to want to support them and their project." She gave examples of landowners neighboring the school that have allowed the students to take measurements from their land and even construct the bank stabilization without any liability releases or signatures. "The older couple across the creek allow easy access to area, always granted access, talk to kids, said we can use property anytime." The students' restoration project was implemented on private property. "It is actually owned by a guy in California. I called the guy to work on the land- he said it's fine. I think he thought the kids were doing a cool project and wanted to support it."

A sudden pulse of community engagement and participation was described in the Press Pulse Dynamics framework (Collins *et al.*, 2010). As stated by the former DEQ employee, "I felt like [the student's] projects really came when the timing and the people were right, and really spiked the number of projects". The student-led water quality project in the watershed pressed the community into a restoration and conservation pulse.

Investments in youth capital have also contributed to data resources through a student citizen science water quality monitoring program. At the point of the interviews, the 5th grade students were the only local actors in the community monitoring BMP effectiveness, and since 2008, student-led water quality monitoring is the only monitoring in the basin that has been granted funding. When we asked about current water quality monitoring, four actors from state agencies referred us to the teacher's data from the student water quality monitoring. The USFS biologist described their monitoring. "They are working on surveying and monitoring [the forested baseline] portion and then comparing it to the area outside their school where they had done restoration work."

Through this, we also learn that there may be a need for investment in greater human capital regarding water quality monitoring, if agency members are currently relying on elementary school snapshot water quality monitoring as a potential data source. While the efforts of the school to monitor water quality is noteworthy, the snapshot data have no quality control or assurance protocols, and were collected with very basic monitoring kits. The former DEQ employee did collect "scatter shot" monitoring data, but funding for the monitoring program was eliminated in 2009. The limited dataset is also an issue of financial capital.

Human Capital

Fey *et al*. (2006) found that human capital within community organizations is often a rich resource and replaces the need for financial capitals. Not only is there a tightly knit network of actors and organizations, the actors with the greatest betweenness centrality also contributed essential human capital investments to conservation. One of the USFS described the former DEQ officer, who sought out opportunities for collaboration between EE groups, conservationists, and landowners as "top notch when it comes to grant writing. She is good at what she does." When addressing restoration funding through 319 grants, one landowner stated that the FG biologist "usually always gets quite a bit because she has such a good success record. She gets much work done for the money because of those volunteers. That's why she is so successful."

In addition to these two major actors possessing strong grant writing and leadership skills, the volunteers that FG used as labor for BMP implementation also had the effect of contributing to the human capital. A landowner described why the restoration project on his property was successful.

> It was definitely predominantly, because [FG] have kind of a knack for it because they do a good job getting volunteers. Its hard work, it was tough, they want these [plants] planted correctly and those holes are pretty damn deep. They don't let [the volunteers] mess around and drop them on the ground and throw a little dirt on them. They were well planted so I think we have a decent chance of having a good success rate on them. (landowner)

Other landowners and SWCD employees echoed this notion that the FG adult and student volunteers bring a level of skill and hard work to the projects, which improves the likelihood of BMP effectiveness.

The adult and student volunteers are examples of bridged social capital, or external resources mobilized into the community due to the bonded capital of the local SWCD, DEQ and the regional FG. The volunteers travel up to two hours to work in the watershed. Since 2008, FG works with a new local master naturalist group, initiated by the State Park and the EE organization, which are also mobilizing local volunteers and working with additional partners to engage in restoration efforts. According to Emery and Flora (2006), this mobilization of external and internal resources maybe the vital first step of creating a community "spiral up" effect, and thus increase conservation behavior.

Another unique aspect of the partnerships is the mobilization of hydrologic expertise. Through the student's projects, the USFS fishery biology and restoration specialists have partnered with the DEQ officer to offer recommendations for restoration designs and student water quality monitoring. USFS typically does not work on private lands, but through their outreach mission, they got involved. The USFS fisheries biologist described her role as, "helping [the teacher] administer [the grant], studying up on guidelines on what she could do with the grant, and then working with other US Forest Service employees to help her with the actual field [work]."

In addition, the teacher solicited the USFS restoration specialist. “She came to me, because she knew that I did restoration work in the forest, and she asked me about this erosion that they had on the slope in the [school] back yard, and was trying to do some kind of environmental science behind it.” He then “examined the bank, developed plans for treatment, and talked to the class about different restoration ideas.” He later offered oversight to ensure that the restoration project was implemented correctly. With support from the USFS leadership, graduate students working with the university outreach organization, and DEQ, the teacher also began a water quality monitoring program. These actions also reflect the teacher’s role as a key facilitator in building working partnerships between agency members and local organizations, creating investments in social and youth community capitals.

Financial and Built Capital

Collaboration between actors allowed for the mobilization of internal and external resources (e.g., funding, volunteers). Using K-12 education as a key focus in many of the grants helped mobilize financial and built capital, and opened up nontraditional opportunities for funding. The teacher has brought in over $30,000 for the restoration and monitoring projects since she began the project in 2008. The only EPA 319 grants awarded to this watershed since 2008 have had an educational focus. SWCD granted over $7,000 in water quality-based K-12 education funding in 2013. Local, regional, and state foundations have also granted funding to these educational efforts that have led to creek restoration.

All costs of supplies and labor for BMPs were provided to all landowners at no expense, overcoming the key financial barrier to conservation (Baumgart-Getz *et al.*, 2012). An agricultural landowner stated, “I’m not going to make a nickel enhancing the creek but I want to help as long as it doesn’t cost me anything.” The residential landowner said, “[The DEQ] said that [the FG] would just come out, with volunteers, and it wouldn’t cost me anything.” The other actors understand the financial barriers for landowners, and accommodate it in order to persuade landowners to participate in projects. The FG targets that economical value when working with landowners. “Farmers and ranchers don’t have money. They have land. We try to make the restoration projects as easy as possible by providing resources and volunteers.”

Similarly, the DEQ also caters towards the economical and utilitarian values that may prevent landowners from restoring banks. “If I know that [the landowners] are losing ground-if they are losing pasture ground, I'll use that [when approaching about restoration project]. [There is] no cost, farmers don't pay a cent for the restoration." Even the students expressed economical values when managing personnel for their bank stabilization project. "The students thought it was important to pay people what they were worth, and not ask for discounts because of the economy," said their 5th grade teacher. The USFS restoration specialist echoed this, indicating "one of the concepts too [for the student's bank stabilization project] was that the grant money would help the local contractors." As a result, local resources were purchased, and a local hydro seeder, contractor, and an otherwise unemployed USFS watershed technician was hired to oversee the project. Stabilization logs were donated by USFS.

Political Capital

City council has played a role in the dissemination of information and the social linkages between partners. Since 2008, every year, students have presented their water quality monitoring data at a city council meeting, promoting intergenerational learning. On average 40-50 people from the community, agencies, landowners, and organizations have attended. By 2013, the city council awarded the elementary school students with stewardship awards for the preservation of the local creek. On another occasion in 2013, when a grant writer for a regional organization approached City Council "looking for ways to collaborate with the city on projects and perhaps form a partnership for grant writing proposals", "the clerk reiterated that the [elementary school] was looking for a small grant to monitor water quality … year round and the price of equipment needed was $2700". Promoting EE and conservation provides evidence that the political leaders of the town valued the student work as a result of the intergenerational learning that took place during the students' city council presentations, and helped mobilize human and financial resources to support the projects.

Community Capitals Impacts on Conservation Action

Since the student-led water quality projects began in 2008, a vast network of social, human, political, built, and financial assets were initiated to enact restoration projects on private land through the community and family ties. Because of the limited financial capital, affordability of the mentioned conservation efforts proved vital for participation. Using the indicator of landowner BMP implementation for conservation action our qualitative evidence indicates that through investments in environmental education efforts and youth capital, more social, human, political, and financial capitals were mobilized to enhance conservation action.

Natural Capital and Water Quality Response

Landowners' perceive the restorations as successful, as described by one landowner, "Absolutely the fish habitat is 100 times better. You can see the riparian area coming back, the FG [restoration] area was particularly effective…it's like an adrenaline boost for growing. I mean hopefully, rather than waiting for mother nature to recover which is going to take a long time, this is a big jump start by putting in the native species that we want to see and we think have a good chance of surviving of course."

Despite community efforts, there is still significant streambank instability on private properties with landowners who are disinterested or disengaged in the project. Thirty-eight percent of the areas within the riparian zone have been treated. Engaging all landowners along the creek has also not yet been optimized. How can the pulse of collaborative energy be harnessed to motivate more to take conservation actions? The student bank stabilization project was placed in a prime "visual" location to evoke community engagement and thus may be an effective method to improve intergenerational communication when financial capital is limited. Agency groups donated the materials and volunteers for the BMPs, established trust, and addressed the economic values of the landowners, therefore initiating successful adoption of the BMPs without asking the landowners to significantly change farming practices.

Case Study Discussion

The case study demonstrates the potential of applied and intergenerational PBL education as a powerful catalyst to create a community movement towards conservation practices (5.2). The relationship between place-based EE, social capital, and natural capital reflects two pathways for community capital interactions, also described by Krasny *et al.* (2013). The K-12 EE programs used an intergenerational, place- and community- based approach that developed bonds and links in social capital, leading to youth development, and created a feedback into improving human capital and natural capital. Since the students began working on this project, standardized test scores have improved, improving youth capital. School communities often bring people together, particularly in rural environments, enhancing opportunities for bridged connections, building partnerships and mobilizing internal and external human and financial capitals (Flora *et al*., 2007; Tompkins, 2008). The social capital developed has facilitated collective action in BMP implementation, potentially enhancing ecosystem services and natural capital.

Through the development of partnerships, the watershed has made itself more attractive for future funding. From the community-based educational initiatives in the watershed, intellectual capital may also increase, leading to more informed citizens in the future (Lieberman and Hoody, 1998; Smith, 2007). Particularly in rural communities, when students can see themselves as vital contributors in a community and develop a sense of pride in living and supporting their community, they are more likely to become community leaders, adding capacity to community problem solving (Tompkins, 2008). The social landscape has become more amenable to BMP adoption through the social partnerships and youth capital. An increase in intellectual capital may create a future social landscape with fewer barriers for conservation action.

Further research could investigate the impacts that the PBL outreach program has on the students' attitudes towards engaging in conversation behavior. This analysis could also be scaled up to larger outreach efforts in both urban and rural communities to assess if the pattern of relationship building, mobilizing resources, and overcoming individual's barriers to conservation through PBL efforts is unique to rural communities, or if it applied at all scales when youth are involved in collaborative approaches to watershed management.

CONCLUSIONS

Using the community capitals framework, we identified that investments in human and social capital through environmental education efforts can enable external and internal resources to be mobilized to overcome financial and cultural barriers for conservation action. Youth can play the role as key facilitators and drivers behind enhancing social capital (Roth and Lee, 2004; Thorton and Leahy, 2012). Investments in youth capital and social partnerships because of socioecological place-based education initiatives have the potential to open up innovative and collaborative approaches and funding towards watershed restoration by building linked and bridged bonds between conservationists and landowners. Within six years of the start of the student-led water quality monitoring and restoration projects, five new landowners have adopted BMPs with materials and labor provided. Community-based education offers unique opportunities for intergenerational interactions and learning between adults and students.

For educators, this only strengthens the evidence that socioecological place-based pedagogies and effective service-learning projects give students the opportunities to be conservation leaders in their communities, overcoming that sense of powerlessness that environmental education initiatives can sometimes cause (Schon *et al.*, 2014). For conservationists, this demonstrates the power of investing in youth capital and using environmental education as a key component to developing collaborative approaches to conservation.

Implementing socioecological place-based approaches to watershed management is limited by a lack of experience and training by both the conservationists and educators. Educators may not have the confidence, time, or skills to pull off a place-based learning initiative and conservationists may see schools as too bureaucratic to be feasible as potential partners (Bartsch, 2008). Developing training programs with teachers to create meaningful community-based environmental education opportunities can tap open a new network of informed and active citizenry and resources (Bingaman and Eitel, 2010; Schon *et al.,* 2014; Rittenburg *et al*., 2015). Student participation through relevant, socioecological place-based science education may shorten the social lag to promote conservation action down the road and create a cultural shift towards a stronger conservation ethic within community.

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TABLES

TABLE 5.1 Community capitals axial codes and coding definitions.

Axial Codes	**Code definitions**
Social	Partnerships, descriptions of professional, friend, and family relationships (Flora *et al*. 1996; Larsen *et al*., 2004), trust, cooperation, collaboration
Human	Skills, knowledge, grant writing experience, monitoring experience, expertise, leadership skills, education, youth (Emery and Flora, 2006)
Financial	Donations, resources, grants, funding, tax revenue, volunteers, leveraged resources
Built	Conservation practices, fencings, bank stabilization, restoration materials
Natural	Ecological benefits, improvements to water quality (Costanza *et al*., 1997; Pretty, 1998)
Cultural	Aesthetics, historic and family history, connections to sense of place (Klamer, 2002)
Political	Agency members, city council, county commissioner, mayor, connections to community leaders within and outside community, key community members who have capacity to create shifts in community actions (Vidich and Bensman, 1968; Turner, 1999)
Youth	Connections to children or grandchildren, students, role of K-12 education in community, role of students as actors in watershed conservation (Emery and Flora, 2006; Krasney *et al*., 2013)

FIGURES

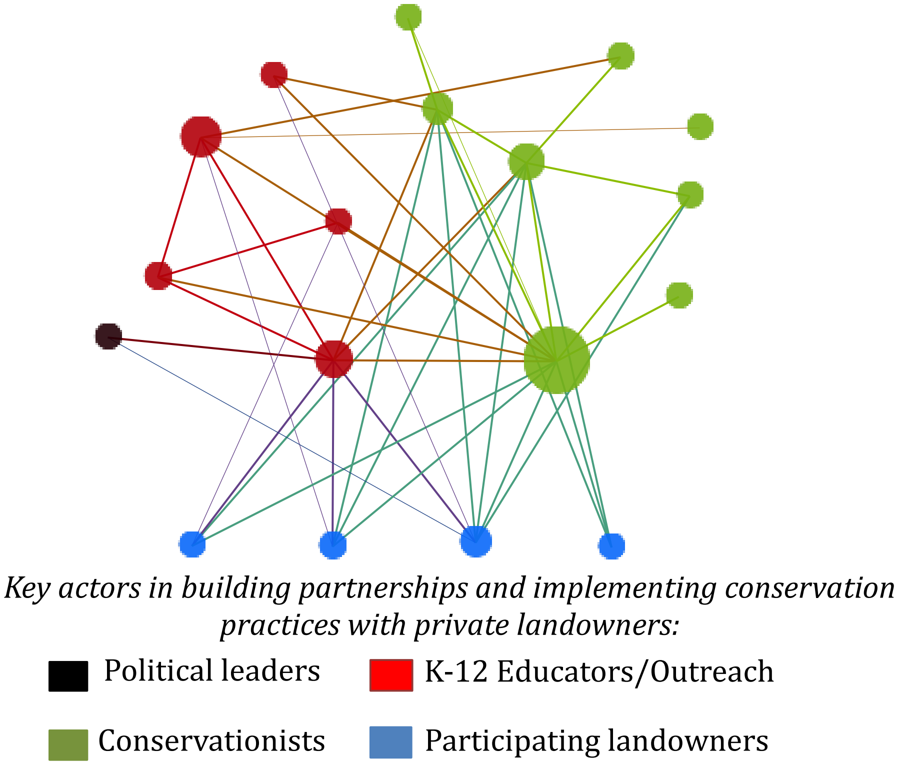

FIGURE 5.1 Network map of key actors active in building partnerships to implement conservation practices

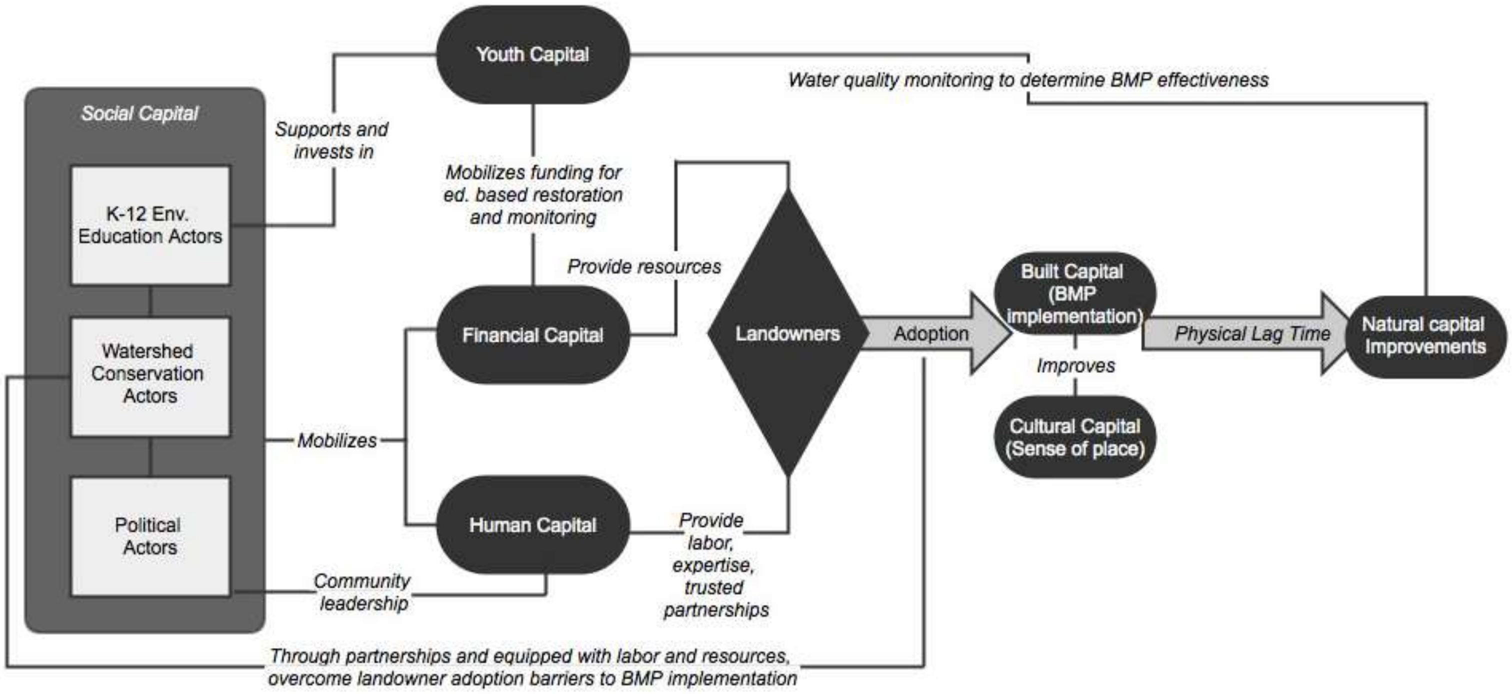

FIGURE 5.2 Community capitals interactions impact on conservation action and water quality improvements in context of case study.

CHAPTER 6: THE COMMUNITY CONNECTION: ENGAGING STUDENTS AND PARTNERS IN COMMUNITY-BASED SCIENCE

Rittenburg, R.A., B.G. Miller, C. Rust, J. Esler, R. Kreider, R.Boylan, and A. Squires, 2015. The Community Connection: Engaging students and partners in community-based science. National Science Teacher Association The Science Teacher. 82(1): 47-52.

ABSTRACT

This article explores how a yearlong place and project-based science pedagogical approach can immerse high school students in the process of designing solutions to personally relevant local issues, and align well with the Next Generation Science Standards. We present two project-based science approaches that engaged students in science and engineering practices by getting them outside and bringing community partners into the classroom. Students explored local environments, collected and analyzed relevant water resource data, identified personally relevant water resource issues, and used evidence to design and propose solutions at a regional student summit. We include examples of our project framework, assessment tools, and student samples to provide a blueprint for practitioners to incorporate an innovative and effective project-based science practice into their curriculum to bring science and engineering practices to life.

INTRODUCTION

Bring education back into the neighborhood. Connect students with adult mentors, conservation commissions, and local businesses. Get teachers and students into the community, into the woods and on the streets—closer to beauty and true grit. Get the town engineer, the mayor, and the environmental educators onto the schoolyard and inside the four walls of the school.

—Sobel 2004, p.7

In a regional gathering called the *Youth Water Summit,* students present scientific posters, interactive presentations, films, art projects, and game simulations in response to the driving question: How can you address a significant water resource challenge in your community's watershed? The Youth Water Summit is the culminating event for The Confluence Project (TCP), a year-long, project-based science (PBS) model implemented in five schools, including three biology classes (grade 10), one International Baccalaureate Environmental Systems and Societies class (grades 11 and 12), and one elective environmental science club (grades 9–12). Community representatives from government agencies, businesses, nonprofits, and academic research groups judge student projects.

In this article, we demonstrate two PBS approaches that bring science and engineering to life. First, we immerse students in science and engineering to identify local challenges and design solutions. Then, we showcase examples of student-produced solutions and rubrics aligned with the *Next Generation Science Standards (NGSS)* (NGSS Lead States 2013) and *Common Core State Standards (CCSS)* (NGAC and CCSSO 2010) to assess the projects. Throughout the article, we discuss how to adapt and scale this framework based on resources and how it can apply to various disciplinary core ideas.

PROJECT-BASED SCIENCE

TCP engages students in a science and engineering PBS curriculum and develops disciplinary core ideas (DCIs) around the hydrologic cycle, ecosystems, and Earth and human activity. The TCP model has deep PBS (Marx *et al*. 1997) and place-based learning (PlBL) roots (Sobel 2004).

The goal of PBS is for students to answer a driving question by exploring scientific concepts related to a real-world issue, developing deeper understanding, and creating more relevant, accessible, and applicable knowledge (Hmelo-Silver, Duncan, and Chinn 2007). Integrating PlBL and PBS within a local environment aligns well with the *NGSS* framework in that:

> [the] actual doing of science or engineering [can] pique students' curiosity, capture their interest, and motivate their continued study; the insights thus gained help them recognize that the work of scientists and engineers is a creative endeavor—one that has deeply affected the world they live in (NRC 2012, p. 42).

In TCP's PBS approaches, students collect and analyze local water resource data, identify personally relevant water resource issues, and use evidence to design and propose solutions to answer the driving question. Students then share their watershed solutions with community experts and peers at the culminating Youth Water Summit.

"DOING SCIENCE" and "DOING ENGINEERING"

The field-based approach

Because we were working with five different classes with varied resources, time, and curricular constraints, we tested two different PBS approaches. One approach involved field trips and the other was based in the classroom. All students attended the same year-end Youth Water Summit.

In the field-based approach, students engaged in three fieldwork experiences that teachers wove into their curricular objectives. We took one field trip per academic quarter, sandwiched between prelessons of independent student research and post–field trip data analysis and reflection (Table 6.1). After the three field experiences, students defined the challenge and possible solutions they wanted to explore in their respective watersheds for their final projects.

The first two field trips focused on the *NGSS* science practices—"doing science"—as students answered questions through data collection and constructed explanations through data analysis. These scientific inquiry trips included citizen-science water quality monitoring and snowpack analysis. Students analyzed data and used videoconferences to discuss their conclusions with classes from other schools. They used a free content management system, WordPress, to document and share experiences (wowconfluenceproject.wordpress.com).

One field experience included collecting baseline water quality data at a stream restoration site for a local lake homeowner's association (Figure 6.1). Students measured instream water temperature, dissolved oxygen, pH, turbidity, nitrates and conductivity and also identified macroinvertebrates by species. Basic water quality monitoring kits were assembled and provided by the University of Idaho Extension's Master Water Stewards Program (http://www.uidaho.edu/cda/idah2o). In following the Department of Environmental Quality citizen-science protocols, students uploaded their data to a statewide hydrological database. Students worked with a local engineering firm to improve future water quality by stabilizing the eroding banks of a stretch of the stream.

In the second field experience, students went fishing with Idaho Fish and Game biologists. This field trip helped students experience the true biological benefits of clean water and tied back into the 10th-grade biology curriculum by prompting discussion about the effect of photosynthesis and respiration on dissolved oxygen levels (a result of excess nutrients) during eutrophication.

Collecting data through field-based science positively affected many student attitudes toward scientific inquiry. As one student reflected on the project's website:

> The process to gain the information was much more hands on and more active for me to participate in. The data itself was also not something based off of past events, like a lab about Mount Saint Helen's, or made-up, like some school labs. It is information that can and will be used for our area and to help with real life issues. Knowing that made the whole experience quite different.

The third field experience engaged students in the *NGSS* engineering practices—"doing engineering"— by defining and solving a problem. Students worked with local organizations to implement an engineered solution to a community water resource issue. These projects included reducing bank erosion by restoring a stream and improving storm water infiltration at a community garden. Students designed and tested different combinations of natural materials (e.g., clay, gravel, sand, vegetation) as biofilters for storm water.

During the field experiences, we provided snacks, water, life jackets, and extra layers during unpredictable weather. By developing strong partnerships, we implemented the field-based component with minimal funding; the only trip costs were bus transportation and substitute teachers for our remaining classes.

The classroom-based approach

The classroom-based approach works for classes that do not have the flexibility, funding, or time for field trips and provides the appropriate scaffolding for students to respond to the same driving question and produce a final project. Community partners visit the classroom to share scientific research and act as mentors as students develop solutions.

For example, a partnership with a local aquifer committee focused on research and solutions for the community's declining aquifer challenge. A hydrologist, staff from the wastewater treatment plant, the public works director, and representatives from a local nonprofit met with students and described current scientific research and potential community-driven solutions. Using recent research articles, interviews, system models, and existing datasets, students identified the greatest challenges for the aquifer and posed a number of improved solutions. The committee prioritized student solutions based on what was realistic, using student-identified criteria. Students then used this feedback to develop their final projects.

Both PBS approaches successfully mobilized students to "design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, [and] prioritized criteria" (NRC 2013, p.12). Both approaches succeeded because of diverse partnerships among high school students, nonprofit organization, a university graduate program, government agencies, and local businesses to provide expertise, resources, and exposure to careers. Though developing these community partnerships may seem daunting, we initiated many of these relationships during the pilot program and found many community partners who were willing and excited to get involved in PBS. Some agencies are even looking for opportunities such as this one because they have youth outreach requirements.

CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Both PBS approaches concluded with all five schools participating in the Youth Water Summit. We hosted this summit at a local university, but a classroom, city council meeting, or community science open house night at school would work, as well. Students presented their individual or group projects using a medium of their choosing (e.g., poster, presentation, video, art project, video game), allowing them to connect their hobbies and talents (e.g. art, engineering, journalism, computer programming) to their science class (Figure 6.2).

To prepare for the Youth Water Summit, each participating class brainstormed topics of local importance and divided into groups of one to four based on interest. Students chose the size of their groups. The final project rubric accounts for each group member's effort and gives credit to students who took on individual projects (see standards-aligned final project rubric, Table 6.2).

Student groups researched their topics and, three weeks before the event, submitted abstracts (Figure 6.3) that defined their topics and its importance, proposed solutions, and communication plan. The Youth Water Summit abstract writing and submission process engaged students in an authentic experience of registering for a professional conference and aligned well with the *NGSS* practices of constructing explanations and designing solutions.

We developed an *NGSS*-aligned proposal rubric (Table 6.3) and provided feedback to address any scientific misconceptions in students' abstracts, probing them to think critically about their proposed solutions and connecting them with community experts to improve their projects. This exercise aligned with the Common Core writing, reading informational texts, and scientific and technical standards and could be used in many PBS curricula (see Appendix C). After receiving feedback on their abstracts, students developed their projects. Some of the teachers gave students class time to complete the projects, and others assigned the projects as homework.

YOUTH WATER SUMMIT AND PROJECT ASSESSMENT

At the Youth Water Summit, student groups presented their projects, which included a prototype rain catchment system, a model of a system for reducing farm runoff, a Prezi presentation about the polluting effects of roadway de-icing chemicals, a slope protection system to preserve water quality in a pristine local lake, and many more (Figure 6.2). Each group gave a 5-minute project presentation to a set of two judges, followed by 5–10 minutes of discussion—exercising students' abilities to orally communicate scientific concepts and engage in scientific argumentation. Students exhibited true professionalism as they presented solutions to local water resource issues. One student commented that she had never worked on a presentation where everyone in the group cared so much about the content and appearance. The judges displayed equal levels of enthusiasm as they fostered connections with students and brainstormed future ways in which students could implement their solutions.

To assess the final projects, we developed a *NGSS*- and *CCSS*-aligned performance assessment rubric (Table 6.3), The creation of this assessment was the greatest challenge of this project because we wanted to assess all projects using the same criteria—regardless of curriculum, PBS approach, or each group's media—and create a rubric that could be easily modified to PBS curriculum for other DCIs. Our judges, who represented multiple fields of expertise, vetted the rubric.

CONCLUSIONS

Although this particular curriculum embraced a water theme, teachers can apply the same field- or classroom-based model at a smaller scale and around many DCIs (Table 6.4). Incorporating community partners strengthened the project's impact, students' level of work, and their accountability. Expanding the traditional classroom provided students with a valuable context to develop meaningful explanations from evidence and produce feasible solutions for community issues.

Results from a pre- and post- program student survey suggest that after participating in TCP, more students believe that community problems can be solved with scientific and engineering solutions (Appendix D). Similar PBS approaches to watershed education can catalyze intergenerational environmental action within a watershed (Schon *et al*. 2014).

The unexpected outcomes of this project will likely affect students as well as communities in ways that traditional science labs may not. By moving beyond the typical classroom approach to science education and embracing real-world issues with this project, students saw the importance of contributing to science as citizen scientists, the applicability of engineering, and the potential of science as a career. Two students summed up this growth when asked about their favorite aspect of science in the post program evaluation, "everything you do in daily life has a scientific explanation" and "my favorite aspect is learning how to apply science in real-life situations."

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TABLES

TABLE 6.1 Learning objectives and curriculum timeline.

Driving question	**How can you address a significant water resource challenge in your community's watershed?**
Student learning objectives	Students will explore water resources through scientific inquiry and community partnerships to develop understanding of local issue(s) Students will research, synthesize, and prioritize applicable solution(s) Students will communicate the science of watershed issues and solutions
1.Classroom: Explore watershed ***September-October***	*Connect students to local watershed.* Activities included: delineating watershed; mapping land uses; exploring importance of water quality parameters; researching current challenges in local water resource management; asking scientific questions; developing hypotheses; reaching out to experts
2.Doing science: Water quality and snow science ***November-December***	*Field investigations themed around exploring impacts of abiotic factors on biota.* Activities included: working with local community experts; citizen science data collection; engaging in scientific inquiry; analyzing data; disseminating results to other schools through website and video conferences
3.Doing engineering: Implement solution in community ***January-February***	*Partner with local organizations and agencies to participate in service learning activity to address water resource issue*. Activities included: solution implementation; discussion and reflection to promote critical thinking about how designed solution addresses water resource issue
4. Research and develop solution ***All year, but finalize in March-April***	*Final project development.* Activities included: researching local water issues of personal interest; supporting ideas using data; exploring and designing solutions to address issue; including limitations and opportunities for improvements; developing a project that effectively communicates the science behind their chosen water resource issue and proposes and evaluates solution.

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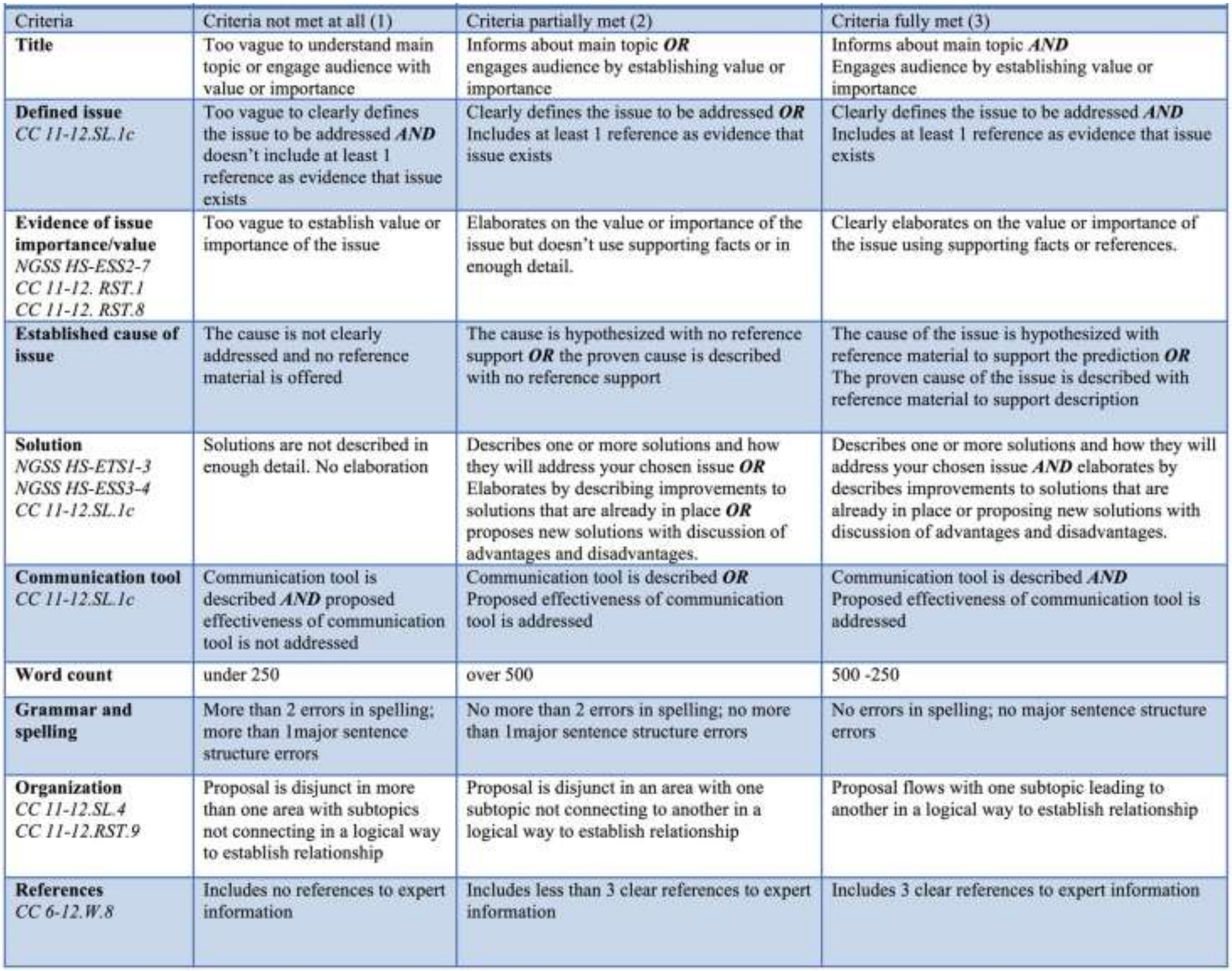
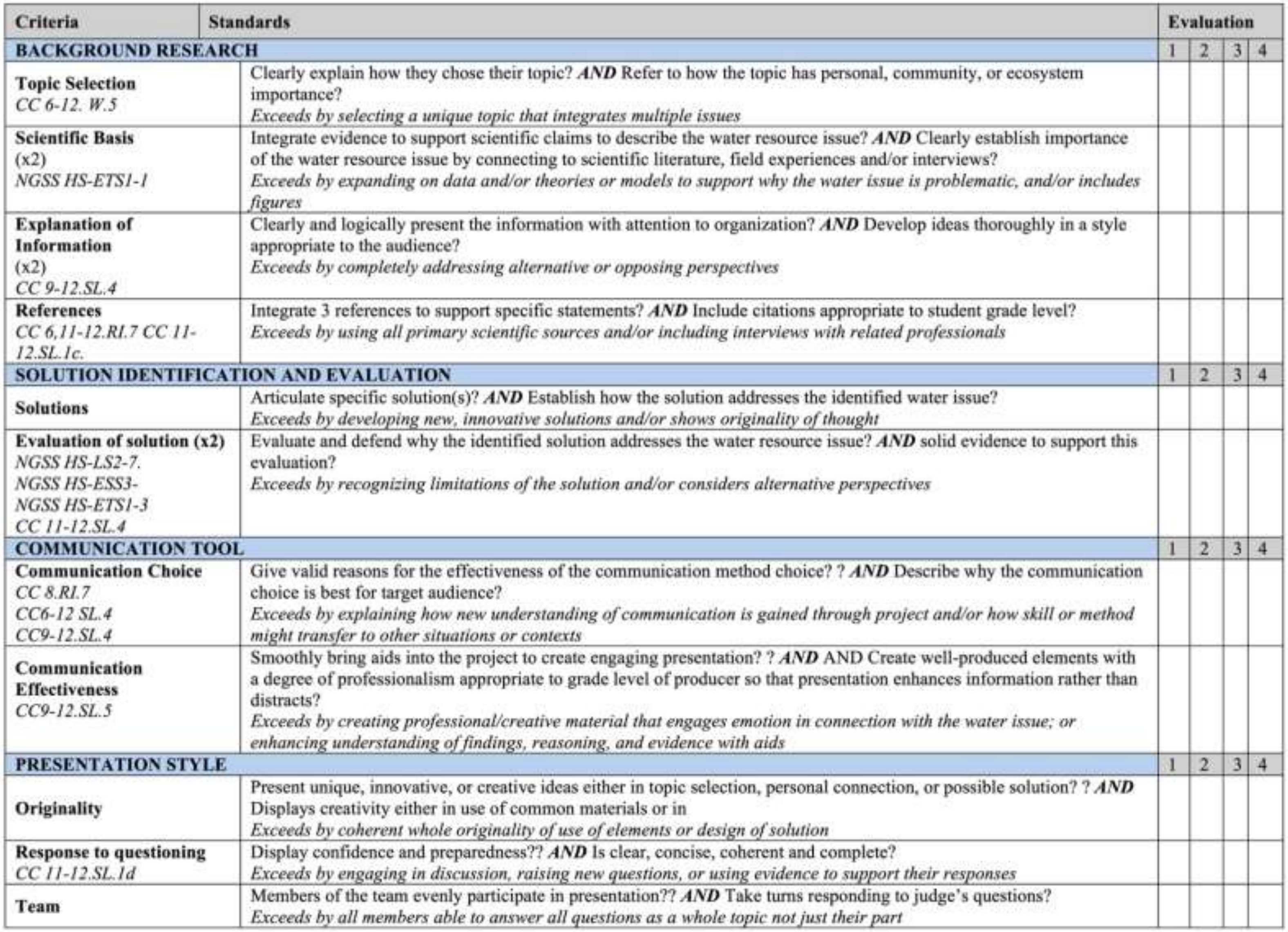
TABLE 6.2 Conference proposal rubric. See Appendix C for description and application of education standards



Criteria	Criteria not met at all (1)	Criteria partially met (2)	Criteria fully met (3)
Title	Too vague to understand main topic or engage audience with value or importance	Informs about main topic ***OR*** engages audience by establishing value or importance	Informs about main topic ***AND*** Engages audience by establishing value or importance
Defined issue *CC 11-12.SL.1c*	Too vague to clearly defines the issue to be addressed ***AND*** doesn't include at least 1 reference as evidence that issue exists	Clearly defines the issue to be addressed ***OR*** Includes at least 1 reference as evidence that issue exists	Clearly defines the issue to be addressed ***AND*** Includes at least 1 reference as evidence that issue exists
Evidence of issue importance/value *NGSS HS-ESS2-7* *CC 11-12. RST.1* *CC 11-12. RST.8*	Too vague to establish value or importance of the issue	Elaborates on the value or importance of the issue but doesn't use supporting facts or in enough detail.	Clearly elaborates on the value or importance of the issue using supporting facts or references.
Established cause of issue	The cause is not clearly addressed and no reference material is offered	The cause is hypothesized with no reference support ***OR*** the proven cause is described with no reference support	The cause of the issue is hypothesized with reference material to support the prediction ***OR*** The proven cause of the issue is described with reference material to support description
Solution *NGSS HS-ETS1-3* *NGSS HS-ESS3-4* *CC 11-12.SL.1c*	Solutions are not described in enough detail. No elaboration	Describes one or more solutions and how they will address your chosen issue ***OR*** Elaborates by describing improvements to solutions that are already in place ***OR*** proposes new solutions with discussion of advantages and disadvantages.	Describes one or more solutions and how they will address your chosen issue ***AND*** elaborates by describes improvements to solutions that are already in place or proposing new solutions with discussion of advantages and disadvantages.
Communication tool *CC 11-12.SL.1c*	Communication tool is described ***AND*** proposed effectiveness of communication tool is not addressed	Communication tool is described ***OR*** Proposed effectiveness of communication tool is addressed	Communication tool is described ***AND*** Proposed effectiveness of communication tool is addressed
Word count	under 250	over 500	500 -250
Grammar and spelling	More than 2 errors in spelling; more than 1major sentence structure errors	No more than 2 errors in spelling; no more than 1major sentence structure errors	No errors in spelling; no major sentence structure errors
Organization *CC 11-12.SL.4* *CC 11-12.RST.9*	Proposal is disjunct in more than one area with subtopics not connecting in a logical way to establish relationship	Proposal is disjunct in an area with one subtopic not connecting to another in a logical way to establish relationship	Proposal flows with one subtopic leading to another in a logical way to establish relationship
References *CC 6-12.W.8*	Includes no references to expert information	Includes less than 3 clear references to expert information	Includes 3 clear references to expert information

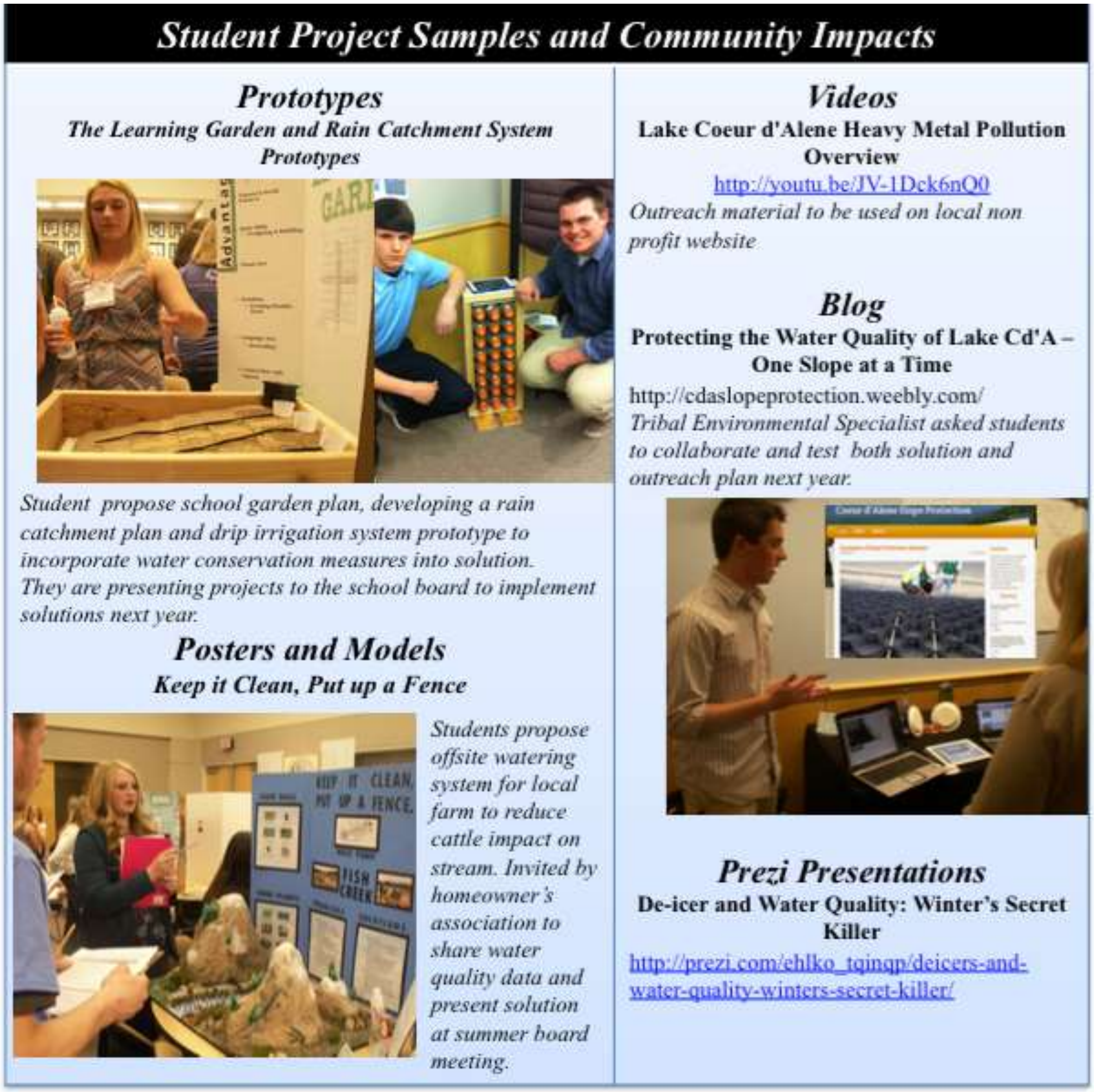
TABLE 6.3 Final project rubric. See Appendix C for description and application of education standards



Criteria	Standards	Evaluation			
BACKGROUND RESEARCH		1	2	3	4
Topic Selection *CC 6-12. W.5*	Clearly explain how they chose their topic? ***AND*** Refer to how the topic has personal, community, or ecosystem importance? *Exceeds by selecting a unique topic that integrates multiple issues*				
Scientific Basis (x2) *NGSS HS-ETS1-1*	Integrate evidence to support scientific claims to describe the water resource issue? ***AND*** Clearly establish importance of the water resource issue by connecting to scientific literature, field experiences and/or interviews? *Exceeds by expanding on data and/or theories or models to support why the water issue is problematic, and/or includes figures*				
Explanation of Information (x2) *CC 9-12.SL.4*	Clearly and logically present the information with attention to organization? ***AND*** Develop ideas thoroughly in a style appropriate to the audience? *Exceeds by completely addressing alternative or opposing perspectives*				
References *CC 6,11-12.RI.7 CC 11-12.SL.1c.*	Integrate 3 references to support specific statements? ***AND*** Include citations appropriate to student grade level? *Exceeds by using all primary scientific sources and/or including interviews with related professionals*				
SOLUTION IDENTIFICATION AND EVALUATION		1	2	3	4
Solutions	Articulate specific solution(s)? ***AND*** Establish how the solution addresses the identified water issue? *Exceeds by developing new, innovative solutions and/or shows originality of thought*				
Evaluation of solution (x2) *NGSS HS-LS2-7.* *NGSS HS-ESS3-* *NGSS HS-ETS1-3* *CC 11-12.SL.4*	Evaluate and defend why the identified solution addresses the water resource issue? ***AND*** solid evidence to support this evaluation? *Exceeds by recognizing limitations of the solution and/or considers alternative perspectives*				
COMMUNICATION TOOL		1	2	3	4
Communication Choice *CC 8.RI.7* *CC6-12 SL.4* *CC9-12.SL.4*	Give valid reasons for the effectiveness of the communication method choice? ? ***AND*** Describe why the communication choice is best for target audience? *Exceeds by explaining how new understanding of communication is gained through project and/or how skill or method might transfer to other situations or contexts*				
Communication Effectiveness *CC9-12.SL.5*	Smoothly bring aids into the project to create engaging presentation? ? ***AND*** AND Create well-produced elements with a degree of professionalism appropriate to grade level of producer so that presentation enhances information rather than distracts? *Exceeds by creating professional/creative material that engages emotion in connection with the water issue; or enhancing understanding of findings, reasoning, and evidence with aids*				
PRESENTATION STYLE		1	2	3	4
Originality	Present unique, innovative, or creative ideas either in topic selection, personal connection, or possible solution? ? ***AND*** Displays creativity either in use of common materials or in *Exceeds by coherent whole originality of use of elements or design of solution*				
Response to questioning *CC 11-12.SL.1d*	Display confidence and preparedness?? ***AND*** Is clear, concise, coherent and complete? *Exceeds by engaging in discussion, raising new questions, or using evidence to support their responses*				
Team	Members of the team evenly participate in presentation?? ***AND*** Take turns responding to judge's questions? *Exceeds by all members able to answer all questions as a whole topic not just their part*				

FIGURES

FIGURE 6.1. Environmental scientists and engineers at work.



Student Project Samples and Community Impacts

Prototypes

The Learning Garden and Rain Catchment System Prototypes

Student propose school garden plan, developing a rain catchment plan and drip irrigation system prototype to incorporate water conservation measures into solution. They are presenting projects to the school board to implement solutions next year.

Posters and Models

Keep it Clean, Put up a Fence

Students propose offsite watering system for local farm to reduce cattle impact on stream. Invited by homeowner's association to share water quality data and present solution at summer board meeting.

Videos

Lake Coeur d'Alene Heavy Metal Pollution Overview

http://youtu.be/JV-1Dck6nQ0

Outreach material to be used on local non profit website

Blog

Protecting the Water Quality of Lake Cd'A – One Slope at a Time

http://cdaslopeprotection.weebly.com/

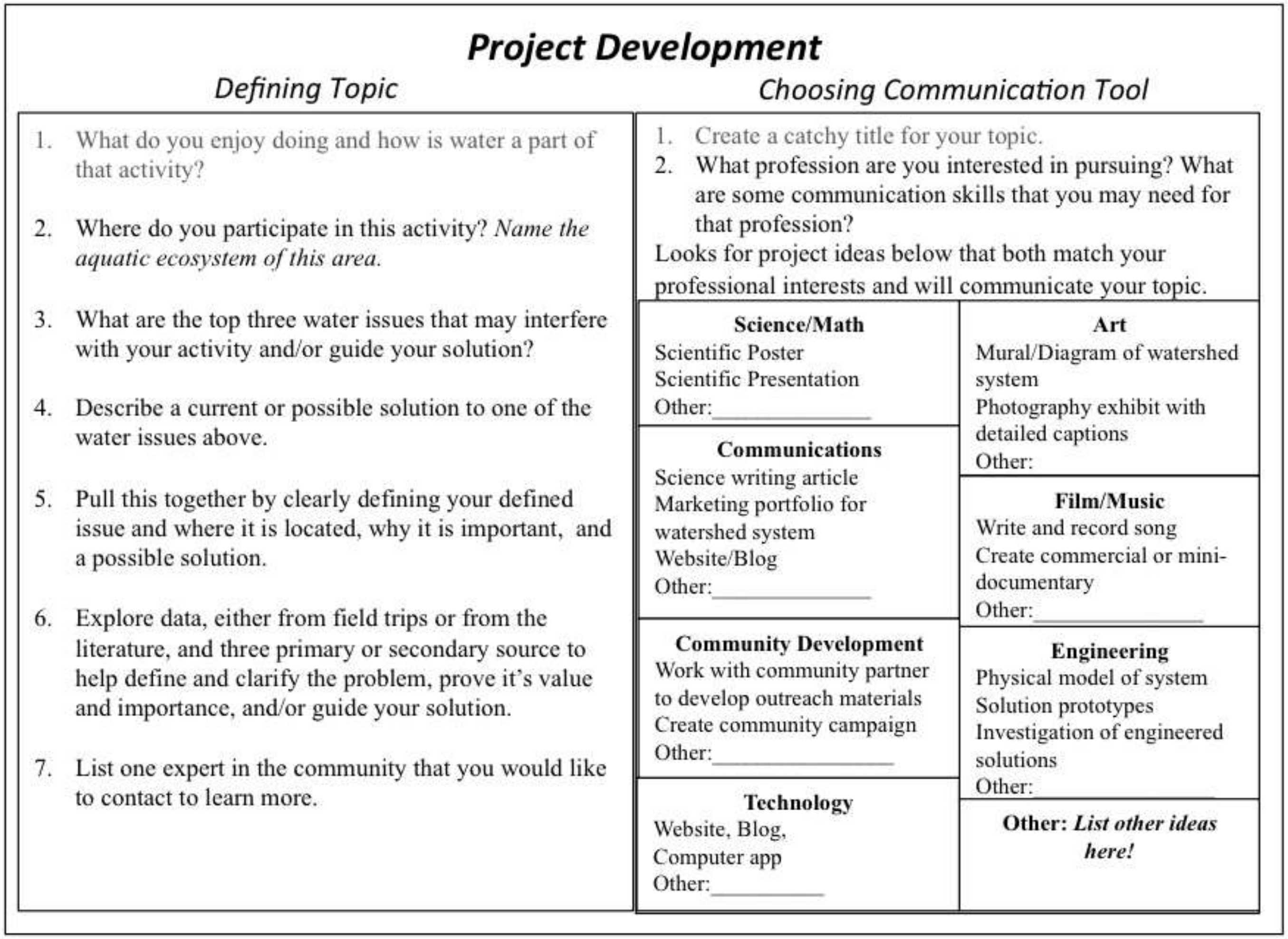
Tribal Environmental Specialist asked students to collaborate and test both solution and outreach plan next year.

Prezi Presentations

De-icer and Water Quality: Winter's Secret Killer

http://prezi.com/ehlko_tqinqp/deicers-and-water-quality-winters-secret-killer/

FIGURE 6.2 Selected student project samples and partnerships developed with community members during Youth Water Summit.



Project Development

Defining Topic

1. What do you enjoy doing and how is water a part of that activity?
2. Where do you participate in this activity? *Name the aquatic ecosystem of this area.*
3. What are the top three water issues that may interfere with your activity and/or guide your solution?
4. Describe a current or possible solution to one of the water issues above.
5. Pull this together by clearly defining your defined issue and where it is located, why it is important, and a possible solution.
6. Explore data, either from field trips or from the literature, and three primary or secondary source to help define and clarify the problem, prove it's value and importance, and/or guide your solution.
7. List one expert in the community that you would like to contact to learn more.

Choosing Communication Tool

1. Create a catchy title for your topic.
2. What profession are you interested in pursuing? What are some communication skills that you may need for that profession?

Looks for project ideas below that both match your professional interests and will communicate your topic.

Science/Math
Scientific Poster
Scientific Presentation
Other:______________

Art
Mural/Diagram of watershed system
Photography exhibit with detailed captions
Other:

Communications
Science writing article
Marketing portfolio for watershed system
Website/Blog
Other:______________

Film/Music
Write and record song
Create commercial or mini-documentary
Other:_______________

Community Development
Work with community partner to develop outreach materials
Create community campaign
Other:________________

Engineering
Physical model of system
Solution prototypes
Investigation of engineered solutions
Other:________________

Technology
Website, Blog,
Computer app
Other:__________

Other: ***List other ideas here!***

FIGURE 6.3 Condensed project development student worksheet. Customizable to project-based curriculum theme or disciplinary core idea

CONCLUSIONS AND RECOMMENDATIONS

Despite widespread efforts to improve water quality in agricultural watersheds through conservation and outreach efforts, agricultural nonpoint source pollution remains a leading cause of water impairment in the U.S. This dissertation addressed the mismatch between intensive conservation investments and significant pollutant reductions by 1) developing a conceptual framework to better target best management practices (BMPs) to pollutant "hotspots" in a watershed; 2) pairing and verifying a hillslope hydrology and fluvial sediment transport model as a management tool to address how stream systems respond to upland management practices and impact watershed sediment loads; 3) investigating the role of place-based education and youth capital in catalyzing agricultural conservation efforts amongst landowners through mobilizing internal and external resources and building capacity for stakeholder partnerships; and 4) creating and testing a place and project-based K-12 outreach solution to engage watershed stakeholders and communities in watershed conservation and monitoring efforts. In this dissertation, I integrated the disciplines of hydrology, erosion and sediment transport, social science, science education to address water quality in agricultural watersheds.

This collection of works provides recommendations to measure and improve the effectiveness of BMPs in agricultural landscapes, demonstrates that the stream channel can both buffer the impacts of upland conservation efforts, and generate streambank and bed sediment with drastic changes in sediment supply and runoff volume due to land use management, and validates the role of K-12 outreach programs and students as potential community catalysts to increase BMP adoption behavior. The integration and application of the lessons learned could occur with a shift in how local agencies prioritize BMPs and interact with landowners, by altering the way in which monitoring approaches track water quality response, and by shifting how conservation funding is distributed at the local level.

Truly improving water quality requires localized nonpoint source management that 1) emphasizes restoring watershed hydrologic, ecologic, and fluvial function to sustain beneficial uses within surface waters, and 2) includes conservationists that manage water quality at the watershed scale but can also build trust, and work with landowners at the field scale. To do this, conservationists should apply watershed-scale understanding to critically prioritize conservation efforts while addressing the relationship between upland hydrologic processes and instream pollutant transport and transformation processes, and approach landowners in conservation prioritization areas with a collaborative perspective. To develop prioritization areas for BMP implementation at the watershed-scale, process and physically-based models should be the standard tools used as the best available science informing conservation recommendations. Pairing local knowledge from landowners with the best available science to increase BMP effectiveness is the recommended approach to both attain trust and build relationships between landowners and agency members, improve the effectiveness of BMPs, and ideally engage the landowner in maintaining and sustaining BMPs. Effective and sustained conservation could benefit by strong emphasis on recruiting conservationists in regional conservation offices who possess a strong scientific understanding of the landscape as well as the ability to build social capital in a watershed community through well-developed interpersonal intelligence

Often, conservation effectiveness and water quality response are not observed due to insufficient monitoring. Monitoring of conservation effectiveness and water quality response should consider the appropriate temporal and spatial scale to capture conservation impacts. Given the challenge in funding and employing long term monitoring studies, indicators of water quality response that best demonstrate the restoration of beneficial uses and watershed function should be prioritized for monitoring. For example, rather than measuring solely sediment loading at the watershed outlet in excess sediment TMDLs, qualitative rapid geomorphic assessments could be implemented to track stream recovery and sediment storage and generation within the stream channel to predict response to watershed-scale flow and sediment supply dynamics. Watersheds with thermal loading TMDLs developed for cold water biota beneficial uses could implement a bio indicator monitoring program to track recovery of ecological systems as was implemented in The Confluence Project, rather than just temperature assessments.

Monitoring programs provide excellent opportunities for community and landowner engagement. Integrating insights of landowners, community members, and students into monitoring programs not only leverages human and financial capital for conservation programs, but can also improve social capital within a watershed, strengthening stakeholder and landowner networks. Findings from this work shows that engaging students and citizens in place-based science education will have lasting impacts on broader engagement in community conservation issues. In developing effective citizen science and student monitoring programs, conservation agencies should prioritize indicators of water quality response that are both logistically and financially feasible for citizen scientists to collect, and that will also generate reliable and meaningful data.

Ideally, integrating these recommendations into the funding priorities for local conservation agencies involved in nonpoint source pollution management could allow for targeted and effective BMPs, improved social capital and trust between conservation agencies and landowners, and engaged students and community members in water quality monitoring and conservation.

Outlined below is a list of recommendations for each chapter for future research to further improve both hydrologic and social understanding of agricultural conservation effectiveness for nonpoint source management.

CHAPTER 2

- Develop a conceptual framework and synthesis of effective BMPs for irrigated and tile drained watersheds.
- Integrate recommendations for land types with the online WEPP-UI Hydrologic Characterization Tool (http://wepp.ag.uidaho.edu/cgi-bin/HCT.pl)

CHAPTER 3

- Investigate the role of reed canary grass in channel evolution trajectories.
- Assess the sediment and pollutant loading from storm water outflows as well as the impacts of streambank scour from outflow discharge in urban reaches of Paradise Creek.
- Use CONCEPTs to assess reach length pre- and post restoration response in urban reaches of Paradise Creek.

CHAPTER 4

- Employ GeoWEPP to improve sediment deposition routines where hillslopes converge to improve sediment delivery to stream channel. The cell-based approach of GeoWEPP could potentially improve the sediment deposition at toe slopes and in valleys, and further research could investigate coupling GeoWEPP and the WEPP-UI subsurface flow routines with CONCEPTS to assess the impacts on sediment delivery to the stream.
- Allow temporal change of vegetation green up, senesce, and decomposition to be represented by changing Manning's n roughness values.
- Downscale daily streamflow values into hourly time steps using an empirical hydrograph method to improve CONCEPTs simulation of peak events.
- Improve model stability to allow for 30-year simulations.
- Develop stream reach length testing scenarios using CONCEPTS that could be integrated into the Hydrologic Characterization Tool (Brooks *et al*., 2015) to assess stream response to changes in sediment supply and runoff volumes from upland management

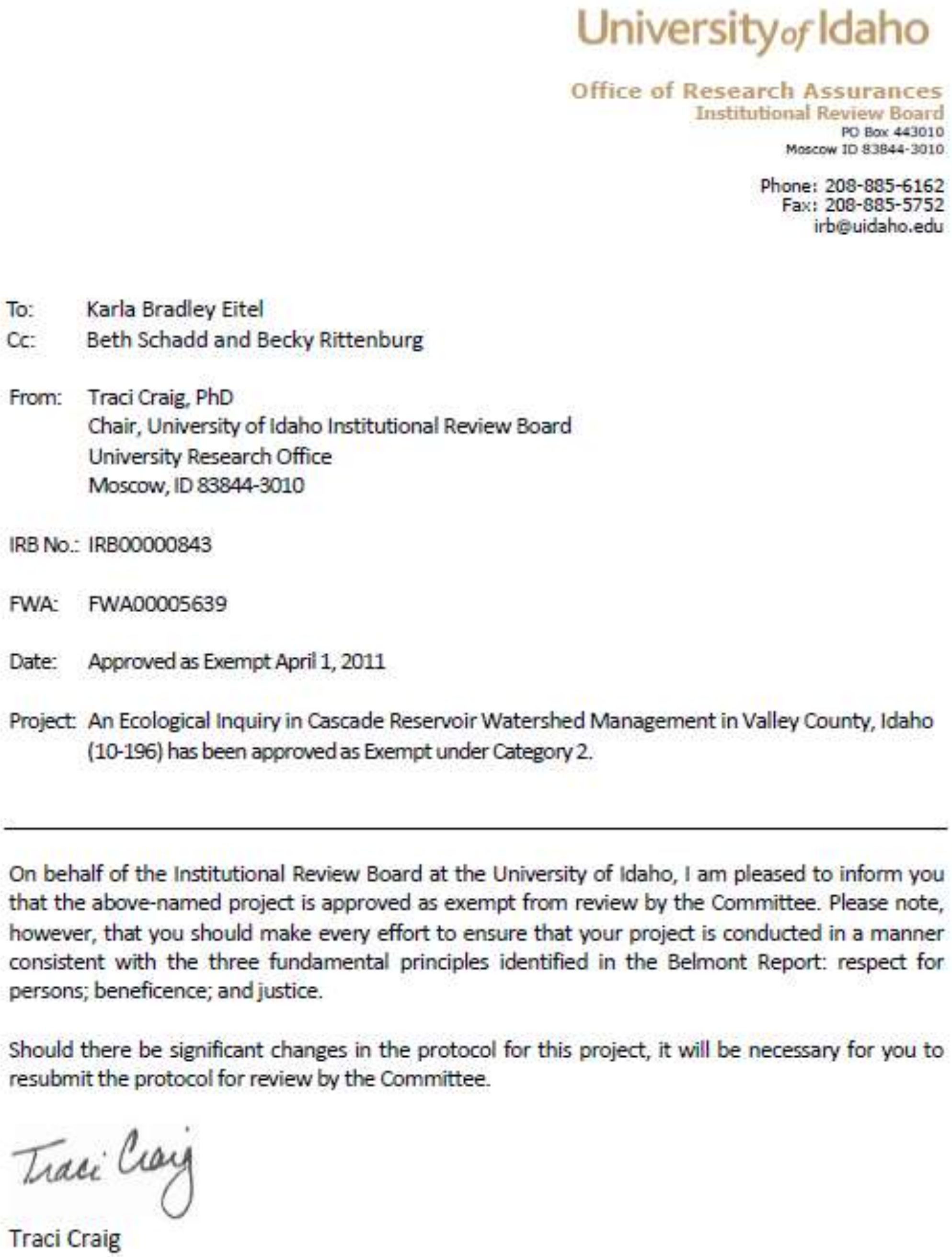
CHAPTER 5

- Scale this study by assessing other regional watershed place-based and citizen science education programs and their impact on landowner engagement in conservation and the spiraling up of community capitals.

CHAPTER 6

- Develop a network analysis study of stakeholders involved in watershed outreach programs like The Confluence Project (wowconfluenceproject.wordpress.com) to investigate impacts on stakeholder relationships and social capital.

APPENDIX A: CH 5 INSTITUTIONAL REVIEW BOARD APPROVAL



University of Idaho

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irb@uidaho.edu

To: Karla Bradley Eitel
Cc: Beth Schadd and Becky Rittenburg

From: Traci Craig, PhD
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

IRB No.: IRB00000843

FWA: FWA00005639

Date: Approved as Exempt April 1, 2011

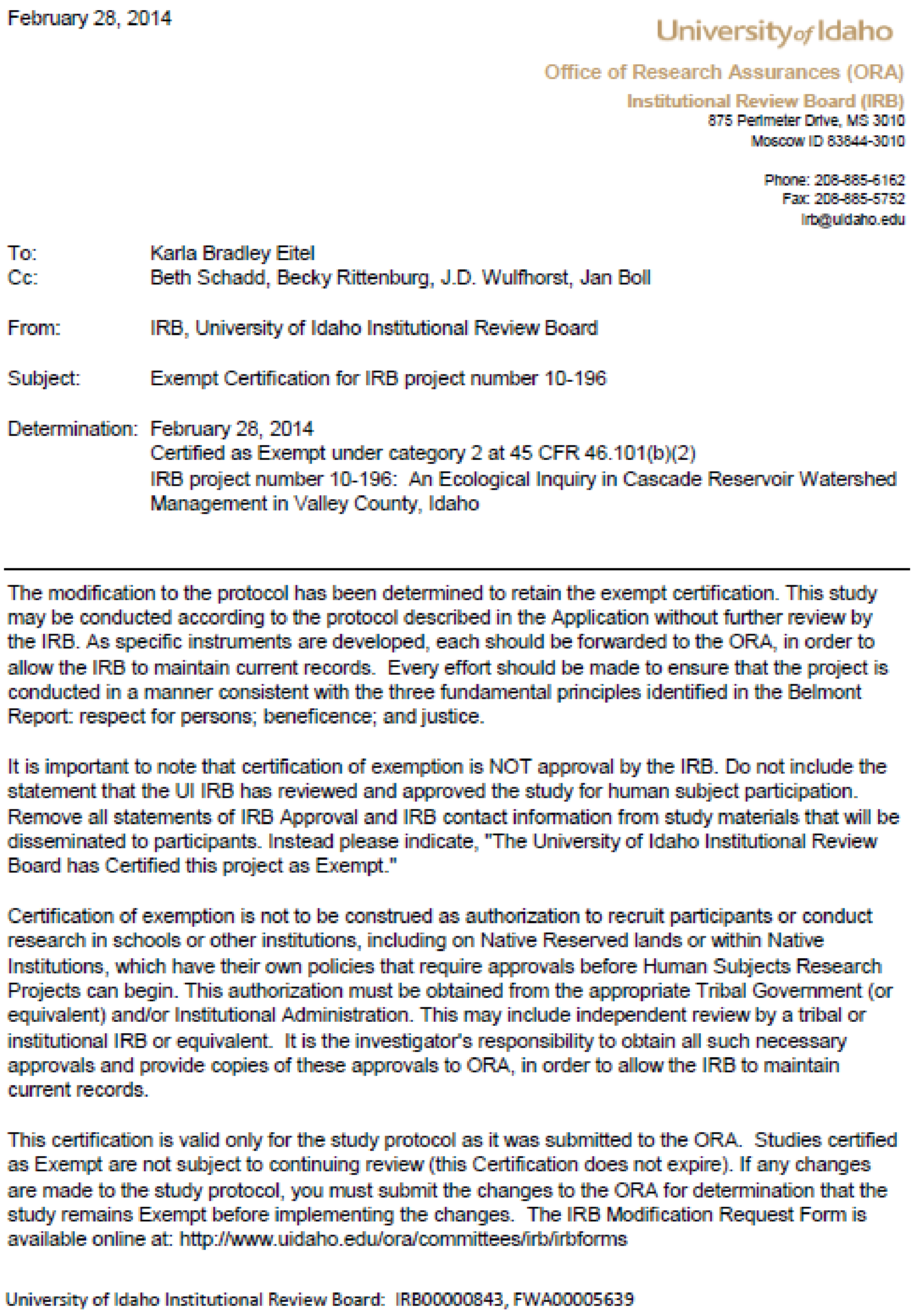
Project: An Ecological Inquiry in Cascade Reservoir Watershed Management in Valley County, Idaho (10-196) has been approved as Exempt under Category 2.

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the above-named project is approved as exempt from review by the Committee. Please note, however, that you should make every effort to ensure that your project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

Should there be significant changes in the protocol for this project, it will be necessary for you to resubmit the protocol for review by the Committee.

Traci Craig

Traci Craig



February 28, 2014

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To: Karla Bradley Eitel
Cc: Beth Schadd, Becky Rittenburg, J.D. Wulfhorst, Jan Boll

From: IRB, University of Idaho Institutional Review Board

Subject: Exempt Certification for IRB project number 10-196

Determination: February 28, 2014
Certified as Exempt under category 2 at 45 CFR 46.101(b)(2)
IRB project number 10-196: An Ecological Inquiry in Cascade Reservoir Watershed Management in Valley County, Idaho

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The modification to the protocol has been determined to retain the exempt certification. This study may be conducted according to the protocol described in the Application without further review by the IRB. As specific instruments are developed, each should be forwarded to the ORA, in order to allow the IRB to maintain current records. Every effort should be made to ensure that the project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

It is important to note that certification of exemption is NOT approval by the IRB. Do not include the statement that the UI IRB has reviewed and approved the study for human subject participation. Remove all statements of IRB Approval and IRB contact information from study materials that will be disseminated to participants. Instead please indicate, "The University of Idaho Institutional Review Board has Certified this project as Exempt."

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University of Idaho Institutional Review Board: IRB00000843, FWA00005639

APPENDIX B: SEMI-STRUCTURED INTERVIEW GUIDE

Questions modified based on type of stakeholder (i.e. conservationist, educator, landowner). Watershed name kept anonymous in this manuscript to respect stakeholder privacy.

1. Tell me about your role in watershed conservation efforts within this basin.
2. Has management of XX Creek Watershed been successful? Why or why not? (Probe for evidence)
3. Do you monitor your projects to evaluate impacts to water quality? If so, describe your monitoring strategies. If not, do you know any other individuals or groups who are implementing monitoring programs in the basin?
4. How were conservation projects initiated?
5. Have you noticed any trends in conservation efforts in XX Creek?
    a. Could you tell me about the conservation project on XX Creek and how it was initiated?
    b. What partnerships have allowed you to implement restoration/conservation practices? How were those partnerships established and implemented? (Probe here to see what, if any, trends there have been in community engagement; who the key drivers behind conservation are, and the quality of relationships between landowners and private landowners)
    c. Have educational initiatives impacted watershed conservation? If so, how?
        i. What is the relationship between conservation with K-12 watershed education efforts?
        ii. Do you think elementary school students understood the value of their work?
    d. Was there any opposition to conservation practices initially? Is there any opposition now? How did you approach the opposition/other stakeholders?
6. How many meters of stream have you been involved in restoring? How many acres of land have you been involved in conserving to improve water quality in XX creek?
7. How much funding have you raised or used to implement the projects?
8. How many people have volunteered with your projects? How did you connect and recruit volunteers? How many hours would you estimate were invested in the projects?
9. How do you choose where to target conservation/restoration practices?
    a. Was conservation something you were thinking about doing anyway?
10. Have any of your conservation practices affected the community? How? Do you think your conservation efforts have inspired any others to implement practices?
11. Are there any other key stakeholders working on watershed conservation in this basin that you would recommend contacting?

APPENDIX C: EDUCATION STANDARDS ALIGNMENT

Next Generation Science Standards

Field Experiences: Conducting water quality and quantity field experiments, analyzing data, and presenting results to peers

Performance Expectations

HS-ESS2-5: Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

Disciplinary Core Ideas:

HS-ESS2.C: The Roles of Water in Earth's Surface Processes

The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store and release large amounts of energy, transit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting point of rocks.

Cause and effect: Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects

Stability and Change: Feedback (negative or positive) can stabilize or destabilize a system)

Science and Engineering Practices

Planning and carrying out investigations
Analyzing and interpreting data
Engaging in argument from evidence

Water Resource Projects: Defining a water resource challenge, using evidence to design and evaluate solutions:

HS-ETS1: Engineering Design

Performance Expectations

HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)

Crosscutting Concept

Systems and System Models: Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions…

Science and Engineering Practices

Asking Questions and Defining Problems: Formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

Constructing Explanations and Designing Solutions: Explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories; design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations; and evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Influence of Science, Engineering, and Technology on Society and the Natural World

New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Performance Expectations

HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Disciplinary Core Ideas

LS4.D: Biodiversity and Humans

Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

Crosscutting Concepts

Stability and Change: Much of science deals with constructing explanations of how things change and how they remain stable.

Science and Engineering Practices

Constructing Explanations and Designing Solutions: explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories; design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations; and evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Common Core State Standards Alignment

D**eveloping abstracts and final product:** Using evidence from data, technical reports, and scientific articles

Writing

CC 6-12.W.5: Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.

CC 6-12.W.8: Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

Project Presentations: Presenting final product to peers and community partners and engaging in a ten minute discussion with community partners

Speaking and Listening

CC 9-12.SL.5: Analyze and evaluate the effectiveness of the structure an author uses in his or her exposition or argument, including whether the structure makes points clear, convincing, and engaging.

CC 11-12.SL 1c: Propel conversations by posing and responding to questions that probe reasoning and evidence; ensure a hearing for a full range of positions on a topic or issue; clarify, verify, or challenge ideas and conclusions; and promote divergent and creative perspectives.

CC 11-12.SL.4: Present information, findings, and supporting evidence, conveying a clear and distinct perspective, such that listeners can follow the line of reasoning, alternative or opposing perspectives are addressed, and the organization, development, substance, and style are appropriate to purpose, audience, and a range of formal and informal tasks.

Science and Technical Subjects

CC 11-12. RST.1: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

CC 11-12. RST.8: Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

CC 11-12. RST.9: Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Reading Informational Text

CC 6.11-12.RI.7: Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

APPENDIX D: PRE/POST ASSESSMENT RESEARCH SUMMARY

RESEARCH QUESTIONS

1) How does project-based learning impact student attitudes towards science as a career and subject?
2) How does project-based learning impact student attitudes towards science as a tool for solving environmental problems at the community level?

METHODS

Primary Participants: St. Maries HS honors bio (19 students); Post Falls HS honors bio (51 students); Lake City IB Environmental Science (24 students); n=94 students

Survey Instrument: Pre- and post- program student survey with 18 likert scale items related to attitudes towards science and the environment and three short answer questions related to favorite course subjects in high school, career goals, and attitudes towards science.

Quantitative Data: Likert scale survey item analysis using paired t-tests to assess student change in attitude pre and post program participant (p-value <0.05=significant).

Qualitative Data: Thematic analysis of open responses to determine emerging themes related to student attitude towards science as a career and subject, and science as a tool for solving environmental problems at the community level.

RESULT SUMMARY

Results from a pre- and post- program student attitude survey suggest that:

1. After completing this program, more students agree that community problems can be solved with scientific solutions (p-value =0.03)

2. More students agree that outside of school, they found themselves reading, listening, or watching current events that discuss scientific topics (p-value=0.02).

3. Post program, more students agreed that it is hard to know what to trust about science because science is always changing (p-value=0.0001)

4. In response to the short answer question “what are your favorite aspects of science class?””
    - Common responses pre-program included science content-driven or lab activity-specific responses
        - “I like doing labs”
        - “doing experiments”
        - “living organisms”
        - “hands on activities”
        - “learning about the human body
    - After participating in the program, responses were more sophisticated and more commonly elaborated on the value and process of science as it applies to the real world and to knowledge generation and discovery.
        - **the real world applicability of science**
            - “I like putting my skills to the test in real world applications”
            - “discovering how we can connect what we learned in class to our everyday lives”
            - “perform experiments and find solutions to a problem”
        - **the nature of science**
            - “how you discover new things every day”
            - “learning how things work”
            - “learning the physical aspects of the world to know why things happen”
            - “Figuring out how two different areas of science work together even in the most unlikely situations. I love that "wow!" moment”
        - **The act of doing and communicating science**
            - “Fieldwork”
            - “when I learn something new, and I get to explain how it works to others”

5. In response to the short answer question, “What is your dream job?”, 46% of students responded with science-oriented careers both during their pre- and post- survey, 11% of students changed their response from a non-science related career to a science-oriented career, 3% changed out of a science-oriented field, and 38% had non-science related career choices for both their pre and post survey (Figure 6. Overall, after completing the program, interest in careers in science increased.

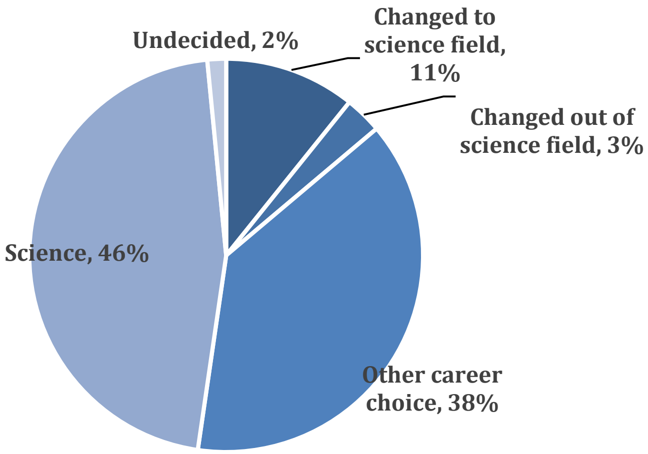


FIGURE 6.4 Students post program career choice selection (n=94).

Survey Instrument: Student Attitudes

We are asking you to help us with this program by completing this survey. Please answer the best you can. Completing this survey will not affect your grade, but it will help us improve the program.

Instructions: Read each statement. Check the box that most closely matches your opinion of the statement. There are no right or wrong answers.

Attitudes Toward Science and the Environment:

	I strongly agree	I agree	I disagree	I strongly disagree
1. Much of what I learn in science classes is useful in my everyday life.	☐	☐	☐	☐
2. I would dislike being a scientist after I leave school.	☐	☐	☐	☐
3. I would like to learn more about science.	☐	☐	☐	☐
4. The things I do in science have nothing to do with the real world.	☐	☐	☐	☐
5. When I leave school, I would like to work with people who make discoveries in science.	☐	☐	☐	☐
6. I will be glad when I am done taking science classes.	☐	☐	☐	☐
7. School should have more science lessons each week.	☐	☐	☐	☐
8. I would be wasting my time if I took more science courses.	☐	☐	☐	☐
9. Science is one of the most interesting school subjects.	☐	☐	☐	☐
10. A career in science would be dull and boring.	☐	☐	☐	☐
11. I dislike spending time in natural settings.	☐	☐	☐	☐
12. I make connections from my science classes to the natural world.	☐	☐	☐	☐
13. Science classes I take in the future will be interesting.	☐	☐	☐	☐
14. The material I learn in science classes helps me understand how the	☐	☐	☐	☐

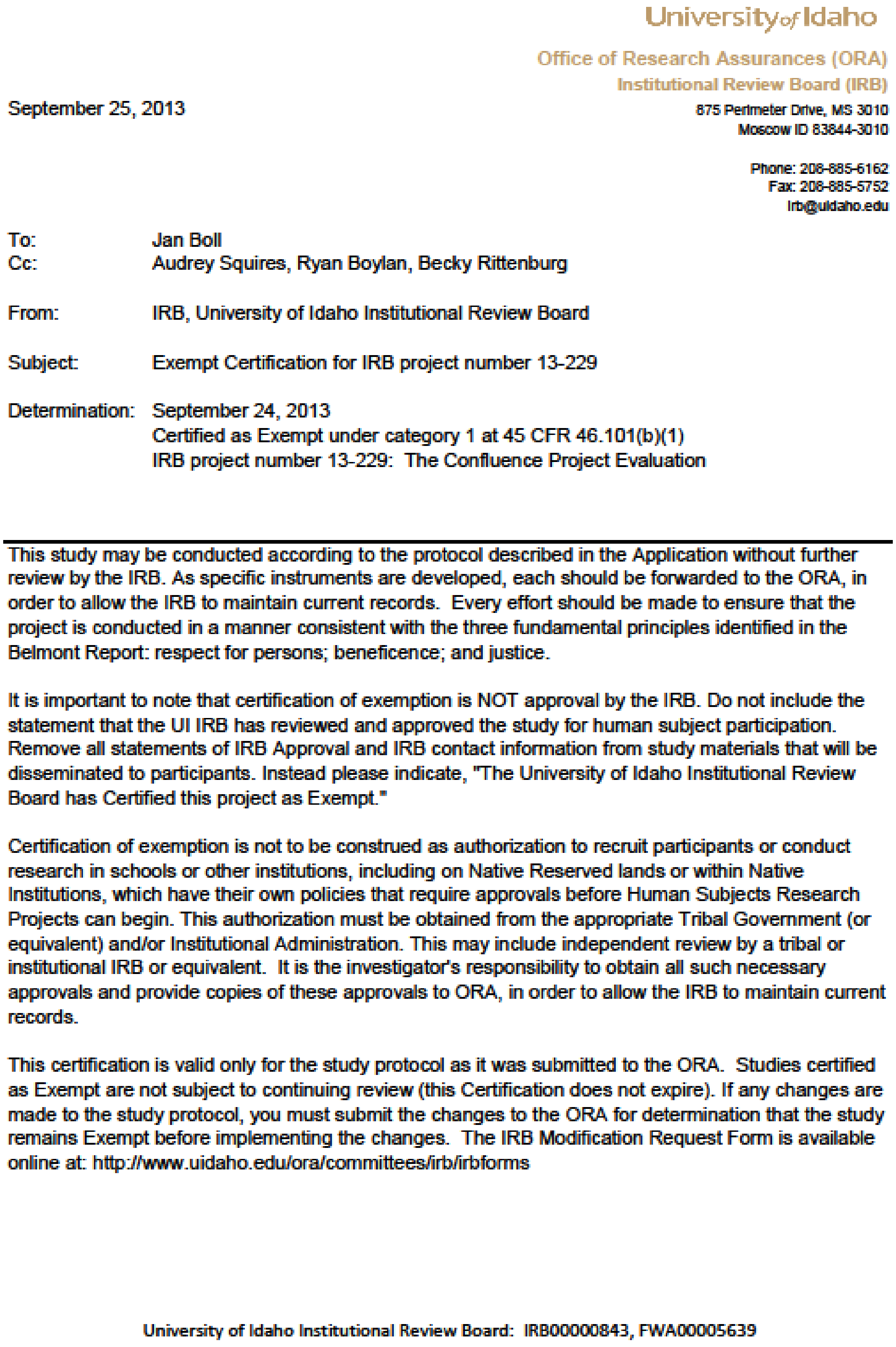
natural world works.				
15. I would dislike becoming a scientist because it requires too much education.	☐	☐	☐	☐
16. I would like to be a scientist when I leave school.	☐	☐	☐	☐
17. I enjoy spending time in natural settings.	☐	☐	☐	☐

18. What is your favorite aspect of science class?

19. What is your least favorite aspect of science class?

20. What is your dream job?

APPENDIX E: CH 6 INSTITUTIONAL REVIEW BOARD APPROVAL



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September 25, 2013

To: Jan Boll
Cc: Audrey Squires, Ryan Boylan, Becky Rittenburg

From: IRB, University of Idaho Institutional Review Board

Subject: Exempt Certification for IRB project number 13-229

Determination: September 24, 2013
Certified as Exempt under category 1 at 45 CFR 46.101(b)(1)
IRB project number 13-229: The Confluence Project Evaluation

This study may be conducted according to the protocol described in the Application without further review by the IRB. As specific instruments are developed, each should be forwarded to the ORA, in order to allow the IRB to maintain current records. Every effort should be made to ensure that the project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

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University of Idaho Institutional Review Board: IRB00000843, FWA00005639