HYDROLOGIC ALTERATION AND SEDIMENTATION IN THE
UPPER HENRY'S FORK WATERSHED

A Thesis
Submitted to
the Faculty of California Polytechnic State University,
San Luis Obispo

DEPARTMENT OF EARTH AND SOIL SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN AGRICULTURE AND A SPECIALIZATION IN
SOIL SCIENCE

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April, 2011

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Abstract
Hydrologic Alteration and Sedimentation in the Upper Henry's Fork Watershed
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The Henry's Fork of the Snake River is venerated by the global recreational community as one of the finest trout fishing streams on the planet. Furthermore, this remarkable waterway flows within the bounds of one of the most important ecological corridors in the equally world-renowned Greater Yellowstone Ecosystem. While the recreational and biological features of this corner of Idaho may capture the interest of the broader public, the waterway is equally significant to the livelihoods of local interests, such as the ranching and farming communities. With the stakes running high for all interest groups, a case study of the Henry's Fork watershed provides a valuable baseline narrative for understanding decision-making related to water resources not only in Idaho, but also in other Western states.

Environmental impacts of the Henry's Lake Dam and management of the stream below the structure were evaluated by literature review and GIS mapping, with research emphasis placed on the ecological integrity and fisheries of the Upper Henry's Fork Subbasin. The literature review focused on natural processes in stream ecosystems and anthropogenic impacts, with the goal of providing information for the development of management policies that minimize the negative impacts of current flow management and land use.

Literature sources overwhelmingly agree that the alteration of natural hydrologic regimes is the most serious and continuing threat to the sustainability of river ecosystems. In recent decades, downstream recreational fishing declined on the upper Henry's Fork due to increased sedimentation, inciting investigation as to the source. Three major

anthropogenic factors targeting one section of the river, the Henry's Lake Outlet, set the stage for excess sedimentation.

First, the Henry's Lake Dam was constructed in 1923, impacting the Outlet's hydrology through changes in the timing, magnitude, and frequency of low and high flows. Second, an artificial stream channel was constructed in the 1920s to bypass the meandering Outlet in order to increase conveyance capacity of irrigation water from Henry's Lake to downstream water users. Third, long-term livestock grazing along this section of river dramatically reduced riparian and upland vegetation, triggering the loss of stream-bank stability and increasing erosion and sedimentation. These management practices have resulted in significant loss of biodiversity in the stream ecosystem and an increased rate of erosion in the Outlet.

The Henry's Lake Outlet restoration project, led by the Henry's Fork Foundation, provides the opportunity to predict potential effects of large-scale restoration in the Henry's Fork watershed. The project seeks to reduce sediment delivery downstream from the Outlet by rerouting flow from the straightened channel into the historic channel. The project tests the hypothesis that, by restoring the meandering stream channel, and thereby adding a half-mile to the Outlet, bank erosion and channel instability will decrease, the interaction between stream and riparian habitats will improve, and overall ecosystem health will benefit.

In spite of the proactive intentions of the project, it will not change the current management of stream flow. In order to restore the Henry's Lake Outlet to a state of dynamic equilibrium in terms of erosion and sediment load, the flows from Henry's Lake Dam must more closely reflect the natural hydrologic regime. However, the ability to

implement full restoration of the Outlet is complicated by the conflict between the requirements for ecosystem health and economic and socio-political pressures, a story common to many water systems throughout the West. Ultimately, it is hoped that this research may be integrated into policy and conservation strategy to mitigate streambank erosion and sedimentation in the Henry's Fork Subbasin.

TABLE OF CONTENTS

Section	Page #
TABLE OF FIGURES	XI
TABLE OF TABLES	XIII
1.0 INTRODUCTION	1
1.1 Research Objectives.....	7
2.0 LITERATURE REVIEW PART I: THE NATURAL FLOW REGIME	8
2.1 Introduction.....	8
2.2 Ecological Integrity of Stream Ecosystems	9
2.3 Hydrologic Connectivity as a Continuum.....	10
2.3.1 <i>Channel Stabilization and Equilibrium</i>	13
2.3.2 <i>Spatial and Temporal Scale</i>	15
2.3.3. <i>Sub-levels of Systems: The Example of the Watershed Scale</i>	18
2.4 Sediment Transport in Channels.....	21
2.4.1 <i>Sources of Sediment</i>	21
2.4.2 <i>Aggradation and Degradation</i>	23
2.4.3 <i>Bankfull Discharge</i>	24
2.5 Streamflow and Its Alteration.....	26
2.5.1 <i>Effects of Streamflow Alteration</i>	27
2.5.2 <i>Hydrologic Regime</i>	28
2.5.3 <i>Analyzing Streamflow: The Natural Flow Regime</i>	29
2.5.4 <i>Riverine Rehabilitation and the Need for Collaboration</i>	30
2.6 Summary	31

3.0 LITERATURE REVIEW PART II: ANTHROPOGENIC IMPACT ON THE	
HENRY’S LAKE OUTLET	32
3.1 Introduction.....	33
3.2 Disturbance and Response to Anthropogenic Alteration in Aquatic Ecosystems .	36
3.3 Dams and Reservoirs	37
3.4 Channelization	39
3.5 Livestock Influences on Stream and Riparian Ecosystems	41
3.6 Sedimentation	44
3.7 Summary	44
4.0 SITE CHARACTERISTICS.....	47
4.1 Introduction.....	47
4.2 Study Area	49
4.3 Climate.....	50
4.4 Hydrology	51
4.5 Geology.....	52
4.6 Soils.....	57
4.7 Vegetation	58
5.0 MANAGEMENT OF HENRY’S FORK WATERSHED.....	60
5.1 Introduction.....	60
5.2 Irrigated Agriculture	60
5.2.1 <i>The Snake River</i>	60
5.3. History of Human Settlement and Water Use in Eastern Idaho	62
5.4 Water Development Projects on the Henry’s Fork	63

5.4.1	<i>Henry's Lake Dam</i>	63
5.4.2	<i>Channelization of the Henry's Lake Outlet</i>	64
5.4.3	<i>Island Park Reservoir</i>	65
5.4.4	<i>Cattle Grazing on the Henry's Fork</i>	66
5.5	Henry's Fork Fishery	66
5.6	Concerns with Sedimentation	67
5.7	Collaboration.....	68
5.7.1	<i>The Henry's Fork Foundation</i>	68
5.7.2	<i>Henry's Fork Watershed Council</i>	69
5.7.3	<i>The Nature Conservancy's Flat Ranch</i>	70
5.8	Summary	72
6.0	HENRY'S LAKE OUTLET RESTORATION EFFORTS	73
6.1	Introduction.....	73
6.2	Anthropogenic Impacts & Sedimentation.....	74
6.2.1	<i>Channelization</i>	74
6.3	Preliminary Results of the Henry's Lake Outlet Restoration Project	76
6.3.1	<i>Stakeholder Reactions to Preliminary Results</i>	78
6.4	The Restored Channel.....	79
6.5	Options to Appease Irrigator Concerns: Back to the Straightened Channel?	80
6.6	Summary	81
7.0	CURRENT WATER POLICY IN FREMONT COUNTY, IDAHO AS IT RELATES TO STREAMFLOW	82
7.1	Introduction.....	82

7.2 The Significance of Water as Expressed in Idaho State Legislature	83
7.3 Idaho's Water Allocation System	84
7.4 Instream Flows and the Minimum Stream Flow Act.....	85
7.5 State Water Transfer Program	87
7.6 State Water Banking Program	88
7.7 The Endangered Species Act	89
7.8 Summary	93
8.0 SUMMARY.....	95
References.....	99
APPENDIX A:.....	117

TABLE OF FIGURES

Topic	Page #
Figure 1. Location of the Upper Henry's Fork Subbasin, origin of the Henry's Fork of the Snake River.	1
Figure 2. Megasite Irreplaceability vs. Vulnerability of sites in the Greater Yellowstone Ecosystem (Noss et. al, 2002).....	2
Figure 3. Map of Henry's Fork watershed showing the three major rivers and primary geological provinces.	4
Figure 4. The Outlet was identified as the major source of sediment to the upper Henry's Fork (Wesche, 1992; Stumph, 1995; Wesche, 1996).	6
Figure 5. The Hydrologic Cycle.	10
Figure 6. Stream and river structure (Mekong River Commission for Sustainable Development).	11
Figure 7. The hydrologic pathways connecting the landscape to streams and rivers.	12
Figure 8. Lane's scale of dynamic equilibrium (Rosgen, 1996).	14
Figure 9. Relationship between recovery time and sensitivity to disturbance for	16
Figure 10. A spatially nested hierarchical organization of a stream system and its habitat subsystems. (Frissell et al., 1986).....	17
Figure 11. General zones of a river based on dominant physical processes (FISRWG, 1998).....	19
Figure 12. Stream ordering in a drainage network. “1” represents first order streams, “2” second order streams, etc. (FISRWG, Federal Interagency Stream Restoration Working Group).	20
Figure 13. Relations between discharge, sediment transport rate, frequency of occurrence and the product of frequency and transport rate (Wolman and Miller, 1960).	26
Figure 14. The ecological integrity of river ecosystems depends upon their natural dynamic character (Poff et al., 1997).....	30
Figure 15. Map of Henry's Fork Watershed. The Henry’s Lake Outlet	

is the stream section between Henry’s Lake Dam and Big Springs.	32
Figure 16. Representative picture of the Henry’s Lake Outlet (photo courtesy Henry’s Fork Foundation).....	34
Figure 17. Streambank erosion on the Outlet caused by anthropogenic influence (photo courtesy of Henry’s Fork Foundation).	34
Figure 18. Streambank erosion on the Outlet caused by anthropogenic influence (photo courtesy of Henry’s Fork Foundation).	35
Figure 19. Streambank erosion on the Outlet caused by anthropogenic influence (photo courtesy of Henry’s Fork Foundation).	35
Figure 20. Maximum, mean, minimum (1972 - 2008), and Water Year 2008 discharge in Outlet (data from Water Year 2008 are PROVISIONAL; data from USGS Gage 13039500 Henrys Fork near Lake ID).	37
Figure 21. Hydrologic unit codes for the Uppers Henry’s Fork and adjacent Idaho subbasins. The confluence of the Henry’s Fork and South Fork in the Idaho Falls subbasin marks the beginning of the Snake River (IDEQ-IFRO, 1998).	48
Figure 22. Map of Henry’s Lake Outlet highlighting the wet meadow complex of Henry’s Lake Flat in blue.	49
Figure 23. Relief map of Idaho showing the location and elevation of the Snake River Plain.....	55
Figure 24. Map showing the Island Park Caldera and Henry's Fork Caldera.....	56
Figure 25. Land and water use near Rexburg: canals, farms, irrigation-enhanced wetlands, new subdivisions.	62
Figure 26. Island Park Dam.	65

TABLE OF TABLES

Table 1. General zones of a river based on dominant physical processes	20
Table 2. Summary of climate data collected from February 1, 1937 to June 30, 1997 at Island Park1 and from August 1, 1948 to June 30, 1997 at Ashton (Western Regional Climate Center)	51
Table 3. Descriptions of generalized geologic units in the Upper Henry's Fork subbasin and their water-bearing characteristics (Whitehead, 1978; Christiansen & Embree 1987).....	54
Table 4. Percentages of Henry's Lake shoreline and tributary streambanks classified by the <i>Henry's Lake SA WQP Final Planning Report/Environmental Assessment</i> (YSCD 1995) as slightly, moderately, or severely eroding. Moderately and severely eroding banks were designated critical areas eligible for receiving funding for treatment. The percentage of total critical area under contract for treatment is shown for each waterbody (Beckman and Bradford 1998).....	75
Table 5. Stakeholder groups holding interest in the Henry's Fork Outlet Restoration Project and their identified needs.	78
Table 6. State recognized beneficial uses for water resources.	86
Table 7. State and Federal Yellowstone Cutthroat Trout Designations. *The petition to list the Yellowstone cutthroat trout was found 'not warranted' by the U.S. Fish and Wildlife Service on February 21, 2006. The final decision can be found posted in the Federal Register volume 71, number 34.	93
Table 8. USDA Soil Survey for Henry's Lake Watershed.	117

Figure 1. Location of the Upper Henry's Fork Subbasin, origin of the Henry's Fork of the Snake River.

1.0 INTRODUCTION

The Henry's Fork of the Snake River is one of the most prominent watersheds in the West. The Upper Henry's Fork Subbasin, located in northeast Idaho, is the origin of the Henry's Fork of the Snake River (Figure 1). Situated at the top of the Snake River system and within the Greater Yellowstone Ecosystem (GYE)—a region of wildness and rich natural resources and one of the last essentially intact temperate ecosystems on the planet (Glick & Clark, 1998)—the Henry's Fork hosts world class fishing, internationally recognized scenic value and one of the richest wildlife habitats in all of the GYE. The

Henry's Fork attracts tens of thousands of anglers and other river recreationists each year, generating millions of dollars of business for both the local economy and the state of Idaho. The area is also heavily managed for the world's most intensive seed potato agriculture production (Van Kirk & Gamblin, 2000). The water from this headwater drainage is used to irrigate a quarter of a million acres of southeastern Idaho cropland. The Henry's Fork drainage has been identified as one of the most vulnerable and ecologically irreplaceable areas within the GYE (Figure 2) (Noss et al., 2002).

Figure 2. Megasite Irreplaceability vs. Vulnerability of sites in the Greater Yellowstone Ecosystem (Noss et. al, 2002).

Dams have been used to control flows in the Henry's Fork watershed since the early 1920s causing changes in the river's hydrologic regime. The hydrologic regime of a river is defined by magnitude, timing, frequency, duration and rates of change of stream flow (Poff et al., 1997). A river's natural hydrologic regime is determined by regional climate, geology, topography and vegetative cover and is the primary driver of ecological processes in the stream channel and riparian areas (Petts, 1984; Poff & Ward, 1990; Gore, 1994; Poff et al., 1997). The alteration of hydrologic regimes is often cited as the most serious and continuing threat to ecological sustainability of rivers and their associated ecosystems (Ward et al., 1999).

Flows from Henry's Lake, in the headwaters of the Henry's Fork, have been controlled since 1923 by a dam constructed by North Fork Reservoir Company (NFRC) on the Henry's Lake Outlet (the Outlet). The Outlet conveys water from Henry's Lake reservoir to Big Springs (Figure 3). Recently, quality of recreational fishing has declined, and is attributed to an increase in sedimentation. The Outlet has been identified as the major source of sediment to the upper Henry's Fork (Figure 4) (Wesche, 1992; Stumph, 1995; Wesche, 1996). The majority of the sediment delivered into the upper Henry's Fork comes from the Outlet (HabiTech, 1997), even though the Outlet and its tributaries account for only about 20% of the total annual flow in the upper Henry's Fork (VanKirk & Burnett, 2004).

In addition to the flow management practices below the dam, historic channel straightening (or "channelization"), overgrazing of livestock, and a highly altered hydrograph have caused a heightened level of erosion and a compromised ecosystem.

With the exception of the Teton River, in reaches affected by the failure of the Teton Dam in 1976, the Outlet is the most altered stream channel in the entire Henry's Fork watershed.

Figure 3. Map of Henry's Fork watershed showing the three major rivers and primary geological provinces (Henry's Fork Foundation).

Figure 4. The Outlet was identified as the major source of sediment to the upper Henry's Fork (Wesche, 1992; Stumph, 1995; Wesche, 1996).

The morphology of natural channels is a function of flow, sediment transport, the nature of bed and bank materials, vegetation and valley slope (Hey, 1992; Baker & Walford, 1995). Natural channels are dynamic systems that are continually responding to disturbances in order to reach a state of equilibrium. As land within a watershed is developed, managers must often choose between maintaining infrastructure and human use and protecting natural systems. Ideally, the managed hydrologic regime of a river reflects the natural one, maintaining dynamic stability. Thus far, however, economic and socio-political demands have precluded restoration of the natural hydrologic regime of the Outlet, and thereby are granted preference over protection of the natural systems.

1.1 Research Objectives

The research presented in this thesis reviews the literature related to channel morphology and streambank stabilization, with the ultimate goal of suggesting management strategies to reduce sedimentation in the Henry's Fork watershed and to restore, or at least maintain, the ecological integrity of upper Henry's Fork. Recognizing interactions between the flow regime and ecological processes in the river is necessary to develop ecologically sound flow management strategies. The present study focused on physical aspects of hydrology that influence ecosystem function; chemical and biological effects of streamflow were beyond the scope of this research. The specific research objectives were to:

1. propose strategies to reduce sediment deposition in Island Park Reservoir originating from drainage of upstream agricultural land, and
2. provide community, governmental, and private stakeholders with direction and incentives to cooperate in implementing long-term solutions to current sedimentation problems in the upper Henry's Fork watershed.

Research was conducted with the understanding that identifying specific cause-effect relationships in complex systems is difficult, that management of the Henry's Fork watershed involves cooperation by many different interest groups, and that decisions concerning management policies are ultimately made by political systems that are not necessarily guided by the results of scientific research. The conclusions were made with recognition that Idaho's current water laws make restoration of this watershed to its original natural state impossible.

2.0 LITERATURE REVIEW PART I: THE NATURAL FLOW REGIME

2.1 Introduction

Scientific research has undergone significant change over the last several decades. What would have been claimed unnatural and unlikely acts of scientific collaboration several decades ago are increasingly becoming the norm. These acts point to a trend in scientific research that renowned biologist E.O. Wilson dubbed “consilience,” that is, bridging the gaps between branches of knowledge to enhance understanding of the natural world. The study of waterways is likewise experiencing intensive revision through interdisciplinary exchange.

Traditionally, fluvial geomorphologists were concerned with abiotic factors such as stream flow, sediment movement and channel morphology, while biologists focused on the biotic components of streams. By linking research from both disciplines, rivers are now often studied as integrated eco-geomorphological systems (Heede & Rinne, 1990; Fisher, 1997). Over the past several decades, scientific research on biotic and abiotic aspects of fluvial environments has increasingly adopted a system perspective in which rivers constitute open systems characterized by fluxes of matter and energy. Following in this vein of consilience, this chapter will discuss principles of both disciplines to illustrate the compromised hydrological and ecological conditions impacting the Outlet, a waterway marred by highly altered flow regime, historic channel straightening (channelization), and overgrazing of livestock. Chapter 3 will explore the disruption of these processes as evidenced in the Outlet.

2.2 Ecological Integrity of Stream Ecosystems

The 1972 U.S. Water Pollution Control Act Amendments (now called the Clean Water Act (CWA), section 101(a)) set a standard for defining a river's health. It reads: "The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Congress chose the word "integrity" to convey a concept that refers to a condition in which the natural structure and function of ecosystems is maintained (Karr, 1999).

When human activities within a watershed are minimal, the biota is determined by the interaction of biogeographic and evolutionary processes in the regional climatic and geological context (Karr, 1999). Riverine landscapes are expansive, intricately interrelated systems whose functional and structural elements are determined by the river, its flow regimes and its surroundings (Jungwirth et al., 2002). When these landscapes are altered by human activity, resulting changes to the river's biota, and thus the entire biological context of the river, cause ecosystems to diverge from integrity.

Ecological integrity as defined by Angermeier & Karr (1994), is the ". . . maintenance of all internal and external processes and attributes interacting with the environment in such a way that the biotic community corresponds to the natural state of the type-specific aquatic habitat, according to the principles of self-regulation, resilience and resistance." The ecological integrity of rivers is a function of hydrological connectivity operating across a range of spatio-temporal scales (Amoros & Roux, 1988; Ward, 1989; Stanford & Ward, 1993).

2.3 Hydrologic Connectivity as a Continuum

Figure 5. The Hydrologic Cycle.

Hydrological connectivity is the hydrologically mediated transfer of mass, momentum, energy, or organisms within or between compartments of the hydrologic cycle (Figure 5) (Pringle, 2001; Freeman et al., 2007). Hydrologic connectivity is understood in the global water cycle, in which the hydrosphere is seen as a single hydrological system comprised of hydrologically connected components (Winter et al., 1998). Stream networks are characterized by a high degree of spatial and temporal heterogeneity with mass, momentum, energy and organisms flowing in four dimensions: longitudinally (i.e., channel-channel), laterally (i.e. channel-floodplain), vertically (i.e. channel-aquifer), and temporally (i.e. time-time) (Ward, 1989). This four dimensional model provides a useful framework for the discussion of the roles of hydrologic

connectivity in maintaining the physical, chemical and biological integrity of waterways (Figure 6) (Nadeau & Rains, 2007).

Figure 6. Stream and river structure (Mekong River Commission for Sustainable Development).

Hydrologic connectivity is essential to maintaining the ecological integrity of ecosystems. Conversely, hydrologic connectivity also directs and facilitates the flow of exotic species, human-derived toxins and sediment in the landscape. Hydrologic connectivity at large scales is a formidable concept because of the inherent complexity of water movement within and between atmosphere, surface-subsurface systems and the ocean (Winter et al., 1998) and the extent and magnitude of human alterations (Pringle & Triska, 2000).

Scientific concepts of connectivity differ from legal definitions. Hydrologist view connectivity as a continuum because the entire landscape is hydrologically connected (Figure 7). Biological connections among waterbodies are not restricted to water flow pathways (e.g., migratory birds, amphibians and aquatic insects all travel across watershed boundaries). Legally, however, the concept of connectivity extends only by virtue of stream's direct hydrologic and biological linkages to interstate or navigable waters. Given the complexity of hydrologic connections, it is essential that political and legal determinations of thresholds of connectivity be informed by scientific understanding of connectivity and ecological functions at larger scales.

Figure 7. The hydrologic pathways connecting the landscape to streams and rivers.

2.3.1 Channel Stabilization and Equilibrium

Stream systems naturally strive to achieve a state of dynamic equilibrium.

This basic principle of fluvial geomorphology holds that a river channel's form—its cross-sectional shape, planform, and gradient—is adjusted so that the amount of sediment delivered to the channel from the watershed is sustained in long-term balance with the capacity of the stream to transport and discharge that sediment (Leopold et al., 1964; Leopold & Bull, 1979). It is this balance between deposition and erosion that renders a stream stable (Leopold & Wolman, 1960; Leopold & Langbein, 1966; Hey, 1990).

Understanding alluvial channel behavior, channel response to disturbances and stable channel forms can be accomplished by concentrating on those factors that directly control the balance or imbalance between applied forces and boundary resistance. This requires correctly identifying active processes. If force and resistance are generally in balance over a period of years, a channel reach will not experience net erosion or deposition, and will transport the bed-material sediment load delivered from upstream reaches.

Lane's (1955) classic description of channel stability states that dynamic equilibrium exists between stream power and the discharge of bed-material sediment. Figure 8 illustrates that the product of sediment load and sediment size is proportional to the product of stream slope and discharge, that is, stream power. A change in any one of these variables causes rapid physical adjustment in the stream channel.

Figure 8. Lane's scale of dynamic equilibrium (Rosgen, 1996).

One of the principle geomorphic tasks of a stream is to transport particles out of the watershed. In this manner, the stream functions as a transporting “machine”, and as a machine, its rate of doing work can be calculated as the product of available power multiplied by efficiency. The balance between force and resistance indicates a stability of channel dimensions and is mathematically expressed as the stream power proportionality (Lane, 1955). *Stream power* can be calculated as:

$$\Psi = \gamma Q S$$

Where:

Ψ = Stream power

γ = Specific weight of water

Q = Stream discharge

S = Slope.

Sediment transport rates are directly related to stream power (i.e., slope and discharge). Baseflows that follow the highly sinuous thalweg (the line that marks the

deepest points along the stream channel) in a meandering stream generate little stream power; therefore, the stream's ability to move sediment (i.e. *sediment-transport capacity*) is limited. At greater depths, the flow follows a straighter course which increases slope, causing increased sediment-transport rates.

Stream power is the power *available* to transport sediment load. Critical power is the power *needed* to transport sediment load. The threshold of critical power is the point at which stream power/critical power = 1.0. Where stream power exceeds critical power during long time spans, additional sediment load is obtained.

The stream power equation indicates that if available stream power were augmented by an increase in the discharge or the gradient of the stream, there would be an excess amount of stream power relative to the discharge of bed-material sediment whose resistance is a measure of particle diameter. A similar response would be expected from a decrease in the erosional resistance of the channel boundary, or a decrease in the size of bed-material sediment. In contrast, a decrease in available stream power or an increase in the size or discharge of bed-material sediment would lead to aggradation on the channel bed.

Other factors, such as changing land use in the drainage basin (leading to adjustments to the flow regime), increased sediment supply, climate change and succession of riparian vegetation, likewise influence the rate at which equilibrium of the stream is reached (Thorne, 1998; Nunnally, 1978).

2.3.2 *Spatial and Temporal Scale*

Because streams are open systems, an alluvial channel adjusts to altered environmental conditions (indicated in the stream power equation). Scour and/or fill may occur over the course of a storm hydrograph, but this does not necessarily indicate

instability, because the short time period of the event is not indicative of progressive change over a period of years. For example, a stream may undergo drastic adjustments in its form due to the impact of a large flood or other natural stochastic event, however, a stable form is eventually recovered (Figure 9). Many rivers exhibit significant morphological changes when viewed over decades or centuries and are still considered stable. On the other hand, these same rivers may be classified as unstable when changes are observed over a short time, such as in response to a single hydrologic event.

Figure 9. Relationship between recovery time and sensitivity to disturbance for different spatial scales associated with stream systems (Frissell et al., 1986).

The important distinctions between the processes of scour and degradation, and fill and aggradation are issues of scale. The management of any organism requires an understanding of responses to environmental change, but these vary not only in space, but also in time (Durance et al., 2006).

For example, temporal aspects of channel behavior are based on a snapshot in time, providing no means of determining the magnitude, frequency or duration of processes, and neglect the history of the landscape system. This example highlights the importance of time scales in interpretation and analysis of channel form. In a classic paper, Schumm and Lichty (1965) demonstrate how even the dependency of variables can change as a function of the time scale considered. Variables describing channel form are indeterminate over geologic time, dependent over medium time scales and independent over short time scales.

Several different classification systems describe spatial and temporal scales associated with stream systems. Frissell et al. (1986) proposed a hierarchical organization of a stream system (Figure 10) to encompass the relationships between a stream and its catchment.

Figure 10. A spatially nested hierarchical organization of a stream system and its habitat subsystems. (Frissell et al., 1986).

Six hierarchical system levels were named: watershed, stream, segment, reach, habitat (or pool-riffle) and microhabitat systems. Each system develops and persists at a

characteristic spatial and temporal scale, and smaller-scale systems develop within the constraints set by the larger-scale systems of which they are a part (Frissell et al., 1986).

A fluvial system consists of the physical/abiotic (hillslopes, channels, river networks, etc.) and the biological/biotic (terrestrial vegetation, riparian and riverine habitat, etc.) environment which interact across a range of scales in space and time. At the drainage basin (i.e. watershed) scale, the sensitivity of the fluvial system to disturbance is low but the recovery time is long, while at the river habitat scale, the sensitivity is high but the recovery time is short (Frissell et al., 1986). The degrees of resilience and resistance circumscribed in this model hold important implications for understanding the dynamics of fluvial systems, as well as their management.

2.3.3. Sub-levels of Systems: The Example of the Watershed Scale

At the watershed scale, stream channel formation is governed by climatic change and geologic resistance to weathering. These factors may influence the watershed characteristics over hundreds of thousands of years (Kern, 1995).

The watershed can be sub-divided into three zones: the Production Zone, Transfer Zone, and Deposition Zone (Figure 11, Table 1). The headwater area, or Production Zone, contains the smallest streams in the watershed, that is first and second order streams (Figure 12). This area also consists of the steepest sloping streams that may be intermittent or ephemeral, with flow characterized as turbulent. In terms of hydrology, the headwater streams receive the smallest flows, as their contributing drainage areas are limited in size. Headwater streams are often carved out of the topography due to the force of overland flows alone, and not as a result of major geologic

events. The headwaters typically consist of a high density of finger-like tributaries and provide the main source of sediment for the watershed (McRae, 1997).

Figure 11. General zones of a river based on dominant physical processes (FISRWG, 1998).

Headwaters Zone:	Transfer Zone:	Deposition Zone:
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Main source of water and sediment for a river system. Water and sediment are generally moving from the watershed to the channel.	Principle region of sediment transport in a river system. Channel and valley become larger, more developed.	Region of sediment dispersal and deposition. River has a well developed valley over which the channel is free to meander. At its mouth, the river may divide into multiple channels as it flows across a delta of built up sediment into the receiving water body.
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Table 1. General zones of a river based on dominant physical processes

Figure 12. Stream ordering in a drainage network. “1” represents first order streams, “2” second order streams, etc. (FISRWG, Federal Interagency Stream Restoration Working Group).

The mid-reach, or Transfer Zone, contains first to third order streams. It is characterized by less turbulent flow, gravel substrate and moderately fluctuating stream temperatures. The large river section, called the Deposition Zone, consists mainly of large third and fourth order streams, This zone is distinguished by less turbulent flow and higher, more stable temperatures, as well as a bed composed of sands and mud. While bedrock channels are usually found in headwater regions, they progressively grade into alluvial channels downstream.

2.4 Sediment Transport in Channels

Recent National Water Quality Inventory (NWQI) reports consistently implicate sediment as a leading cause of water quality impairment in rivers, streams and reservoirs. Accelerated erosion and sediment deposition have impaired the Henry's Fork and these adverse sediment impacts include harmful effects on recreation and water storage. The economic and ecological consequences of excessive sediment, deposition and transport problems will continue unless land-use and water management practices are changed.

It is necessary to isolate the various processes of accelerated sediment loadings in order to identify relative source contributions and to appropriately prescribe effective and practical mitigation. Sediment is naturally supplied to channels from surface erosion on slopes, mass wasting, stream banks and tributaries. Changes in land use, streamflow characteristics, and drainage patterns can alter the natural sedimentation rate. Historically, agriculture has been a main source of human-enhanced sediments in waterbodies. Farming in the U.S., for instance, accounts for an annual erosion loss of over three billion metric tons of soil. The discussion on the following pages provides a detailed summary of key principles associated with sediment sources and natural channel processes.

2.4.1 Sources of Sediment

Sediment is naturally-occurring material that is broken down by processes of weathering and erosion and is subsequently transported by fluvial processes. Streams naturally move and change their shape due to erosion and redistribution of bed and bank materials. The major anthropogenic sources of sediment to streams are agriculture (especially row-crop cultivation in floodplains and livestock grazing in riparian zones),

forestry (with logging roads contributing far more sediment than other practices, including clear-cutting), mining, and urban development. Of these, agriculture is by far the most significant source of anthropogenically derived sediment.

In the context of stream hydrology, sediment is inorganic and organic material that is transported by, suspended in, or deposited by streams. Sediment load, which is the quantity of sediment transported by a stream, is a function of stream discharge, soil and land-cover features, weather conditions, land-use activities, and many other factors. Sediment load carried by streams and rivers can be composed either of fine materials, mostly silts and clays, or larger materials such as sand.

Solid sediment load can be divided into two components on the basis of the mode of sediment transport: suspended sediment, and bedload sediment, each of which is produced by mechanical weathering processes, is clearly visible, and is able to settle out of water. Suspended sediment consists of silt-sized and clay-sized particles held in suspension by turbulence in flowing water. Bedload sediment consists of larger particles which slide, roll, or bounce along the streambed by the force of moving water. Dissolved load consists of inconspicuous material in solution moving downstream. It is produced by chemical weathering processes, and does not settle out of water.

Sediment yield is the total quantity of sediment transported from a watershed (drainage basin) at a given location in a given period of time. Low suspended sediment yields can be attributed to, among other factors, a region's low erosion rate. Permeable soils and low topographic relief, in general, help limit the availability of eroded material from within a watershed. Conversely, relatively impermeable soils and steep topography can yield high erosion rates and therefore greater sediment yield.

Excess sediment can profoundly affect the productivity of a salmon or trout stream (McHenry et al., 1994). The habitat complexity of a stream may be greatly compromised if there is a high sediment supply and negative effects extend to spawning, egg and alevin survival, rearing habitat and adult holding habitat (Frissell, 1992).

There are several processes by which altered hydrologic processes may increase sediment loads in the watershed. Increased and accelerated runoff response, commonly referred to as “flashiness”, suggests increased overland flow, increasing erosion rates and increasing sediment transport from hillslope to channel. In addition, developed land has often meant the eradication of buffer strips by riparian landowners, which may cause a significant increase in the amount of sediment and pollutants reaching a river channel. Several physical processes are associated with erosion and sediment transport that are highly sensitive to changes in streamflow and velocities. All of the processes are proportional minimally to the squared power of flow, while others are proportional to the fourth and up to the sixth power of flow (Cotton, 1999). With these relationships, a seemingly insignificant increase in watershed response, such as a 10% increase, can result in sedimentation processes accelerated by 21%, 46% and 77%, for processes proportional to the second, fourth and sixth powers of streamflow, respectively.

2.4.2 Aggradation and Degradation

As described above, erosion and deposition of sediment are natural processes that occur in stable streams. Aggradation and degradation are used to describe contrasting processes that can occur when a stream becomes unstable. Stream gradients become steeper (aggradation) or less steep (degradation) due to excess deposition or erosion of sediment. Aggradation and degradation are often the symptoms of problems within the

watershed, such as changes in land use or in hydrologic regime. A stream may also aggrade or degrade very quickly if the problem is caused by a very large storm event or a localized disturbance.

2.4.3 Bankfull Discharge

In 1978, Dunne and Leopold provided a generally accepted definition of bankfull discharge: “The bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels.”

The term bankfull was originally used to describe the incipient elevation on the bank where flooding begins. The bankfull stage is associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain (Leopold et al., 1964). This stage and its attendant discharge serve as a consistent morphological indices which can be related to the formation, maintenance and dimension of the channel as it exist under the modern climatic regime. The bankfull discharge does not transport the most sediment at one time, but cumulatively, it is the most effective at transporting sediment over time.

The bankfull, or effective, discharge is the discharge most efficient at doing work within the stream channel. Small storms occur frequently, but the resulting flows are incapable of moving much sediment or causing significant erosion. On the other hand, very large storms cause floods that potentially move substantial sediment and cause a large amount of erosion. The bankfull discharge, the flow which has the optimum combination of power and frequency, lies between these two extremes. This bankfull

discharge is usually the focus of stream restoration designs.

It is this discharge, along with the range of flows that make up an annual hydrograph, which governs the shape and size of the active channel. Bankfull discharge is associated with a momentary maximum flow that has an average recurrence interval of 1.5 years, as determined using a flood frequency analysis (Dunne & Leopold, 1978). Although great erosion and enlargement of steep, incised channels may occur during extreme fluvial events, it is the modest flow regimes that transport the greatest quantity of sediment material over time, due to the higher occurrence for such events (Wolman & Miller, 1960).

Figure 13 displays an example of the relationship between flow magnitude and frequency of flow occurrence. The dominant, effective or bankfull discharge is associated with the peak of cumulative sediment transport for a given streamflow magnitude and frequency of occurrence. The majority of work overtime is accomplished at moderate flow rates, as shown in the illustration.

Figure 13. Relations between discharge, sediment transport rate, frequency of occurrence and the product of frequency and transport rate (Wolman and Miller, 1960).

2.5 Streamflow and Its Alteration

Streamflow patterns are a major feature of stream ecosystems, critical to shaping aquatic communities (Resh et al., 1988; Poff & Ward, 1989; Poff et al., 1997). The natural structure and function of riverine systems are based on five components, all of which are affected by flow: hydrology, geomorphology, biology, water quality and connectivity. The objective of maintaining an adequate flow should be to sustain, rehabilitate or restore ecosystem processes through seasonal and annual regimes. Stream flow regimes must address in-stream and out-of-stream needs, as well as integrate biotic and abiotic processes (Annear et al., 2004). As a consequence of changes in streamflow

patterns, many rivers no longer support native species or sustain healthy ecosystems that can provide important goods and services (Poff et al., 1997).

2.5.1 Effects of Streamflow Alteration

Recent research concludes that streamflow is the “master variable” controlling riverine physical, biological, and chemical processes (Poff et al., 1997; Annear et al., 2004). Streambank erosion, habitat availability, and dissolved oxygen concentrations are examples of physical, biological, and chemical components that all are highly impacted by the flow regime, as flow affects the stream power, water depth, habitat connectivity, water temperature and numerous other factors. The quantity and timing of flow are critical to the function, health, and ecological integrity of riverine systems as they affect nearly every other process that occurs within the system.

When altered, streamflows exhibit changes in magnitude, timing, duration, frequency, and rate of change (Poff et al., 1997). Loss of water retention capacity within a watershed through land clearing, increased impervious surfaces (e.g., urban development), wetland drainage, and stream channelization leads to increased magnitude and frequency of high flows and more extreme low flows (Karr & Schlosser, 1978; Menzel, 1983; Poff et al., 1997). Groundwater pumping can also result in more extreme low flows and generally destabilizes streamflow (Poff, 1997; Wiley et al., 1997). Dam operation for flood control results in reduced magnitude and frequency of high flows (Poff, 1997), resulting in the loss of floodplain connectivity and habitat diversity (Copp, 1989; Sparks, 1995).

Streamflow increases can potentially alter the sediment transport relations and morphological character of rivers. The response of the stream to increased streamflow is

a function of both the stream type and the stability of the channel, as well as the magnitude and duration of flow changes. Flow increases due to water releases from a reservoir can create shear stress and stream power in channels leading to enlargement, degradation and excessive bank erosion. Decreases in flow or dewatering of mainstem channels can reduce the available energy of the channel to maintain transport capacity, thus the sediment delivered to the regulated stream by unregulated tributaries leads to aggradation.

2.5.2 Hydrologic Regime

The hydrologic regime of a river is defined by magnitude, timing, frequency, duration and rates of change of stream flow (Poff et al., 1997). Regional climate, geology, topography and watershed vegetative cover determine a river's natural hydrologic regime. As the primary driver of ecological processes in the stream channel and riparian areas, it directly and indirectly affects energy pathways, water quality, physical habitat, and biotic interactions (Petts, 1984; Poff & Ward, 1990; Gore, 1994; Poff et al., 1997). The ecological integrity in a riparian ecosystem is determined largely by hydrologic regime and geomorphology (Poff et al., 1997).

The alteration of hydrologic regimes is often claimed to be the most serious and continuing threat to ecological sustainability of rivers and their associated ecosystems (Ward et al., 1999). Alteration of the natural flow regime through impoundment and flow regulation for irrigation has severely compromised the ecological integrity of most of the world's rivers (Karr & Chu, 1999). This anthropogenic alteration can have profound direct and indirect effects on all aspects of aquatic and riparian ecosystem function.

The hydrologic regime of a watershed determines an array of geomorphic processes and properties and provides the link between rivers and the riparian zones, ultimately maintaining the diversity and functions of these increasingly threatened habitats (Stanford & Ward, 1993). In arid and semi-arid areas of North America, riparian zones comprise only one to two percent of the landscape but provide critical habitat for a large percentage of terrestrial species and account for the majority of biodiversity in these areas. The effects of their degradation do not end here, extending far beyond the river/riparian corridor (Patten, 1998).

As the role of hydrologic regime in maintaining stream and riparian ecosystem function has become more widely understood and accepted, an increasing number of river research and restoration efforts focus on assessment of hydrologic alteration and restoration of natural hydrologic regimes (Hesse & Mestl, 1993; Sparks et al., 1998; Galat & Lipkin, 2000; Wildhaber et al., 2000). With this enhanced knowledge, the metrics for determining hydrological standards have also adapted.

2.5.3 Analyzing Streamflow: The Natural Flow Regime

Beginning in the 1970s, the minimum stream flow concept served as the standard method for analyzing stream flow needs of aquatic organisms. But recent advances in stream ecology identify the importance of the entire flow regime. For example, the landmark synthesis paper of Poff et al. (1997) set the stage for the modern ecosystem-based approach. In this method, a watershed's natural hydrologic regime is used as the basis for determining effects of flow regulation on aquatic species, and for designing flow management strategies to optimize aquatic and riparian ecosystem functioning in regulated river systems (Figure 14) (Van Kirk, 2004).

Figure 14. The ecological integrity of river ecosystems depends upon their natural dynamic character (Poff et al., 1997).

Flow regime is a major component of the physical river environment and regulation through dam construction and diversions results in severe river ecosystem stress (Thomas & Sheldon, 1997). As a result, the need to allocate water to satisfy the needs of riverine ecosystems has been somewhat acknowledged (e.g. Richter et al., 1997) through restoration efforts.

2.5.4 Riverine Rehabilitation and the Need for Collaboration

Rehabilitation of the hydrological and ecological integrity of rivers is a major thrust of contemporary fluvial ecology (Callow & Petts, 1992). The restoration of river-floodplain systems requires expertise from a range of disciplines. This insight requires cooperation in interdisciplinary teams at all stages of the planning, implementation and evaluation process. Key disciplines in watershed restoration include geomorphology,

hydrology, landscape ecology, landscape planning, hydraulic engineering, and aquatic and terrestrial ecology.

In spite of the recognition for the need for interdisciplinary cooperation, communication between practitioners of hydrology and biology is weak, at best (Newbury & Gaboury, 1993). Pressing watershed issues in the 21st century will provide a testing ground for synergy and innovation between the two parties, hopefully resulting in creative solutions to riverine rehabilitation and restoration.

2.6 Summary

The short review of the central principles of fluvial geomorphology and related concepts presented here are important for understanding deviations from natural form and processes of river restoration. Accounting for ecological integrity, dynamic equilibrium, spatial-temporal scale, streamflow standards hydrologic regime, and natural flow regime is essential to proper planning, design and implementation of river restoration projects.

Understanding these principles and processes provides a baseline that may be applied in diverse riverine contexts to gauge watershed health. In the following chapter, the results of their disruption becomes evident through the examination of the Henry's Fork Outlet, a waterway dramatically impacted, and thereby compromised, by anthropogenic influence.

3.0 LITERATURE REVIEW PART II: ANTHROPOGENIC IMPACT ON THE HENRY'S LAKE OUTLET

Figure 15. Map of Henry's Fork Watershed. The Henry's Lake Outlet is the stream section between Henry's Lake Dam and Big Springs.

3.1 Introduction

The Henry's Lake Outlet (Figure 15) is an environment dominated by human activity and a stream channel geomorphology that is strongly influenced by anthropogenic factors. Many of the global demands placed on water systems are highlighted in this small corner of Idaho.

Two major human disturbances transpired in the 1920s, drastically altering the health of the waterway: dam construction and channel straightening. In 1923, the Henry's Lake Dam was constructed, impacting the Outlet's hydrology, primarily through changes in the timing, magnitude and frequency of low and high flows. These changes produced a hydrologic regime differing significantly from the pre-impoundment natural flow regime. Channel straightening, to more rapidly convey irrigation storage water from Henry's Lake to croplands lower down the watershed, affected both the abiotic and biotic components of the stream. Compounding these events, intensive livestock grazing dramatically reduced riparian and upland vegetation in the Outlet, triggering a loss of stream-bank stability and an increase in erosion.

Over the course of eighty years, the Outlet transformed from a complex, multi-channeled system with extensive riparian zones to a wide, entrenched, single-thread stream with narrow riparian zones (Figure 16 – 19). The Outlet provides a microcosm within a broader riverine system through which to examine the resulting deviation from natural processes due to anthropogenic influence, as well as explore options for watershed rehabilitation at the stream- and policy-levels.

Figure 16. Representative picture of the Henry's Lake Outlet (photo courtesy Henry's Fork Foundation).

Figure 17. Streambank erosion on the Outlet caused by anthropogenic influence (photo courtesy of Henry's Fork Foundation).

Figure 18. Streambank erosion on the Outlet caused by anthropogenic influence (photo courtesy of Henry's Fork Foundation).

Figure 19. Streambank erosion on the Outlet caused by anthropogenic influence (photo courtesy of Henry's Fork Foundation).

3.2 Disturbance and Response to Anthropogenic Alteration in Aquatic Ecosystems

Humans are increasingly impacting the world's ecosystems through a variety of disturbances such as changing land use, species introductions and extinctions, alteration of nutrient cycles, and the use of more than fifty percent of available fresh water (Vitousek et al., 1997). As the global human population grows, we will rely more heavily on aquatic resources for food, drinking water, and recreation (Naiman et al., 1998; Naiman & Turner, 2000; Jackson et al., 2001). In light of these increased demands, ecologists are challenged with making predictions about the response of aquatic ecosystems to changes in the abiotic and biotic environment under a variety of natural and anthropogenic disturbances (Pace, 2001; Carpenter, 2002).

Stream organisms maintain a complex relationship with the habitats they occupy, which can vary greatly across spatial, temporal, or taxonomic scales. Anthropogenic modification of ecosystems generally causes alteration to the temporal regime of natural variation and disturbance. Although stream ecosystems are a product of historic geologic and climatologic attributes, large-scale human disturbances can change the landscape. The combined effects of a highly altered hydrograph, channelization, and livestock grazing on the Outlet has caused long-term deleterious effects, resulting in an increase in sediment, discharge and temperature, and a decrease in dissolved oxygen levels (Figure 20). Each of these human-caused disturbances contributes specific challenges to the overall integrity of the watershed.

Figure 20. Maximum, mean, minimum (1972 - 2008), and Water Year 2008 discharge in Outlet (data from Water Year 2008 are PROVISIONAL; data from USGS Gage 13039500 Henrys Fork near Lake ID).

3.3 Dams and Reservoirs

Although anthropogenic alteration of hydrologic regime can and does occur via changes in vegetative cover, channelization of streams, urbanization, and groundwater withdrawals (Vorosmarty & Sahagian, 2000), dams usually cause the greatest hydrologic alteration attributable to human activity (Magilligan et al., 2003). While they provide numerous socioeconomic benefits, considerable re-evaluation has revealed significant ecological costs associated with their development.

Dams profoundly affect river hydrology, primarily through changes in the timing, magnitude, and frequency of high and low flows (Benke, 1990; Ligon et al., 1995; Power et al., 1996; Graf, 1999; Graf, 2001; Magilligan & Nislow, 2001; Nislow et al., 2002), ultimately producing a hydrologic regime differing significantly from the pre-impoundment natural flow regime (Poff et al., 1997). The most common geomorphic alterations observed downstream of dams are caused by decrease in the magnitude and

frequency of peak flow events. These changes include an increase in fine sediment in the stream channel, simplification of the channel and the aquatic habitat it provides, and disconnection of riparian areas from the stream system (Ligon et al., 1995; Collier et al., 1996). The combination of these indirect (habitat change) factors and direct effects on fish life cycles (e.g., loss of physical cues to initiate spawning behavior) (King et al., 1998) has exacerbated the widespread replacement of indigenous fish species with non-natives (Bain et al., 1988; Freyrer & Healey, 2003; Hughes & Noss, 1992; Scheidegger & Bain, 1995; Richter et al., 1997).

The resulting reduced floodplain inundation causes a loss of native riparian vegetation in both humid and arid climates (Collier et al., 1996; Meriglanio, 1996; Patten, 1998; Nilsson & Berggren, 2000; Magilligan & Nislow, 2001; Stromberg, 2001; Nislow et al., 2002). In arid and semi-arid areas of North America, riparian areas comprise only one to two percent of the landscape. However, the effects of their degradation extend far beyond the river/riparian corridor, as they provide critical habitat for a large percentage of terrestrial species and account for the majority of biodiversity in these areas (Patten, 1998). A watershed's hydrologic regime defines geomorphic processes and properties and provides the link between rivers and the riparian zone, ultimately maintaining the diversity and function of these increasingly threatened habitats (Stanford & Ward, 1993).

Although popular with certain stakeholders, the thrust for the removal of dams has received less public and political support in recent years. In the meantime, management strategies of flow regulation have emerged as more viable options for channel and riparian restoration. While stakeholder concerns tend to focus on the highly

visible dam structures themselves, the greatest risk to watershed health from dams emanates from a more subtle threat, that is, sedimentation, a process discussed in further detail at the end of this chapter.

3.4 Channelization

Channelization is the group of engineering practices used to control flooding, improve drainage for irrigation, drain wetlands, improve river channels for navigation, control stream bank erosion and improve river alignment (Brookes, 1988). Research in fluvial geomorphology has shown that stream channelization results in decreased spatial variation of channel morphology (Rhoads & Urban, 2003). Through this variation, channelization also affects biotic factors like species diversity (Brookes, 1988). Studies in stream ecology indicate that decreased spatial variation of channel morphology results in decreased habitat diversity and a corresponding decrease in species diversity (Swales, 1988).

Consequences of channelization can be divided into those which occur within the modified reach and those repercussions which arise beyond the modified reach as a consequence of connectivity in the fluvial system, especially in the downstream direction (Brookes, 1987). While the immediate effects of channelization are well noted, the downstream impacts are only now beginning to take shape in the Henry's Fork. The accumulating sediment downstream, in the Island Park Reservoir, is threatening the downstream trout fishery, broadening the area of ecological disturbance.

Numerous studies conducted in Europe and North America over the last two decades demonstrate that the channelization of rivers has wide-ranging adverse effect on river ecology (Simpson et al., 1982; Swales, 1982). A stream's response will be evident

through changes in stream morphology (Brookes, 1988; Rhoads, 1990). Bed forms are eradicated, producing smooth bed topography and uniform velocity and sediment conditions. The decrease in channel roughness results in an increase of flow velocity and this may have direct ecological implication in-stream, because many aquatic organisms require specific water velocity for optimal health (Milner et al., 1981).

Channel straightening produces a steeper channel slope and therefore, higher shear stresses and erosive forces (Conyngham, 2007). This results in head cutting (channel down-cutting) and side cutting as the channel tries to re-establish a meander pattern. As a response to the immediate increase in bed gradient, the channel will widen (Ritter, 1979), which may lead to channel instability through increased stream power (Rhoads, 1990). In a natural system, channel width and depth are adjusted to flow regime and any destruction of this equilibrium may lead to the erosion of bed and bank material, with elevated concentrations of suspended material and subsequent sedimentation (Wolman & Miller, 1960). The removal of bank-side vegetation and decreased soil stability are likely to lead to increased sediment load to rivers (Karr & Schlosser, 1978). Because most streams receive their chief source of energy in the form of organic matter (Cummins, 1979), often as tree leaves and terrestrial invertebrates associated with the vegetation canopies, losses of bank side vegetation may also substantially reduce energy flow in the aquatic system.

The elimination or modification of natural river features such as channel meandering and pool-riffle pattern, combined with other major changes in river morphology and hydrology, can be particularly damaging to fish populations (Jenkins et al., 1984). Post-impact studies carried out in channelized streams and rivers demonstrate

significant reductions in fish community diversity and abundance, together with changes in community composition as a direct result of changes in fish habitat conditions (Swales, 1982). Most of these investigations evaluate the short-term impacts of river channelization. However, other studies carried out some time after the completion of channel alterations show that the ecological changes produced through channelization may continue for many years (Trautman & Gartman, 1974; Hurtle & Lake, 1983).

The recovery of fish populations from the effects of channelization depends largely on the re-creation of suitable habitat conditions which, in turn, is determined by the morphological recovery of the river (Simpson et al, 1982; Swales, 1982).

3.5 Livestock Influences on Stream and Riparian Ecosystems

Cattle currently graze on more than 250 million acres of public land (US-GAO, 1992) throughout the continental U.S. Numbers of cattle have significantly increased in the western United States in the 20th century (Trimble & Mendel, 1995); between 1940 and 1990, the number of cattle in the western U.S. (AZ, CA, CO, ID, MT, NM, NV, OR, WA, WY) increased from 25.5 million to 54.4 million (US Census of Agriculture). This common livestock species is recognized as a key agent of current and historical riparian and stream channel changes throughout much of the West (Trimble & Mendel, 1995). Livestock grazing affects watershed hydrology, stream channel morphology, soils, vegetation, wildlife, fish and other riparian-dependent species, and water quality at both the local and landscape scales.

Because riparian and stream ecosystems represent only 0.5 to one percent of the surface area of arid lands of the eleven western United States (US-GAO 1988; Ohmart, 1996), they were historically ignored by land managers. Altogether, less than 20% of

potential riparian habitat in the western United States still exists (USDI, 1994). In spite of mild improvements in grazing management, the increased number of cattle suggests that grazing impacts will likely continue.

Recent studies document that livestock grazing remains a key factor in the continued degradation of riparian habitats (US-GAO, 1988; Szaro, 1989; Platts, 1991; Fleischner, 1994; McIntosh et al., 1994; USDI, 1994; Ohmart, 1996). Extensive field observations in the late 1980s suggest that riparian areas throughout much of the West were in their worst condition in history (USE-EPA, 1995). Riparian areas continued to decline such that today, 20% of the riparian areas managed by BLM are non-functioning, and 46% are functioning at risk (USDI, 1994).

Heavy grazing on upland communities impacts riparian areas primarily by increasing runoff and erosion. Cows directly reshape the earth by compacting the soil. They weaken biological resistance and trample and loosen soil, changing its susceptibility to both water and wind erosion (Trimble & Mendel, 1995). This leads to reduced water infiltration and increased runoff, soil bulk density, erosion, and sediment delivery to streams. In addition, cattle form trails and terracettes (also called “bovine terraces”) (Trimble & Mendel, 1995), which are also subject to erosion.

Plants on undisturbed uplands and streamsides slow the downhill flow of rainwater, promoting its infiltration into soils. Water that percolates into the ground moves downhill through the sub-soil and seeps into stream channels throughout the year, creating perennial flows. As livestock removes upland and riparian vegetation, and as hillsides and streambanks are compacted by their hooves, less rainwater enters the soil and more flows overland into streams, creating larger peak flows. This process was

illustrated in a simulation by Trimble and Mendel (1995), who estimated that peak storm runoff from a 120 hectare basin in Arizona would be two to three times greater when "heavily" grazed than when "lightly" grazed. Moderate and high rainfall events in grazed sites are, therefore, more likely to result in high energy and erosive floods, which deepen and reshape stream channels.

Where streams flow over deep soils or unconsolidated substrates, the erosive energy of floods causes channel downcutting, or incision. As the channel deepens, water drains from the flood plain into the channel, causing a lowering (subsidence) of the water table. The roots of riparian plants are thereby left suspended in drier soils. Eventually, riparian plants and their associated wildlife species are replaced by upland species such as sagebrush (*Artemesia* spp.) and juniper (*Juniperus* spp.), which can tolerate these drier soils. Additionally, with less water entering upslope and riparian soils, less is available to provide late-season flows. Consequently, the high intensity floods of the spring and early summer are often followed by low and no flow in late summer and fall.

Healthy riparian areas also act as giant sponges during flood events, raising water tables and maintaining a source of stream water during dry seasons. The result is a more stable streamflow throughout the year (US-GAO, 1988).

Damage can be reduced by improving grazing methods, herding or fencing cattle away from streams, reducing livestock numbers, or increasing the period of rest from grazing (Armour et al., 1994; Elmore & Kauffman, 1994). With improved livestock management, previously denuded streambanks may revegetate, and erosion may decline (Elmore & Kauffman, 1994), but recovery will take longer than if grazing were terminated completely (Myers & Swanson, 1995; Ohmart, 1996).

3.6 Sedimentation

Aside from dam failure due to faulty design or natural hazards, reservoir sedimentation is the greatest threat presented by these structures. A sharp increase in global water storage occurred between the 1960s and 1980s galvanized the construction of dams and reservoirs, and the ensuing siltation problems are now becoming evident.

Alluvial channels are channels which flow through sediments of clay, silt, sand and gravel materials that were previously deposited (Brooks, 1992). These channels generally experience bank failure due to toe erosion, over-heightened or steep banks, or internal pore pressure (Bowie, 1995). Floodplain, bank and aquatic (submerged) plants all play a role in forming channels. Before addressing the role of anthropogenic factors in streambank erosion, it is important to understand the suite of input parameters that affect bank stability (Hey, 1990).

Streams can be classified as stable, eroding or aggrading. Eroding streams experience progressive downcutting or widening. Conversely, aggrading streams experience deposition of sediment. Both processes are the byproduct of an imbalance of system inputs and outputs (Nunnally, 1978). A stable, or “regime,” stream is defined as one that exhibits a balance between sediment supply and the ability of the river to transport that sediment (Hey, 1990). While dams notably contribute to destabilizing sedimentation in regime streams, channelization and livestock grazing also trigger detrimental sedimentation.

3.7 Summary

Riverine landscapes protect essential hydrologic functions (e.g. flood peak reduction, retention of water and nutrients, groundwater recharge) and various other

benefits to human societies, (e.g. opportunities for hunting, fishing, recreation, education and research, and aesthetic and economic values (Henry & Amoros, 1995; Sparks, 1995). Preserving or re-establishing the natural form and processes of riverine systems is one of the most important tasks of modern water management) (Ward & Tockner, 2001). Human alterations in riverine landscapes cause not only ecological, but also socio-political and economic consequences (Jungwirth et al., 2002). Maintaining or restoring the ecological integrity of riverine landscapes is therefore an important goal at the stream and policy-levels.

Channel alterations disrupting natural river form and process are so prolific that it is difficult to find healthy reference reaches to serve as templates for restoration. The historic alteration of the Outlet has left the channel incised and disconnected from its floodplain. An incised channel is more unstable, has reduced spatial habitat heterogeneity, and often contains shifts in biological community structure (Sheilds et al., 1998). Limited flood dissipation areas increase the instream power during flooding because incised channels hold limited mechanisms of energy reduction. The result is often continued channel incision.

Conceptually, comprehensive resource management at the watershed or ecosystem level is essential to successful restoration efforts. Any attempt to implement truly comprehensive ecosystem management must address the physical, chemical, evolutionary, and ecological processes that interact to produce rivers and their landscapes. Because most restoration efforts aim at explicitly biological goals (e.g. return of fish), a more integrative model is needed to protect the health of rivers (Karr, 1999). In the case of the Outlet, the anthropogenic impacts of dam construction,

channelization, and livestock grazing were eventually addressed at the local level through the multi-dimensional lens of geomorphology and biology by diverse stakeholder interests, providing a case study for discussion in Chapter 6. Addressing these impacts at the policy-level, however, proves more difficult, a topic for exploration in Chapter 7.

4.0 SITE CHARACTERISTICS

4.1 Introduction

The Henry's Fork flows 45 river miles, from the Outlet of Henry's Lake to the southern boundary of the Upper Henry's Fork Subbasin at Ashton Dam (Figure 21). After exiting the subbasin, the river continues in a southwesterly direction for 79 miles through the Lower Henry's Fork Subbasin before reaching its confluence with the South Fork of the Snake River. The Henry's Fork and South Fork join near Menan Buttes in Madison County to form the Snake River.

The Henry's Fork Subbasin encompasses 1,068 square miles, including 30 square miles in Wyoming and 60 square miles in Yellowstone National Park (Whitehead, 1978). The northern extent of the subbasin is bounded by the Continental Divide, which also delineates the boundary between Idaho and Montana. The eastern boundary of the subbasin is marked topographically by the Yellowstone Plateau, and meanders east and west of the Idaho-Wyoming state line. The southwestern edge of the subbasin is the northeastern extent of the Snake River Plain geologic formation, and does not coincide with any political boundaries.

The subbasin is located within the Greater Yellowstone Ecosystem, and possesses many of the unique geological, scenic, recreational, and wildlife attributes for which Yellowstone National Park is valued, with the majority managed by the U.S. Forest Service (USFS). The economy of the region has historically been based on livestock grazing and timber production, with cultivated agriculture limited to the southern edge of the subbasin. Irrigated agricultural lands outside the subbasin are supplied with water stored in two subbasin reservoirs: Henry's Lake and Island Park.

Figure 21. Hydrologic unit codes for the Uppers Henry's Fork and adjacent Idaho subbasins. The confluence of the Henry's Fork and South Fork in the Idaho Falls subbasin marks the beginning of the Snake River (IDEQ-IFRO, 1998).

Figure 22. Map of Henry's Lake Outlet highlighting the wet meadow complex of Henry's Lake Flat in blue.

4.2 Study Area

The present study focused on the Outlet, a stream section located in the Henry's Fork watershed. The Outlet is the stream channel which conveys water from Henry's Lake reservoir to Island Park reservoir, beginning below Henry's Lake dam and flowing through the Henry's Lake Flat (the Flat), an extensive wet meadow complex on alluvial sediments with springs, seeps, and creeks contributing to the flow of the Henry's Fork (Figure 22). The Flat is characterized by level to gently undulating swale topography. Elevations range from 6,332 to 6,430 feet (1,930 to 1,960 meters). A mosaic of wet and

seasonally wet meadows covers most of the Flat. Much of these meadows are flood irrigated during the growing season via an extensive ditch system. Large portions of the Flat were converted to hay meadows in the past, and livestock grazing continues to be the main land use. As a result, introduced pasture grasses dominate the vegetation in many places. Communities dominated by upland vegetation, such as mountain big sagebrush and bunchgrass, are limited.

4.3 Climate

The climate of the Upper Henry's Fork subbasin is considered the harshest in Idaho due to low winter temperatures. The record low statewide temperature of -59.8°F (-51°C) was recorded at Island Park in 1943 (Abramovich et al., 1998). According to long-term records collected at National Weather Service and Natural Resource Conservation Service (NRCS) climate stations, average monthly temperatures range from a minimum of approximately 2°F (-16.6°C) at Island Park in January to a maximum of 81°F (27.2°C) at Ashton in July (Table 2). Temperature extremes for the subbasin, recorded from 1961 to 1990, were 54°F (12.2°C) at Island Park in 1982, and 96°F (35.5°C) at Island Park and Ashton in 1961 (ISCS, 1998).

Monthly precipitation records for the Upper Henry's Fork subbasin are consistent with regional weather patterns. Precipitation is greatest during November through June, and most falls as snow (Table 2). Due to temperature differences between the central and southern portions of the subbasin, Island Park receives more than twice as much snow as Ashton, but only 50% more total precipitation.

Period	Average Maximum Temperature (°F)		Average Minimum Temperature (°F)		Average Total Precipitation (Inches)		Average Total Snowfall (Inches)		Average Snow Depth (inches)	
	Island Park	Ashton	Island Park	Ashton	Island Park	Ashton	Island Park	Ashton	Island Park	Ashton
January	25.9	27.9	1.9	9.2	3.76	2.11	47.6	22.5	38	19
February	31.6	33.3	4	12.7	3.14	1.81	37.5	16.7	48	23
March	37.9	40.5	9.5	18.6	2.58	1.57	29.4	11.2	49	17
April	48	53.1	21.1	28.1	1.93	1.45	12	4.5	30	2
May	59.5	64.9	31.1	36.3	2.44	2.1	4.1	1.5	3	0
June	68.8	73.3	37.7	42.5	2.72	1.74	0.4	0	0	0
July	78.5	81.5	42.7	46.9	1.29	0.89	0.4	0	0	0
August	77.9	80.5	40.6	45	1.47	1.07	0.1	0	0	0
September	68.1	71.1	32.8	37.6	1.62	1.18	1.2	0.1	0	0
October	54.8	58.6	25.1	29.4	1.86	1.4	6.5	2.5	1	0
November	36.7	40.1	14.6	19.9	2.69	2	24.8	13.6	8	2
December	27.3	29.7	5.2	11.1	3.55	2.22	45	23.1	25	11
Annual	51.3	54.6	22.3	28.1	29.05	19.54	208.9	95.8	17	6

Table 2. Summary of climate data collected from February 1, 1937 to June 30, 1997 at Island Park1 and from August 1, 1948 to June 30, 1997 at Ashton (Western Regional Climate Center).

4.4 Hydrology

Spring snowmelt is the major source of runoff to streams and recharge to aquifers in the Upper Henry's Fork subbasin (Whitehead, 1978). Due to the volcanic nature of the drainage, most of the streams have a substantial degree of groundwater influence (Van Kirk & Benjamin, 2000). The hydrologic regime of these spring-influenced systems was altered throughout the system by water storage in Henry's Lake and Island Park Reservoir (Van Kirk & Burnett, 2004).

Discharge data for the subbasin have been collected near Ashton discontinuously since 1890 (USGS, 1996). Continuous record-keeping by the USGS began in 1920, with

six gauging stations currently operating throughout the subbasin. Annual mean discharges below Ashton Dam range from 996 cfs to 2,361 cfs, which corresponds to an average annual runoff of approximately 1.1 million acre-feet or 1,052 acre-feet per square mile of area drained (USGS, 1996). This runoff volume is almost twice that produced by either the Henry's Fork downstream near Rexburg, which drains 2,920 square miles, or the South Fork near Lorenzo, which drains 5,810 square miles (USGS, 1996).

4.5 Geology

Volcanic features dominate the Henry's Fork drainage, a result of the southwestward movement of the North American tectonic plate over the Snake River Plain-Yellowstone Hotspot (Link & Phoenix, 1996) that now lies beneath Yellowstone National Park (Hackett & Binnichsen, 1994). The continental crust melts as it passes over the hotspot, producing explosive eruptions of light-colored lava or ash composed of rhyolite. Rhyolitic volcanic eruptions coincide with collapse of calderas, topographic depressions above what had been magma chambers (Link & Phoenix, 1996).

There are more than 30 distinct geologic units within the Upper Henry's Fork subbasin (Figure 23, Table 3). These units include: metamorphic rock formed during the Precambrian Era, more than 4.5 billion years ago, shallow and deep marine materials deposited during the Paleozoic and Mesozoic Eras, more than 245 and 65 million years ago, debris left by the Bull Lake glaciations, 130,000 years ago (Good & Pierce, 1996), and a variety of volcanic materials formed as recently as 10,000 years ago.

Three of the geologic units, Plateau Rhyolite, Basalt, and Yellowstone Group, formed during relatively recent volcanic events and are responsible for many of the unusual topographic features of the subbasin. Island Park, the central portion of the

Upper Henry's Fork subbasin, constitutes a geological transition zone between the northeastern end of the Snake River Plain (Figure 24) and the western margin of the Yellowstone Plateau (Christiansen & Embree, 1987).

	Description	Water-bearing Characteristics
	Alluvium, colluvium, landslide and glacial materials deposited 10,000 years before present (yr. B.P.), consisting chiefly of unconsolidated silt, sand, and gravel.	<i>Yields adequate supplies of water for domestic and stock use. Very few irrigation wells are present in the area, but yields should be adequate for restricted irrigation use, at most places, from properly constructed wells. -- Whitehead 1978</i>
	Rhyolitic ash-flow tuffs of the West Yellowstone, Summit Lake, and Buffalo Lakeflows during the third volcanic cycle responsible for production of the Yellowstone Plateau (6-700,000 B.P.). Light grey, dense, lithoidal, fine grained to aphanatic. Angular to round phenocrysts of quartz, sanidine, clinopyroxene, orthopyroxene, fayalite, and sphene make up about 25 percent of volume of rocks.	<i>Generally unknown... the area contains no wells; but the unit has good permeability, as indicated by the rapid percolation of surface runoff to the subsurface and the presence of large springs downgradient at its base. No well-defined stream patterns on its surface. Important to the basin's water yielding capability. -- Whitehead 1978</i>
	Includes the Snake River Group and Falls River Basalt if the third volcanic cycle, and Warm River and Shotgun Valley basalts of the second volcanic cycle. Flows consist chiefly of olivine basalt. Generally, the younger basalts are of the aa and pahoe-hoe types, and older basalts are of the pahoe-hoe type.	<i>Yields abundant water for most uses. An important aquifer in parts of the area. -- Whitehead 1978</i>
	Rhyolitic ash-flow tuffs of the first (2 million yr. B.P.), second (1.3 million yr. B.P.), and the third (6-7,000 yr. B.P.) volcanic cycles, which produced Huckleberry Ridge, Mesa Falls, and Lava Creek formations. Phenocrysts of quartz, sanidine, and oligoclase are common; phenocrysts of clinopyroxene, fayalite, hornblende, chevkinite, allanite (?), apatite, and zircon are less common.	<i>Generally yields adequate supplies of water for domestic and stock use in this area. Highly permeable at places. But in other places, the unit is tightly welded and will not yield adequate supplies of water for irrigation use. Important to the basin's water-yielding capability. -- Whitehead 1978</i>
d	Igneous volcanic rocks formed less than 65 million years ago, and sedimentary and metamorphic rocks formed more than 65 million years ago. The volcanic rocks occupy a 15-square mile area centered on Sawtell Peak and another that extends from Mount Two Top to Reas Pass. Sedimentary and metamorphic consisting of limestone, dolomite, sandstone, siltstone, and quartzose sandstone are exposed along the Continental Divide.	<i>Unknown, but will probably yield enough water at most places for domestic and stock use. -- Whitehead 1978</i>

Descriptions of generalized geologic units in the Upper Henry's Fork subbasin and their water-bearing characteristics (Whitehead, 1978; Christiansen &).

Figure 23. Relief map of Idaho showing the location and elevation of the Snake River Plain.

The Island Park basin formed during three cycles of eruption of the Yellowstone volcano (Christiansen & Embree, 1987). The first cycle, approximately two million years ago, produced a volume of more than 588 cubic miles of volcanic material and formed the Huckleberry Ridge caldera, which extends 56 miles, from the west side of Island Park to the Central Plateau of Yellowstone National Park (Figure 25).

Figure 24. Map showing the Island Park Caldera and Henry's Fork Caldera.

The second cycle, approximately 1.3 million years ago, produced at least 67 cubic miles of material, and formed the Henry's Fork caldera, which is about 18 miles in diameter. This caldera, nestled against the northwest wall of the Huckleberry Ridge caldera, is commonly known as the Island Park caldera. The Henry's Fork Caldera is nested inside of the Island Park Caldera, and the two calderas share a rim on the western

side. The older Island Park Caldera is a much larger oval, and extends into Yellowstone Park. The smaller Henry's Fork Caldera is 18 miles (29 km) long and 23 miles (37 km) wide, and its curved rim is plainly visible from many locations in the Island Park area. The Henry's Fork river flows through the Henry's Fork Caldera and drops from the caldera at Upper and Lower Mesa Falls.

4.6 Soils

A soil survey of the western part of Fremont County was published by the United States Department of Agriculture (USDA) in cooperation with other federal and state agencies in 1993 (USDA, 1993). In the area of Fremont County located within the Upper Henry's Fork Subbasin, survey data are limited to private and state-owned lands, and lands managed by the Bureau of Land Management (BLM). The survey identified twelve general soil map units, each representing a distinct pattern of soils, relief, and drainage (Appendix A). Four of the units are located entirely within the Upper Henry's Fork Subbasin, four are partially within the subbasin, and four are outside the subbasin. General soil map units are subdivided into detailed soil map units, which are identified on soil survey sheets.

The northwestern edge of the Lower Henry's and Island Park watersheds includes general map unit 11 (Katseanes-Vadnais-Rock Outcrop), described as "very shallow, deep, and very deep, nearly level to very steep, well-drained soils formed in alluvium." The major uses are rangeland, summer homesites, woodland, and grazable woodland. The only bodies of water in this unit are unnamed perennial ponds and reservoirs in an area characterized by "slight" erosion hazard.

Henry's Lake Watershed includes three map units: general unit 2 (Fourme-

Raynoldson-Trude), “very deep, nearly level, very cold, well-drained soils formed in alluvium,” unit 3 (Bootjack-Chick Creek), “very deep, nearly level, very cold, poorly drained soils formed in alluvium,” and unit 12 (Raynoldson-Kitchell-Lionhead), “very deep, gently sloping to very steep, very cold, well-drained soils formed in residuum and alluvium.” “Severe” erosion hazards and slopes up to 15% exist in unit 2, as well as detailed map units 83 and 41, which are adjacent to Henry’s Lake, Ingals Creek, Timber Creek, and Rock Creek. “Very severe” erosion hazards and slopes up to 55% exist in general units 3 and 12, as well as detailed map units 61, 47, and 126, which are adjacent to Howard Creek, Dry Fork of Targhee Creek, Targhee Creek, and Garner Springs. Major uses in these areas are rangeland, pasture, summer homesites, woodland, and grazable woodland.

Surveyed land in the central and northern part of the subbasin is used as range. The use of rangeland is limited mainly by the short growing season and wet soils in spring. All soils are saturated during spring runoff. Most areas are dry by mid-June, but low-lying areas in Island Park are not dry until July. Crop production is also limited by the short growing season, as well as the hazards of wind and water erosion. Water erosion caused by spring runoff is a particular hazard in the survey area, and recommended conservation practices include minimum tillage, chiseling, terracing, establishing grassed waterways, and maintaining permanent plant cover.

4.7 Vegetation

The lower elevations of the Henry’s Fork Subbasin lie in the Snake River Basin/High Desert ecoregion (Omernik, 1987). Prior to the development of cultivated agriculture in the subbasin, elevations below 1,800 meters (5,906 feet) were primarily

grassland and shrub steppes. Dominant species included wheatgrasses (*Agropyron* spp.), needlegrasses (*Stipa* spp.), Idaho fescue (*Festuca idahoensis*), big sagebrush (*Artemesia tridentata*), rabbit brushes (*Chrysothamnus* spp.), bitterbrush (*Purshia tridentata*), and serviceberry (*Amelanchier alnifolia*) (Marston & Anderson, 1991). Most of these native grassland and steppe communities have been replaced by cultivated cropland.

The higher elevations of the subbasin lie in the Middle Rockies ecoregion. The vegetation types consist of Rocky Mountain juniper (*Juniperus scopulorum*), lodgepole pine (*Pinus contorta*), and Douglas fir (*Pseudotsuga menziesii*). Aspen groves (*Populus tremuloides*) often occur at the steppe-forest transition. Mixed forests of Engelmann spruce (*Picea engelmannii*) and Subalpine fir (*Abies lasiocarpa*) are found immediately below the tree line. High alpine meadows occur in all of the subbasin's mountain ranges.

Riparian vegetation assemblages are dominated by sedges (*Carex* spp.) along spring-fed streams, willows (*Salix* spp.) along most other high-elevation streams, and cottonwoods (*Populus* spp.) along low-elevation streams (Jankovsky-Jones & Bezzerides, 2000).

5.0 MANAGEMENT OF HENRY'S FORK WATERSHED

5.1 Introduction

On both the local and global scale, the control of water remains an enduring and contentious natural resource conflict. The overall aridity of the western United States continues to shape this conflict in many rural communities, not only because of its scarcity, but because livelihoods depend upon it. For instance, without irrigation along the Snake River, Idaho could not have established its well-known socio-cultural identity as the leading potato producer (Van Kirk & Benjamin, 2000).

The Henry's Fork of the Snake, the headwaters of the Snake River located just west of Yellowstone National Park, is fed from countless natural springs. The geothermal nature of the area provides an abundance of nutrients for an ideal environment for aquatic insects and vegetation. The rich and abundant natural resources of the Henry's Fork have historically attracted the Shoshone and Nez Pearce Indian tribes, explorers, trappers, and livestock operations. Today, the Henry's Fork attracts people from around the world in pursuit of yet another resource, the large rainbow trout that have made the Henry's Fork famous. The settlement pattern of agricultural and leisure interests under the strain of limited land and water have made conflicts between agricultural and recreational uses more pronounced.

5.2 Irrigated Agriculture

5.2.1 The Snake River

The Snake is an intensely managed river. As irrigated agriculture in Idaho expanded throughout the 20th century, its growth spurred the development of complex dams and reservoir storage systems. On its journey through sections of Wyoming, Idaho,

and Washington, it passes through twenty-five dams. Its waters are used to produce hydroelectric power and to irrigate approximately 4.1 million acres of agricultural land. Today, approximately 21.6 billion gallons of Idaho's water are used each day for agricultural purposes (Mahler et al., 1991). Idaho's per capita water consumption is second in the nation only to California, and irrigators use almost 90 percent of the state's diverted water on more than 4.1 million acres of farm land.

The Snake is the United States' tenth longest river (Palmer, 1991). From its headwaters in Wyoming's Yellowstone and Teton National Parks, the Snake follows 1,056 miles, dropping 9,500 feet in elevation, to its confluence with the Columbia River in Washington. With its approximate flow of 37 million acre-feet of water per year, the Snake is the principal tributary to the Columbia River. The West Coast's most eastern seaport, located 465 miles from the Pacific Ocean on the Snake, is Lewiston, Idaho.

5.2.2 The Henry's Fork of the Snake River

Located in the upper reaches of the Snake River, the Henry's Fork watershed provides irrigation for over 250,000 acres and sustains a world-class trout fishery. The Henry's Fork is a major tributary to the Snake River and partially overlies the Eastern Snake River Plain Aquifer. In addition to its importance to the agriculture and economy of the basin, its contribution to the Snake River Plain aquifer is significant. Past estimates of this inflow have been on the order of 10% of the ground water budget to the aquifer (deSonnevill, 1974). The Henry's Fork is heavily managed to store and deliver irrigation water to irrigate the world's largest seed potato agriculture production area (Van Kirk & Gamblin, 2000), and to generate hydroelectric power. Even during normal precipitation

years, natural surface flows in the Upper Snake River basin during the peak irrigation season are fully appropriated (IDWR, 1997).

5.3. History of Human Settlement and Water Use in Eastern Idaho

The Mormons are generally given credit for pioneering simple but extensive modern irrigation systems, especially in the western United States (Reisner, 1986). With Mormon settlement in the 1860s, large-scale irrigation came to the Snake River Plain. One of the world's largest and most successful networks of gravity flow canals was built near the town of Rexburg, Idaho (Figure 26). Under the prior appropriations doctrine, competition for water increased and irrigation districts formed to help reduce local water conflicts. As Idaho grew, private water projects at the turn of the century gave way to larger state and federal projects and dams, many of which still operate. Such large-scale water projects symbolize southeastern Idaho residents' utilitarian valuation of water.

Figure 25. Land and water use near Rexburg: canals, farms, irrigation-enhanced wetlands, new subdivisions.

As the water rights to the Henry's Fork were acquired by irrigators downstream and the Snake River plain was developed by sophisticated irrigation systems, the Henry's Fork saw a change in dynamic. Its tributaries attracted homesteaders, ranchers and wealthy investors – a settlement pattern of agriculture and leisure interests that would inevitably conflict decades later. With the extension of railroads to West Yellowstone, the Island Park area grew into a tourist community known for its fisheries and scenic attractions.

As more settlers arrived, limits on land, water and resources became more apparent and conflicts between agricultural and recreational users became more pronounced. Because the waters in the Upper Snake River basin were already appropriated for irrigation and livestock use, river management decisions were driven by agricultural interests.

5.4 Water Development Projects on the Henry's Fork

5.4.1 Henry's Lake Dam

In the 1923, the Henry's Lake Dam was built at Henry's Lake on the Henry's Fork to create storage reservoir dedicated to expanding irrigated acreage in the Upper Snake River Valley. Due to their deep, well-drained volcanic soils, the communities of St. Anthony, Ashton and Driggs were well suited for growing potatoes and grains. To meet the rapid development of agricultural lands and the continued demand for water, in 1938 the Island Park Dam was built downstream from the Henry's Lake dam.

The Henry's Lake Dam was constructed in 1923 by North Fork Reservoir Company on the Henry's Lake Outlet, dramatically increasing the surface area and capacity of Henry's Lake. Hydrologic alteration in the Henry's Lake Outlet between 1972 and 2002 was extreme, with high alteration in more than half of the measured years,

resulting in the elimination of normal base flows, excessive sedimentation, and loss of wetland function (Van Kirk & Burnett, 2004). Alteration in this reach is the highest of any reach in the watershed.

Water is typically stored in Henry's Lake during the natural spring runoff period and then released in mid to late summer, when the outlet would have historically carried relatively little flow, effectively reversing the normal hydrograph. This situation is exacerbated by the fact that Henry's Lake's storage capacity is roughly twice the average runoff from the lake's small catchment basin, making the lake difficult to fill. It is further problematic in that the lake's biologically and recreationally important fishery (in particular Yellowstone cutthroat trout) makes the maintenance of high lake levels a priority for resource managers. In addition to providing irrigation water to downstream users, the Outlet provides habitat for rainbow and native cutthroat trout. Recently, downstream recreational fishing has become less favorable and the decline has been attributed to the increase in sedimentation from the Outlet.

Because Henry's Lake is operated as part of the federal Upper Snake River Reservoir system, and NFRC stockholders own space in Island Park Reservoir, Henry's Lake management has varied little since the Island Park Reservoir commenced operation in 1938. This management has allowed the lake to be maintained typically at or near full pool, creating a world-famous recreational trout fishery, while significantly limiting the ability to provide ecological base flows in the outlet.

5.4.2 Channelization of the Henry's Lake Outlet

To more rapidly convey water from Henry's Lake to croplands further down the watershed, historical channel straightening on the Outlet was completed in the 1920s. The diverted Henry's Lake Outlet has been identified as the major source of sediment to

the Henry's Fork watershed (Wesche, 1992; Stumph, 1995; Wesche, 1996). The straightened channel resulted in a steeper channel slope and therefore, higher sheer stresses and erosive forces. These processes led to head cutting (channel down-cutting) and side cutting as the channel tried to re-establish a meander pattern. Because the new channel is also shorter than the natural channel, it is likewise steeper. The increased gradient in the constructed channel resulted in bank and bed erosion and thereby increased downstream sedimentation.

5.4.3 Island Park Reservoir

Island Park Reservoir is a 135,000 acre-feet (167 million cubic meter) irrigation storage reservoir that was completed in 1938 (Figure 27). It is owned and operated by the U.S. Bureau of Reclamation, and stores water owned by the Fremont-Madison Irrigation District (and other water rights holders) as part of the Eastern Idaho Minidoka Project (Van Kirk & Benjamin, 2000). Island Park Dam, a 73-foot earth-fill dam, contains the water, which is released from the lower level of the reservoir.

Figure 26. Island Park Dam.

5.4.4 Cattle Grazing on the Henry's Fork

Bison, antelope, moose, elk and deer have grazed the Henry's Fork watershed for thousands of years. Cattle and sheep have grazed the Henry's Fork watershed for the past century. As was typical of livestock grazing practices over other areas of the West, the Henry's Fork watershed was overgrazed from the turn of the century to the 1960s.

During the grazing heyday, more than three million sheep and cattle grazed the watershed (Brooks, 1986). Today, livestock numbers have been drastically reduced, thanks in part to the Henry's Fork Foundation, but some grazing problems remain, particularly on the Henry's Lake Outlet.

5.5 Henry's Fork Fishery

Voted "Best Trout Stream in America" by Trout Unlimited members in 1998, this stretch of water is one of the most unique and revered fly fishing locations in the United States. Over the past decade, however, researchers and anglers agree that the health of the river has declined. Less fish, smaller insect hatches, and a reduction in the quality and quantity of aquatic habitat are the product of a complex set of factors affecting the river. As a result, the legendary fishing which made the Henry's Fork such a special place has also suffered.

Recreation is a major new economic player in in-stream flow protection and regulation (Abeln, 2004). In 2002, anglers spent approximately \$423 million in Wyoming. Anglers spend approximately \$46 million annually on the Henry's Fork and South Fork of the Snake River in Idaho and would spend \$32 million more each year if the fishing were better (Loomis, 2005). Recreation instream flow will be a useful policy tool in the future (Bonham, 2006).

Not only does the decline of the Henry's Fork threaten a world-renowned trout fishery, it threatens habitat identified as a reintroduction site for the native Yellowstone cutthroat trout (YCT) (*Oncorhynchus clarki bouvieri*). The YCT has long been the aquatic icon of the GYE and is a keystone species in the headwaters of the Henry's Fork because of its ties up and down the ecological ladder. The YCT is the only trout native to the Henry's Fork Subbasin (Behnke, 1992), and historically was present in all of the Teton and Henry's Fork watersheds, with the possible exceptions of Split Creek (an Island Park Caldera stream that sinks without joining another stream), the Fall River watershed upstream of Cave Falls, and alpine streams in the steep, mountainous parts the basin (Jaeger et al., 2000).

5.6 Concerns with Sedimentation

In the summer of 1992, sediment incidents plagued the watershed when the Island Park Reservoir was drawn down to a critically low level to satisfy irrigation demand. The reservoir pool reached a minimum elevation of 6,242.42 feet, which corresponds to a pool volume of 270 acre-feet (0.33 million cubic meters) (Gregory, 2009).¹ Before the gates were shut in late September, an estimated 50,000 to 100,000 tons of sediment were mobilized and leaked from the reservoir (Van Kirk & Griffin, 1997). Both organic and inorganic sediment were observed in the river below the dam during late October 1992. Tests to assess the chemicals contained in the sediment were not conducted.

It is unknown how much sediment has accumulated in the Island Park Reservoir since Island Park Dam was completed. Under certain conditions, accumulated sediment can regain momentum and move downstream, especially during reservoir drawdown like

¹ Full capacity is 135,000 acre-feet.

that of 1992. The event of 1992, during which sediment from Island Park Reservoir was mobilized into the Henry's Fork below Island Park Reservoir, will likely happen again in the future (Gregory, 2009).

It is important to note that sediment transport is a naturally occurring and ecologically important phenomenon in streams. Stream reaches below dams can become “sediment-starved” when the natural process of sediment transport into the reach is cut off artificially, with the potential for a variety of negative results. However, as soon as sediment inputs to a stream are increased due to manmade causes—such as grazing or poorly built infrastructure, or the accumulation and subsequent sudden release of sediment stored behind a dam—the natural balance is upset.

To offset the negative influence of sedimentation in the watershed, the Henry's Fork Foundation has spent considerable time and effort designing, implementing, and now monitoring a stream channel restoration project on the Henry's Lake Outlet as it flows through the Nature Conservancy's Flat Ranch.

5.7 Collaboration

5.7.1 The Henry's Fork Foundation

By the early 1980's, those familiar with the Henry's Fork watershed began to notice deteriorating watershed health. Low winter stream flows, fewer fish, vegetation changes, irregular or reduced insect hatches and more sediment embedded in the gravelly stream bottom were all indicators of distress. In addition to these symptoms of long-term damage, a new threat appeared. Hydroelectric projects were being proposed throughout the basin in response to federal incentives, threatening to dewater several river stretches. A small group of local residents and summer homeowners organized the Henry's Fork

Foundation (HFF) in 1984 in response to hydroelectric plans and a precipitous decline in river productivity.

The Henry's Fork Foundation was incorporated in 1984, and its first target was to begin a comprehensive program to create a cattle-free zone along the most sensitive and fragile streambanks on the Harriman Ranch. Ultimately, 20 miles of solar-powered electric fence, stretching from Last Chance to Pinehaven, fenced cattle away from the world's best known reach of spring creek. The HFF cemented its place in conservation history when it succeeded, through intensive lobbying and the help of Idaho Senator James McLure, in convincing Congress to pass legislation forbidding any new hydroelectric development between Island Park Dam and Ashton Dam. No fewer than four separate hydro projects had been proposed, threatening irreparable damage to the river.

The Henry's Fork Foundation is a nonprofit, member-based organization whose mission is to preserve and protect the unique qualities of the Henry's Fork watershed located in eastern Idaho. Members come from all corners of the United States as well as abroad, and work in diverse professions, but are drawn together through a common interest in the health of the Henry's Fork.

5.7.2 Henry's Fork Watershed Council

As interest and usage in the watershed diversified over time, the Henry's Fork weathered intense pressure to satisfy irrigation demand, hydropower requirements and in-stream flow needs for fisheries and recreation (Van Kirk & Benjamin, 2000). In 1994, the Henry's Fork Watershed Council (the Council) was organized and chartered by the

Idaho Legislature in order to facilitate a collaborative approach to resource decision-making in the watershed for the sake of improving governance of the watershed.

The Council is an innovative, collaborative forum comprised of citizens, scientists, and agency representatives with diverse interests who reside, recreate, work or have legal responsibilities in the watershed. This ensures a more collaborative approach to resource decision-making (Weber, 2000). The objectives of the Council are: to use stakeholder consensus to solve watershed problems and prioritize watershed projects; to respect and leverage the diverse interests held in the watershed; to understand, restore, and enhance watershed resources; and to strive to meet these objectives in a non-adversarial atmosphere that transcends jurisdictional boundaries (Weber, 2000).

The Council has been recognized as a significant and leading example in community ecosystem management that integrates the diverse needs and desires of the community. The Council's commitment to education, collaboration, and communication among over 24 government agencies and many water users hopes to achieve long-term management goals. The cooperation that has evolved provides the opportunity to work toward a healthier, more sustainable watershed.

5.7.3 The Nature Conservancy's Flat Ranch

Scientists have identified the Upper Henry's Fork Basin as one of the top priority sites in the West. In 1991, the National Office of The Nature Conservancy (TNC) designated the Henry's Fork as one of its "Last Great Places". Only 75 ecosystems were recognized by TNC scientists for such national recognition. The mission of TNC, the largest private land-protection organization in the United States, is to save "the last of the least and the best of the rest" (Jenkins, 1985) by protecting natural areas that harbor rare

species and communities and high-quality samples of all natural communities. In 1994, The Nature Conservancy of Idaho purchased the 1,600 acre Flat Ranch (formerly the Flying R Ranch), which is located in the Upper Henry's hydrologic unit and includes five miles of Henry's Lake Outlet, with the objective of protecting and enhancing the important wildlife values and aquatic natural community of the property.

The ranch is characterized by riverine influenced wet meadows embedded with spring creek aquatic systems and associated riparian wetlands. Long-billed Curlews (*Numenius americanus*) and approximately 200 pairs of Sandhill Cranes (*Grus Canadensis*) nest and stage on the Flat Ranch property each year. Raptors, waterfowl, and migratory songbirds likewise utilize the habitat on the property for essential behaviors such as hunting, foraging, nesting, and brooding. Wildlife such as moose (*Alces alces*), elk (*Cervus canadensis*), pronghorn (*Antilocapra americana*), and beaver (*Castor canadensis*) frequent the ranch for forage, travel, cover, and the rearing of young.

The section of outlet that flows through the ranch provides spawning habitat for an adfluvial population of Henry's Lake Yellowstone cutthroat trout. Unfortunately, fry survival seems to be limited (Gregory, 2000), and a fish ladder to allow passage back to the lake is lacking. Resident fishery consist primarily of rainbow and brook trout. This fishery is transitory and heavily influenced by irregular flow regimes and water temperatures.

The Flat Ranch provides education and recreational opportunities to visitors and members of the community. Restoration activities have included revegetation of the stream channel (streambank willow planting), riparian fencing, wetland restoration and development of efficient stock watering systems. TNC has operated the Flat Ranch as a

productive, viable cattle operation and has worked within the community to demonstrate that ranching and wildlife habitat protection are compatible practices. Although cattle grazing occurs on the Flat Ranch, a holistic rotational grazing plan is employed, and cattle are excluded from the riparian areas.

TNC recognizes the changing demographic trends in the GYE and has identified the area of Henry's Lake (including the Flat Ranch) as a critical migratory corridor for wildlife. The area provides a migration route for pronghorn antelope, spawning area for cutthroat trout, nesting area for sandhill cranes and offers the promise of a haven for Yellowstone's wildlife and the ranching lifestyle of the area, as the rest of the region will likely continue to experience exurban development.

5.8 Summary

Because of the river's socioeconomic importance to both the agricultural and recreational angling communities, conflicts over water resource management on the Henry's Fork date back to the 1970s. Because 99% of the consumptive uses of water resources in the state are directed toward agriculture, this sector will be instrumental in developing meaningful statutory and regulatory changes that will restore the rivers and protect the long-term viability of the economies, people, fish and wildlife that rely on them. Fragmentations of philosophy, policies and management objectives have plagued the Henry's Fork watershed.

6.0 HENRY'S LAKE OUTLET RESTORATION EFFORTS

6.1 Introduction

Many components affect the integrity of the natural ecosystems of the Henry's Fork watershed. In order to protect, maintain, and possibly restore ecological integrity, it is necessary to assess the state of the ecosystems within the watershed. Concerns over excessive sediment input into the Henry's Fork and its effect on fish habitat lead the Henry's Fork Foundation (HFF), in partnership with several conservation organizations, to explore options for reducing that input. The Henry's Lake Outlet was identified the main source of sediment to the Upper Henry's Fork watershed.

Beginning in 2002, the Henry's Fork Foundation began working with The Nature Conservancy in an effort to reduce sediment delivery downstream from the Henry's Lake Outlet. The goal of this effort was to restore a one-half mile section of the channel located four miles downstream of the lake. The meandering Outlet was bypassed by a straight constructed channel in the 1920s. The purpose of the constructed channel was to increase conveyance capacity of irrigation water from Henry's Lake to downstream water users. This was to be accomplished by rerouting flow from the channel constructed in the 1920s back into the historical channel. Subsequently, work towards designing, permitting, funding, and excavating the historic channel began, with the Foundation and the Conservancy working in tandem to execute the project.

6.2 Anthropogenic Impacts & Sedimentation

6.2.1 Channelization

In 2002, HFF contracted geomorphologist Jock Conyngham (River Research, LLC) to assess the situation and provide recommendations to alleviate the erosion and sedimentation problems. Conyngham's research concluded that the excessive sedimentation was a result of historical channel straightening on the Outlet which was completed in the 1920s to more rapidly convey irrigation storage water from Henry's Lake to croplands further south in the watershed. The straightened channel resulted in a steeper channel slope and therefore, higher shear stresses and erosive forces. These processes led to head cutting (channel down-cutting) and side cutting as the channel tried to re-establish a meander pattern. Because the new channel is also shorter than the natural channel, it is likewise steeper. The increased gradient in the constructed channel resulted in bank and bed erosion, and thereby increased downstream sedimentation (Table 4).

Conyngham recommended that an abandoned section of the outlet channel be reactivated to reduce sedimentation downstream. HFF's Outlet restoration project, begun in 2004, rerouted a half-mile long section of stream from an artificial delivery ditch to its natural, historic stream channel on property owned by The Nature Conservancy, the Flat Ranch. This project holds the potential to reduce sediment and improve habitat in the river reaches between the Flat Ranch and Island Park Reservoir, as well as set a precedent for future water management in the Henry's Fork watershed, using the tools of science while forging alliances across stakeholder groups to collaboratively address water issues.

Waterbody	Length surveyed (feet)	Percentage of Waterbody Classified Within the Following Erosion Categories			Percentage of Total Critical Area Under Contract ¹
		Slight ²	Moderate ³	Severe ⁴	
Henry's Lake	107,100	33	37	30	3
Henry's Lake Outlet	49,809	28	35	36	49
Duck Creek	20,811	77	21	1	86
Hope Creek	5,939	95	0	5	0
Howard Creek	28,646	79	14	7	100
Targhee Creek	26,953	48	12	41	100
Timber Creek	12,859	100	0	0	0
Tygee Creek	15,524	55	30	15	0
Twin Creek	11,338	52	48	0	13
Crooked Creek	46,973	100	0	0	0
Stephens Creek	10,702	85	7	7	50
Meadow Creek	12,574	67	33	0	0
Canyon and Jones Creek	17,617	63	13	24	10
Jesse Creek	16,349	17	59	25	19
Enget Creek	2,251	100	0	0	0
Hidden Creek	4,858	33	33	33	0
Rock Creek	4,148	0	100	0	44

1 Critical area includes portions of the waterbody classified as moderately and severely eroding.

2 Slight erosion indicated by a lateral recession rate of 0.01 to 0.05 feet per year.

3 Moderate erosion indicated by a lateral recession rate of 0.06 to 0.2 feet per year.

4 Severe erosion indicated by a lateral recession rate of 0.3 to 0.5 feet per year.

Table 4. Percentages of Henry's Lake shoreline and tributary streambanks classified by the *Henry's Lake SA WQP Final Planning Report/Environmental Assessment* (YSCD 1995) as slightly, moderately, or severely eroding. Moderately and severely eroding banks were designated critical areas eligible for receiving funding for treatment. The percentage of total critical area under contract for treatment is shown for each waterbody (Beckman and Bradford 1998).

6.2.2 Other Stakeholder Groups & Conflict

While the Foundation spearheaded the channel restoration effort, other stakeholder groups from the non-profit, government, and private sectors hold an interest in the results of this project. Since 2003, representatives from the Henry's Fork Foundation, The Nature Conservancy, Trout Unlimited, Idaho Department of Fish and Game, North Fork Reservoir Company, and Fremont-Madison Irrigation District have

met annually to determine winter flow conditions to balance the needs of the fishery and those of the irrigators. Because of a perceived lack of communication about the objectives and expected results of the restoration project, the Fremont Madison Irrigation District and the North Fork Reservoir Company submitted a protest letter in August 2005 to suspend work on the Flat Ranch restoration project. As a result, the parties came together to sign a memorandum of understanding (MOU).

Dated December 2006, the MOU provided for a three-year evaluation period which allowed the Henry's Fork Foundation and The Nature Conservancy to continue the work to restore the historical channel, bypassing the straightened channel, and to monitor water quality and sediment transport (Fremont Madison Irrigation District et al., 2006). In addition, the document stated:

"...therefore [the Henry's Fork Foundation] shall assure that the restored channel will have a carrying capacity of no less than 300 cfs together with the additional tributary flows which enter the restored channel throughout the entire reach of the restored channel" (Fremont Madison Irrigation District et al., 2006).

To honor these conditions, nonpartisan agencies have provided monitoring services to assess the Outlet conditions, and HFF has likewise conducted research to provide data to stakeholders.

6.3 Preliminary Results of the Henry's Lake Outlet Restoration Project

In 2008, the United States Geological Society (USGS) performed tests on the restored channel to determine the channel capacity (Appendix B). During the testing period, measured flows of 180 cfs resulted in out-of-channel flooding and sections of backwater along the restored channel. The results showed that the channel capacity was less than the 300 cfs agreed upon by the memorandum.

Since water was first diverted into the reactivated channel on 9 October 2007, flows have exceeded 200 cfs during approximately a one week period. Additionally, with the exception of a short spike in flows in early September 2008, flows recorded within the reactivated channel were within the range of those occurring post-1972.

While these preliminary results indicate successful stream restoration in terms of rerouting the water, and furthermore, provide important data for enhancing future research and monitoring, stakeholder groups responded with mixed responses to the decreased stream flow. Pressing questions arose, and the needs of distinct parties were identified to facilitate the stakeholder communication process.

Stakeholder Group	Identified Needs
<i>Irrigators</i>	<ul style="list-style-type: none"> • Maintain flexibility in storage and conveyance options to maximize efficiency of water delivery in wet and dry periods • Maintain ability to control quantity and timing of water deliveries to irrigation customers • Understand effects of vegetation on conveyance capacity and bank erosion
<i>Landowners</i>	<ul style="list-style-type: none"> • Maintain water elevations in Henry's Lake throughout summer for recreation and visual aesthetics • Stop artificial flooding of pasture land, at times when the pasture is used and not usually inundated • Minimize channel maintenance

<i>The Henry's Fork Foundation, The Nature Conservancy</i>	<ul style="list-style-type: none"> • Restore the natural condition and ecological function of the stream and floodplain • Understand whether the restored channel can maintain a condition of dynamic equilibrium and result in lower downstream sedimentation, minimize routine maintenance in the channel and minimize the use of artificial structures and channel protection • Improve riparian habitat in the Outlet to improve landscape function and ecological diversity
<i>All groups</i>	<ul style="list-style-type: none"> • Reduce bank erosion to minimize sediment source and loss of pasture • Reduce downstream sedimentation in the Henry's Lake Outlet and Island Park Reservoir • Understand sediment dynamics and transit times for any/all channels used to convey water • Understand sources of erosion within Henry's Lake Outlet • Understand effects of high flows in restored channel on tributaries (backwaters) and channel stability (bank erosion) • Maintain world famous trout fishery • Improve downstream water quality and aquatic habitat by reducing deposition of fine sediment • Equal benefit solution(s) • Restore cooperative and productive communication channels

Table 5. Stakeholder groups holding interest in the Henry's Fork Outlet Restoration Project and their identified needs.

6.3.1 Stakeholder Reactions to Preliminary Results

As the evaluation period expired, the Fremont Madison Irrigation District and the North Fork Reservoir Company raised concerns about flow capacity within the restored historic channel, riparian flooding, channel erosion and sediment loading to the system.

Several questions were raised, including:

- What is the effect of riparian vegetation in both the restored and straightened channels on conveyance capacity and bank erosion?
- Is there a solution to the conveyance issue that also meets the riparian restoration goals of The Nature Conservancy and the Henry's Fork Foundation?
- Can the problem be solved by equal benefit problem solving techniques, restoring goodwill within the Council?

During the group discussion process, distinct needs for each stakeholder group were

identified. Table 5 outlines the parties and their specific needs. While these groups continue to debate the costs and benefits of the project, possible ecological scenarios and management options for the restored and straightened channel should be considered to address some of these questions and concerns.

6.4 The Restored Channel

Two major management issues have been observed thus far in the newly restored channel: the water transport time (as noted in the preliminary findings), and the median sediment size. In the restored channel, the delivery of irrigation water downstream may take longer than in the past, so modifications in the timing of releases from Henry's Lake may be required. To decrease the conveyance time, vegetation can be removed from the restored reach. However, if vegetation is taken out to increase the conveyance it is likely that this could be a destabilizing influence on the channel and constant maintenance will be necessary to protect banks and maintain the conveyance.

The present analysis also reveals that the bankfull discharge in the restored channel can only transport fine sediments, and furthermore, that larger sediments on the channel bed only move at the highest flood flows. This supports the previous findings that the sedimentation in Island Park Reservoir is due to fine sediment (Wesche & Wesche, 1997). Adding larger sediment, such as gravel or cobbles, to the channel might mitigate the issue. Larger grain sizes may allow formation of riffle-pool sequences in the channel, which in turn would enhance aquatic habitat and also increase the median grain size in the channel.

The delayed transport time and sediment size should be addressed by managers, however, the ecological benefits of allowing water to flow through this channel should

not be overlooked. Managers may choose to make decisions with the optimal health of the ecosystem in mind.

As a result of the channel meandering across the valley floor, a floodplain is created adjacent to the stream's main channel. The overbank flows provide water, nutrients, and sediments to the floodplain, and these support the growth of riparian vegetation. The flood flows can reduce the vigor of upland vegetation, including some invasive species that may have encroached on the floodplain during the period of exclusion of the overbank flows. The increase in vegetation creates a positive feedback where future overbank flows would result in greater deposition of sediment and nutrients. The restored riparian area would provide habitat for several animal and plant species, a food source for aquatic macro-invertebrates, and shade for the stream during summer months.

The highest flows in local unregulated streams occur in the spring snowmelt months. The vegetation and animals that are endemic to this area therefore have adapted to the spring high flow regimes. These native populations are likely to benefit from high flows that occur earlier in the year, rather than the later inundation that occurred under the regulated flow regime. A few days of overbank flow during the early part of the growing season could contribute to the reduction of upland vegetation in the riparian area and may provide other benefits to aquatic life.

6.5 Options to Appease Irrigator Concerns: Back to the Straightened Channel?

The straightened channel maintains higher velocities than the restored channel, therefore, returning flow to the straightened channel presents another option to meet the water conveyance needs. The predicted sediment transport rate in the straightened channel is greater, and using the straightened channel would result in more downstream

sedimentation than if the restored channel were used, resulting in a situation similar to that prior to the restoration project. If this option were implemented, several management actions would have to take place to meet the expectations of non-irrigators.

Bank protection could mitigate some erosion, and would probably result in less sedimentation. Physical or vegetative protection as described above would be two management options to consider if flow was restored to this channel. Installing check dams or another means of sediment storage would reduce sediment transport rates, but these structures would affect flow capacity, require regular periodic maintenance, and would not reduce the occurrence of erosion.

If water were to be rerouted to the straightened channel, several considerations must be made, including creating new regulatory requirements, evaluating the effects of storage devices on the potential for overbank flows, and predicting downstream effects of the in-stream storage devices.

6.6 Summary

The frequency and duration of floodplain flows were reduced for more than 80 years due to the straightened channel and regulation of the flows in Henry's Lake Outlet. Once a state of dynamic equilibrium is attained, the sediment transport and flow regimes will be better balanced. The time period needed to restore the dynamic equilibrium to the reach is unknown, but probably is on the order of several years. Field monitoring of the rate of channel adaptation and the development of a hydrologic/geomorphologic model would help estimate the timing required to attain channel equilibrium. The results of this project provide important lessons in watershed management, however the sociological aspects of the endeavor are equally significant.

The Henry's Lake watershed is a complex system with multiple expectations and objectives from diverse interests and is therefore typical of many watersheds in the Western U.S. These objectives include managing lake elevations, reliability of irrigation deliveries, ecologic function of the stream and floodplain, and aesthetics. While each party holds special interests in the watershed, the unifying theme between them is the desire for mindful stewardship of the resource and minimization of uncertainties and conflict in management decisions every year. The Outlet Restoration Project points to the potential for non-profits to collaborate to address common concerns, and the ability of those same groups to cooperate with seemingly antithetical interests (i.e. irrigators) to debate management options and identify equal benefit solutions.

7.0 CURRENT WATER POLICY IN FREMONT COUNTY, IDAHO AS IT RELATES TO STREAMFLOW

7.1 Introduction

The West's most precious resource has reached a crossroads: water management, water law, and water policy present complicated challenges with few easy solutions.

Contemporary regional water decisions affect millions of people, demanding that decisionmakers place emphasis on problem solving and practical results instead of employing stale status quo approaches. Slowly, local communities, agencies, governments and stakeholders are forging negotiated resolutions that apply water fairly to the greatest number of beneficial uses. In Idaho, many stakeholders are taking notice of watershed-specific partnerships, such as that on the Lemhi River, which is home to a successful flow-leasing program.

While compromise has progressed in some areas, battles over water control have grown more heated and bitter as the stakes have risen. The Snake River Basin Adjudication, launched in 1987, was designed to address two criteria: to whom should water be allocated, and in which order. Idaho's water law has become so complex and salient since then that practices specializing in water law are among the most successful in the state, and an entire section of Idaho Code is devoted entirely to water.

7.2 The Significance of Water as Expressed in Idaho State Legislature

Water shapes Idaho's economy, culture, politics and society. In recent years, this single resource has dominated the state's legal landscape as well. Idaho's water laws are contained in Idaho Code, Title 42 (<http://www3.state.id.us/idstat/TOC/42FTOC.html>).

The Idaho Supreme Court has long noted that water is the foundation of much of Idaho's economic well-being. In *Kunz v. Utah Power & Light Co.*, 117 Idaho 901, 792 P.2d 926 (1990), the Idaho Supreme Court stated:

"Idaho's extensive agricultural economy would not exist but for the vast systems of irrigation canals and ditches which artificially deliver stored or naturally flowing water from Idaho's rivers and streams into abundant fields of growing crops . . . This Court has long been cognizant of the crucial role which artificial water systems serve in this state." *Id.* at 904, 792 P.2d at 929.

In *Miles v. Idaho Power Co.*, 116 Idaho 635, 778 P.2d 757 (1989), the Idaho Supreme Court wrote:

" . . . [t]he water of this arid state is an important resource. Not only farmers, but industry and residential users depend on it. Facilitating the settlement of competing claims to our scarce supply of water is an important governmental objective." *Id.* at 645-46, 778 P.2d at 767-768.

The same is true to claims of water quality as well as water supply, because quality affects the amount available for beneficial uses. The Idaho Supreme Court, in another context, noted that conflicting claims to water use on the Snake River " . . . are of large significance to the majority of the people of the state." *Idaho Power Co. v. State*, 104 Idaho 575, 578, 661 P.2d 741, 744 (1983).

Idaho's Constitution declares the state's waters a public resource, albeit a public resource in which private rights to use water may be obtained through an appropriation. Idaho's statutes, as well as comprehensive administrative regulations govern Idaho's water appropriation system. The state's water allocation system typifies many Western states, and likewise, raises questions and disputes.

7.3 Idaho's Water Allocation System

Two organizations oversee the important task of managing Idaho's water resources. The Idaho Department of Water Resources (IDWR) is responsible for regulating the use and appropriation of surface and groundwater water rights, protecting the state's stream channels, flood plains and groundwater, and conducting safety inspections on dams. The Idaho Water Resources Board (IWRB) is responsible for developing Idaho's water policy, including: developing and implementing the state water

plan, administering grants for water infrastructure development, appropriating minimum in-stream flows, and managing a state "water supply bank."

For over a century, Idaho has managed its water resources pursuant to the doctrine of prior appropriation, or "first in time, first in right." To appropriate water in Idaho, a party must submit an application and receive a permit from the IDWR (except for exempted single family domestic wells and in-stream livestock watering), and then put the water to beneficial use. When an IDWR hearing officer determines that an application meets statutory requirements, the agency issues a permit. After the permit holder develops the project and shows proof of beneficial use of the water, IDWR issues a license that describes the completed appropriation. In times of shortage, IDWR rations scarce water resources using the "first in time, first in right" principle.

Idaho has defined a number of provisions to consider stream flows, including the minimum stream flow statute, the consideration of local public interest criteria in water appropriation and transfer proposals, and the development of the state water supply bank and district rental pool system. However, most of these provisions have either substantive limitations or were not designed to specifically address stream flow needs especially in fully appropriated river systems. Some legislation has sought to address these shortcomings, with varying degrees of effectiveness.

7.4 Instream Flows and the Minimum Stream Flow Act

Instream flows were first recognized in the state in 1978 through legislation that established them as a beneficial use (IDWR 1978). Prior to this date, only agriculture, hydropower, mining and manufacturing were considered beneficial use and provided a legal water right in Idaho. In that same year, the Idaho Supreme Court (in *State*

Department of Parks v. Idaho Water Resources Department) confirmed that an appropriation of water does not require a physical diversion.

Idaho's instream flow program was further developed in 1978 when the state legislature adopted the Minimum Stream Flow Act. State law requires that instream flow rights be the ". . . minimum flow of water required to protect the fish and wildlife habitat, aquatic life, recreation, aesthetic beauty, navigation, transportation, or water quality of a stream in the public interest" (Idaho Code 42-1502(f)). The Act allows the IWRB to apply for and hold minimum stream flow rights through new appropriation (Table 6).

State recognized beneficial uses for water resources	
▪ Aesthetic	▪ Manufacturing
▪ Aquatic Life	▪ Mining
▪ Commercial	▪ Municipal
▪ Cooling	▪ Navigation & Transportation
▪ Domestic	▪ Power
▪ Fire Protection	▪ Recreational Use
▪ Fish Propagation	▪ Stock Watering
▪ Ground Water Recharge	▪ Water Quality Control
▪ Industrial	▪ Wildlife
▪ Irrigation	

Table 6. State recognized beneficial uses for water resources (Idaho Code 42-1502(f)).

The IWRB is the only entity that can apply for and hold new appropriations for instream flow water rights.² As with any water right in Idaho, the holder is limited to the

² Private ownership is possible on a temporary basis through water banks, described in section 7.5.

minimum amount necessary for the beneficial use. When applying for a new instream flow right, the IWRB must quantify the minimum amount necessary for the beneficial use indicated. In practice, however, the IWRB most often applies for all unappropriated water in a stream segment in order to protect aesthetic beauty and preserve the natural habitat.

Because unappropriated water is a scarce commodity in Idaho, the utility of the minimum stream flow statute is severely limited. The minimum stream flow levels are not met on rivers like the Henry's Fork because water was fully appropriated prior to the Minimum Stream Flow Act. Therefore, water is not available for the Board to apply for a minimum stream flow water right.

7.5 State Water Transfer Program

Instream flows may be established through water right transfers, but are limited to temporary transfers of storage rights. Storage water rights can be leased on an annual basis through the state's water banking program, described below.³ The depositor of the water, however, cannot specify their preferred intended use. In other words, an individual cannot deposit water in a bank and state that it must be allocated to instream flow. The renter of the water determines the use and water banks give preference to irrigation. The Lemhi River basin legislation offers one exception to this, in which an entity can deposit water in the water bank for the express purpose of instream flow. This exception is legislatively stipulated and resulted from endangered species concerns in the basin.

³ The federal government has effectively used this method in the past to augment stream flows for salmon.

Entities furthermore cannot transfer water rights to the water board to be held in trust for instream flow. In theory, a water right could be gifted to the IWRB and the IWRB could then apply to have it transferred to an instream flow right. Although permissible, this has not been attempted and it is not certain that the IWRB would have the political will to change the use to instream flow or that the process would not be challenged in court.

Water rights can be transferred directly between individual buyers on a permanent basis. This requires filing change of owner and change of use applications with the IDWR. Water rights can also be transferred on a temporary basis through Idaho's water banking program.

7.6 State Water Banking Program

Any entity can hold a water right in Idaho. The water right can be in the name of an individual, group of individuals, organization, corporation, government agency, etc. However, as mentioned previously, the Idaho Water Resource Board is the only entity permitted to apply for and hold instream flow water rights. An Idaho water rights holder is considered to hold real property right to that water, much like property rights for land. The constitution and statutes of the state of Idaho protect water rights as private property rights, which may be bought and sold. Idaho therefore hosts a thriving water market.

Idaho water banks are operated by the Water Resource Board and facilitate temporary water transfers. If a water right holder owns excess water, that water can be deposited in the water bank. An entity that needs water may then rent that water on a one year basis, paying the water right holder a fixed price depending upon the purpose and location of use.

A water right holder may abandon or forfeit a right. Abandonment requires proof of intent, whereas forfeiture occurs if the water right is not used for five consecutive years. Water rights lost through abandonment or forfeiture revert back to the state for further appropriation.

Idaho state water provisions present a legislative labyrinth through which policymakers, landscape managers, ranchers, conservation interests, and other stakeholders must navigate. Federal law further complicates these arcane state doctrines, in particular, law related to wildlife management.

7.7 The Endangered Species Act

The federal government, through the Constitution, maintains the ability to establish policy over wildlife and their habitat throughout the United States, which has been supported by the Supreme Court in numerous cases. The federal government's authority to regulate wildlife is exercised through federal laws such as the Migratory Bird Treaty Act of 1918, the Wild Free Roaming Horses and Burrow Act of 1971, and the Endangered Species Act (ESA) of 1973 and its amendments.

States hold strong authority over wildlife within their own borders. The state ownership doctrine established in the cases of *Martin v. Waddell* (1842) and *Geer v. Connecticut* (1896) cemented the right of individual states to manage and regulate wildlife within the state's borders. While wildlife are owned by no one, it is legislated that they are held in trust by the states for the benefit of the people. This has led to a protracted debate over the demarcations between state and federal authority concerning wildlife policy.

The mission of the U.S. Fish and Wildlife Service (USFWS) is theoretically preservationist in orientation and serves as the lead agency in designating and coordinating species and species habitat under the ESA, resulting in profound consequences throughout the Mountain West. The ESA, and thereby, the bureaucratic bodies by which it is implemented, are increasingly viewed as an impediment to economic development in the region, generating an “us versus them” mentality.

The Endangered Species Act of 1973 and its amendments have substantially impacted the actions and activities of federal management agencies, as well as private citizens. Sections 4, 7, and 9 are the most salient sections of the Act in the context of state wildlife management. Federal authority over wildlife has increased dramatically with the tenets outlined in Section 4 of the ESA, which grant federal authority over “critical habitat,” that is, wildlife habitat in which a species is threatened, in danger of going extinct, or currently extirpated throughout all or a portion of its range.

Section 7 of the ESA prohibits the federal government from undertaking any actions that would jeopardize a listed species and requires various processes of consultation and biological assessment in order to ascertain whether or not a species and its habitat will be put at risk by a proposed federal agency action. Section 9 prohibits any entity, federal government or private citizen from committing the “take” of a listed species, which includes activities that harm or harass a listed species.

The USFWS interprets “harm” in a broad and contentious manner, that includes not only the physical injury of a species, but also indirectly injurious activities, such as habitat alteration. This broad definition, coupled with the ability to curtail activities on

private property, has led to a number of court cases that have affirmed the agency's broad definition and application of the term.

In the Mountain West, the ESA arouses mixed feelings, as it is perceived as inflicting undue economic hardship on a minority of citizens (Marzulla 1996). This sentiment is characteristic of many public land users and private property owners. The restrictions placed on the use of federal land through section 7 of the ESA, coupled with the USFWS' broad interpretation of "harm," set the stage for potentially sweeping land policy change. However, restrictions placed on private property through section 9 have given rise to claims that regulation of private property under ESA is equitable to Fifth Amendment takings, not to be confused with "taking" as defined under the ESA itself. In a region such as the Mountain West, where dependency on public lands and the stalwart defense of private property are deeply ingrained social values, one can see how implementation of the ESA leads to conflict and volatility.

The Greater Yellowstone Ecosystem, and its subcomponent, the Henry's Fork watershed, contain lands managed and administered by countless agencies and private parties. Because the ecosystem and its wildlife do not fall under the arbitrary political boundaries of one specific agency, the potential for conflict to arise over wildlife policy is evident. The case of one aquatic species, the Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*), illustrates the dichotomy between state and federal perspectives on management.

Two legal attempts were made to list the species under the Endangered Species Act, the first in 2004 and the second in 2006. Although both attempts to list the species

have failed, the Act has nonetheless had a substantial impact on Yellowstone cutthroat trout policy at the state-level (Table 6).

- Idaho – Imperiled
- Montana – Species of Concern
- Wyoming – Species of Greatest Conservation Need
- Bureau of Land Management – Imperiled
- Forest Service – Sensitive
- Fish and Wildlife Service – Petitioned Candidate *

Table 7. State and Federal Yellowstone Cutthroat Trout Designations. *The petition to list the Yellowstone cutthroat trout was found ‘not warranted’ by the U.S. Fish and Wildlife Service on February 21, 2006. The final decision can be found posted in the Federal Register volume 71, number 34.

7.8 Summary

Like other western states, Idaho is facing an increased demand for essential, yet limited water supplies. With projections that Idaho’s population will increase by an additional one-half million people by 2025, the difficulty in meeting water demand will become even more challenging. Rivers and streams in the state face similar issues: water that is captured for irrigation delivery leaves tributary streams devoid of water during critical time periods, thereby debilitating their natural capacity.

Extreme polarization between conservation and agricultural interests presents a tremendous challenge. Idaho has yet to make modest adjustments to the existing water laws to benefit water users, fish populations, and the rivers. Diverse stakeholders, including traditional farm and ranch operations, state and federal resource agencies, and conservation interests, are working to address some of these issues, but are often delayed

because Idaho water law is prohibitively inflexible. As a result, many rivers and streams in Idaho continue to decline while controversy increases. However, with the projected change in demographics and the inevitable urbanization of rural areas, the highly utilitarian legislative values of the state will be put to the test, as new residents express their natural resources values.

8.0 SUMMARY

Like other western states, Idaho is facing an increased demand for essential, yet limited water supplies. With projections that Idaho's population will increase by an additional one-half million people by 2025, the difficulty in meeting water demand will become even more challenging. Rivers and streams in the state face similar issues: water that is captured for irrigation delivery leaves tributary streams devoid of water during critical time periods, thereby debilitating their natural capacity.

This paper reviews the central topics of natural channel form and process (Chapter 2.0), river system alteration (Chapter 3.0), a restoration project on the Henry's Lake Outlet (Chapter 6.0), and policy issues related to river restoration in the State of Idaho (Chapter 7.0). Spatial and temporal scale are key aspects of river structure and function, and the ability to properly identify disturbances and perform restoration at the appropriate scales is a major factor that determines the success of projects. At the root of impairment to the river corridor is the alteration of the balance between sediment and water. This equilibrium is fundamental for understanding change and rehabilitating natural process, and a useful foundation for investigating hydrologic alteration.

On-going debate in the legal and policy arenas continues to focus attention on the watershed scale. Based on the literature reviewed in this paper, scientific evidence supports the concept of connectivity and integrated hydrological systems. The impacts of flow augmentation, channelization and grazing on local riparian and stream environments and on stream morphology may be acute, but they also often extend far beyond their immediate surroundings. Streams connect uplands to lowlands, terrestrial ecosystems to

aquatic, and arid ecosystems to moist. They act as corridors for migrating animals, provide moisture for aquatic, riparian, and upland species, and distribute sediments and nutrients downstream.

A large-scale perspective is clearly important for informing jurisdiction, management and conservation decisions regarding activities that alter ecological integrity. Cumulative effects of channelization, hydrologic alteration (due to dams) livestock grazing and irrigation demands have had negative consequences on the integrity of the Henry's Fork with respect to important issues such as water quality, economically important fisheries, aquatic and terrestrial biodiversity and storage issues in the reservoirs due to sedimentation. We cannot discount the linkages between the Henry's Lake Outlet and the downstream problems in the Henry's Fork watershed, including sedimentation, regional decline in water quality, fisheries and biodiversity.

The goal of this research was to develop a framework for better management of future water withdrawals on the existing flow regime in the Outlet, with an emphasis on sustaining ecological flow conditions. The fundamental premise was that maintaining a stream's ecological integrity depends on maintaining an appropriate flow regime (magnitude, timing, frequency and duration).

Further scientific data are required to assess the impacts of altered streamflow, grazing practices and channelization on the Outlet ecosystem in order to promote wise resource decisions. An understanding of the complexity and dynamics of the key components of the ecosystem is needed in order to adaptively manage resources in the upper Henry's Fork watershed below Henry's Lake dam. In order to design realistic, effective and efficient restoration strategies that will meet ecological objectives, an

understanding of both the natural system and the extent to which it has been altered is needed.

The legacy of alteration in the Henry's Lake Outlet is quite extensive. Restoration attempts to correct the resulting degraded habitat and return some level of natural channel form and process has proven to be costly, risky, and ultimately ineffective over the long-term. Practitioners and managers must be faced with the ongoing challenge to attempt to relate science to decision-making and policy. There are many ways in which science can inform the process, although the existing political infrastructure has proven to be prohibitively inflexible. Although sound, scientific data is available to inform the process, in order to make that science useful requires an effective interface between science, policy and public participation. Strengthening that interface is critical for the Henry's Fork community to achieve effective water resource management in the watershed. Only then will comprehensive management plans be generated that move future watershed, river corridor, and channel activities towards the over-arching goal of natural channel form and process that lead to channels that are stable, self-sustaining, and capable of supporting a diverse biota.

This extreme polarization between conservation and agricultural interests presents a tremendous challenge. Idaho has yet to make modest adjustments to the existing water laws to benefit water users, fish populations, and the rivers. Diverse stakeholders, including traditional farm and ranch operations, state and federal resource agencies, and conservation interests, are working to address some of these issues, but are often delayed because Idaho water law is prohibitively inflexible. As a result, many rivers and streams in Idaho continue to decline while controversy increases. However, with the projected

change in demographics and the inevitable urbanization of rural areas, the highly utilitarian legislative values of the state will be put to the test, as new residents express their natural resources values.

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APPENDIX A:

Table 8. USDA Soil Survey for Henry's Lake Watershed.

General Soil Map Unit and Soil Survey Sheet Numbers	Detailed Soil Map Unit	Slope and Elevation	Erosion Hazard	Major Use	Dominant Vegetation or Crop	Waterbodies
2 Fourme-Raynoldson-Trude: Very deep, nearly level, very cold, well drained soils formed in alluvium	83 Raynoldson gravelly loam: 80% Raynoldson soil, 20% contrasting inclusions	2-15% 6,700 feet	Severe	Rangeland, pasture, summer homesites	Idaho fesue, slender wheatgrass, mountain brome, mountain big sagebrush	Henry's Lake Ingals Creek Rock Creek Timber Creek
	36 Henryslake gravelly loam: 80% Henryslake soil, 20% contrasting inclusions	0-4% 6,400 feet	Slight	Rangeland	Sedge, wheatgrass, mountain brome, tufted bairgrass	Henry's Lake Timber Creek
	47 Kitchell gravelly loam: 85% Kitchell soil, 15% contrasting inclusions	15-55% 6,900 feet	Very severe	Woodland, grazable woodland, homesites	Douglas fir, pine reedgrass, blue wildrye, mountain brome, Columbia needlegrass, mountain snowberry, low Oregongrape	
	61 Lionhead gravelly loam 85% Lionhead soil, 15% contrasting inclusions	20-55% 7,800 feet	Very severe	Rangeland, summer homesites	Idaho fesue, bluebunch wheatgrass, mountain big sagebrush	
	21 Fourme loam 85% Fourme soil, 15% contrasting inclusions	0-4% 6,500 feet	Slight	Rangeland, hayland, pasture, summer homesites	Idaho fesue, bluebunch wheatgrass, Nevada bluegrass, arrowleaf basalmroot	Duck Creek Henry's Lake Hope Creek Jesse Creek
	128 Tepete-Bootjack complex: 60% Tepete peat, 25% Bootjack silty clay loam, 15%	0-1% 6.650 feet	Slight	Non-irrigated pasture, rangeland	Tufted hairgrass, sedge, shrubby cinquefoil, Kentucky bluegrass, mountain brome, clover	Duck Creek Gillman Creek Henry's Lake Hope Creek

	contrasting inclusions					Kelly Creek
10	Bootjack silty clay loam: 85%, Bootjack soil 15% contrasting inclusions (Note: Area characterized by this soil unit is known as Antelope Flat)	0-1% 6,350 feet	Slight	Rangeland, building site development	Kentucky bluegrass, slender wheatgrass, mountain brome, sedge, clover	Henry's Lake

Appendix B—Table 5, continued.

General Soil Map Unit and Soil Survey Sheet Numbers	Detailed Soil Map Unit	Slope and Elevation	Erosion Hazard	Major Use	Dominant Vegetation or Crop	Waterbodies
2 Fourme-Raynoldson-Trade: Very deep, nearly level, very cold, well drained soils formed in alluvium	41 Judkins gravelly loam: 80% Judkins soil, 20% contrasting inclusions	1-15% 6,600 feet	Severe	Summer homesites, woodland, grazable woodland	Douglas fir, lodgepole pine, pine reedgrass, bluegrass, western snowberry, lupine, heartleaf arnica, slender meadowrue	Rock Creek
	126 Targhee loam: 90% Targhee loam, 10% contrasting inclusions	15-40% 6,400 feet	Very severe	Woodland, grazable understory, homesites	Douglas fir, lodgepole pine, pine reedgrass, bluebunch wheatgrass, Idaho fescue, bluegrass, sticky geranium, lupine, serviceberry, mountain snowberry	
	125 Targhee loam: 90% Targhee loam, 10% contrasting inclusions	1-15% 6,400 feet	Severe	Woodland, grazable understory, homesites	Douglas fir, lodgepole pine, pine reedgrass, bluebunch wheatgrass, Idaho fescue, bluegrass, sticky geranium, lupine, serviceberry, mountain snowberry	
	81 Pits, Gravel: Open excavations from which volcanic cinders on basalt plains and gravel and sand on alluvial plains and river terraces are removed	Not specified	Not specified	Not specified	Not specified	
	109 Sawtelpeak silty clay 75%	0-2%	Slight	Rangeland,	Sedge, tufted hairgrass, slender	Jesse Creek

	Sawtelpeak soil, 25% contrasting inclusions	6,450 feet		irrigated pasture	wheatgrass, clover	
120	Stamp loam: 85% Stamp loam soil, 15% contrasting inclusions	0-4% 6,400 feet	Slight	Rangeland, summer homesites	Slender wheatgrass, tufted hairgrass, sedges	

Appendix B—Table 5, continued.

General Soil Map Unit and Soil Survey Sheet Numbers	Detailed Soil Map Unit	Slope and Elevation	Erosion Hazard	Major Use	Dominant Vegetation or Crop	Waterbodies
12 Raynoldson-Kitchell-Lionhead: Very deep, gently sloping to very steep, very cold, well drained soils formed in residuum and alluvium	83 Raynoldson gravelly loam: 80% Raynoldson soil, 20% contrasting inclusions	2-15% 6,700 feet	Severe	Rangeland, pasture, summer homesites	Idaho fescue, slender wheatgrass, mountain brome, mountain big sagebrush	
	61 Lionhead gravelly loam: 85% Lionhead soil, 15% contrasting inclusions	20-55% 7,800 feet	Very severe	Rangeland, summer homesites	Idaho fescue, bluebunch wheatgrass, mountain brome, mountain big sagebrush	Howard Creek
	47 Kitchell gravelly loam: 85% Kitchell soil, 15% contrasting inclusions	15-55% 6,900 feet	Very severe	Woodland, grazable woodland, homesites	Douglas fir, pine reedgrass, blue wildrye, mountain brome, Columbia needlegrass, mountain snowberry, low Oregon grape	Dry Fk Targhee Ck Targhee Creek
	128 Tepete-Bootjack complex: 60% Tepete peat, 25% Bootjack silty clay loam, 15% contrasting inclusions	0-1% 6,650 feet	Slight	Non-irrigated pasture, rangeland	Tufted hairgrass, sedge, shrubby cinquefoil, Kentucky bluegrass, mountain brome, clover	
3 Bootjack-Chickcreek: Very deep, nearly level, very cold, poorly drained soils formed in	125 Targhee loam 90% Targhee loam, 10% contrasting inclusions	1-15% 6,400 feet	Severe	Woodland, grazable understory, homesites	Douglas fir, lodgepole pine, pine reedgrass, bluebunch wheatgrass, Idaho fescue, bluegrass, sticky geranium, lupine, serviceberry, mountain snowberry	
	10 Bootjack silty clay loam, 85% Bootjack soil, 15%	0-1% 6,350 feet	Slight	Rangeland, building site development	Kentucky bluegrass, slender wheatgrass, mountain brome, sedge, clover	Crooked Creek Enget Creek Henry's Fork

alluvium		contrasting inclusions (Note:Area characterized by this soil unit is known as Antelope Flat)					Jones Creek Meadows Creek Stephens Creek
	109	Sawtelpeak silty clay: 75%, Sawtelpeak soil 25% contrasting inclusions	0-2% 6,450 feet	Slight	Rangeland, irrigated pasture	Tufted hairgrass, slender wheatgrass, sedge, clover	Jesse Creek

Appendix B—Table 5, continued.

General Soil Map Unit and Soil Survey Sheet Numbers	Detailed Soil Map Unit	Slope and Elevation	Erosion Hazard	Major Use	Dominant Vegetation or Crop	Waterbodies
3 Bootjack- Chickcreek: Very deep, nearly level, very cold, poorly drained soils formed in alluvium	126 Targhee loam: 90% Targhee loam, 10% contrasting inclusions	15-40% 6,400 feet	Very severe	Woodland, grazable understory, homesites	Douglas fir, lodgepole pine, pine reedgrass, bluebunch wheatgrass, Idaho fescue, bluegrass, sticky geranium, mountain snowberry, lupine, serviceberry	Garner Springs
	21 Fourme loam: 85% Fourme soil, 15% contrasting inclusions	0-4% 6,500 feet	Slight	Rangeland, hayland, pasture, summer homesites	Idaho fescue, mountain big sagebrush, bluebunch wheatgrass, Nevada bluegrass, arrowleaf basalmroot	
	120 Stamp loam: 85% Stamp loam soil, 15% contrasting inclusions	0-4% 6,400 feet	Slight	Rangeland, summer homesites	Slender wheatgrass, tufted hairgrass, sedges	
	119 Stamp sandy loam: 75% Stamp sandy soil, 25% contrasting inclusions	0-4% 6,300 feet	Slight	Woodland, grazable woodland, summer homesites	Lodgepole pine, slender wheatgrass, Kentucky bluegrass, sedge, mountain brome, common yarrow, lupine.	