HOW LANDFORMS AND GEOLOGY AFFECT THE STRUCTURE OF RIPARIAN AREAS

by

Dustin Carl Anderson

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APPROVAL

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Dustin Carl Anderson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency and is ready for submission to The Graduate School.

Dr. Brian L. McGlynn, Co-Chair
Dr. Clayton B. Marlow, Co-Chair

Approved for the Department of Land Resources and Environmental Sciences

Dr. Tracy M. Sterling

Approved for The Graduate School

Dr. Carl A. Fox

STATEMENT OF PERMISSION TO USE

Dustin Carl Anderson

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ABSTRACT

Current riparian zone assessments focus on the morphological features of the stream channel and ocular vegetation measurements. This procedure fails to address the hydraulic features responsible for the floristic structure and composition of the riparian zone. We looked at how the geology and landforms function as drivers of groundwater and surface-water exchange. These can mitigate watershed processes via groundwater availability to shape riparian processes; e.g. discharge, seasonality. We hypothesized that groundwater surface-water exchange is a first order process and that it dictates riparian water availability and that the underlying geology and landform can serve as a tool to gain greater understanding of a properly functioning riparian ecosystem. We tracked groundwater surface-water exchange using wells, piezometers, water temperature, conservative tracer injections and solute conductivity on an alluvial fan in the Gallatin valley. Southwestern Montana Conservative tracer injection indicated 3% tracer losses over the 1.5km reach. Through spring and summer 2011 groundwater wells and piezometers indicated flashy transient shallow groundwater. Significant late growing season stream discharge (~300 l/s) and standard riparian monitoring assessments would suggest a larger floristic community than what is present at the site. These metrics together suggest a disconnection between the surface-water and groundwater ultimately limiting the extent of the riparian vegetation community. We further determined that the surface water is disconnected from the local groundwater table. We conclude that the lack of surface water - groundwater connectivity drives the floristic structure and character of the riparian zone. Skewed or inaccurate views of riparian functionality may occur because; the current assessment fails to address surface water - groundwater connectivity.

CHAPTER 1

INTRODUCTION

Scientific Background

"Riparian zones are transitional semi-terrestrial areas regularly influenced by fresh water, normally extending from the edge of water bodies to the edge of upland communities" (Naiman et al., 2005). These areas occur wherever streams or rivers occasionally cause flooding beyond their channel confines. Riparian zones first appear along a stream "where the flow in the channel changes from ephemeral to perennial; that is, where groundwater enters the channel in sufficient quantity to sustain flow through non-storm periods (Leopold et al., 1964).

Riparian zones strongly influence the organization, diversity and dynamics of communities associated with aquatic ecosystems (Gregory et al., 1991). They possess distinct ecological characteristics because of persistence of water. Thus, their boundaries can be delineated by changes in soil conditions (hydric soils), vegetation (obligate), and other factors that reflect this aquatic-terrestrial interaction (Naiman and Decamps, 1997).

Riparian zones vary widely in their physical characteristics, which are vividly expressed by successional patterns of vegetation. Consequently, these areas are among the biosphere's most complex ecological systems and most important for maintaining a healthy riverine landscape (Naiman and Decamps 1997). The variability of natural riparian zones reflects the inherent physical heterogeneity of the drainage network, the processes shaping stream channels, and the characteristics of the biotic community. In effect, riparian zones are a product of the past and the present interactions among biophysical factors (Naiman et al., 2005).

Riparian ecosystems are important in landscapes as they provide a disproportionally wide range of ecosystem services and conservation benefits. For example, riparian ecosystems serve as both natural water filters and storage mechanisms (Jones et al., 2007) that latter sustain plant and animal communities, while serving as critical winter habitat for large ungulates (Wyman, 2006). Riparian-wetlands are similar in function but have unique processes.

The riparian zones of the semiarid western United States differ from those found in the humid eastern and southern United States. The ecosystems of the western United States are grasslands, sagebrush steppes, deserts or other non-forested ecosystems. In these ecosystems riparian zones are a conspicuous feature of the landscape (Brinson et al., 1981). Western riparian zones are commonly narrow and sharply defined in contrast with the wide alluvial valleys of the Midwest and Eastern United States. It is the eco-services afforded by this “oasis” that has produced much of the state and Federal regulation focused on management and sustainability of riparian zones.

The idea of riparian - wetland management has different meanings to different people. Until the middle of the twentieth century, riparian management meant drainage to encourage development for agriculture, industry, grazing or flood controls. Today, floodplain management is zoned to minimize human encroachment and maximize floodwater retention. This management has been accomplished through a variety of policies, laws and regulations, ranging from land use policies, to zoning restrictions

(Mitsch and Gosselink, 1986). The principle aim of these policies has been to protect of recover floodplain and riparian processes.

An understanding of the physical and biological processes that control infiltration and subsurface storage is fundamental to developing comprehensive management strategies for rehabilitation and restoration of riparian systems (Baker et al. 2004). Physical and biological processes are closely coupled in riparian systems, but physical processes ultimately govern system structure and function (Naiman et al. 2005). Landscape features are an underlying driver of the physical processes that shape riparian zones.

The landscape position of a stream determines its ability to develop and support significant riparian - wetland vegetation (TR 1737-15, 1998). Several stream classification systems have been developed that describe both the landscape/watershed setting and the potential riparian attributes. Chief among these efforts has been the classification systems based on topographic position. Suggested attributes range from the stream ordering systems of Horton (1945), sediment transport and channel adjustment processes, (Schumm, 1977; Montgomery and Buffington, 1993), and channel morphological characteristics (Rosgen, 1996). The overall purpose of these stream classification efforts has been to describe the stream's position in the landscape and the expected range of variability for composition of bed and bank materials and for channel size, shape, and pattern (TR 1737-15, 1998).

The most commonly employed classification by federal agencies is Rosgen’s system. It uses stream channel geometry to define eight primary stream channel types.

Rosgen's scheme relies on in-field channel measurements, making it reproducible. The core set of measured attributes are: entrenchment ratio, width-depth ratio, dominant channel materials (from the cross section), slope, bed features (from the long profile), sinuosity and meander width ratio (from the plan-form). The Rosgen scheme provides a detailed description of the reach within the stream network, but there is no link to the watershed. This weakness contradicts the accepted view that the structure and dynamics of a stream are determined by the watershed (Wadeson and Rowntree, 1994).

The role of geomorphology in stream management is to link the local site management concerns to the wider catchment and channel processes, define an acceptable level of instability within the system, lengthen the time scale of concern to management, identify system thresholds, and provide a conceptual and communicative link between engineering and ecology (Gilvear, 1999). Vegetative inventories using hydrophilic indicator species have been employed to support fluvial geomorphic measurements or as standalone metrics for assessing riparian health.

Vegetation

Riparian vegetation play a critical role in maintaining riparian ecosystem function by promoting stream-bank stability and water quality, reducing the potential for erosion, trapping sediment, increasing the storage of nutrients and water, and providing forage and habitat for wildlife (Baker et al., 2004). Attempts to quantify these services have developed current assessment methods that focus on ocular measurements of riparian vegetation. Cumulative ocular measurements are compiled to describe vegetation succession patterns which, in turn, are used to forecast trend. This is accomplished through ecological sites description and state-and-transition models incorporating at some level vegetation classification (wetland indicator species). An underlying assumption is that successional complexes (states) reflect fluvial-geomorphic processes.

Ecological sites are used to establish a land stratification system and associated vegetation composition, function, and dynamics to form ecological site descriptions. An ecological site is “a distinctive kind of land with specific physical characteristics that differs from other kinds of land in the amount of vegetation, and in its ability to respond to management actions and natural disturbances” (draft Interagency Ecological Site Handbook for Rangelands, 2003). This approach allows for recognitions and communication of important and repeatable differences in vegetation, soils, and ecological processes occurring across different parts of a landscape (Brown, 2010).

State-and-transition models (STMs) are synthetic descriptions for the dynamics of vegetation and surface soils within specific ecological sites. State-and-transition models are developed using an array of evidence including historical information, local and professional knowledge, general ecological knowledge, monitoring and experimental data from a specific ecological site or similar sites (Bestelmeyer et al., 2010).

Most riparian classifications focus on hydrophilic plant associations (Cowardin et al., 1985). These classifications adequately characterize terrestrial plant communities, but they fail to address the wide array of ecological processes and communities associated with the land- water interface and encourage an inappropriately rigid delineation of riparian boundaries (Gregory et al., 1991).

Hupp and Osterkamp's (1996) compared eastern bottomland vegetation pattern as a function of fluvial-geomorphic processes with western bottomland vegetation pattern. They found that in humid eastern riparian areas, where water is relatively abundant, vegetation patterns are related to fluvial landforms created by flooding. However, in the semi-arid west, vegetation establishment is influenced by surface flow (floods) but groundwater levels determine the persistence and pattern of vegetation (Hupp and Osterkamp, 1996). Surface water is the primary source of terrestrial water input to riparian-wetland; yet, many riparian wetlands are primarily groundwater features, and the persistence of the wetness is the result of a relatively stable influx of groundwater throughout changing seasonal and annual climate cycles (Winter and Llamas, 1993). In turn, groundwater and surface water are controlled largely by geologic characteristics such as topography, permeability of soils, and hydraulic characteristics of the underlying geologic framework (Winter and Llamas 1993).

Groundwater

"Given an area of uniform precipitation and infiltration, coupled with an undulating surface. A groundwater flow system will develop. Groundwater flow systems are driven by a water-table surface that is a subdued replica of the land surface. This flow system is controlled by the water-table configuration and the subsurface geology" (Hubbert, 1940).

Groundwater moves along flow paths that are organized in space laterally and vertically forming a flow system. The available subsurface flow domain of a region with irregular topography contains multiple flow systems of different orders of magnitude and relative position in space (Sophocleous, 2002). There are three distinct types of flow systems; local, intermediate, and regional. A local flow system is generally close to the ground surface over short distances and reemerges at the nearest topographic low or break in slope. An intermediate flow system is characterized by one or more topographic highs and lows located between its recharge and discharge area. Regional flow travels the greatest distance and occupies the topographic high and low of the basin. These systems can overly one another or are nested within a groundwater basin. Regional flow systems are at the top of the hierarchical organization; all other flow systems are nested within them (Tóth, 1963).

Flow systems depend on the landscape position and the hydrogeological characteristics of soil and rock (Freeze and Whitherspoon, 1967). Areas of high topographic relief tend to have local flow systems, and areas of shallow relief have intermediate and regional flow systems. Consequently, topography has fundamental importance in controlling interactions between regional and local groundwater flow and water exchange between groundwater and surface water (Harvey and Bencala, 1993).

Large-scale hydrologic exchange of groundwater and surface water in a landscape is controlled by, the distribution and magnitude of hydraulic conductivities, both within the channel and the associated alluvial-plain sediments, the relation of stream stage to the adjacent groundwater level, and the geometry and position of the stream channel with-in the alluvial plain (Woessner, 2000). The direction of exchange depends on the hydraulic gradient. There are two directions of water flow: influent (losing), where surface water contributes to groundwater and effluent (gaining), where groundwater drains into the stream.

Brunke and Gonser, (1997) summarize the interactions between stream and groundwater as net-gaining or net-losing systems. Under conditions of low precipitation, baseflow in many streams constitutes the discharge for most of the year (gaining). In contrast, under conditions of high precipitation (snow-melt in the semi-arid west), in-channel discharge is high, leading to higher hydraulic pressures in the stream. High hydraulic pressures cause the stream, to change from net gaining system to a net losing system. Discharge loss can occur as water infiltrates the stream's banks or through the channel bottom directly entering local groundwater.

During peak run-off, overbank discharge gradients can cause in-channel water infiltration into the stream banks or inundation of the floodplain; this reduces the stream's energy and recharges the aquifer. The volume of bank storage depends on the timing, frequency and duration of flooding, as well as vadose-zone hydraulic properties, available storage volume in the vadose zone, channel geometry, wetted perimeter, flow duration and depth, antecedent soil moisture, clogging layers on the channel bottom, and water temperature (Bower and Maddock, 1997). During the dry season, the release of stored water compensates for a decrease in stream discharge. In some reaches, the water released to the stream from bank storage originating from previous overbank flow exceeds groundwater discharge under baseflow conditions. The characteristics of the local groundwater table in the near stream area can drive the floristic structure and composition of the riparian zone.

Depth to groundwater and the rate of decline has been shown to influence the abundance, age structure, and composition of riparian vegetation in the floodplain (Stromberg et al., 1992). Obligate riparian species (water dependent) species are sensitive to the persistence of local groundwater within 1m of the ground surface. While, facultative and upland species have adapted to drier conditions and are far less sensitive to groundwater levels. Groundwater processes, therefore, drive the floristic composition of the riparian zone. Ultimately, the degree of connectivity between stream water and groundwater determines the structure and function of riparian zones in semi-arid environments.

Study Area Background

The study area occupies 1.5 km of the south fork of Ross Creek (45° 49’03.91” N and 111° 03’07.78” W elevation 1413 m) at the distal end of an alluvial fan. It is 1 km up gradient of the break in slope as Ross Creek emerges into the Gallatin Valley. Ross Creek is a second order stream originating on the western slope of the Bridger Mountains.

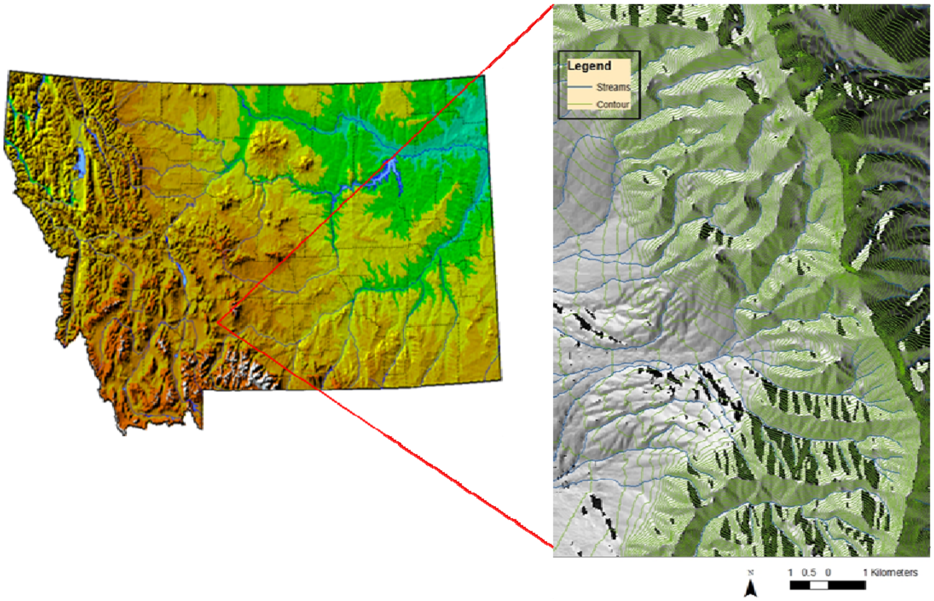


Figure 1.1. The location of the Ross Creek watershed in Southwest Montana. Zoomed in view of the landform the SFRC originates and flows through.

The Bridger Mountains of southwest Montana define the east side of normal-faulted tectonic valley located at the northern edge of the “Yellowstone Hotspot” thermal buldge (Barnosky and Labar, 1989). The area is also at the north-eastern end of the “Basin and Range” physiographic province of western North America (Barnosky and Labar, 1989). It exceeds 2748 m in height and is bounded on the east and west by inter-montane valleys of 1350-1450 m elevation.

The climate is semiarid with annual precipitation ranging from ~43 cm in the valley to ~80 cm along the mountain crest (Western Region Climate Center). The Ross Creek watershed is 15.67 km^2. The focus reach is a low-gradient sub-reach of the main Ross Creek. Baseflow from June 20 through December 12, 2011 ranged from ~1.0 m^3/s - 0.2 m^3/s. Previous research indicated relatively low sediment export from this watershed

(McMannis, 1955). Both Ross Creek and the south fork flow through valley fill derived primarily from Paleozoic and Precambrian rocks of igneous and sedimentary lithology.

Geology

The under lying geology is Tertiary-age strata consisting of coarse conglomerates with inter-bedded silt, sand, and ash beds. The series is estimated to be more than 120 meters thick (Montana Bureau of Mines and Geology, 2002). Volcanic pebbles make up the largest part of these conglomerates, with some chert and Paleozoic limestone pebbles. This Tertiary surface passes beneath the Quaternary fan deposits over which the south fork flows (McMannis, 1955).

Quaternary deposits in the Ross Creek area consist primarily of unconsolidated light gray to light brown gravel, sand, silt, and clay. The distribution of clasts size varies; in general, coarser sediment dominant near the head of the fan and finer sediments dominate downslope. Clasts are generally matrix supported, and poorly sorted, although sediment deposited in the distributary channel is moderately to well sorted and clast supported. Larger clasts are angular to sub-angular. These gravels are derived from Paleozoic and Precambrian rocks of the Bridger Range in the form of glacial outwash and poorly consolidated alluvial-fan deposits. The thickness of the Quaternary deposits is ~ 60 m (Montana Bureau of Mines and Geology, 2002).

Landform

The alluvial fan at the study site was likely built by seasonal high-runoff events during the Pleistocene probably during the Wisconsin stage (McMannis, 1955); the fan has been incised by Ross Creek ≥ 30 m in many places. Little coarse debris is carried by the stream today, even in high-water periods (McMannis, 1955). The fan is therefore not being aggraded but rather dissected (McMannis, 1955).

South Fork of Ross Creek (SFRC) is an underfit stream, flowing in a relict streambed that reflects higher discharge from Pleistocene glacial melt. The stream currently is reworking debris-flow sediment and glacial-outwash materials. The SFRC is a managed stream impacted by roads, culverts, and irrigation diversions. The riparian zone is narrow (1 to 10 m), and is dominated by upland species with few obligate or riparian species. Anecdotal field observations determined that obligate species are sustained by in-channel rooting.

Soils

The soil is loamy-skeletal over sandy-skeletal mixed, superactive, frigid Typic Argiustolls of the Beaverton series. The Beaverton series consists of young soils that form in glacial outwash materials. The soil texture is gravelly sand at a depth of 25 cm. The soil is well-drained, with moderate permeability in the solum with rapid permeability in the C horizon (NRCS 2011).

Purpose

This study used shallow groundwater monitoring wells, in-channel piezometers, stream gauging stations, and conservative tracers, to investigate the following questions:

1) What is the degree of connectivity between the stream channel and the local groundwater?

2) How can landscape position and setting inform interpretation of stream-water groundwater connectivity?
3) What are the implications of stream-water-groundwater connectivity for riparian area assessment and rehabilitation?

These questions were addressed through hydric soil analysis, geologic observations and physical hydrology techniques. Multiple techniques were necessary to determine the physical controls of the South Fork of Ross Creek's riparian potential. This approach allowed us to incorporate multiple lines of evidence from soil analysis, hydrologic monitoring and vegetation surveys to assess the current state of the stream and its restoration potential given the unique hydrologic and geologic physical influences of the landform.

CHAPTER 2

HOW LANDFORMS AND GEOLOGY AFFECT THE STRUCTURE OF RIPARIAN AREAS

Abstract

Riparian zone assessments have traditionally rested on the perception that vegetation assemblages and channel morphological features reflect local hydrologic processes. Recent efforts to improve assessments have suggested the addition of landform parameter to the evaluation criteria. Valley form has been suggested however, we hypothesized that groundwater - surface-water exchange is the more determinate process that dictates riparian water availability and that the underlying geology and landscape position can serve as a tool for understanding this exchange. This understanding will facilitate an informed assessment of properly functioning riparian ecosystems. To test this concept we tracked groundwater surface-water exchange using wells, piezometers, conservative tracers and solute conductivity on an alluvial fan in Montana's Gallatin valley. Late growing season stream discharge (~300 l/s), valley form and standard riparian monitoring assessments suggest a larger scale riparian vegetation community than what is present at the site. Conservative tracer injection indicated 3% tracer losses over the 1.5km reach. Through spring and summer 2011 groundwater wells and piezometers indicated in-channel discharge losses with limited local groundwater-surface water connectivity. Based on this evidence we determined that the South Fork of Ross Creek is a losing, disconnected stream. The lack of surface water - groundwater

connectivity has set the bounds of the floristic structure and character of the study riparian zone. Ultimately, a riparian area that might have been rated functioning – at - risk with a conventional riparian assessment was found to be properly functioning as a function of the physical processes; groundwater- surface water connectivity.

Introduction

Current riparian assessments of functionality of riparian areas focus on stream channel classification stating: the position of a stream in its landscape and watershed setting is a strong determinant of that stream's ability to develop and support significant riparian-wetland resources (TR 1737-15, 1998). Several stream classification systems have been proposed to describe both the landscape/watershed setting and the potential attributes of the stream corridor (e.g. Leonard et al., 1992, Montgomery and Buffington 1993; Rosgen, 1996). However, the focus of these classifications is on surface water and associated stream channel morphological features. Current assessments mention the importance of the landform and geology, along with climate as drivers of stream channel morphological features but, they fail to adequately describe how and to what extent the landscape position and its related landforms and geology determine the hydrology of the riparian area. Hupp and Osterkamp (1994) suggested that surface water plays a role (flooding, hyporheic flow, etc.), but it is the shallow groundwater (GW) table that sustains riparian vegetation during late season flow.

Landscape position and geology influence surface and GW flow systems. Winter and Llamas (1993) concluded that the terrestrial water components, GW and surface water are controlled largely by geologic characteristics such as land-surface slope, permeability of soils, and hydraulic characteristics of the underlying geologic framework. Similarly, Larkin and Sharp (1992) found that geomorphic features influence subsurface flows and these flow paths drive the stream and riparian dynamics. Phillips et al. (1993) suggested that soil characteristics (well drained v. poorly drained), land cover, topography and hydrogeology determine GW flow paths and the potential for by pass flows below the rooting zone of riparian vegetation. These principles are exemplified by Covino et al. (2007), who reported two different hydrologic behaviors effluent (gains groundwater from the alluvial aquifer) or influent (loses water to the alluvial aquifer), as a consequence of landscape position on an alluvial fan, in southwest Montana.

Recently, attention has focused on exchanges between near-channel and in-channel water. These exchanges were found to be key to evaluating the ecological structure of stream systems and are critical to stream restoration and riparian management (Sophocleous, 2002). Given an area of uniform precipitation and infiltration, coupled with an undulating surface a nested GW flow system will develop. GW flow systems are driven by total potential gradients often represented by the water-table surface elevation that is typically a subdued replica of the land surface. This flow system is further controlled by the water-table configuration and the subsurface geology (hydraulic conductivity, Hubbert, 1940).

Flow systems also depend on landscape characteristics and the hydrogeological characteristics of soil and rock (Freeze and Whitherspoon, 1967). In areas of high topographic relief local flow systems tend to dominate. While, in areas of shallow relief intermediate and regional flow systems dominate. Topography and elevation potential has fundamental importance in controlling interactions between regional and local GW flow and water exchange between GW and surface water (Harvey and Bencala, 1993).

Brunke and Gonser (1997) summarized the interactions between stream and GW as net-gaining or net-losing systems. Under conditions of low precipitation, baseflow in many streams constitutes the discharge for most of the year (gaining). In contrast, under conditions of high precipitation (snow-melt in the semi-arid west), in-channel discharge can be high, leading to hydraulic gradients from the stream to the groundwater system causing the stream to change from net gaining system to a net losing system. Discharge loss can occur as water infiltrates through the stream's banks or through the channel bottom directly entering the local GW table. Ultimately, it is the characteristics of the local GW table that drives the floristic structure and composition of the riparian zone in semi-arid riparian areas (Hupp and Osterkamp, 1994).

Depth to GW and the rate of decline has been shown to influence the abundance, age structure, and composition of riparian vegetation in the floodplain (Stromberg et al., 1992). Obligate riparian species (water dependent) species are sensitive to the persistence of local GW within 1m of the ground surface. Facultative and upland species have adapted to dryer conditions and are far less sensitive to GW decline. Therefore, GW processes can influence the floristic composition of the riparian zone. Thus, the degree of connectivity of stream-water-GW can help determine the structure and function of riparian zones.

In this study we used shallow GW monitoring wells, in-channel piezometers, sequential stream gauging stations, and conservative tracers, to investigate the following questions:

1) What is the degree of connectivity between the stream channel and the local groundwater?
2) How can landscape position and setting inform interpretation of stream-water groundwater connectivity?
3) What are the implications of stream-water-groundwater connectivity for riparian area assessment and rehabilitation?

South Fork of Ross Creek (SFRC) has been classified as having a relatively poor riparian community. This study implements hydrologic measurements and landform surveys to describe the physical attributes of the site and its potential for rehabilitation. By observing the nature of SFRC geology and its relation to GW, we hope to learn if the low assessment rating is the function of historic and current land management or is a reflection of landform influences.

CHAPTER 3

STUDY AREA AND METHODS

Study Area

The study area occupies 1.5 km of the South Fork of Ross Creek (45° 49’03.91” N and 111° 03’07.78” W elevation 1413 m) at the distal end of an alluvial fan. It is 1 km up gradient of the break in slope as Ross Creek emerges into the Gallatin Valley.

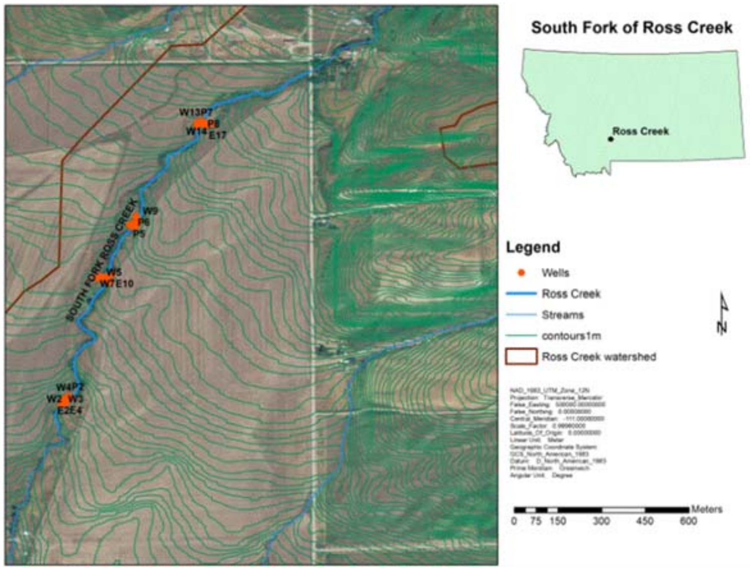


Figure 3.1. Study location within the Ross Creek watershed in Southwest Montana. The site lies within the Lutz Farm unite of the Montana Agriculture Experiment Station.

Ross Creek is a second order stream originating on the western slope of the Bridger Mountains. The Bridger Mountains of southwest Montana define the east side of a normal-faulted tectonic valley located at the northern edge of the “Yellowstone Hotspot” thermal bulge (Barnosky and Labar, 1989). The area is also at the north-eastern end of the Basin and Range physiographic province of western North America (Barnosky and Labar, 1989). Bridger Mountains exceeds 2748 m in height and is bounded on the east and west by intermundane valleys of 1350 to1450 m elevation.

The climate is semiarid with annual precipitation ranging from ~43 cm in the valley to ~80 cm along the mountain crest (Western Region Climate Center). Ross Creek watershed is 15.67 km^2. The focus reach, SFRC, is a low-gradient divergent stream of the main Ross Creek with study period baseflow, over the course of the study (June 20 to December 12, 2011) ranging from ~1.0 m^3/s - 0.2 m^3/s. Previous research indicated relatively low sediment export from this watershed (McMannis, 1955). Both Ross Creek and the SFRC flow through valley fill derived primarily from Paleozoic and Precambrian rocks of igneous and sedimentary lithologies.

Geology

The under lying geology is Tertiary-age strata (Figure 3.2. QTaf) consisting of consolidated to unconsolidated coarse conglomerates with inter-bedded silt, sand, and ash. The series is estimated to be more than 120 meters thick (Montana Bureau of Mines and Geology 2002). Volcanic pebbles make up the largest part of these conglomerates, with some chert and Paleozoic limestone pebbles. This Tertiary surface passes beneath the Quaternary fan deposits over which the South Fork flows (McMannis, 1955).

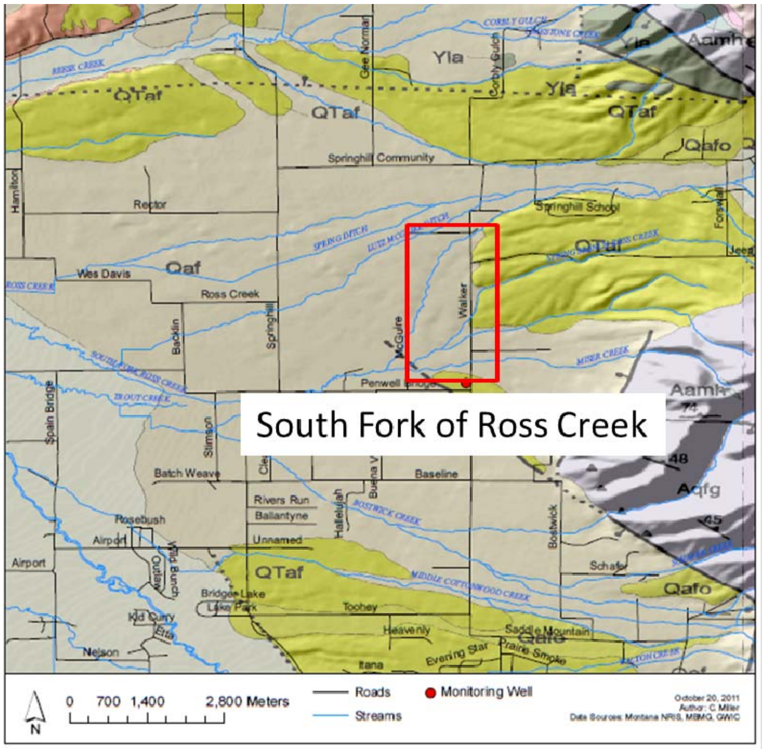


Figure 3.2. Geologic map of Ross Creek.Qaf. Alluvial fan deposit (Holocene and Pleistocene) sand silt and clay of various size. Thickness of ~120 m. Coarser sediments at mountain front with fine sediments near the margins. QTaf. Similar to Qaf with a thickness of ~60 m.

Quaternary deposits (Figure 3.2. Qaf) in the Ross Creek area consist primarily of unconsolidated light gray to light brown gravel, sand, silt, and clay. The distribution of clasts size varies according to distal/proximal location on the fan; in general, coarser sediment dominates near the head of the fan and finer sediments dominate downslope. Clasts are generally matrix supported and poorly sorted, although sediment deposited in the distributary channel is clast supported and moderately to well sorted. Larger clasts are angular to sub-angular. These gravels are large snowmelt outwash and other poorly consolidated alluvial-fan deposits derived from Paleozoic and Precambrian rocks of the Bridger Range. The thickness of the Quaternary deposits is ~ 60 m (Vuke et al., 2002.

Landform

The alluvial fan at the study site was probably built by seasonal high-runoff events during the Pleistocene, Wisconsin Stage (McMannis, 1955). Little coarse debris is carried by the stream today, even in high-water periods (McMannis, 1955). The fan is therefore not being aggraded, but rather dissected (McMannis, 1955).

Ross Creek is an underfit stream, flowing in a relict streambed that reflects higher discharge from Pleistocene. The stream currently is reworking debris-flow sediment. Ross Creek is bounded by a narrow (1 to 10 m) riparian area. The upland and riparian vegetation communities include woody species, sedges, forbs and grasses (Table 3.1).

Soils

The soil is loamy-skeletal over sandy-skeletal mixed, superactive, frigid Typic Argiustolls of the Beaverton series (Figure 3.3). The Beaverton series consists of young soils that are reported to have formed in glacial outwash materials. The soil texture is gravelly sand at a depth of 25 cm. The soil is well-drained and moderate permeability in the solum with rapid permeability in the C horizon (NRCS, 2011).

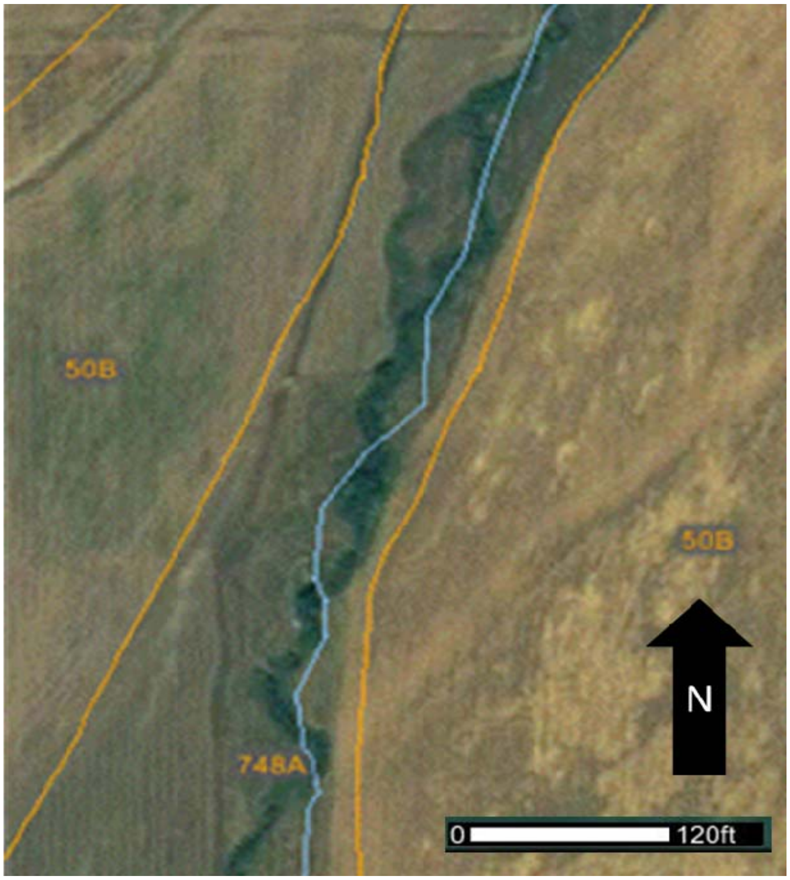


Figure 3.3. (NRCS Soil Survey, 2012) 748A is Beaverton series. The Beaverton series consists of deep, well drained soils formed in gravelly alluvium or glacial outwash materials. 50B is Blackdog series. The Blackdog series consists of deep, well drained soils formed in loess. These soils are on relict stream terraces.

Methods

Hydric Soil Assessment

We excavated soil pits to assess indications of a persistent groundwater table, as evidenced by redoxomorphic features. Three pits were mechanically excavated using a backhoe, within ~ 6m of the stream channel, to a completion depth of three meters. Three additional pits were manually excavated to 60 cm completion depth within the active floodplain (the area inundated by periodic above bank flows). The manually excavated pits were located within approximately 1 m of the stream channel. Soils were described by color using a Munsell color guide for hue, value, and chroma), pH (using a Hanna combination pH and EC handheld meter; model HI 98130), structure (visually following NRCS field book, Schoeneberger, 2002) and calcareous matrix cementation (by reation with [10%] hydrochloric acid. Soil samples were then collected and transported to Montana State University for particle size analysis (Gee and Bauder, 1986; Hydrometer method) for texture and Loss on Ignition testing to quantify organic carbon content (LOI following Heri et al., 1999). The NRCS Field Book for describing and sampling soils, version 2.0 was used to sample, code and describe the soil samples.

Groundwater Measurements

We installed four sites of wells, about 50 m apart. Wells were place in the floodplain to measure the shape and dynamics of the local groundwater table surrounding the stream (Figure 3.1). Wells were 1.5-inch diameter, schedule 40, poly vinyl chloride (PVC) pipe with 1.5 cm screening intervals. Well completion depths varied, with most wells achieving depths of two meters below the ground surface. Wells were installed by applying vertical continuous hydraulic pressure to a metal rod inserted into the PVC pipe. Rod circumference inhibited sediment infiltration. The rod was subsequently extracted following refusal or when maximum depth of the rod was achieved (3 m). Wells were labeled as W to indicate westside of the channel and E as the eastside with number value increasing moving upstream. We manually measured depth to GW using a 101 P2 Water

Level Meter by Solinst with 1 mm accuracy at variable intervals (typically three times per week).

Piezometers were installed in the center of the stream channel at roughly one-meter completion depths, to determine the vertical GW gradient (Figure 3.1) Piezometers were 1.5-inch diameter PVC pipe, and were open only at completion depth (no screening). Piezometers were installed by driving them into the ground with a removable piezometer driver that occupied the volume of the PVC pipe, prohibiting sediment infiltration. We manually measured stream stage height and depth to GW to determine the groundwater total potential. Measurements were taken at variable intervals, typically three times weekly. Well and piezometer measurements began on June 15, 2011 and extended through December 12, 2011.

Stream Chemistry

We used specific electrical conductivity (SC) of the SFRC to characterize surface-GW dynamics, and to help identify loss or gain of water from or to the local GW aquifer. Weekly manual SC measurements were used to infer changes in total dissolved- ion concentrations of SFRC. SC can also help differentiate GW and upstream surface-water contributions to downstream locations when their signatures are distinct. SC was manually measured over the 1.5-km study reach following the thalweg, recording EC at the beginning and end of each riffle-run sequence.

Gross and Net Groundwater – Surface water Exchange

We installed Ecotone$^{\text{TM}}$ WM water-level monitors in stilling wells at the upper-most and lower-most ends of the study reach, 1.5 km apart to calculate and develop stage-discharge rating curves. Water level monitors recorded at 30-minute intervals have an accuracy of +/- 3 mm. Discharge was calculated from developed stage-discharge rating curves measured on the study reach. Gauge measurements began on June 15, 2011 and continued until December 12, 2011.

We utilized a Marsh-McBirney Flo-Mate 2000 portable flow meter for velocity-area gauging of the stream, and the six-tenths depth method was applied (following the U.S. Geological Survey protocol to use six-tenths depth method when $Y_i < 0.75$ m; Dingman, 2002). Velocity-area gauging occurred three times weekly from the middle of June to the middle of December, 2011. Dilution gauging with sodium chloride (NaCl) was also employed to calibrate the rating curves. We obtained breakthrough curves with Campbell CS547A conductivity and temperature probe connected to a Campbell CR10X data logger. Campbell CS547A conductivity probes are accurate to ± 10% over a 0.005 to 0.44 mS cm^{-1} range. Measurements were taken every five seconds during dilution gauging experiments (Covino et al. 2011). Discharge was calculated by integrating the area under the breakthrough curve (Dingman, 2002).

We also used conservative tracers (NaCl) to quantify gross gains, gross losses, and net changes in discharge across the SFRC study reach. We preformed conservative tracer (chloride Cl^-) injections at the end of July and August. The results were used to assess whether SFRC was gaining water from GW, losing water to GW, or both gaining and losing water (Covino et al 2010).

Finally, net discharge was determined by subtracting the upper gauge discharge from the lower and refining this measure with information from conservative tracer additions. Negative values indicated loss to GW; positive values indicate GW contributing to the stream.

Vegetation

Vegetation surveys were conducted to describe the width and structure of the riparian community. The vegetation community within the floodplain was described from cover estimates made along 15-m transect lines intersecting each set of monitoring wells. Transects were anchored within the greenline (Winward, 2000) or bankfull zone and ran perpendicular to the channel into the upland community. Species foliar canopy cover, litter and bare ground were estimated in a 0.2-m x 0.5-m microplot (Daubenmire, 1968) beginning at the greenline and repeated at 1.5-m intervals to 15-m. A second transect was laid out on the opposite side of the creek and cover estimates recorded again. Foliar cover estimates were combined into obligate, facultative wetland, facultative, and upland groupings based on wetland indicator status (Lesica and Husby 2006) and then graphed for each 1.5-m interval to identify the width of the riparian community on each side of channel.

CHAPTER 4

RESULTS

Hydric Soil Assessment

Soil pit analyses revealed that the underlying clasts are course, angular, matrix supported, and poorly sorted. In all pits outside the active stream channel, the absence of redoxomorphic color and the earthy soil odor are evidence against an elevated persistent GW table. Pits in the active channel were characterized by a thin Mollic epipedon of ~ 30 cm and the organic content ranges from 12 to 14.3%. The clastic material, in the stream channel pits, was subangular and clast supported in the C horizon, suggestive of fluvial transport and deposition. There was weak iron oxidation in the upper extent of the C horizon with earthy odor. The matrix material of the A/B horizon reacted slightly with HCl.

Groundwater Measurements

Depth to GW was typically greater than the well completion depths of ~1.5m below ground surface. Shallow GW well data suggested limited relationship between in-channel discharge and the local GW table. Data from representative wells were graphed to show the measured GW level relative to in-channel stream discharge.

Site one, on the upstream end of the study area contained five of the ten wells that contained measurable water levels during peak discharge (Figure 4.1; 4 of 10 well are graphed). Wells W13 and W14 located adjacent and proximal (<1m) to the stream channel indicated that GW declined below 1.5m quickly after overbank flows dissipated. Well W15-located on an island in the center of the channel and W12 located on the stream bank characterized the upper extent of the water-table on the upstream end the study area. Well W12 had water at or near completion depth (~1.3 m) throughout the study with little vertical vacillation (Figure 4.1). GW in all wells where it was recorded declined post flooding and before base flow discharge was achieved.

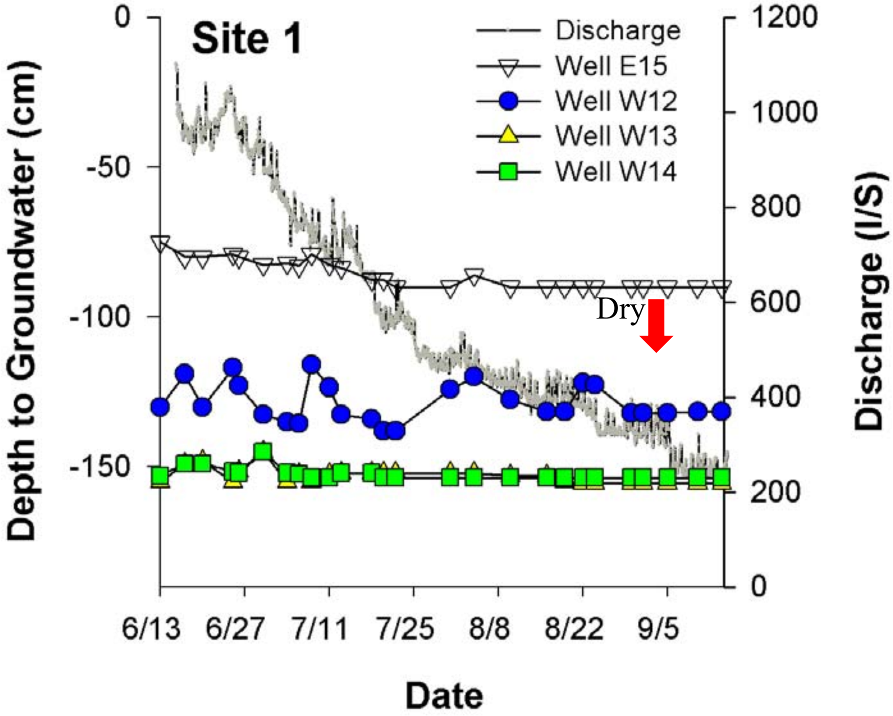


Figure 4.1. Study site 4 South Fork of Ross Creek shallow groundwater well data from June 12 through September 5, 2011.Colors indicate distance from the stream, dark blue is on stream bank, yellow being ~ 1.5 m and green being ~2m from the channel. Symbol shape and fill are used to represent multiple wells in similar location to the stream channel.

Site three, near the center of the study area and had four of the seven wells with measurable water elevations during the study period (Figure 4.2; 4 of 7 wells graphed). Wells held water for ~ 2 to10 days during peak discharge. As flows dissipated, GW precipitously decreased below 1.5m below the ground surface. Again, there was no evidence of a dynamic relation between steam discharge and floodplain GW elevation. With the cessation of overbank flooding, the floodplain water recessed to depths > 1.5 m below the ground before base flow discharge was achieved.

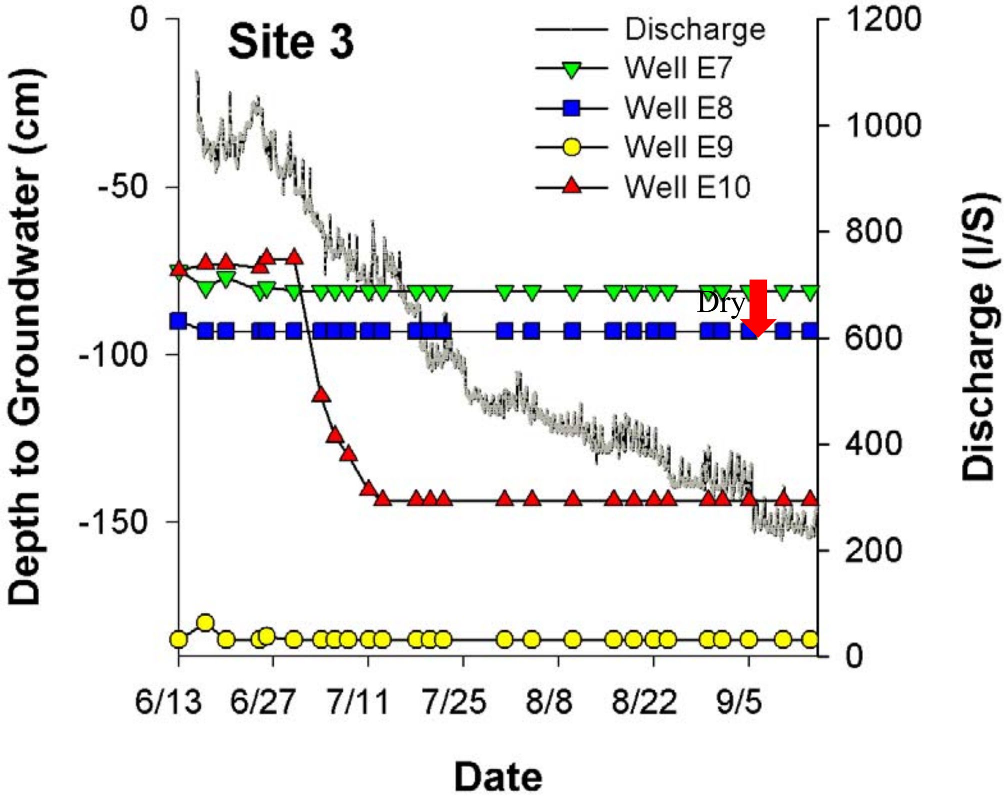


Figure 4.2. Study site 4 South Fork of Ross Creek shallow groundwater well data from June 12 through September 5, 2011.Colors indicate distance from the stream, dark blue is on stream bank with green being ~2m and red 5m from the channel.

Site four, located at the downstream end of the study, had six of the ten wells with measurable water during the study (Figure 4.3; 6 of 10 wells graphed). Wells W2 and W3 held water ~8 days following above-bank flows. Both wells located ≤1.5m from the stream channel had measurable water levels decline to depths ≥1.5m below the ground while stream discharge remained significantly above base-flow discharge. There was little relationship between in-channel discharge and the local GW table.

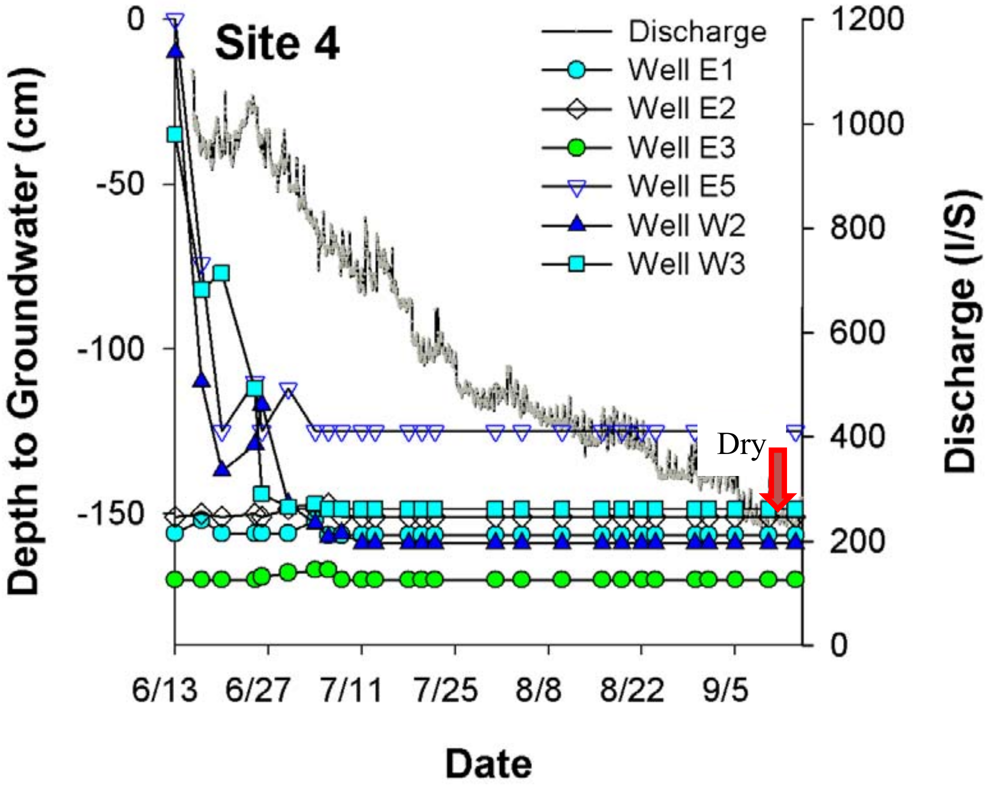


Figure 4.3. Study site 4 South Fork of Ross Creek shallow groundwater well data from June 12 through September 5, 2011. Colors indicate distance from the stream, dark blue is on stream bank with green being ~2m from the channel.

Piezometer Data

Depth to the GW table was compared to stage height at each piezometer to determine the vertical hydraulic gradient. All piezometer measurements throughout the study suggest negative hydraulic gradients (downward); with many having GW elevations below the instruments' completion depth. The piezometer data for the entire reach indicate a negative hydraulic gradient.

Stream Chemistry

Stream water specific electrical conductivity (SC) was measured at the upper gauge and lower gauge. Electrical conductivity was similar between the upper and lower gauge (~ 270 μ/S cm^{-1}) and showed limited oscillation. There wasn't enough variability (increase or decrease) between gauges to suggest GW contributions to the stream during the study. Sampling stream SC of the ripple–run sequence across the 1.5-km reach did not indicate GW contributions to the stream. These measurements are further evidence that there was little GW contribution to the SFRC within the study area.

Gross and Net Groundwater – Surface Water Exchange

The stream reach water balance provides volumetric descriptions of the inputs and outputs of stream discharge. Water coming into the study area was subtracted from that leaving the study area. Based on this calculation the SFRC appears to have been contributing water to local GW (Figure 4.4.) However, the amount of water loss is uncertain; our measurements were taken in an open channel (i.e. we didn't install a weir or flume) limiting small-scale detectability of stream water gains and losses from discharge alone. We were, however, able to determine a trend in the data indicating that SFRC is in fact losing limited water to GW.

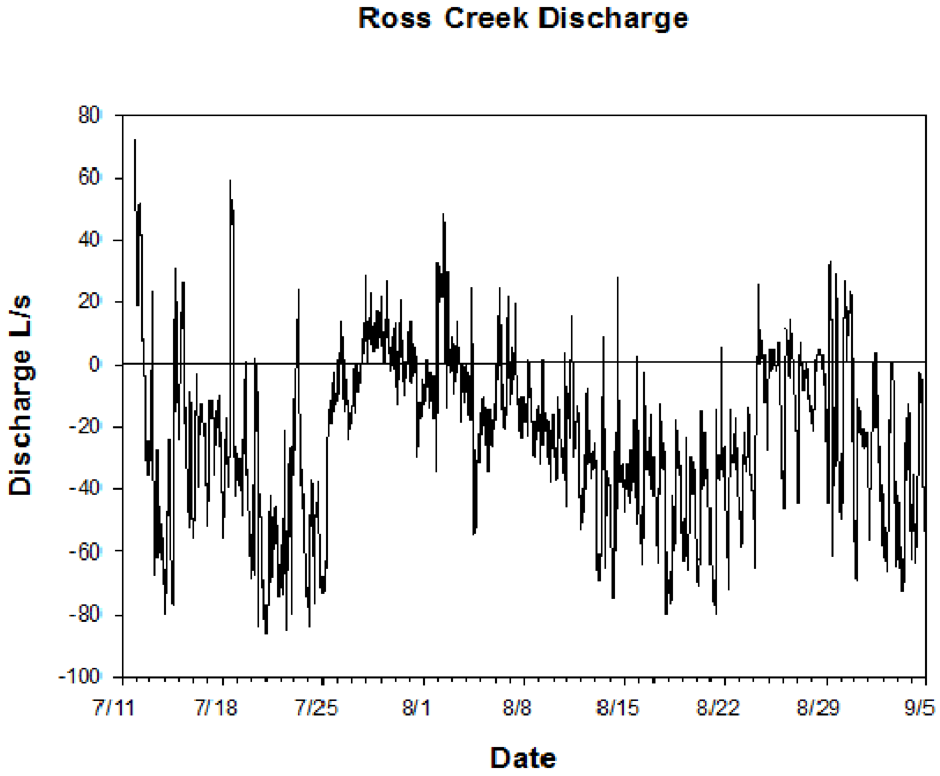


Figure 4.4. Measured net discharge as gross discharge of incoming water is subtracted from gross incoming water over 1.5 km of the South Fork of Ross Creek Gallatin, Montana.

Vegetation

The vegetation survey (Figure 4.5; 2 of 9 transects shown) documented a constricted riparian area with limited hydrophilic (obligate) species cover. Upland and introduced species dominated most of the ground surface within 15m of the greenline. Site two was characterized by <10% cover of obligate-facultative wetland species with < 25% upland species within the greenline or first 1m away from the stream bank, trending to introduced and upland species at a distance of 15m from channel. Site 3c east was characterized by >15% upland with ~5% FACW in the greenline, trending to introduced, facultative and upland 15m of the South Fork of Ross Creek (Figure 4.5).

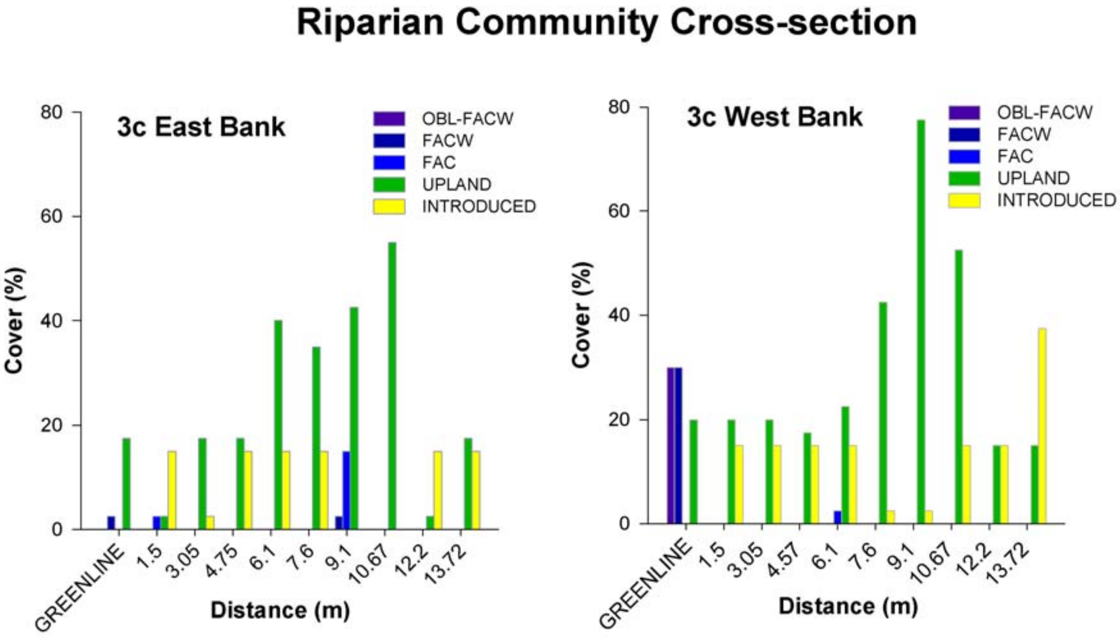


Figure 4.5. Plant community composition from the greenline out to ~15m for the South Fork of Ross Creek Gallatin, Montana. Species are categorized by wetland indicator status.

Site 3c west showed ~30% OBL-FACW in the greenline, trending to predominantly upland within 3m of the stream channel. The obligate species were constrained to the stream channel. In-field observations determined that the OBL-FACW vegetation was rooting directly into the stream channel. This rooting accounts for their existence and proximity to the stream channel.

Table 4.1. The upland and riparian vegetation communities include woody species, sedges, fobs and grasses. Species are categorized by wetland indicator status for the South Fork of Ross Creek, Gallatin, Montana.

	Species Type	
Riparian	**Upland**	**Nonnative/Introduced**
Arrowleaf groundsel (*Senecio triangularis*)	Ballhead sandwort (*Arenaria congesta*)	Bulbous bluegrass (*Poa bulbosa*)
Baltic rush (*Juncus balticus*)	Bluebunch wheatgrass (*Pseudoroegnaria spicata*)	Butter and Eggs (*Linaria vulgaris*)
Black cottonwood (*Populus trichocarpa*)	Canada bluegrass (*Poa compressa*)	Dandelion (*Taraxacum officinale*)
Buttercup (*Ranuculus spp*)	Chokecherry (*Prunus virginiana*)	Hounds Tongue (*Cynoglossum douglasii*)
Cow parsnip (*Heracleum sphondylium*)	Douglas Hawthorne (*Crataegus douglasii*)	Kentucky bluegrass (*Poa pratensis*)
False Solomon's-seal (*Smilacina racemosa*)	Gray sagewort (*Artemisia ludoviciana*)	Orchardgrass (*Dactylis glomerata*)
Hairy willow-herb (*Epilobium ciliatum*)	Golden-banner (*Thermopsis rhombifolia*)	Redtop bent (*Agrostis stolonifera*)
Horsetail (*Equisetum spp*)	Hawksbeard (*Crepis spp*)	Salsify (*Tragopogon dubius*)
Northern bedstraw (*Galium bareale*)	Hairy goldenaster (*Chrysopsis villosa*)	Smooth Brome (*Bromus inermus*)
Sun sedge (*Carex pennsylvanica*)	Hoods Phlox (*Phlox hoodii*)	Timothy (*Phleum pratense*)
Thinleaf alder (*Alnus incana*)	Idaho fescue (*Festuca idahoensis*)	White clover (*Trifolium repens*)
Viola (*Viola spp*)	Junegrass (*Koeleria pyrimidata*)	
	Long-leaf (*Phlox longifolia*)	
	Missouri goldenrod (*Solidago missourensis*)	
	Needleandthread (*Heterostipa comata*)	
	Onion (*Allium spp*)	
	Quaking aspen (*Populus tremuloides*)	
	Scarlet butterfly-weed (*Gaura coccinea*)	
	Silky lupine (*Lupinus sericeus*)	
	Snowberry (*Symphoricarpos occidentalis*)	
	Spotted gay-feather (*Liatris punctata*)	
	Starry false Solomon's-seal (*Smilacina stellatum*)	
	Swamp currant (*Ribes lacustre*)	
	Threadleaf sedge (*Carex filifolia*)	
	Western wheatgrass (*Pascopyrum smithii*)	
	Woods rose (*Rosa woodsii*)	
	Yarrow (*Achillea millefolium*)	

CHAPTER 5

DISCUSSION

What is the Degree of Connectivity between the Stream Channel and the Local Groundwater?

Alluvial fans are hydrologically dynamic landforms where surface water and groundwater (GW) are often closely connected by regional-scale GW flow paths (Herron and Wilson, 2000; Woods, 2006). Most research on alluvial fan hydrology has focused on regional-scale flow paths affording limited attention to local- and intermediate-scale flow paths. It is the local-scale flows functioning as a persistent water table that influence the structure and composition of the riparian area which, in turn, influences riparian assessment outcomes. The dynamics of the water table determine the size, extent and persistence of riparian vegetative communities. Therefore, an understanding of the degree of connectivity between stream-water-GW is essential in assessing the floristic potential of riparian zones.

We determined three lines of evidence suggesting disconnection between surface-water and local GW in the South Fork of Ross Creek (SFRC) study area. First, there was little evidence of a persistent GW table discovered in the six soil pits. Second, shallow GW wells show no relationship with in-channel discharge: as flooding flows dissipated the local GW table declined rapidly, while in-channel discharge remained significantly elevated above base flow discharge. This pattern was determined at all four study sites.

Third, there was a negative hydraulic gradient recorded in all seven in-channel piezometers.

Persistent perched water tables can influence floristic structure (Stromberg et al. 1996). There are indications of transient water tables including site one wells. Site 1 wells W12, W13, E14, and E15 express the limited depth and thickness of GW mounding, or accumulation of water between the bottom and sides of the stream channel and the unsaturated zone. Well W12 vacillated throughout the study with the water table consistently <1.5 m below ground. Wells W13, E14 and E15 mark the lower limits of sub-channel mounding. It is clear that although saturated water mounding occurred below the channel, it was constrained immediately adjacent to and below the channel. The persistent mounding depth below the channel influences what vegetation could be sustained. Obligate vegetation requires water to be within 1m for ≥ 6 of 12 months (Stromberg et al. 1996). Present GW mounding depth and duration makes the character of the perched water table important as it determines the site potential for alluvial fan riparian community structure. Our data indicates the site potential for SFRC is a facultative and upland community type.

Shallow GW data, hydric soil assessment, and hydraulic potential determined that SFRC is disconnected from regional-scale GW. Mounding of water below the channel is present, but, the persistence, mounding depth, and thickness is > 1m below the ground-surface; unreliable for obligate and facultative wetland species. We conclude that despite the perching of water below the stream channel, the SFRC is not connected with the local GW, and has limited potential to sustain hydrophilic obligate species. This information allows land managers to make an informed decision about the site potential as a function of the hydrologic constraints and how to manage the SFRC.

How Can Landscape Position and Setting Inform Interpretation of Stream-Water Groundwater Connectivity?

The position of the stream in its landscape and watershed setting is a strong determinant of that stream's ability to develop and support significant riparian resources. Flow systems depend on both the hydrogeological characteristic of the soil/rock material, depth of the soil to bedrock, and landscape position (Winter, 1999). Local flow systems are dominant in areas of pronounced topographic relief, while intermediate and regional flow systems commonly occur in (flatter) areas of shallow relief (Sophocleous, 2000).

The SFRC is located on the distal end of an alluvial fan. The topographic relief is shallow (~ 3%), the subsurface soil/rock material is deep (~60m) and coarse (cobbles and sand). Soils that are deep and coarse have high permeability in the subsurface. This results in enhanced downward percolation of water deeper into the subsurface material (Freeze and Witherspoon, 1967). This enhanced downward movement of water and the shallow topographic relief of the fan could promote intermediate and regional flow paths. As a result of the dominant flow paths and likely downward gradients to the regional aquifer, the local water table was limited in elevation and persistence. The data from our shallow GW wells and piezometers confirm the dominance of regional-scale flow paths in the Ross Creek fan.

Through assessing the topographic relief and depth of the soil to bedrock, it was possible to infer the dominant flow direction and type of the mid fan GW. In the mountains, where the soils are shallow and the topographic relief is steep, local flow will dominate. On alluvial fan landforms, like the Ross Creek fan, where the topographic relief is shallow and the depth of the soil or alluvium is deep (~60m), intermediate and regional flow paths will likely dominate and will continue to do so as the landform flattens (Tóth, 1970).

These interpretations can be applied to the hydrologic behavior of mountain to valley stream systems (Covino et al., 2007). An understanding of the dominant GW flow system type enables land managers to make an assessment of the likely in-channel surface-water-GW exchange (net gaining or losing steams) of a particular stream reach. SFRC is positioned at the toe of the fan or break in slope. We determined GW to be within 70-cm of the ground surface at that the break in slope (in-field observations), consistent with alluvial fan conceptual models (Covino et al., 2007).

The SFRC is a net losing stream as a function of its landscape position and location in the larger mountain to valley GW flow system. Gross and net GW-surface exchange metrics suggest that losses are modest (Figure 4.4). It is likely that there is clogging of the channel bottom by fines as described by Bower and Maddock (1997). We suggest this clogging is partially due to the geology of the watershed (Paleozoic and Precambrian rocks). The igneous lithology, when weathered, produces clays which are carried and deposited in the stream channel. In field observations determined the cementation of in-channel clasts by clay.

With a basic understanding of the topographic relief, geologic and geomorphic setting, and depth to bedrock land managers can infer groundwater flow systems. Basic understanding of subsurface- hydrology is critical to determine if a fluvial or riparian system is functioning within its natural possibilities and to project the floristic potential of a particular riparian community.

What are the Implications of Stream-water-groundwater Connectivity for Riparian Area Assessment and Rehabilitation?

By their nature, riparian areas require far greater amounts of water than other terrestrial (non-aquatic) ecosystems. GW is often critical to maintenance of the riparian zone, particularly in climatic regions were snow melt is the primary source of water. In these regions the connectivity of stream water and GW connectivity determines the plant species present and ultimately the structure and character of the riparian ecosystem. Therefore, the connectivity of the stream-water-GW becomes key in assessing the site potential or restoration potential of a particular site.

One of the most fundamental hydrologic determinations to be made concerning fluvial and riparian areas is whether a stream is gaining water from GW, losing water to GW or in equilibrium with respect to GW. There is general agreement that riparian vegetation along losing reaches is more sensitive to flow reductions than along gaining reaches: the shallow water table in a losing reach is dependent on in-channel discharge while the gaining reach is connected with the water table and / or upland sources (Risser et al., 1984).

Depth to GW and the rate of water table decline has been shown to influence the abundance, age structure, and composition of riparian vegetation in the floodplain (Stromberg et al., 1992). Winter and Llamas (1993) determined that GW and surface water are controlled largely by the geologic characteristics such as topographic relief, permeability of soils, and the hydraulic characteristics of the underlying geologic framework. Here, we determined that SFRC is a largely disconnected stream due to its underlying geologic framework and landscape position. As expected the floristic structure of the riparian area is dominated by plant species more adapted to drier conditions (e.g. FAC, upland species).

Our vegetation surveys were consistent with a riparian area occupying regional-scale-GW flow path. The width and structure of the riparian community was dominated by species adapted to drier conditions (Figure 4.5). Despite flooding during snowmelt and relatively constant discharge, the shape and depth of GW determined the floristic structure. Constrained by the depth >1m to GW, hydrophilic species cannot be sustained at this site. It is therefore evidenced by our study that the degree of connectivity of stream-water-GW is the primary driver of riparian vegetation structure and character.

CHAPTER 6

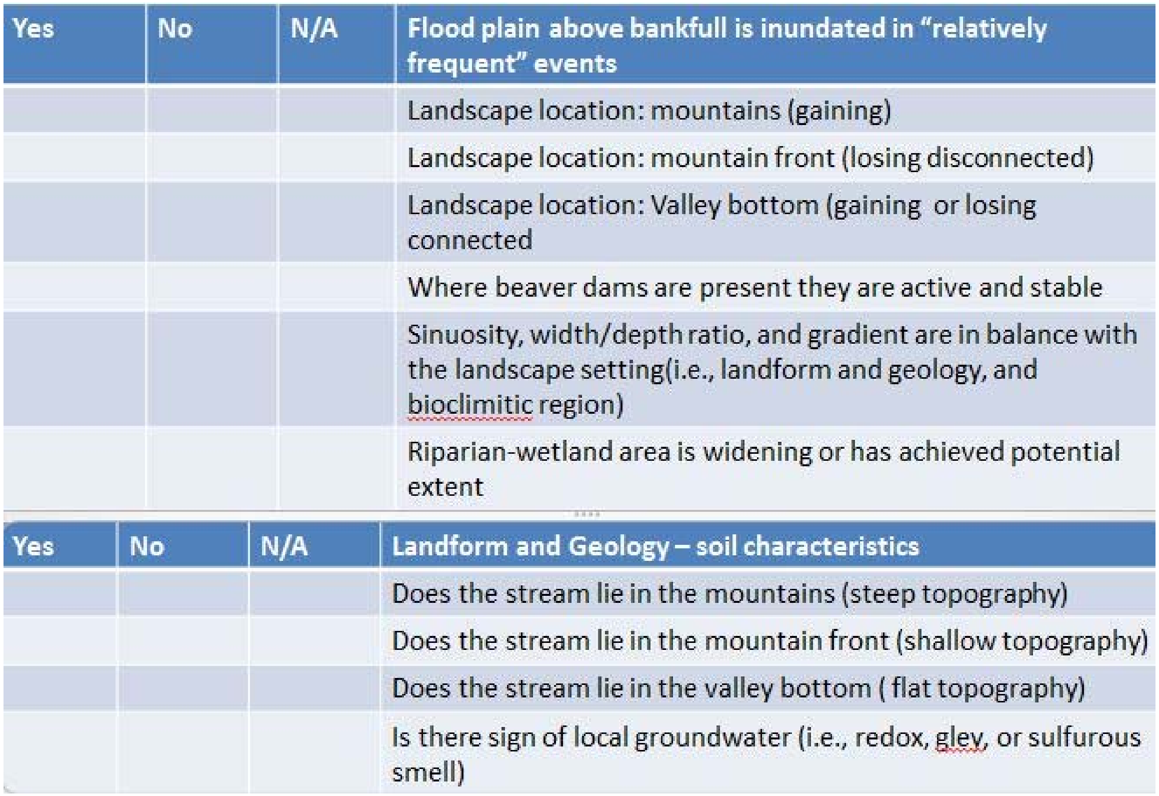
CONCLUSION

Stream and groundwater hydrometrics coupled with soil assessments and geologic observations of the South Fork of Ross Creek suggest that:

1) The stream channel is disconnected from the local groundwater table.
2) The landscape position of the study site has shallow gradient (3%) and deep soils. The dominant groundwater flow system is intermediate and region in scale. As such, the South Fork of Ross Creek is losing water to GW. Further, because the regional GW is so deep there is no connection between surface water and GW.
3) The stream-water-groundwater connectivity determined the structure and character of the riparian zone. This, in turn, will likely affect assessment outcomes.

A better understanding of large-scale stream-groundwater exchange is important to hydrologists, ecologists, and land managers. This research provides insight into the impacts that large scale-groundwater exchanges can have on riparian vegetation structure and character. This study will inform managers and scientists at to the assessment of riparian zone expression and the restoration of site potential for a particular area as a function of its landscape position. The results presented in this paper highlight the necessity of a combined approach to the study of dynamic stream-groundwater exchange and how these exchanges drive riparian zone character and structure. With an understanding of the nature of GW-surface water dynamics (i.e. gaining, losing and losing-disconnected) flow systems, and the target reach's landscape position in the mountain to valley transition; land managers can make accurate assumptions of the persistence of local GW. This enables more informed interpretation of riparian processes. We propose the addition of geology and landscape position to the checklist for determining riparian; e.g. such as those outlined in the TR 1737-15 (1998) guide for assessing proper functioning condition for lotic areas (Table 5.1). The inclusion will produce a more accurate portrayal of riparian function and the extent of future restoration accomplishments.

Table 5.1. Addition to the properly functioning condition checklist.



Yes	No	N/A	Flood plain above bankfull is inundated in "relatively frequent" events
			Landscape location: mountains (gaining)
			Landscape location: mountain front (losing disconnected)
			Landscape location: Valley bottom (gaining or losing connected
			Where beaver dams are present they are active and stable
			Sinuosity, width/depth ratio, and gradient are in balance with the landscape setting(i.e., landform and geology, and bioclimitic region)
			Riparian-wetland area is widening or has achieved potential extent

Yes	No	N/A	Landform and Geology – soil characteristics
			Does the stream lie in the mountains (steep topography)
			Does the stream lie in the mountain front (shallow topography)
			Does the stream lie in the valley bottom (flat topography)
			Is there sign of local groundwater (i.e., redox, gley, or sulfurous smell)

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