An examination of channel geomorphology, hydraulic characteristics, and fish habitat in Cottonwood Creek on the Montana University Systems Bandy Ranch
by Stephanie Ann Hallock

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University

Abstract:
A baseline study was completed in the summer of 2003 on Cottonwood Creek along the portions that flow through the Bandy Ranch. This reach will likely be the host for studies of management practices and corresponding channel change in the future.

This study was initiated after the closure of an irrigation ditch in 2002, raising interest in the immediate and long term impacts on the channel. Data collection focused on fish habitat, channel geomorphology, macroinvertebrate composition, and riparian vegetation. The methods in this study could be repeated in future studies at the ranch.

The riparian health of Cottonwood Creek was established from a variety of field observations. Lack of large woody debris, lack of overhead cover, and lack of deep pools were found to be limiting factors on this stretch of Cottonwood Creek.

Macroinvertebrate data showed that the most upstream reach might be under more stressed conditions compared to the rest of the reaches. Channel geometry has been steady over the period of 1996-2003, while Rosgen classification showed that the creek was in a transition state. Hydraulic modeling was performed, and showed that small changes in flow during low flow periods have little effect on stream physical conditions. A thorough fish assessment was not included in this study, and would complete the baseline data set.

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APPROVAL

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Stephanie Ann Hallock

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

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ABSTRACT

A baseline study was completed in the summer of 2003 on Cottonwood Creek along the portions that flow through the Bandy Ranch. This reach will likely be the host for studies of management practices and corresponding channel change in the future. This study was initiated after the closure of an irrigation ditch in 2002, raising interest in the immediate and long term impacts on the channel. Data collection focused on fish habitat, channel geomorphology, macroinvertebrate composition, and riparian vegetation. The methods in this study could be repeated in future studies at the ranch.

The riparian health of Cottonwood Creek was established from a variety of field observations. Lack of large woody debris, lack of overhead cover, and lack of deep pools were found to be limiting factors on this stretch of Cottonwood Creek. Macroinvertebrate data showed that the most upstream reach might be under more stressed conditions compared to the rest of the reaches. Channel geometry has been steady over the period of 1996-2003, while Rosgen classification showed that the creek was in a transition state. Hydraulic modeling was performed, and showed that small changes in flow during low flow periods have little effect on stream physical conditions. A thorough fish assessment was not included in this study, and would complete the baseline data set.

INTRODUCTION

The focus of this thesis is the stream ecosystem in Cottonwood Creek on the Montana University System's Bandy Ranch in the Blackfoot River Watershed. This thesis is not the traditional hypothesis test, but is the examination of a collection of baseline data and corresponding research methods that could be duplicated in future studies in the same location.

Objectives

The primary objectives of this study were to develop a base-line data set of parameters that 1) measure stream ecosystem health in Cottonwood Creek on the Bandy Experimental Ranch and 2) can be used to evaluate the long term changes in channel morphology and in-stream habitat.

Supporting objectives of this study were as follows: 1) examine stream cross-section data on Cottonwood Creek from 1996 to 2003 to identify a possible channel response, 2) gather habitat data to describe the impact of increased late summer flows on habitat quality and distribution in Cottonwood Creek, 3) perform a riparian assessment to quantify current riparian health, and 4) perform macroinvertebrate studies as an indirect measure of water quality.

Description of paper

Due to the non-traditional nature of this thesis, there is an extensive literature review that is a broad overview of many different subjects. The literature review focuses on concepts important to hydraulic engineering as well as the biological sciences, all of which relate to different aspects of the stream ecosystem (chapter 2). Topics discussed include fish habitat characteristics, irrigation impacts on the stream ecosystem, the relationship between vegetation and bank stability, and an overview of river hydraulics. It is hoped that this background information will not only give the reader an understanding of the complex nature of stream ecosystems but that it will be valuable when future studies are completed.

Other chapters focus on the observations and results of the study. A description of the Blackfoot River Watershed is given in chapter 3 while chapter 4 focuses on the Bandy Ranch itself. Chapter 5 describes the methods used in this study which will be repeated in future work. The baseline data is summarized in Chapter 6. Finally, chapter 7 offers a discussion of the collected data and gives recommendations for the future. These conclusions are broad in scope because of the limited years of data.

LITERATURE REVIEW

Why Are We Concerned With Low-Order Streams?

In recent years, there has been a focus on restoring fish habitat that has been lost or degraded due to human activity. Agriculture, grazing, mining, logging, and recreation all have led to changes in the physical, chemical, and biological condition of many western streams. Small streams are often the most directly impacted by these activities. Such streams have unique geomorphology that results from a combination of "flow conditions, sediment transport, distribution of channel roughness elements, and management activities" (Beschta and Platts, 1986). Channel change is a natural process and streams can undergo this change in subtle ways through the year. Channel change impacts the whole stream ecosystem from riparian vegetation to macroinvertebrate and fish populations. Determining what changes are due to natural conditions and which changes are human caused is the challenge that watershed managers face when making mangement decisions.

The increased demand for water has impacted management practices over the last few decades and has made management of water resources increasingly complex. In the western United States, irrigation is often used to maintain forage for cattle grazing. In 1990, 98% of surface water withdrawals were for irrigation purposes comprising of 9,990 thousand acre-feet of water in the state of Montana (Moore et al, 1996). Many of the same water bodies used for irrigation also contain important habitat for threatened native fish populations. As a result of the awareness of how water management has impacted these fish populations, instream flow methodologies have been developed to determine minimum flow requirements for waterways depending on their designated use. According to Colby (1990), the key to preserving fish habitat in arid regions like Montana, where water is heavily diverted, are adequate instream flows.

Some people question the importance of enhancing habitat on small streams. They are more concerned with the fishery on large rivers and believe that money should be focused there. However, small streams play an important role in the life history of native trout species like Bull Trout (*Salvelinus confluentus*) and Westslope Cutthroat Trout (*Oncorhynchus clarki lewisi*). Protecting these smaller tributaries will help maintain a sustainable fishery. Goldman (1994) notes that

> "fish are extremely vulnerable to a variety of dangers during their early life stages. Due to their high fecundity, a small change in the proportion of offspring that survive the critical early life stages translates into large difference in the abundance of year classes that can persist over their life span. Survival is positively correlated to body size."

By increasing the habitat quality and quantity for fry and juvenile trout, there is a higher probability of a greater number of trout reaching adulthood and returning to their birth areas to spawn.

Fish Populations and Habitat

The relationship between fish populations and stream habitat is complex. Trout need spawning, incubation, feeding, and rearing habitats. Many factors influence fish distribution. These factors include chemical properties such as pH and dissolved oxygen, and physical properties such as water temperature, velocity, water depth, cover, and substrate composition. Competition within and between species along with predation, food availability, and disease also play a role in habitat selection (Leftwich et al, 1997). Each of these factors must be studied if the limiting factor for a given fish population is to be understood. Often stream habitat enhancement projects focus on one aspect, such as cover, while another limiting factor is actually causing a bottleneck in the population.

Habitat forming processes are often impacted by land use and many of these processes that create habitat "operate on time scales of decades or longer" (Roni et al, 2002). It often hard for scientists to study habitat change because of the time involved to observe habitat change as well as the lack of funding to do so. "Several years may also be required for optimum physical conditions to develop after restoration or enhancement, and fish populations may not respond for several more years" (Reeves et al, 1991). Often times fish habitat enhancement projects only change where the fish are located in the channel instead of actually increasing fish biomass as a whole. This is known as redistribution. The only way to detect if habitat change has caused an impact in biomass is to look at the whole drainage and not just a particular section of stream.

Examining the stream ecosystem is essential to habitat enhancement projects. There are many spatial scales that should be considered depending on the study involved. Macrohabitat analysis concerns regional scale, mesohabitat analysis looks at the stream system as a whole, and microhabitat analysis involves the actual habitat present like pools and riffles (Rabeni and Sowa, 1996). Understanding how these spatial scales are interlinked plays a vital role in determining the impact of land management activities on a stream. Fish habitat is a combination of the characteristics of the watershed that create it.

A stream's physical habitat consists of fast and slow water habitat types. Fast water types consist of riffles, glides, and runs. Slow water habitats are pools which can be formed by scour or damming. During low flows, much of the water volume of a stream resides in pools (Beschta and Platts, 1986). During high flow events, pools dissipate energy. These same high flows flush out sediment from riffle areas. Changes in longitudinal profile, sinuosity, roughness, and hydraulic radius all can result from changes in flow, sediment deposition/removal, and structures in the stream (Beschta and Platts, 1986). Many studies have shown that placement of instream structures into a channel cause pool frequency, depth, sediment retention, and woody debris retention to increase (Roni et al, 2002). The addition of instream structures also increases habitat complexity. Beschta and Platts (1986) note that "although generalization is difficult, the effects of sediment availability and streamside land use seem to be more important than possible flow changes brought about by management practices" in impacting habitat formation.

The spatial distribution of pools and riffles is important and can have impacts on fish distribution. Pool-riffle morphology is common in many streams. It has been observed that deep pools with low velocities and plenty of cover support stable fish populations (Beschta and Platts, 1986). For the most part, older trout prefer deeper water. Correlations have been made between yearling and adult biomass with pool volume and depth (Horan et al, 2000). However, good quality pools might still not be enough to support fish populations. For example, young-of the-year fish quite frequently choose lower quality pools to rear in until they are large enough to compete with the larger fish that are present in the deeper pools. Riffles provide food and spawning areas for salmonids. Salmonids often select spawning areas that are not in the "best" riffle habitats in order to provide their young with high quality rearing areas and thus increase their survival (Beschta and Platts, 1986). The surface area and the lower amount of fines in the bed material in riffle areas cause these areas to be highly productive in terms of macroinvertebrate production. However, though not a permanent barrier, riffles can also be barriers to fish passage under certain conditions. Low flows produce the greatest difference between stream habitats. Long riffle reaches become barriers because they "may significantly reduce daily excursions between habitat patches and limit the ability of fish to track variability in food resources and predator densities" (Lonzarich et al, 2000). Because of the variations in habitat use, it has been found that a variety of habitats, such as both shallow and deep pools, are needed to support a healthy fishery. Complexity is the key to fish diversity, and diversity leads to a sustainable fish population. Discharge interacts with the physical and biological aspects of the channel to create this complexity.

Flow in natural channels is three-dimensional. Variations in time and space make water flow complex; yet understanding the velocity patterns in a channel is required to understand the distribution of organisms in the channel. Flow patterns must be considered if fish habitat management plans are to be implemented. Because of this complexity, an "average" water velocity is used in hydraulic calculations. In open channels, average velocity is around 85% of the surface velocity at 0.6 of the depth from the surface (Giller and Malmqvist, 1998; Julien 1995). This can be verified using the

Prandtl-Von Karmen log velocity profile for turbulent flow (Julien, 1995). An example of an idealized velocity profile is shown in figure 2.1.

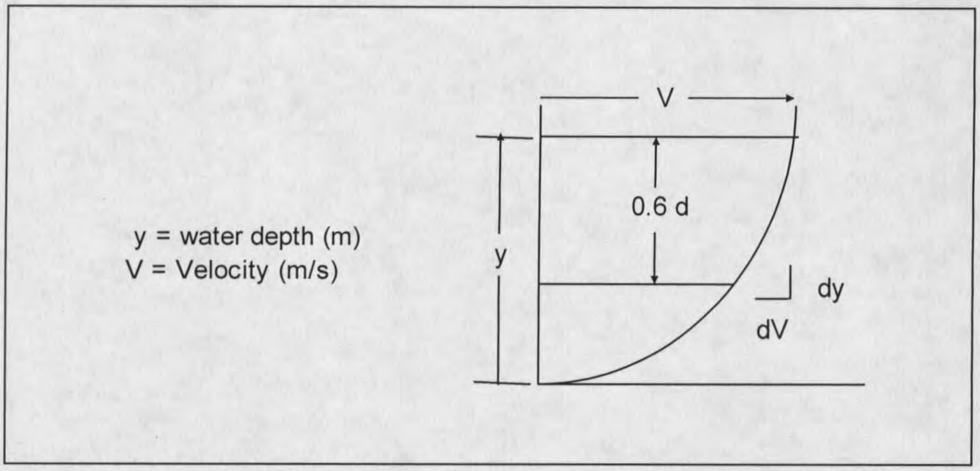

Figure 2.1. Idealized velocity profile for a natural channel.

Another relationship between water velocity and depth is the Reynolds number. This is a dimensionless quantity that is often used to describe fluid flow:

$$\mathrm{Re} = \frac{VD}{\nu} \qquad (2.1)$$

where;

Re= Reynolds number,

V= velocity (m/s),

D= characteristic length (m),

ν= kinematic viscosity of the fluid (m^2/s).

Reynolds numbers below 2000 indicate laminar flow and values greater than 2000 indicate turbulent flow. These two flow regimes create vastly different habitat settings for aquatic organisms. Reynolds number can also be interpreted as an indicator of the

various lift and drag forces experienced by an aquatic organism. According to Giller and Malmqvist (1998), "both the movement of the fluid and the movement of the animal will govern the Reynolds number." Thus, small macroinvertebrates and protozoa that live close to the stream bed have low Reynolds values because of the low velocities there. Organisms that have low Reynolds values are more subject to viscous forces than inertial forces. Macroinvertebrtes live initially at low Re (1-10) areas and have Reynolds numbers higher than 1000 (Giller and Malmqvist, 1998). Fish and other large organisms are more subject to inertial forces and have higher Reynolds values. Trout, for example, have Reynolds numbers ranging from 50,000-200,000 (Giller and Malmqvist, 1998). In order to holds its position in the channel, a fish must use enough energy to overcome the shear stress it is experiencing (Giller and Malmqvist, 1998). Thus each species of aquatic organism reacts in different ways to flow conditions and because of this, changes in flow conditions influence the composition and structure of a stream community.
It can best be summed up as: "the reason why we find certain species in a particular aquatic habitat has to do with the ability of these organisms to utilize and survive under the special set of biotic and abiotic conditions that characterize the habitat" (Giller and Malmqvist, 1998).

Velocity and the drag, lift, and shear forces experienced by fish and macroinvertebrates are more important biologically then the range of discharges (Giller and Malmqvist, 1998). Velocity is considered to be the greatest limiting factor for various fish lifestages. Velocity is involved in influencing community structure, stream carrying capacity, reducing effects of predation on younger fish, and the choosing of spawning sites (Utah State, 1976). Most cobble and gravel bed streams have hydraulically rough flow patterns and flow close to the bed can be complex due to irregularities. In many cases, high velocities can occur close to the bed. Rocks and other materials present on the bed cause flow separation downstream and create a dead zone where the current is lessened. These areas are depositional and are also resting areas for organisms from the current (Giller and Malmqvist, 1998). Depth is the second most important factor in stream habitat. Depth helps maintain pool and riffle quality, wetted areas for spawning, fish passage both up and downstream, and helps maintain food producing riffles (Utah State, 1976).

As velocity of water increases, so too does the magnitude of shear stress. Therefore, flood events help shape the channel due to the large shear stress they exert on the stream bed and banks. Particle size and the amount of bed load are also related to shear stress and velocity because shear stress is proportional to the square of the velocity (Giller and Malmqvist, 1998). The variation in flow and shear stress helps creates the habitat template of streams.

One common formula used to describe the relationship between velocity, area, slope, and roughness to flow rate in an open channel is Manning's Equation (Chow 1959):

$$Q = \frac{C}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{2.2}$$

where;

Q = flow rate (m^3/sec),

C = 1.00 for SI units and 1.486 for English units,

n = Manning's roughness coefficient,

A = cross-sectional area (m^2),

R = hydraulic radius (m),

S = slope (m/m).

Mannings equation was derived for uniform flow conditions (i.e. that the depth, area, and velocity in a reach are constant and that the energy line, water surface, and bed slopes are equal). For natural streams, where these parameters change, the standard step method, as detailed in the methods section in this thesis, can be used with Manning's equation to predict water surface profiles that result from the interaction of discharge with the channel characteristics.

Irrigation Impacts on the Stream Channel

Irrigation diversions can alter flow regimes and sediment transport capacity, in turn impacting channel morphology. Sediment deposition can occur below a diversion if the stream flow is reduced without a reduction in sediment loading. This sediment provides substrate for vegetation to establish in areas that were previously inundated. Channel bed friction increases and further promotes sediment deposition and thus a reduction in channel size (Bohn and King, 2000). As the width decreases, there is also a "loss of lateral aquatic habitat and complexity, which has important implications for fish and macroinvertebrate populations" (Ryan, 1997). Variations in flow due to irrigation demands can also impact the channel. Wohl and Carline (1996) found that recruitment in salmonid numbers may decrease due to variable flow rates in degraded streams. In regards to flow reduction, surface velocity is the hydraulic variable that is most influenced by irrigation withdrawals (Reiser and White, 1990).

Still, it is hard in some ways to predict channel response to irrigation diversions. This is because in many cases, water is not diverted during higher critical flows which shape the channel about every 1.5 years (Ryan, 1997). Diverting during discharges that are below bankfull may not produce any "noticeable" change to the channel. Ryan (1997) notes that diversion impacts depend on the total amount of water diverted, how the peak and sustained flows have changed, and the time that the diversion has been operating. During dry years, lower peak flows can impact the channel morphology but these changes are often "removed" during extreme flow events of wetter years. It is also can be hard to link certain changes in channel dimensions to irrigation diversions because sediment transport from upstream sources, riparian vegetation, and large woody debris are just a few of the many hydraulic controls that might be causing the channel change. Another factor that makes channel prediction difficult is the direct manipulation of the channel by irrigators themselves. Irrigators can alter the channel by straightening the channel, adding riprap to the banks, and by removing large woody debris and other instream features to improve irrigation efficiency. "The wide variety of channel types, the adjustment of individual channels to local factors, and potential time lags between perturbation and channel response" as well as direct human impacts make it hard to predict the reasons for channel change (Montgomery et al, 1993).

Complexity plays an important role in the persistence of fish populations. Horan et al (2000) mention that an isolated population needs more area to survive in a stream segment that lacks complexity versus a highly complex one. Complexity influences the "size, structure, distribution, and stability of populations" (Horan et al, 2000). Diversity in water depth, velocity, and substrate adds complexity to a stream ecosystem. Hydraulic and structure variation also increase the ability of a stream to support life. During extreme events, complexity enables a population to persist where it would fail otherwise. It is also thought that predation is less in complex habitats because the ability of predators to catch prey is reduced (Horan et al, 2000). It has been found that an increase in cover can increase salmonid abundance. In fact, some fish prefer overhead cover to instream cover (Horan et al, 2000).

Effect of Grazing

Overgrazing is one land use that impacts complexity. Some of the results of over grazing included upland erosion, loss of riparian vegetation, breakdown of streambanks, and a lower water table. Streams also have poorer instream structure and an overabundance of nutrients in overgrazed pastures (Meehan, 1991). As a result, fish populations decrease or move elsewhere. Cattle concentrate in riparian areas during certain times of the year to feed on high quality forage. If the area is overgrazed for extended periods, small trees and shrubs may be eliminated from the riparian area (Maloney et al, 1999). According to Maloney et al (1999), "improvements in vegetation and stream channel morphology have generally taken 10 years or more after exclusion of cattle". They also note that protecting streams from grazing, by fencing for example, increases the amount of stream cover, increases the quality of riparian vegetation, and improves channel morphology.

Overgrazing can also cause a decrease in biomass, vigor, and a change in composition of the riparian vegetation (Kauffman and Krueger, 1984). Cattle grazing changes the composition and density of plant species in the riparian zone. One study found that shrubs provided 75% of cover, in an area that was devoid of shrub cover 10 years previously, when the cattle excluded from the area (Kauffman and Krueger, 1984). Because of the impacts that cattle have on the riparian zone, grazing management is very important in minimizing fish habitat degradation. Kauffman and Krueger (1984) note that "aquatic ecosystems can be restored through intensive livestock management at a lower cost than through installation of instream improvement structures".

Irrigation Impacts on Stream Biology

Though physical changes may be hard to see, the result of lower flow regimes due to irrigation does have an impact on the chemical and biological characteristics of the stream. Temperature, dissolved oxygen, nutrient transport are some factors impacted by lower flows. Water temperature can increase as the result of irrigation diversions (Rockford, 1998). Nutrient transport is reduced because flow is reduced. The reduction in velocity due to flow reduction leads to a reduction in intersediment velocity flowing through the spawning gravels. As a result, dissolved oxygen levels are lowered. Freezing in the redds can also be caused by low flows, especially in areas that have high sediment concentrations (Reiser and White, 1990). Lower flow rates can cause water temperature to increase. High temperatures are of concern because they stimulate fish metabolism and have a negative effect on swimming ability and feeding rate (Horan et al, 2000). Higher temperatures also make it harder for species like Bull trout to compete with introduced species like Brown trout. It should also be noted that different life stages of many aquatic species are "triggered by seasonal fluctuations in light, nutrient delivery, and water flow" (Ryan, 1997).

Species like Bull trout and Westslope Cutthroat trout require certain instream flows in order to maintain their populations. It is believed that the minimum instream flow to maintain sustainability is 30% of the average annual flow for the whole year (Moore et al, 1996). If a channel is diverted heavily enough, fish populations can become isolated and migration can be stopped. Irrigation diversions reduce cover, spawning area, and rearing capacity of the stream (Reiser and White, 1990). Trout respond to these reductions by moving to more suitable habitat but deposited eggs obviously cannot respond and are left to deal with these reductions.

Irrigation diversions often create barriers to fish movement during low flows. These barriers have caused decreases in fish populations due to the reduction in the number of fish able to migrate downstream or return upstream to spawn. Horan et al (2000) note that "bull trout also appear to be sensitive to fragment size and will be vulnerable to extinction if fragmentation continues to limit their range, especially in small headwater streams." Many irrigation diversions on small streams utilize horizontal boards that span the stream and are anchored by supports on the bank. Water backs up behind the dam and is funneled into a ditch. During times when water is not diverted, the boards are removed and water flows freely through the structure. Removal of these dams has been noted to increase "migratory fish usage of previously disjunct areas" (Schmetterling et al, 2002). In order to increase fish passage through these structures, denil fish ladders or other fishway structures can be installed at the diversion. Fish species and size both play a role how well these structures aid in fish passage (Schmetterling et al, 2002). Another alternative to increase fish passage is for the complete removal of the structure.

Managing streams for fish passage is difficult because the time of migration and the time of spawning vary from species to species. Westslope trout migrate and spawn during spring high flows. Diversion dams often have little impact on fish movement at this time because water is not being diverted. This is often not the case for fall spawners like Bull Trout. Bull trout enter tributaries during the summer months when irrigation diversions are active and then migrate downstream after spawning.

Riparian Vegetation and Slope Stability

Geomorphologic and hydrologic processes are the primary drivers of riparian ecosystems but slope, elevation, water quality, bed sediment, and streamside vegetation also influence the riparian zone. Riparian areas are open systems with large amount of energy and nutrient exchanges between the stream ecosystem and the upland ecosystem (Kauffman and Krueger, 1984). These areas have higher diversity and productivity then the adjacent uplands. "It is believed that, on land, the riparian/stream ecosystem is the single, most productive type of wildlife habitat, benefiting the greatest number of species" (Kauffman and Krueger, 1984). Riparian vegetation provides insects and organic material for the organisms residing within the stream. In fact, up to 90% of the organic matter that supports headwater streams comes from the surrounding vegetation (Kauffman and Krueger, 1984). Riparian vegetation helps buffer a stream from excess sediment inputs. These riparian areas also serve as travel corridors for big game as they move between their summer and winter ranges.

Land use can impact riparian vegetation in negative ways. It has been observed that disturbances like trampling can cause a riparian vegetation to change to plant species that have shallower and weaker roots (Winward, 2000). These species are not adapted to withstand the erosive forces of high flows and erode easily. Stabilizer species, on the other hand, have root masses that are deep and fibrous as well as strong crowns which enables these plants to buffer the bank against water shear stress. They also catch sediment which helps rebuild eroding banks. It is said that these "species play a significant role in attaining and maintaining proper functioning of riparian and aquatic ecosystems" (Winward, 2000). Geyer willow is an example of a stabilizer plant species. Consequently, knowing the species composition of a riparian zone can indicate the health of the system and streambank stability.

Riparian vegetation is influenced by factors upstream which may cause shifts in community type due to shifts in propagule delivery, to change in the water table or channel form. This must be taken into account when trying to determine the impacts that adjacent land use has on riparian vegetation. Riparian species such as alder, cottonwoods, birch, and willow have become adapted to colonizing disturbed areas or newly developed gravel or sand bars. Some grasses and sedges also colonize these areas. Water sources, valley slope, elevation, climate, and substrate characteristics all lead to the development and function of a riparian system. Land use can alter the water table, discharge level, and sediment supply, ultimately impacting plants directly which in turn causes human induced changes to the plant communities. Water level and sediment size combine to favor certain species over others. For example, willows prefer areas that are dominated by silts and clays while cottonwoods prefer areas that are sandy. Sedges and willows colonize areas that have ground water depths from 0.2 m to 0.4 m from the surface while cottonwoods can handle drier conditions and grow in areas with ground water depths of 0.6 m (Law et al, 2000).

Riparian ecosystems are unique because they are the interface between land and water. These ecosystems are driven by water flow. Establishment of vegetation initiates bank building through sediment entrapment as well as protection during high flows. Variation in discharge truncates vegetative succession, regularly resetting the "succession trajectory". As a result, succession in riparian areas are unpredictable because disturbances vary in magnitude and frequency. Vegetation is known as the great integrator. A stream ecosystem gains stability by having a diversity of functional groups. As a result, even if a population is wiped out, another population can take its place and there is no net loss in biomass or species richness. Bank erosion is a natural process that is the response of the channel to its conditions (Leopold et al, 1964). However, excess erosion can cause vast alteration in stream morphology. Streams with unstable banks tend to more shallower and wider than streams that have more armored banks. Landowners often place rock riprap on eroding streambanks to prevent erosion. However, rock riprap often increases near-bank velocities due to its smooth face and thus smaller roughness. Erosion of the channel bed and downstream banks is enhanced and scour around the riprap may enhance bank erosion at the site (Lee et al 1997). Understanding how bank erosion as well as bank building happens is important in evaluating channel change

In Montana, the soil may be unsaturated during certain times of the year. In this case, the soil has increased cohesion due to matric suction as described by (Simon et al, 2000):

$$c_a = c' + (\mu_a - \mu_w)\tan\phi^b = c' + \psi\tan\phi^b \tag{2.3}$$

where;

c_a = apparent cohesion (kPa),

c' = effective Cohesion (kPa),

μ_a = pore-air pressure (kPa),

μ_w = pore-water pressure (kPa),

θ^b = 10 to 20 degrees, describes increase in shear strength due to an increase in matric suction,

ψ = matric suction (kPa).

However, when water levels decrease very rapidly bank instability is promoted. This is due to the loss of water pressure since the water level in the channel decreases.

(ASCE, 1998). After water levels have decreased and the banks have time to dry out and recover, cohesion increases.

Vegetation can be very effective at protecting streambanks during extreme conditions. Beshta and Platts (1986) note that during flood periods, bank vegetation becomes a “mat” that reduces velocity and this reduction in velocity causes sediments to settle. As these sediments begin to settle, the channel will narrow and deepen as the bank is built up. Besides protecting banks during high flow periods, vegetation can also be beneficial during winter low flows. Degraded streams often are very susceptible to anchor ice formation. Vegetation can help reduce ice cover; trees and shrubs can reduce the erosive impact of floating ice during melting events (Beshta and Platts, 1986). Bank vegetation is essential to maintaining a dynamically stable stream channel.

Vegetation can promote bank stability by adding strength to the soil via their roots that in turn increases the resistance to failure (FISRWG, 1998). This is viewed by many to be the most important way that plants enhance bank stability. For example, one study showed that the tensile strength of soil with roots present was 10 times greater than soil samples with no roots (Lawler et al, 1997). This addition of tensile strength is important because soil tends to be weak in tension and stronger in compression (Simon and Collison, 2002). Plant roots are the opposite being stronger in tension and weaker in compression. Combining soil with vegetation helps increase the soils tensile strength and thus adds strength to the streambank. Shear stresses in the soil are then transferred to tensile stresses in the roots. The semi-continuous root system of plants transfers the load from high stress regions to regions of lower stress (Abernathy and Rutherfurd, 2001).

Tractive forces also develop between the soil and the root fibers to add additional strength between the fibers and the surrounding matrix. Because of this, the spatial density of the roots is also important in soil strength.

As soil depth increases, the strength of the roots decreases. Most of the reinforcement by plant roots are concentrated in the top 20 cm of the bank and a sharp boundary occurs below (Simon and Collison, 2002). Beyond the root zone failure planes are not reinforced. Knowing the distribution of strength with depth is important in predicting the effect of roots on stability. If the bank is taller than the root zone, reinforcement might not be effective since bank failure can occur underneath. This is often the case with cantilever banks. Riparian vegetation can strengthen cantilevered banks via root reinforcement. However, bank failure due to flow erosion and tensile failure occur below the root zone. These root strengthened cantilevers fail by beam or shear (ASCE, 1998). Thorne and Tovey (1981) developed an equation to predict stable widths for a cantilever bank (described in figure 2.2):

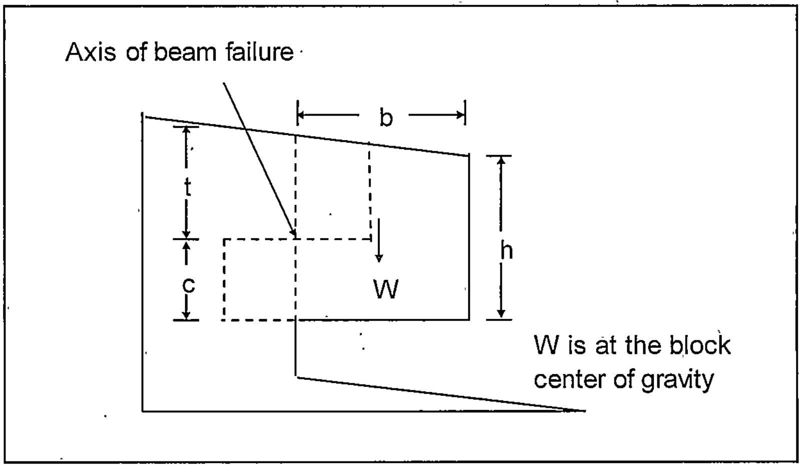

Figure 2.2. Failure of a cantilever bank.

The stable bank width is;

$$b = \sqrt{\frac{\sigma_t t^2 + \sigma_c c^2}{\gamma h}} \tag{2.4}$$

where;

b = Stable bank width (m),

σt, σc = Tensile and Compressive Strengths (kN/m^2),

t = Block height under tensile stress (m),

c = Block height under compressive stress (m)

h = Total block height (m),

γ = Saturated bulk density (kN/m^3).

The size and density of plant roots impacts their mechanical effect on the soil. The tensile strength of the roots depends on the species. Abernathy and Rutherfurd (2001) found that root tensile strength can be expressed as a non-linear function of root diameter raised to a species specific exponent. Strength within a species depends on the environment, seasonality, root orientation and diameter. Tests have shown that as the root mass increases, the shear strength increases linearly (Wu et al, 1988). How the root density is distributed then can be assumed to exert a strong influence over how the root reinforcement is distributed (Abernathy and Rutherfurd, 2001). Bank stability is less impacted by the differences in tensile strength of interspecies roots compared to interspecies differences in root distribution. A parameter that has been developed to measure density is the root-area-ratio (Abernathy and Rutherfurd, 2001):

$$\frac{Ar}{Aw} = \frac{\sum n_i a_i}{Aw} \tag{2.5}$$

where;

Ar = sum of the cross-sectional area of the roots intersecting the profile wall (m^2),

Aw = the wall's total cross-sectional area (m^2),

n_i = number of roots in size-class i,

a_i = average cross-sectional area of the roots in size-class i (m^2).

High concentrations of flexible, long roots per unit volume of soil favor soil strength. Grasses have a high root area ratio which gives them their strength instead of stronger roots (Simon and Collison, 2002). It has been found that roots with a diameter greater than 20 mm do not contribute significantly to soil strength (Abernathy and Rutherfurd, 2001). These roots instead act as anchors.

BLACKFOOT RIVER WATERSHED

The Blackfoot River Watershed in central Montana has a diversity of land uses, including logging, grazing, mining, crop production, and recreation, that have all impacted fish and wildlife populations to some extent. Bull trout and westslope cutthroat trout are of specific interest to fisheries biologists of the Blackfoot watershed due to their current population. Westslope cutthroat trout are listed as a species of special concern. Rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and brook trout (*Salvalinus fontinalis*) also are trout species that occupy the Blackfoot. Fisheries biologists have noted that the numbers and size of sport fish in the Blackfoot River have declined over the last couple decades (Rothrock et al, 1998). Declines in benthic macroinvertebrate populations have also occurred. Habitat assessment of 19 principal tributaries of the Blackfoot in 1988 and 1989 revealed significant habitat degradation (Pierce et al, 1997). Further studies from 1990-1996 showed 26 of 33 additional streams to be impaired. As a result, local groups including landowners, federal and state agencies, and non-profit groups like Trout Unlimited, have come together to try to restore lost habitat, reduce non-point source pollution, remove migration barriers, and increase instream flows. The Bandy Ranch, located by Ovando, MT is a participant of this effort and is the focus of this thesis.

Bull trout populations have declined in the Blackfoot watershed due to spawning and rearing habitat degradation, competition, hybridization with brook trout, and irrigation practices (Swanberg, 1997). Bull trout are the largest native piscivore in the

Blackfoot river and they have a high fecundity and diverse age structure. Fluvial bull trout rear in 2^{nd}-3^{rd} order tributaries during their first 3-4 years and then migrate downstream. At age 5-7 they are sexually mature. These fish spawn in September or October (Swanberg, 1997). Both spawners and non-spawners use tributaries over the summer to avoid warm temperatures in the Blackfoot River. These fish spawn every year or every other year during their lifetime. Bull trout require clear, cold, complex, and connected habitat. They prefer cold water less than 15 C. The U.S. Fish and Wildlife Service has listed Bull Trout as a threatened spices under the Endangered species act (Federal Register, June 10, 1998).

Watershed Description

The Bandy Ranch is part of the Blackfoot River watershed. The Blackfoot River flows from the top of the continental divide westward 212 kilometers (132 miles) to the Clark Fork River by Missoula, MT. Figure 3.1 shows a land use map of the watershed. The watershed is composed of 6,070 square kilometers (1.5 million acres) with 49% of the watershed being federal lands. Other major land owners include the state of Montana, Plum Creek Timber Company, and private owners. This area is relatively undeveloped with ranching and logging being the main economic uses. Glacial activity during the Pleistocene era has helped shape the landforms of the region. Upland communities include grasslands, pine forests, and sagebrush steppe. Vegetation includes ponderosa pine (*Pinus ponderosa*), Douglas fir (*Psendotsuga monziessi*), cottonwood (*Populus*

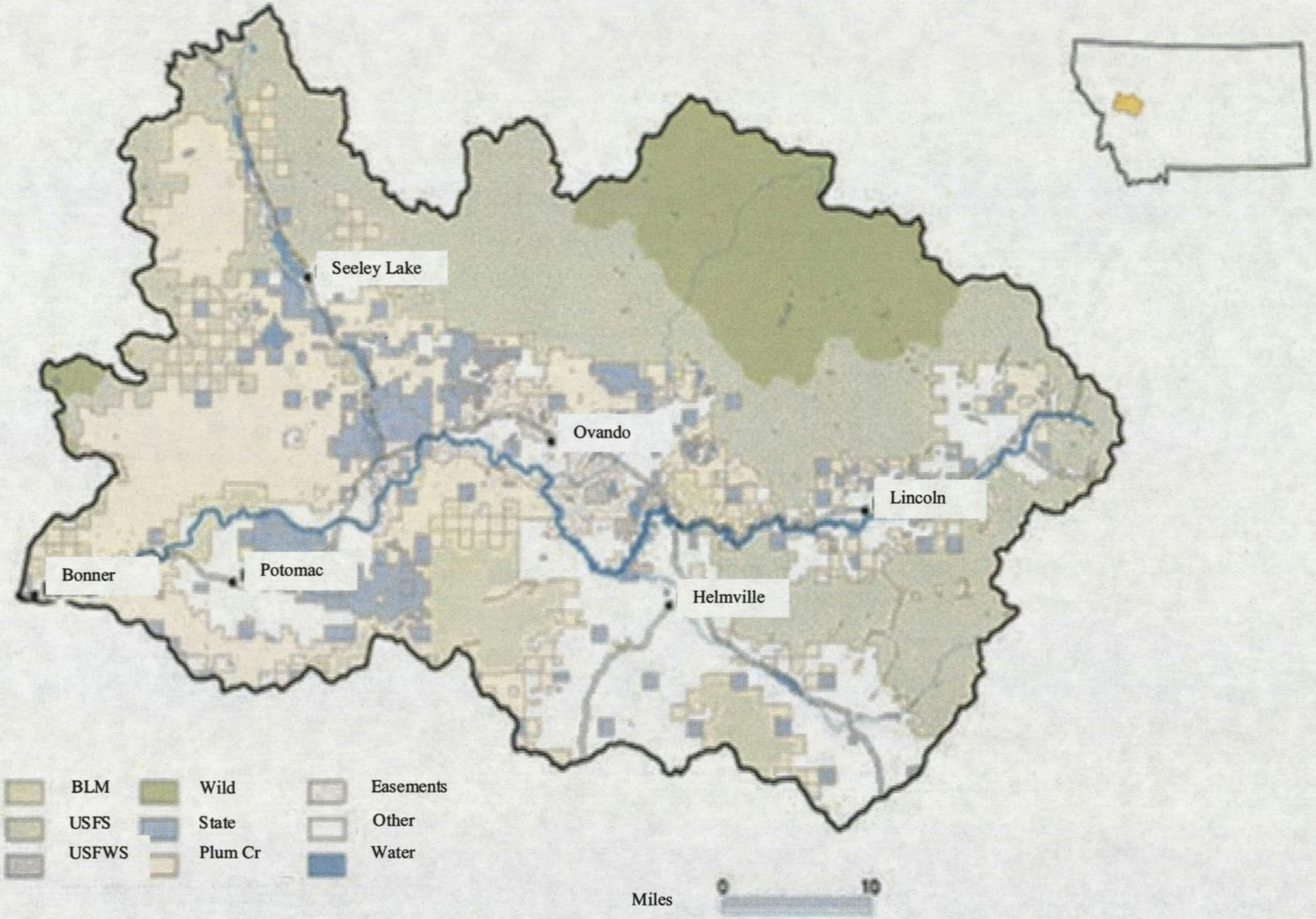

Figure 3.1. Map of the Blackfoot River Watershed (Montana Fish, Wildlife, and Parks).

trichocarpa), aspen (*Populus tremuloides*), and willow (*Salix spp.*). Mean annual precipitation is 400 mm in Ovando. Typically, only a 40 frost-free day growing season occurs (Rothrock et al, 1998). On a historical note, the Lewis and Clark expedition passed through the area in July 1806.

SITE DESCRIPTION

The Bandy Experimental Ranch is located 64 km (40 miles) northeast of Missoula, Montana. About 200 head of cattle are raised on the ranch's 12.9 km^2 (3,200 acres). The ranch has 3.4 km^2 (850 acres) of irrigated/dryland hay, 4.65 km^2 (1,150 acres) of native range, and 4.9 km^2 (1200 acres) of forested land (see figure 4.1). Grazing is shifted throughout the year so that the different pastures have time to recover from grazing and provide vegetation for elk and deer.

The location of the ranch makes it a unique place. It is located close to the Bob Marshal Wilderness area. Next door to the ranch is the Blackfoot/Clearwater Game range. The ranch contains important elk, deer, sandhill crane, and red-tailed hawk habitat. Grizzly bears have also have been spotted on the ranch proper. This interface between wildlife and human activity lets researchers examine how to manage the ranch to promote both cattle and wildlife.

Two creeks run through the ranch property, Shanley Creek and Cottonwood Creek, which ultimately drain into the Blackfoot River. Flows in upper Shanley Creek are diverted into the Bandy Reservoir. Water is released from this reservoir during the summer months to flood irrigate portions of the ranch. Trout species found in these creeks include brown, western cutthroat, rainbow, and bull trout. Bull trout are present in the upper reaches of Cottonwood Creek, but have not been observed in Shanley Creek in recent years. Therefore, much of the research done by Montana State involves field reconnaissance to find ways to maintain a cold water fishery while still diverting water for irrigation purposes. A center pivot was added to the ranch in 2001 in order to improve irrigation and conserve water. It is believed that improving water management will increase instream flows and thus improve fish habitat. It will also make it easier for fish to migrate to spawning sites upstream.

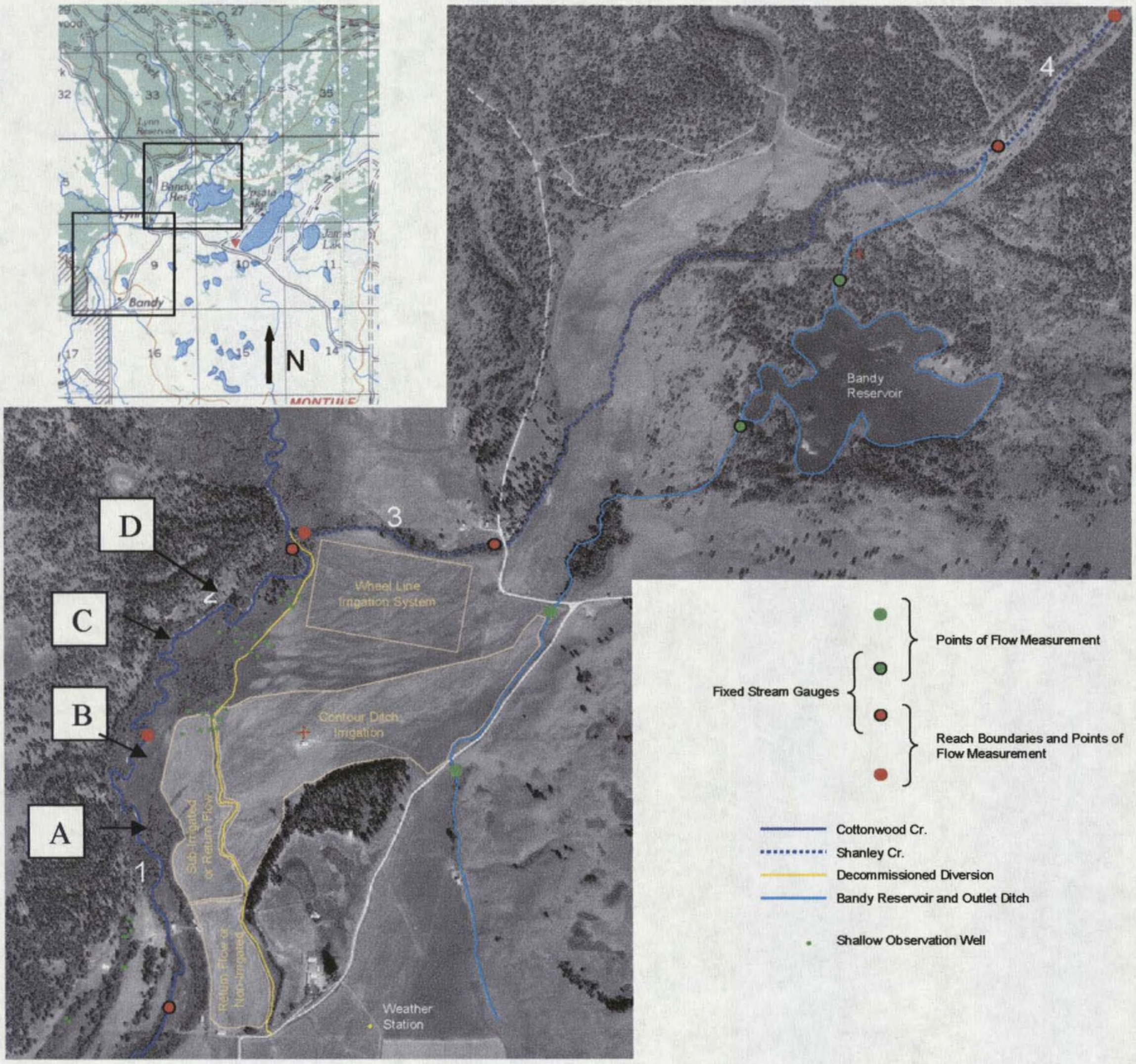

Figure 4.1. Aerial map of the Bandy Experimental Ranch (reach labels indicated).

Shanley Creek is a second-order stream that runs 14.5 km (9 miles) from its headwaters to confluence with Cottonwood Creek on the Bandy Ranch. Base flows are approximately .06 m^3/sec (Pierce et al, 1997). Timber harvest, livestock grazing, and hay production are land uses in this watershed. Shanley Creek ranked 21 of 83 streams surveyed for restoration priority by fisheries biologists (Pierce et al, 2002). Shanley creek is heavily diverted with 3 diversions and one irrigation pump, along 2.57 km (1.6 miles) from its confluence with Cottonwood.

Cottonwood Creek, a tributary of the Blackfoot River, has been described by fisheries biologists as moderately impaired (Pierce et al, 1997). The creek flows 25.8 km (16 miles) from the headwaters to the confluence of the Blackfoot River, changing from a high gradient confined channel to a pool-riffle channel once it exits the canyon. Near this interface, it starts to lose water and becomes intermittent. Irrigation diversions further reduce flows in the creek (figure 4.2). Fisheries Biologists have ranked Cottonwood as 5 out of 83 for prioritized restoration (Pierce et al, 2002). Nine miles from the confluence with the Blackfoot, Cottonwood beings to gain groundwater and becomes a gaining stream. Beavers are present in this middle section of the creek and influence the channel. Three spring creeks bring water into the creek between stream kilometer 10.3 and 12.07. Populations of rainbow and brown trout inhabit lower reaches of the creek in low densities. Brown trout and brook trout dominate the middle reaches in moderate numbers. Cutthroat trout and bull trout dominate the upper reaches, bull trout survive precariously (Pierce et al, 1997).

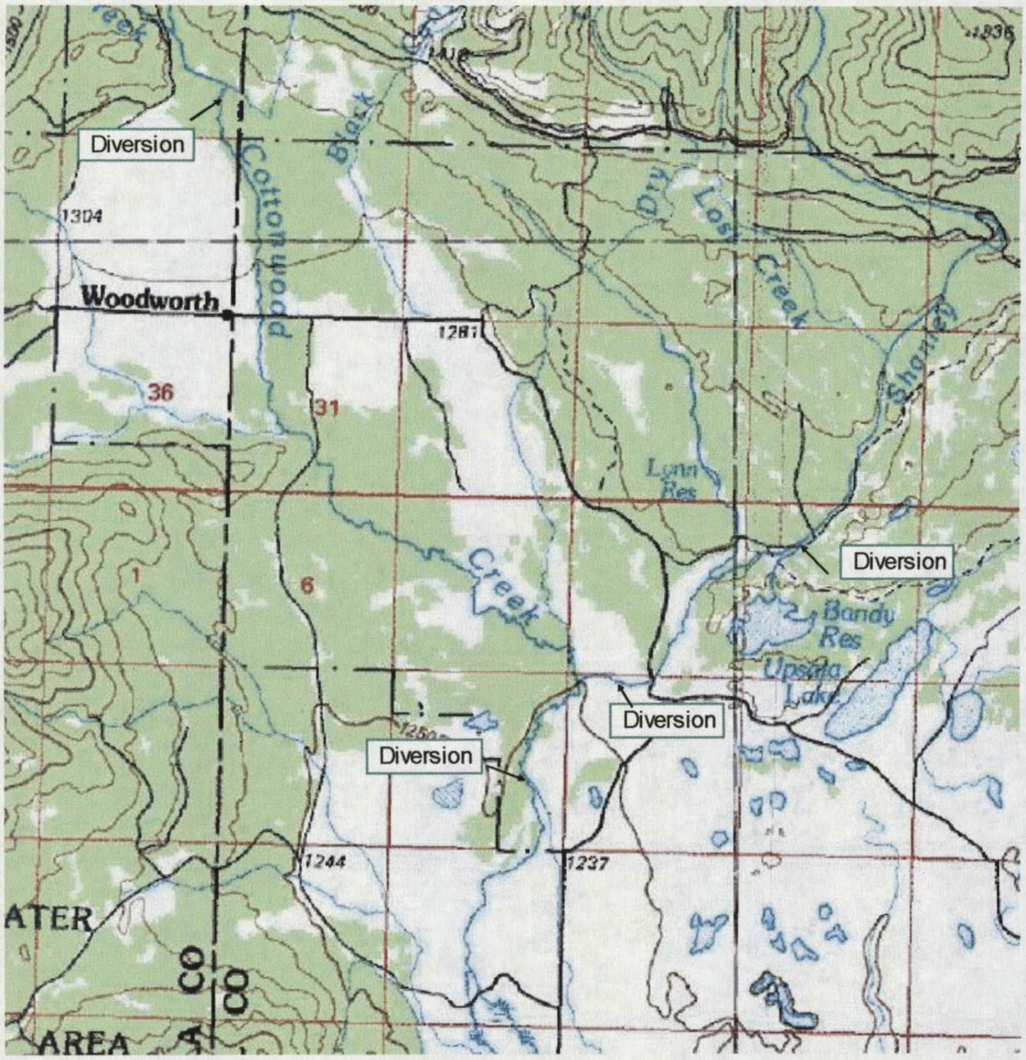

Figure 4.2. Cottonwood Creek Drainage Map (including location of major diversions)

Two major irrigation diversions are present on the Cottonwood creek at kilometers 8 and 19.3 (Pierce et al, 1997). The diversion at kilometer 8.0 is on the Bandy Ranch and is known as the Boyd Diversion. In the past, below the diversion at kilometer 19.3, the creek dried out in low flow years. Because of this, bull trout and westslope cutthroat trout have been isolated in this area resulting in fish kills. Also, both major diversions were identified as barriers to fish passage upstream. The upstream diversion ditch, at kilometer 19.3, was inefficient at carrying water, and though .23 m^3/sec (8 cfs) was diverted, only 28% of this flow reached the irrigation pump (Pierce et al, 1997). Denil fish ladders were added to both major diversions in 1991. Paddle-wheel driven fish screens with 1/8 size screens were also installed on both diversions to reduce entrainment of young of the year fish. The upper diversion ditch was also lined with an impervious liner to improve efficiency. During the irrigation season, 8,663 acre feet of salvage water is being leased to increase instream flows (Pierce et al, 1997). It is believed that by increasing instream flows in the parts of the creek that traditionally were intermittent, that bull trout and cutthroat trout populations will increase and that riparian communities will also be improved. Fish sampling completed in September 2001 downstream of the diversion at kilometer 19.3 showed significant increases in cutthroat trout populations and slight changes in bull trout populations. In 2001, 7.7 fish/ 30.5 m (100 ft) was the catch per unit effort while in 1997, only .7 fish/ 30.5 m (100 ft) for young of the year (YOY) cutthroat trout were found. Age 1+ cutthroat found increased from 2.5 to 14.3 fish/ 30.5 m (100 ft). YOY bull trout were recorded in 2001 but not 1997.

Watershed management projects on Cottonwood Creek also include rotational grazing systems, culvert replacement, conservation easements, and removal of stream-side livestock corrals. Simplified habitat and reduced riparian health still limit fish populations in the middle reaches.

Cottonwood Creek flows through about 1.61 km (1 mile) of ranch property from approximately 7.2 km (4.5 miles) upstream of the confluence with the Blackfoot. Cottonwood Creek confluences with Shanley Creek at kilometer 9.0. The lower denil fishladder on Cottonwood Creek is located on the Bandy Ranch between the confluence with Shanley Creek and the withdrawal location of the center-pivot pump. This ladder is 6.1 meter long and 0.59 meters high. The ladder has a slope of 9.6% and a mean velocity range of 12 to 72 cm/s (Schmetterling et al, 2002). At the lower property boundary, water is pumped out of the creek to the center pivot. There is an old dam structure still in place that is not in use. A diversion located at the confluence of Cottonwood Creek and Shanley Creek that supplied water to wheel lines in the hay pasture was closed in 2002. This diversion, prior to closure, diverted approximately .14 m^3/sec (5 cfs) from the channel. The diverted water traveled 1.6 km across the ranch property losing .113 m^3/sec of water between the point of diversion and the wheel line. This field is now irrigated by a 402 m (1320 ft) center pivot and the water is supplied via a 2.84 m^3/min (750 GPM) pump that takes water out of the creek at the edge of the property. The ranch now leases the .113 m^3/sec of formally diverted water to Montana Fish, Wildlife, and Parks. It is expected that since this water remains in the channel there will be an impact on stream morphology as well as fish habitat directly downstream.

METHODS

Both short term and long term monitoring is required to evaluate the effects of structural modification to the channel due to the large variability in abundance of both juvenile and adult salmonids (Beschta et al, 1986; Roni et al, 2002). The purpose of this study is to develop a baseline data set, and data was collected in July and August of 2003. This data will serve as the starting point for the next 10 years of monitoring that will be required to detect a fisheries and riparian response to changes in management. Hydraulic, fish habitat, riparian vegetation, and macroinvertebrate data were collected to get the overall picture of the status of Cottonwood Creek on the Bandy Ranch, the methods for collection of each of these data sets are described below.

Stream Cross-Sections

There are six monumented cross-sections located on Cottonwood Creek on the Bandy Ranch. Data for these cross-sections was collected previously from 1996 to 2000 twice per year, and from 2002 to 2003 once per year. Multiple annual measurements were taken at different times of the year to coincide with different grazing strategies. One set of measurements was completed before cows had access to the creek and measurements were also taken following grazing in late summer or early fall. Only data from pre-grazing observations were used to examine channel change.

Stakes were used to mark the end of the cross-sections, which were located near the bankfull edges. Each transect was oriented perpendicular to water flow. A measuring tape was stretched level above and perpendicular to the channel and connected to the two stakes. Measurements from the channel bottom to the tape were completed every 10 cm using a stadia rod starting from the right bank facing upstream. For each cross-section, the waters edge on both banks was recorded. Bankfull depth and width were also found following Rosgen (Rosgen, 1996).

Bankfull width/depth ratio, net percent change in area, and the Gini coefficient were calculated from the channel measurements to determine channel change. These parameters are described below.

Absolute percent change in area measures the cumulative change in channel form:

$$|\Delta A\%| = \frac{\sum_{i=1}^{k} |(Y_i before - Y_i after)|}{\sum_{i=1}^{n} Y_i before} * 100 \qquad (5.1)$$

where;

$|\Delta A\%|$ = absolute percent change in area,

Yi= the distance from the stream bed to the tape (cm),

k= number of data points.

The Gini coefficient ranges from 0 to 1 and is a way to quantify change independent of stage height and cross-sectional area.

$$G = \frac{\sum_{i=1}^{k}\sum_{j=1}^{k} |Y_i - Y_j|}{2k^2 \overline{Y}} \qquad (5.2)$$

where;

G = Gini coefficient,

$Y_i - Y_j$ = differences between all pairs of depths (cm),

$\overline{Y}$ = average of all the differences (cm).

Values close to 0 occur in channels that have low channel diversity in depth while values closer to one occur for more channels that have high depth diversity. The difference between one year and the next indicates the direction of change; if the difference is negative the channel is becoming less diverse in terms of depth, if it is positive the channel is becoming more depth diverse.

Habitat Surveying

Habitat surveys were completed on Cottonwood Creek on August 5-7, 2003. The surveys were taken according to the U.S. Forest Service's R1/R4 Fish and Fish Habitat Procedures. Further information was collected using techniques recommended by Platts et al (1983) and Overton et al (1993). Four reaches were chosen for surveying. The most downstream reach, Reach A, was located directly above the Boyd Diversion Dam (figure 3.1). The starting point of the reach was monumented cross-section #3. Each of the other reaches also began at a monumented cross-section so that Reach D corresponded to cross-section #6. These reaches were surveyed for 100 meters upstream of the permanent cross-section.

A variety of parameters were measured to get an overall picture of the various habitats present in each of the four reaches. It should be noted that these habitats are to some extent stage dependent (Montgomery et al, 1993) and would be slightly different if measured at different times of the year, say late September. Another factor that has to be considered is that the R1/R4 method is subjective and habitat delineation can be influenced depending on the observers experience and bias (Overton et al, 1993).

Habitats were delineated according to habitat type (see figures 5.1, 5.2). These habitat types were categorized according to average velocity, cause of formation, and location in channel. Once the habitat was identified, measurements were taken for length, mean width, and mean depth. The habitat length was measured along the thalwag. Bankfull height and width were estimated but not for all habitat units. Mean width was determined by taking multiple width measurements along the channel (approximately 2 for every 4.6 m). A tape was stretched across the channel at these points and depth measurements were taken at 20%, 40%, 60%, and 80%. Average width was found by averaging all of the width measurements taken for the habitat unit.

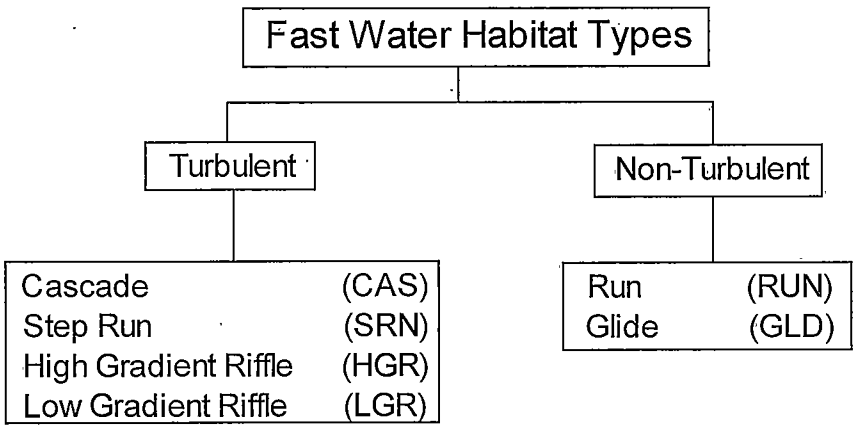

Figure 5.1. Fast water habitat types used in the stream surveys (Overton et al, 1993).

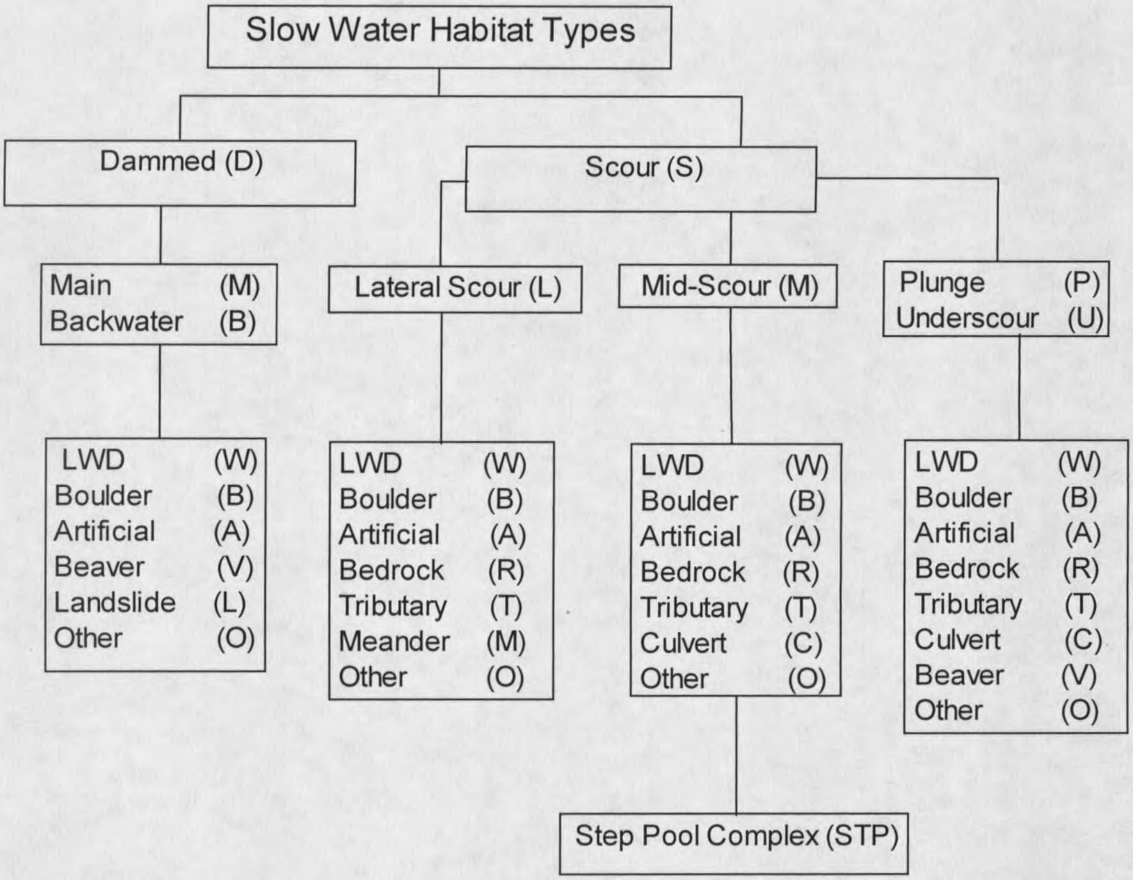

Figure 5.2. Slow water habitat types used in the stream surveys (Overton et al, 1993).

Average depth was determined by first averaging the individual cross-section depths (a value of 0 was included for each measurement to get a representation of the channel bank). The resulting depth values were then averaged to get the overall average depth. For pool habitat types, the maximum depth, crest depth, and average depth (mean of the maximum depth and crest depth) of the thalweg were first identified and the width cross-sections were taken perpendicular to these points.

Pocket Pool

In fast water habitats, pools that were between 10 and 30% of the wetted width were recorded as pocket pools.

Bank Stability

A streambank was assumed to be unstable if slumping, tension cracking, or breakdown was occurring, or if less than 50% of the bank was covered with vegetation or debris and the bank angle was steeper than 80 degrees.

Cover

Cover was defined as the vegetation and undercut banks that shaded the "wetted" portion of the channel (Platts et al, 1983). Vegetative cover was found by measuring from the edge of the water surface (perpendicular to the channel) to the farthest point along the wetted width that was covered by vegetation (multiple measurements were taken if necessary) as well as the length of the vegetation to get the total area of vegetative cover for each bank. Undercut banks were recorded if they were at least 5 cm deep and within 0.1m of the water surface (Overton et al, 1993). The depth and length of each undercut was recorded.

Large Woody Debris

Large woody debris were counted if a piece was longer than 3 m or 2/3 the wetted width, and were 0.1m in diameter 1/3 of the distance from the base. The number and volume of debris jams were also recorded for the entire reach.

Rosgen Classification

Stream gradient was found by using an auto level and a stadia rod held at the water surface (Platts et al, 1983). Sinuosity, the ratio of channel length to straight line distance between two points along the stream, was found from field observation and aerial maps. Platts et al (1983) and others found sinuosity by using a channel distance of 20 times the bankfull width. Entrenchment as well as the bankfull width/depth ratio was computed in order to determine the Rosgen classification for each unit. Table 5.1 shows the characteristics of Rosgen stream types expected at the Bandy Ranch.

Table 5.1. Rosgen classification criteria for selected stream types.

Stream type	Entrenchment ratio	W/D ratio	Sinuosity	Slope
B	1.4-2.2	>12	>1.2	.02-.039
C	>2.2	>12	>1.4	<.02

B stream types have moderate slope, width/depth ratios and entrenchment ratios. They occur in narrow valleys that have gentle slopes. Scour pools and rapids are predominate. For C streams, riffle/pool bed morphology dominate with well-defined meandering channels that are only slightly entrenched. Rosgen (1996) uses these parmeters along with sediment composition and flow characteristics to refine stream classification.

Sediment Composition

Wolman pebble counts were completed for each of the four surveyed reaches (Wolman, 1954). This method gives the percentage of occurance of a certain size particle on the channel bed surface where other geotechnical methods give a volumetric distribution or, in other words, they use total weight of a size class instead of number of particles in that size class to develop sediment distribution curves (Bunte and Abt, 2001). Starting downstream of the permanent transect, the creek was traversed from bankfull edge to bankfull edge moving upstream. At each step, a sediment particle was chosen at random and measured along the intermediate axis. The sediment particle was then deposited downstream. This continued until 100 particles were counted. These particles were divided into the substrate classes in table 5.2

Table 5.2. Substrate size classes (Overton et al, 1993).

Substrate Class	Size classes (mm)
Fines	<2
Small gravel	2-8
Gravel	Aug-64
Small cobble	64-128
Cobble	128-256
Small boulder	256-512
Boulder	>512
Bedrock	Solid Rock

Because the Wolman pebble count can underestimate the percentage of fines, a second technique was used to refine the sediment distribution (Platts et al, 1983). A surface fines grid was used to differentiate fines. The grid was made of 320 mm square Plexiglas with a 7 mm by 7mm grid drawn atop it, the lines being 40 mm apart (Krueger, 2002; Tom McMahon, personal communication). Each grid line was 2 mm wide. Non-fines were sediment that were visible from under the line intersections. The number of non-fines was divided by 49 to get an estimate of the portion of non-fines for the entire sample. Subtracting this value from 1 gave the portion of fines in the sample. Pool tail outs and shallow riffle areas were chosen for this test. Deeper riffle sections were not tested because it was too hard to see the fines grid.

Flow Rate

Flow rate was determined by using the standard USGS methodology (Rantz et al, 1982). A flow meter was used to take measurements at .6 times the water depth measured downward from the water surface. The channel was broken into a minimum of 12 sections to improve accuracy.

Fish Surveying

Fish surveying was not completed on the four reaches for this study due to a lack of resources, but archived data are included in Appendix B from previous studies completed by Montana Fish, Wildlife, and Parks for different sections along Cottonwood Creek.

Riparian Assessment

A riparian assessment was completed for each reach following the Greenline Riparian Assessment method (Winward, 2000). This method examines the percent composition of "disturbance type vegetation" and "natural type vegetation" of the target riparian area. A measuring tape was laid along the bankfull edge of the channel for 110.6 m (363 ft) starting on the right bank and proceeding downstream to the start of each reach at its permanent cross-section. The bank was then paced at an average of .91

m (3 ft) per step. The top 3-5 plant species were identified at each step. This was completed on both banks. The cows had not been allowed to graze in this area since October 2002.

Benthic Macroinvertebrates

Seasonal variability and summer adult insect emergence are two factors that impact use of benthic macroinvertebrates to detect impairment of a stream (Richards, 1996). Because of this, benthic macroinvertebrates were chosen to be sampled at the 4 Cottonwood reaches during late Auguest. The use of riffles for macroinvertebrate analysis can maximize microhabitat variability (Rothrock et al, 1998). Samples were collected using a standard D-frame net with a 1 mm mesh. This net was placed on the substrate and the substrate upstream of the net was vigorously kicked. Sampling was done for one minute working across the channel and upstream. Collected samples were preserved in a jar that contained 95% ethanol. A total of three samples were taken in each reach so that 12 samples in all were collected for the entire study reach. Pool tailouts and riffle habitat units were chosen randomly for sampling. Pool habitats were not sampled due to their depth and limited sampling time. Organisms were taken to the Montana State University Fish Lab, placed in Whirlpack standup bags, and preserved in a mixture of Kahles Solution and water. The Kahles solution consisted of 180 ml water, 40 ml glacial acetic acid, 220 ml formalin, and 560 ml 95% alcohol. The samples were rinsed and put in 70% ethanol when identification took place. The macroinvertebrates were picked, sorted, identified to the family level, and then counted by family with the aid of a dissecting microscope. Species level identification was not completed because identification to the family level required less experience, time, and provided a higher degree of precision (Barbour et al, 1999).

Metrics that were determined include taxa richness, total abundance, EPT richness, EPT abundance, Taxonomic group composition and percent dominant taxa, and were summarized with the Hilsenhoff Biotic Index (Rothrock et al, 1998). These metrics are explained in table 5.3.

Table 5.3. Metrics used in the macroinvertebrate analysis (from Rothrock et al, 1998, Resh and Jackson, 1993).

Total Richness: Total number of different taxa in a sample. The general trend is that richness decreases as water quality becomes poorer.

Total Abundance: Total number of organisms in the samples.

EPT Richness: Total number of family taxa from the Ephemeroptera, Plecoptera, and Trichoptera orders. The members of these three orders, for the most part, are sensitive to pollution.

Taxonomic Group Composition and Percent Dominant Taxa: Percentage of individuals in each taxonomic group and the taxa with the greatest percentage of individuals. A community might be experiencing stress if there are only a few dominant taxa present.

Hilsenhoff's Biotic Index (HBI): Values are scaled from 0 to 10 for each family dependent their tolerance to pollution. Higher values indicate higher tolerance to pollution.

Ordinal Relative Abundance (EPT: Chironomidae ratio): This ratio looks at the proportion of Chironmidae to EPT abundance. A ratio less than 1 indicates that there is an imbalance between the groups and that environmental stress may be occuring. The abundance of Chironomidae generally increases with increasing organic enrichment.

Hydraulic Analysis

To examine the channel morphology of Cottonwood Creek in depth, a detailed survey of Reach C and Reach D was completed. These two cross-sections were chosen because they were adjacent to one another and because of their differences in geomorphology. Cross-section elevation and water surface data was collected using an autolevel. Distances between the cross-sections were measured using steel tapes. Flow rate was measured at the beginning of Reach C. This information was then placed into HEC-RAS to develop a water-surface profile plot for the reach.

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) was designed by the U.S. Army Corps of Engineers to allow the user to "perform one-dimensional hydraulic calculations for a full network of natural and constructed channels" (US Army Corps of Engineers, 1997). Water surface profiles for steady, gradually varied flow can be found using this software for subcritical, supercritical, and mixed flow regimes. The standard-step method is used to determine water surface profiles by utilizing the energy equation and the concept of gradually varied flow. Figure 5.3 shows the theory behind gradually varied flow. Head losses between two adjacent cross-sections result from friction losses or contraction/expansion losses. If flow is subcritical, the standard-step method works in the upstream direction starting from an intial known water surface elevation (Chow, 1959). If the intial water surface elevation is not known, an assumed elevation at a distant section may be used. The velocity is calculated from the desired flow rate and cross-sectional area. From this the velocity head is determined and the head losses are computed. The water surface profile is then found by identifing the depth that makes the current total head minus the previous total head + head loss equal to zero.

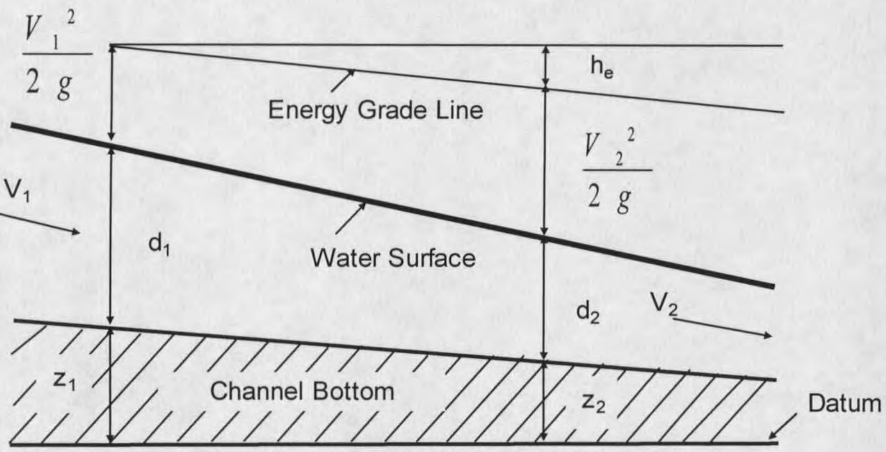

Figure 5.3. Explanation of the theory behind gradually varied flow.

The energy equation is:

$$\frac{V_1^2}{2g} + d_1 + z_1 = \frac{V_2^2}{2g} + d_2 + z_2 + h_e \qquad (5.3)$$

where;

h_e = energy losses (m),

z = elevation head above a datum (m),

V = mean velocity (m/s),

d = water depth (m),

The energy losses can be found by:

$$h_e = SL + C\left|\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right| \qquad (5.4)$$

where;

C = coefficient of expansion or contraction

L = reach length (m)

Elevation and station data for each cross-section, the distances between each cross-section (including the right bank, left bank, and thalwag distances), values for manning's roughness coefficient, values for contraction/expansion losses, flow regime, and a known boundary condition are all inputted into HEC-RAS before steady-flow analysis can be performed. The water surface elevation of the most downstream reach is a typical boundary condition. Boundary conditions can also be assumed including the normal depth or the critical depth.

RESULTS

Habitat Surveys

Four approximately 100 m long reaches were surveyed for habitat assessment on Cottonwood Creek below its confluence with Shanley Creek (figure 6.1). These reaches were all located within the Riparian Pasture of the Bandy Ranch. This pasture is grazed during August and September. Data collected for each reach is located in the appendix.

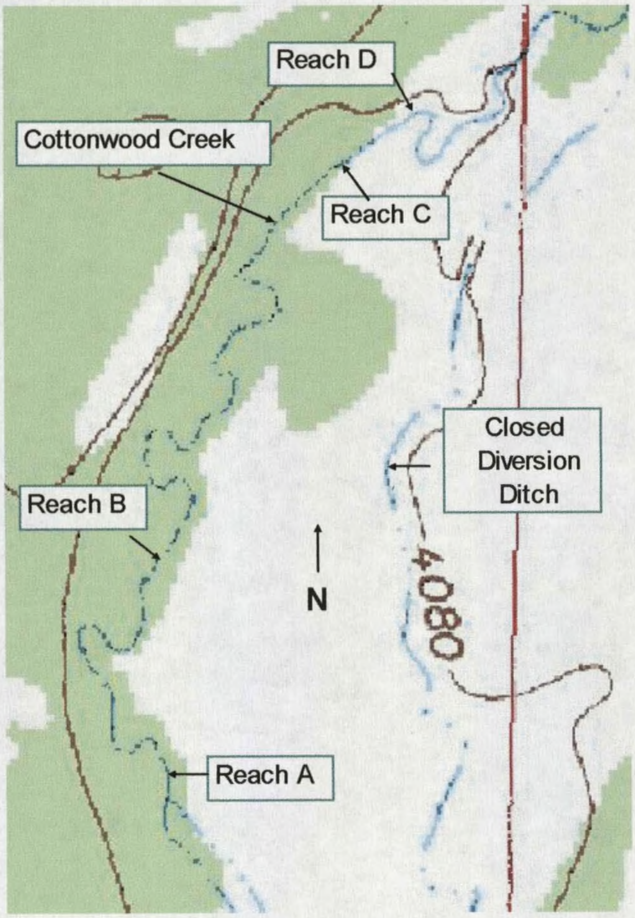

Figure 6.1. The location of the surveyed reaches.

Reach A

Reach A was located at 47.04.159° N and 113.15.930° W. This reach is directly upstream of the Boyd dam diversion structure. Willows dominate the left bank (facing upstream) while sedges and grasses dominate the right bank. Rock riprap has been placed along a meander in this reach to reduce erosion. This reach had the most habitat units, 9 total, of any of the surveyed reaches. Pools dominate the upper end while riffle habitat dominates the lower end (table 6.1). Eight pocket pools were counted for the entire reach. Figure 6.2 gives a general overview of reach A.

Figure 6.2. Looking downstream towards the beginning of reach A.

Table 6.1. Summary of the habitat units of reach A.

Habitat Number	Habitat Type	Total Length (m)	Mean Wetted Width (m)	Mean Depth (cm)	Total Volume (m^3)	Width Depth Ratio
1	LGR	15.50	7.30	24.07	27.23	30.33
2	HGR	12.00	6.40	22.30	17.13	28.70
3	LGR	10.50	6.35	28.70	19.14	22.13
4	SLM	14.00	7.37	45.13	46.55	16.32
5	LGR	6.50	6.70	25.60	11.15	26.17
6	SLM	22.60	7.23	35.33	57.76	20.47
7	SLM	17.00	7.57	38.40	49.40	19.70
8	DMW	9.00	8.10	34.80	25.37	23.28
9	SLM	34.50	7.13	37.67	92.70	18.94
Entire reach		141.60	7.13	32.44	346.41	

Reach B

Reach B is a predominantly riffle reach located upstream of Reach A (47.04.266° N, 113.15.946° W). Figure 6.3 is a picture taken along this section of Cottonwood Creek. Along the left bank (facing upstream) at the start of reach B is a bare cut bank. There are two pool habitat units in reach B. One of the pool habitats actually consists of two small pools that are adjacent to one another. A beaver dam complex is responsible for creating these two pools along with scouring along the bank. The other pool habitat is at the upstream end of the reach. This pool is formed due to a confluence of two braided channels. The mean wetted width of this channel was 10.6 m and mean depth was 22.72 cm. This pool might not be representative of Cottonwood Creek above Reach B.

Figure 6.3. Looking upstream at the beginning of reach B.

Figure 6.4. Beaver dam remains in reach B.

Table 6.2. Summary of the habitat units of reach B.

Habitat Number	Habitat Type	Total Length (m)	Mean Wetted Width (m)	Mean Depth (cm)	Total Volume (m^3)	Width Depth Ratio
1	LGR	84.00	6.63	23.32	129.75	28.41
2a	SLM	8.30	4.73	31.13	12.22	15.19
2b	SUV	9.00	3.40	28.13	8.61	12.09
3	LGR	8.90	6.20	24.20	13.35	25.62
4	SMO	6.30	10.60	22.72	15.17	46.65
Entire reach		107.85	6.31	25.90	179.11	

Reach C

This reach begins at monumented cross-section #5 (47.04.481° N, 113.15.819° W) and ends at monumented cross-section #6. This reach is also dominated by riffle habitats (table 6.3) and has a crossing area (figure 6.5) that is used by cattle and wildlife. One weakly developed pool was identified for this reach. A high gradient riffle section is directly downstream due to a change in slope. Rock riprap has been placed along portions of the right bank (figure 6.6).

Table 6.3. Summary of the habitat units of reach C.

Habitat Number	Habitat Type	Total Length (m)	Mean Wetted Width (m)	Mean Depth (cm)	Total Volume (m^3)	Width Depth Ratio
1	LGR	74.70	8.55	20.77	132.65	41.17
2	HGR	6.10	10.75	17.90	11.74	60.06
3	SMW	6.10	8.17	25.00	12.46	32.68
4	LGR	29.60	8.90	22.70	59.80	39.21
Entire reach		116.50	9.09	21.59	216.65	

Figure 6.5. Crossing area in reach C (right bank facing upstream).

Figure 6.6. High-gradient riffle and pool in reach C. Note the rock riprap on the banks.