RIVER RESTORATION OF THE UPPER REACH OF THE SAN MIGUEL RIVER,

COLORADO: A POST APPRAISAL GEOMORPHOLOGICAL ANALYSIS

A Thesis

by

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ABSTRACT

The upper reach of the San Miguel River has undergone river restoration in a two-phase approach. The first phase was carried out in 2001; the second phase was completed in 2004. Although detailed plans were developed for the restoration of part of the river, only short-term (i.e., three year) monitoring occurred. Thus, one can ask: was river restoration on this part of the San Miguel River effective after ten years? For the purpose of this research, if the river channel and its meanders maintained the relative geometries, then the restoration is considered effective. To assess the effectiveness of the restoration, a one-km section of the San Miguel River in Telluride, Colorado, was studied. This section begins ~ 150 m above the confluence of the river with Bear Creek on the eastern side of Telluride and ends at the Mahoney Street Bridge on the western side.

To answer the research question, changes in the channel width, meander location, and sinuosity were determined using a series of Google Earth® images, measured cross-sections at twenty-two sites and high-resolution video collected with an Unmanned Aerial Vehicle. In addition, published hydrological, ecological and geomorphological data collected by the State of Colorado, the USGS, NOAA and the Town of Telluride were used. These data include rates of sedimentation and discharge, weather patterns, aquatic biomass and vegetation presence, changes in land use, and alterations to the channel.

The bank-to-bank width averaged ~10.2 -10.5 m in 2014, and depth ranged from 0.2 to 1 m, resulting in width/depth (W/D) ratios of >10. Sinuosity remained consistent

at 1.16 during the period 1998 – 2014. Sediment continued to be deposited in the channel during the ten-year period despite the construction of a sediment retention basin at the start of the project. As a result of high volume of sediment, the Town of Telluride excavated the sediment retention pond yearly from 2001 to August 2014. Approximately, 500 m^3 of sediment was removed annually. Hydrologically, no significant difference in mean discharge occurred from 1992-2014.

Water chemistry parameters including nitrate, conductivity and dissolved oxygen were consistent between the upstream and the downstream sections. Dissolved oxygen concentrations were within the water quality limit of 6 mg/L (Class 1 Cold Water Biota). Conductivity levels increased consistently from 2004 – 2012, above the limit of 0.500 mS/cm for “good quality inland waters”, as defined by national standards. By August 2014, the conductivity had returned to historical levels of 0.35 mS/cm. Total trout biomass roughly doubled from 22 to 44 kg/ha. Despite channel movement and sediment deposition, the restoration was considered effective.

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CHAPTER I

INTRODUCTION

I.i. Background

River restoration in the United States is a developing discipline (Wohl *et al.* 2005). The main objective of restoration is to restore a river with a degraded ecosystem to its natural functioning state (Bradshaw 1996; Wohl *et al.* 2005). River restoration encompasses multiple goals, including improved geomorphological, ecological, hydrological and anthropological functions of the river (Bradshaw 1996; Wohl *et al.* 2005, Bernhardt *et al.* 2005, Palmer *et al.* 2005). It can be difficult to quantify the impact of restoration projects despite substantial investment in a project.

Lack of monitoring and maintenance can lead to failures of designed instream structures. Miller and Kochel (2010, 2013) recorded in a twenty-six site study that thirty percent of all structures failed; a least 60 percent of all structures had greater than twenty percent change in channel capacity. The authors suggest using an adaptive management and adjustment approach that prioritizes high-risk sites over natural channel design.

I.ii. Nature of Problem

The San Miguel River in the San Juan Mountains of Colorado (Figure 1) is one of the last minimally altered rivers in the United States (Fleener 1997; Allred and Andrews 2000; Wolff et. al 2000). Channelization, mining, and urban growth damaged the San Miguel River and resulted in temporal imbalance of various parameters of the river (Wolff *et al.* 2004). Telluride, in consortium with Aquatic and Wetland Company, Mussetter Engineering and Ecological Resource Consultants Inc., undertook restoration in the early 2000s along the San Miguel River as it flows through town (Figure 1). After a three-year planning and design period starting in 1998, phase I was completed in 2001. Phase II was completed in 2004. The effects of restoration on the San Miguel River channel were monitored by town officials for three years after each phase.

The design of the channel was based on a type C3 stream, a meandering alluvial stream, from Rosgen (1986, 1994). The design plans were based on literature for natural stream channel shape and planform as discussed by Leopold *et al*. (1964) (Appendix B).

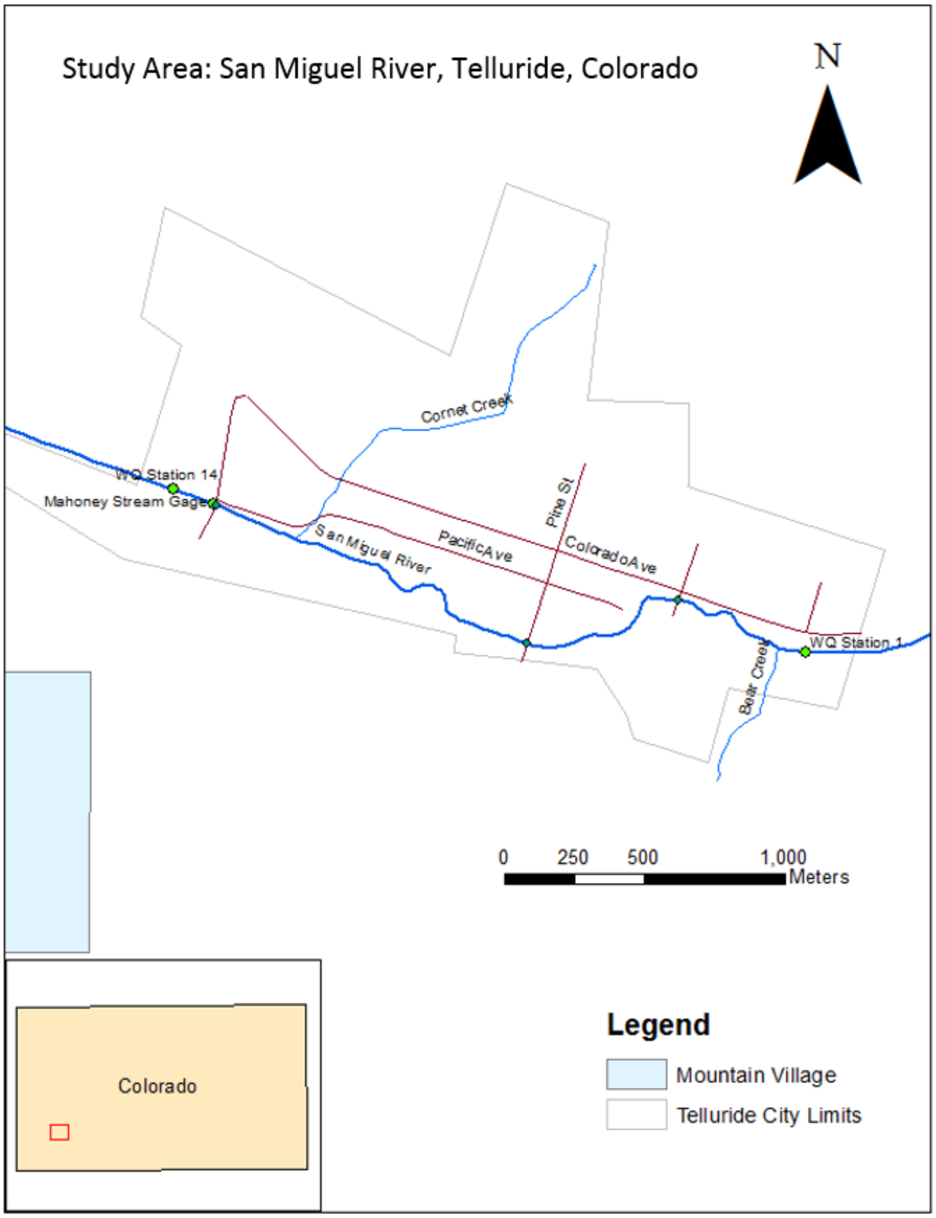


Figure 1: Location of study area: San Miguel River as it flows through Telluride. Inset map shows location of Telluride in the San Juan Mountains, located in Southwestern Colorado.

The main goal of the restoration was to restore aquatic, wetland, and riparian habitat throughout the San Miguel River corridor within the town limits of Telluride. Developing a natural functioning channel with features that enhance aquatic habitat was the goal of the project (San Miguel River Corridor Restoration Plan 1998).

The objectives of the restoration (San Miguel River Corridor Restoration Plan 1998) were: 1) improve hydraulic conditions; 2) balance sediment movement; 3) provide aquatic habitat; 4) improve wetland habitat; 5) re-establish diversity of flora and fauna species; and 6) develop a monitoring plan.

During the short-term monitoring, hydraulic conditions were improved by reduction of backwater after replacement of bridges and undersized culverts along the channel. The observed rates of sediment erosion and deposition approached dynamic equilibrium with the installation of a sediment retention basin. Sediment was removed from the basin every year, however, to maintain the function of the basin. The creation of wetlands and various aquatic habitat were effective with ~ 95 percent of wetlands surviving three years after creation. Additionally, most of the vegetation planted along the banks survived during the three-year period.

During the summer of 2014, the longer-term effectiveness of the river restoration was assessed, focusing on Phase I of the restoration, ~ one kilometer of the San Miguel River as it flows through the Town of Telluride. Thus one can ask: Was river restoration on the San Miguel River effective over ten years?

To answer the research question, field methods, interviews, and analysis comparing 2014 data to 2000 and 2004 data, pre- and post-restoration, respectively, were conducted.

I.iii. Objectives

To determine the changes of the San Miguel River, along a 1 km stretch, the following were established: 1) Assess changes in the channel; 2) Assess changes in the floodplain along the river; and 3) Evaluate whether the restoration goals were met and maintained over ten years.

By assessing the changes in the channel and floodplain in this reach of the San Miguel River over ten years, the long-term geomorphological, hydrological, ecological, and anthropological effects of restoration can be observed and studied. The analysis will establish whether the restoration goals were met in addition to whether the river met the design standard used for a meandering alluvial stream. Stabilization of the river can be evaluated by comparing the river today with a type C3 stream, based on Rosgen's 1986 stream classification. The goal of this thesis was to evaluate the impact of river restoration on the San Miguel River over ten years.

I.iv. Hypotheses

Two working hypotheses were established:

H_1: The reach was stable ten years after completion of restoration.

H_0: The reach was not stable ten years after completion of restoration.

For the purpose of this thesis, stable was defined as the channel geometry and sinuosity maintained the design standards since completion of restoration.

The second hypothesis was:

H_1: The goals of the restoration were achieved.

H_0: The goals of the restoration were not achieved.

The rationale behind the proposed hypotheses stems from the initial restoration plan. The rapid urban development in Telluride has constrained the potential movement of the channel (San Miguel River Corridor Restoration Plan 1998). Development includes parks, roadways and private property. These changes challenged the placement and configuration of the channel within the floodplain to prevent damage from flooding during high spring flows and balance the sediment movement. Thus, the width/depth ratio of the channel that ranged from 30:1 to 45:1 pre-restoration was modified to 25:1, which required the narrowing and deepening of the channel into a single thread channel (Wolff et. al 2000).

I.v. Significance of Research

This research describes the ten-year long restoration of the San Miguel River via a case study. Because of elevated levels of lead, zinc, cadmium and manganese in the San Miguel River, likely resulting from mining tailings upstream of Telluride, the river is not a source for drinking-water (Vhay 1962; Nash 2002; Wolff et. al 2000; Church *et* *al.* 2007; Idarado Mine Natural Resource Damage Site, www.colorado.gov). Therefore, the town was provided funds to restore the river as part of the federal mandate of the Idarado Mine Natural Resource Damage Site cleanup upstream of Telluride. Additionally, the infrastructure in Telluride, in the recent decades, has contributed to the changes in the spatial dimensions of the floodplain along the San Miguel River as it flows through town (www.city-data.com, 2015).

This research attempts to assess the effectiveness of river restoration using a multi-faceted, long-term approach. Therefore, this post-appraisal study can serve as a basis for future restoration design, and for post-restoration monitoring methodology.

CHAPTER II

LITERATURE REVIEW

Over the last century many scientists have tried to classify streams to understand the processes that shape and define river systems, including Davis (1899), Melton (1935), Thornbury (1969), Leopold and Wolman (1957), Lane (1957), Schumm (1963), Khan (1971) and many others (Rosgen 1986). Many early classifications follow the academic school of thought, where streams are classified based on function (Ward *et al.* 2008). A few, such as Leopold and Wolman (1957), characterize streams based on pattern: meandering, straight or braided. Rosgen (1986) simplified Leopold and Wolman's approach by characterizing streams based on natural features that are easily measured, including width, depth, discharge, velocity and slope. Rosgen's stream classification (1986), first developed when he was employed by the US Forest Service, laid the foundation for the field of river restoration. Rosgen's approach, however, created a series of controversies. To this day, a form vs. function approach to stream classification is debated between Rosgen and various individuals who question his methodology, including Simon *et al.* (2005, 2007). These discussions (Rosgen 2008, Simon 2008) have been otherwise known as the Rosgen Wars (Lave 2009, 2012). This tension has been aired at technical meetings in the past but without resolution (Simon *et al.* 2013).

The science of river restoration became prominent when Rosgen, *via* help from Leopold, published his previous 1986 work in *Catena* in 1994. This work provided the foundation for his 1996 book, *Applied River Morphology* (Malakoff 2004). Rosgen

(1986, 1994, 1997) proposed a new stream classification system that included seven main and 41 overall types of streams. In addition, Rosgen suggested the concept of natural channel design, using trees and rocks to alter the hydraulics of a river, instead of concrete to line channels (Rosgen 2006, 2014). His work proposed a simple way to use field techniques and feature identification (Malakoff 2004, Lave 2012).

Academics and agency-based scientists including Bernhardt (2005), Fitzpatrick (2003), Juracek (2003), Kondolf (2005), Palmer (2005), and Simon (2005) have criticized Rosgen's work as too simplified because it does not incorporate processes (Lave 2009). Unexperienced practitioners follow the guidelines too loosely resulting in errors have wasted large amounts of money (Juracek and Fitzpatrick 2003; Simon *et al.* 2005, 2007, 2008; Malakoff 2004, Lave 2012). Simon *et al.* (2007) argued that the application of the form-based classification along with natural-channel design proposed by Rosgen (1986, 1994, 1997, 2006) has led to inconsistencies. Problems with defining the bankfull level and defining a dominant channel have resulted in incorrect classifications when multiple options were present (Simon *et al.* 2007, 2008). Rosgen's classification also ignores spatial and temporal scales (Simon *et al*. 2007). Miller and Kochel (2010, 2013) demonstrated that instream structures, a critical component of Rosgen's natural channel design approach, fail or become ineffective over time. Many projects do not define or understand the expected design life of a structure, which creates confusion and lack of maintenance (Miller and Kochel 2010).

Rosgen's methods have become popular, as demonstrated by the numerous companies and governmental organizations that use the system. A caveat of its use, however, is it requires experience with the correct application of its classification system. This requirement further causes contention with academically-trained scientists (Malakoff 2004, Simon *et al.* 2005).

Rosgen filled a gap in the science of restoration with his classification system. Many in industry use his methodology. With time and better dialogue between scientists and stream rehabilitation practitioners that improvements to restoration science can be achieved (Nagle 2007). Other classifications, proposed by Montgomery and Buffington (1997) serve as alternatives.

Montgomery and Buffington's (1997) channel-reach morphology classification system in mountain-drainage basins also separates rivers into seven reach categories, including colluvial, bedrock and five types of alluvial channels. The characteristics of mountain channels are highly variable based on external influences. These influences include mean hydrologic residence time and residence time of surface water based on storage in an alluvial aquifer and rate of discharge. Inundation hydrology has an important control on the characteristics of the channel (Helton *et al.* 2012).

Moreover, an important connection between channel process and form exists, as bed morphology conveys a stable roughness configuration for sediment supply, as well as transport capacity (Montgomery and Buffington 1997). One can survey and analyze changes in sediment supply and transport capacity to assess whether the type of changes in a reach are temporary or permanent. By analyzing parameters based on measurements acquired at different times, instead of focusing on a generic form, one can understand a given stream system in more detail. This classification scheme, however, calls for more adaptive management and complex data collection and analysis, similar to other process-based methods. Therefore, the potential costs can deter individuals for using the classification. Currently, organizations want the simplest river restoration approach with minimal cost, making a more complex, process-based stream classification less desirable because it requires considerable education in geomorphology and channel hydraulics to understand and apply correctly.

Other scientists, such as Wohl (2005), have emphasized the need to understand the regional land-use and history of a river. Wohl explains that the goal to restore the form of the river often overshadows the desire to restore the ecological and hydrological function of the river. Many practitioners focus on redesigning a given river to meet the desired form based on Rosgen or other classifications, without incorporating the historical context of why the river was damaged (Wohl 2005, Palmer *et al.* 2005).

Historical use of rivers and land by humans have altered the function of streams. Channels have been altered for better transportation of logs. Mining activities have impacted secondary channels and overbank areas (Wohl 2005). River restoration can be achieved using various approaches including, ecological standards, as proposed by Bradshaw (2008) and Palmer *et al.* (2005), geomorphological and hydrological standards (Hey 2006), or based on geostatistics (Legleiter 2014), provided that the right reference reach is identified.

Ecological restoration is still a relatively young but growing discipline (Palmer *et al.* 2014). Many restoration projects focus on protection of infrastructure, or creation of parks and other aesthetically pleasing features, but do not focus on the improvement of ecological functions of the river (Palmer *et al.* 2005; Bernhardt and Palmer 2011). Thus, Palmer *et al.* (2005) suggest five ecological standards to be incorporated: 1) historical information can be used to establish prior conditions; 2) less disturbed reference sites can be used to frame restoration goals; 3) an analytical approach with empirical models can be used to guide project design; 4) stream classification systems can be used as a basis for design, but not one classification systems covers all situations; and 5) common sense can be used for most projects. Although these standards are straightforward, the combination of collecting historical data, finding the right reference reach, understanding the full nature of the chosen stream classification scheme, and subsequently devising analytical approaches can prove to be difficult. Many restoration efforts do not incorporate the complexities in system dynamics and temporal changes in state (Palmer 2009).

Like ecological restoration, geomorphological methodology also depends on choosing the correct reference reach. The critical boundary conditions and flow processes will result in equal width/depth ratios and sinuosities in a designed natural channel (Hey 2006). By following geomorphic procedures carefully and obtaining measured data on stream channel dimension, pattern, profile and other parameters from a stable reference reach, practitioners can create successful restoration designs (Rosgen 1998; Hey 2006). The reference reach must be in a similar location to the area of the reach that will be restored (Hey 2006).

The most recent advancements in river restoration practices are in the fields of geostatistics, spatial analysis and GIS (Geographical Information Systems). Legleiter

(2014) compared the spatial variability in restored and reference channels over time at reach scale. He noted that quantitatively characterizing the spatial structure of channel form in conjunction with fluid theory could aid in understanding the interactions between morphology, hydraulics, and bed material transport (Legleiter 2014). The combination of analysis at larger scales using digital elevation models with current techniques for channel design can help advance the science of river restoration.

Despite the increased number of projects that were constructed with different restoration methods and goals, many projects still have an emphasis on channel stability. Palmer *et al.* (2014) highlighted > 660 projects assessing restoration goals and methods. Biodiversity and channel stability, thirty-three and twenty-two percent respectively, were the most common goals. In-stream hydromorphic and channel hydromorphic projects, thirty-eight and thirty-two percent respectively, were the most common methods.

Standards for successful restoration should be established. The development of a database that makes pre- and post-restoration assessment data available would provide a basis for future work (Palmer *et al.* 2005). Bernhardt *et al.* (2005) addressed this problem by synthesizing information for numerous projects in their National River Restoration Science Synthesis (NRRSS) database. The database is segmented into 13 categories based on restoration priorities (Table 1). The two most prevalent project goals were water quality management and riparian management. These two are also the cheapest restoration initiatives listed, suggesting that faster more cost-effective methods are preferred over more thorough methodologies. The database also illustrates the paucity of post-restoration monitoring. Despite 37,099 completed projects analyzed in the study, only ~ ten percent of all projects were monitored following restoration.

Table 1: Restoration goal categories, and median costs (From Bernhardt *et al.* 2005).

MEDIAN COSTS FOR GOAL CATEGORIES		
NRRSS goal category	**Median cost**	**Examples of common restoration activities**
Aesthetics/recreation/education (A/R/E)	$63,000	Cleaning (e.g., trash removal)
Bank stabilization (BS)	$42,000	Revegetation, bank grading
Channel reconfiguration (CR)	$120,000	Bank or channel reshaping
Dam removal/retrofit (DR/R)	$98,000	Revegetation
Fish passage (FP)	$30,000	Fish ladders installed
Floodplain reconnection (FR)	$207,000	Bank or channel reshaping
Flow modification (FM)	$198,000	Flow regime enhancement
Instream habitat improvement (IHI)	$20,000	Boulders/woody debris added
Instream species management (ISM)	$77,000	Native species reintroduction
Land acquisition (LA)	$812,000	
Riparian management (RM)	$15,000	Livestock exclusion
Stormwater management (SM)	$180,000	Wetland construction
Water quality management (WQM)	$19,000	Riparian buffer creation/maintenance

Although post-monitoring has become more prevalent in restoration projects, only a few incorporated long-term monitoring (Tague *et al.* 2008, Hammersmark *et al.* 2008, Buchanan *et al.* 2013, Januschke *et al.* 2013, Scrimgeour *et al.* 2014; Theiling *et al.* 2014; Kristensen *et al.* 2014).

Tague *et al.* (2008) analyzed a stream restoration project completed in 2001 on Trout Creek, near Lake Tahoe, California. The authors wanted to determine the effects of climate variability on stream restoration in the snowmelt-dominated watershed. To determine these effects, the authors separated hydrologic response from restoration response. The results suggested that restoration effectiveness and success depends on the given season.

Hammersmark *et al.* (2008) analyzed river restoration on Bear Creek in northern California. A hydrological model was created for the 230 ha area of the mountain meadow along the 3.2 km restored reach of Bear Creek. The authors suggested inter-annual climate variability factor as being too misleading to use as a basis for restoration projects that only looked at the hydrology pre- and post-restoration. The authors suggested that the common 'pond and plug' stream restoration approach does restore hydrologic functions of a damaged stream.

Buchanan *et al.* (2013) revisited a third-order stream in central New York that was restored in 2005. An original post-project assessment was completed in 2007. They suggested that despite major flooding, the restoration resulted in significant improvements in bank and channel stability, as well as habitat enhancement *via* increases in riparian vegetation. Moreover, their assessment, completed in 2013 was more favorable than their previous 2007 assessment.

Januschke *et al.* (2014) investigated the temporal effects of restoration on river morphology and species composition. From this ecological study, three sites in the Lahn River, Germany were surveyed to examine the response of floodplain vegetation, functional composition of invertebrates and species pool to restoration. The river was studied in 2005 and 2009: 3-5 years and 7-9 years after restoration, respectively. The results suggest that, from an ecological standpoint, restoration efforts should be focused on key ‘bio-indicators’. Furthermore, greater diversity in habitat and more varied species compositions were found in the restored sections compared to non-restored areas. The authors concluded that the restored sections enhanced the local species diversity and overall health of the system.

Scrimgeour *et al.* (2014) and Theiling *et al.* (2014) also used long-term monitoring. The former examined the changes in ecosystem structure over a 14 year period in a constructed stream in the Northwest Territories in Canada whereas the latter study analyzed changes in the Upper Mississippi River since 1986. In comparison to reference streams, Scrimgeour *et al.* (2014) found that the constructed channel had lower growth of benthic species, as well as lower leaf retention. The authors question the proper timescale for habitat compensation.

During the same time period, in the Upper Mississippi, Theiling *et al.* (2014) concluded that, despite limited published monitoring results in restoration efforts, adaptive management and active stakeholder involvement held the keys to managing large, navigable rivers.

Kristensen *et al.* (2014) also proposed adaptive management, as the restoration process is very slow. The study analyzed the hydromorphological changes on the Skjern River, ten years after the completion of a twenty-six kilometer restoration project. The project demonstrated that instream habitats changed little over ten years although erosion and sedimentation have altered the cross-sectional profiles. Furthermore, the restoration did not restore the lost habitat from previous channelization prior to restoration. The authors concluded that on the large scale, restoration success is a slow but dynamic process.

The literature suggests that adaptive management and maintenance coupled with continuous stakeholder involvement should be incorporated for any river restoration effort. The best projects incorporate all aspects of restoration, whether hydrological, geomorphological, ecological, or anthropological. The use of the current practices in tandem with adaptive management ultimately can result in the success of a restoration project.

CHAPTER III

STUDY AREA AND DESIGN

III.i. Location

The San Miguel River is located in the western San Juan Mountains of southern Colorado (Figure 1). The headwaters are located above Telluride (N 37.9493˚, W -107.874˚), ~ 4,250 m above sea level (13,945 ft) at its highpoint. The river flows ~ 135 km from an alpine climate into a desert climate before it reaches the confluence with the Dolores River at 1,469 m (4,819 ft) (San Miguel River Restoration Assessment 2001).

The study area for this thesis was a reach of the San Miguel River that flows through the town of Telluride. The San Miguel River was restored in a two-phased project. Phase I of the restoration begins just above the confluence of the San Miguel River with Bear Creek. Phase II begins at the Pine Street Bridge and extends to the Mahoney Street Bridge (Figure 1). The Idarado Mine and Natural Resource Damage Site is located to the east of town (San Miguel River Corridor Restoration Plan 1998; Hardy *et al.* 2009).

The urban area of Telluride encompasses ~ 2.6 km^2. The town was established in 1875 when John Fallon filed the first mining claim for Marshall Basin, just above Telluride (Telluride History n.d.). Difficult accessibility to Telluride resulted in isolation and slow growth of the town. Mining was the main industry and chief employment until November 30, 1978, when the Idarado Mining Company closed the Pandora mine (Hardy *et al.* 2009). Following the arrival of the Rio Grande Southern Railroad in 1892, increased transfer of supplies and products produced an economic boom for the area

(Blair 1996). In the late 20th century, Telluride Ski Corporation brought a change of focus for the town as mining was undergoing a major decline in importance. With the creation of Mountain Village to the southwest of the town on the adjacent face of Telluride Mountain in 1987, the Telluride area experienced major increases in development. This expansion included the construction of ski lodges and resorts to accommodate the new ski community. A free-of-charge gondola connects the two towns. In tandem with these developments, the town has seen growth in population, from 1,309 in 1990 to 2,395 in 2010 (www.city-data.com, 2015).

Land-use changes and increased development, as well as the remnants of mine tailings on the floodplain of the San Miguel River, have influenced the water quality of the San Miguel River (San Miguel River Restoration Assessment 2001). Lead and other heavy metals from mining tailings have the potential to cause adverse health effects in humans; elements such as zinc and manganese have adversely affected the aquatic system (www.colorado.gov, 2014).

The U-shaped Telluride Valley, surrounded by steep slopes, provides challenges for transportation. With a seasonal airport, Telluride has limited accessibility *via* air travel. Also, on the ground, access is limited because Highway 145 provides the only major access to the town. Highway 145 connects Telluride with Placerville on the northwest and Rico to the south. Jeep trails over Imogene Pass and Black Bear Pass connect Telluride to Ouray. Neither jeep trail is open year-round.

III.ii. Climate and Vegetation

Despite fluctuations in climate in response to recent drought years, the average temperature for Telluride is 3.7 – 7.7 ˚C (38.7 – 45.9 ˚F), with mean daily highs and lows of 13.3 and -4.5 ˚C (55.9 and 23.9 ˚F), respectively (www.wrc.dri.edu 2014). Annual precipitation averages ~ 591 mm (23.2 in) (www.wrc.dri.edu 2014). Precipitation varies greatly depending on elevation. Mean annual precipitation ranges from ~ 300 mm (11.8 in) in the lower basin to ~ 1,300 mm (51.2 in) on the upper mountain tops (Allred and Andrews 2000). Drought conditions have dominated the past decade (2000-2014) (US Drought Monitor 2015).

Vegetation in the area follows the generalized vegetation pattern of the San Juan Mountains, with vegetation-free slopes on the mountain tops grading into forests consisting of pine, spruce, and aspen with parks and meadows disbursed throughout the forests and the lower slopes generally covered with shrubs and grasses (Blair 1996). In the valley in which the San Miguel River flows, cottonwood (*Populus* spp.), willow (*Salix* spp.), spruce and a variety of brushes are the dominant vegetation cover. Because Telluride is located at a mean elevation for the San Juans at 2,667 m (8,750 ft), mixed conifer forests and shrubs dominate the area, including ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and southwestern white pine (*Pinus strobiformis*). Englemann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*), as well as aspen (*Populus tremuloides*). Forests grow along the slopes from the valley floor to almost the upper reaches of the slopes. Tree line ranges from 3,500-3,600 m (11,480 – 11,810 ft). Alpine vegetation, including a variety of grasses and shrubs, such as whitlowort (*Draba graminca*), alpine dandelions (*Taraxacum* spp.), moss campion (*Silene acaulis*), alpine phlox (*Phlox condensata*) and *Koenigia islandica,* extends from tree line to the upper reaches of many of the south-facing slopes (Blair 1996).

III.iii. Geology and Hydrology

The San Juan Mountains were formed by Tertiary volcanoes, sculptured by Quaternary glaciation, and slightly modified by hillslope erosion, deposition and fluvial activity (Blair 1996). The mountains are large, erosional remnants of a volcanic field that covered much of the southern Rocky Mountains in middle Tertiary (40 to 25 million years BP) (Chronic 1980). Basement rocks range from Precambrian to Tertiary. These formations include igneous, plutonic rocks, sedimentary rocks, and metamorphic rocks, formed from various stages of erosion, deformation and uplift (Blair 1996).

The Telluride valley floor consists of fluvial-glacial deposits over the underlying geologic formations of the Morrison, Cutler, Dolores, Entrada and Wanakah, Telluride Conglomerate and San Juan Formation (Figures 2, 3). The valley walls towards the north and south consist of Paleozoic and Mesozoic strata with a slightly western dip direction (Blair 1996).

The major Quaternary units consist of moraines and a large valley train deposit covering the floor of the valley. These Quaternary deposits have been altered and partially covered by talus, alluvial cone deposits, avalanche deposits, and landslide deposits during the Holocene. Humans have also played a major role in removing some of the moraines. For example, a large recessional moraine at the west side of the valley, near Society Turn, was removed in the late 1990s and used as a borrow source (Giardino, per. comm. 2014). These units have been deposited over time on top of the Cutler Formation as other formations have been eroded over time. The San Miguel River, Cornet Creek and Bear Creek all transport alluvium into and out of the area.

Age		Formations	Thickness (meters)	Description	mya
Cenozoic	Quaternary (Holocene)	Landslide Deposits, Glacial Drift, Alluvium, Talus	30 - 50	Alluvium, Talus, Rock Glacier Deposits	--0.0110--
	Quaternary (Pleistocene)	Landslide Deposits, Glacial Drift			----2.4-----
	Tertiary	San Juan	~ 650	Volcanics	---5.3-- ----23-----
		Telluride Conglomerate	76	Conglomerate, Sandstone, Shale	----34----
Mesozoic	Cretaceous	Mancos Shale	115 - 120	Shale, thin SS+ limestone beds	-----65.5---
		Dakota	58-60	Sandstone	----99.6---
	Upper Jurassic	Morrison	85-90	Upper – Shale Lower - Sandstone	----145---
		Wanakah	38 - 42	Mudstone, SS, Limestone	
		Entrada	10 - 12	Sandstone	--165----
	Upper Triassic	Dolores	92 - 98	Mudstone, Limestone	--200---- ----228---
Paleozoic	Permian (299-251 mya)	Cutler Formation	>150	Arkosic Sandstone (locally)	----251--- ----299---

Figure 2: Geologic column of the Telluride Valley showing formations and their respective ages and names (Burbank, W.S., and Luedke, R.G.; Vhay 1962; and Blair 1996.

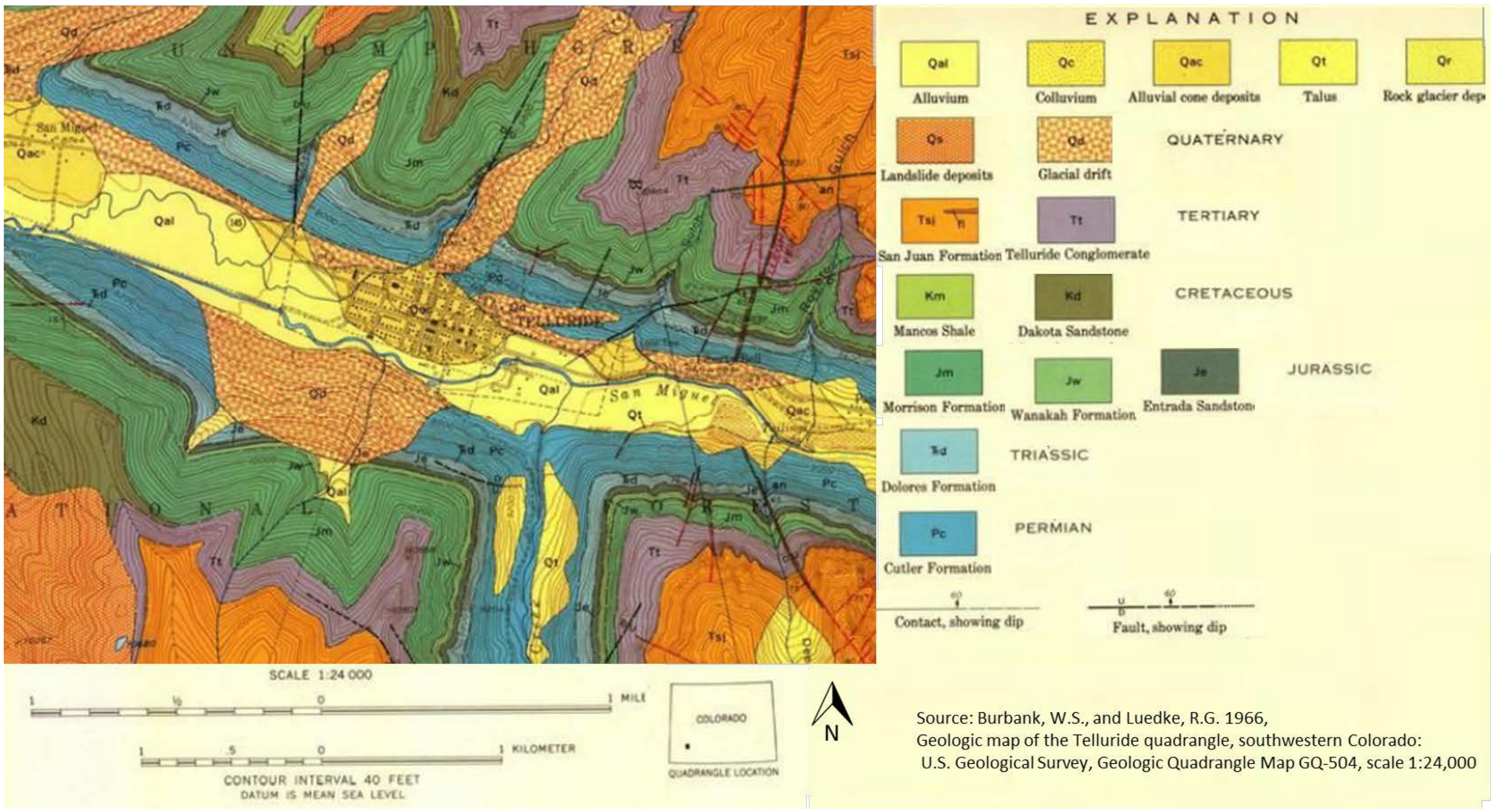


Figure 3: Geology of Telluride (Burbank, W.S., and Luedke, R.G (1966)).

Hydrologically, the San Miguel River is a third-order river that drains over 4,000 km^2 (1,544 mi^2), with the majority of the drainage basin in the Colorado Plateau (Figure 4) (San Miguel River Restoration Assessment 2001). Smaller tributaries, Cornet Creek, Butcher Creek and Bear Creek, rise in areas near former mining sites, including the Idarado Mine Superfund Site. Because these creeks begin in former mining areas, they transport debris and heavy metals to the San Miguel River. Telluride is situated on the floor of the valley and adjacent to the San Miguel River. This location places the town at a high risk for flooding. The greatest potential for flooding is from Cornet Creek, as the town is built on the Cornet Creek alluvial fan (Appendix C) (Burbank and Luedke 1966; Cornet Creek Drainage Maintenance and Flood Mitigation Study 2008; p.c. Karen Guglielmone 2014). The most recent flood occurred in 2007. Prior to this flooding, the last two major floods and associated debris flows occurred in 1914 and 1969 (Cornet Creek Drainage Maintenance and Flood Mitigation Study 2008; Clifton 2012).

The discharge of the San Miguel River is variable, depending on the season (Figures 5 and 6). The discharge ranges from highs during the spring and occasional summer, convective downpours to minimal or no flow during the winter months. This discharge is fed by surface water runoff and water from the spring melting of winter snow (Allred and Andrews 2000). The lower part of the basin has a peak flow greater than 50 cms (1,800 cfs) as measured at Placerville. Discharge ranges from as low as 0.10 cms (0.50 cfs) in the upper reaches of the river to greater than 50 cms (1,800 cfs) near Placerville; ~ 85 cms (~ 3,000 cfs) at Naturita (USGS, Telluride Public Works 2014). Figures 5 and 6 display hydrographs of discharge over time in (cfs) at two USGS gages near Placerville and Naturita, respectively. The gage near Naturita was operational until 1981 whereas the gage near Placerville is still active and has records from 2007 to the present.

Heavy spring flows cause bankfull discharge and occasional flooding, and also cause increased channel migration and sediment transport. These flow conditions result in dynamic channel morphology. These high flows facilitate the transport of mining tailings and other unconsolidated materials in the valley resulting in high sediment loads and increased concentrations of metals downstream (Nichols 2009, Harvey et al. 1999). The transport of large volume of sediment and heavy metals has resulted in increased degradation of water quality in the San Miguel River over the years. Poor water chemistry has a negative impact on aquatic flora and fauna and creates a risk of health-related problems for the citizens of Telluride (Hardy et al. 1999, Wolff et. al 2000).

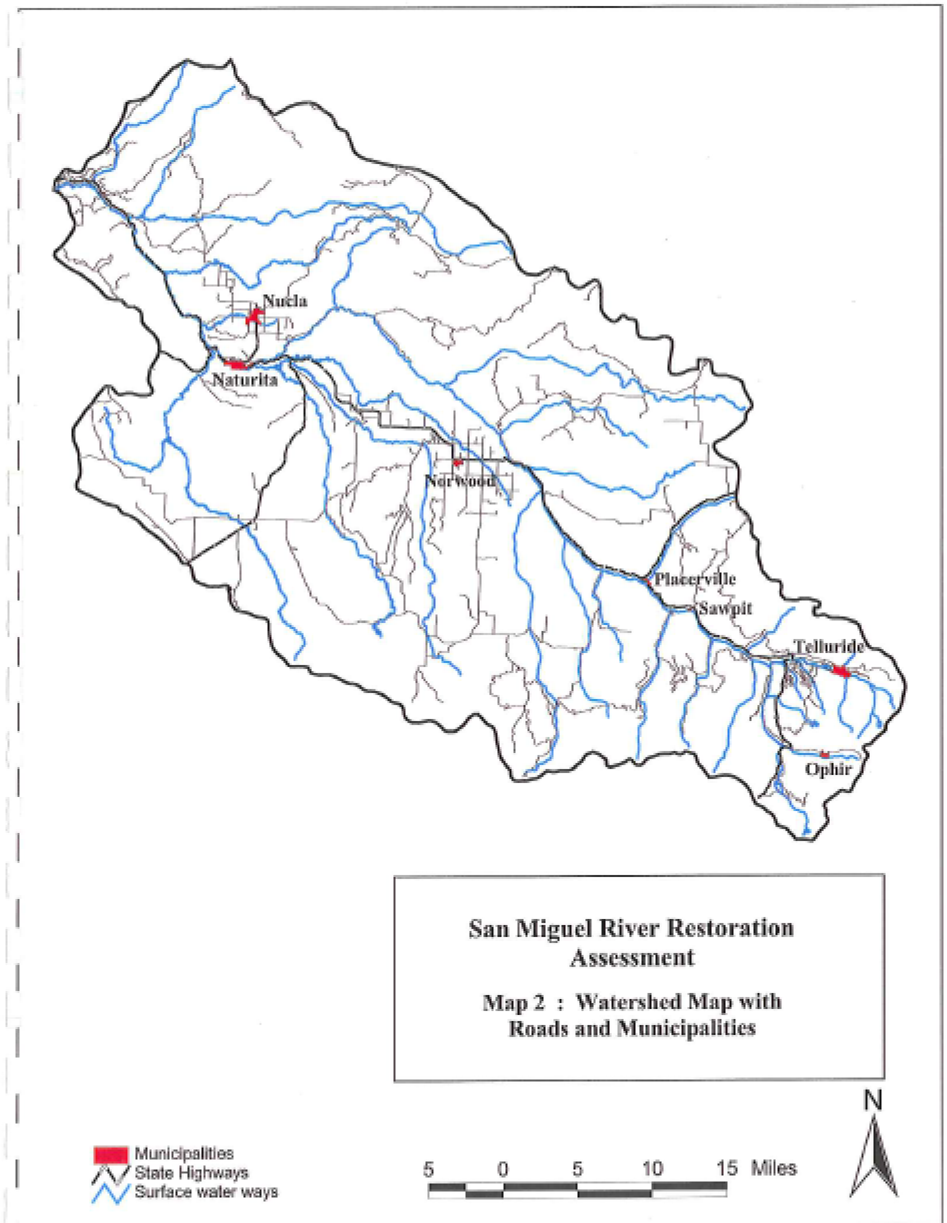


Figure 4: San Miguel River watershed (San Miguel River Restoration Assessment – Volume 1 – Final Report, 2001).

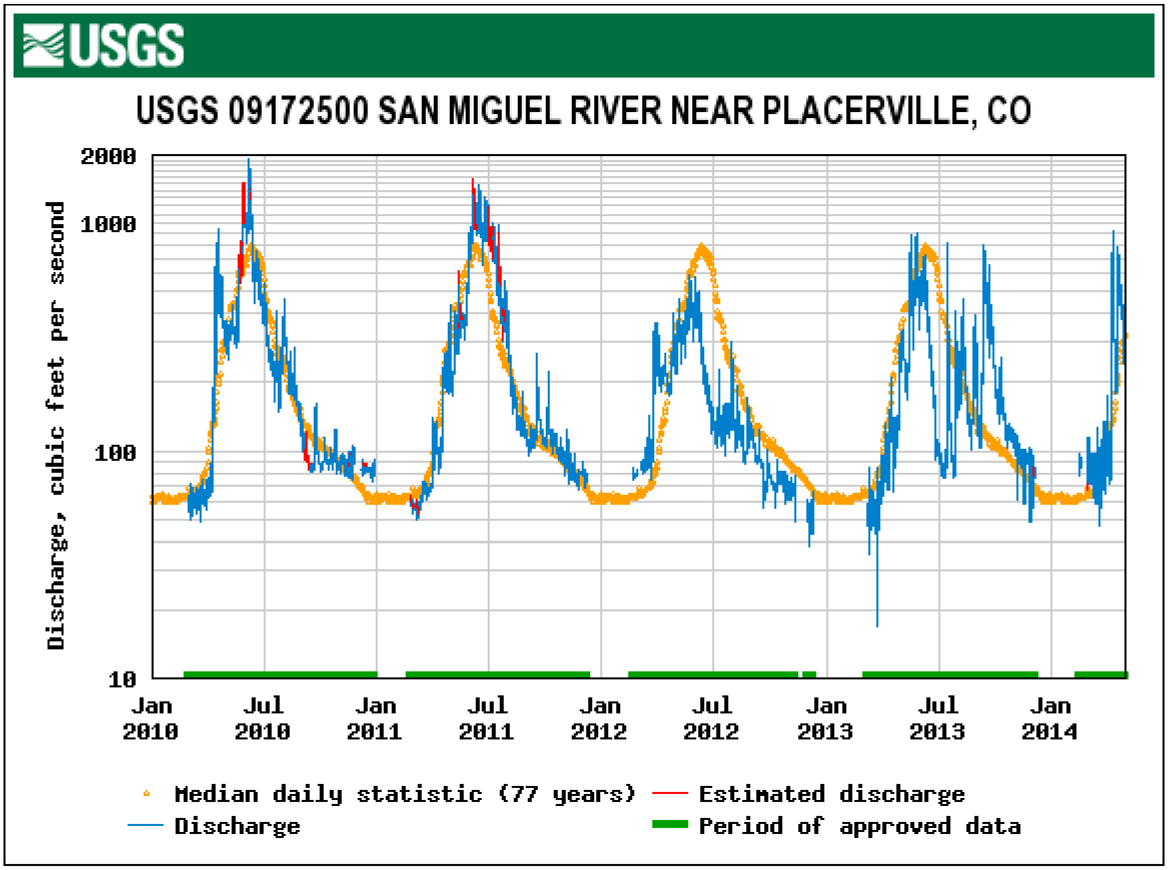


Figure 5: Discharge (cfs), estimated discharge (cfs) and mean daily statistic of San Miguel River at USGS gage 09172500 near Placerville, Colorado, from January 2010 – May 2014. Peak discharge ~ 1800 cfs (50 cms) (http://nwis.waterdata.usgs.gov/nwis/uv/?site_no=09172500&agency_cd=USGS).

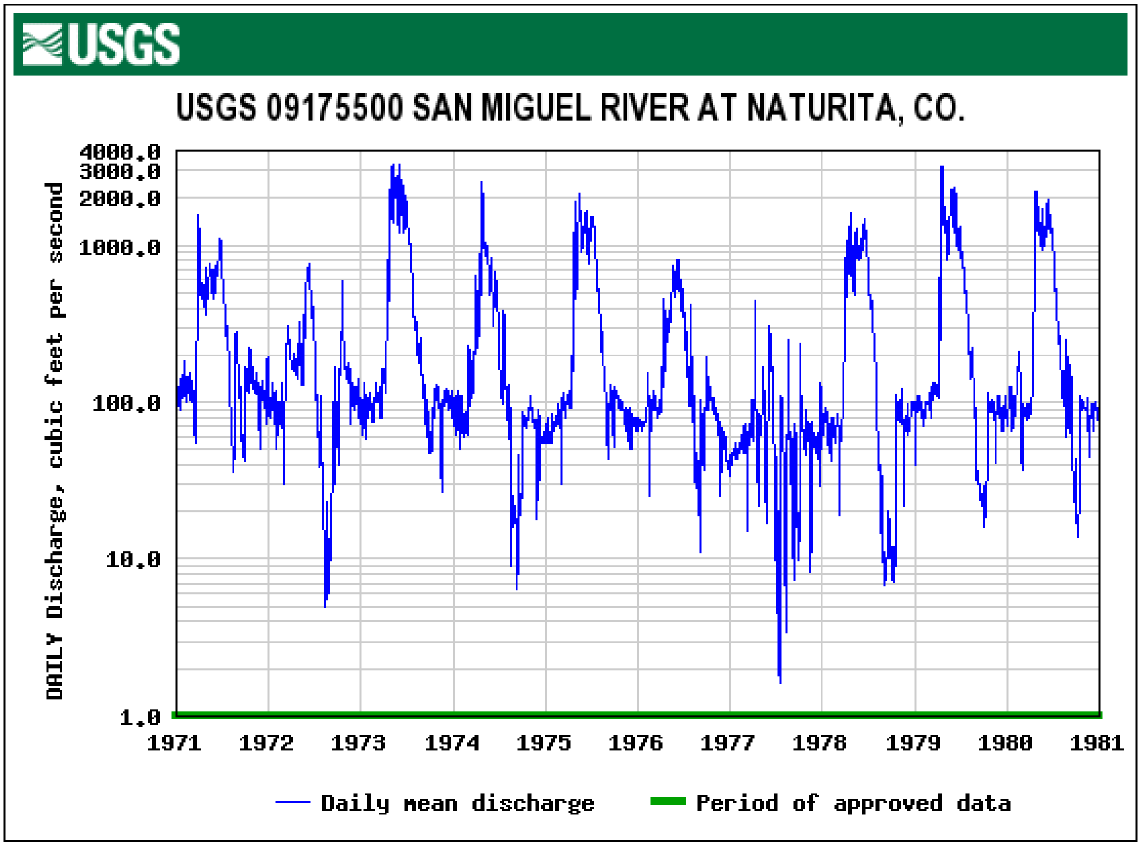


Figure 6: Discharge (cfs) of San Miguel River at USGS gage 09175500 near Naturita, Colorado, from January 1971 – 1981. Peak discharge ~ 3000 cfs (85 cms) (http://waterdata.usgs.gov/nwis/dv/?site_no=09175500&agency_cd=USGS&referred_module=sw).

Ultimately, all of the geological and hydrological components of the San Miguel River floodplain and the surrounding Telluride Valley combine to create an unpredictable and potentially dangerous river system to the Town of Telluride. The river can combine with the alluvium during high flow events to alter rates of sediment erosion and create hazardous conditions for anthropological structures. The seasonal climate variation also can create variations in flow and sediment transport. This dynamic scenario as well as the problems resulting from mining and other human activities, led to restoration of the San Miguel River in the recent decade.

III.iv. Restoration Design

The combination of mining, land-use changes, and increased development along the San Miguel River over the past twenty years created a high risk of potential flooding. To address this risk, restoration plans for various sections of the 135 km river were developed (Fleener 1997; Allred and Andrews 2000; Wolff et. al 2000). As part of the settlement from a lawsuit in 1969 between the State of Colorado and Idarado Mining Company over mandated cleanup of tailings, Telluride was awarded $527,500 to establish a Natural Resource Damage Restoration Fund (Idarado Mine Natural Resource Damage Site, www.colorado.gov). The Idarado site was designated Superfund status and came under the jurisdiction of the U.S. Government. The Natural Resource Damage Restoration Fund was supplemented with other local grants to restore a reach of the San Miguel River beginning just north of the confluence of the San Miguel River with Bear Creek, down to the Pine Street Bridge (Figure 7). This reach was designated a priority reach and was the focus of phase I of the restoration (San Miguel River Corridor Restoration Plan 1998).

The priority reach was chosen as the focus of restoration, in part, as a result of the less developed and constrained areas adjacent to the river, which allowed for more freedom in restoration design. A year later, an additional $16,000 was awarded to restore the more constrained reach from Pine Street Bridge to Mahoney Street Bridge (Figure 7) (www.colorado.gov). This restoration was phase II of the restoration of the San Miguel River (San Miguel River Corridor Restoration Plan 1998).

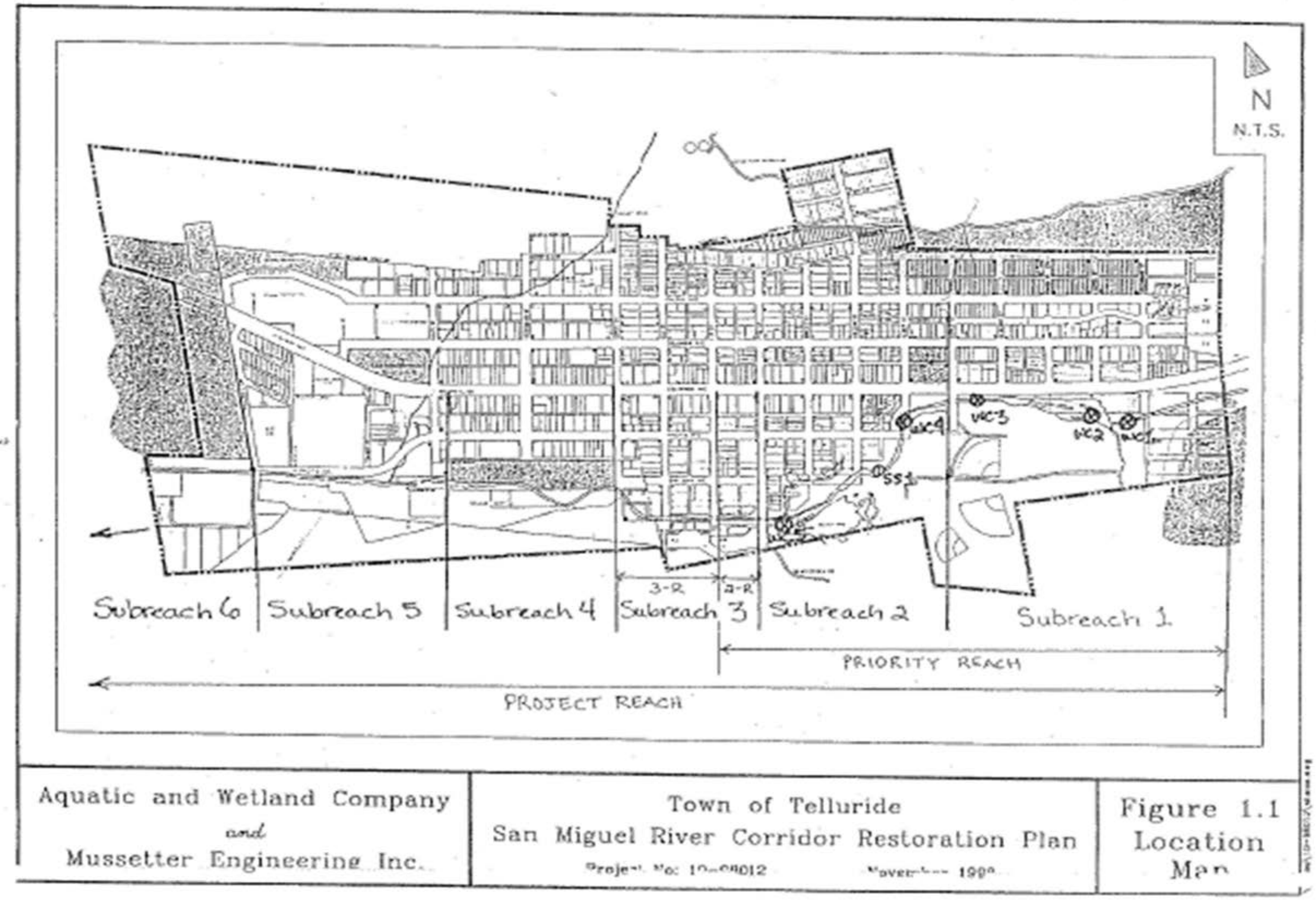


Figure 7: Site map for restoration design of the San Miguel River in Telluride (San Miguel River Corridor Restoration Plan 1998). Project reach and subreaches are delineated.

An extensive pre-construction plan was developed, including the existing conditions of the river, project goals, design of the restoration, design of the accompanying river park, and a monitoring plan (San Miguel Corridor Restoration Plan 1998, Wolff et. al 2000). Restoration of the priority reach was completed in 2001, and three years of monitoring followed. Phase II restoration was completed in 2004.

For phase I, ~1.5 ha (3.8 acres) of wetland and an instream sedimentation basin were created, and a channel structure was designed to control flooding and capture sediment (Figures 8 and 9) (San Miguel River Corridor Restoration Plan 1998). The sediment basin was developed to minimize sediment transport in the river because the priority reach did not have the ability to transport sediment through the reach (San Miguel River Corridor Restoration Plan 1998; Wolff et. al 2000).

To meet US Fish and Wildlife Service Habitat Suitability requirements, 24 instream structures were constructed to establish a 1:1 pool-to-riffle ratio, with pools, and silt-free riffles constructed with structures for roughness (San Miguel River Corridor Restoration Plan 1998). The pools were designed with a top width of 9.1 m (30 ft) and a depth of one m whereas the riffles were designed with a top width of 8.5 m (28 ft) and a depth of 0.7 m (Figure 10) (Wolff et. al 2000). This resulted in width/depth ratios of 9 and 12 for the pools and riffles, respectively. A spacing pattern for the pools and riffles of 61 m (~200 ft) was used, ~ seven times the average width of the channel, based on Rosgen's natural channel design and Leopold *et al.* (1964) (Wolff et. al 2000).

The riparian corridor with the wetlands was designed to provide habitat for different terrestrial species, with installation of flora such as native willows, alders and rushes. Cover logs, plunge pools, boulder covers and point bars (Figure 11a-c) were also designed to enhance aquatic habitat. These designs would also allow for additional bank stability (San Miguel River Corridor Restoration Plan 1998).

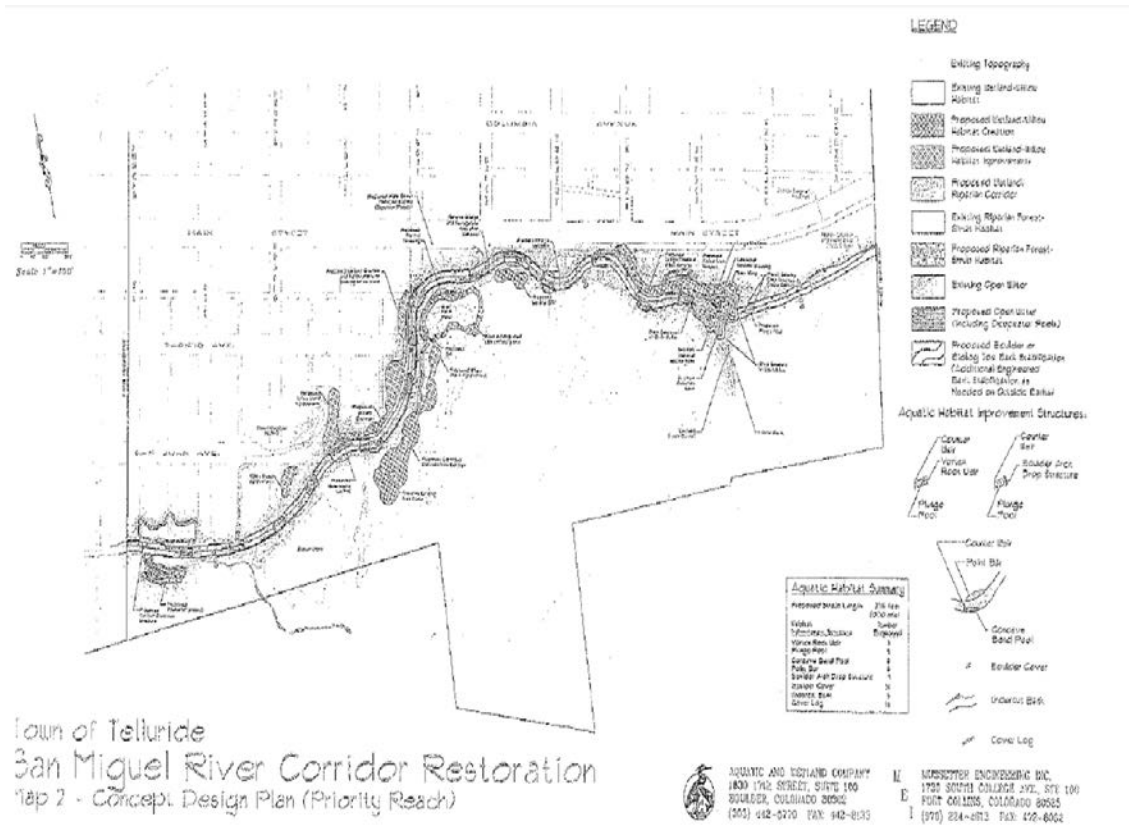


Figure 8: Habitat Concept Design Plan (1998) for priority reach of San Miguel River restoration (From San Miguel River Corridor Restoration Plan 1998).

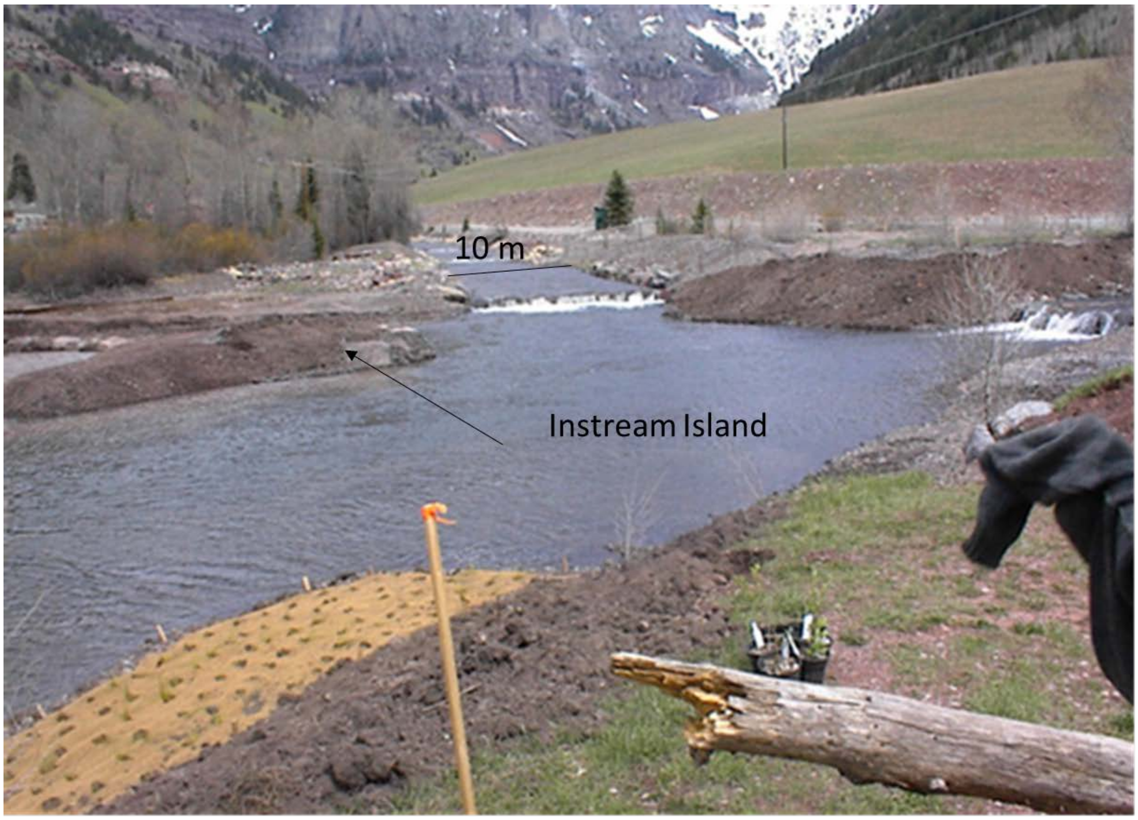
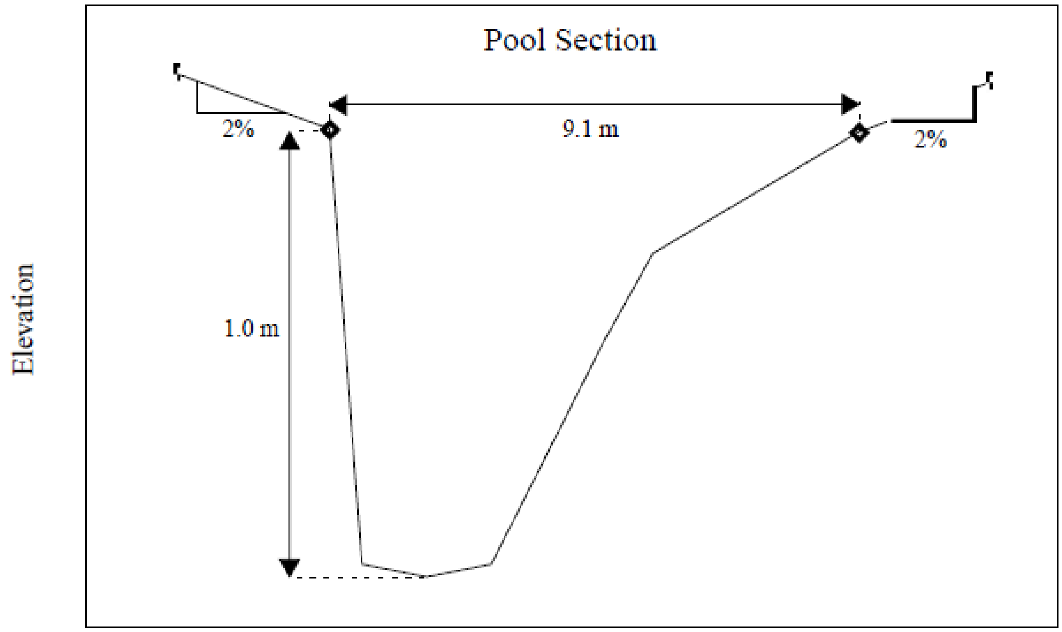
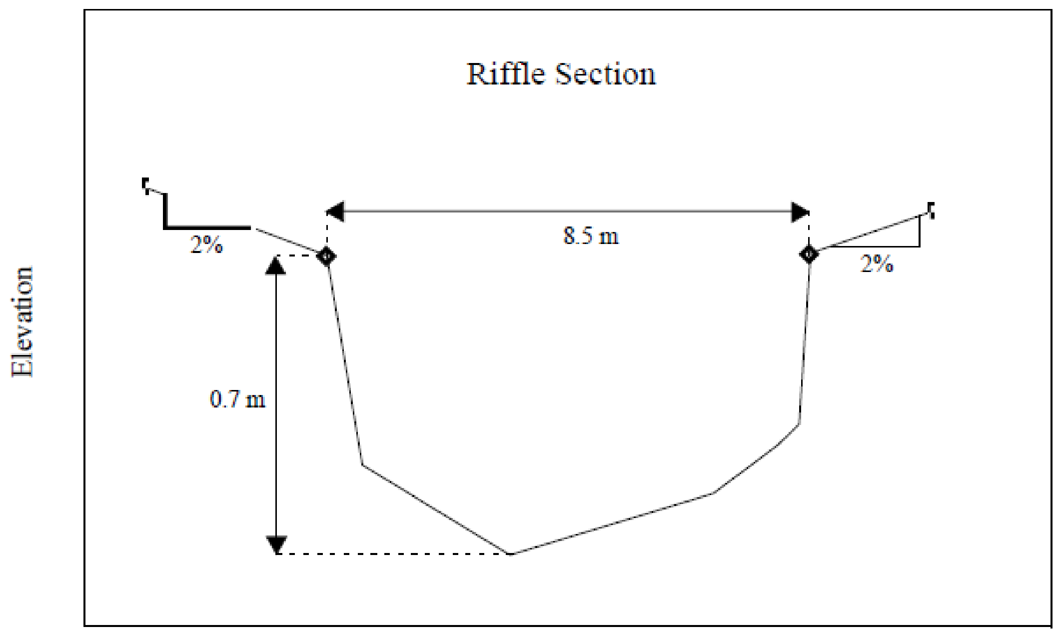


Figure 9: Instream Sedimentation Basin and Instream Island: Project start 2001, looking east.



a)



b)

Figure 10: a) Template Pool Design; b) Template Riffle Design; (From Wolff et. al 2000).

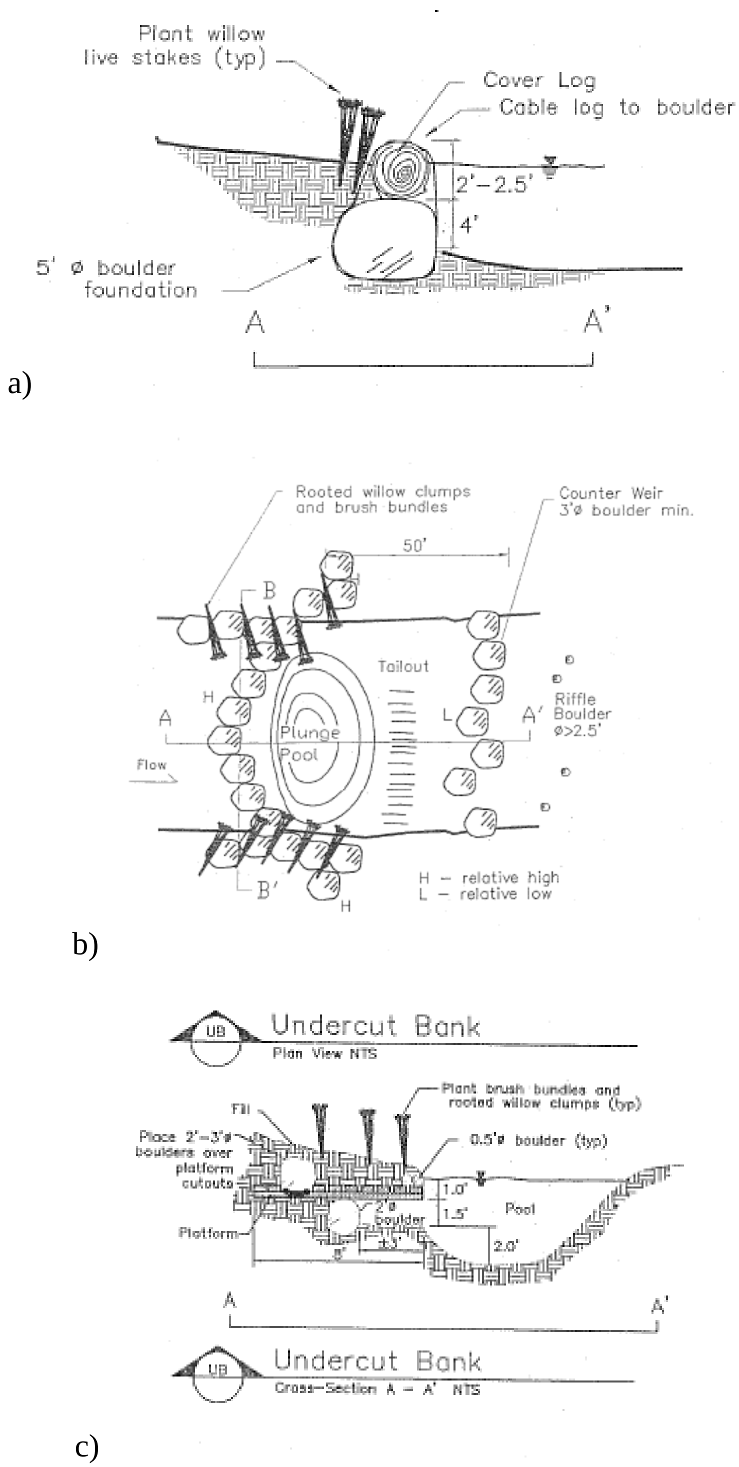


Figure 11: Concept designs for various structures to enhance aquatic habitat: a) cover log cross-section view; b) plunge pool, plan view; c) undercut bank and boulder covers. (From San Miguel River Corridor Restoration Plan 1998).

CHAPTER IV

METHODOLOGY

Data collection were undertaken to study the effects of river restoration since completion of restoration in 2004. Collection of geomorphic and hydrologic channel and floodplain data in the field facilitated assessment of channel movement and stability, effects of floods, changes in hydrological parameters, and changes in ecology of the river system.

The objectives of the study were to assess changes in the channel, assess changes in the floodplain and evaluate whether the restoration goals were met and maintained over the previous ten years.

The following sections discuss the specific methodology for data collection used to address these objectives.

IV.i. Assess Channel Changes

Objective 1: Assess changes in the channel.

Few published studies have examined long-term channel changes in river systems (Kristensen *et al*. 2014). Therefore, techniques from various disciplines as well as short-term studies were used as a basis to assess channel movement and stability of instream features. These techniques included the use of aerial imagery, an Unmanned Aerial Vehicle (UAV), measuring cross-sections, and documentation of features using ground photography.

Increased availability of satellite imagery has allowed for greater opportunities to study river morphology (Lejot *et al.* 2007). New technology and quantitative land-surface analysis have made the study of spatial variation using aerial imagery much easier (Hengl and Reuter 2009).

Although imagery can be used to assess large-scale changes in river systems, limitations arise because of the lack of specific imagery in relation to a particular area, and the individual problems with imagery types in response to weather and geographic features (Lejot *et al.* 2007). In addition, contract flights to obtain data for a given area have significant costs. Low-flying aerial vehicles, whether commercial or designed for the purpose of a study, have been used to create imagery where data were not present. This has been done by users in industry and academia alike as the images captured by the UAV are combined to create Digital Elevation Models (DEMs) and other aerial imagery (Lejot *et al.* 2007; Tamminga *et al.* 2014). These low-flying aerial vehicles have been popular in recreational and academic use because of typically lower costs than what private companies charge for flights.

Advances in UAV technology have facilitated increased usage for temporal-based studies. Previous studies (Koh and Wich 2012, MacVicar *et. al.* 2009, Quilter and Anderson 2000) used larger-sized drones for remote sensing, with designs ranging from miniature planes to paramotor unmanned vehicles. Advances in UAV development have produced quadcopters, which allows for high-resolution imagery at reach-level scale, or smaller and less accessible flying areas. Lejot *et al.* (2007) used a low cost radio-controlled UAV to obtain images of a five km reach and created DEMs at various time periods or intervals. These DEMs were later compared with each other to assess changes in channel morphology. The high-precision imagery from low flying vehicles coupled with topographic data and ground surveys increased the visualization of structure of a river (Tamminga *et. al.* 2014).

For the purpose of this thesis, aerial imagery and UAV images provided the data to study channel movement and instream features. Available imagery from 1990 – 2014 assisted in the study of channel dynamics over ten years following restoration. The imagery was collected in 1990, 1995, 1998, 2000, 2003, 2004, 2005, 2007, 2011, and 2014, respectively. Images included Landsat, Google Earth® and Bing images®, and USGS and SMWC aerial photographs.

The scale and resolution varied among the types of imagery. For example, the Landsat images have 30 m resolution whereas the Bing® and Google Earth® images have resolutions ranging from 15 cm to 1 m. The resolutions alter depending on which image is currently being used, as Google Earth mosaics many different types of images, resulting in different dated imagery at varied zoom levels. The scales also vary depending on the zoom level in Google Earth® and Bing® platforms, and this plays a role in proper data measurement. The distance-measurement tools in Google Earth, Bing and ArcMap®10, as well as data type conversion tools including the Kml to Shapefile tool, were used to create new GIS data points, polygons, and paths.

During the 2014 field season, a UAV was used to collect high-resolution videos and images along the 1 km reach of the river at an average altitude of 18 meters (60 ft.). For this study, a DJI Phantom 2 Vision Plus® quadcopter was used to fly the length of the reach. The altitude of the UAV varied between 18-28 m (60 and 90 ft.) above ground level so as to avoid trees and power lines. This created a problem, however, with changing scale.

The Phantom 2 has a high-precision camera that collects HD video at 1080p/30fps and 720p/60fps, with a 14-megapixel camera for single image collection. Although this UAV can be programmed for a specific flight path, the flight paths were flown manually to avoid the treetops along the river. Figure 12 shows the UAV flying above the river.

To assess changes in the channel bed, additional methods were used to collect channel data. These methods included: cross-sections to measure channel depth, roughness, bank-to-bank width and the wetted distance (stream width); and current photography for comparison with historical images. The cross-sections followed methods developed by The Royal Geographical Society (with the Institute of British Geographers) (Rivers n.d.).

Figure 12: DJI quadcopter recording video on traverse downstream (circled in red). Altitude ~ 18 m above ground level.

The data collected, coupled with instream structures and data on channel changes obtained from the Public Works Department (per. comm. 2014) from their three-year monitoring period, were used to evaluate the changes in the channel geometry.

In August 2014, twenty-two cross-sections were measured along the 1 km reach of the San Miguel River (Figure 13). The cross-sections were spaced ~50 m (165 ft.) apart. Measurements of river depth were recorded at 50 cm intervals across the channel. At each location, the bank-to-bank width and the width of the river (wetted distance) were recorded, also. Measurements were taken using a tape measure and surveying pole (Figure 14). Location and elevations, with ~ 1 m possible error, of each cross-section were taken using a Garmin Oregon® (450t) GPS unit, which has a 1-2 meter location error (Palowicz n.d.).

The cross-section measurements were collected to obtain present-day channel-bed structure and overall shape of the channel. These measurements were compared with the restoration design plan.

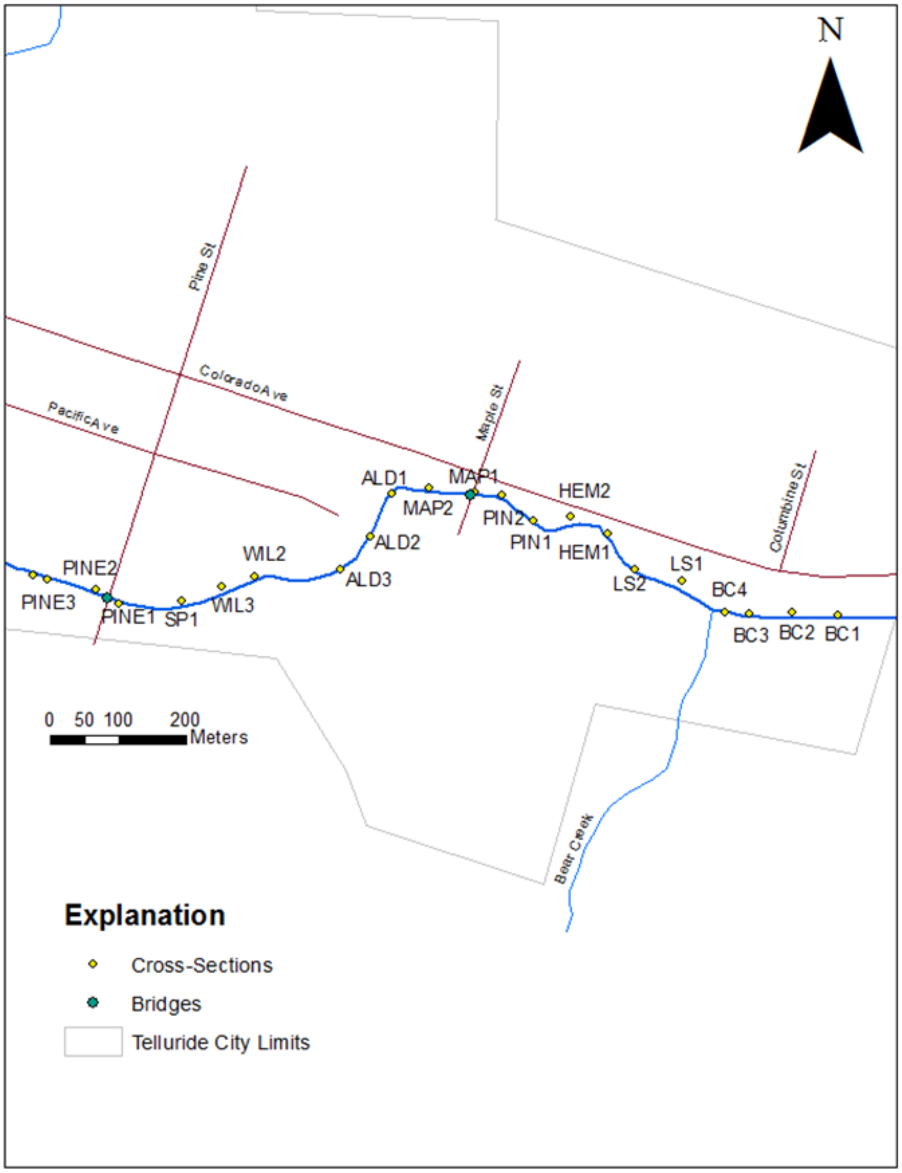


Figure 13: Locations of cross-sections along priority reach of San Miguel River as it flows through Telluride.

a)

b)

Figure 14: Photographs of performing a cross-section: a) Example of cross-section measurement using measuring tape; b) Field assistant (1.8 m, 6 ft. tall) measuring bank-to-bank width, holding measuring tape (denoted by arrow). Image taken from midstream.

Ground photography was taken for documentation of geomorphic features in the study area. Images of the river and study area were taken with a 13-megapixel camera on a Samsung S4 phone, as well as with a Sony Nex-6 camera. Historical photographs from pre-restoration in 1998, post-completion in 2001 and during the monitoring period from 2001 – 2004 were obtained from the Town of Telluride.

IV.ii. Assess Floodplain Changes

Objective 2: Assess changes in the floodplain along the river.

To assess changes in the floodplain, available hydrological, ecological and data were used for comparisons over time. More advanced and larger-scale (in both extent and involvement of stakeholders) use modeling techniques to determine temporal changes in the floodplain (Tague *et al.* 2008, Hammersmark *et al.* 2008, Buchanan *et al.* 2013, Kristensen et al. 2014). Discharge, precipitation, water chemistry, aquatic biomass and vegetation data were collected by various governmental agencies and used in the analysis.

IV.ii.i. Changes in Hydrological Parameters and Water Chemistry

Changes in hydrological parameters of the San Miguel River and its watershed, discharge and precipitation data were observed by comparing collected data sets. River-gage data were collected at the Mahoney Street Gage (Public Works Department of Telluride) (Figure 1). Unfortunately, the closest USGS river gage, that was still operational, is located in Placerville, Colorado; ~ 25 km (~16 miles) from the study area and not applicable. Precipitation data were obtained from USGS, Western Regional Climate Center, Telluride Airport, and NOAA data. The incomplete nature of most of the data resulted in only two reliable sets of average daily precipitation for two thirty-year periods, 1971-2000 and 1981-2010, respectively.

Water chemistry data from 2004 to 2014 and summary memorandums from 2010 and 2015 were obtained from the Public Works Department in Telluride.

IV.ii.ii. Changes in Geomorphology and Ecology

Data from the project start to 2004 monitoring changes in plant-growth rate, wetland acreage, habitat suitability, and instream structural integrity were obtained from the Telluride Public Works Department and engineering and monitoring reports (San Miguel River Corridor Restoration Plan 1998; Year 3 Final Monitoring Report 2005). The San Miguel River Corridor Restoration Plan highlights the design of restoration and existing conditions in 1998, design of template cross-sections for the constructed riffle and pools, and existing geomorphic parameters. The three-year monitoring report provided detailed descriptions of instream structures and vegetation data from 2001-2004 (Appendix B). The vegetation data included taxonomy and survival rates, as well as the design and implementation data of created wetlands, riparian areas, and aquatic habitat.

Fish reports from 2002 and 2013 containing total biomass, types of fish, and sizes were obtained *via* the Colorado Division of Wildlife.

IV.ii.iii. Human Impact on Floodplain

Similar to the method used to assess the ecological changes on the floodplain, land use changes associated with restoration design were examined by qualitatively comparing available photography from project start to 2004, field work in 2014, and UAV imagery. Maps and designs from the San Miguel River Corridor Restoration Plan 1998 highlighting the planned changes for recreational areas - including parks, walkways along the river, and access points - also provided additional background to understand the human impact on the floodplain.

CHAPTER V

ANALYSIS AND RESULTS

V.i. Channel Changes

The following data were used to assess the geomorphological changes to the priority reach channel. Google Earth Images from 1998, 2005, 2011, and 2014 were used to analyze changes in the location of the thalweg, calculate sinuosity, measure point bar changes and assess whether the channel has stabilized. Bing® images from 2014 in ESRI ArcMap 10.2 were used to help check for scale and projection errors. Cross-section data from 2014 were used to compare the change in bank-to-bank width and depths from restoration design and construction. UAV videos and images as well as ground photographs were used to analyze qualitative changes to instream engineered structures and aquatic habitat, in addition to providing visual support of features seen in aerial imagery. Structural integrity data provided in the Town of Telluride monitoring reports were used in tandem with the measured cross sections to observe changes in the engineered instream structures.

All quantitative measurements were done in accordance to the known scale of the image, based on image resolution for aerial imagery, identified scales in ground photography, and known sizes of various structures such as bridges from field work and data collection. For map production, all GIS data, whether created or imported, were projected into WGS 1984 datum in ArcMap 10.2. This allowed for proper overlay of images with the same scale.

V.i.i. Large Scale Changes

To assess channel stabilization over the ten years following restoration, a collection of available imagery from 1990 to 2014 was used. Unfortunately, the size of the study area and river was too small for the use of Landsat imagery. To map and calculate changes in channel location, available Google Earth® imagery with one meter resolution was used. The Google Earth® measurement tool with centimeter precision was used to digitize the path of the river along the thalweg for each year. The digitized paths were exported as Kml files and subsequently brought into ArcMap 10.2 with projection to the WGS 1984 datum for later use. Bing® base images were used to check for proper projection and image overlay.

As seen from the comparisons of Google Earth® images from 1998 – 2014, minimal changes in the channel shape have occurred along the one km priority reach. The maintenance and yearly management by the town appears to have minimized change. When combining all the paths into a single image using ArcMap 10.2, a difference exists between the pre-restoration and post-restoration location of the thalweg. Channel movement, however, has been minor since restoration (Figure 15).

The Google Earth® images were also used to assess the sinuosity of the river. The sinuosity of the river at a given year was determined by using the following equation from Mueller (1968):

SI = channel length / downvalley length, where SI = sinuosity index.

Sinuosity is measured as the total stream length measured along the river thalweg divided by the straight-line valley length (Mueller 1968). For the purpose of this analysis, the starting point was ~ 150 meters upstream of the confluence with Bear Creek, with the ending point being at the Pine Street Bridge, the end of phase 1. Comparisons of the calculated sinuosity between each year were then compiled to determine overall channel movement.

From the comparisons, the sinuosity has not changed during the study period (Table 2). Therefore, from the larger scale, the channel appears to be stable and the hypothesis is accepted. In addition, the sinuosity of 1.16 was close to the proposed sinuosity of 1.2 for a C3, Rosgen-classified stream.

Table 2: Sinousity (Mueller 1968) of San Miguel River reach based on Google Earth® imagery.

Year	Priority Reach Length (m)	Sinuosity
1998	917.66	1.16
2005	917.01	1.16
2006	919.37	1.16
2011	921.63	1.16
2014	919.00	1.16
Average (2003-2014)	923.19	1.16
Stdev	7.04	0.01

With more frequent and higher resolution imagery, such as higher resolution aerial LiDAR and aerial photographs, a more robust data set, however, would be available to better assess any large-scale changes.

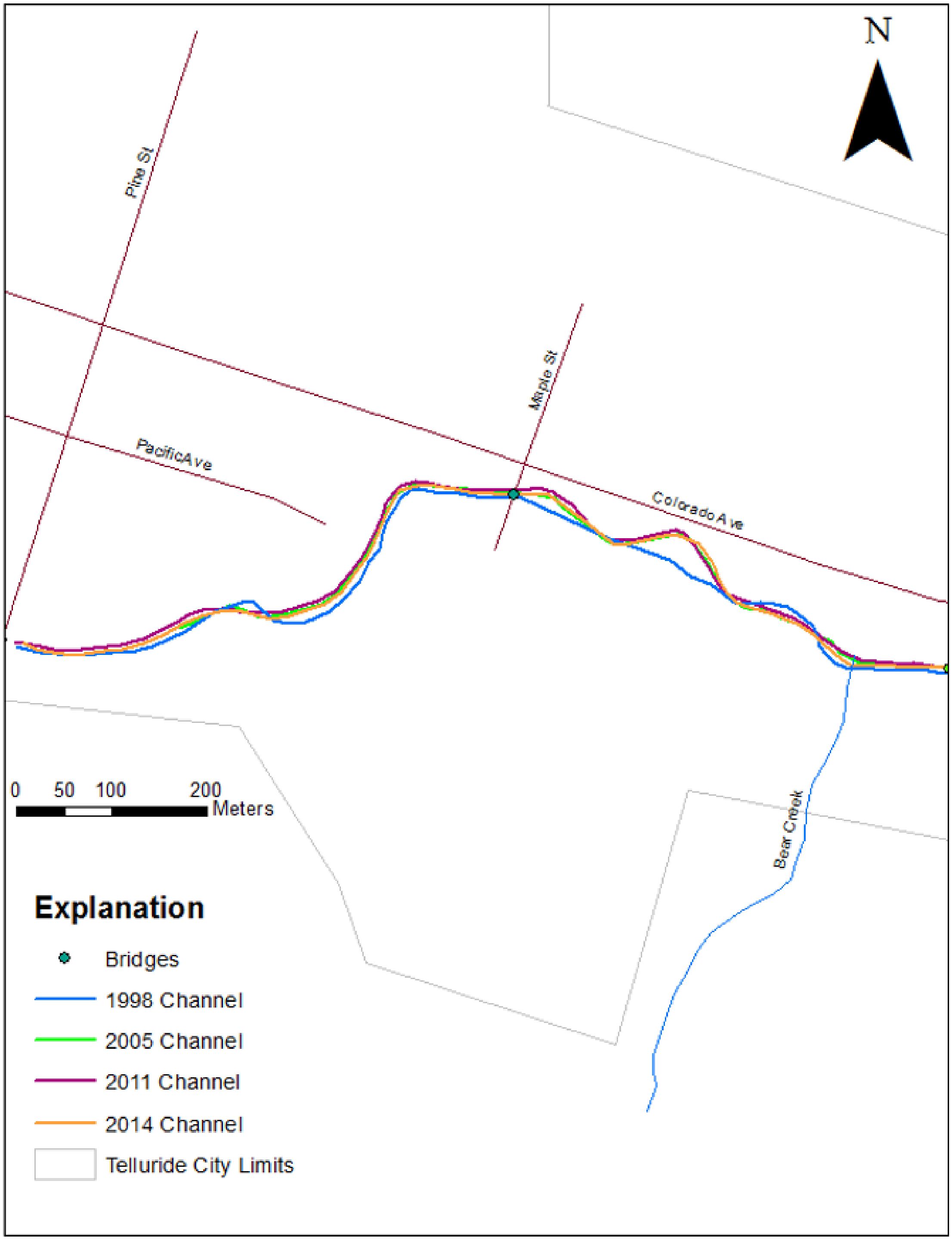


Figure 15: Thalweg (main channel) movement of the San Miguel River, Telluride, Phase I of restoration. The 1998 channel is pre-restoration, 2005 is 1 year after completion of phase I and II. Movement is minimal between 2005 and 2011.

As the imagery improved, as seen in the later years of the Google Earth® images, evidence of erosion was observed altering the instream channel over time, because the sizes of point bars changed over time.

Table 3 highlights increases and decreases in perimeter up to 30% and up to about 50% in area of the various point bars in the 1 km priority reach. These changes in size for point bars in between Laurel Street and Pinion Street, ~ 15 meters upstream of Pacific Avenue Bridge, and just south of Willow Street are displayed in Figures 16, 17, and 18 (Google Earth 2014). The various polygons represent the different years: Green is 2005, Yellow is 2011, and blue is 2014.

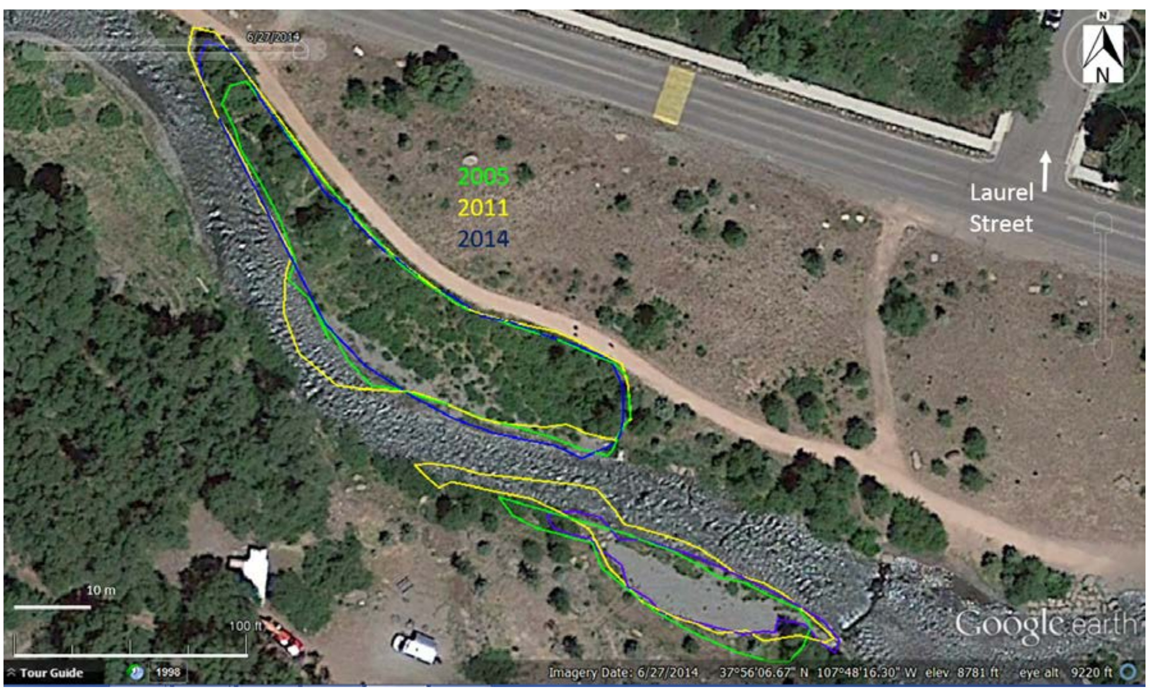


Figure 16: Changes in point bar sizes along the San Miguel River, between Laurel Street and Pinion Street. Point bar outlines from 2005, 2011 and 2014 are shown in green, yellow and blue respectively. Base is Google Earth® Image from 06/27/2014

Figure 17: Changes in point bar sizes along the San Miguel River, upstream of Pacific Avenue Bridge. Point bar outlines from 2011 and 2014 are shown in yellow and blue respectively. Base is Google Earth® Image from 06/27/2014

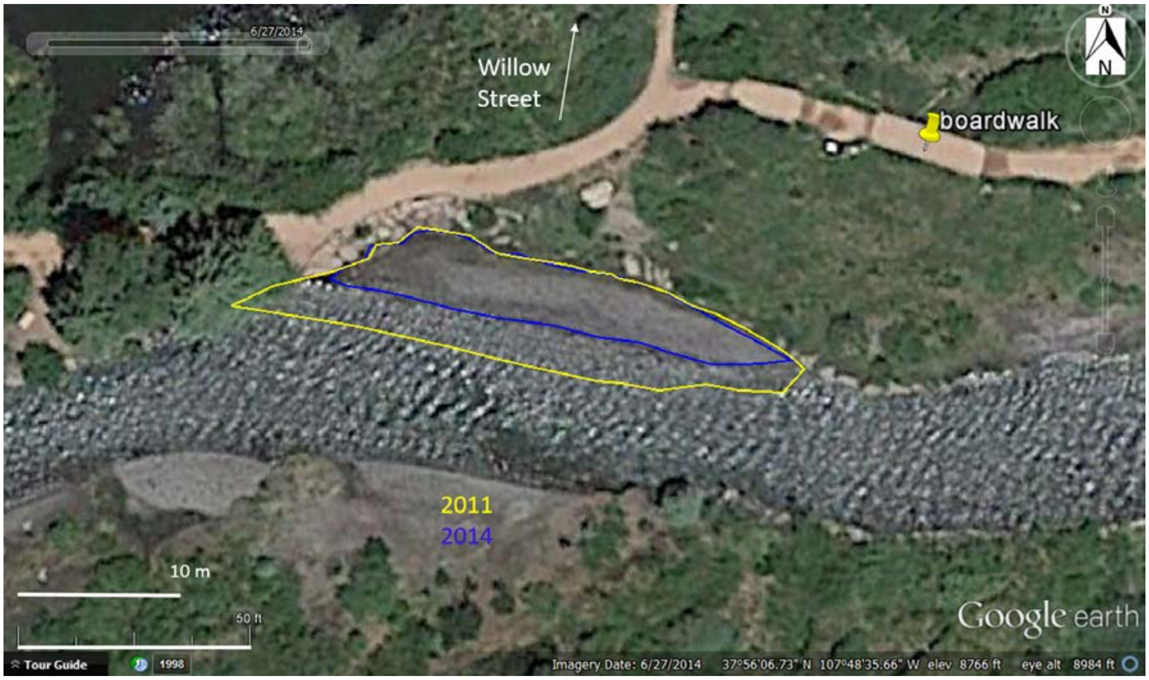


Figure 18: Changes in point bar sizes along the San Miguel River, upstream of Pacific Avenue Bridge. Point bar outlines from 2011 and 2014 are shown in yellow and blue respectively. Base is Google Earth® Image from 06/27/2014

Table 3: Changes in perimeter and area over time for point bars along phase I reach of San Miguel River restoration

Bar location	Year	Perimeter (m)	% diff.	Area (m^2)	% diff.
East bank, 15 m north of Pacific Ave Bridge	2011	67.71		127.38	
	2014	72.73	7.41	106.25	-16.59
North bank, Willow St	2011	77.94		194.66	
	2014	64.91	-16.72	104.76	-46.18
North bank between Pinion and laurel street	2005	168		784.45	
	2011	180.11	7.21	914.23	16.54
	2014	170.26	-5.47	840.37	-8.08
South bank between Pinion and Laurel Street	2005	97.54		257.32	
	2011	128.26	31.49	306.15	18.98
	2014	93.63	-27.00	207.18	-32.33

The polygon tool in Google Earth® was used to measure the relative perimeters and areas of the observed point bars. The tool has cm accuracy; however, human error can arise. Therefore, these tools are better used for generic changes and field measurements are needed to confirm full measurements. Unfortunately, the 2014 Google Earth® image was not available for the Telluride Valley during the time of field work. This resulted in the prevention of field measurements of these point bars.

V.i.ii. Changes in the Channel Bed

To assess the instream changes in the channel, a combination of field methods were used to collect channel data. The collected cross-section data, coupled with instream structure and channel change data obtained from the Public Works Department from a three-year monitoring period were used to qualitatively assess changes in the channel bed, channel shape, planform and instream structural integrity. Therefore, the measurements were compared to the design standards from 1998. The original design called for 8.5 m top width for riffles and 9.1 m top width for pools with a W/D ratio of twelve and nine, respectively. Depths should be no greater than one meter.

Images and videos collected from the UAV and ground photography were compared with historical photos to identify local geomorphic changes associated with the engineered structures. Additionally, comparisons between tables from the Year 3 Final Monitoring Report (2005), which provide further data on the instream engineered structures up to 2004, and 2014 cross-section measurements were used to observe further changes (Appendix B4). The provided tables allowed for easier recognition of structures that had failed prior to monitoring completion and identified structures that were starting to fail.

The videos from the UAV also allowed for recognition of existing flow paths, and for verification of the thalweg identified by Google Earth® as well as point bars and other river features shown in the aerial imagery.

Overall movement of the main channel has been minimal since the completion of restoration. At various points along the study reach, however, increases and decreases in point bar sizes were observed. With the town constraining the movement of the river channel by yearly maintenance (per. comm. Guglielmone 2014), the river appears to move side-to-side within the confined area. Data from the cross-sections, UAV videos, monitoring reports, and from the Public Works Department show slight changes in the channel structure, thalweg path and sediment aggradation along the channel bed. Two instream structures failed in response to high spring flows during the three-year monitoring period for phase I and were replaced. Other structures have transformed, for example, from a counter weir to a grade control, because of erosion (Appendix B4).

Other structures have begun to fail since the 2001 to 2004 monitoring, whereas erosion and deposition, in and around instream structures, have occurred over the length of the study period.

The field-measured cross-sections (Appendix A) demonstrated differences in the shape of the channel bed along the course of the study reach. This suggests that the channel bed has been altered from the original riffle and pool structure design in 2001 in response to sediment deposition and scouring over time. The locations of the cross-sections are shown in Figure 19. In addition, Figures 20 and 21 show examples of the variations in bed structures and depths.

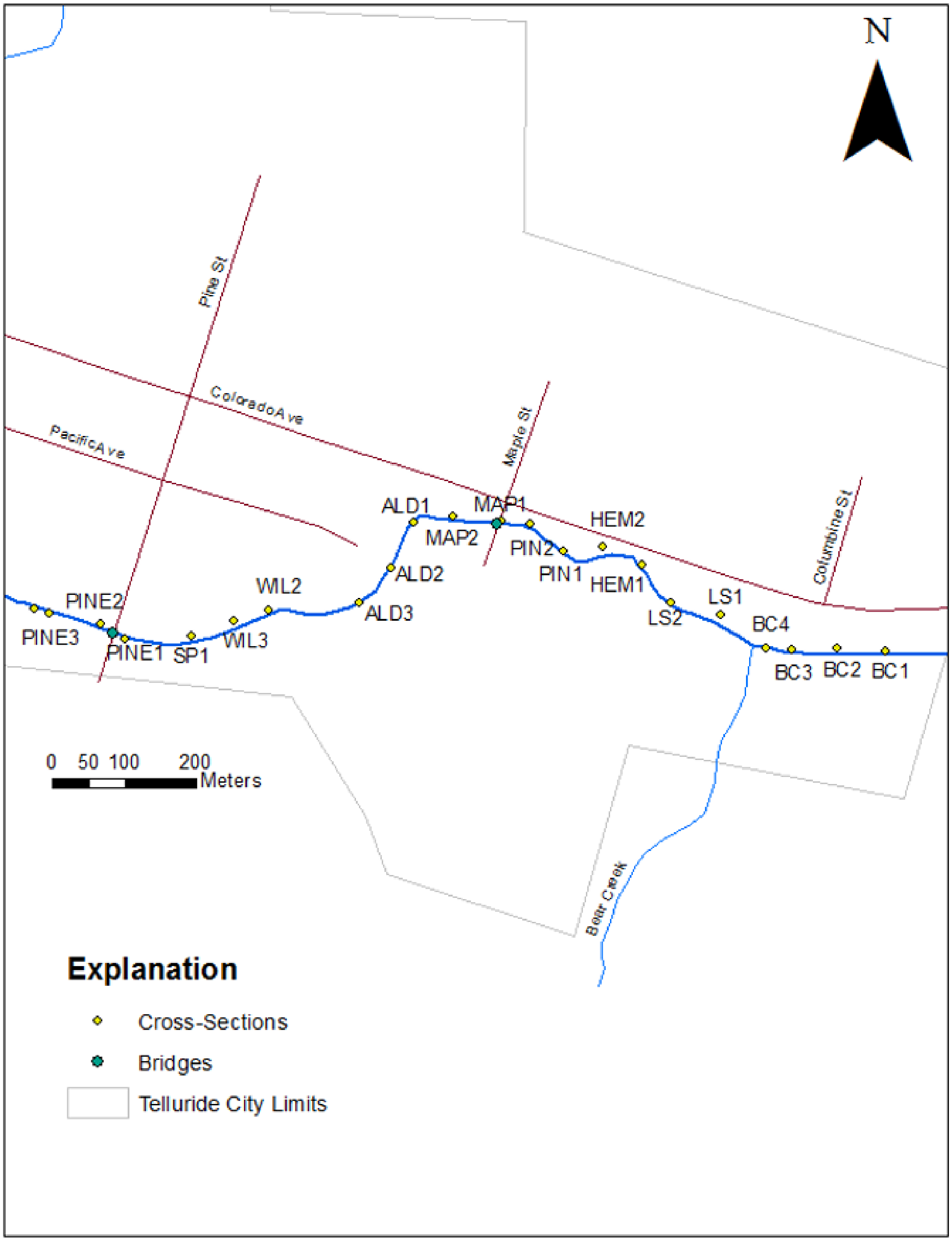
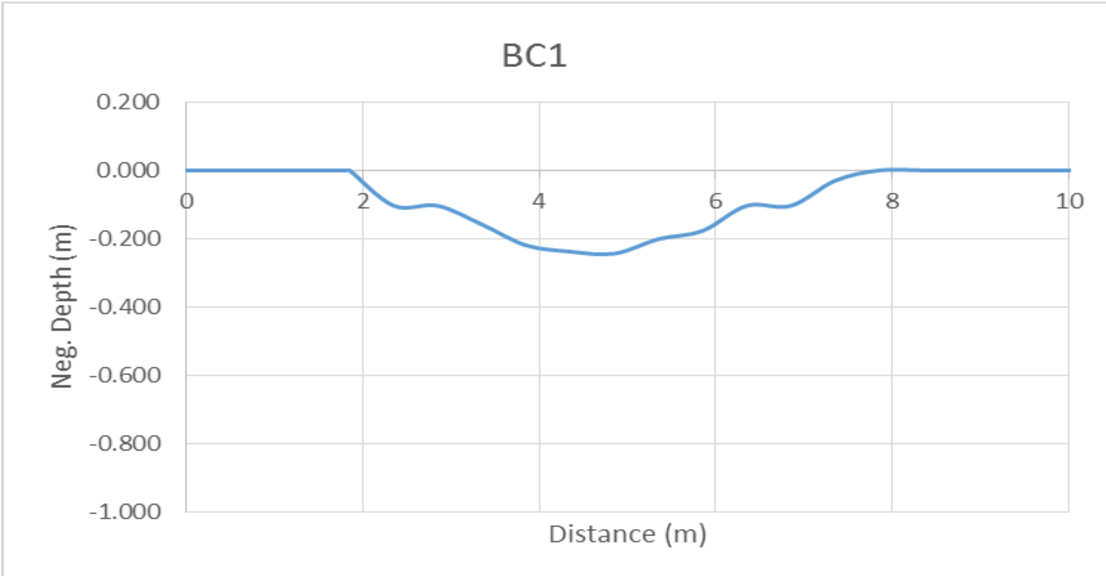
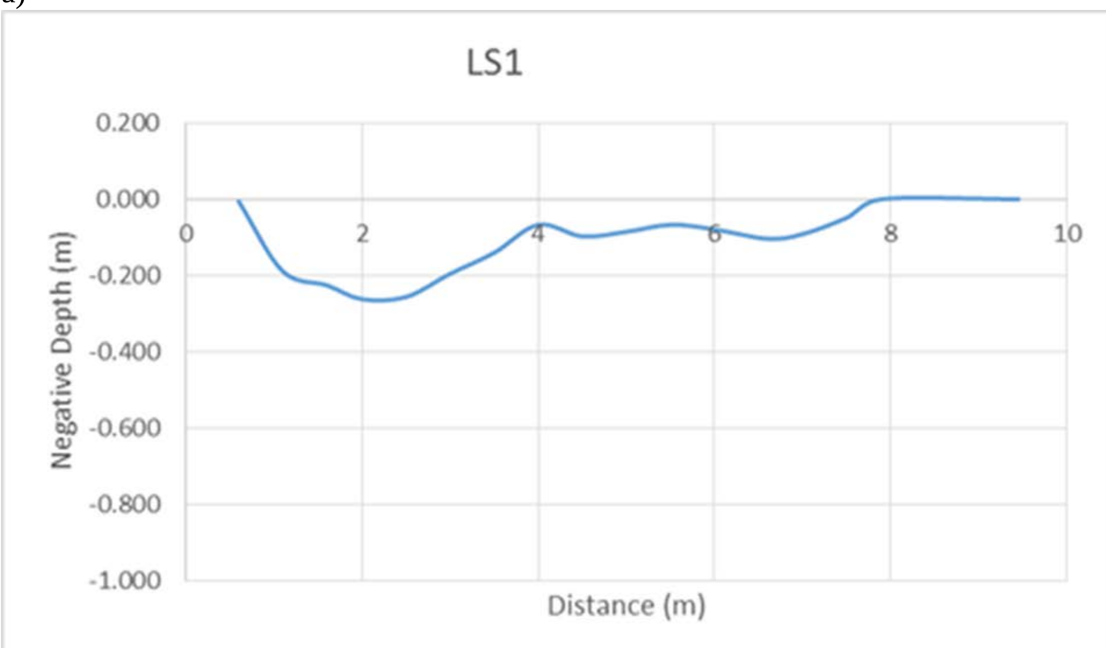


Figure 19: Cross-section locations along 1 km study reach of San Miguel River, Telluride.

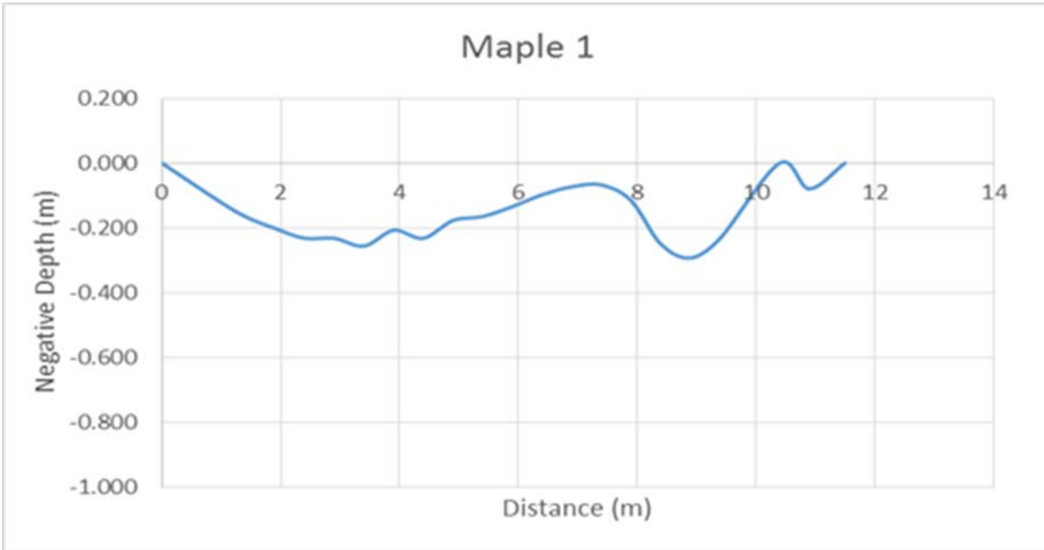


a)



b)

Figure 20: Variations in channel bed geometry at different waypoints: a) 150 m (~490 ft) upstream of Bear Creek confluence; b) Pool aligned with Laurel Street.



a)

Figure 21: Variations in channel bed geometry at different waypoints: a) At Maple Street Bridge; b) Pool 50 m (~165 ft) downstream of Pacific Avenue Bridge.

Table 4 shows bank-to-bank widths and stream widths for the measured cross-sections. The average bank-to-bank width (without the instream sedimentation basin at the confluence of Bear Creek) was 10.16 meters (33.33 feet). Coupled with the depths that ranged from 0.2 to 1 m, the resulting W/D ratios ranged from ~ 10:1 to 25:1, which aligned with the standard of > 10:1 ratio for a Rosgen (1986) C3 stream. The majority of the cross-sections demonstrated ratios > 12:1, which was the design goal for the project. This suggests that despite changes to the channel bed in response to scour and deposition, restoration efforts have maintained the goals for overall channel geometry.

The average stream width was on the order of two to three meters less than the bank-to-bank width. This low number, however, was a result of the time of data collection in August, when the river had low flow.

Table 4: Bank-to-Bank widths (BW), Stream widths (SW), Averages and Standard Deviations (meters) of San Miguel River at 22 measured cross-sections throughout priority reach. Location Lat/Long from Garmin Oregon® 450t.

Location	Latitude	Longitude	BW (m)	SW (m)
BC1	37.93445	-107.80225	10.05	5.90
BC2	37.934667	-107.80265	10.10	4.60
BC3	37.93465	-107.803217	13.90	11.30
BC4 (BC confluence and sed. Pond)	37.934667	-107.80355	43.10	42.50
LS1	37.934985	-107.804122	9.45	8.00
LS2	37.93511	-107.804746	7.80	6.80
PIN1	37.935482	-107.805094	9.50	6.50
PIN2	37.935661	-107.805606	9.10	5.50
Hemlock 1	37.935619	-107.806087	9.78	5.30
Hemlock 2	37.935899	-107.80651	12.80	5.85
MAP1	37.935916	-107.806871	11.50	10.10
MAP2	37.935963	-107.807472	9.25	5.40
ALD1	37.9359	-107.807967	13.20	6.50
ALD2	37.93545	-107.80825	7.35	6.15
ALD3	37.935117	-107.80865	9.75	9.50
Willow 1	37.935	-107.809294	10.00	9.50
Willow 2	37.935035	-107.809797	8.22	6.20
Willow 3	37.934929	-107.810231	12.20	11.05
Spruce 1	37.934859	-107.810792	10.50	9.50
PINE 1	37.934753	-107.81161	13.40	7.60
PINE 2	37.9349	-107.811917	6.35	5.90
PINE 3	37.935	-107.81255	9.25	7.60
Average with Sedimentation Pond (BC4)			11.66	8.97
Average without Sedimentation Pond			**10.16**	**7.37**
Stdev			**1.98**	**1.97**

Images and video captured by the UAV from altitudes between 18-28 m (60-90 ft) also provided detailed images of the point bars, and banks (see supplemental UAV videos I and II). Coupled with field photographs and prior knowledge of where structures had previously failed or were starting to fail, the UAV videos provided a tool that was used for retrospective observations.

The UAV videos showed the flow paths and sediment accumulation areas. These features are apparent in the instream sediment basin where an average ~ 535 m^3 (700 yd^3) of sediment is removed annually (Figure 22) (per. comm. Karen Guglielmone 2014). Figure 23 shows an example of the excavation of sediment.

Undercutting of the banks can lead to potential failures of the bank structures where large boulders are entrenched (Figure 24). UAV imagery and ground photography provided the different vantage points, which show instream grade controls, vanes and weirs that were failing. The grade control structure just downstream of the Pacific Avenue Bridge was altered by the flow during the time of the study period (Figure 25). Others structures that failed during the three-year monitoring period were identified by the Town of Telluride and subsequently replaced (Appendix B4). The reconstructed grade control located at the confluence with Bear Creek has remained stable since it was redesigned and replaced in 2004 (Figure 26).

Even continuous maintenance and alterations to the designs of the instream structures by the town could not prevent erosion of certain banks. Sediment deposition and erosion of the banks occurs along with movement of point bars along the 1 km reach, regardless of the sedimentation basin and instream structures. Another example of changes in bank stability was the falling tree on the western bank in between Willow and Spruce Street. The placement of boulders mid-channel by the town was intended to help divert the flow away and prevent the further undercutting of the bank. With constant erosion by the river, the tree now leans at a 45˚ angle, with the roots holding the bank in place (Figure 27).

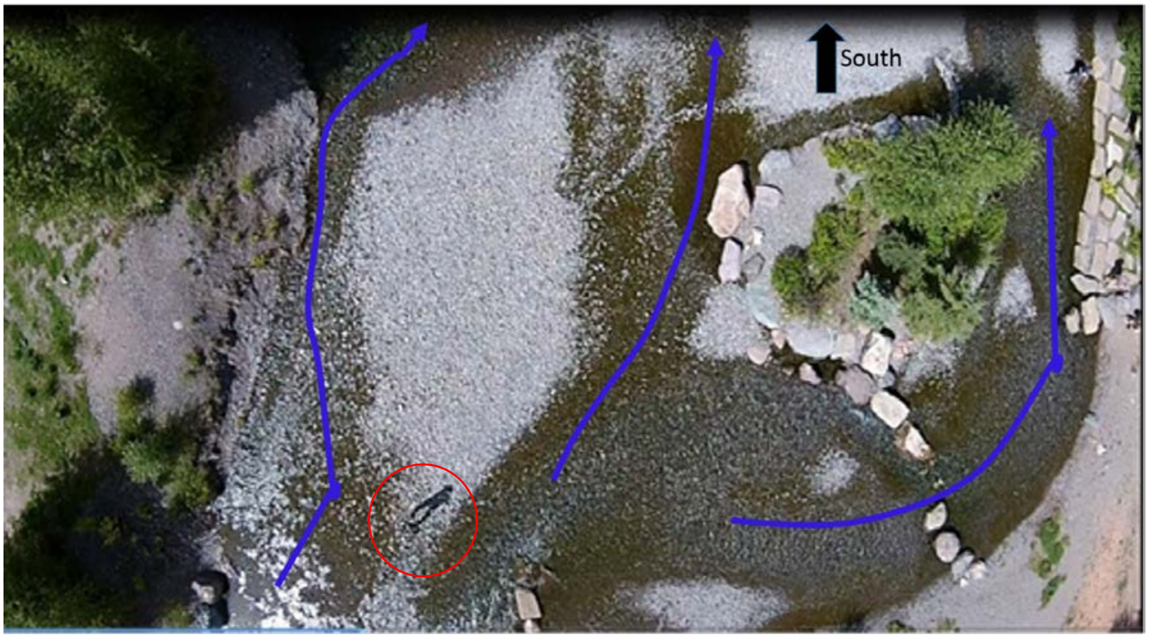


Figure 22: Flow paths in Instream Sedimentation Basin, 2014: Screenshot from UAV video, 6-foot shadow of field assistant for scale.

Figure 23: Excavation and maintenance of Instream Sedimentation Basin, 2003.

Figure 24: UAV video (screenshot) (2014) depicting undercutting banks.

a)

b)

Figure 25: Bear Creek Drop Structure re-engineered: a) original structure in 2001; b) new design in 2004.

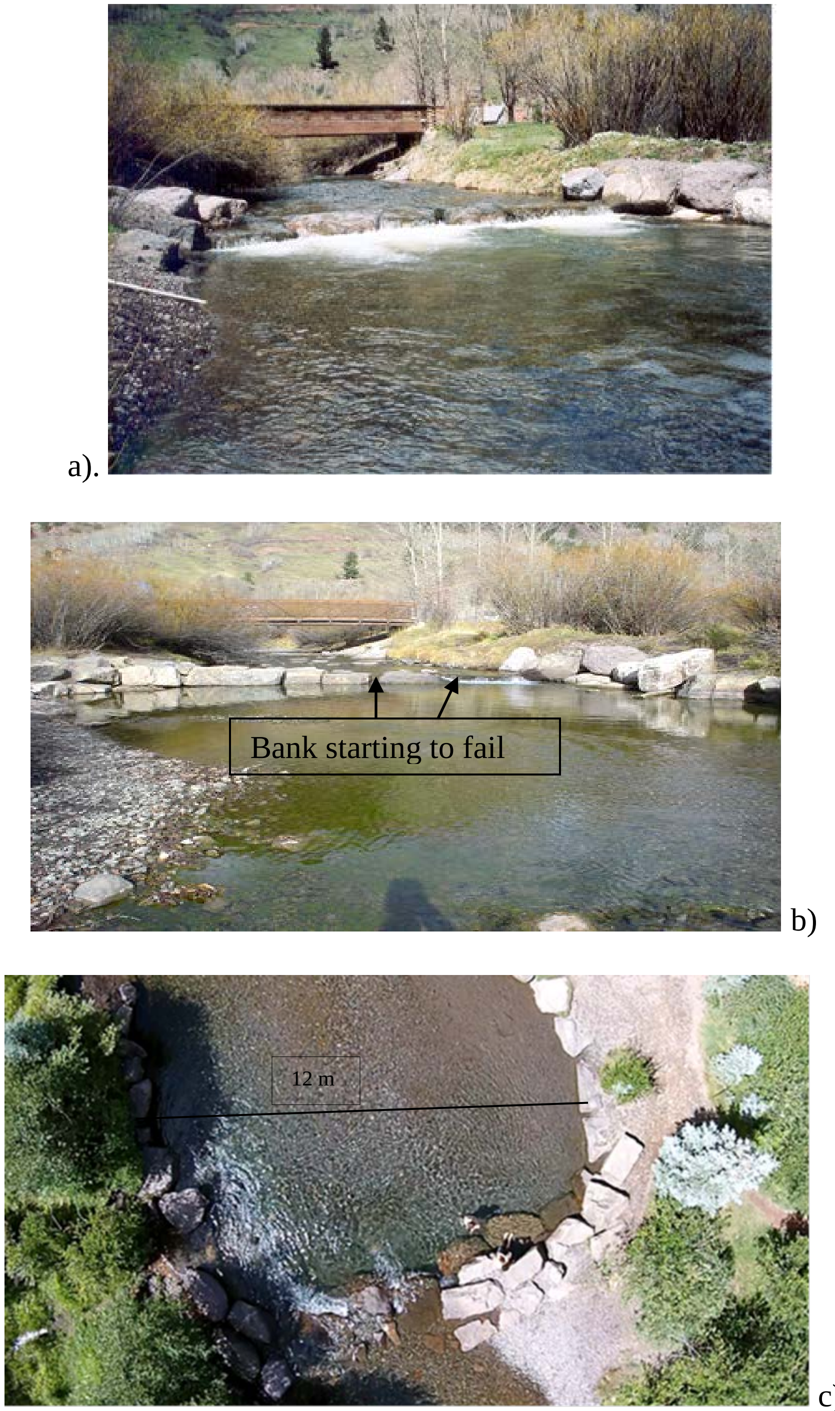


Figure 26: Drop Structure directly downstream of Pacific Avenue Bridge: a) 2002 a year after construction; b) Eastern side starting to fail in 2004; c) Grade control has minimal effect, Screenshot of UAV video, 2014.

Figure 27: Image of falling tree and undercut bank in between Willow and Spruce Streets; Photograph taken August 2014. Field assistant used for scale, about 1.75 m tall.

V.ii. Floodplain Changes

V.ii.i. Hydrological Changes

A major objective of the restoration effort was to improve the hydraulic conditions in the river channel by narrowing the low-flow channel, reduce flooding by use of wetlands and reduce back-water at bridge locations (San Miguel River Corridor Restoration Plan 1998). Upon completion, the channel had been reduced from width/depth ratios ranging from 30:1 to 45:1 along the study reach to a constant 25:1.

This ratio remained the same through the three-year monitoring period until 2004 (Appendix B1). In 2014, with the aforementioned sediment accumulation along the channel bed, the width/depth ratios ranged from 10:1 to 25:1 depending on the part of the 1 km reach.

As part of the restoration efforts, the town monitored discharge at a gage at the Mahoney Street Bridge. To evaluate the temporal change in the discharge of the river, statistical comparisons of the weekly discharge data for a ~ 20-year period were undertaken using Microsoft Excel® and JMP Pro 11®. Means, standard deviations, regressions, and comparisons of the means were examined. To compare the means of weekly discharge over the years, an analysis of variance (ANOVA) test that assumed a normal distribution and a five-percent error level was conducted. An ANOVA test was used in preference to a Chi-Square test to compare the means of continuous data rather than categorical proportions (Ott and Longnecker 2008).

According to gage data (Public Works Department in Telluride), the average discharge did not vary from 1992 to 2013. Figure 28 shows discharges for 2002, 2012 and 2013, respectively. The average discharge from 1992 to 2013 is also shown.

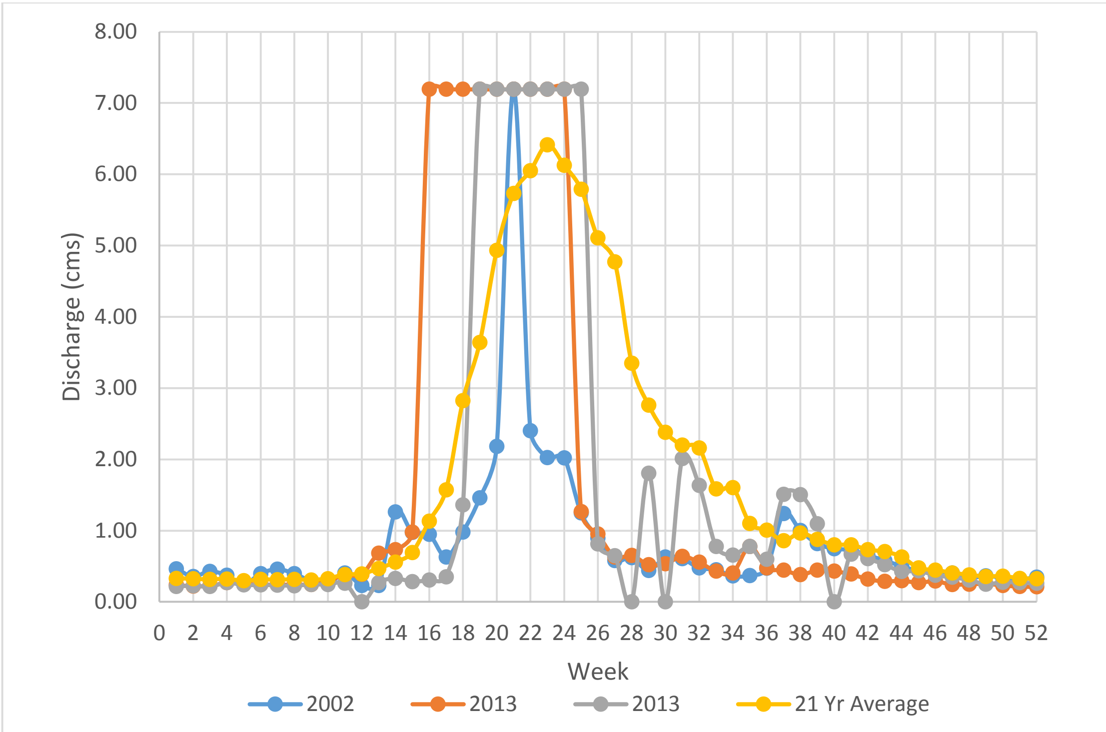


Figure 28: Simplified Discharge Graph for Mahoney Gage comparing discharges in 2002, 2012, 2013 and a 21 year average (Public Works Dept. of Telluride, August 2014).

The distribution of the average discharges of the weekly data over the years is shown in Figure 29. An analysis of variance (ANOVA) test between the 13 sets of weekly discharges of the river from 1992 and 2014 resulted in a p value of 0.088. The 13 groups refer to the 13 sets of four-week groupings in the calendar year. The result shows that no significant difference occurred in average discharge from 1992-2014, which suggests restoration did not alter the hydrologic function of the channel. This result was observed despite alterations to the channel shape. Spring run-off was not gaged accurately because the gage was undersized and the maximum capacity was exceeded by the majority of the spring run-off values. Therefore, the ANOVA test did not incorporate these inaccurate measurements. Appendix D has the weekly average discharge data used.

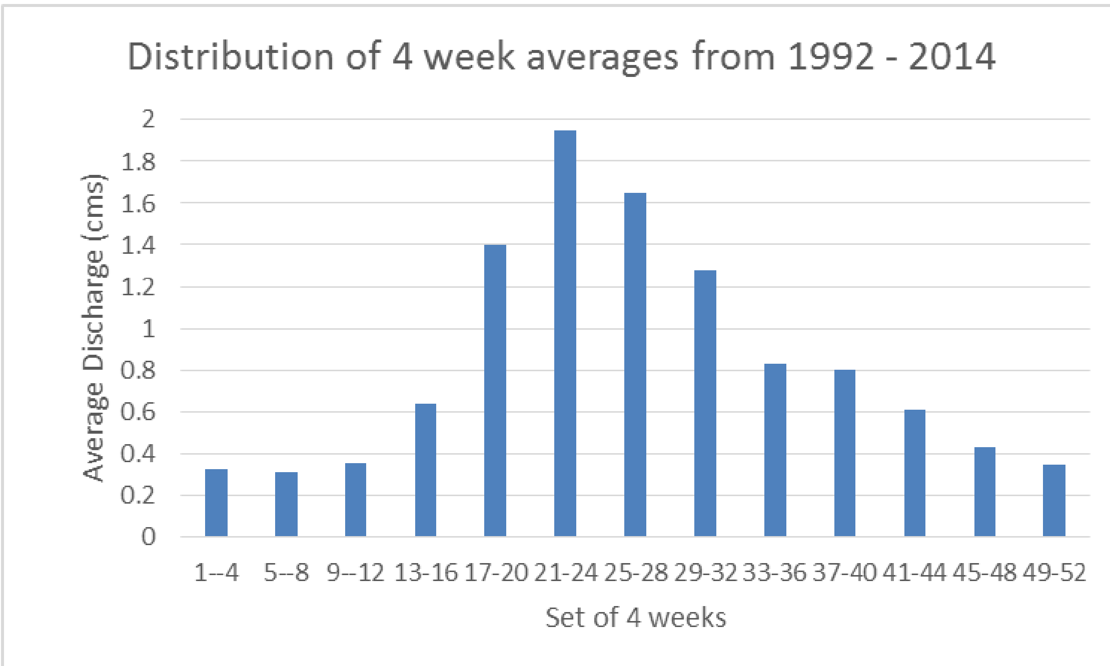


Figure 29: Distribution of 4 week averages from 1992 – 2014.

In addition, an examination of daily precipitation over two thirty-year time periods, 1971-2000 and 1981-2010, demonstrated that precipitation in the area was consistent (Figures 30, 31). An R^2 value of .897 suggests overall minimal differences in rainfall between the two time periods.

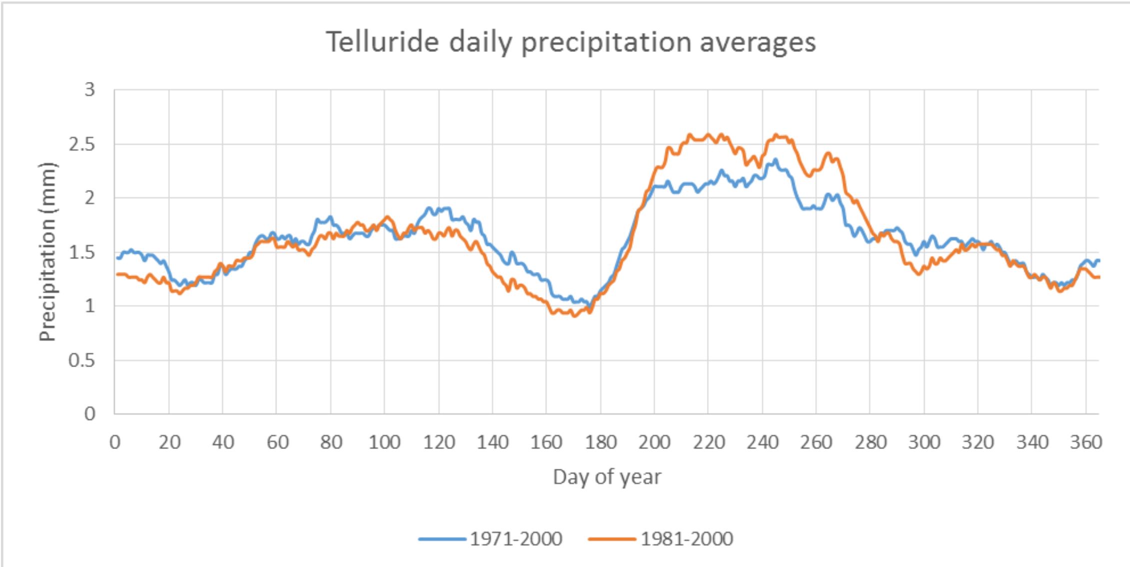


Figure 30: Daily precipitation averages for two thirty-year time periods for Telluride, Colorado.

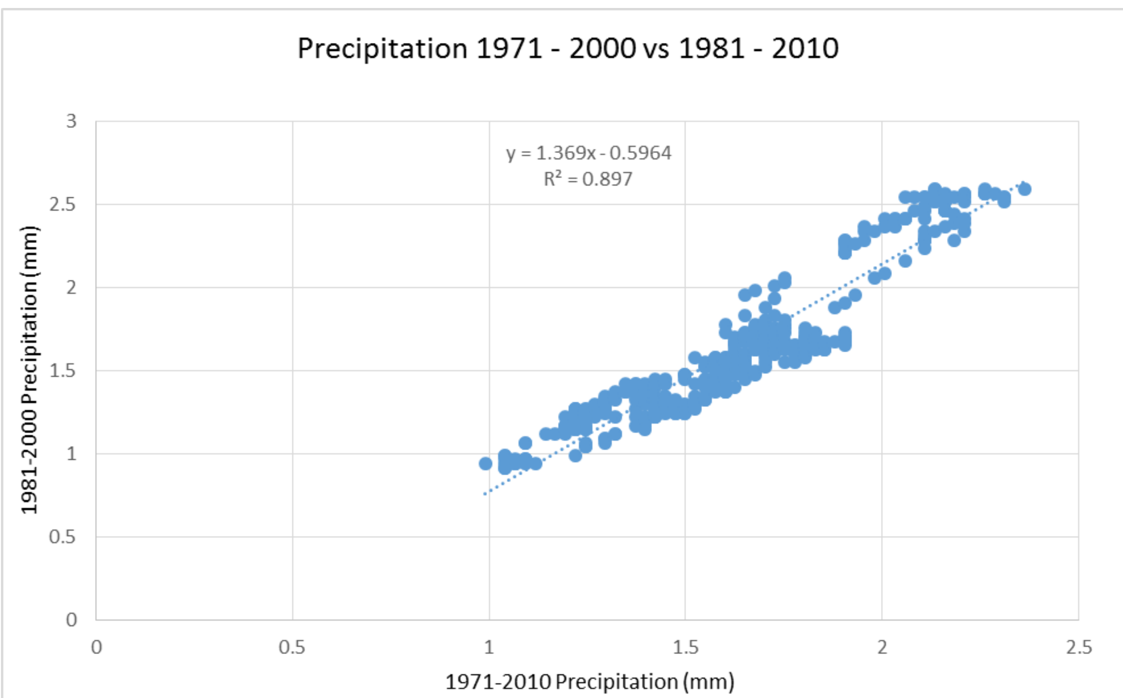


Figure 31: Linear Regression comparing average precipitation of 1971-2000 and 1981-2010.

When comparing discharge and precipitation, however, no statistical correlation was observed. Linear regression between average discharge and average precipitation resulted in an R^2 value of 0.0001 (Figure 32).

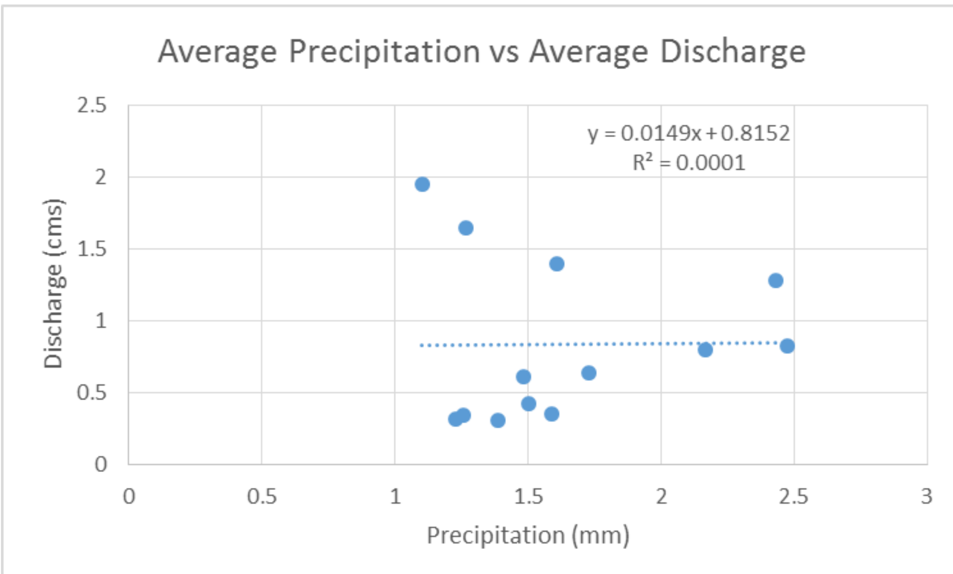


Figure 32: Linear Regression comparing average precipitation vs average discharge from 1992 to 2014.

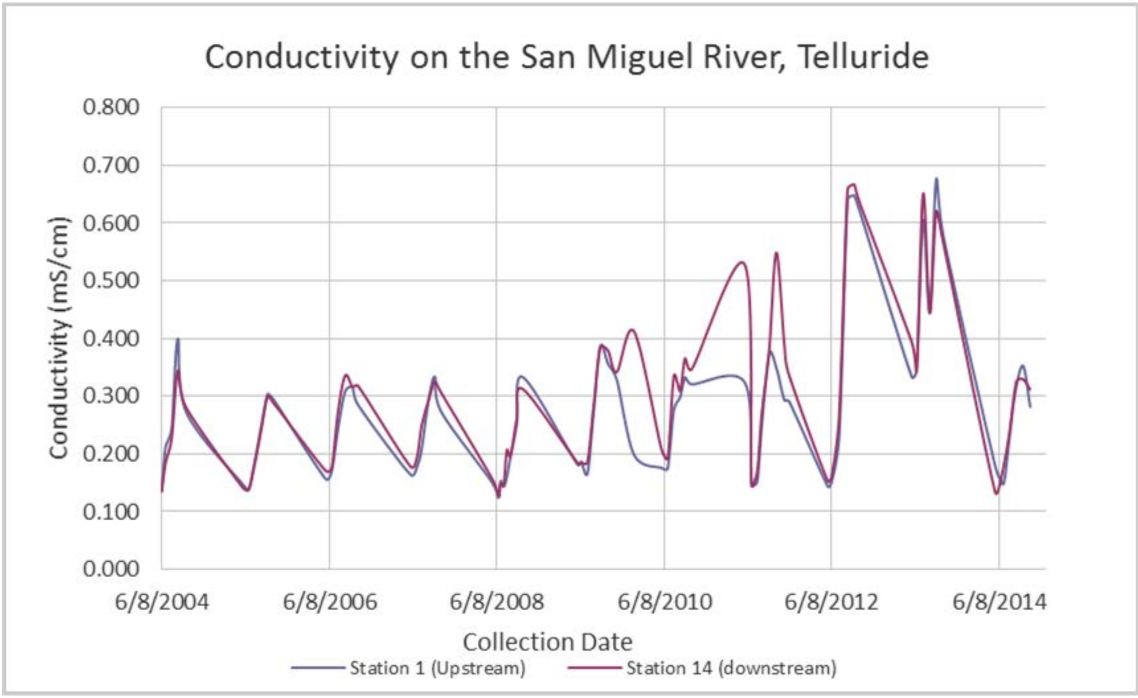
Water chemistry data (Public Works Department) were also examined using regression analysis. A comparison between the upper station, which was located ~ 50 m upstream of the confluence of Bear Creek and the San Miguel River, and the downstream station, which was located ~ 50 meters downstream of the Pine Street Bridge, was used (Figure 1).

Discharge, dissolved oxygen, nitrogen, conductivity and temperature were compared the upstream (phase I) and downstream (phase II) portions of the river were drawn to examine whether the two sections of the river had a hydrologic connection. With fewer options for phase II restoration for the Town of Telluride because of the building constraints and roadways along the downstream reach, in addition to less funding, an assessment was made on the one km upstream reach. Ideally, proper restoration upstream would allow for less work downstream.

The upstream sampling station (Station 1) was located ~50 m upstream of the confluence of Bear Creek and the San Miguel River, whereas the downstream sampling point (Station 14) was ~ 50 m downstream of the Pine Street Bridge (Figure 1). Appendices E-I have the conductivity, dissolved oxygen, nitrate, temperature and flow data for these two stations. Note that these stations are on the edges of the reaches restored by the town.

Figures 33 – 37 suggest that a strong connection exists between the upstream and downstream sections. Except for dissolved oxygen, all of the parameters had R^2 values of greater than 0.6 between the upstream and the downstream. The reason dissolved O_2 was not consistent in the evaluation was the result of a probe not functioning correctly. This probe was fixed in 2009 (Guglielmone 2015). As of February 2015, the pH was slightly alkaline in town and more acidic downstream of town. All measurements were within the water quality standards of pH 6.5-9. The dissolved oxygen levels were within the quality limit of 6 mg/L (Cold Water Biota, Class 1). The upstream portion of Bear Creek was well below standard up until 2012, but now is above standard (Guglielmone 2015).

Conductivity increased consistently from 2004 – 2013 to above 0.500 mS/cm, but now is back to historical levels of 0.35 mS/cm for the river. Temperature ranges, however, have remained constant over time. Interestingly, the downstream section had lower temperatures compared to the upstream section. The Public Works Department hypothesizes that cold groundwater is being added to the system towards the end of town, although the hot springs near the fault upstream of Telluride help create the inflated upstream temperatures. Nevertheless, temperatures fell well below the chronic standard of 17.0 ºC (62.6 ºF) and the acute standard of 21.2 ºC (70.2 ºF) (Guglielmone 2015).



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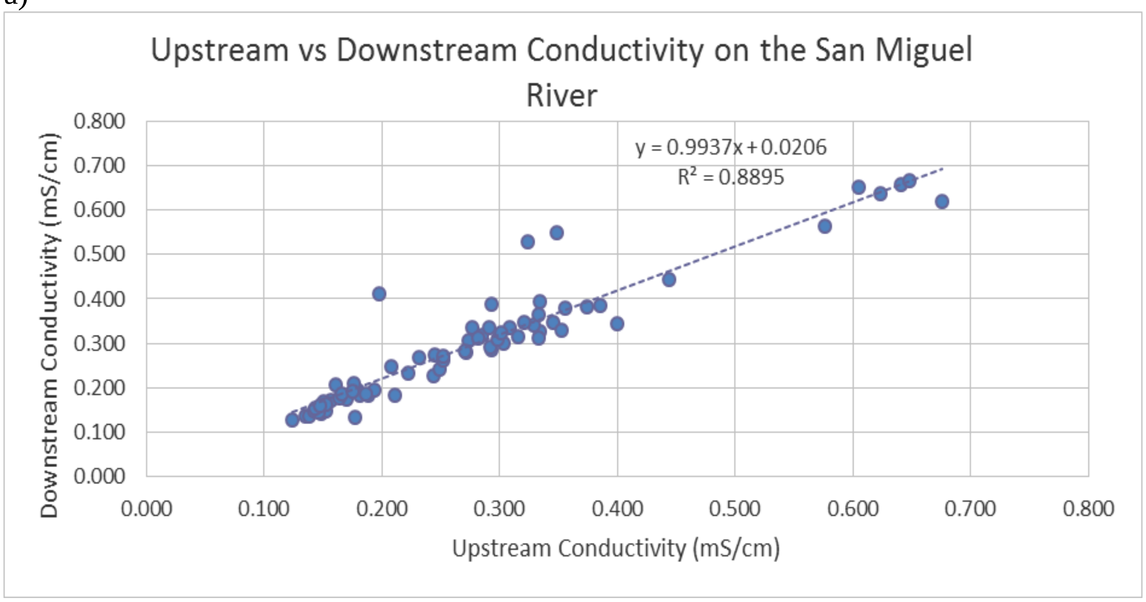
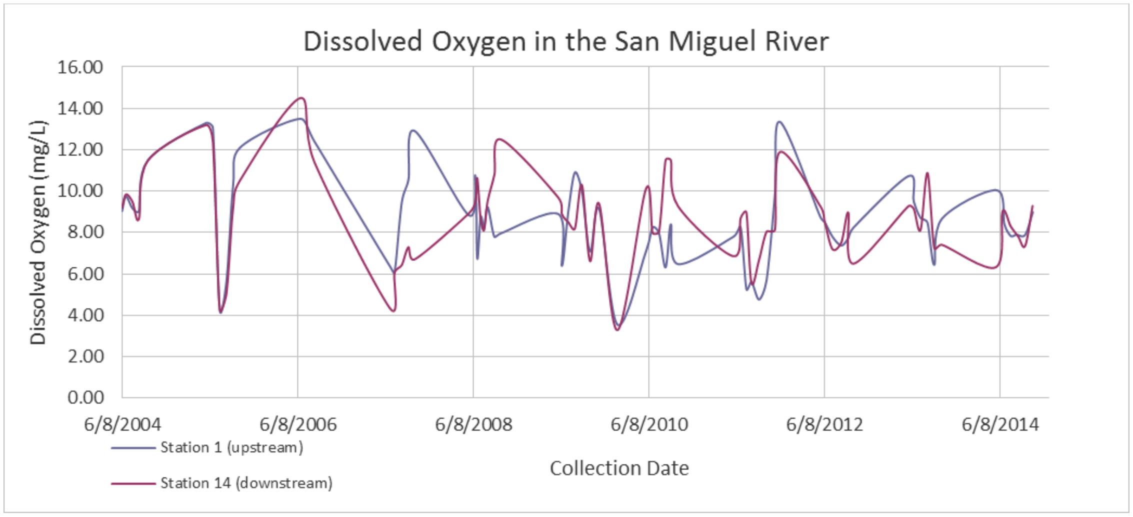


b)

Figure 33: Upstream vs Downstream Conductivity, San Miguel River in Telluride: a) Conductivity (mS/cm) vs Time, b) Linear Regression between Upstream and Downstream Conductivity. R^2 of 0.89 shows connection between the two sections.



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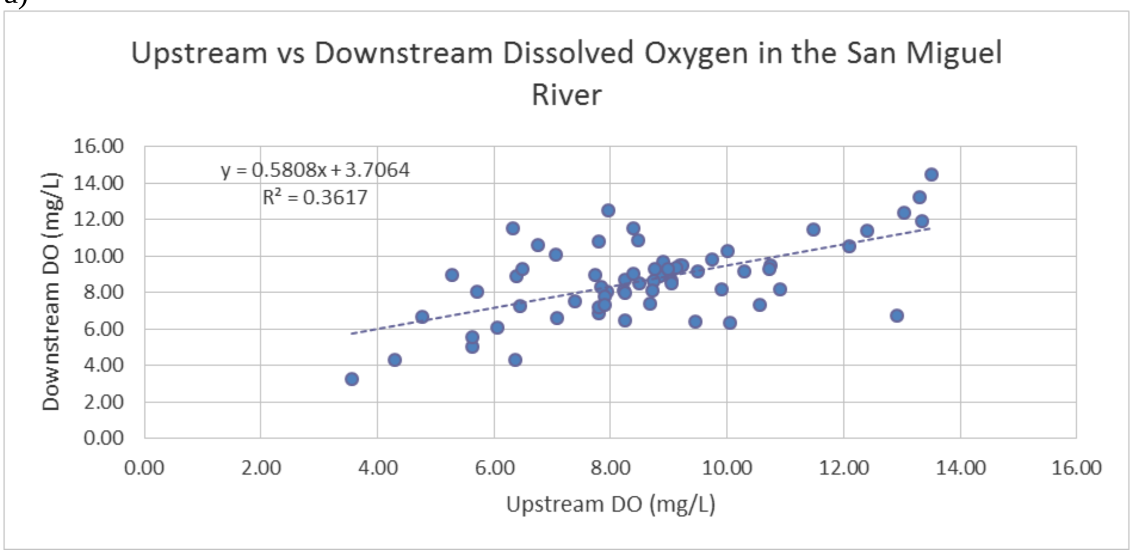
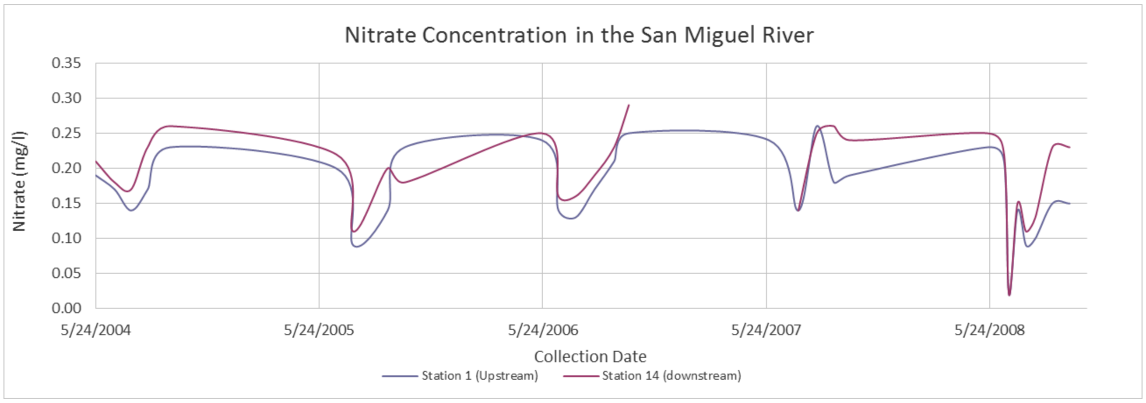
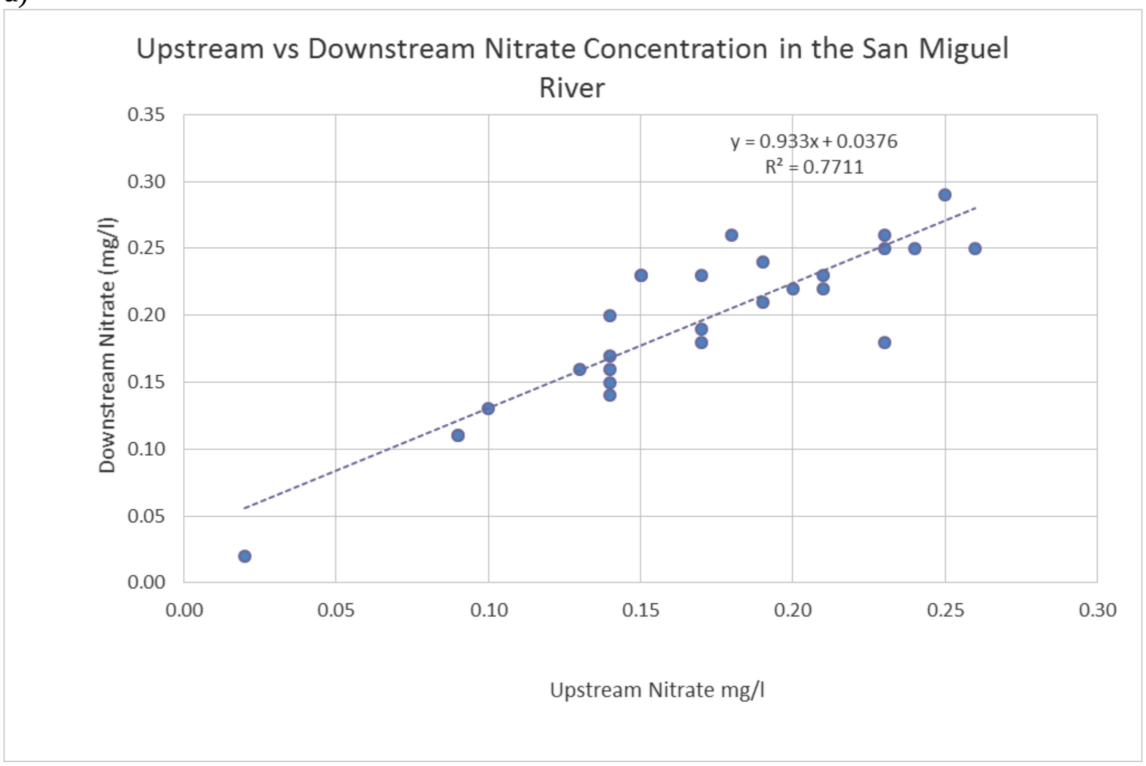


b)

Figure 34: Upstream vs Downstream Dissolved Oxygen, San Miguel River in Telluride, a) Dissolved Oxygen (mg/L) vs Time, b) Linear regression between Upstream and Downstream Dissolved Oxygen. Note that probe was not functioning properly up until 2009, resulting in the large variation from 2004 – 2009.

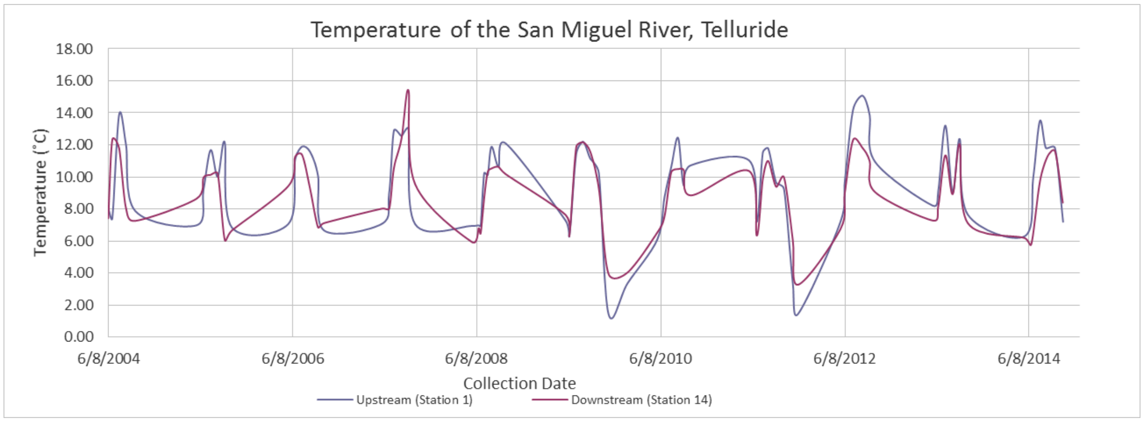


a)

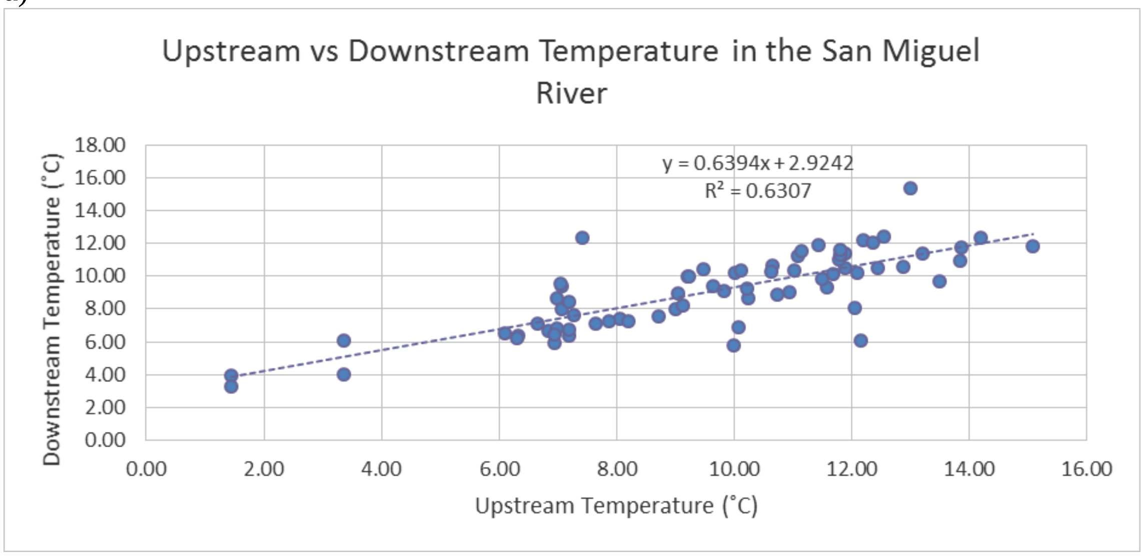


b)

Figure 35: Upstream vs Downstream Nitrate, San Miguel River in Telluride, a) Nitrate (mg/l) vs Time, b) Linear regression between Upstream and Downstream Nitrate concentration. R^2 of 0.77 shows connection between the two sections.

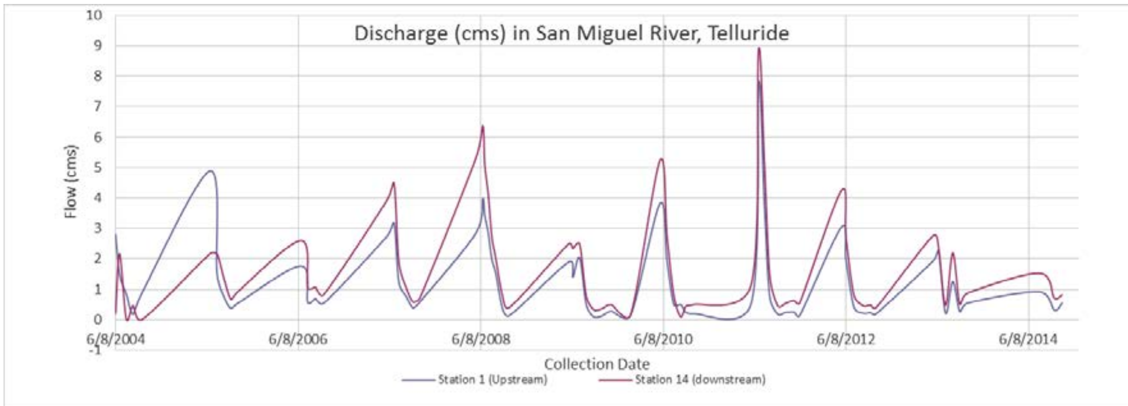


a)

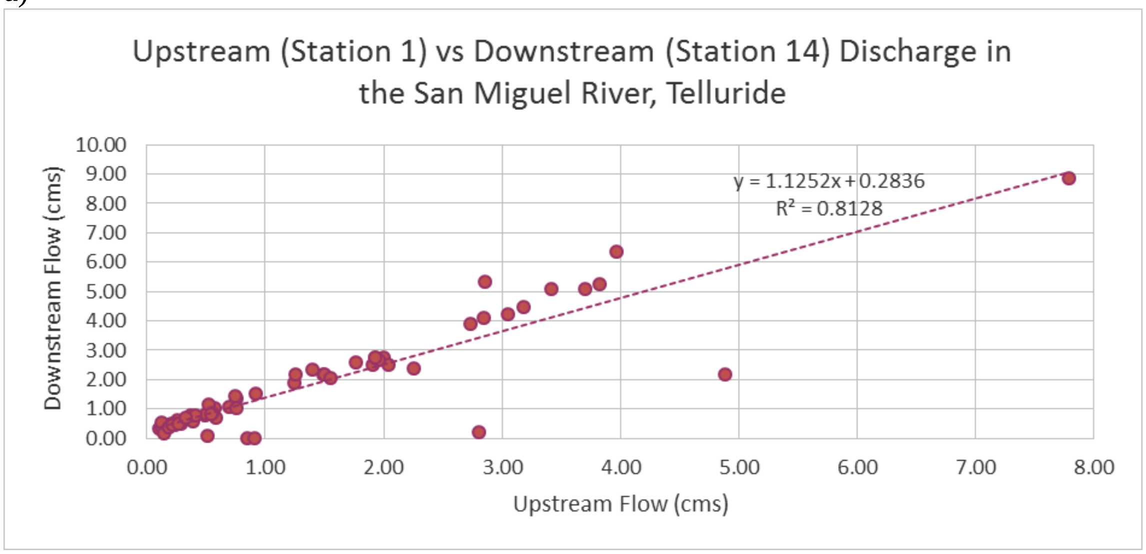


b)

Figure 36: Upstream vs Downstream Temperature, San Miguel River in Telluride, a) Temperature (˚C) vs Time, b) Linear regression between Upstream and Downstream Temperature. R^2 of 0.63 shows connection between the two sections.



a)



b)

Figure 37: Upstream (Station 1) vs Downstream (Station 14) Flow, San Miguel River in Telluride, a) Flow (cfs) vs Time, b) Linear regression between Upstream and Downstream Flow. R^2 of 0.81 shows connection between the two sections.

V.ii.ii. Ecological Changes

The restoration efforts included creation of 3.8 acres of wetlands and an additional 0.7 acres of riparian habitat in 2001. In addition, aquatic habitat was created for the local fish populations that included undercut banks, cover logs, and vortex rock weirs (Figure 8). After the end of project monitoring in 2004, 3.6 acres of wetlands and 0.6 acres of riparian habit survived, with the willow survival rate ranging from 40 – 95 percent depending on the area (Appendix B2, B3).

Other ecological factors include change of stream dynamics in response to beavers and other animals. Prior to 2004, beavers had created a dam near instream structure 24 (near Pine Street Bridge) that caused higher localized flows and sediment deposition from standing water downstream. After removal of the dam, the nearby pool started to scour back to normal bed levels of the rest of the river.

To assess the ecological changes to the floodplain from restoration completion to August 2014, qualitative comparisons regarding vegetation location and density were conducted. UAV flight videos and ground photography from 2014 were compared with the provided historical photos (Town of Telluride) from 2001 to 2004. In addition, larger scale changes could also be visualized with the available Google Earth® Imagery from 1998 – 2014. Total biomass of brook trout pre- and post-restoration was compared to examine the effectiveness of the restoration on aquatic habitat.

Changes in vegetation density can be seen in every photo comparison (Figures 38-40). The actual densities were not quantified in this study. The 2003-2004 images were obtained from the Public Works Department in Telluride after field pictures were taken in August 2014.

Finally, examining reports acquired from Eric Gardunio, the Area Aquatic Biologist for the Colorado Parks and Wildlife, Montrose office, the data suggest that the creation of aquatic habitat and overall restoration led to an increase in the fish population since restoration. Table 5 summarizes the change in biomass over time from project start to 2013, ranging from five times (2003) to double (2013) the initial biomass (Data from 2002 and 2013 reports). Despite the loss in biomass, the average brook trout size, which consisted of 99 percent of the catch, was not significantly different between 2005 and 2013 (San Miguel River-Town Park 2013 Report).

a)

b)

Figure 38: Upper San Miguel South Side Riparian Area (HA1), a) looking east, October 2003, b) looking east, August 2014. Arrow points to place of comparison. The river at the fence line has a bank-to-bank width of ~10 m for scale.

a)

b)

Figure 39: Town Park Parking Lot South Side, HA18 (upstream of Town Park/Maple Street Vehicle Bridge), a) looking west towards bridge September 2004, b) looking northeast away from bridge August 2014. Arrow points to place of comparison. The bank-to-bank width at the bend is ~ 9.5 m.

a)

Figure 40: Pine Street Northeast Riparian Area between river trail and river upstream of bridge (HA30), a) looking southwest, September 2004, b) looking southwest towards Pine Street Bridge, August 2014. Note an abundance of grass and shrubs 14 years later.

Table 5: Biomass amounts from 2002 – 2013; sampling site near Town Park, Telluride.

Year	Biomass (kg/ha)
2002	22.4
2003	114.3
2005	74.3
2013	43.5

V.ii.iii. Anthropological Effects

The restoration has provided new means for recreation. The town enhanced features of the town park, added to existing walkways and improved the river walk (Figure 41). While conducting field research, we saw many people out with their dogs, playing in the water and walking along the river. In addition, the UAV videos also provided examples of people interacting with the river including fishing, camping and enjoying the river (Figure 42). This interaction can harm bank vegetation, because people and their pets sometimes use unauthorized access points to the river. Nevertheless, the most profound human impact has been the creation and improvement of the wetlands which has created a buffer for the town, with fewer buildings in the new flood plain (FEMA 2014).

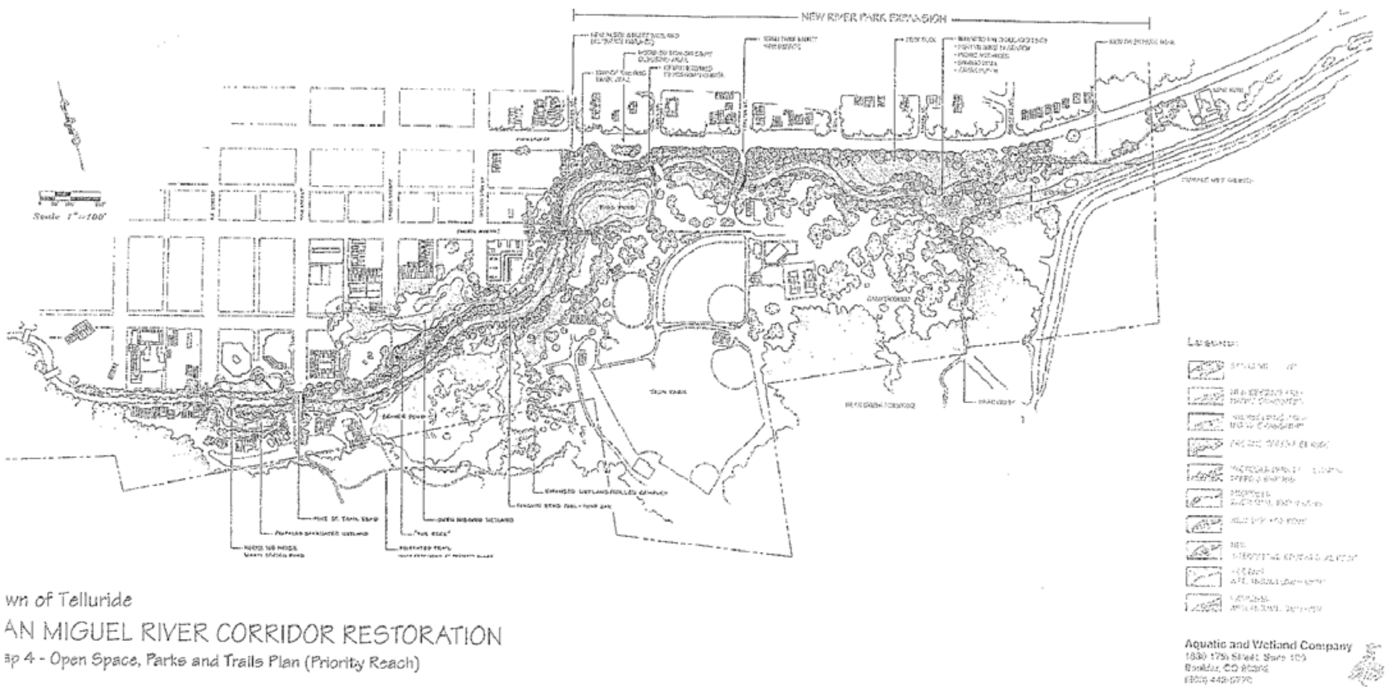


Figure 41: Open Spaces, Parks and Trails Plan (From 1998 San Miguel River Corridor Restoration Plan).

Figure 42: UAV Imagery (~ 18 meters elevation) depicting human use of river: Person playing with dog in upper left; Fishing in upper right, lawn chairs in lower left; and picnic in lower right. People, chairs and tables are used for scale.

CHAPTER VI

DISCUSSION

VI.i. Channel and Floodplain Changes

The results have shown evidence of change and no change from the restoration design over the ten-year study period. Geomorphologically, the San Miguel River was altered from the restoration design because of the efforts of the Town of Telluride to improve sediment balance, enhance bank stability and strengthen instream structures. Although overall sinuosity was not altered, the local channel bed had sediment accumulation and scouring along the studied reach. Point bars formed and later eroded away. This change over time was expected as rivers have natural cycles of erosion and deposition. Flowing water scours, transports and deposits the sediment along the path of the river, especially in minimally altered rivers such as the San Miguel River (Nichols 2009, Allred and Andrews 2000). The rate of erosion and deposition varies based on the rate of flow and the sinuosity of the river (Ritter *et al*. 2011).

Furthermore, any unnatural alteration of the system, like removal of sediment, can cause greater erosion and deposition downstream. Obstructions, such as bridges, can cause buildup of sediment and debris upstream (Kattell & Eriksson 1998). Likewise, removal of these obstructions or improvements in the design of unnatural structures, such as culverts, can help improve the overall sediment balance. At the start of restoration, this improvement in sediment balance occurred in Telluride once the bridges near the Town Park were replaced and the culvert sizes were increased.

Hydrologically, the restoration has also improved floodplain parameters and water quality, although the overall discharge was not altered. The data suggest that despite less restoration completed in phase II compared to phase I, the water chemistry in the two portions of the river was similar. The fairly constant measurements for the presented parameters suggest successful management by the town from a hydrological perspective. This success came despite two phases and two different groups working with the town. Overall, several factors showed that restoration had no detrimental impact to the hydrology of the San Miguel River as it flows through town. These factors included changes in water chemistry, the limited changes in hydrological parameters such as discharge and the much lessened back-water at the recently constructed bridges.

VI.ii. Restoration Effectiveness

Success of restoration was also judged on whether the goals set out for the project were met over the study period. The main goal of the restoration was to restore aquatic, wetland, and riparian habitat throughout the San Miguel River corridor within the Town of Telluride boundaries. This would be achieved by developing a natural functioning channel with features that enhance aquatic habitat (San Miguel River Corridor Restoration Plan 1998).

The objectives of the restoration were: 1) improve hydraulic conditions; 2) balance sediment movement; 3) provide aquatic habitat; 4) improve wetland habitat; 5) re-establish flora and fauna species diversity; and 6) develop a monitoring plan.

The town of Telluride addressed the improvement of hydraulic conditions at project start by replacing bridges and undersized culverts that had caused high levels when the flow was interrupted. The channel was narrowed and altered from a braided river to a single thread meandering river (San Miguel River Corridor Restoration Plan 1998). The town also created wetlands to help buffer the high spring flows. The installation of new bridges and increased culvert sizes were shown to be effective during the period of monitoring from 2001 to 2004. In 2005, a report given to the Federal Emergency Management Agency (FEMA) demonstrated much lower 100-year water levels in the area (Year 3 Monitoring Report, Telluride 2005).

Discharge remained constant from 1992 – 2013, with the statistical tests demonstrating no significant changes. This was shown despite the restoration efforts and the local alterations in channel bed structure. The water chemistry data suggests that the restoration efforts in the floodplain, such as the creation of wetlands, have helped improve overall quality. The wetlands may have acted as a filter to the urban runoff. This was an added benefit because the restoration did not focus on the improvement of water quality. Over the course of the study period, these improvements in conjunction with the lowered back-water levels and the constant discharge levels have exhibited that the first goal has been met.

In contrast, the second goal of balancing sediment movement has not been met. From the analysis of channel bed structure and shape, sediment aggradation and scour led to varied bed structures and depths. The local channel geometry altered over time in response to yearly flows and excavation of sediment from the sedimentation basin. The latter had the most impact on the sediment balance because artificial capture and excavation of sediment upstream caused erosion downstream. This was evident with instream structures having been covered and uncovered by sediment over the study period. Similar observations have been recorded in other locations (Miller & Kochel 2010, 2013; Ritter *et al.* 2011). Changes in sizes of the point bars, along with bank erosion, were also observed along the reach. The sedimentation basin was designed to control the amount of sediment that moved through the restored reach (Wolff et. al 2000). The town had assessed that the channel did not have the adequate transport capability to completely move all suspended sediment through the system (San Miguel River Corridor Restoration Plan 1998). Nevertheless, by attempting to control the sediment upstream, the river will try to balance itself by scouring more downstream (Nichols 2009, Ritter *et al.* 2011).

The third and fourth goals of providing aquatic habitat and improving wetland habitat were addressed together by the town. Increases and improvements in wetland areas and aquatic habitat resulted in increased aquatic biomass (San Miguel River-Town Park 2013 Report). The local brook trout population more than doubled since restoration in the Town Park area. The success of the ecological efforts was validated by the observed increases in density along many areas of the floodplain. Unfortunately, some areas were affected by improper use by people and their pets. Regardless, the majority of the created 3.8 acres of habitat remained in 2014 (per. comm. Guglielmone 2014).

The fifth goal was to reestablish the diversity of flora and fauna. Data from 2001-2004 showed healthy species diversity and survival rates, with ~ 34,000 different plants introduced at the project start (Phase 1 San Miguel River Restoration Project Final (Year 3, 2004) Monitoring Report). I assessed the increase and decrease of vegetation over time with a comparison of photos, but did not assess the diversity of the flora and fauna species over time. The fish reports obtained from the Colorado Parks and Wildlife indicated little diversity because brook trout were 99 percent of the catch (San Miguel River-Town Park 2013 Report).

The final goal of the restoration was to develop a monitoring plan. As part of the funding agreement, the town was required to monitor for three years after completion of the restoration. From their results in 2004, the town decided it had to monitor the level of sediment in the instream sedimentation basin each year and decide whether excavation was needed. This yearly examination of the basin was planned in addition to checking the functionality of the instream structures. If the structures failed, the town would replace them. If the structures maintained their function, however, the town would not tamper with them (per. comm. Guglielmone 2014). Finally, the Public Works Department in tandem with the newly reorganized San Miguel Watershed Coalition has monitored water quality from 2004 to present.

Overall, despite limitations in available data and field-collected data, this study suggests that restoration of the San Miguel River met most of the design goals. Although the design called for balancing of sediment, the design did not fully account for channel movement, sediment deposition and erosion. The imbalance in sediment deposited in the sedimentation basin forces yearly extraction of sediment and causes alterations in the channel structure. The cost of excavation will have to be factored in over the long term.

The use of cost-effective technology and software, such as UAVs, Bing® and Google Earth® software allowed for detailed, close-up imagery despite the limited funding for the project. Major limitations of this study include a limited field data set, and the lack of availability of some temporal imagery. A further limitation was the timing and receipt of the engineering reports and historical change data from the Town of Telluride, Idarado Mining Co., and other organizations after the collection of field data. These limitations led to smaller sample counts than desired and difficulties in quantitative comparisons between pre-restoration, post-restoration, and ten years after restoration completion.

CHAPTER VII

CONCLUSIONS

The purpose of the study was to conduct a post assessment of the restoration efforts on the San Miguel River as it flows through the town of Telluride. The specific research question was: Was river restoration on the San Miguel River after a ten-year period effective? For this thesis, effective was defined as the river channel and its meanders maintaining the relative geometries.

The first hypothesis about the study reach showed that it was stable ten years after the restoration was completed. For the purpose of this thesis, stable means the channel geometry and sinuosity meet the design standards over the ten years since completion of restoration and phase I monitoring. The second hypothesis was the goals of the restoration had been met ten years after completion of restoration.

The main objectives were:

1) Assess changes in the channel; 2) Assess changes in the floodplain along the river; and 3) Evaluate whether the restoration goals were met and maintained over the ten-year period of study.

These objectives were addressed by a combination of field methods including measurement of cross-sections, and the use of an UAV. Statistical comparisons were used to assess if changes in discharge and water chemistry parameters were significant. Comparisons of photos and data provided by the Town of Telluride and other agencies with collected data and videos from the UAV allowed for assessment of local channel changes and floodplain changes.

Over the course of the study period, the channel did not alter its sinuosity, and the width/depth ratios stayed within the design parameters of an alluvial, meandering (C3) stream (Rosgen 1986, 1994). Nevertheless, the data demonstrated that the river continues to erode and deposit sediment along the channel bed. This suggests that the sedimentation basin does not allow for complete balance of sediment in the reach. Although the channel retained its relative geometry, the continuous erosion and deposition within the channel suggests that monitoring and maintenance should continue. This idea supports the view of process geomorphologists (Simon *et al*. 2007; Miller & Kochel 2010; Ritter *et al*. 2011). The restored reaches will require yearly monitoring from the Town of Telluride in response to the movement of sediment over time and the erosion and deposition in and around the instream engineered structures (Miller & Kochel 2010, 2013).

Fifteen years after the start of the restoration efforts, the data and other information demonstrate the following key points:

1. Long-term monitoring (ten years) is useful for early detection of possible channel migration and structure failures.
2. Lack of monitoring and maintenance will result in failures and restructuring.
3. The use of technology aids in long-term monitoring. Cost-effective technologies have been developed to assess channel change.
4. Sinuosity did not change, whereas the channel has maintained W/D ratios of > 10.

5. Excavation of sediment from sedimentation basin did not prevent sediment imbalance downstream.
6. The San Miguel River does not depend on precipitation as the main water source.
7. Brook Trout biomass doubled since the start of restoration.

In this case study geomorphological methods were used to assess effectiveness of remediation efforts. By utilizing understanding of the hydrogeological, anthropological and ecological aspects of the river, the town has used dynamic management and monitoring to turn an unbalanced and damaged river with a high sediment load into a more controlled river system that protects the town from flooding and debris flows. Continual yearly monitoring allows the town to maintain the channel within the project design goals, though erosion does alter the channel bed structure. Although all projects differ, this dynamic monitoring and restoration plan provides a basis for future projects. Suggested research for the future includes more thorough examinations of restoration efforts in other locations in addition to a return to the Telluride area in a decade to assess further long-term effects. Given the limited sample sizes in this study, a more thorough study would allow for complete characterization of effects of restoration. The advancements in technology allow for a combination of techniques, such as using an Acoustic Doppler Profiler (ADP) to determine flow levels and sediment transport in larger rivers, a UAV to capture surface changes over time, aerial LiDAR to help map surface changes, and resistivity instruments to determine bank stability. The combination of technology and improved knowledge of restoration effects can lead to improved restoration efforts and much more cost-effective procedures going forward.

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Google Earth V 6.2.2.6613. (June 27, 2014). Telluride, Colorado, USA. 37° 56’ 06.73”N, 107° 48’ 35.66”W, Eye alt 8984 feet.

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APPENDIX A

CHANNEL BED CROSS-SECTIONS

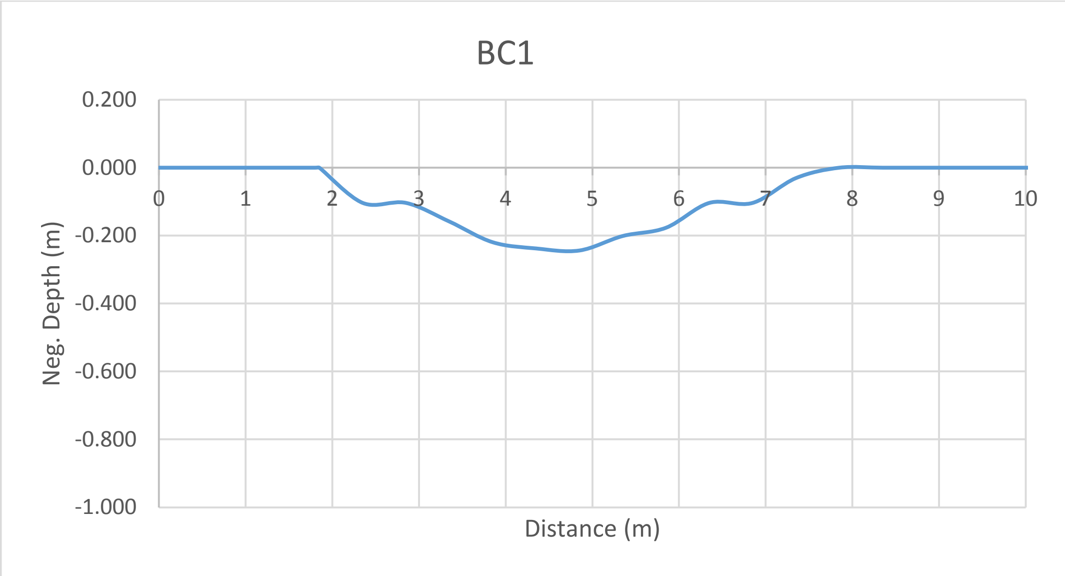

Figure A1: Channel bed geometry at waypoint BC1 (N 37˚56.067, W 107˚48.135), ~ 150 meters upstream from the confluence of Bear Creek and San Miguel River

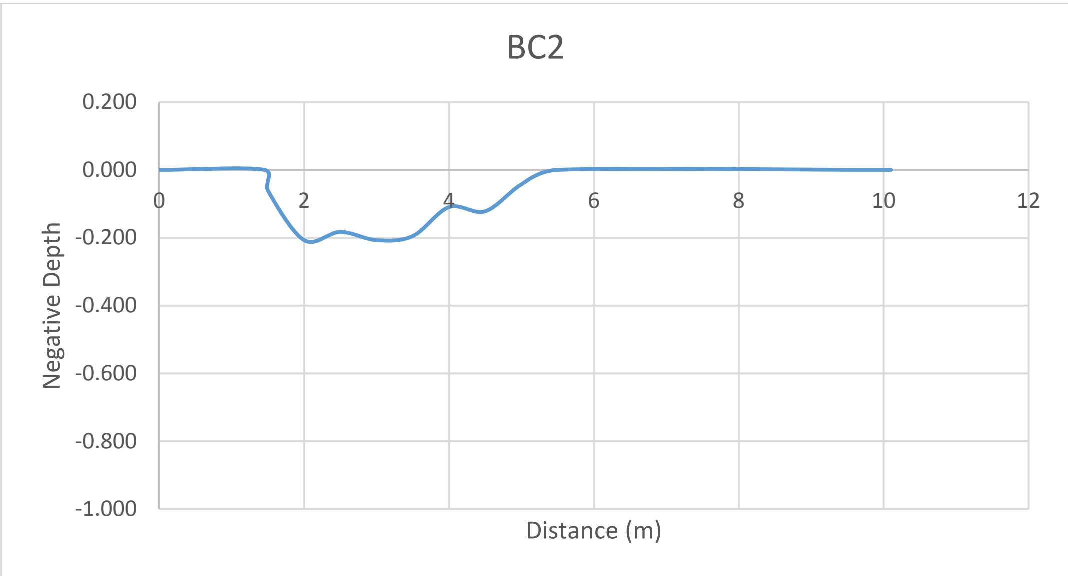

Figure A2: Channel bed geometry at waypoint BC2 (N 37˚56.080, W 107˚48.159), ~ 100 meters upstream from the confluence of Bear Creek and San Miguel River

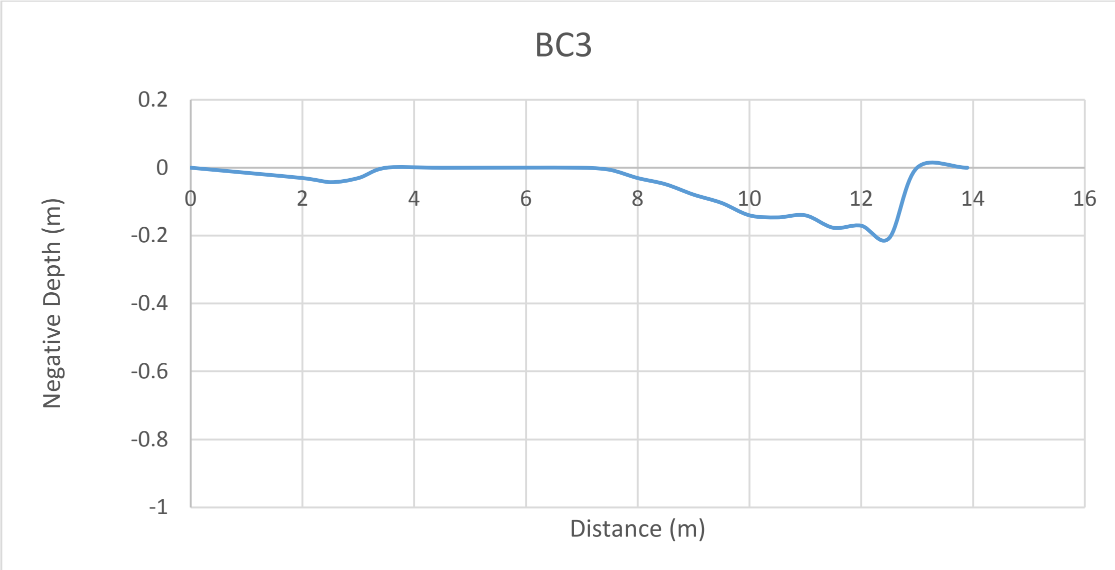

Figure A3: Channel bed geometry at waypoint BC3 (N 37˚56.100, W 107˚48.753), ~ 50 meters upstream from the confluence of Bear Creek and San Miguel River

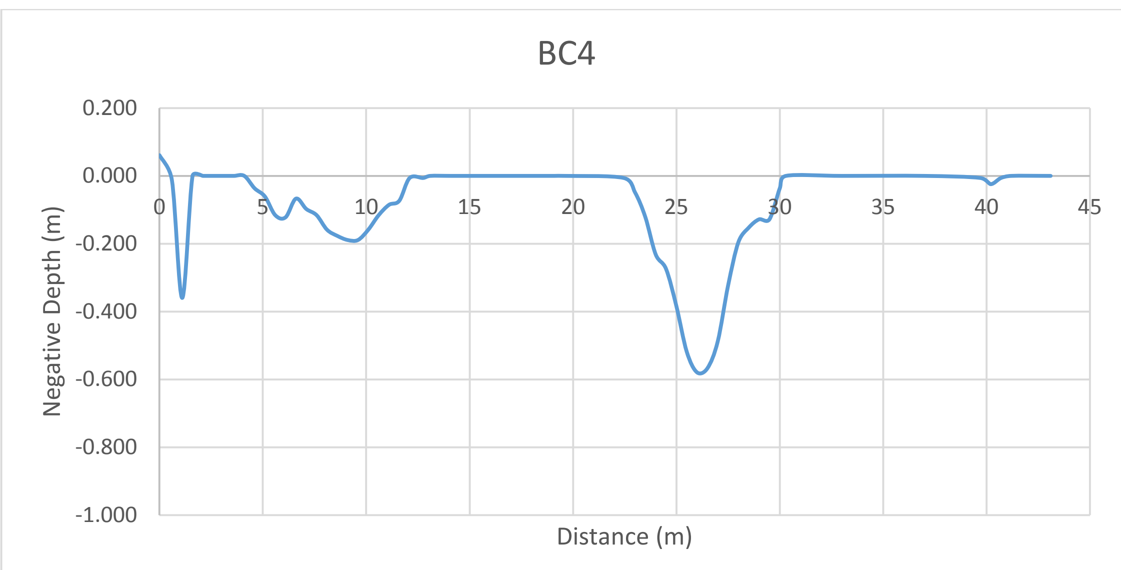

Figure A4: Channel bed geometry at waypoint BC4 (N 37˚56.080, W 107˚48.213), at the confluence of Bear Creek and San Miguel River. This is the location of the Instream Sedimentation Basin.

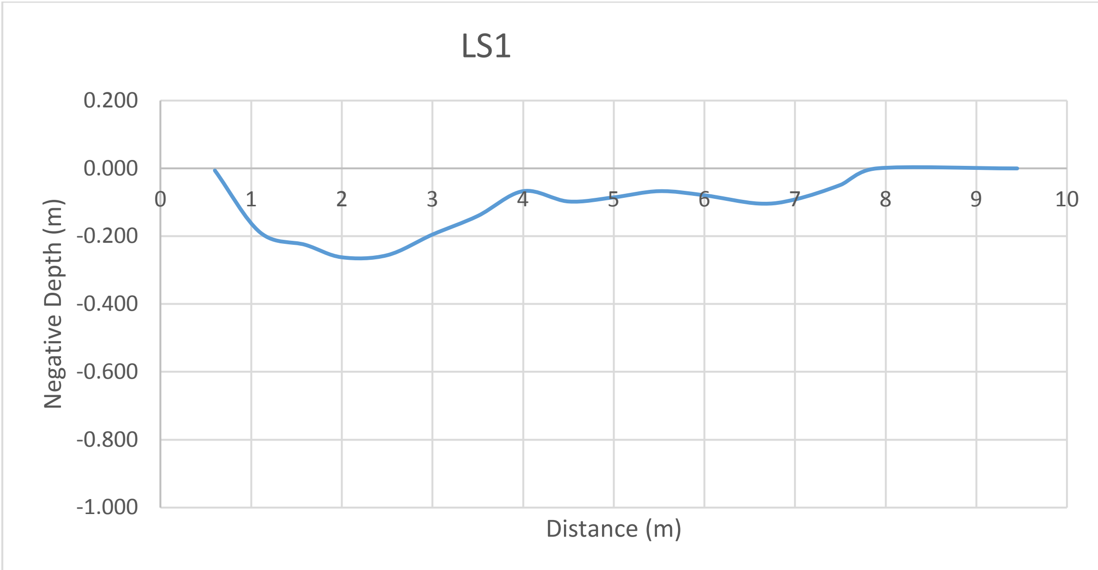

Figure A5: Channel bed geometry at waypoint LS1 (N 37˚56.099, W 107˚48.247), align with Laurel Street

Figure A6: Channel bed geometry at waypoint LS2 (N 37˚56.106, W 107˚48.285), ~ 50 meters downstream of Laurel Street

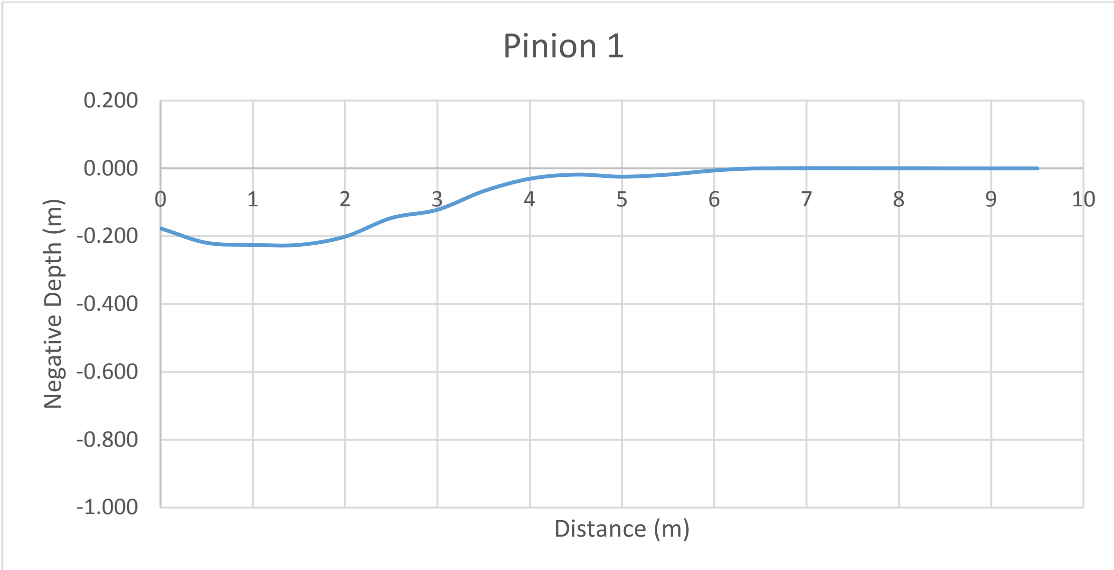

Figure A7: Channel bed geometry at waypoint Pin1 (N 37˚56.129, W 107˚48.306), align with North Pinion Street

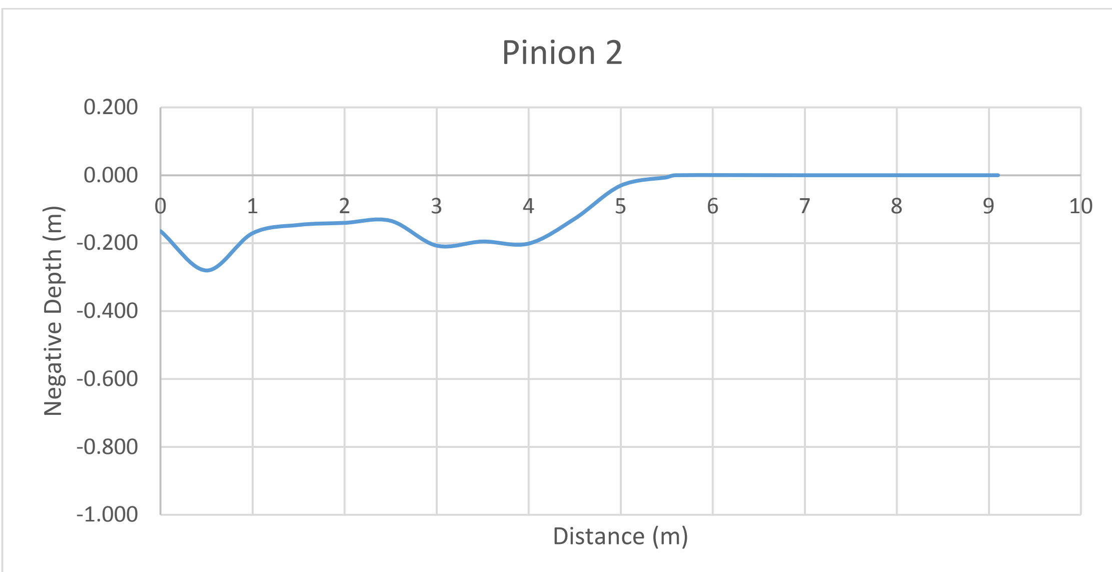

Figure A8: Channel bed geometry at waypoint Pin2 (N 37˚56.140, W 107˚48.336), ~ 50 meters downstream from North Pinion Street

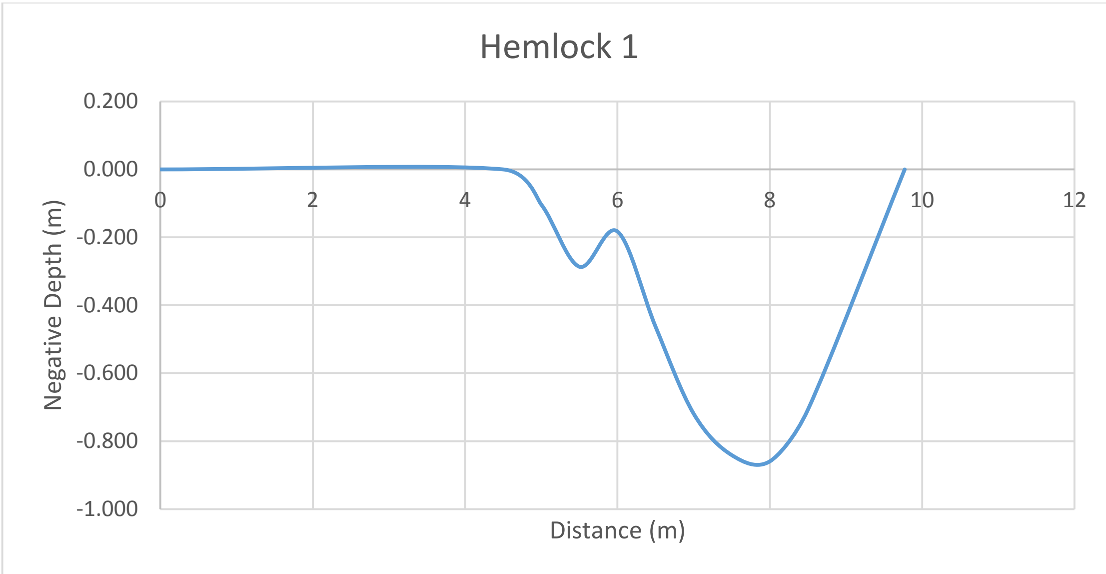

Figure A9: Channel bed geometry at waypoint 013 (N 37˚56.137, W 107˚48.365), align with Hemlock Street

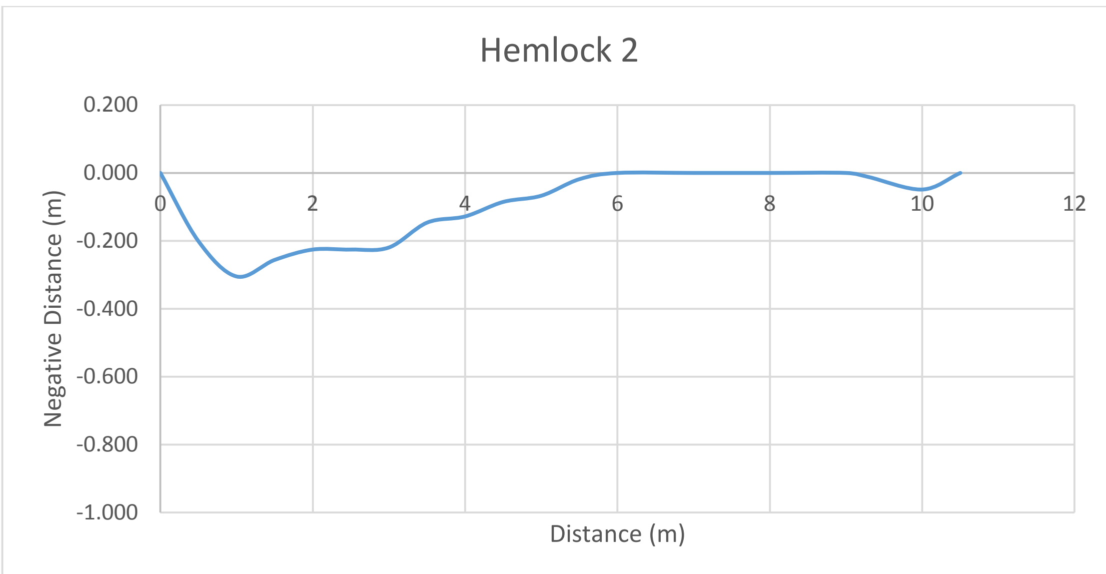

Figure A10: Channel bed geometry at waypoint 014 (N 37˚56.154, W 107˚48.391), 50 meters downstream of Hemlock Street

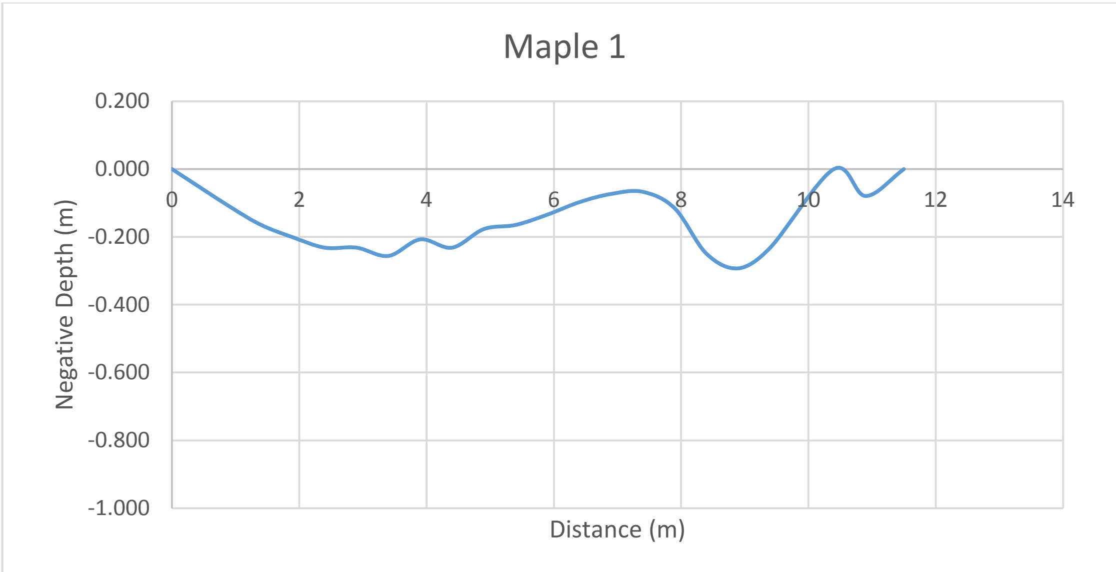

Figure A11: Channel bed geometry at waypoint MAP1 (N 37˚56.155, W 107˚48.412), at Maple Street Bridge

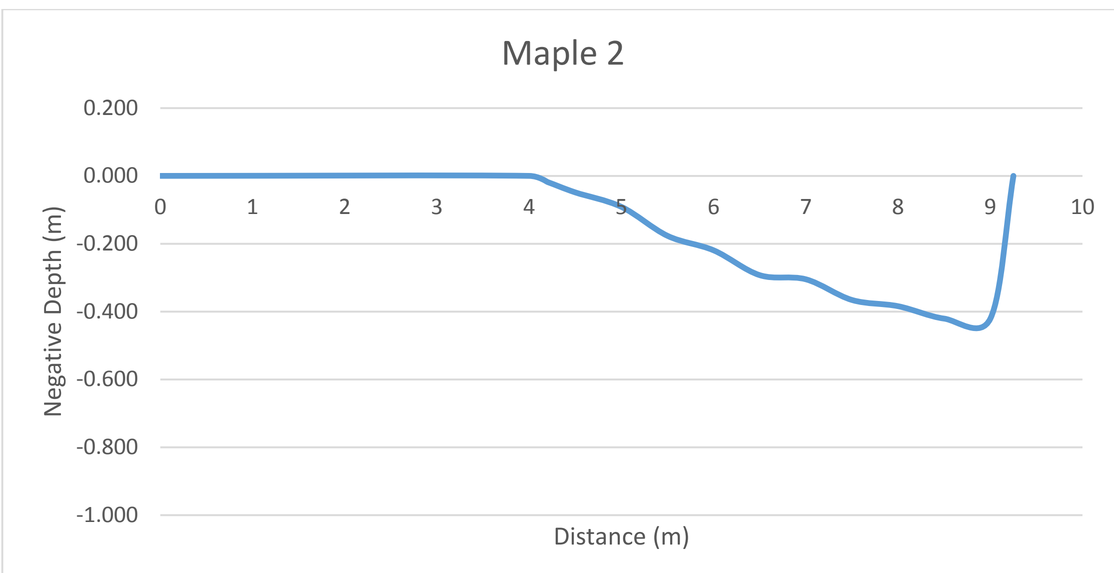

Figure A12: Channel bed geometry at waypoint MP2 (N 37˚56.158, W 107˚48.448), 50 meters downstream of Maple Street Bridge

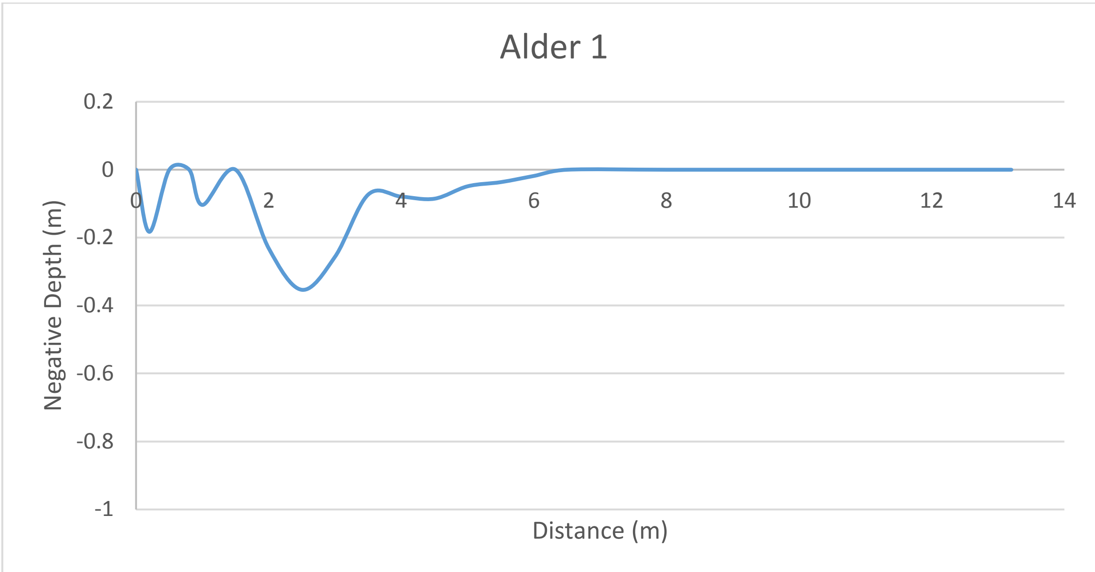

Figure A13: Channel bed geometry at waypoint ALD1 (N 37˚56.154, W 107˚48.478), align with North Alder Street

Figure A14: Channel bed geometry at waypoint ALD2 (N 37˚56.127, W 107˚48.495), 50 meters downstream of North Alder Street, just below Pacific Ave Bridge

Figure A15: Channel bed geometry at waypoint ALD3 (N 37˚56.107, W 107˚48.519), slightly more than 50 meters downstream of Pacific Ave Bridge

Figure A16: Channel bed geometry at waypoint 015 (N 37˚56.100, W 107˚48.558), aligned with South Willow Street

Figure A17: Channel bed geometry at waypoint WIL2 (N 37˚56.102, W 107˚48.588), ~ halfway between South Willow Street and South Spruce Street

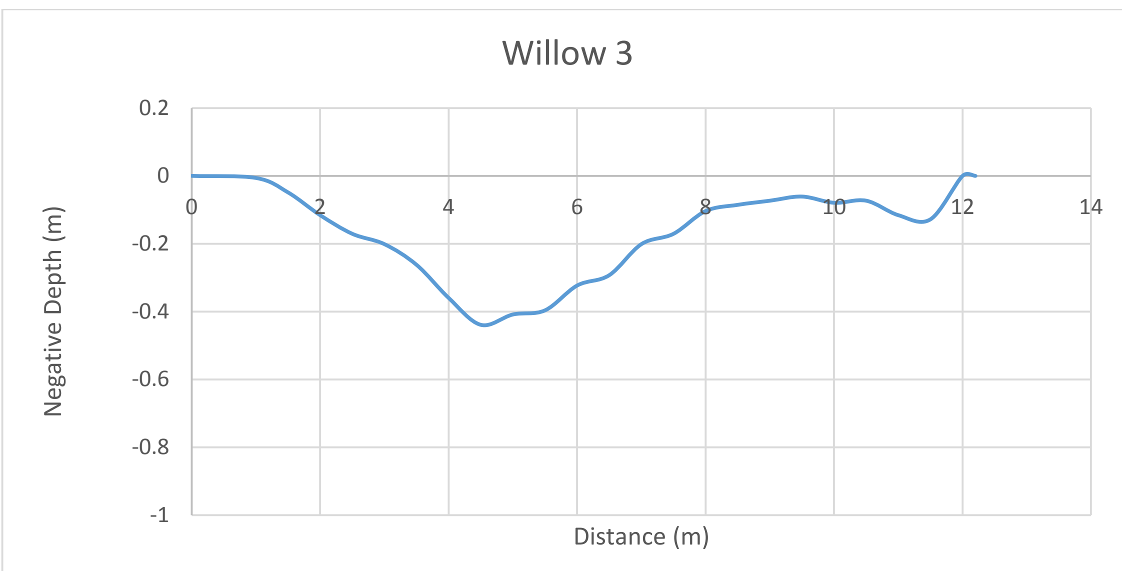

Figure A18: Channel bed geometry at waypoint WIL3 (N 37˚56.096, W 107˚48.614), slightly upstream of Spruce Street.

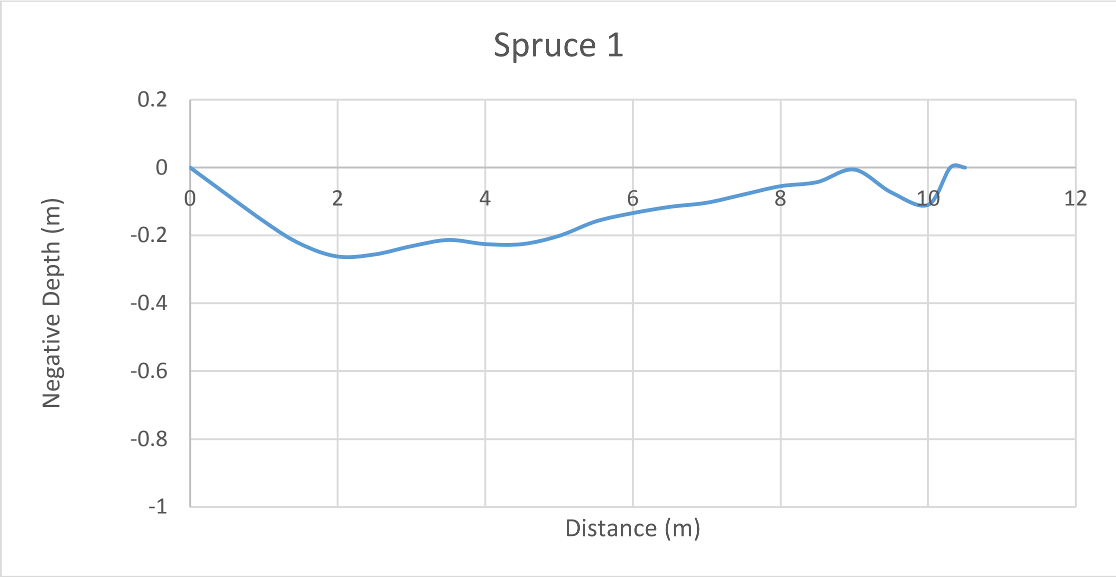

Figure A19: Channel bed geometry at waypoint SP1 (N 37˚56.092, W 107˚48.647), slightly downstream of Spruce Street.

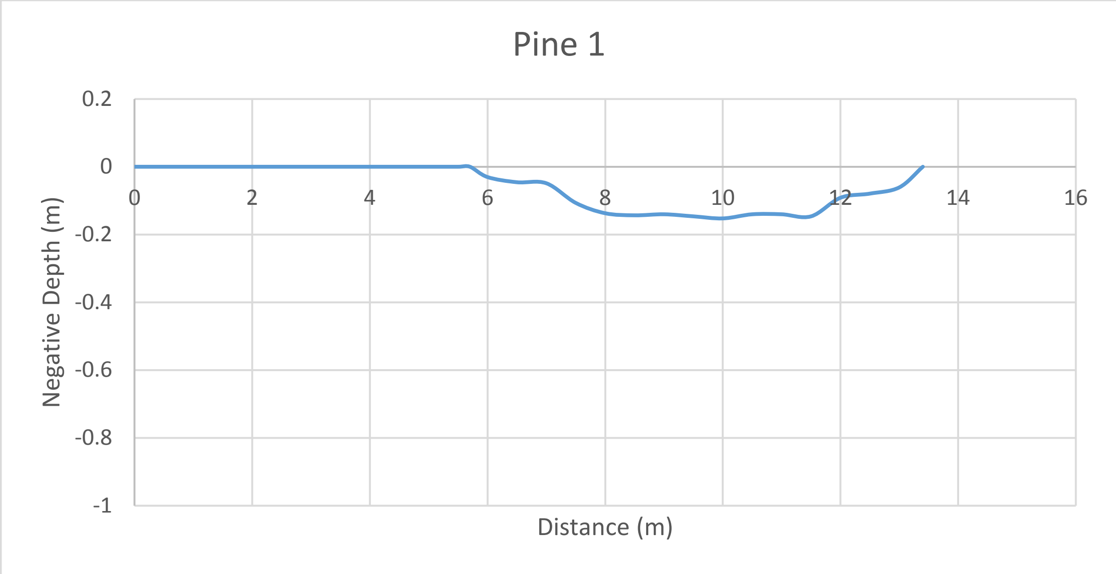

Figure A20: Channel bed geometry at waypoint PINE1 (N 37˚56.085, W 107˚48.696), slightly upstream of Pine Street Bridge.

Figure A21: Channel bed geometry at waypoint PINE2 (N 37˚56.094, W 107˚48.715), ~ 20 meters downstream of Pine Street Bridge.

Figure A22: Channel bed geometry at waypoint PINE3 (N 37˚56.100, W 107˚48.753), ~ 70 meters downstream of Pine Street Bridge.

APPENDIX B

TABLES FROM PUBLIC WORKS DEPARTMENT YEAR 3 MONITORING

REPORT

Table B1: Geomorphic Parameters of Upper San Miguel (Phase I) 2000 – 2004, (From Table 2 of Phase 1 San Miguel River Restoration Project Final (Year 3, 2004) Monitoring Report).

Parameter	Pre-Restoration, 2000		Design Goals[a]		Constructed, 2001		Measured, data collected 2003 & 2004	
Relative to Town Park Bridge	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
LEVEL 1 & 2								
Stream Type	D4	B3, C4	C3	C3	C3	C3	C3	C3
Entrenchment	~1.6	~3, ~9	>2.2	>2.2	>2.2	>2.2	~3.3	~2.5, ~16
Width/Depth Ratio	~45	~30	>12	>12	25	25	25	25
Sinuosity	1.0	0.9	>1.2	0.9	1.09	0.9	1.12	0.92
Slope	0.004	0.004		0.004	0.006	0.004	0.006	0.004
LEVEL 3								
Stream size (order)	S-5(3), S-6(3)	S-5(3)	S-4(3)	S-4(3)	S-4(3)	S-4(3), S-5(3)	S-4(3)	S-4(3), S-5(3)
Flow regime	P1	P1	P1	P1	P1	P1	P1	P1
Depositional features	B5	B2	B1	B1	B1	B1	B2	B2
Meander Patterns	M3	M3	M1	M3	M1	M3	M1	M3
Debris/blockages	D1, D10	D1, D10	D3, D10	D3, D10	D3, D10	D3, D10	D3, D10	D3, D7, D10
Channel stability (Pfankuch)	NA	NA	NA	NA	NA	NA	NA	NA

[a] The Design Goals for these parameters adopted for this report are based on the Construction Drawings and various other design documents. The design consultants did not specify them.

[a] Explanation of nomenclature.

S4(3)—Bankfull width 4.6-9 meters (15-30 feet). Third-order stream. S5(3)—Bankfull width 9-15 meters (30-50 feet). Third-order stream. S6(3)—Bankfull width 15-22.8 meters (50-75 feet). Third-order stream.

P1—Perennial stream channel. Surface water persists year long. Seasonal variation in stream flow dominated primarily by snowmelt runoff.

B1—Point bars B2—Point bars with few mid-channel bars B5—Diagonal bars

M1—Regular meander M3—Irregular meander

D3—Moderate. Increasing frequency of small to medium sized material, such as large limbs, branches, and small logs that when accumulated effect 20% or less of the active channel cross-sectional area.

D7—Beaver Dams-Few. An infrequent number of dams spaced such that normal stream flow and expected channel conditions exist in the reaches between dams.

D10—Human Influences. Structures, facilities, or materials related to land sues or development located within the floodprone area, such as diversions or low-head dams, controlled by-pass channels, velocity control structures, and various transportation encroachments that have an influence on the existing flow regime, such that significant channel adjustments occur.

Table B2: Creation and Survival Rate of Wetlands 2001 – 2004 (From Table 11 of Phase 1 San Miguel River Restoration Project Final (Year 3, 2004) Monitoring Report).

TABLE 11. Comparing designed, constructed, and functioning wetland acreage created/improved for Phase 1 San Miguel River Restoration

ID	Description	Station	Map #	Habitat Type		Design Acreage		Constructed Acreage		Final Surviving Acreage 2004	
				Design	Actual	ft^2	acres	ft^2	acres	ft^2	acres
HA1	Upper San Miguel South Side Riparian Area							3,000.0	0.07	3,000.0	0.07
HA2	Bear Creek Riparian Area	65+5-67	20	Created	Created	3,058.3	0.07	4,608.0	0.11	4,610.0	0.11
HA3	ISB SW Wetland #2	66-66+5			Created			1,400.0	0.03		
HA4	ISB SW Wetland #1	65+5-66	17.5	Created	Created	630.0	0.01	583.3	0.01	580.0	0.01
HA5	Upper San Miguel North Side Riparian Area	67+4-68+2		Created	Created			2,009.3	0.05	2,000.0	0.05
HA6	Sediment Pond Wetland Northeast	67-69+2	22	Created	Created	4,453.3	0.10	4,800.0	0.11	4,800.0	0.11
HA7	Sediment Pond Northeast Wetland Bench	67-67+2	portion of 26	Created	Created	1,845.0	0.04	1,841.8	0.04	1,850.0	0.04
HA8	Sediment Pond North Wetland East	64-65+5			Created			700.0	0.02		
HA9	Sediment Pond North Wetland West	65+5-67	portion of 26	Created	Created	1,410.0	0.03	944.0	0.02		
HA10	Upper San Miguel River South Side	64-65+5	17	Created	Created	2,955.0	0.07	2,700.0	0.06	2,700.0	0.06
HA11	Large Wetland Bench S across from Pinon	60-63	16	Created	Created	10,085.0	0.23	6,943.0	0.16	6,940.0	0.16
HA12	Upper SM N Side (across #10) Riparian Area							3,500.0	0.08	3,500.0	0.08
HA13	N Pinon Street Wetland	62+8-64	28	Created	Created	3,565.0	0.08	7,200.0	0.17	7,200.0	0.17
HA14	East Big Bend Riparian Area	61+5-62			Created			1,050.0	0.02	1,050.0	0.02
HA15	West Big Bend Riparian Area	60-61+5			Created			1,170.0	0.03	1,170.0	0.03
HA16	North Hemlock Wetland East	59-60	32	Created	Created	7,750.0	0.18	1,826.0	0.04	1,825.0	0.04
HA17	N Hemlock Riparian Area	57+5-59			Created			1,500.0	0.03	1,500.0	0.03
HA18	Town Park Parking Lot South Side	56-58	14	Created	Created	8,741.7	0.20	7,539.8	0.17	3,770.0	0.09
HA19	Wetland Berm between SMR and Fishing Pond	52-55	13	Created	Created			4,500.0	0.10	7,500.0	0.17
HA20	Muscatel Flats Scrape Down Wetland	50	35.5	Created	Created	413.3	0.01	750.0	0.02		
HA22,23	Willow Street Wetland-Dog Beach & Northwest	46+5-50	36.5, 37.5, 38	Created	Created	4,825.0	0.11	17,357.0	0.40	17,350.0	0.40
HS24	Town Park Wetland Northeast	48	7	Created	Created	2,665.0	0.06	2,665.0	0.06		
HA25	Town Park Wetland Middle	49	8	Created	Created	14,496.7	0.33	14,496.7	0.33	20,000.0	0.46
HA26	Town Park Wetland South	50	10	Created	Created	3,652.5	0.08	3,652.5	0.08	3,650.0	0.08
HA27,28,29	Beaver Dam Breach Repair	41-47+3	5,9	Created	Created	6,136.7	0.14	20,564.7	0.47	16,500.0	0.38
HA30	Pine Street Northeast Riparian Area	57+5-59			Created			1,500.0	0.03		
HA31	Pine Street Pond Wetland	37-39	2	Created	Created	9,950.0	0.23	11,797.0	0.27	11,800.0	0.27
HA35	Sediment Pond SE Wetland Point Bar	67+4-68+2	20.5	Created	Created	816.7	0.02	1,050.0	0.02		
	SUBTOTAL CREATED WETLAND ACREAGE					87,449.38	2.01	117,918.8	2.71	106,465.0	2.44
	SUBTOTAL CREATED RIPARIAN ACREAGE							18,337.30	0.42	16,830.00	0.39
HA6, --	Upper SMR North Spoil Area	67+4-68+2	23, 25	Improved	Improved	11,565.0	0.27	2,915.0	0.07	2,900.0	0.07
HA19	Wetland Berm between SMR and Fishing Pond	52-55	13	Improved	Improved	5,073.3	0.12	4,500.0	0.10	4,500.0	0.10
HA21	Willow Street Wetland Northeast	46-51	35, 36, 37	Improved	Improved	21,106.7	0.48	21,106.7	0.48	21,100.0	0.48
HA28	Pine Street Northeast	40	42	Improved	Improved	331.7	0.01	437.5	0.01	450.0	0.01
HA32,33	Drew Hobgood	42+5-46+5	39, 41	Improved	Improved	24,098.4	0.55	24,098.4	0.55	24,100.0	0.55
HA34	Bear Creek Enhancement East Bank of Channel	65+5-67	19	Improved	Improved	5,653.3	0.13	5,653.3	0.13	5,650.0	0.13
--	Wetland behind New Post Office	52	34	Improved	Improved	2,760.0	0.06	225.0	0.01	225.0	0.01
	SUBTOTAL IMPROVED WETLAND ACREAGE					70,588.4	1.6	48,782.6	1.1	48,775.0	1.12
	SUBTOTAL IMPROVED RIPARIAN ACREAGE							10,153.3	0.2	10,150.0	0.2
TOTAL WETLAND ACREAGES							**3.6**		**3.8**		**3.6**
ADDITIONAL RIPARIAN ACREAGES									**0.7**		**0.6**

Table B3: Willow growth and survival along the Phase 1 San Miguel River Restoration (Modified from Table 10 of Phase 1 San Miguel River Restoration Project Final (Year 3, 2004) Monitoring Report).

	Key				
	Wetland and Riparian Fringe,	WRF			
	Instream Feature,	IS			
	Undercut Bank,	UB			
Tag #	**Description**	**Station**	**Date**	**One Year's Growth, inches**	**Survival Rate, percent**
WS1	N side San Miguel **IS1** entering ISB	67+50	10/12/2001	9-24	95
			7/29/2002	2-6	95
			10/6/2003	2-6	95
			9/27/2004	2-8	95
WS2	N side ISB main **IS1** entering San Miguel	65+50	10/12/2001	1-5	90
			7/29/2002	12-18	75
			10/6/2003	5-10	85
			9/27/2004	5-9	85
WS3	S side ISB **IS1** entering San Miguel	65+50	10/12/2001	2-13	95
			7/29/2002	8-16	40
			10/6/2003	2-16	75
			9/27/2004	2-7	80
WS4	Bear Creek upstream **WRF** by	67+00	10/12/2001	3-114	85

	upper photo stake				
			7/29/2002	12-26	95
			10/6/2003	10-20	85
			9/27/2004	8-12	85
WS5	S side UB, first **IS** downstream of ISB	63+70	10/12/2001	18	85
			7/29/2002	12-30	95
			10/6/2003	9-16	90
			9/27/2004	6-14	90
WS6	S side CW, **WRF** at "shade sitting rocks"	63+40	10/12/2001	2-4	85
			7/29/2002	0-9	80
			10/6/2003	2-8	80
			9/27/2004	2-5	75
WS7	N side bank stabilization across from Pinon St	62+50	10/12/2001	12-24	95
			7/29/2002	10-24	95
			10/6/2003	12-20	95
			9/27/2004	10-16	90
WS8	N side **IS** at UB at "big bend" Pinon St	61+00	10/12/2001	6	90
			7/29/2002	6-20	90
			10/6/2003	10-17	80
			9/27/200	10-14	80

			4		
WS9	N side bank stabilization at CW downstream IS8	59+80	10/12/2001	0	25
			7/29/2002	6-28	90
			10/6/2003	12-24	85
			9/27/2004	10-17	75
WS10	S side **IS** at UB, Park Office	59+00	10/12/2001	4-8	60
			7/29/2002	6-24	40
			10/6/2003	10-12	50
			9/27/2004	9-14	50
WS11	N side Maple St revegetation area at Bus Turn-around	54+50	10/12/2001	5-20	95
			7/29/2002	16	95
			10/6/2003	10-16	95
			9/27/2004	10-14	90
WS12	S side **WRF** at berm-Fishing Pond/stream	54+80	10/12/2001	0	25
			7/29/2002	3-20	60
			10/6/2003	4-16	60
			9/27/2004	4-16	60
WS13	S side berm **WRF** "	54+20	10/12/2001	0-18	75
			7/29/2002	4-18	25
			10/6/200	6-18	45

			3		
			9/27/2004	6-12	45
WS14	SE side bank stabilization downstream Pac. St. bridge	50+00	10/12/2001	0-4	100
			7/29/2002	10-22	50
			10/6/2003	12-20	75
			9/27/2004	12-16	75
WS15	NW side bank stabilization/**WRF** up str. Pac. St. bridge	51+50	10/12/2001	18	100
			7/29/2002	18-24	100
			10/6/2003	10-16	100
			9/27/2004	9-15	95
WS16	SE side bank stabilization upstream large cosmetic rock	49+20	10/12/2001	0-2	85
			7/29/2002	10-24	50
			10/6/2003	2-10	80
			9/27/2004	2-8	75
WS17	NW side **WRF** transplant Willow St rock	49+50	10/12/2001	24-30	90
			7/29/2002	9-21	95
			10/6/2003	12-16	95
			9/27/2004	10-14	90
WS18	S side **IS** willow	47+80	10/12/20	11	100

	stake, UB across Willow Street		01		
			7/29/2002	0	0
			10/6/2003	0	0
			9/27/2004	0	0
WS19	N side **IS** at UB/fish platform at Willow Street trail	46+00	10/12/2001	9-24	85
			7/29/2002	1-12	75
			10/6/2003	8-20	75
			9/27/2004	6-12	70
WS20	N side willow stake in bank stabilization at drop structure	45+00	10/12/2001	4-9	100
			7/29/2002	2-12	80
			10/6/2003	6-16	95
			9/27/2004	6-14	90
WS21	S side **WRF** at Beaver Dam Breach repair	42+50	10/12/2001	0-1	85
			7/29/2002	0	0
			10/6/2003	0	0
			9/27/2004	0	0
WS22	S side transplant **WRF** upstream WS 21	43+30	10/12/2001	6-24	85
			7/29/2002	8-22	80
			10/6/200	4-12	85

			3		
			9/27/2004	4-8	85
WS23	S side **IS** at drop structure across WS 20	45+00	10/12/2001	1-24	100
			7/29/2002	4-9	85
			10/6/2003	6-12	85
			9/27/2004	5-10	80
WS24	WRF willow stake N side at CW below pool	44+40	10/12/2001	2-33	95
			7/29/2002	3-8	95
			10/6/2003	4-8	95
			9/27/2004	2-4	90
WS25	Willow stake at bank stabilization N side Pine St	40+00	10/12/2001	5-15	90
			7/29/2002	2-20	90
			10/6/2003	2-12	85
			9/27/2004	2-6	80
WS26	Pine St Pond **WRF** willow transplant at drop structure	38+80	10/12/2001	12-30	100
			7/29/2002	8-14	95
			10/6/2003	6-10	95
			9/27/2004	4-6	90

Table B4: Structural Integrity of Instream Features along Phase 1 San Miguel River Restoration Reach, 2001-2004. UB: Undercut Bank, Concave Bend Pool: CBP, Drop Structure: DS, Counter Weir: CW, Vortex Rock Weir: VW. (From Table 13 of Phase 1 San Miguel River Restoration Project Final (Year 3, 2004) Monitoring Report)

ID	Location	Station	Date	Bankfull Depth, ft	Drop Height, ft	Erosion / Deposition	Comments
IS1	San Miguel DS into ISB	67+50	10/8/2001	3.0	1.5	Both	Stable, upstream deposition area intact, downstream. scour pool stable and maintaining integrity until Sed Pond clean out next spring 2002.
			7/18/2002	2.1	1.9	Both	Water level considerably lower than last spring. Depth of Deposition pool = 3.4'. "Deposition pool" is an experiment to see if buffering scour pool can maintain HSI.
			9/15/2003	1.6	1.9	Both	No pool is maintained during depositional spring flows. Recreation no recommended to secure feature integrity.
			10/21/2004	1.9	1.9	Both	One boulder in DS appears to be shifting forward.
IS2	DS at Bear Creek confluence	66+50	10/8/2001	1.2	4.0	Both	DS stable, upstream deposition intact, downstream scour pool stable until Sed. Basin clean out spring 2002.
			7/18/2002	2.0	3.1	Both	Drop gradient/height measured at center rock TW for consistency.
			9/15/2003	--	--	Both	Scour around west edge. Deposition at drop and downstream.
			10/21/2004	2.0	4.0	Both	The original structure failed with spring flows and was rebuilt to a different design in July 2004.
IS3	Instream sedimentation basin (ISB)	65-67+00	10/8/2001	1-2.5	na	Deposition	Volume of material deposited since construction 12/00 calculated upon removal in spring 2002.
			7/18/2002	2.0-3.0	na	Deposition	720 CY material excavated from basin.
			9/15/2003	2.0-3.0	na	Deposition	750 CY material excavated from basin.
			10/21/2004	2.0-3.0	na	Deposition	~1,000 CY material excavated from basin, removed to lower island, and removed to reconstruct IS2. Excavation best done immediately following spring runoff in late June/early July.
IS4	DS below ISB	65+50	10/8/2001	1.8-3.5	1.0	Both	Gaps between boulders when placed creating problematic deposition in downstream pool. Small 0.5'-1.0' rocks filling gaps between boulders, presently stable, but could blow and lower ISB level. DS stable.
			7/18/2002	2.4	1.0	Both	Deposition pool depth = 4.53'. Scour pool sloping into deposition pool, not as armoured or separated as drops upstream. Toe of slope is 3:1 and stable.
			9/15/2003	2.7	1.0	Stable	
			10/21/2004	2.2	1.0	Stable	

IS5	Pool above CW at UB	63+50	10/8/2001	4.0	na	Both	stable
			7/18/2002	3.6	na	Both	River has deposited and shaped pools into one stable, efficient TW along meander profile. Self scouring exactly at the UB location.
			9/15/2003	--	na	--	
			10/21/2004	0.5	na	Deposition	UB has filled completely.
IS6	CW below UB	63+50	10/8/2001	1.5	0.7	Erosion	Potential for blow out during spring runoff; too much gradient scouring below CW; needs larger boulders to be stable.
			7/18/2002	1.5	0.6	Erosion	Problem area. CW has become DS. Post-deposition Year 2 feature. Drop height measured at center of TW. Scour pool formed at center. 2.0-ft deep scour cut along feature's south side interface w/bank stabilization.
			9/15/2003	1.5	0.6	Stable	CW has remained a DS
			10/21/2004	1.1	0.5	Deposition	CS has remained a DS
IS7	Pool above CW above UB	61+00	10/8/2001	1.5	na	Deposition	point bar
			7/18/2002	2.6	na	Deposition (point bar)	Stable feature w/root wad/log on inside channel. Point bar deposit allows erosion on the inside of meander. TW velocities flushing sufficiently to maintain feature.
			9/15/2003	--	na	--	
			10/21/2004	2.1	na	Deposition	Point bar formation on opposite bank.
IS8	Above CW below UB	61+00	10/8/2001	3.1	0.7	Erosion?	Potential for blow out during spring runoff, too much gradient scouring below CW, needs larger boulders to be stable.
			7/18/2002	1.6	0.3	Erosion?	CW has turned into DS. Boulders 2x3' too small. May blow out with high flows.
			9/15/2003	1.5	0.5	Stable	Point bar formation has appeared to widen the bankfull width
			10/21/2004	1.3	0.5	Stable	
IS9	Pool above CW at UB	59+00	10/8/2001	3.9	na	Stable	Erosion stable at UB, point bar inside
			7/18/2002	3.2	na	Stable (point bar)	Best UB in project. In 2002, CW downstream rebuilt and root wad placed over UB for cover. Erosion on inside of meander keeps UB stable.
			9/15/2003	1.3	na	Deposition	
			10/21/2004	1.3	na	Stable	
IS10	CW below pool	59+00	10/8/2001	2.0	1.0	Erosion	Potential to blow during spring runoff, excessive scour below CW, needs larger boulders to be stable.
			7/18/2002	2.2	0.5	--	Rebuilt 2002 w/larger boulders under warranty 4/02. Gradient drop = 0.45 feet
			9/15/2003	1.8	0.5	Deposition	CW failed but is dissipating energy. The bankfull width of channel has widened slightly, perhaps in response. to channel deposition.
			10/21/2004	1.2	0.5	Deposition	CW continues to function.
IS11	Pool above CW	57+00	10/8/2001	1.9	na	Stable	
			7/18/2002	--	na	--	
			9/15/2003	--	na	--	

			10/21/2004	2.0	na	Stable	Deposition occurring along point bar on opposition bank.
IS12	CW below pool	56+50	10/8/2001	1.5	0.7	Erosion	DS created by erosion below CW, gradient problem, needs replacement with larger boulders or will fail.
			7/18/2002	1.1	0.4	Deposition	
			9/15/2003	1.4	0.5	Stable	
			10/21/2004	1.4	0.5	Stable	
IS13	Pool under foot bridge	55+00	10/8/2001	2.5	na	Deposition	Lots of deposition.
			7/18/2002	2.5	na	Deposition	
			9/15/2003	1.3	na	Deposition	
			10/21/2004	2.0	na	Erosion	
IS14	CW downstream of new bridges	55+00	10/8/2001	--	0.5	Stable	
			7/18/2002	0.9	0.4	Stable	
			9/15/2003	0.9	0.4	Stable	
			10/21/2004	0.9	0.4	Stable	
IS15	Alder St Pool at wetland outlet	52+50	10/16/2001	3.0	na	Erosion	Unintended UB caused by erosion. UB = 2.3' upstream. UB = 2' downstream
			7/18/2002	2.7	na	Deposition	Well-built with good boulders. Scour at TW made channel of this 90 degree dog leg meander is stable after several years of higher flows. Much smaller pool than in 2001.
			9/15/2003	2.1	na	Deposition	Pool is maintaining through erosion. Point bar forming opposite bank.
			10/21/2004	2.0	na	Erosion	Pool is maintaining through erosion. Point bar forming opposite bank.
IS16	Vortex weir downstream of Alder Outlet	52+00	10/16/2001	--	na	--	
			7/18/2002	--	na	--	Point bar forming and beginning to encroach.
			9/15/2003	0.5	na	Deposition	V-weir covered by point bar deposition.
			10/21/2004	0.9	na	Deposition	1/2 v-weir uncovered and functioning.
IS17	Pool upstream of Pacific Ped. Bridge	51+50	10/16/2001	4.0	na	--	
			7/18/2002	3.9	na	--	v-wier/TW right is stable and functioning as designed. Stable pool feature and VW.
			9/15/2003	1.6	na	Deposition	
			10/21/2004	1.3	na	Deposition	
IS18	Pool below Pacific St drop structure	50+00	10/16/2001	3.1	--	Erosion	Upstream of drop =2.5' erosion, slump erosion = 5.5 - 6.
			7/18/2002	2.7	0.38	Erosion	deposition in pool exacerbated by failed west half of drop structure. scour depth upstream = 1.97'
			9/15/2003	1.1	0.50	Deposition	Rebuilt west half.
			10/21/2004	4.0	0.50	Erosion	East side is failing. Eroding around eastern boulders

IS19	UB south side Willow St Wetlands	48+00	10/16/2001	2.5-3.5	na	Stable	
			7/18/2002	2.5	na	Stable	
			9/15/2003	2.0	na	Stable	
			10/21/2004	2.1	na	Stable	
IS20	CW below UB near Willow	47+00	10/16/2001	2.1	--	Erosion	
			7/18/2002	0.8	0.5	Deposition	
			9/15/2003	1.6	0.5	Erosion	
			10/21/2004	1.2	0.5	Deposition	
IS21	UB/CBP at Willow N side	46+00	10/16/2001	4.2	na	Erosion	
			7/18/2002	4.25	na	Stable	Rock is stable. Log cover is poorly constructed and washing away slowly.
			9/15/2003	5.1	na	Erosion	Log cover extremely poor. River Trail failing. Reconstruction needed.
			10/21/2004	4.7	na	Stable	Rebuilt in response to to bank failure. UB now of rock
IS22	DS between Drew Hobgood and beaver dam	45+00	10/16/2001	2.7-3.2	--	Erosion	2.7' upstream erosion, loose rocks. North side river stable, 1.5' rock on south side shifted downstream creating 2'-gap between rock and bank, gaps allow excess deposition in pools.
			7/18/2002	3.0	0.5	Erosion	2.16' scour upstream of DS. Downstream CS is excellent. DS functioning and stable other than scour. Needs key wedge rock and backfill.
			9/15/2003	3.1	0.5	Stable	
			10/21/2004	2.7	0.5	Stable	
IS23	VW at "Rudy Deck"	43+00	10/16/2001	3.5	na	Stable	
			7/18/2002	2.8	na	Stable	V-weir stable. Downstream CW stable also. Deposition appears to be stabilized. Beaver activity downstream last 2 high flow runoff events caused standing water that increased potential for deposition.
			9/15/2003	2	na	Stable	
			10/21/2004	1.5	na	Stable	
IS24	Pool upstream of Drew Hobgood Outlet	41+00	10/16/2001	3.9	na	Stable	
			7/18/2002	2.5	na	Stable	Beaver dam under Pine Street Bridge has maintained higher flow grade over weir.
			9/15/2003	2.7	na	Deposition	Pool is filling but water depth is great in response to back up behind dam.
			10/21/2004	4.6	na	Eroded/stable	Pool has scoured out nicely after Beaver Dam removal
*	Large Beaver Pond/Dam height compared with SM River	44+50	10/16/2001	na	na	Stable	Survey Data #1: CW = 8.07'. Waters edge = 7.83'. Beaver pond = 3.77'. (Difference = 4.3')
			7/18/2002	na	na	Stable	No change on restored bank integrity. 2001 elevations should be same.

			9/15/2003	na	na	Stable	
			10/21/2004	na	na	Stable	
*	Large Beaver Pond/Dam height compared with SM River	43+50	10/16/2001	na	na	Stable	Survey data #2: Drop structure = 8.6'. Waters edge = 8.55'. Beaver pond = 3.8'. (Difference = 4.8'). Correlate to Mahoney St. staff gauge = 0.58
			7/18/2002	na	na	Stable	No change on restored bank integrity. 2001 elevations should be same.
			9/15/2003	na	na	Stable	
			10/21/2004	na	na	Stable	

na = category not applicable

-- = missing data

APPENDIX C

ADDITIONAL FIGURES

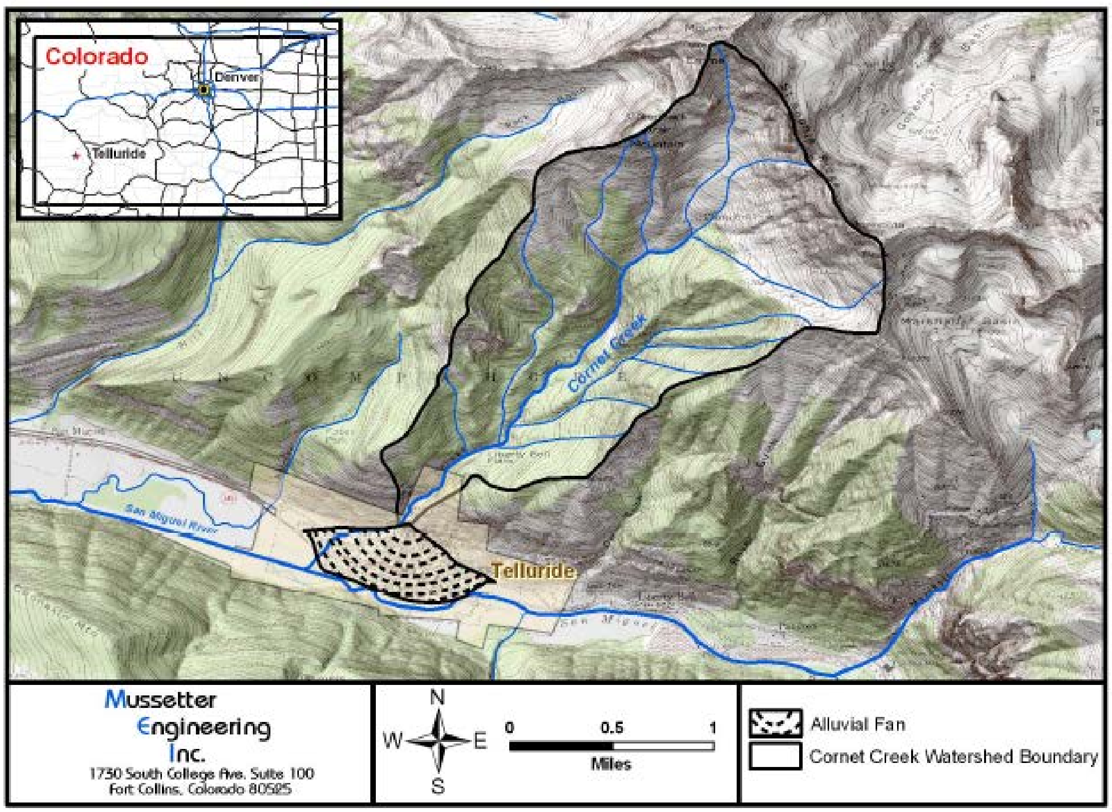

Figure C1: Cornet Creek Drainage area and location (From Cornet Creek Drainage Maintenance and Flood Mitigation Study 2008, by Mussetter Engineering, Fort Collins, Colorado).

APPENDIX D

DISCHARGE (RAW) DATA FROM MAHONEY STREET STREAM GAGE (CMS)

4 week average	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1--4		0.33	0.27	0.27	0.28	0.31	0.41	0.33	0.51	0.51	0.41
5--8		0.24	0.23	0.30	0.28	0.30	0.36	0.33	0.54	0.42	0.38
9--12		0.32	0.23	0.39	0.29	0.44	0.40	0.32	0.52	0.34	0.30
13-16		0.40	0.39	0.47	0.57	0.61	0.52	0.89	0.99	0.71	0.85
17-20		1.63	1.16	1.05	1.66	1.46	0.58	1.39	2.52	2.02	1.31
21-24			2.78	1.67	1.94	1.10	1.54				2.15
25-28		1.71	1.68		1.31	2.22	2.18		2.13	4.27	0.84
29-32		1.30	0.50	1.85	0.78	1.85	1.14		1.14	2.50	0.54
33-36		0.66	0.48	1.67	0.54	1.26	0.82		0.98	1.58	0.41
37-40		0.40	0.37	0.74	0.77	1.12	0.64	1.57	0.91	0.90	0.95
41-44	0.35	0.40	0.31	0.48	0.72	0.92	0.71	1.00	0.87	0.84	0.62
45-48	0.36	0.31	0.25	0.33	0.47	0.60	0.63	0.66	0.49	0.55	0.40
49-52	0.35			0.29	0.34	0.48	0.38	0.51	0.48	0.40	0.34

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	22yrAvg	stdev
0.31	0.38	0.30	0.31	0.28	0.34	0.29	0.25	0.23	0.24	0.23	0.24	0.32	0.08
0.29	0.36	0.31	0.30	0.31	0.32	0.29	0.26	0.23	0.25	0.23	0.23	0.31	0.07
0.32	0.54	0.32	0.33	0.52	0.35	0.35	0.26	0.26	0.33	0.25	0.25	0.35	0.09
0.54	0.85	0.73	0.59	0.68	0.88	0.52	0.74	0.41	0.80	0.30	0.59	0.64	0.19
1.58	0.85	0.81		1.82		1.21	1.01	0.84		0.86	0.67	1.29	0.49
3.04												2.03	0.63
1.93	2.64						0.98		0.88	0.73		1.81	0.92
0.91	1.73	1.74	0.98			1.13			0.56	1.82	1.06	1.27	0.55
1.21	0.61	0.73	0.65		0.79	0.49	0.69	0.55	0.52	0.70		0.81	0.36
1.12	0.99	0.71	0.76	1.21	0.65	0.51	0.47	0.57	0.43	1.37		0.82	0.32
0.60	0.53	0.80		0.80	0.37	0.36	0.48	0.61	0.32	0.56		0.60	0.21
0.45	0.45	0.41	0.47	0.52	0.33	0.32	0.30	0.31	0.26	0.37		0.42	0.12
0.37	0.33	0.29	0.33	0.38	0.32	0.24	0.28	0.26	0.23	0.27		0.34	0.08

APPENDIX E

CONDUCTIVITY DATA (MS/CM) FOR STATION 1 (UPSTREAM OF BEAR CREEK) AND STATION 14 (DOWNSTREAM OF MAHONEY STREET BRIDGE)

Date	Downstream Conductivity mS/cm (Station 14)	Upstream Conductivity mS/cm (Station 1)
6/8/2004	0.136	0.135
6/24/2004	0.184	0.211
7/21/2004	0.227	0.244
8/17/2004	0.344	0.4
9/23/2004	0.280	0.272
5/24/2005	0.143	0.149
6/21/2005	0.137	0.138
7/19/2005	0.184	0.189
8/16/2005	0.243	0.249
9/13/2005	0.300	0.304
10/11/2005	0.287	0.293
5/23/2006	0.171	0.157
6/19/2006	0.175	0.17
7/17/2006	0.275	0.245

8/17/2006	0.336	0.309
9/18/2006	0.316	0.316
10/12/2006	0.318	0.285
5/29/2007	0.178	0.164
6/27/2007	0.196	0.179
7/16/2007	0.249	0.208
8/15/2007	0.293	0.292
9/12/2007	0.326	0.334
10/8/2007	0.307	0.274
5/20/2008	0.156	0.15
6/16/2008	0.127	0.124
6/24/2008	0.148	0.153
7/8/2008	0.147	0.143
7/22/2008	0.207	0.161
8/6/2008	0.196	0.194
9/3/2008	0.262	0.252
10/1/2008	0.312	0.333
5/27/2009	0.184	0.181
6/11/2009	0.185	0.187
7/8/2009	0.185	0.166
8/4/2009	0.282	0.271

9/2/2009	0.385	0.386
10/6/2009	0.379	0.356
11/13/2009	0.342	0.329
1/28/2010	0.412	0.198
5/26/2010	0.210	0.176
6/23/2010	0.192	0.175
7/20/2010	0.335	0.277
8/16/2010	0.309	0.298
9/7/2010	0.366	0.333
10/6/2010	0.347	0.321
5/25/2011	0.528	0.324
6/24/2011	0.146	0.147
7/18/2011	0.168	0.151
8/8/2011	0.272	0.252
9/9/2011	0.381	0.374
10/10/2011	0.549	0.349
11/14/2011	0.389	0.293
12/5/2011	0.336	0.291
5/21/2012	0.153	0.144
6/8/2012	0.163	0.153
7/10/2012	0.268	0.232

8/16/2012	0.659	0.641
9/14/2012	0.667	0.648
10/5/2012	0.638	0.624
5/22/2013	0.394	0.334
6/13/2013	0.347	0.346
7/11/2013	0.651	0.605
8/9/2013	0.445	0.444
9/6/2013	0.621	0.676
10/8/2013	0.564	0.576
5/21/2014	0.134	0.1778
6/17/2014	0.160	0.1473
7/21/2014	0.233	0.223
8/21/2014	0.325	0.301
9/19/2014	0.330	0.353
10/20/2014	0.312	0.282

APPENDIX F

DISSOLVED OXYGEN (MG/L) DATA FOR STATION 1 (UPSTREAM OF BEAR CREEK) AND STATION 14 (DOWNSTREAM OF MAHONEY STREET BRIDGE)

Date	Downstream (Station 14)	Upstream (Station 1)
6/8/2004	9.20	9.04
6/24/2004	9.84	9.75
7/21/2004	9.50	9.18
8/17/2004	8.66	9.04
9/23/2004	11.47	11.49
5/24/2005	13.20	13.3
6/21/2005	12.37	13.04
7/19/2005	4.30	4.3
8/16/2005	5.04	5.62
9/13/2005	9.19	10.29
10/11/2005	10.51	12.1
6/19/2006	14.5	13.5
8/17/2006	11.4	12.4
6/27/2007	4.3	6.37
7/16/2007	6.1	6.06
8/15/2007	6.4	9.46

9/12/2007	7.3	10.57
10/8/2007	6.7	12.91
5/20/2008	8.9	8.84
6/16/2008	9.5	10.74
6/24/2008	10.6	6.76
7/8/2008	8.7	8.74
7/22/2008	8.1	8.23
8/6/2008	9.5	9.24
9/3/2008	10.8	7.8
10/1/2008	12.5	7.97
5/27/2009	9.7	8.9
6/11/2009	8.9	6.39
7/8/2009	8.5	9.05
8/4/2009	8.2	10.91
9/2/2009	10.3	10.01
10/6/2009	6.6	7.08
11/13/2009	9.4	9.13
1/28/2010	3.3	3.55
5/26/2010	10.1	7.07
6/23/2010	8.0	8.25
7/20/2010	8.1	7.95

8/16/2010	11.5	6.32
9/7/2010	11.5	8.4
10/6/2010	9.3	6.48
5/25/2011	6.9	7.8
6/24/2011	8.7	8.25
7/18/2011	9.0	5.27
8/8/2011	5.6	5.63
9/9/2011	6.7	4.76
10/10/2011	8.1	5.7
11/14/2011	8.2	9.9
12/5/2011	11.9	13.35
5/21/2012	9.3	8.75
6/8/2012	8.5	8.5
7/10/2012	7.2	7.8
8/16/2012	7.5	7.38
9/14/2012	9.0	7.74
10/5/2012	6.5	8.24
5/22/2013	9.3	10.73
6/13/2013	9.1	9.5
7/11/2013	8.1	8.71
8/9/2013	10.9	8.47

9/6/2013	7.3	6.44
10/8/2013	7.4	8.67
5/21/2014	6.3	10.05
6/17/2014	9.0	8.4
7/21/2014	8.3	7.84
8/21/2014	7.8	7.9
9/19/2014	7.4	7.89
10/20/2014	9.3	8.99

APPENDIX G

NITRATE DATA (MG/L) FOR STATION 1 (UPSTREAM OF BEAR CREEK) AND STATION 14 (DOWNSTREAM OF MAHONEY STREET BRIDGE)

Date	Downstream (Station 14)	Upstream (Station 1)
5/24/2004	0.21	0.19
6/24/2004	0.18	0.17
7/21/2004	0.17	0.14
8/17/2004	0.23	0.17
9/23/2004	0.26	0.23
6/21/2005	0.22	0.20
7/19/2005	0.11	0.09
9/13/2005	0.20	0.14
10/11/2005	0.18	0.23
5/23/2006	0.25	0.24
6/19/2006	0.16	0.14
7/17/2006	0.16	0.13
8/17/2006	0.19	0.17
9/18/2006	0.23	0.21
10/12/2006	0.29	0.25
		0.24

7/16/2007	0.14	0.14
8/15/2007	0.25	0.26
9/12/2007	0.26	0.18
10/8/2007	0.24	0.19
5/20/2008	0.25	0.23
6/16/2008	0.22	0.21
6/24/2008	0.02	0.02
7/8/2008	0.15	0.14
7/22/2008	0.11	0.09
8/6/2008	0.13	0.10
9/3/2008	0.23	0.15
10/1/2008	0.23	0.15

APPENDIX H

TEMPERATURE DATA (˚C) FOR STATION 1 (UPSTREAM OF BEAR CREEK)

AND STATION 14 (DOWNSTREAM OF MAHONEY STREET BRIDGE)

Date	Downstream (Station 14)	Upstream (Station 1)
6/8/2004	7.42	8.06
6/24/2004	12.32	7.42
7/21/2004	11.79	13.88
8/17/2004	8.08	12.05
9/23/2004	7.26	7.88
5/24/2005	8.64	6.98
6/21/2005	9.96	9.22
7/19/2005	10.13	11.68
8/16/2005	10.21	10.01
9/13/2005	6.07	12.15
10/11/2005	6.65	6.85
5/23/2006	9.43	7.06
6/19/2006	11.26	11.09
7/17/2006	11.37	11.9
8/17/2006	9.30	11.58
9/18/2006	6.86	10.07

10/12/2006	7.12	6.66
5/29/2007	8.02	7.07
6/27/2007	8.02	9
7/16/2007	10.56	12.8888889
8/15/2007	12.39	12.55555556
9/12/2007	15.39	13
10/8/2007	9.56	7.055555556
5/20/2008	5.94	6.94
6/16/2008	6.80	6.98
6/24/2008	6.48	6.95
7/8/2008	8.68	10.24
7/22/2008	10.32	10.12
8/6/2008	10.53	11.89
9/3/2008	10.63	10.65
10/1/2008	10.18	12.1
5/27/2009	7.63	7.27
6/11/2009	6.39	6.32
7/8/2009	11.87	11.44
8/4/2009	12.17	12.2
9/2/2009	11.56	11.14
10/6/2009	9.25	10.22

11/13/2009	3.96	1.45
1/28/2010	4.04	3.37
5/26/2010	6.54	6.11
6/23/2010	7.53	8.72
7/20/2010	10.29	10.63
8/16/2010	10.49	12.44
9/7/2010	10.43	9.48
10/6/2010	8.85	10.73
5/25/2011	10.37	11.03
6/24/2011	6.34	7.19
7/18/2011	9.85	11.51
8/8/2011	11.00	11.79
9/9/2011	9.39	9.64
10/10/2011	9.97	9.24
11/14/2011	6.05	3.36
12/5/2011	3.27	1.45
5/21/2012	6.75	7.2
6/8/2012	9.07	9.84
7/10/2012	12.31	14.2
8/16/2012	11.82	15.08
9/14/2012	10.98	13.85

10/5/2012	9.06	10.95
5/22/2013	7.28	8.21
6/13/2013	8.18	9.13
7/11/2013	11.35	13.21
8/9/2013	8.92	9.05
9/6/2013	12.04	12.37
10/8/2013	7.12	7.65
5/21/2014	6.19	6.3
6/17/2014	5.8	10
7/21/2014	9.7	13.5
8/21/2014	11.3	11.8
9/19/2014	11.6	11.8
10/20/2014	8.4	7.2

APPENDIX I

FLOW DATA (CMS) FOR STATION 1 (UPSTREAM OF BEAR CREEK) AND STATION 14 (DOWNSTREAM OF MAHONEY DRIVE)

6/8/2004	0.19991694	2.804783695
6/24/2004	2.172185333	1.491165163
7/21/2004	0.023502983	0.849788578
8/17/2004	0.464679459	0.183493169
9/23/2004	0.014158424	0.906422272
6/21/2005	2.172185333	4.889186803
7/19/2005	2.16907048	1.505040418
8/16/2005	1.345050233	0.753794467
9/13/2005	0.666578578	0.372649707
10/11/2005	0.931057929	0.548780495
6/19/2006	2.605149924	1.768953432
7/17/2006	1.049139181	0.570867636
8/17/2006	1.073208501	0.694329088
9/18/2006	0.820905395	0.538020093
5/29/2007	3.917069446	2.73540742
6/27/2007	4.485105396	3.181680929
7/16/2007	1.91365252	1.243109583
8/15/2007	1.043475812	0.76059051

9/12/2007	0.580212195	0.387940804
10/8/2007	0.70877068	0.583327048
5/20/2008	5.323567236	2.855187683
6/16/2008	6.371290575	3.96435858
6/24/2008	5.09703246	3.421524623
7/8/2008	4.101695288	2.844427281
7/22/2008	2.740787621	1.998603061
8/6/2008	2.05806844	1.555444406
9/3/2008	0.784376662	0.366136832
10/1/2008	0.407479428	0.141017898
5/27/2009	2.50604096	1.904874298
6/11/2009	2.338688394	1.396020557
7/8/2009	2.501227096	2.041078332
8/4/2009	0.777014282	0.495827991
9/2/2009	0.338103153	0.101374312
10/6/2009	0.364437821	0.129124822
11/13/2009	0.495544823	0.28316847
1/28/2010	0.155742659	0.141584235
5/26/2010	5.238616695	3.822774345
6/23/2010	2.750132181	1.927244607
7/20/2010	0.817224204	0.500075518

8/16/2010	0.100807975	0.507721067
9/7/2010	0.45335272	0.241259536
10/6/2010	0.501774529	0.205297141
5/25/2011	1.135788733	0.518481469
6/24/2011	8.849014688	7.787132925
7/18/2011	5.09703246	3.706392104
8/8/2011	1.448123556	0.745582582
9/9/2011	0.458732921	0.188307033
10/10/2011	0.541418115	0.242109042
11/14/2011	0.637129058	0.254851623
12/5/2011	0.538020093	0.127425812
5/21/2012	4.24752705	3.047175906
6/8/2012	2.690100465	1.954711948
7/10/2012	0.799667759	0.408045765
8/16/2012	0.460431932	0.218039722
9/14/2012	0.487899274	0.236162504
10/5/2012	0.387091298	0.188873369
5/22/2013	2.760892583	1.928660449
6/13/2013	2.38201317	2.252038842
7/11/2013	0.47940422	0.215208037
8/9/2013	2.194555643	1.255002659

9/6/2013	0.516216121	0.27014272
10/8/2013	0.880087605	0.551329011
7/21/2014	1.527977064	0.918598517
9/19/2014	0.716416229	0.325643741
10/21/2014	0.817224204	0.542833957