BIG THOMPSON RIVER RESTORATION MASTER PLAN

January 2015

AYRES ASSOCIATES

BIG THOMPSON RIVER
RESTORATION MASTER PLAN

Prepared for:

Big Thompson River
RESTORATION COALITION

Prepared by:

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Cover Photos:
Upper Left – Big Thompson Canyon Mouth, August 1, 1976, Bettmann/CORBIS
Bottom Right – Big Thompson Canyon Mouth, September 13, 2013, Ayres Associates

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GLOSSARY

aggradation:	An increase in land elevation due to the deposition of sediment.
avulsed/avulsion:	The rapid abandonment of a river channel and the formation of a new river channel.
channel migration:	The natural lateral motions of a river channel across it's floodplain due to the process of erosion and deposition.
degrade/degradation:	The lowering in land elevation through erosional processes. It is the opposite of aggradation.
deposition:	The same as aggradation.
discharge:	Volume of water passing through a channel during a given time.
exigent:	Pressing or demanding. Used during flood recovery to designate sites that had the most pressing needs for repair after the 2013 flooding and before the 2014 spring runoff.
floodplain:	Naturally flat, alluvial lowland bordering a stream, that is subject to frequent inundation by floods.
100-year flood:	A flood that has a 1 percent chance of occurring in any given year; it is not a flood that will occur once every 100 years.
500-year flood:	A flood that has a 0.2 percent chance of occurring in any given year; it is not a flood that will occur once every 500 years.
floodway:	The channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood (typically the 100-year flood) without cumulatively increasing the water surface elevation more than a designated height. Communities must regulate development in these floodways to ensure that there are no increases in upstream flood elevations.
geomorphology:	That science that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion and deposition.
headcut:	Degradation associated with abrupt changes in a stream bed or floodplain that generally migrates in an upstream direction.
hydraulics:	Applied science concerned with behavior and flow of liquids, especially in pipes, channels, structures, and the ground.
hydraulic model:	Small-scale physical or mathematical representation of a flow situation.
hydrology:	Science concerned with the occurrence, distribution, and circulation of water on the earth.

infrastructure:	The basic physical structures and facilities (e.g., roads, buildings, power supplies, water supplies, etc.) needed for the operation of a society.
LiDAR:	A remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. LiDAR is popularly used to make high resolution topographic maps.
resiliency:	The ability to return to an original state after being disturbed.
riparian:	The area or zone adjacent to a river or stream.
pocket habitat:	An area or pool within a stream created by boulders that provide important habitat for trout.
stream gage:	A location used to monitor the stage and/or discharge of water.

ACRONYMS

AHIP – Aquatic Habitat Improvement Potential

AOP – Aquatic organism passage

BTRRC – Big Thompson River Restoration Coalition

BTRRMP – Big Thompson River Restoration Master Plan

CDOT – Colorado Department of Transportation

CFLHD - Central Federal Lands Highway Division

cfs – cubic feet per second

CPW – Colorado Parks and Wildlife

CWCB – Colorado Water Conservation Board

FEMA – Federal Emergency Management Agency

FR – Flood Risk

GIS – Geographic Information System

GR – Geomorphic Risk

LF – Linear Foot

LS – Lump Sum

LWM – Large woody material (aka, in-stream woody material IWM, or large woody debris LWD)

MCDA – Multi-Criterion Decision Analysis

NFIP – National Flood Insurance Program

NRCS – Natural Resources Conservation Service

REIP – Riparian Restoration Improvement Potential

sMAP – the Social Mapping Application

USACE – U.S. Army Corps of Engineers

USFS – United States Forest Service

WRV – Wildlands Restoration Volunteers

EXECUTIVE SUMMARY

Background and Purpose

The Big Thompson River and the North Fork of the Big Thompson River basins experienced extreme flooding in September 2013. This flood caused two deaths; severe erosion and sediment deposition; extensive damage to property and infrastructure; and loss of substantial ecological, scenic, and recreational resources in the affected river corridors. The river corridors' riparian and aquatic habitat was severely disrupted, impacting wildlife and devastating the recreational fishery. Flooding and erosion damaged or destroyed homes and businesses. Large portions of US Highway 34 (US 34) and County Road 43 (CR 43) were damaged, severing the connections between Loveland and Estes Park, stranding people who live in the canyon, and eliminating the primary vehicular access route to Rocky Mountain National Park, the largest tourist attraction in Colorado.

The State of Colorado Department of Transportation and Federal Highway Administration Central Federal Lands Highways Division (CFLHD) rebuilt US 34 and CR 43, respectively, using emergency construction methods, by the end of November 2013 — less than two months after they were destroyed. The Natural Resources Conservation Service (NRCS) funded emergency projects to protect private property and critical infrastructure at risk of being damaged or destroyed due to the 2014 high spring runoff. These construction projects were temporary measures designed to protect infrastructure and property until permanent repairs and recovery measures could be designed, permitted, and implemented.

CDOT and CFLHD are now designing permanent roadway repairs to US 34 and CR 43, respectively. Other long-term recovery efforts have begun, including numerous volunteer projects led by non-profit organizations. More than one mile of instream and riparian restoration on the North Fork upstream of Drake, which is being implemented by the Colorado Department of Parks and Wildlife.

The Big Thompson River Restoration Coalition (BTRRC) was formed as a grass-roots organization soon after the flood to help property owners and other stakeholders with cleanup, debris removal, and to facilitate longer-term recovery of the river corridors. The BTRRC and its fiscal and project management partner, Wildlands Restoration Volunteers (WRV), received a grant from Colorado Water Conservation Board (CWCB) in the spring of 2014. This grant, along with funding from the Community Foundation of Northern Colorado, Larimer County, the City of Loveland, Northern Water Conservancy District, and New Belgium Brewing, was dedicated to develop a Big Thompson River Restoration Master Plan (BTRRMP). The BTRRC selected a consulting team led by Ayres Associates in March, 2014 to develop the BTRRMP.

The purpose of the BTRRMP is to define an overall recovery vision and to identify priority projects for restoring more than forty miles of the Big Thompson River and eleven miles of the North Fork of the Big Thompson River. The plan includes the Big Thompson River corridor from Olympus Dam at Lake Estes to its confluence with the Platte River in Weld County, Fox Creek, West Creek, and the North Fork of the Big Thompson River to its confluence with the Big Thompson River at Drake. Within these limits, the BTRRMP primarily covers that portion of these watersheds identified as part of the regulatory floodplain by the National Flood Insurance Program. **Figure 1** presents the study area.

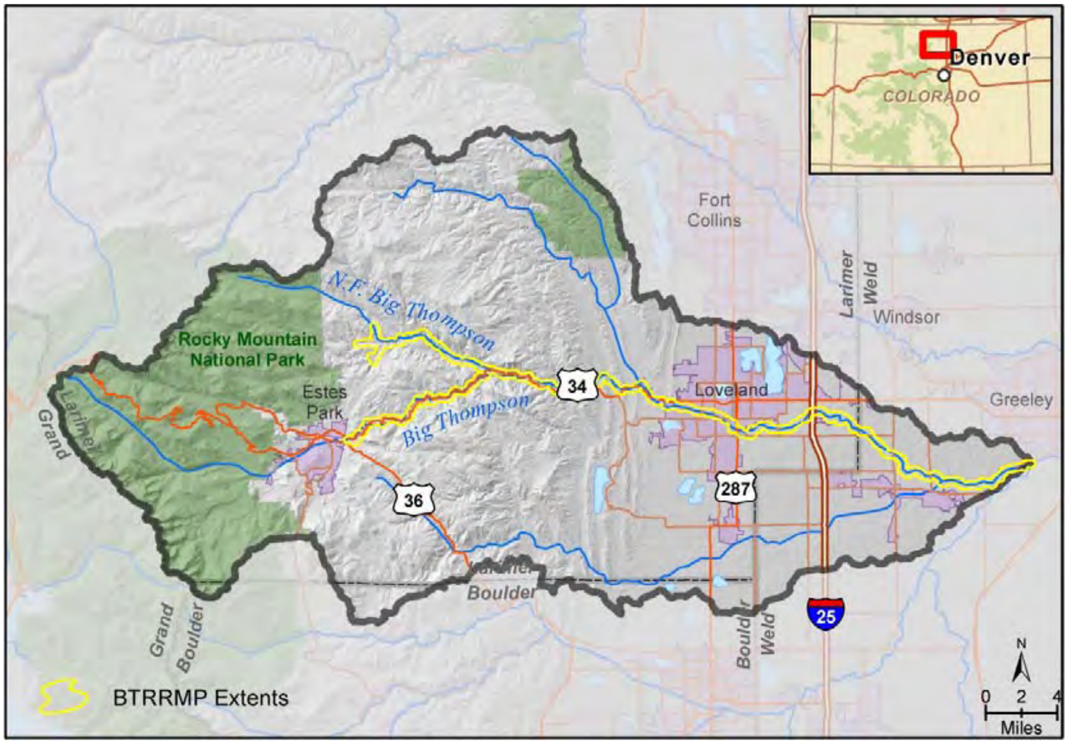


Figure 1. BTRRMP Vicinity Map.

This Master Plan provides a holistic framework for restoration and recovery, prioritization methodology and tools, project reach identification and a project prioritization list. The Master Plan also presents conceptual stabilization and restoration techniques consistent with:

- Overall recovery vision identified by the BTRRC and its stakeholders
- Watershed, geomorphic, hydrologic, and hydraulic characteristics of the river corridors
- Property, landowner, and critical infrastructure constraints in the study reaches

With this master plan, private landowners and public agencies can identify individual or collective projects, prioritize and design these projects consistently, and use this document as a basis for applying for funding assistance from a multitude of potential sources. Entities providing funding can evaluate project applications with respect to their priority and their consistency with the holistic recovery approach presented by the BTRRMC. CDOT and CFLHD will use the master plan as a guide to ensure that the roadway corridor adjacent to the river corridors covered by the BTRRMP is reconstructed in a flood-resilient and environmentally-sensitive manner.

Vision and Goals

The vision for restoration is to create a more resilient river system. The specific restoration goals of the master plan are to:

- Improve river function over a broad range of discharges, including flood events
- Reduce risk to lives and property (flooding, erosion, safe access)
- Protect infrastructure
- Limit negative impacts to private property
- Rehabilitate ecological function

Master Plan Overview

The BTRRMP effort consisted of the following major elements:

- Flood and geomorphic risk assessments
- Aquatic and riparian habitat improvement potential assessments
- Multi-criterion decision analysis tool (MCDA) to score these assessments and support project prioritization
- Project priority list
- Design concepts for flood resiliency and restoration treatments
- Conceptual cost estimates
- Key implementation and management recommendations
- Stakeholder engagement to elicit feedback on goals, prioritization, projects, conceptual designs, and recommendations

The major components of the master plan are described below.

Reach Delineation

The study area was divided into fifty-nine project reaches for restoration conceptual design and project prioritization. Forty-eight reaches are along the Big Thompson River main stem, and the remaining eleven are on the North Fork of the Big Thompson River and its tributaries. **Section 4.3** presents the detailed reach delineations.

Risk Assessments

The cause of the 2013 flood was a broadly-distributed and long-duration series of heavy rainfall events between September 9 and September 13, 2013. The resulting flood on the Big Thompson River and its tributaries generated a 15,500 cfs peak discharge at the mouth of the Big Thompson Canyon, with flood flows lasting more than two weeks. As a result, extensive erosion and sedimentation occurred throughout the river corridors and east of the canyon in Loveland, Larimer County, and Weld County to the confluence with the Platte River. The BTRRMP team performed risk assessments to support an MCDA score for project reaches within the river corridors.

Flood Risk Assessment. The Flood Risk Assessment identified over 2,500 mapped infrastructure elements (buildings, utilities, bridges, etc.) within mapped flood areas (floodway, 100-year floodplain, and 500-year flood fringe) and assigned each element a score from 5 (fully in floodway) to 1 (in 500-year flood fringe) based on its location. Because post-flood regulatory floodplain information was not available, this flood risk assessment was based on the effective (pre-flood) mapping with post-flood adjustments using preliminary FEMA LiDAR data. This base flood risk was weighted by the proportion of infrastructure elements within each reach and scaled to result in a score between 1 and 5, with 5 being the most severe Flood Risk.

The six reaches with the highest Flood Risk assessment scores were:

- Glade Road (5.0)
- Jasper Lake (4.9)
- Upper North Fork (4.6)
- Rock Canyon (4.4)
- Fairgrounds Park/Fox Creek (tie; 4.1)

Geomorphic Risk Assessment. Flood inundation is not the only risk to infrastructure. In September 2013 there were numerous infrastructure elements that were not within the regulatory floodplain, but were severely damaged when the channel shifted from its pre-flood alignment or flooding caused erosion and deposition.

The Geomorphic Risk Assessment was developed to account for this source of risk. Ayres geomorphologists and hydraulic engineers reviewed maps and aerial photographs for the 1976 flood and the 2013 flood, field-verified the degree of erosion or deposition of material in the 2013 flood, and identified potential lateral stream instability in the river corridor. Scores were assigned based potential risk to infrastructure due to future erosion or deposition, with areas of highest geomorphic risk receiving a score of 5 and lowest risk receiving a 1. Twelve reaches were identified that had maximum geomorphic risk. **Table 1** presents these reaches and the major instability types identified for each reach.

Table 1. Reaches With Maximum Geomorphic Risk Scores.

Reach		Instability Type		
Number	Name	Deposition	Erosion	Lateral
14	Drake	X		X
15	East Drake	X		X
16	Midway		X	X
24	Sylvan Dale	X		X
25	Loveland WTP		X	X
49	Upper West Creek		X	
50	Glen Haven		X	
51	Fox Creek		X	
52	Upper North Fork		X	
54	Dunraven		X	
58	Fish Hatchery			X
59	North Drake		X	X

Habitat Improvement Assessments

With the extreme erosion and deposition associated with the flood event and the heavy post-flood channelization and mining of the river for construction materials performed as part of the emergency road and infrastructure repairs, most of the aquatic and riparian habitat in the canyon corridor was damaged to varying degrees. Historic land use practices have also contributed to the ecological health of the river corridor. Hydraulic variability, adequate flows and depths, food sources, cover, bank vegetation, riparian vegetation, large woody material, organic material sources, continuous fish passage, and riparian corridors are all vital to aquatic and riparian functions in the corridor. Aquatic and riparian habitat improvement potential was assessed for the river corridors and scores weighted for each project reach to inform an MCDA tool and to score project reaches for future project prioritization.

Aquatic Habitat Improvement Potential. Miller Ecological Consultants, Inc. (MEC) evaluated the study area to identify reaches that would benefit from restoration. The ratings range from five (5) for areas that have little or no instream variability and for which establishment of appropriate in-channel aquatic habitat structure is recommended, to zero (0) for areas where no restoration is needed or possible. **Table 2**. presents the reaches with the top five Aquatic Habitat Improvement Potential (AHIP) scores.

Table 2. Reaches With High Aquatic Habitat Improvement Potential Scores.		
Reach		AHIP Score
Number	Name	
50	Glen Haven	5.0
25	Loveland WTP	4.3
24	Sylvan Dale	4.1
57	Crosier Mt Trail	4.0
21	Cedar Cove	3.9

Reaches with low to moderate AHIP scores are mostly in need of revegetation, while isolated improvements are needed to create fish passage, such as at irrigation diversion structures.

Riparian Ecological Improvement Potential. Alpine Ecological Resources evaluated the study area for the potential to assist natural riparian recovery processes, enhancing or creating riparian complexes of forbs, shrubs, and trees on floodplain benches. The riparian ecological improvement potential (REIP) ratings range from five (5) for areas with high potential to one (1) for areas with low potential or need. Areas rated highly are disturbed areas that have substantial potential to restore large riparian floodplain complexes, such as gravel pond locations in Loveland. Areas rated two (2) to three (3) are important to restore as well to improve aquatic habitat, and to provide filtering of storm runoff before it reaches the main river channel. Areas rated one (1) are characterized by little or no available floodplain, steep canyon walls with exposed bedrock, little soil present, or relatively intact riparian habitat. The top five scoring reaches are presented in **Table 3**.

Table 3. Reaches With High Riparian Habitat Improvement Potential Scores.		
Reach		REIP
No.	Name	
39	I-25	5.0
31	Namaqua - Wilson	5.0
38	Kauffman's	5.0
37	Boise - CR 9e	5.0
22	Jasper Lake	4.8

MCDA Scoring and Project Reach Prioritization

The four assessment scores were weighted equally for each reach presented in the BTRRMP, and a composite weighted score presented for each reach in **Section 4.3**. These composite MCDA scores were used to rank project reaches. The resulting composite score ranged from 4.5, at the Jasper Lake reach, to 1.9, at the USFS-1 reach.

Appendix B presents the MCDA analysis and summary for each project reach.

Based on the MCDA rankings as presented in this Master Plan, the top six project reach rankings are:

1. Reach 22 - Jasper Lake along the Big Thompson
2. Reach 50 - Glen Haven along West Creek
3. Reach 27 - Glade Road along the Big Thompson
4. Reach 29 – Morey Open Space along the Big Thompson
5. Reach 21 - Cedar Cove along the Big Thompson
6. Reach 24 - Sylvan Dale along the Big Thompson

These six projects present a maximum total benefit to the river corridors based on an even weighting of the MCDA factors summarized above.

Due to planned roadway work in the canyons along US 34 and CR 43 there may be unique opportunities to restore sections of the river in conjunction with permanent roadway repairs. Because of this opportunity to partner with other agencies working in the river corridor it may benefit the BTRRC to prioritize additional projects along these road corridors. All canyon reaches could potentially become opportunities during permanent road repair work. However, the following project reaches along the Big Thompson and the North Fork are the highest priority reaches to focus on in conjunction with permanent road repair projects:

For US 34

1. Reach 15 – East Drake along the Big Thompson
2. Reach 14 – Drake along the Big Thompson
3. Reach 18 – Idlewild along the Big Thompson

For CR 43

1. Reach 59 – North Drake along the North Fork
2. Reach 58 – Fish Hatchery along the North Fork
3. Reach 57 – Crosier Mt Trail along the North Fork

Sections 4.4-4.15 presents the recommended restoration projects in these high-scoring reaches in more detail.

The MCDA tool used to generate these composite scores is available to stakeholders should a different weighting scheme for assessment scores be desired.

Restoration Design Concepts

Conceptual restoration plans for the entire study area were prepared to respond to the risks and improvement potentials that were identified by the assessment process. The overarching principles are to establish a main river channel to accommodate ordinary flows and to create a continuous connection for movement of fish and other aquatic species; develop an alluvial floodplain where practicable, maximizing floodplain conveyance and storage during flood events; and either removing critical infrastructure and structures from the floodplain or protecting them from failure.

When the channel is connected to an alluvial floodplain, floodwaters have room to spread out, velocities and flood depths are lower, and flood intensity is attenuated by the increased storage volume this floodplain provides. Floodplain benches are critical to this concept, achieving many restoration goals simultaneously. Inset floodplain benches that are inundated with water during moderate and higher flow events contain riparian vegetation that provides habitat for wildlife, slows velocities, and whose roots anchor soil during floods. They also improve water quality in the river by filtering out contaminants and sediment carried by stormwater runoff.

The plans include details for more naturalistic approaches to bank stabilization, such as coir lifts, willow stake plantings, and the use of large woody material to assist in the establishment of bank vegetation. The BTRRMP recommends an environmentally-sensitive approach to bank stabilization wherever neither critical infrastructure nor structures are threatened by its failure. **Figures 2 and 3** presents a typical channel segment.

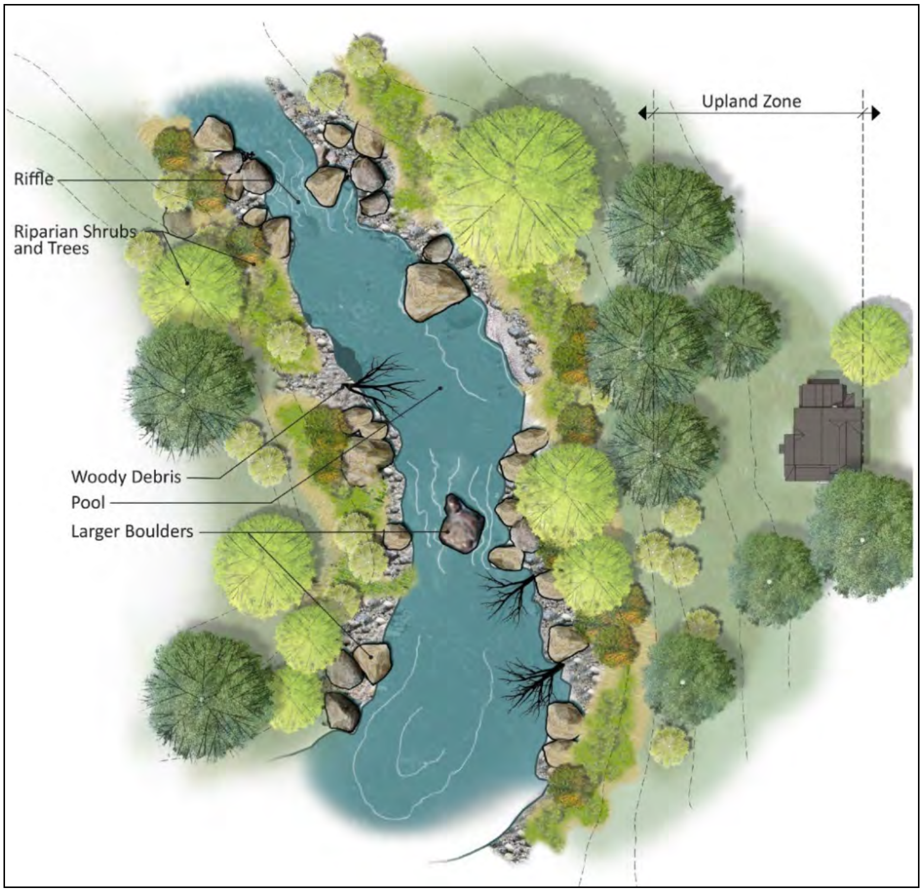


Figure 2. Restored Channel Prototype – Canyon Segments.

Unfortunately, unreinforced vegetative treatments cannot be expected to survive design-level flood velocities and shear stresses in many project reaches on this high-gradient stream, particularly in reaches where the riparian corridor is, or has been, substantially constricted. Consequently, if it is desirable to protect infrastructure elements from design-level flood events, and it is not practicable to remove those features from the floodplain, it may be necessary to use hard stabilization treatments, such as buried and planted rock revetment, articulating concrete block mats, rockery designs, or toed-down retaining walls, to protect these elements. Alternatively, infrastructure may be designed to survive its design condition without armor, such as by placing roadway on an elevated section or founding it on competent bedrock material.

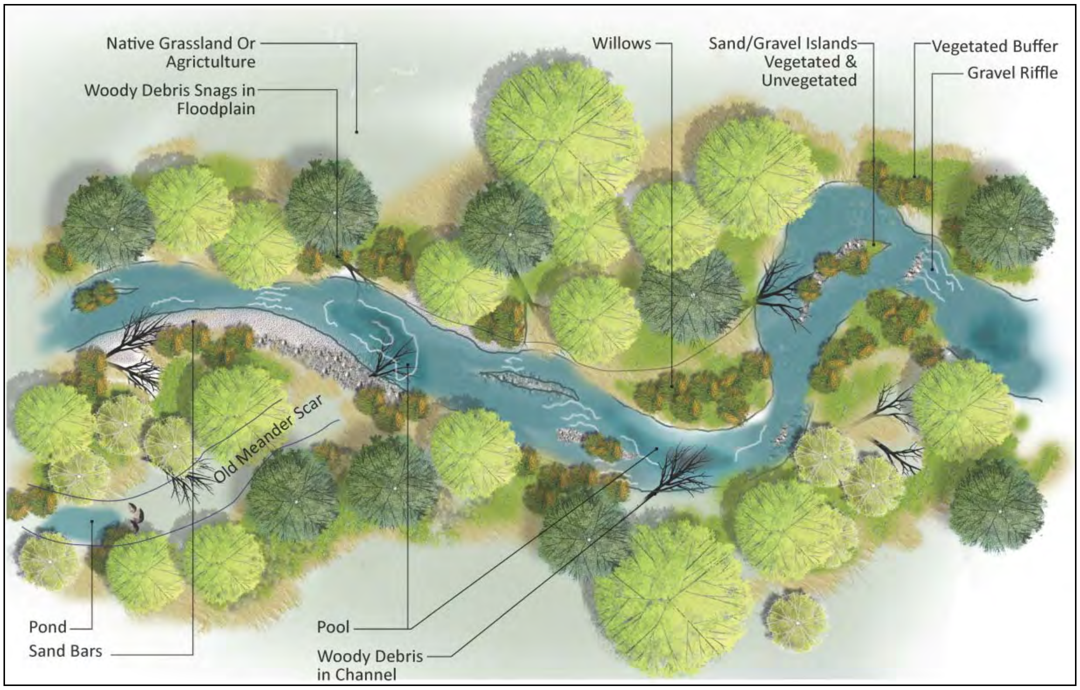


Figure 3. Restored Channel Prototype – Plains Segments.

The BTRRMP recommends that any revetment treatments be properly designed in accordance with established engineering principles and based on accurate hydraulic and geotechnical site data. Stabilization should be set well back from the channel to the extent practicable. All engineered treatments should be buried. Porous treatments should be buried, soil-filled with suitable planting material, and planted with native riparian or upland species.

Figure 4 presents a typical channel section including a setback revetment, an inset floodplain bench, stream bank protection, and in-stream channel variability.

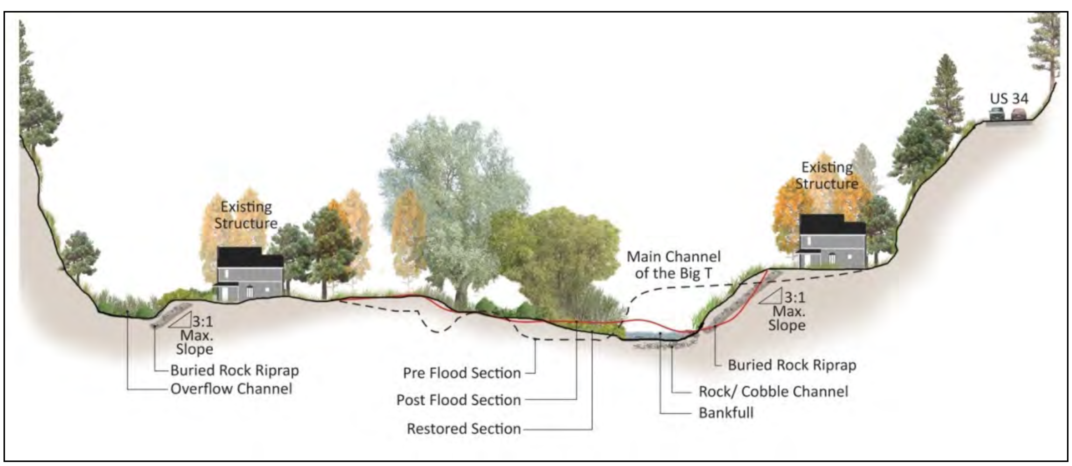


Figure 4. Illustrative section near Jasper Lake Road – view looking downstream.

Conceptual restoration treatments and designs for each reach are presented in **Appendix C.**

Cost Estimates

Restoring the river corridors will require intensive investment over time. If the conceptual plans for the entire study area were implemented, the BTRRMP cost estimate of non-roadway related restoration activities is $69,134,632 to $225,202,785, depending on assumptions. The higher estimate is more consistent with fully engineered and contractor-constructed solutions typical of work performed in urban areas or for owners of critical infrastructure, while the lower estimate assumes locally sourced/donated materials, donated labor/equipment, and minimal engineering or regulatory compliance efforts.

Table 4 presents the five most-expensive project reaches.

Table 4. Top Five Project Costs (2014 Dollars).

Reach		Non-Roadway Cost		Roadway Cost	
#	Name	(low)	(high)	(low)	(high)
43	Great Western RR	$3,014,594	$12,642,394	na	na
37	Boise – CR 9E	$3,032,483	$10,179,938	na	na
22	Jasper Lake	$3,212,044	$8,958,084	na	na
32	Wilson – Taft	$2,256,754	$7,966,035	na	na
27	Glade Road	$4,568,144	$7,966,035	$625,000	$2,625,000

Implementation and Management Strategies

The long term reduction of flood losses will require that the current floodplain management ordinances be enforced. In addition, a revision of the existing technical support data is necessary. It will require an understanding of the current floodplain management environment. Even prior to the 2013 flood, floodplain ordinance enforcement in the Big Thompson basin was impaired by multiple factors, including outdated hydrology, model deficiencies, mapping inaccuracies, and undocumented floodplain modifications. Additional challenges have arisen as a result of the geomorphic changes to the river and floodplain associated with the flooding and the immediate repair activities in the wake of the flood.

The river changes caused by the flood have created complications in the details of evaluation and procedures for floodplain permitting, including:

- Expedited floodplain permitting needed for flood recovery efforts
- Appropriate baseline for floodplain impact evaluation
- Rapid and ongoing changes to physical channel and floodplain conditions during recovery
- Disposition of existing vulnerable structures

BTRRMC recommends a basin-wide revision to the technical tools and data that form the non-statutory basis for floodplain management. Some of the required work is underway, including the following immediate needs:

- Hydrology (peak flood discharges updated)
- Hydraulics (flood water surface elevation profiles and floodway analysis updated and revised)
- Mapping (floodplain and floodway delineations).

Current regulatory processes within the context of federal, state, and affected local floodplain management regulations focus on flood inundation hazards and to a very limited extent on erosion hazards within floodplain limits, also known as the Special Flood Hazard Area. These Special Flood Hazard Areas can include Erosion Hazard Zones. Many communities incorporate Erosion Hazard Zones into their zoning codes and ordinances, and some enforce building and infrastructure setback requirements within these zones. Erosion Hazard Zone delineation may be a useful informational tool to regulators and property owners even if they do not include zoning restrictions.

Some of the September 2013 flood damages were attributed to irrigation canals conveying and discharging flood flows outside the river floodplain. BTRRMC recommends a joint effort between floodplain management jurisdictions and irrigation companies to identify the most problematic canal features and segments and to mitigate the associated risks.

Several of the access bridges to private property in canyon reaches of the Big Thompson River were damaged and destroyed. Some of these bridges also caused channel instability and substantial infrastructure and private property damage. The existing 25-year design standard should be reviewed for suitability given local access bridge performance in the 2013 flooding. Local access bridge replacement location and bridge design requirements should consider debris potential, river function and the bridge's potential to cause channel instability, particularly in confined high-gradient reaches of the river.

Stakeholder Engagement

The BTRRMP development process included substantial stakeholder engagement. Stakeholder engagement was necessary to develop a viable master plan document addressing stakeholder values, interests, and concerns; to educate stakeholders on master plan elements; and to develop stakeholder investment in the resulting master plan. The development team held four public progress meetings, maintained a geospatially-linked online comment tool, held monthly institutional stakeholder meetings, and reported to monthly BTRRC steering committee meetings. Stakeholder input was elicited throughout the BTRRMP development process and incorporated into the master plan.

1. INTRODUCTION

1.1 Purpose of the Master Plan

The Big Thompson River Restoration Master Plan (BTRRMP) is a guidance document, not a final design plan or a regulatory document. Its purpose is to guide stakeholders towards prioritization and implementation of stream rehabilitation projects that provide increased resiliency in our communities, economies, and river ecology. The recommendations included in this report are aimed at reducing the risk of impacts to life and property during future flood events while improving the aquatic and riparian habitat throughout the river corridor.

1.2 Big Thompson River Restoration Coalition

The BTRRMP was prepared for the Big Thompson River Restoration Coalition (BTRRC). The BTRRC is a coalition of government agencies, private landowners, and non-profit organizations working to implement restoration of the Big Thompson River after the flooding in September 2013. Working with the river and the public, the BTRRC seeks to restore and enhance the Big Thompson River Corridor to meet the needs of local stakeholders while protecting fish and wildlife habitat, water quality, native riparian and wetland communities and other critical ecosystem services that a healthy watershed provides. The BTRRC is seeking a collaborative, voluntary process to maximize the economic, social, and environmental benefits of the Big Thompson River.

The BTRRC Steering Committee includes the following members:

John Giordanengo - BTRRC Chairperson, AloTerra Restoration Services
Lukas McNally - Wildlands Restoration Volunteers
David Jessup - Sylvan Dale Ranch
Arnfinn Austfjord – Landowner
Mary Myers – Resident
Shar Wamsley – Landowner
Laura Emerson – Resident
Dan Stubbs - Landowner and Teacher, Big Thompson School District
Ralph Trenary – Landowner
Chris Carlson – City of Loveland
Greg Dewey - City of Loveland
David Piske - Trout Unlimited
Matt Lafferty - Larimer County Planning Department
Gordon Gilstrap - Big Thompson Conservation District
Casey Cisneros - Larimer County Natural Resources

1.3 Project Team

River rehabilitation/restoration is a complex field and requires an interdisciplinary team to properly address all the various facets. The creation of a master plan also involves substantial stakeholder engagement. The BTRRMP was completed by a team with expertise in river hydraulics, river restoration, engineering, geomorphology, riparian and wetland ecology, aquatic habitat ecology, and landscape architects/planners and included:

Company	Ayres Associates	Logan Simpson Design, Inc.	Miller Ecological Consultants, Inc.	Alpine Ecological Resources, LLC
Role	Lead, hydraulics, river restoration, engineering, geomorphology	Landscape planning and stakeholder engagement	Aquatic habitat ecology	Riparian and wetland ecology
Location	Fort Collins, CO	Fort Collins, CO	Fort Collins, CO	Denver, CO
Primary Contact	Dusty Robinson	Jana McKenzie	Bill Miller	Andy Herb

1.4 Stakeholder Engagement

Stakeholders and agencies helped direct the development of the plan, and provided input via meetings, work sessions, emails to the BTRRC, and a web-based comment tool. Monthly meetings with agency representatives were convened at Loveland's City Hall from March through September 2014 by the Wildlands Restoration Volunteers (WRV) master plan leaders to share information regarding each agency's available data, programs, projects, schedule and potential funding and implementation tools. A list of people that participated in the interagency meetings and the organizations that they represent includes:

Big Thompson Conservation District: Gordon Gilstrap

Big Thompson River Restoration Coalition (BTRRC): Mary Myers, Ralph Trenary, Laura Emerson, David Jessup

Big Thompson Watershed Forum: Zack Shelley

City of Loveland: Steve Adams, Chris Carlson, Greg Dewey, Debbie Eley Kevin, Jeff Bailey, Brian Hayes, Loralee Holt, Gail Bernhardt

Colorado Department of Transportation (CDOT): Scott Ellis, Jim Eussen, Steve Griffin, Patrick Hickey

Colorado Parks and Wildlife (CPW): Larry Rogstad, Ben Swigle

Colorado Water Conservation Board (CWCB): Jeff Crane

Larimer County: Matt Lafferty, Mark Peterson, Zac Wiebe, Jeff Boring, Casey Cisneros, Suzanne Bassinger, Meegan Flenniken, Gary Darling, Lori Hodges

Long Term Recovery Group: Darlene Bassetti, Phyllis Kane

Natural Resources Conservation Service (NRCS): Todd Boldt, Steve Yochum

Northern Colorado Water Conservancy District (NCWCD): Judy Billica

Town of Estes Park: Scott Zurn

Town of Milliken: Omar Herrera (contract engineer), Seth Hyberger

Trout Unlimited: David Piske

US Bureau of Reclamation (USBR): Monica Griffith

US Forest Service (USFS): Lori Bell, Ben Johnson, Carl Chambers, Kevin Atchley, Deb Entwhistle, Dan Cenderelli, Jane Gordon, Cheryl Hazzlit

Weld County: Diana Aungst

Wildlands Restoration Volunteers (WRV): John Giordanengo, Lukas McNally, Amy Gage, Claire Griebenow

BTRRC, WRV, and the Ayres team conducted four interactive work sessions with stakeholders during the master plan development process. These meetings were held on: April 12, June 12, July 31, and August 28, 2014. Approximately 75 to 90 people, including agency representatives, attended each meeting. The stakeholders were primarily landowners along the Big Thompson River who were affected by the flooding, and were seeking advice on how to restore their properties, as well as potential sources of funding to assist with reconstruction. Information on current activities in the Big Thompson and North Fork drainages was provided as well, including NRCS work to stabilize and protect properties that were defined as "exigent;" current and future work on US 34 and CR 43 by CDOT and the Central Federal Lands Highway Division of the Federal Highway Administration (CFLHD); Larimer County bridge and road repair projects; clean-up and restoration projects by volunteer groups; and Larimer County trash and debris removal program. At each work session, participants gave site-specific feedback directly to the master planning team in small group breakout sessions corresponding with four reaches of the river: North Fork, Upper Canyon, Lower Canyon, and Plains. In the smaller groups, stakeholders received additional details on site assessments, and examined conceptual cross sections and conceptual plan maps. They identified issues and ideas, discussed restoration concepts, and wrote comments on aerial maps of the study area. The meeting minutes and presentations that were given were posted to the BTRRC website, and are located in **Appendix A**.

After the July 31 stakeholder meeting, a web site was made public to collect additional comments regarding the preliminary master plan maps. This interactive web-based application, created and hosted by sMAP, was available for comments from August 1 to August 21. From this web site, landowners and other interested stakeholders provided location specific comments and suggestions. The individual maps that were created by each stakeholder could be viewed over a street map or satellite aerial photo. Examples of the graphics and comments that were made are shown in **Figures 1.1** and **1.2**.

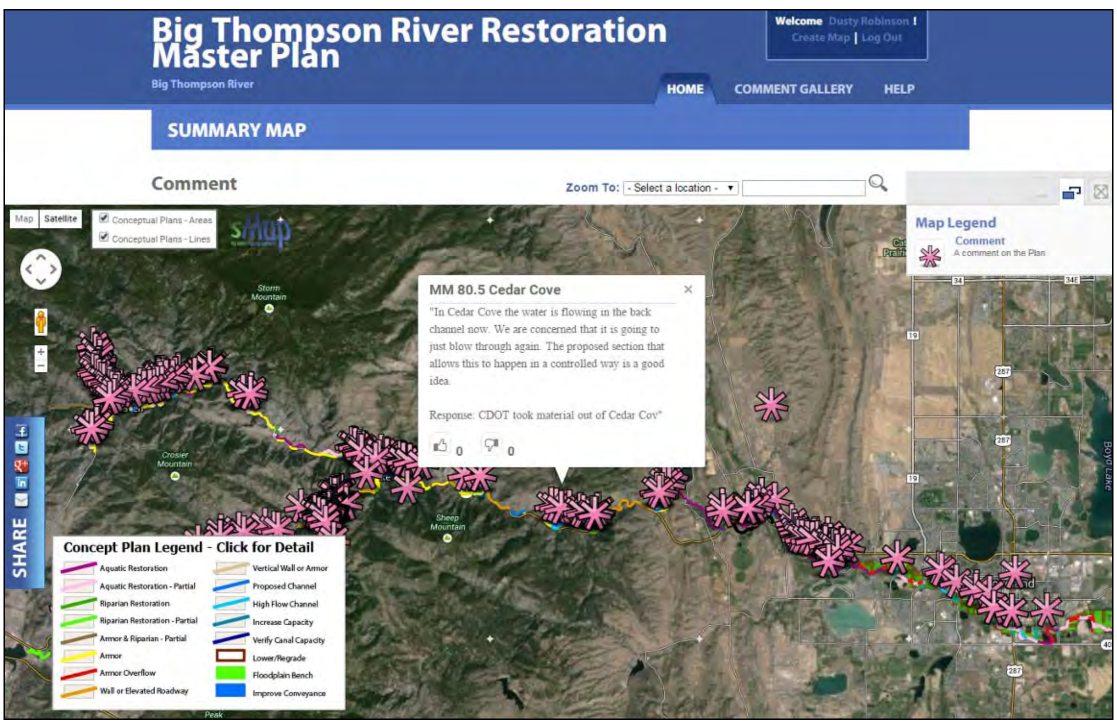


Figure 1.1. sMAP screenshot with comment markers and one comment.

Figure 1.2. sMAP screenshot conceptual plan features, comment markers, and one comment.

A complete list of comments received through this interactive tool is located in Appendix A.

Monthly meetings of the BTRRC Steering Committee included discussions regarding the master plan, which often focused on how to best inform and engage stakeholders; tools that could be employed to implement recommendations; how to assist in forming neighborhood groups that can work together to apply for funding assistance for projects that include multiple properties; and how the BTRRC should organize itself going forward to be most effective.

A joint work session with Larimer County Commissioners and the Larimer County Planning and Zoning Board was conducted on July 9, 2014 to inform both boards of the preliminary concepts for restoration and obtain their feedback. The commissioners and board members consider the master plan as an advisory document that will inform and update to the County's Comprehensive Plan, as well as provide direction for design of county infrastructure and private property improvements. Larimer County staff acknowledged limitations regarding the accuracy of existing floodplain and floodway mapping, and the challenges associated with protecting homes and businesses in high geomorphic risk areas. Geomorphic risk was assessed as part of this master plan, but is not mapped in detail, nor regulated as part of the Larimer County's, Loveland's, or Milliken's land use permitting process.

1.5 Project Extents

The geographic extents of this master plan include the following sections of river:

- Big Thompson River from Olympus Dam downstream to confluence with South Platte
- North Fork of the Big Thompson River from the northern end of North Fork Road to the confluence with the main stem.

- Fox Creek from the western extents of Fox Creek Road to the confluence with the North Fork of the Big Thompson.
- West Creek from approximately ½ mile west of Devils Gulch Road along West Creek Road to the confluence with the North Fork of the Big Thompson, including approximately 1,000 feet of Devils Gulch.

The geographic extents were approximately located within the areas of floodplain regulated by FEMA and Larimer and Weld Counties along these drainages. Separate master plans are being completed for other drainages in the Big Thomson Watershed including Fish Creek and Fall River upstream of Lake Estes and the Little Thompson River.

Figure 1.3 displays the Big Thompson River Watershed along with the major urban areas, highways, and rivers. The National Land Cover Database (NLCD) from 2011 for the same area is shown in **Figure 1.4**. The topography of the watershed is shown in **Figure 1.5**.

1.6 Corridor Settlement History

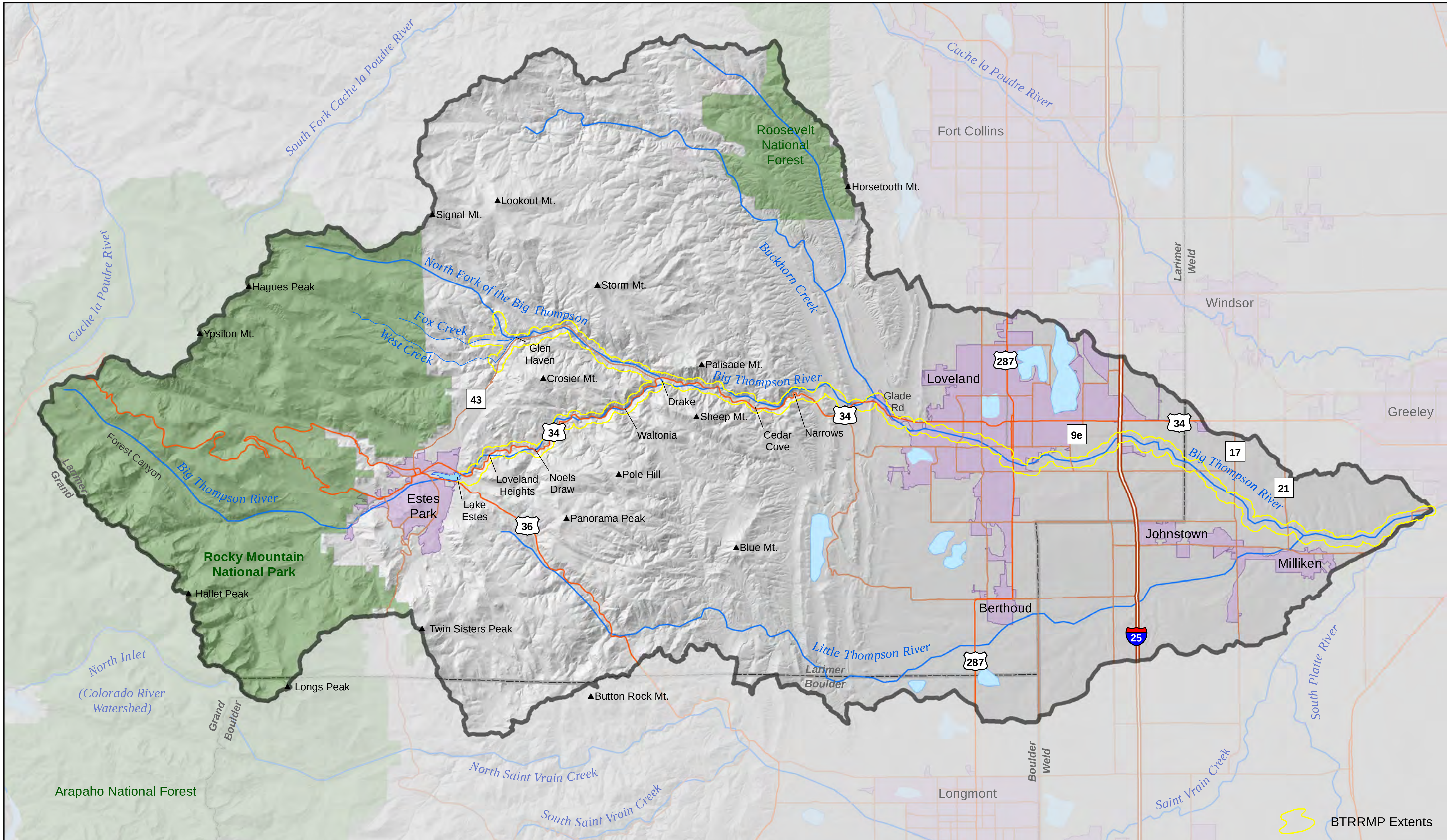
Settlement along the northern Front Range began around the 1850's with the City of Loveland incorporating in 1881. The Estes Park area was settled in 1859 and started to become a tourist destination around 1875. Multiple routes to Estes Park were used and, by 1904, a simple dirt road was established along the existing route of US 34. This road needed yearly repairs due to spring flooding. The State replaced this road in 1937 with a more modern highway that would become US 34. Although there were scattered settlements along the Big Thompson River, construction of US 34 marked the beginning of population growth within the confines of the canyon (Jessen 2013). In 1976 a flash flood destroyed much of the highway within the canyon. After the 1976 flood, the highway was rebuilt and the new road was said to be flood resistant (Jessen 1985).

1.7 Hydrology

The hydrology of the main stem of the Big Thompson River is highly regulated starting at Olympus Dam and continuing all the way to its confluence with the South Platte River. The Colorado Big Thompson Project, along with multiple irrigation diversions, creates a highly controlled flow throughout the Big Thompson River within the BTRRMP corridor. The North Fork flows, however, are completely unregulated and not altered by dams or diversions. All of the dams, including Olympus Dam, and diversions within the river corridor are for water supply purposes only and are not designed to provide significant flood control.

No hydrology studies were completed as part of the BTRRMP. However, it is important to take into account both the flood discharges to design a more resilient corridor, and the typical yearly high spring and low winter discharges to better restore and enhance the ecological resources of the riparian corridor.

A new hydrologic evaluation for flood discharges was conducted for the Big Thompson Watershed following the 2013 flooding (CDOT 2014). This report acknowledges both the existing regulatory flood discharge rates and the newly modeled/proposed discharges for the BTRRMP corridor. A recent study (ERO 2011) related to the Idylwilde Hydroelectric Project presents the most up to date information related to the low flow hydrology. The information provided in both of these reports is recommended to help guide long-term recovery projects.



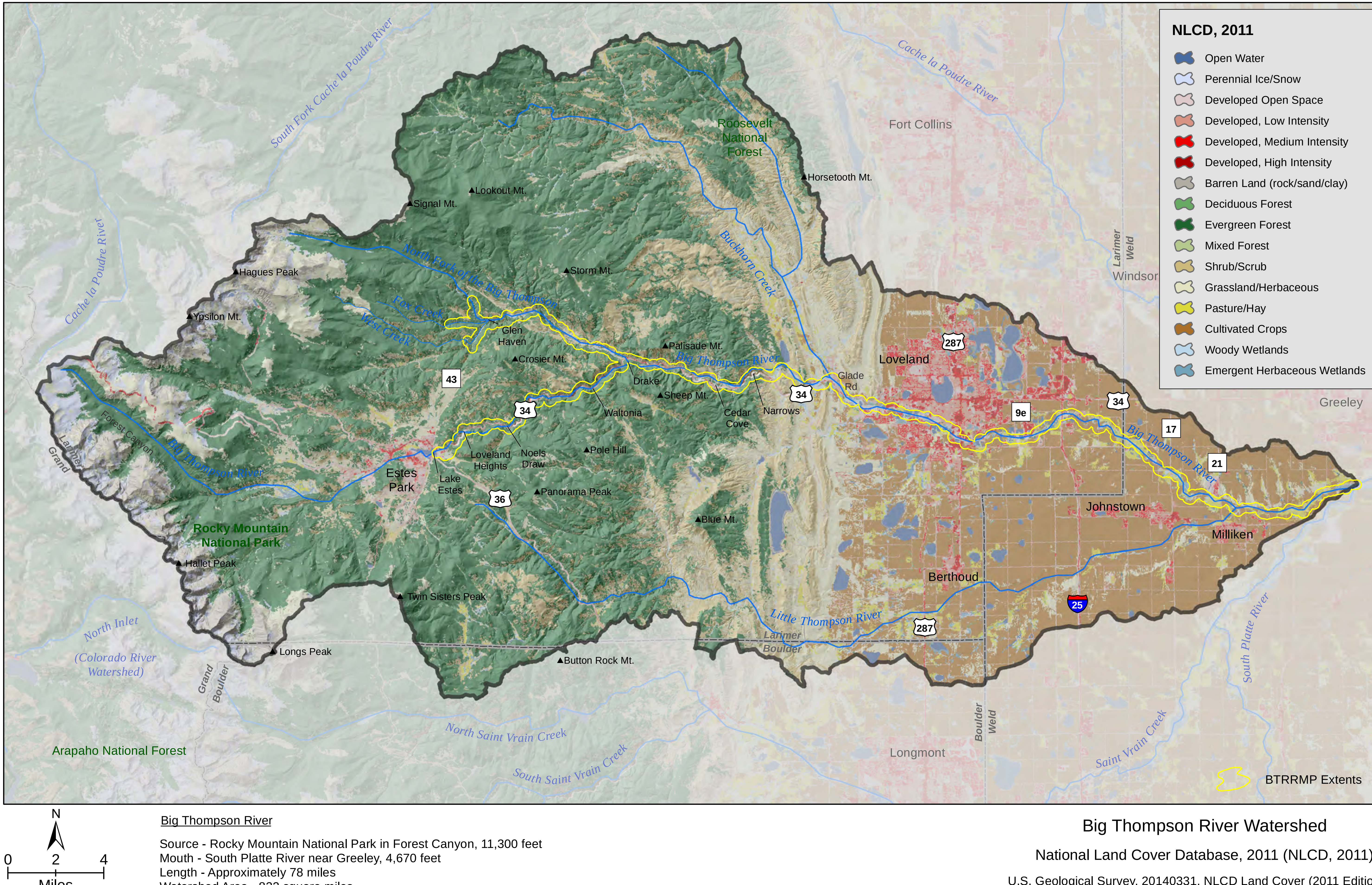
N
0 2 4
Miles

Big Thompson River

Source - Rocky Mountain National Park in Forest Canyon, 11,300 feet
Mouth - South Platte River near Greeley, 4,670 feet
Length - Approximately 78 miles
Watershed Area - 832 square miles

Big Thompson River Watershed

Figure 1.3



<u>Big Thompson River</u>

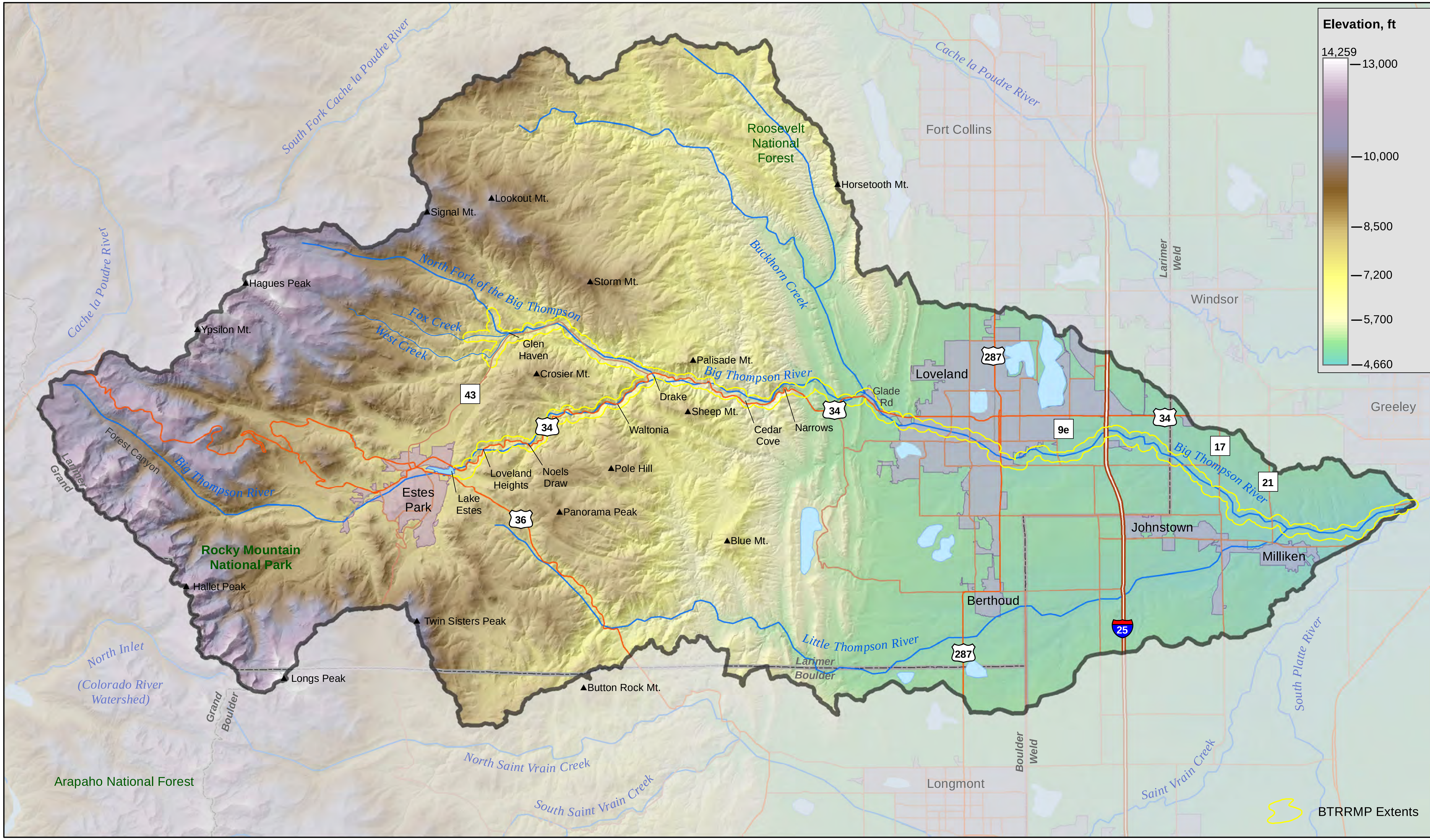
Source - Rocky Mountain National Park in Forest Canyon, 11,300 feet
Mouth - South Platte River near Greeley, 4,670 feet
Length - Approximately 78 miles
Watershed Area - 832 square miles

Big Thompson River Watershed

National Land Cover Database, 2011 (NLCD, 2011)

U.S. Geological Survey, 20140331, NLCD Land Cover (2011 Edition)

Figure 1.4



N
0 2 4
Miles

Big Thompson River

Source - Rocky Mountain National Park in Forest Canyon, 11,300 feet
Mouth - South Platte River near Greeley, 4,670 feet
Length - Approximately 78 miles
Watershed Area - 832 square miles

Big Thompson River Watershed

National Elevation Dataset (NED)

U.S. Geological Survey, National Elevation Dataset http://ned.usgs.gov/

Figure 1.5

According to the CDOT hydrology report, before the 2013 flood approximately 13 significant floods had occurred at Loveland on the Big Thompson River since 1864. These floods occurred in 1864, 1894, 1906, 1919 (8,000 cfs), 1921, 1923 (7,000 cfs), 1938, 1941, 1942, 1945 (7,600 cfs), 1949 (7,750 cfs), 1951, and 1976. All but the 1919 flood did damage to crops, homes, and businesses in the Loveland area. The largest floods at Loveland have also been the most recent ones including the 1951, 1976, and 2013 floods.

There are several resources available that describe both the 1976 and 2013 flood. It is not the intended purpose of this master plan to describe the events surrounding the 2013 flood, but to focus on long-term recovery and preparation for the next flood event. However, it is important to note that the 2013 flood event was unique compared to historical floods in this drainage. Historical floods on the Big Thompson have typically been caused by intense rainfall from localized thunderstorms. These types of floods are typically characterized by high peak discharges of short duration (CDOT 2014). The 2013 flood was unique in the time of year that it occurred and the duration and magnitude of the event.

The 1976 flood generated an estimated peak discharge of approximately 31,200 cfs at the mouth of the canyon. This flood started in the evening and was over by the next day. By contrast, the 2013 flood generated an estimated peak discharge of approximately 15,500 cfs at the mouth of the canyon with higher than normal flows lasting for over a week. While both of these floods produced some very similar results, the extended duration of high flows of the 2013 flood event created more significant erosion and sedimentation problems throughout the corridor. The 2013 flood also impacted more infrastructure east of the canyon. During the 1976 flood, the peak discharge at the confluence of the Big Thompson and South Platte Rivers was about 2,500 cfs. During the 2013 flood the peak discharge near I-25 was approximately 19,000 cfs.

Long term recovery projects should plan and prepare for both types of flooding and the potential damages associated with each.

1.8 Flood Recovery

Responding to a disaster includes several phases. During and after the 2013 event the Northern Front Range and Eastern Plains of Colorado entered into a flood response phase. Flood response includes activities that are aimed at meeting basic needs such as search and rescue, providing immediate assistance, assessing damage, and immediate restoration of critical infrastructure. Flood response related work for this disaster extended into June 2014 and included opening temporary roadways, assessing exigent needs, and stabilizing structures along the river at further risk from potentially high spring runoff.

Most of the work completed along the river corridor during the response phase was temporary in nature in order to provide access and short-term stability while long-term solutions are planned and implemented. If landowners have had exigent work completed on their property by CDOT, Larimer County, NRCS, or their contractors, it is important they understand that this work was likely intended to be temporary. What these agencies completed in a short time frame was commendable. The response-phase regrading and stabilization of banks completed by these entities will likely not survive a future flood event similar to, and potentially smaller than, what occurred in 2013.

The long-term recovery phase is just beginning along the Front Range. This master plan will provide guidance for this next phase within the BTRRMP corridor. Recovering from a disaster of this magnitude is a long process that will likely take years to complete and require the collaboration of several agencies and individual landowners. There is no guarantee that all of the proposed plans in this report will be completed.

2. MASTER PLAN GOALS

The primary goal of the BTRRMP is to guide recovery towards a more resilient, healthy, and functioning river corridor. This guidance includes proposed structural and non-structural mitigation measures including regrading portions of the floodplain and recommendations to protect homes, businesses, roadways, bridges, and other infrastructure and property within the impacted river corridor. It also includes recommendations for improving the ecological health of the river by restoring aquatic habitat, rehabilitating riparian vegetation, and reconnecting the channel to the floodplain. Giving the river more space will help accomplish both the flood resiliency and riparian restoration goals. Restoring healthy functioning rivers is often the best path to better flood resiliency. However, it is important to understand that some locations have challenges and constraints that prevent the full restoration of some natural processes.

While working to restore, rehabilitate, and enhance this corridor it is important to remember that projects on rivers can impact upstream and downstream properties. Regrading, revegetation, infrastructure improvements, and other potential projects within the floodplain can have positive and negative impacts to neighboring properties. These impacts can be in the form of increased or decreased flooding, increased or decreased risk of erosion and sedimentation, and impacts to the aquatic and riparian ecology that is vital to the health of the river and surrounding areas. One of the objectives of a master plan is to provide a comprehensive plan that looks at reach-wide needs and possible solutions. It benefits all stakeholders involved if projects are completed on a reach-wide basis during long-term recovery. Project reaches are described in Section 4.1.

The River Corridor Protection and Management Fact Sheet provided by Colorado Water Conservation Board (CWCB 2013-a) is a helpful resource that provides a brief overview of some of the issues related to understanding river systems, their inherent risks, and their management.

This is not the first master planning and flood recovery effort along this corridor. The Big Thompson Disaster Recovery Planning Report (Toups 1977) was produced following the 1976 flood. While the purpose and goals of the 1977 master plan were primarily focused on guiding future development, it did contain information related to reconstructing infrastructure to be able to withstand future flooding.

There have also been efforts in the past to learn from the 1976 flood and the recovery process (Gruntfest 1986). According to Gruntfest, "After the Big Thompson flood [of 1976], there was grave resolve that a disaster of this magnitude should never happen again." Some steps towards better flood preparedness and resiliency have been made since the 1976 flood, and are among the reasons there were far fewer deaths during the 2013 flood event. However, there are still more steps to be taken as we not only recover from another disaster, but plan and prepare inevitable future events.

2.1 Resiliency

As the work towards long-term recovery begins, it is important not to merely rebuild to pre-flood conditions, but to restore the river corridor and reconstruct infrastructure in such a way that is more resilient to future flooding.

Incorporating more flood resiliency into the master plan corridor will likely include a variety of approaches. This master plan cannot present every possible solution to making the corridor flood resilient. For instance, the removal of high-risk infrastructure, such as homes, buildings, or roadways, would remove the flood risk and could improve the health of the river corridor. However, the complexity and feasibility of such options is beyond the scope of this plan.

In the canyon reaches the US 34 and CR 43 road embankments both have a large impact on the river corridor. The final alignment of these roadways will either provide greater opportunity or similar existing constraints to the restoration of the river corridor. The BTRRMP encourages CDOT and Larimer County to set back the roadways as much as possible along these river corridors and/or seek alternative alignments for the roadways away from the river. Similar to the roadways, the high number of homes and buildings located adjacent to the river channel limit the amount of restoration work along the river corridor by occupying historic floodplain. The BTRRMP encourages buying properties with high risks and high potential for restoration so long as land owners are willing sellers. Removing roadways and structures from high risk areas will provide more opportunity to fully restore the river while reducing and/or eliminating the flood risk to infrastructure.

Rivers are complex and dynamic systems. In addition to moving water they also transport sediment and debris, all of which increase significantly during a flood. During flood events rivers poses a great quantity of energy and the potential to cause significant damage. Steep river reaches, such as the Big Thompson Canyon, are particularly high energy systems with an even greater potential for damage. Living adjacent to river (riparian) corridors comes with risks from flooding and the resultant erosion and/or deposition of sediment. Floods are the most common natural disaster in the United States according to the National Flood Insurance Program (NFIP). Colorado is no exception, and has incurred $83,000,000 average annual flood damages from 1911 - 2013 (inflation-adjusted 2013 dollars) (CWCB 2013).

Future projects will be designed to withstand specific flood levels, or recurrence intervals, expressed in cubic feet per second (cfs). The recurrence interval, expressed in years, is merely the inverse of the annual exceedance probability. A 100-year event is a flow discharge with 1% annual probability of being equaled or exceeded in any given year (USGS 2010). For example, government entities often regulate development within a "100-year floodplain." In the 1960s the 1% AEP was established as the basis for the NFIP.

Nobody knows, or can claim to know, how often flooding will occur, how large it will be, or how long it will last in a particular river or watershed. Flood recurrence intervals are the best statistical method engineers and planners have at their disposal for planning and design. Floodplains are determined for a variety of recurrence intervals and infrastructure is designed to withstand a variety of flood recurrence intervals depending on what is being protected. For instance, a pedestrian bridge would not ordinarily be designed to withstand the same magnitude of flooding as an interstate bridge.

It may not be possible in some locations within the master plan corridor to design feasible solutions that will protect property and/or infrastructure against large flood events similar to the 1976 and 2013 floods. The proposed solutions included in this plan do not guarantee a specific level of protection. The specific design level and feasibility of each treatment will be determined during future design processes.

2.2 Restoration

The main goal of riparian and aquatic restoration along the Big Thompson River and its tributaries is to improve the floodplain function and instream habitat to create a healthier river corridor.

A properly functioning floodplain in the Northern Front Range area of Colorado contains healthy riparian vegetation and includes trees such as cottonwood and aspen; shrubs such as alder, birch, and willow; and often a dense understory of grasses and forbs. Riparian habitat (including wetlands) provides benefits not only to the aquatic and terrestrial ecology of the area, but also to the people living in the communities within and near the river corridor. These benefits or "ecosystem services" are mostly driven by overbank flooding and include elements like water quality improvement, flood attenuation, groundwater recharge, support of both aquatic and terrestrial wildlife habitat, and recreation/tourism.

The degree to which key services are provided depends on many factors, including the relative size of the habitat/floodplain. For instance, reaches along the North Fork and portions of the Big Thompson west of Loveland are ideal locations to restore aquatic habitat. However some sections of narrow canyons are bounded by exposed bedrock and have less potential for riparian vegetation habitat (and the resulting services) than the broad floodplain of the lower reaches where there is a large amount of undeveloped floodplain, including gravel mining ponds.

Much of the riparian habitat in the river corridor was removed or severely degraded by the high velocity flood flows in September 2013, resulting in the reduction and/or elimination of many ecosystem services along these reaches. Plant communities must be restored to regain the ecosystem services lost, and appropriate in-stream structure and pocket habitat (underwater pockets created by large boulders) should be created within the main channel to improve aquatic habitat. Large woody material (LWM) should be incorporated within the floodplain and/or channel where appropriate. LWM provides additional organic material, habitat variability, cover for fish, creates scour pools within the channel, and encourages deposition of sediment within the floodplain. LWM should be used primarily in the lower gradient reaches. There may be appropriate locations to use LWM in the high gradient reaches, but may be difficult to maintain of high velocities that occur during high flows.

Restoration can be accomplished by ensuring that available floodplain areas are left undeveloped and that they are reconstructed at the appropriate elevations to be connected to the river via seasonal overbank flooding and/or shallow (alluvial) groundwater flow. This will provide the conditions needed for the establishment and long-term survival of riparian vegetation.

Healthy functioning river corridors are an ideal means of creating better flood resiliency. As long-term recovery begins, the restoration of this corridor should aim to improve the flood resiliency by restoring functioning floodplains.

3. ASSESSMENTS

Multiple assessments were conducted as part of the BTRRMP to understand current conditions due to impacts from the 2013 flood as well as from historic and existing land use practices within the river corridor. Four assessment metrics were identified to prioritize restoration needs within the Master Plan assessments area: 1) Geomorphic Risk, 2) Flood Risk, 3) Aquatic Habitat Improvement Potential (AHIP), and 4) Riparian Ecological Improvement Potential (REIP). All assessments were completed before specific project reaches were assigned. The assessments were used to create the Multi-Criterion Decision Analysis (MCDA) tool.

The assessments were conducted using a combination of best available digital data as well as site visits as needed and feasible. Conditions along the corridor were often changing as temporary roadway repairs, bank protection, regrading of eroded banks, rerouting of the channel, and additional flood response activities were ongoing. Imagery, topographic LiDAR, and other data used for all the assessments included the following:

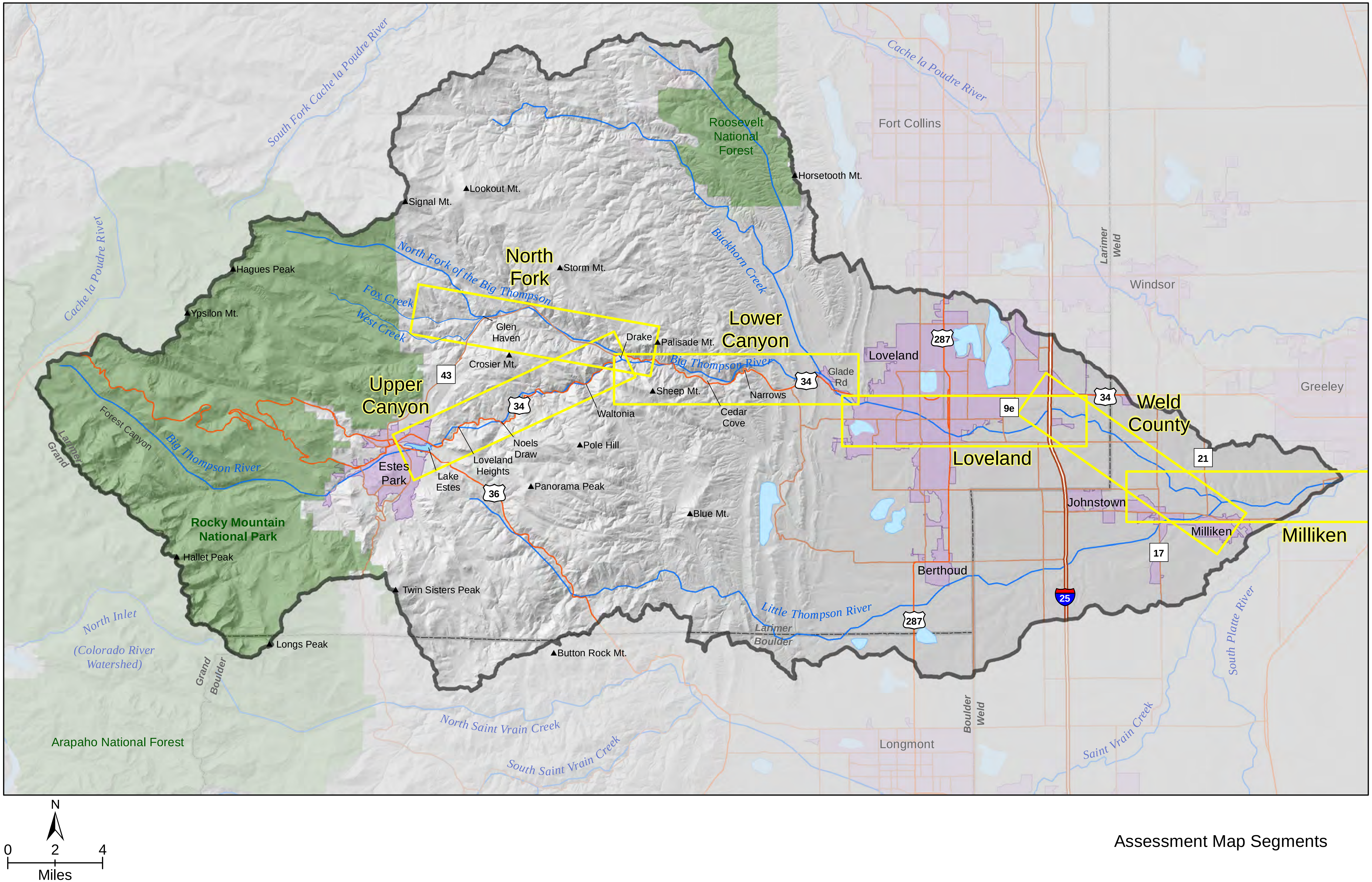
Table 3.1. Digital Data Sources.

			Availability	
	Source	**Date**	**Public**	**Private**
Imagery	Larimer County	May 2013	x	
Imagery	City of Loveland	May 2013	x	
Imagery	City of Loveland	Sept. 14, 2013	x	
Imagery	Larimer Emergency Telephone Authority (LETA)[1]	Oct. 2013		x
Imagery	Digital Globe[1]	Sept. 2013		x
Imagery	National Agriculture Imagery Program (NAIP)	2011 & 2013	x	
Imagery	Imagery available via Google Earth	Multiple	x	
Imagery	Civil Air Patrol oblique imagery	Sept. 2013	x	
Imagery	CDOT oblique imagery[1]	Sept. 2013		x
Imagery	Historic imagery, multiple sources	1976 Flood	x	
LiDAR	Larimer County	May 2013	x	
LiDAR	City of Loveland	May 2013	x	
LiDAR	FEMA (preliminary)	Nov.2013	x	
GIS	Larimer County Parcels	Varies	x	
GIS	City of Loveland Utilities[2]	Varies		x
GIS	FEMA Flood Hazard Areas	Varies	x	

1 – Imagery for the Big Thompson corridor is available for use by agencies involved with flood recovery and river restoration work.

2 – Municipal utility information is subject to Homeland Security regulations and is available upon request for agencies and for select areas by the public.

Maps displaying the assessment results were divided up into four segments: the Upper Canyon, Lower Canyon, Loveland, and North Fork, **Figure 3.1**. All assessment maps and tables are included in Appendix B.



Assessment Map Segments

Figure 3.1

3.1 Geomorphic Risk

The Geomorphic Risk (GR) is a qualitative assessment, conducted by Ayres Associates, that comparatively scores the degree of erosion and/or deposition that occurred during the 1976 flood, the 2013 flood, and the potential risk of erosion/deposition from future flood events. Both the 1976 and 2013 floods made this risk very evident. During floods, rivers can scour vertically and laterally, eroding both stream bottom and banks. This is due to natural processes and/or as a result of impacts from development in the riparian corridor. Because rivers in flood can transport a significant amount of sediment, flooding may also result in deposition of that sediment within the main channel and on floodplains. Both of these impacts occurred throughout the master plan corridor, and similar types of erosion and deposition will occur in future floods.

Ayres Associates conducted multiple field and desktop assessments, using the data listed in Table 3.1, of the changes to the geomorphic characteristics of the BTRRMP corridor following the 2013 flood through May 2014. The information obtained from these assessments was used to determine the GR scores.

GR scores were assigned to the main channels throughout the entire master plan corridor. East of the canyon mouth the channel is often more stable and the geomorphic risk can be greater on the floodplains. Therefore, east of the canyon mouth the floodplains received a GR score when required. Areas with a high GR received a 5, and areas with a low geomorphic risk received a 1, as shown in **Table 3.2**.

Example areas showing pre- and post-flood imagery of GR scores of 5, 3, and 1 are provided in **Figures 3.2, 3.3, and 3.4**, respectively. The example images for areas with a GR score of 5 include areas of deposition, channel migration, new split flow development, severely eroded embankments, and removal and transport of a large amount of sediment. The example images for areas with a GR score of 3 include areas of channel widening, moderate floodplain deposition, bank erosion, channel widening, headcuts developing in floodplain, and local areas of erosion. The example images for areas with a GR score of 1 show minor bank erosion along the channel and no channel movement.

Table 3.2. Geomorphic Risk Scores.

Score	Geomorphic Risk
5	Areas that experienced **significant** erosion/deposition during historic flooding and/or area at a high risk of erosion/deposition from future flooding
4	
3	Areas that experienced **moderate** erosion during historic flooding and/or area at a moderate risk of erosion/deposition from future flooding
2	
1	Areas that experienced **minimal** erosion/deposition during historic flooding and/or area at a low risk of erosion/deposition from future flooding

Figure 3.2. Example GR = 5 at Cedar Cove.

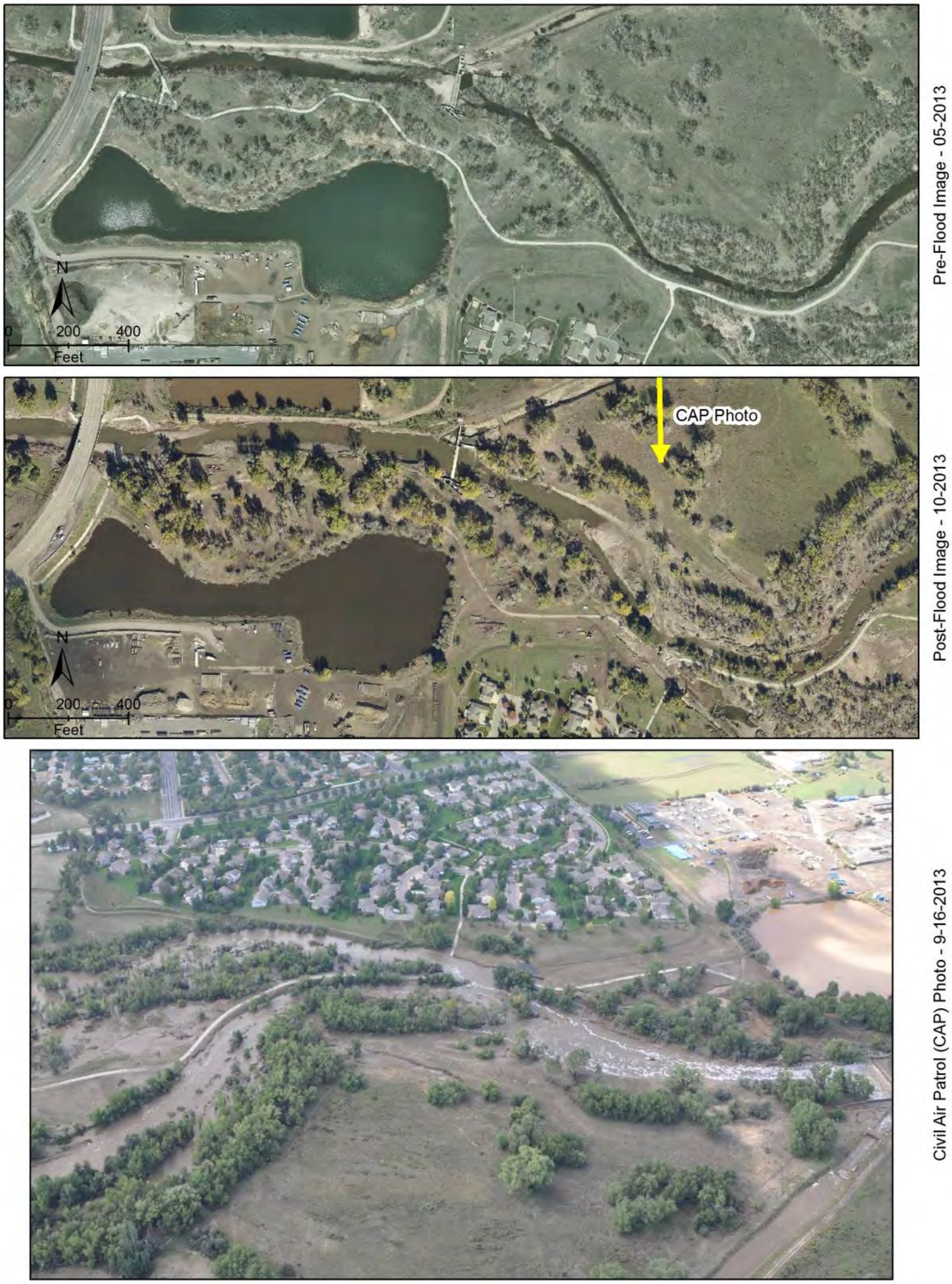


Figure 3.3. Example channel and floodplain GR = 3 downstream of Wilson Avenue in Loveland.

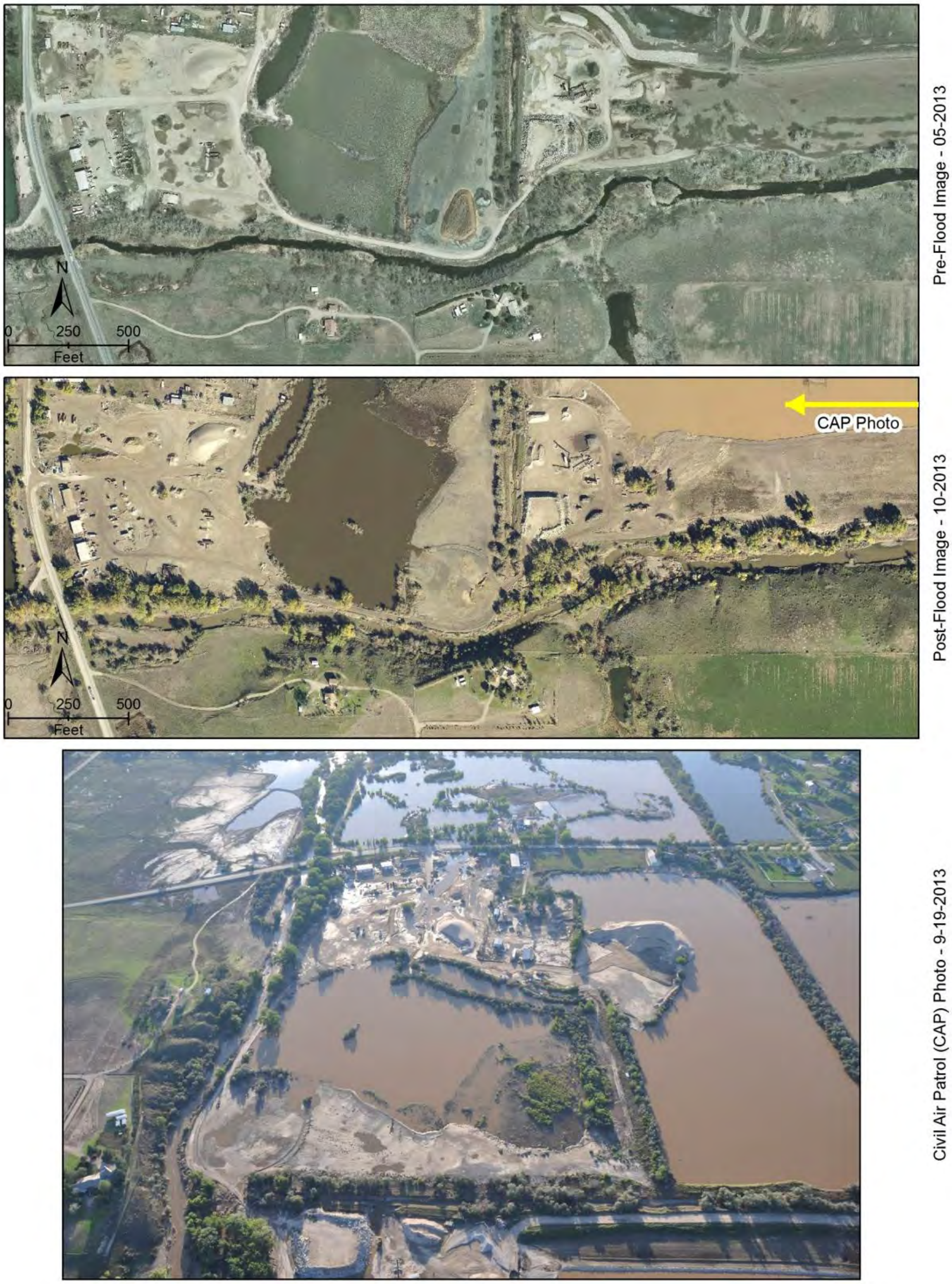


Figure 3.4. Example channel GR = 1 and floodplain GR = 3 downstream of County Road 9E in Loveland.

A few common issues were present throughout the entire BTRRMP corridor. Areas that are unnaturally constricted due to development and infrastructure were also the areas of highest erosion and subsequent flood damage. If the flood has less space to spread out the velocity, depth, and shear stress all increase, leading to increased flooding and erosion potential. Second, debris was a significant factor leading to increased erosion throughout the corridor, especially at bridge crossings. Third, almost all floodplain areas received some amount of deposition throughout the corridor. Deposition occurred in varying amounts at different locations, but was present throughout the study area.

Upper Canyon. The upper canyon segment, Figure 3.1, experienced erosion along the main channel and erosion and deposition in the isolated small floodplains that exist throughout this segment. Several areas at the downstream extents near Waltonia and Drake experienced the most damage in this segment from channel widening, bank erosion, channel shifting, and areas of sediment deposition which impacted both US 34 and the opposing bank including locations with homes and other structures. Overall, the upper canyon received the least amount of erosion and deposition compared to the other segments.

North Fork. The North Fork and upper tributaries were similar to the lower canyon segment. The upper tributaries had significant erosion with channel widening and roadway erosion. Significant portions of West Creek and the North Fork downstream of Glen Haven experienced severe erosion. Large portions of CR 43 and all its culvert crossings were destroyed in this segment. The channel widened in several locations with both erosion and deposition occurring where floodplains existed. At the downstream portion of this segment the channel also migrated laterally in locations with flatter, open valleys and larger floodplains.

Lower Canyon. The lower canyon experienced some of the most severe areas of erosion. US 34 was significantly damaged throughout this segment. Some sections of roadway were completely removed. Locations along the outsides of bends and near local access bridges were the most impacted. The highway through the Narrows also experienced damage from overtopping flow as well as erosion at and behind the toe of the wall that led to the failure of several sections of roadway. The channel migrated and/or widened along most of this segment. The larger flat valley sections, such as Cedar Cove, experienced areas of deposition and channel shifting similar to the Drake area. Several homes were lost or damaged in this section primarily due to the amount of erosion that occurred.

The transitional area from the canyon mouth to the western edge of Loveland was also severely impacted. This area experienced a large amount of sediment deposition as the flood waters exited the canyon. East of the Narrows the gradient decreases and the floodwaters begin to have access to larger floodplains. This resulted in lower velocities leading to the deposit of large amounts of material (sediment, boulders, and flood debris). These areas also experienced significant erosion as the channel migrated into the floodplain in several locations.

Loveland. Within the Loveland area the channel is constricted and cut off from the floodplain in several locations. Because of this constriction, the flood avulsed into several old gravel pits at multiple locations within Loveland. At other locations in this segment the floodplains experienced varying degrees of deposition and erosion in the form of headcuts. The main channel did experience some erosion and widening, specifically near bridge crossings; however, it was not significant compared to other segments in the corridor.

Eastern Plains. Most reaches east of I-25 have low channel geomorphic risk with a few areas of medium risk. The medium risk reaches include areas with road and railroad alignments constricting and/or crossing the floodplain. A floodplain geomorphic risk was only assigned to a few floodplain reaches in this segment. While there was some deposition and erosion within the floodplains it was minor compared to reaches upstream. Some results of the flood even have had a positive impact on this segment. For example, cattle trampled banks have been cleaned up as a result of channel margin erosion and deposition. Bars have been revitalized and new low-flow bars and flow splits have formed along with a few cutoffs of tight meander bends.

3.2 Flood Risk

The Flood Risk (FR) assessment, conducted by Ayres Associates, attempts to identify and qualitatively score flood risks for infrastructure located within the flood hazard areas identified by FEMA. Flood hazard maps used by FEMA existed for the master plan corridor prior to the 2013 flood. These maps were created and updated at various dates since the 1980's and with varying degrees of accuracy throughout the corridor. Updated floodplain mapping was not available during the master plan process, and likely won't be available until well into the long-term recovery phase.

In some locations the river and/or floodplain experienced significant changes that will impact the floodplain extents. The canyon segments experienced the greatest changes due to the 2013 flood and had noticeable errors in the effective mapping extents and location. New approximate floodplain extents were developed for the canyon segments. Preliminary FEMA post-flood LiDAR data was used to remap the effective 100-year water surface elevations for the canyon areas. This created an approximate, but slightly more accurate floodplain compared to using the effective floodplain locations.

The Loveland area floodplain mapping was completed in 2005 and represented the 2013 flood extents very well. For the portions of the BTRRMP within Weld County, recent pre-flood flood hazard mapping data was used for this assessment. These segments experienced areas of erosion and deposition; however, these changes likely had minimal impacts to the floodplain since it is wider east of the canyon. For these reasons, the effective floodplain information was used throughout the Loveland and Eastern Plains segments.

An example of some floodplain designations are provided in **Figure 3.5** (see the NFIP Flood Smart website for additional information related to flood maps and flood risk). These designations were used to create the FR scores shown in **Table 3.3** and **Figure 3.6**. This data set is an attempt to comparatively score similar types of infrastructure within the master plan corridor. Due to outdated floodplain mapping, changing conditions during flood response, lack of complete GIS data of structures and utilities, and temporary condition of some repairs, this dataset may not reflect current conditions.

The greatest amount of infrastructure within the floodplain was located below the canyon near Glade Road and at a few locations within the City of Loveland up- and downstream of Lincoln Avenue. However, most of the infrastructure in the canyon sections had higher individual scores since the floodway is almost equal to the entire floodplain extents in the canyons. The floodway represents the channel of a river and the adjacent land that must be reserved in order to discharge the base flood (typically the 100-year flood) without increasing the water surface elevation more than a designated height. These include locations near Rock Canyon, Loveland Heights, and the upper tributaries of the North Fork. The area near Jasper Lake Road has the highest amount of infrastructure in the canyon. There are a few areas within the canyon and in the transitional area between the canyon and Loveland that have little to no infrastructure located in the floodplain. The highest floodplain risk east of Loveland is primarily due to natural gas wells and road and railroad embankments and bridges.

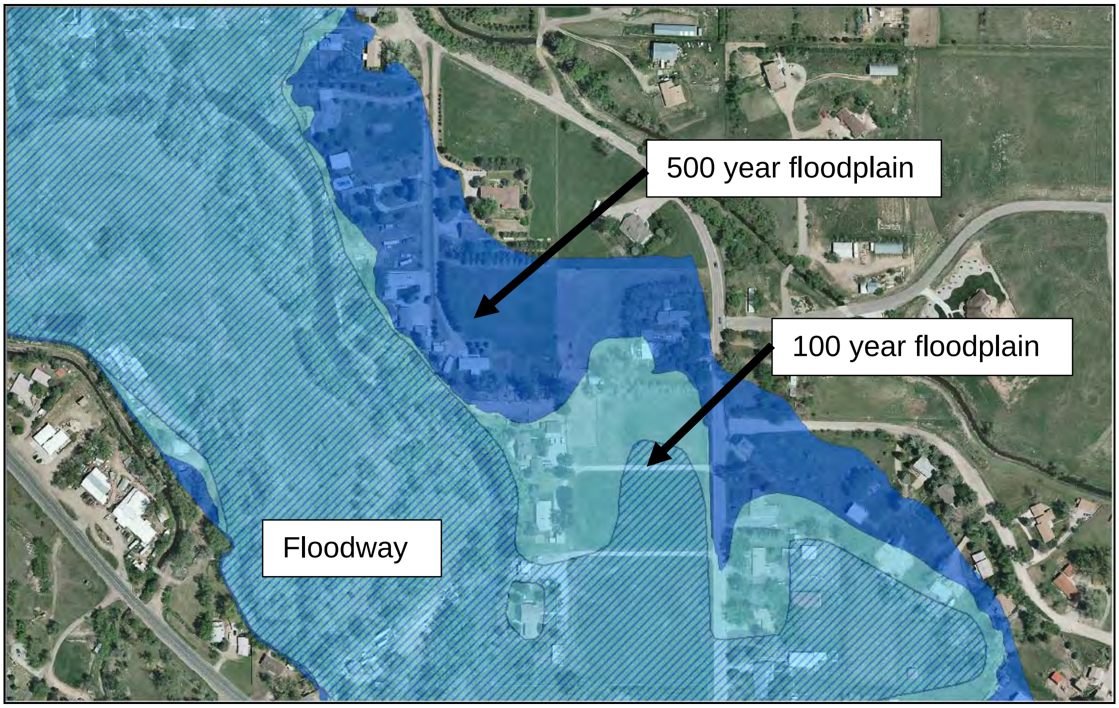


Figure 3.5. FEMA floodplain designations.

Table 3.3. Flood Risk.

Score		Flood Risk
(red)	5	Infrastructure located in the floodway
(orange)	4	Infrastructure located on the floodway/100-year floodplain fringe
(yellow)	3	Infrastructure located in the 100-year floodplain
(green)	2	Infrastructure located on the 100-year/500-year floodplain fringe
(blue)	1	Infrastructure located in the 500-year floodplain

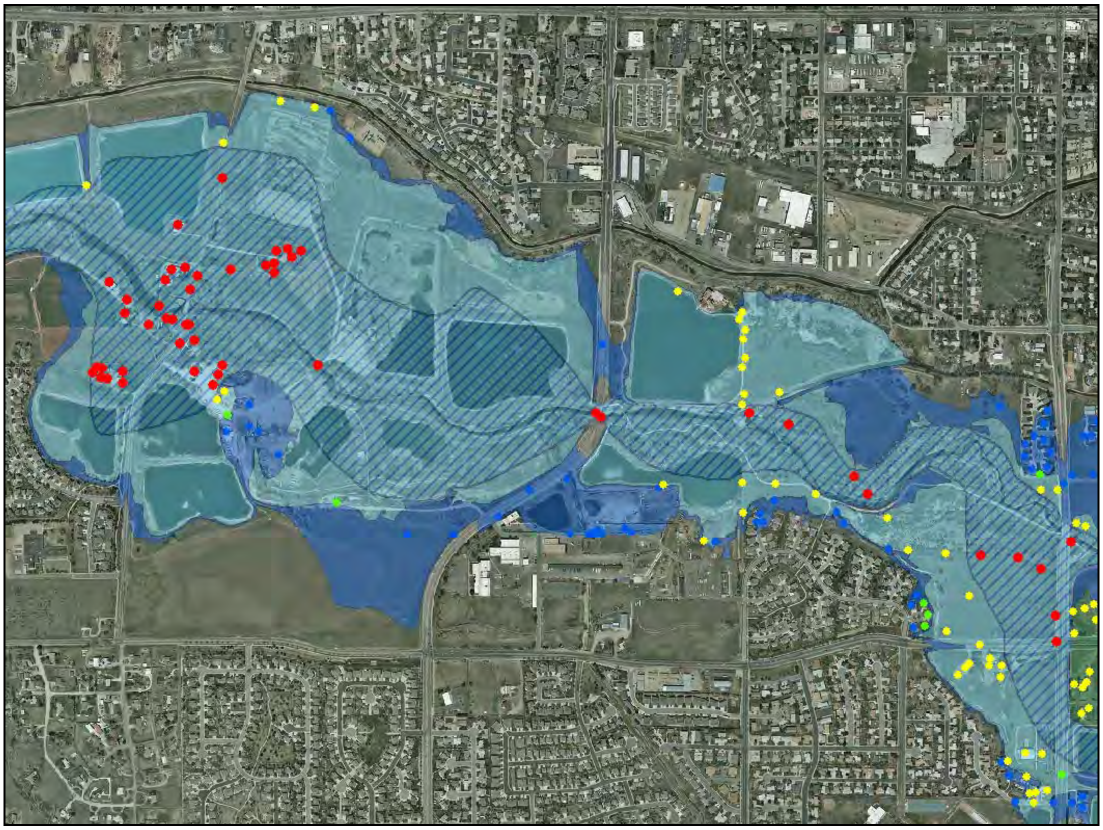


Figure 3.6. Example FR scores.

3.3 Aquatic Habitat Improvement Potential

Miller Ecological Consultants, Inc. (MEC) conducted the qualitative Aquatic Habitat Improvement Potential (AHIP) assessment. Field work was completed for the four western segments on May 19, 2014, and on the two eastern segments in January, 2015. The assessment evaluated aquatic habitat based on the scale provided in **Table 3.4**. MEC used visual observations and aerial imagery to rate each reach of river. Though this assessment did not include the evaluation of riparian vegetation, the restoration of riparian vegetation is a needed improvement related to overall aquatic habitat health.

Table 3.4. Aquatic Habitat Improvement Potential Scores.

Score	Typical Characteristics of the Reach
5	Areas that have little to no instream habitat variability
3	Areas that have minimal aquatic habitat variability and would benefit from restoration
1	Areas that have some aquatic habitat variability and need little restoration
0	No restoration needed

In addition to assigning AHIP scores, MEC also identified fish passage barriers within the master plan corridor. These include features such as diversion dams, culverts, and grade control structures. Some structures were damaged during the flood and may be removed, but were still identified. Fish passage barriers do not impact the AHIP score, but are shown on the maps provided in Appendix B and C.

Upper Canyon. The Big Thompson River from Olympus Dam downstream to the confluence with the North Fork had the most intact and relatively good post-flood aquatic habitat (**Figure 3.7)**. The banks are generally vegetated and stable and have suitable in-channel habitat typical of a high gradient mountain river. Aquatic habitat in these sections includes cascades, high gradient riffles and plunge pools. The pools provide refuge habitat during low flows.

There are several sites between the dam and the North Fork confluence with lower gradient where the channel is braided post-flood, which resulted in extremely shallow, wide habitats that may be passaged impediments or result in dry channels during low flow conditions. These areas would benefit from some restoration work (**Figure 3.8)**. These sections received an AHIP score of 3. These areas would benefit by restoring the channel to a single thread with appropriate habitat diversity of riffle-pool sequence while maintaining connection to the floodplain to improve habitat during summer and winter flow conditions.

The upper canyon had evidence of severe bank erosion and downcutting. The substrate in this reach ranges from bedrock to gravel. Predominate substrate is very large boulders. There are several locations where the bed movement of the large boulders resulted in waterfalls or cascades several feet high. These locations are likely impediments to movement by aquatic species. Since they are natural features, restoration is not recommended at this time; however, these sites should be the subject of further evaluation for future fish passage improvements.

The river channel at the lower end of the canyon upstream of the North Fork confluence has several locations that received a score of 3. These sections were over widened due to the high flood flow and the habitat was mainly limited to wide shallow riffle habitat (**Figure 3.9)**. These sections would benefit from restoration to a narrow channel and by the creation of holding habitat (areas that provide refuge from high velocity and preferred locations for feeding fish) with large boulders.

The temporary road and channel work conducted by the CDOT and others has modified the post-flood channel conditions in some areas. Most of these sections have large boulder riprap placed along the channel banks to prevent channel movement and erosion. While the channel banks and overbank areas need restoration, the in-channel features in most of these areas do provide habitat typical of this high gradient river (**Figure 3.10)**. The channel contains large boulders that create drops and pools similar to the habitat in the undisturbed areas. There is a lack of riparian vegetation in these areas which has a negative impact on the aquatic habitat.

North Fork. Upper reaches of the North Fork of Big Thompson River and tributaries show only minor localized areas where aquatic restoration is recommended. The most severe flood damage related to aquatic habitat is on West Creek and the main stem of the North Fork near Glen Haven (**Figure 3.11)**. In contrast, middle and lower sections of North Fork, did sustain damage to aquatic habitat and fisheries; therefore, much of this reach and the main stem of the North Fork down to the confluence with Big Thompson received a score of 3 or 5.

Figure 3.7. Big Thompson downstream of Olympus Dam, AHIP = 0.

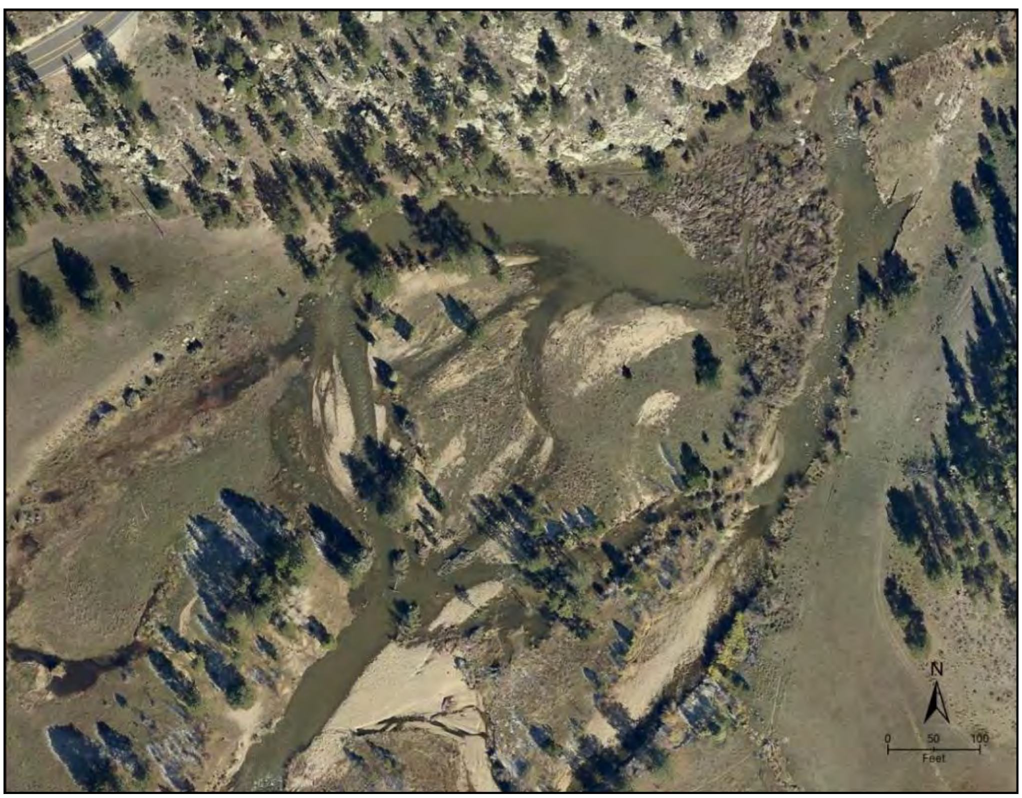


Figure 3.8. Big Thompson downstream of Olympus Dam, split flow, AHIP = 3.

Figure 3.9. Big Thompson upstream of the North Fork, widened channel, AHIP = 3.

Figure 3.10. Example of post flood channel modification and bank stabilization, but with good in-channel features. (Drake).

Figure 3.11. Section of West Creek that experienced degradation and aggradation, AHIP = 5.

Lower Canyon. The lower canyon had the most severe flood damage of all segments evaluated. The increased flow in this section resulted in large areas of the channel with sediment degradation and/or aggradation. There are many areas that received an AHIP score of 3 and several with a score of 5. An example of the sediment movement and channel change is shown in **Figure 3.12**. This example at Viestenz-Smith Mountain Park was formerly vegetated with large trees, willows, and grasses. This segment is typical of the areas with an AHIP score of 3. The in-channel habitat is moderate to low with some features such as large boulders and high gradient riffles that provide some habitat. There are many areas similar to this location in the lower canyon.

The river channel from the mouth of the canyon downstream to Glade Road was also highly modified by the flood. Areas experienced both severe degradation and aggradation (**Figure 3.13)**. Most of the upper portion of this reach received an AHIP score of 5. At the time of the field evaluation, some restoration activities were underway. The majority of the stream channel in the upper portion of this reach is riffle habitat with very little run or pool habitat. The downstream section of this reach is an unconstrained floodplain area where the flood flows occupied the overbank areas and deposited fine sediment.

Figure 3.12. Example of sediment movement and channel change.

Loveland. The AHIP assessment relied on aerial imagery for the assessments downstream of Glade Road through Loveland. The reach from Glade Road downstream to I-25 has some need for restoration although it is less than the needs upstream of Glade Road. There are sections with some damage to in-channel habitat but they are smaller, localized sections. The channel is confined through much of this segment, and lacks access to the floodplain for low flood flows. The channel is also over widened at some locations due to flooding and/or post flood repairs (**Figure 3.14**).

Eastern Plains. The reaches east of I-25 have a wider floodplain with flows accessing the floodplain during the 2013 flood. This resulted in only minor localized damage to in-channel habitat. Most of this area received an AHIP score of either 1 or 3. Some of the sections with a score of 1 may actually be scored 0 with additional field verification. The majority of sections with a score of 3 were near bridge crossing. Two examples of these areas are near CR 17 (**Figures 3.15 and 3.16**) and CR 21. The river through most of the eastern segments is a low gradient stream with smaller substrate than the upstream reaches. Substrate ranges from silt to small cobbles. The river meanders more than in the upstream reaches which creates pools on the meander bends. During large flood events the channel has better access to some areas of the floodplain compared to upstream reaches. This may be the reason for less damage to the channel during the 2013 flood.

Figure 3.13. Areas east of the canyon mouth that experience degradation and aggradation, AHIP = 5.

3.4 Riparian Ecological Improvement Potential

As a result of the 2013 flooding, much of the existing riparian vegetation along the Big Thompson River, including the North Fork, was lost or damaged. In addition, current and historic land use practices in the watershed have resulted in the loss or degradation of riparian habitat. The Riparian Ecological Improvement Potential (REIP) is a qualitative assessment, conducted by AlpineEco, of the condition of the riparian vegetation along the river scored in terms of the restoration potential that exists.

Field surveys were conducted for the western four segments of the BTRRMP corridor on May 5, 8, and 9, 2014 and the eastern two segments during January 2014. Most field surveys were performed in areas accessible by roads; various areas were walked to collect additional data on plant species present and severity of flood damage. Each assessment reach was given a score of 1 to 5, with 1 having low potential for restoration and 5 having high potential. Rating of river reaches for riparian vegetation restoration potential is based on many factors. **Table 3.5** summarizes these factors in the list of characteristics. Representative photographs for each rating are shown in **Figures 3.15 – 3.29**.

Table 3.5. Riparian Ecological Improvement Potential Scores.	
Score	**Typical Characteristics of the Reach**
5	• Large to very large amount of undeveloped floodplain available, namely gravel pond complexes • Little riparian vegetation present in suitable areas and/or very large areas of disturbed ground • Incised or confined channel with disconnected floodplain
4	• Moderate to large amounts of undeveloped floodplain available, including gravel ponds or agricultural land • Some riparian vegetation present in suitable areas but often large areas of disturbed ground • Incised or confined channel with disconnected floodplain
3	• Moderate amount of undeveloped floodplain available • Some riparian vegetation still present in suitable areas
2	• Very small amount of undeveloped floodplain available; usually very narrow and/or discontinous • Some riparian vegetation still present in suitable areas
1	• Very little or no floodplain available • Steep canyon walls with exposed bedrock and/or large boulders along channel • Very little soil present • Relatively intact riparian habitat
*One or more characteristics present for each rating	

Figure 3.14. Example of post-flood stream channel at downstream of Wilson Avenue, AHIP = 1 - 3.

Figure 3.15. Example of post-flood stream channel at Weld County Rd 17, AHIP = 3.

Figure 3.16. Example of post-flood stream channel at Weld County Rd 17, AHIP = 3.

Figure 3.17. Upper Canyon, narrow rocky section with little to no floodplain, REIP = 1.

Figure 3.18. North Fork, narrow rocky section with little to no floodplain, REIP = 1.

Figure 3.19. Upper Canyon, narrow floodplain area including road and structures, REIP = 2.

Figure 3.20. North Fork, narrow floodplain area, REIP = 2.

Figure 3.21. Upper Canyon (Waltonia), some undeveloped floodplain with little vegetation, REIP = 3.

Figure 3.22. Loveland area, some undeveloped floodplain with little vegetation, REIP = 3.

Figure 3.23. Eastern Plains, upstream of CR 27.5, REIP = 3.

Figure 3.24. Loveland area, wide undeveloped floodplain, REIP = 4.

Figure 3.25. North Fork, wide undeveloped floodplain, REIP = 4.

Figure 3.26. Eastern Plains, near CR 52, REIP = 4.

Figure 3.27. Lower Canyon, very large floodplain almost no vegetation, REIP = 5.

Figure 3.28. Loveland area, very large floodplain almost no vegetation, REIP = 5.

Figure 3.29. Eastern Plains, downstream of CR 54, REIP = 5.

It should be noted that the intent the REIP is to prioritize reaches of the BTRRMP corridor for riparian restoration. As such, those reaches that naturally contain very little riparian vegetation because there is minimal suitable land area (i.e. reaches that naturally lack a floodplain or that have exposed bedrock/large boulders) generally scored low. This does not mean that riparian habitat in these areas is not important, especially in terms of local benefits to aquatic and terrestrial habitat and erosion protection. However, most of these areas would naturally only contain riparian vegetation that is in very small patches which are often sparsely vegetated and ephemeral (i.e. frequently lost in large flow events). Additionally, they can be difficult to restore as a result of the lack of soil/nutrients and the struggle to get plant material established between flood events. Thus, these reaches scored lower because they have a somewhat limited capacity to benefit the overall watershed and can be costly to restore. This is in contrast to the reaches with a larger floodplain where substantial riparian habitat would naturally be present, and if restored, would provide the most benefit to the overall system for the effort and money expended.

For the purpose of this assessment the term "riparian vegetation" describes woody vegetation that is found along waterways and is dependent on the surface and groundwater associated with those waterways. The riparian plant associations found in the BTRRMP corridor have an overstory dominated by cottonwood (*Populus* spp.) and a shrub layer usually dominated by willow (*Salix* spp.). At elevations of 6,000 feet above sea level and higher the shrub layer is often dominated by water birch (*Betula occidentalis*) or thinleaf alder (*Alnus incana* ssp. *tenuifolia*) instead of willow. The most common riparian plant associations found in the BTRRMP assessment area, as defined by Carsey et al. (2003), are listed in **Table 3.6** along with additional information on other woody species observed and the general location. All plant nomenclature in this section follows the PLANTS Database (NRCS 2014).

Table 3.6. Common Riparian Plant Associates Found in the Study Area.			
Common Name	**Scientific Name**	**Other Common Woody Species Observed**	**General Location**
Narrowleaf cottonwood/ water birch	*Populus angustifolia/ Betula occidentalis*	Narrowleaf willow (*Salix exigua*) Drummond's willow (*S. drummondiana*) Mountain willow (*S. monticola*) Quaking aspen (*Populus tremuloides*) Thinleaf alder (*Alnus incana*)	Big Thompson and tributary canyons above about 6,000 feet
Narrowleaf cottonwood/ thinleaf alder	*Populus angustifolia/ Alnus incana ssp. tenuifolia*	Narrowleaf willow (*Salix exigua*) Drummond's willow (*S. drummondiana*) Mountain willow (*S. monticola*) Quaking aspen (*Populus tremuloides*) Water birch (*Betula occidentalis*)	Big Thompson and tributary canyons above about 6,000 feet
Plains cottonwood/ narrowleaf willow	*Populus deltoids/ Salix exigua*	Peachleaf willow (*Salix amygdaloides*) Crack willow (*S. fragilis*) Russian olive (*Elaeagnus angustifolia*) Boxelder (*Acer negundo*) Siberian elm (*Ulmus pumila*) Chokecherry (*Prunus virginiana*) Western snowberry (*Symphoricarpos occidentalis*)	Canyon and floodplain below about 6,000 feet
*Plant associations from Carsey, et al. 2003			

Upper Canyon. The large majority of the upper canyon segment has a REIP score of 2 to 3. This is mainly the result of the general lack of floodplain areas. The canyon is relatively narrow and most of the small areas of floodplain that do exist are not suitable for restoration since they contain US 34 and/or residential development. There are two reaches in this zone with a score of 1 and two with a score of 4.

The reaches with higher restoration potential in the upper canyon segment are those that generally have a wider undeveloped floodplain with little or no riparian vegetation present. The reaches with low scores are those that are very confined, very rocky, and/or have exposed bedrock in and along the channel. Many reaches in this segment with REIP scores of 2 to 4 still contain substantial stands of willow along the immediate banks. Some of the reaches with a score of 1 naturally contain little or no vegetation on the banks of the channel. In high gradient, high energy reaches, very little, or no, riparian vegetation naturally exists immediately adjacent to the bank full channel. These reaches will likely have exposed bedrock and/or large boulders as channel banks. Vegetation may establish in these reaches, but only in small isolated pockets.

North Fork. The REIP scores along the North Fork and tributaries are highly varied with most of the upper reaches receiving a score of 1, 2, or 3, except for the reach of West Creek through the town of Glen Haven which has a score of 4. Most of the lower reaches scored as a 3 or 4. Similar to the upper canyon, the reaches scored as having the highest restoration potential are those that have wider undeveloped floodplain with little or no riparian vegetation present. The reaches with lower scores are those that are more confined and/or rocky. The uppermost reach of the North Fork and tributaries all received a score of 2. This is mainly a result of the lack of undeveloped floodplain and the natural absence of riparian vegetation in many areas. The pre- and post-flood habitat along the banks is mainly evergreen forest, not riparian vegetation, dominated by lodgepole pine (*Pinus contorta*) and Douglas fir (*Pseudotsuga menziesii*), and houses that are built right on channel banks in many locations. Thus, there is very little opportunity for riparian vegetation because of development, relatively narrow canyon, rocky soil, and shading from the forest.

Lower Canyon. The REIP scores in the lower canyon are highly varied, with most reaches either scored as a 2 or 5. One reach is scored 1 and two are scored 3. Similar to the upper canyon, the reaches with a score of 5 are those areas that have a wider undeveloped floodplain with little or no riparian vegetation. These are generally located in areas where the channel is slightly flatter and where there was substantial sediment deposition on the floodplain during the flood. Many of these areas have been reconstructed since the flood and the only riparian vegetation left is widely scattered cottonwoods and occasional other trees. While this sediment is often low in organic material and adding soil amendments would generally increase the success of restoration, adding amendments at this scale may be cost prohibitive. Restoration of these areas is still attainable without adding soil amendments, it will just take longer and it may be difficult to obtain a high diversity of desirable plant species.

The reaches with a REIP score of 2 are similar to those in the upper canyon and generally lack floodplain areas because of the relatively narrow canyon or because those small areas of floodplain that do exist are not suitable for restoration since they contain US 34 and/or residential development. The two reaches with a score of 3 have a slightly wider undeveloped floodplain with little or no riparian vegetation present. The Narrows has a score of 1 which is a result of the narrow, rocky canyon with extensive exposed bedrock in and along the channel.

Loveland. East of the canyon mouth to I-25, nearly all of the reaches have REIP scores of 3 to 5, except for one short reach near the CR 29 crossing which has a score of 1 as a result of the narrow rocky canyon. Generally, the reaches that have high scores are those that contain very large areas of undeveloped land, mainly gravel ponds. In many cases, these reaches have large areas devoid of riparian vegetation, either from scouring or deposition associated with the flooding. Additionally, many of these reaches did not contain much riparian vegetation before the flood because the river has been disconnected from its floodplain as a result of down-cutting and/or the installation of levees. Commonly, the only riparian vegetation present in these reaches before the flood was a narrow ribbon of cottonwoods and other trees, and some shrubs immediately adjacent to the channel. Much of this vegetation is still present.

Reaches in this segment with a REIP score of 4 are mostly those that contain large areas of undeveloped floodplain, including some gravel ponds but mainly agricultural lands. Similar to those reaches with a score of 5, many of these reaches did not contain much riparian vegetation before the flood because the river has been disconnected from its floodplain as a result of down-cutting and/or gravel mining. Reaches near I-25 scored in these categories, as well as portions of the river through eastern Loveland where substantial development is present near the channel. These reaches, and a few east of I-25, hold some of the most valuable restoration potential in the corridor. They include dozens or even hundreds of acres of former riparian habitat that could be restored by reconnecting the channel to its floodplain.

The reaches in this segment with a REIP score of 3 are those that contain development relatively close to the channel, have a more confined and narrow floodplain, or still contain substantial areas of riparian vegetation. These reaches are mainly scattered through the City of Loveland.

Eastern Plains. Most of the reaches in this segment have REIP scores of 4 to 5 with a few areas with a score of 3. There is one area near the confluence which has the lowest potential for improvement in the eastern segment with a score of 1. Nearly the entire segment is characterized by large areas of undeveloped land along the channel with agriculture dominating the landscape. The main differentiating factor between a score of 3 and 5 is the amount of existing riparian vegetation on the floodplain.

Generally, the reaches that have a REIP score of 5 are those that contain both gravel ponds and/or agricultural lands with very little existing riparian vegetation. Most of these reaches did not contain much riparian vegetation before the flood because the river has become disconnected from its floodplain as a result of down-cutting, the presence of levees, the encroachment of agricultural or gravel mining activities, and/or changes in hydrology due to diversions upstream. Commonly, the only riparian vegetation present in these reaches before the flood was widely scattered cottonwood and Russian olive (*Elaeagnus angustifolia*), with some pockets of shrubs. Much of this vegetation is still present.

Reaches in this segment that scored a rating of 3 or 4 are those that contain noticeably more riparian vegetation and/or the floodplain appears to be more connected to the river channel (less entrenchment, fewer levees, etc.). The riparian vegetation in these reaches consists of cohesive stands of mature cottonwood mixed with pockets of native shrubs. Russian olive is still very common in these reaches and is co-dominant with cottonwood in many locations.

These reaches also contain some secondary channels and oxbows which are more characteristic of the braided channel system that was likely found here historically. Although this provides more habitat diversity and lowers the potential for restoration slightly (since these features are already present), these reaches still have good restoration potential since: 1) much of the historic floodplain is dominated by agriculture, 2) the amount of riparian vegetation present, including that associated with secondary channels and oxbows, is still less than what would normally be present (as a result of some channel incision, levees, diversions, and general land disturbance), and 3) non-native species are a substantial component of the existing riparian vegetation (namely Russian olive).

The short reach at the confluence with the South Platte River has minor potential for restoration mainly because it is less confined and/or affected by agricultural activities and contains substantial riparian vegetation.

4. MULTI-CRITERION DECISION ANALYSIS (MCDA)

The Multi-Criterion Decision Analysis (MCDA) approach (Pomerol and Romero 2000) provides a flexible, rational, and transparent means to establish decision-making criteria and prioritize alternatives. This approach was recently used for assessments and rehabilitation of streams for the City of Fort Collins (Beeby 2012). River restoration involves multiple objectives, often with a variety of priorities between various stakeholders. Using MCDA provides a tool that multiple stakeholders can customize to their needs during long-term recovery.

4.1 Reach Designations

Assessments of the master plan corridor were conducted prior to the designation of project reaches. In order to prioritize future projects and better organize the conceptual plans the BTRRMP corridor was divided into 51 reaches. Reach designations were chosen based on a variety of factors including approximate neighborhood areas, natural geographic features, road/bridge crossings, and diversion dams. These reaches are not intended to designate exact project extents for future restoration work. Future projects may occur based on these reach limits or they may be completed in smaller or larger lengths. Reach numbers begin with #1 below Olympus Dam and continue along the Big Thompson River east of I-25 to CR 3. Reaches then continue with West Creek, Fox Creek, and the North Fork of the Big Thompson until its confluence with the main stem at Drake.

4.2 Reach Scores

After reaches were designated, the assessment scores were averaged per reach. The AHIP and REIP reach scores were calculated by multiplying the length of each scored section and the associated score, then dividing by the overall reach length. For example, if a reach had half of its length with a score of 5 and half of its length with a score of 3, then the averaged reach score would be 4.

The GR average reach score was computed in a similar manner; however, the GR scores included one or both floodplain (right or left) scores east of the canyon as well. In these cases the channel GR and floodplain scores were averaged together first and then the average reach scores were calculated.

The calculation of the reach FR score was more involved. First the average FR score for each reach was calculated by summing the FR scores for all structures identified in the reach and dividing by the number of structures in the reach. This results in an average FR score for the structures in a given reach.

$\overline{FR}_i = \sum \overline{FR}_i / \sum i$

$\overline{FR}_I$ = *Sum of FR* scores for all the structures in a reach

$\sum FR_i$ = Average FR score for the structures in a reach

$\sum i$ = Total number of structures in a reach

However, this score does not account for the number of structures in a given reach. For example, a reach with a single structure with an individual FR of 5 has the same average score as a reach with twenty structures, all with individual rankings of 5. A score that accounts for the number of structures as well as the individual FR scores better describes the total flood risk for a given reach.

Consequently, the average FR score for each reach was weighted by the number of structures in that reach. The fraction of the total number of structures identified in the BTRRMP which are located in each study reach was computed. Given the long low tail of this fraction data (many reaches had few structures present), it was log-transformed to compress the data range and then scaled and shifted such that the resulting structure density factor (SDF) varied from zero (no structures) to one (361 structures, highest amount of structures in a reach).

$SDF_i = 0.391 * \log_{10} [n_i / \sum n_i] + 1.32$

SDF_i = Structure density factor

n_i = Number of structures in a single reach

$\sum n_i$ = Total number of structures in the BTRRMP corridor

0.391 = SDF Scale Constant

1.339 = SDF Shift Constant

The average flood risk was then weighted by the structure density function and the result re-scaled to range from one to five, consistent with the other MCDA scores.

$FR_{total,i} = 1.084 * SDF_i * \bar{FR}_i$

$FR_{total,i}$ = Total Flood Risk score

1.084 = Total Flood Risk Scale Constant

The total reach score was then determined by calculating the average of all four categories. The MCDA spreadsheet allows individual categories to be weighted based on various stakeholder goals. For all results presented in this master plan all categories are weighted the same.

4.3 Ranking and Potential Uses

The MCDA table provides a summary of the assessments in a flexible format that can be used by various stakeholders in a variety of ways. The calculation of reach scores allows the reaches to be prioritized based on multiple risks and potential for restoration. A total averaged score for each reach is provided. Categories within the MCDA can be weighted, but for this master plan all categories were assumed to be of equal importance. The BTRRC can use this tool to help guide which reaches to prioritize for future restoration work.

Table 4.1 provides a summary of all reach extents and scores. Spreadsheets including the reach average scores, the MCDA table, and associated maps are all provided in Appendix B.

Table 4.1. Reach Designations and MCDA Scores.

Big Thompson River Restoration Master Plan Reach Designations				Assessment Scores				
No.	Name	Upstream Boundary	Downstream Boundary	GR	FR	AH-IP	RE-IP	Total
1	Evergreen Point	Olympus Dam	Evergreen Point Bridge	3.0	3.3	0.3	2.7	2.3
2	Rock Canyon	Evergreen Point Bridge	Elk Island Way Bridge	4.0	4.4	0.0	2.0	2.6
3	Loveland Heights	Elk Island Way Bridge	MM 67	4.0	4.0	0.0	2.0	2.5
4	Bella Vista	MM 67	MM 67.5	4.0	3.5	0.1	2.8	2.6
5	Glen Comfort	MM 67.5	Noels Draw Lane Bridge	4.0	3.2	0.0	2.0	2.3
6	Noels Draw	Noels Draw Lane Bridge	MM 69	4.0	2.3	0.8	2.3	2.3
7	USFS-1	MM 69	Soul Shine Road	4.0	1.0	0.6	2.1	1.9
8	Seven Pines	Soul Shine Road	US 34 Bridge at MM 70.65	4.0	3.4	0.0	2.6	2.5
9	Oxbows	US 34 Bridge at MM 70.65	MM 71.5	4.0	2.9	0.1	2.1	2.3
10	USFS-2	MM 71.5	MM 73	4.0	2.3	0.3	1.4	2.0
11	Waltonia	MM 73	MM 73.9	4.0	2.7	0.3	2.4	2.3
12	Mountain Shadows	MM 73.9	MM 74.7	4.0	3.1	0.0	1.7	2.2
13	West Drake	MM 74.7	MM 75.3	4.7	2.8	0.0	2.4	2.5
14	Drake	MM 75.3	Confluence with North Fork	5.0	3.0	0.0	4.0	3.0
15	East Drake	Confluence with North Fork	MM 76.45	5.0	2.7	2.5	3.9	3.5
16	Midway	MM 76.45	MM 77	5.0	1.9	1.1	3.2	2.8
17	Old Idlewild Dam	MM 77	MM 77.5	4.1	0.0	3.6	4.7	3.1
18	Idlewild	MM 77.5	MM 78.3	4.7	2.5	0.6	3.9	2.9
19	USFS-3	MM 78.3	MM 79.2	4.0	2.0	0.0	2.2	2.1
20	V-Smith Mountain Park	MM 79.2	MM 79.9	4.5	1.6	1.8	3.5	2.9
21	Cedar Cove	MM 79.9	MM 80.55	4.7	3.3	3.9	4.0	4.0
22	Jasper Lake	MM 80.55	MM 81.3	4.7	4.9	3.6	4.8	4.5
23	Narrows	MM 81.3	Handy Dam	4.0	3.3	1.1	1.0	2.4
24	Sylvan Dale	Handy Dam	Loveland Water Storage Dam	5.0	3.3	4.1	3.5	4.0
25	Loveland WTP	Loveland Water Storage Dam	US 34 Bridge at MM 85.15	5.0	1.0	4.3	3.9	3.5
26	River View	US 34 Bridge at MM 85.15	US 34 Bridge at MM 86.05	4.7	2.8	3.4	3.6	3.6
27	Glade Road	US 34 Bridge at MM 86.05	US 34 Bridge at Glade Rd	3.6	5.0	3.7	4.2	4.1
28	Whiteside	US 34 Bridge at Glade Rd	MM 87.7	4.5	2.8	2.9	3.9	3.5
29	Morey Open space	MM 87.7	Rossum Drive	4.9	3.7	3.0	4.6	4.0
30	Rossum - Namaqua	Rossum Drive	Namaqua Road	4.0	4.0	2.4	4.5	3.7
31	Namaqua - Wilson	Namaqua Road	Wilson Avenue	1.3	3.2	1.0	5.0	2.6
32	Wilson - Taft	Wilson Avenue	Taft Avenue	2.8	3.0	1.9	3.0	2.7
33	Taft - Railroad	Taft Avenue	Railroad Avenue	2.5	3.7	1.2	3.5	2.7
34	Fairgrounds Park	Railroad Avenue	Lincoln Avenue (Hwy 287)	2.5	4.1	1.3	4.0	3.0
35	Lincoln - St. Louis	Lincoln Avenue (Hwy 287)	St. Louis Avenue	2.5	3.5	1.0	4.0	2.8
36	St. Louis - Boise	St. Louis Avenue	Boise Avenue (CR 11)	2.0	3.8	1.4	4.0	2.8
37	Boise - CR 9e	Boise Avenue (CR 11)	CR 9E	2.5	2.3	0.9	5.0	2.7
38	Kauffman's	CR 9E	Hillsbroo Ditch Diversion	2.0	3.2	1.0	5.0	2.8
39	I-25	Hillsbroo Ditch Diversion	I-25	1.6	2.5	2.4	5.0	2.9
40	Thompson River Ranch	I-25	CR 3	1.5	2.1	1.1	4.2	2.2
41	County Line Road	CR 3	County Line Road	1.6	1.9	1.1	4.0	2.1
42	CR 54	County Line Road	CR 15 Alignment	2.0	3.0	1.8	4.5	2.8
43	Great Western RR	CR 15 Alignment	CR 17	3.2	2.6	1.7	4.2	2.9
44	CR 48.5	CR 17	CR 21	2.5	2.8	1.3	3.4	2.5
45	Milliken	CR 21	Alice Avenue Alignment	2.1	2.6	1.0	4.3	2.5
46	Milliken East	Alice Avenue Alignment	CR 25	2.0	2.0	1.3	3.4	2.2
47	CR 27.5	CR 25	CR 27.5	2.8	2.6	1.4	4.1	2.7
48	Confluence	CR 27.5	Confluence with South Platte	2.4	3.4	1.1	3.1	2.5
49	Upper West Creek	Private Drive - Last home	West Creek Road	5.0	3.5	1.0	1.8	2.8
50	Glen Haven	West Creek Road	Confluence with North Fork	5.0	3.9	5.0	4.0	4.5
51	Fox Creek	End of Fox Creek Road	Confluence with North Fork	5.0	4.1	0.1	2.0	2.8
52	Upper North Fork	End of North Fork Road	West Creek - North Fork Confluence	5.0	4.6	0.2	2.0	2.9
53	NF - Canyon 1	West Creek - North Fork Confluence	Dunraven Glade Road Bridge	4.2	3.7	2.3	2.5	3.2
54	Dunraven	Dunraven Glade Road Bridge	Old Bridge Road	5.0	3.2	1.5	3.0	3.2
55	NF-Canyon 2 upper	Old Bridge Road	11650 CR 43	4.2	3.2	2.9	1.9	3.0
56	NF-Canyon 2 lower	11650 CR 43	Crosier Mt Trail	4.0	3.3	3.1	2.2	3.1
57	Crosier Mt Trail	Crosier Mt Trail	Galuchie Gulch	4.0	1.0	4.0	3.9	3.2
58	Fish Hatchery	Galuchie Gulch	Storm Mt Road Bridge	5.0	3.3	2.7	3.7	3.7
59	North Drake	Storm Mt Road Bridge	Confluence with North Fork	5.0	2.9	3.8	4.0	3.9

Various stakeholders may use this tool to weight each category based on their goals in order to customize project prioritization. For instance if the City of Loveland is interested in reducing the amount of infrastructure impacted by future flooding the FR score could be weighted higher, or the City could use only the FR assessment, in order to prioritize projects. Similarly if an organization like Trout Unlimited was interested in improving aquatic habitat they could use the AEIP and REIP scores to determine reaches with the highest priority.

Based on the MCDA rankings as presented in this Master Plan the top six project reaches are:

7. Reach 22 - Jasper Lake along the Big Thompson
8. Reach 50 - Glen Haven along West Creek
9. Reach 27 - Glade Road along the Big Thompson
10. Reach 29 – Morey Open Space along the Big Thompson
11. Reach 21 - Cedar Cove along the Big Thompson
12. Reach 24 - Sylvan Dale along the Big Thompson

Due to planned roadway work in the canyons along US 34 and CR 43 there may be unique opportunities to restore sections of the river in conjunction with permanent roadway repairs. Because of this opportunity to partner with other agencies working in the river corridor it may benefit the coalition to prioritize additional projects along these road corridors. All canyon reaches could potentially become opportunities during permanent road repair work. However, the following project reaches along the Big Thompson and the North Fork are the highest priority reaches to focus on in conjunction with permanent road repair projects:

For US 34

4. Reach 15 – East Drake along the Big Thompson
5. Reach 14 – Drake along the Big Thompson
6. Reach 18 – Idlewild along the Big Thompson

For CR 43

4. Reach 59 – North Drake along the North Fork
5. Reach 58 – Fish Hatchery along the North Fork
6. Reach 57 – Crosier Mt Trail along the North Fork

These project reaches are explained in more detail in the following sections.

<u>Reach 22 – Jasper Lake</u>. Reach 22 begins downstream of Cedar Cove near US 34 mile 80.5 and ends at the western end of the Narrows. The main stem of the Big Thompson flows from west to east through the reach with several homes located adjacent to the river throughout the entire reach. US 34 is set back away from the river and crosses it once near the downstream end of the reach. The US 34 roadway and bridge were not damaged within this reach except for the very downstream extent just before the Narrows.

The channel widened throughout most of the reach, and migrated only minimally. The floodplain areas, where homes are located, experienced deposition of sediment and debris. The Jasper Lake access bridge, private access roads, and several homes were severely damaged and/or destroyed.

Bank stabilization should be installed along the right bank from approximately upstream of Jasper Lake Road to the downstream extents of the reach to protect existing homes and access roads. Similar to the Glen Haven reach the channel location should be designed to function correctly from a geomorphic and hydraulic perspective while taking into account limitations due to real estate limitations. Most of the existing floodplains have homes located on them. Existing homeowners should thoroughly evaluate the risks and costs associated with living within a floodplain, including inundation, sediment and debris deposition, and potential damage and/or loss of structures. The proposed high flow channels need to be analyzed further to determine the potential positive impacts and only pursued as a design option if there is sufficient benefit to existing homeowners. These channels would need to be designed with landowner input and consent before being constructed.

Inset floodplain benches should be incorporated into this reach where feasible. The size of the inset floodplains will be limited by existing structures, but should be maximized as topography and real estate allow. The entire channel through this reach needs aquatic habitat improvements. The channel needs more variability in the form of pools and riffles and large boulders. There is little to no riparian vegetation throughout this reach, so restoration efforts should include revegetation of the entire reach.

There were two access roads close to the river that were completely destroyed in the 2013 flood. Due to the location of these roads it will be difficult to protect them during large flood events. Since both of the roads are adjacent to the river it is likely not feasible to set back the bank stabilization. While some hard armor along the toe may be necessary, planting the slope with willows may be the best option to stabilize these banks with the realization that they will likely wash out in large events.

It may be prudent to design and construct Reach 21 in conjunction with Reach 22.

Reach 50 – Glen Haven (West Creek). Reach 42 begins where West Creek Road crosses West Creek and extends downstream about 4000 feet to the confluence with the North Fork of the Big Thompson. County Road 43 parallels the right side of the creek though it does not constrict the floodplain as much as other canyon reaches. The road is located in the 100-yr floodplain for most of the reach and was damaged at multiple locations during the flood. There were seven access bridges or culvert crossings within the reach, all were significantly damaged or destroyed. Several homes, summer cabins, and the community of Glen Haven are also located in the 100-yr floodplain along the creek and road corridor. Several structures were damaged and/or destroyed during the flood. The channel and floodplain experienced widening, channel migration, bank erosion, removal of riparian vegetation, and deposition of sediment in some locations within the floodplain.

This reach has the potential to successfully implement several of the goals of the BTRRMP. Central Federal Lands and Larimer County are planning on repairing CR 43 along its existing alignment. Because of the wider valley width in this location the stabilization treatment applied to protect the roadway embankment can potentially be set back from the channel and buried for most, if not all, of the reach. Due to the number of structures that were damaged in this reach the floodplain will be less developed than before the flood. Structures that still exist within the floodplain are at risk from future flooding and associated geomorphic instability of the channel. In regards to flood risk, the safest and most resilient location for homes and businesses is outside of the flood plain as well as outside erosion hazard zones (currently not mapped). Access roads and crossings should be minimized and combined when possible. Crossings should be increased in size in order to pass more flow and debris during floods. If culverts are used they should be designed to allow aquatic organism passage (AOP). If access roads and bridges cannot be increased in size significantly they should be designed to direct overtopping flows to a designated, stabilized, section of roadway in order to account for debris blockage of the crossing during future flood events.

The main channel should be designed so it functions correctly from a geomorphic and hydraulic perspective while taking into account potential real estate limitations. The existing alignment may be sufficient. There is sufficient area to include several inset floodplain benches. Both the channel and floodplains should be designed to maximize aquatic and riparian habitat by incorporating appropriate in-stream structure and related wetland vegetation. LWM should be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

It may be prudent to design and construct Reach 41, which includes upper West Creek and a small portion of Devils Gulch, in conjunction with Reach 42.

Reach 27 – Glade Road. Reach 27 begins at the US 34 crossing upstream of the confluence of the Big Thompson and Buckhorn Creek and ends when US 34 crosses the channel and floodplain. This reach received the highest flood risk score within the BTRRMP because of the large number of homes and associates infrastructure. The floodplain is much larger in this reach compared to the canyon reaches. This is due to the change in topography as well as the confluence with the Buckhorn. This reach experienced a large amount of sediment deposition on the floodplain, and some channel widening and/or bank erosion along the channel.

There is great opportunity in this reach to restore both the aquatic habitat and riparian habitat in the floodplain. The channel needs more variability in the form of pools and riffles. The large undeveloped floodplains in the upstream portion of this reach have potential for the creation of inset floodplains. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

Downstream of US 34 mile marker 86.5 there are numerous homes, businesses, roads, and associate infrastructure located within the floodplain. In order to reduce the flood risk to these properties it is likely that a combination of treatments will be needed, all of which will require the removal of some structures. Potential treatments may include lowering portions of the floodplain next to the channel to maximize the conveyance along the channel corridor, regrading areas of the floodplain away from the channel to direct flood water to specific areas away from homes and businesses, and constructing a high flow channel within the larger floodplain.

US 34 crosses the floodplain at the downstream end of this reach. There may be sufficient conveyance under and across this roadway with the existing primary bridge, relief bridge, and overtopping of the roadway during large flood events. However, flood mitigation efforts should look at the potential need to increase conveyance at this crossing, which could potentially reduce the flood risk and deposition north of US 34.

Reach 29 – Morey Open Space. Reach 29 begins near the bend in the river at US 34 mile marker 87.7 and continues downstream to Rossum Drive. This reach experienced a significant amount of deposition in the floodplain and channel. The diversion structure for Barnes Ditch is located near the downstream extents of the reach. There is also an overflow weir located on the right bank which protects the diversion structure by preventing the channel from shifting to the low swale along the south of the floodplain during flooding. Sediment deposition during the 2013 flood completely filled in the Morey Open Space Pond. Portions of the Marianna Butte Golf Course and agricultural land to the north of the channel also experienced sediment deposition. Sediment also deposited in the channel primarily in the upper and middle portions of this reach. There are a few structures within the floodplain in this reach and a high number of utilities within this reach.

The location of Marianna Butte Golf Course on the south and active agricultural land on the north will prevent the full restoration of the floodplain in this reach unless one or both properties change how the land is managed. Large flood events will likely continue to flood and deposit sediment on both of these properties.

The Morey Open Space pond has the potential to be restored into a floodplain bench with the possibility of incorporating a high flow channel for additional conveyance during flooding. The channel turns from flowing generally south to generally north in the middle of this reach. At the apex of the bend a bedrock outcrop exists that stabilizes. The area north of the main channel at this location has the potential to be restored to an inset floodplain with a potential high flow channel similar to the upstream section. Additional floodplain benches could be incorporated if there is available land to use due to land use changes.

There is significant opportunity in this reach to restore the aquatic habitat. The channel needs more variability in the form of pools and riffles and small boulders. Additional riparian vegetation immediately adjacent to the channel should be incorporated where needed. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

The only bank stabilization recommended is along north portion of the floodplain along the few structures in and close to the floodplain. A vegetated bank with a buried toe protection would likely be sufficient at this location.

The Barnes Ditch diversion structure creates a fish passage barrier. It is recommended that this structure be replaced to allow for fish passage. Close coordination with the ditch company will be required.

Reach 21 - Cedar Cove. Reach 21 begins at the access bridge upstream of Cedar Cove and ends near US 34 mile 80.5. The upstream extents of the reach experienced erosion along the access road. As the river exits the tight canyon at the upstream end, the valley widens. During the flood the channel and floodplain experienced a combination of deposition and significant channel migration leading to bank erosion that impacted access roads and several homes. The pre-flood channel was completely abandoned and/or filled in with sediment through the lower portion of this reach. Two of the 2013 flood fatalities occurred within this area. The channel was moved back to its pre-flood alignment during post-flood repair work.

The access road at the upstream end of the reach will be difficult to protect during large flood events because it is in a narrow canyon. Ideally it should be located out of the floodplain. If this is not possible the embankment should be stabilized and planted. It is recommended that the channel be relocated close to its post-flood location. The existing alignment with the sharp bend once the channel exists the canyon section is likely not sustainable, especially during large flood events. A bend with a larger radius is recommended downstream of the canyon section. The recommended alignment should then continue east with some minor meandering. The existing channel bend that heads south towards US 34 could be converted into a high flow channel to add some backwater area for mid to high flows and additional conveyance during larger flood events.

The wide valley section of this reach will likely continue to be a depositional zone with associated channel migration during large flood events. It is therefore advisable to limit the infrastructure located within this valley. Existing homeowners should thoroughly evaluate the risks and costs associated with living within a floodplain, including inundation, sediment and debris deposition, and potential damage and/or loss of structures. To provide more flood resiliency for the access road and bridge that bisect this valley they should be located upstream or downstream where the valley width is narrow.

There is an opportunity in this reach to restore both the aquatic habitat and riparian habitat in the floodplain. The channel needs more variability in the form of pools and riffles and large boulders. There is little to no riparian vegetation throughout this reach, so restoration efforts should include revegetation of the entire reach. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

It may be prudent to design and construct Reach 22 in conjunction with Reach 21.

Reach 24 - Sylvan Dale. Reach 24 begins at the diversion dam at the mouth of the Narrows and continues downstream to the Home Supply Ditch and Loveland Water Supply diversion dam. Two county roads cross the channel within this reach, CR 31D and CR 29. The reach has a few buildings near or in the floodplain upstream and downstream of CR 31D. The Sylvan Dale Guest Ranch owns most of the river corridor downstream of CR 31D. The only infrastructure along the downstream portion of this reach is CR 29 and the diversion dam and associated structures.

Upon exiting the Narrows, a significant amount of sediment was deposited within the channel and adjacent floodplain during both flood events. This area of deposition lead to channel migration and severe bank erosion. The CR 31D bridge and roadway were completely destroyed during the 1976 flood. During the 2013 flood the bridge was clogged with debris and the roadway approach to the south was destroyed. The channel migrated over 300 feet at one location downstream of CR 31D. The primary damage to buildings in this reach occurred in the vicinity of CR 31D.

Near the location where the channel turns north several ponds existed before the flood in the western floodplain. This area experienced erosion and deposition. All of the ponds were filled in with sediment and multiple split flow channels formed through the floodplain during the flood. As the channel turns back to the east it enters a narrow rocky canyon. The CR 29 bridge was not damaged during the 2013 flood; however the approach roadway embankments on both sides were damaged and/or destroyed.

There is significant opportunity in this reach to restore both the aquatic habitat and riparian habitat in the floodplain. The channel needs more variability in the form of pools and riffles and large boulders. There is little to no riparian vegetation throughout this reach, so restoration efforts should include revegetation of the entire reach. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

Because of the wider floodplain downstream of CR 31D there is potential for the restoration of a wider vegetated floodplain and a high flow channel similar to what existed post-flood. The final configuration and grading of the floodplain in this reach will require coordination with the landowners.

It is recommended that vertical walls be used to protect CR 29 at the downstream end of the reach. This section is very narrow and walls would provide the most protection for the roadway and provide the most room for the river for more conveyance.

Reach 15 - East Drake. Reach 15 begins at the confluence with the North Fork and continues east to mile marker 76.45. The upstream portion of this reach experienced some deposition and channel migration resulting in multiple channels. As the valley narrows moving east the channel widened and migrated some during the flood. Significant damage in the middle of this reach was the result of the Moody Bridge becoming clogged with debris causing the flanking of the bridge on both sides, but primarily to the south. This caused the flood water to remove a significant portion of the south bank, leading to the destruction of one home. The post-flood repaired channel banks are unnaturally armored and the channel is straight and generally lacks variability.

Larimer County owns Forks Park located in the middle of this reach. The access bridge and the park were completely destroyed. The future status of this park is unknown, and any work that occurs on this reach should be coordinated with Larimer County.

There is significant opportunity in this reach to restore both the aquatic habitat and riparian habitat in the floodplain. The channel needs more variability in the form of pools, riffles, and large boulders. The channel should include more variation in its alignment. There is potential to incorporate inset floodplains and/or a high flow channel in the upper portion of this reach. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding. Both banks lack vegetation in the downstream half of the reach.
The US 34 roadway embankment needs to be stabilized. There may be room to shift the roadway away from the river along the lower portion of this reach. The embankment along Moodie St. also needs stabilized. If possible it is recommended to have one bridge to access the homes along the south side of the river. Replacement bridges at the downstream end of the reach should be higher and wider in order to safely convey floods with associated debris.

Reach 14 - Drake. Reach 14 begins at US 34 mile marker 75.3 and continues downstream to the confluence with the North Fork. This reach experienced significant sediment deposition and channel migration, very similar to what happened in the 1976 flood. US 34 was completely destroyed through most of this reach and/or buried in sediment. Several homes were damaged or completely destroyed. The East Drake Road Bridge was blocked with sediment and debris and the road embankment to the south was washed out. Because of the decrease in channel slope and increase in valley width at this location it is likely that future flooding will result in sediment deposition and associated channel migration.

Existing homeowners should thoroughly evaluate the risks and costs associated with living within a floodplain, including inundation, sediment and debris deposition, and potential damage and/or loss of structures. To provide more flood resiliency for the access road and bridge should be located upstream where the valley width is narrow.

Ideally the roadway and buildings should be removed from the floodplain in this area, however if this is not feasible, the US 34 roadway embankment may need to be raised and should be stabilized. The River Fork Rd embankment and homes should also be stabilized. There is room in this reach to set back and bury both of these stabilization treatments and still construct inset floodplain benches.

The current channel alignment may be sufficient; however the final location of the channel should be determined after major decisions have been made about the location of roadways, the access bridge, and the possible removal of buildings. The existing channel does have riffle/pool structure and large boulders that provide pocket habitat. At a minimum the unnaturally armored channel banks need to be regraded, lowered, and planted.

There is significant potential to create lowered inset floodplains within this reach. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding. This reach does contain a fair amount of large trees along the existing channel. This large vegetation should be preserved as it provides much needed organic material to the channel in the form of leaf litter.

Because of the deposition this area experienced during the flood, and will likely experience in future floods, it is recommended to excavate excess material from this reach for use at other locations along the canyon.

Reach 18 - Idlewild. Reach 16 begins at US 34 mile marker 77.5 and continues downstream to mile marker 78.3. This reach includes several homes on the south side of the river in and/or near the floodplain. US 34 is located along the north boundary of the floodplain, and at times is completely out of the floodplain. The channel widened in several locations and damaged or completely destroyed the US 34 roadway. Both approaches to the access bridge in this reach were completely destroyed. The bridge deck and abutments remained in place.

The US 34 roadway embankment should be set back along the entire reach if feasible. The very upstream portion may need to be protected with a vertical wall since the channel is steep and the roadway is on the outside of the bend. The rest of the US 34 roadway embankment needs to be stabilized. The south bank also needs to be stabilized along the reach where homes and other structures exist. This reach needs little to no in-channel aquatic habitat improvements. The channel at the downstream end was altered after the flood. It is recommended that the channel be realigned primarily along the outside of the bend. There are several variations of channel alignments that could work in this location, and the final alignment should be selected to function correctly geomorphically and hydraulically with appropriate in channel aquatic habitat features. The inside of the bend along this section of channel could be restored to a vegetated floodplain bench.

The access bridge should be higher and wider in order to safely convey floods with associated debris.

Reach 59 - North Drake (North Fork). Reach 59 begins at the Storm Mt. Road Bridge and continues downstream to the confluence with the main stem of the Big Thompson. This reach is similar to Reach 14 in that it is a depositional area. During the 2013 and 1976 flooding this area experienced significant sediment deposition and channel migration. CR 43 was damaged at the upstream extents of this reach, but is completely out of the floodplain for most of the reach. There are several structures located within the right floodplain. Due to the amount of deposition this area experiences during large floods the US 34 bridge crossing gets filled in and most of the flood overtops the roadway.

Existing homeowners should thoroughly evaluate the risks and costs associated with living within a floodplain, including innundation, sediment and debris deposition, and potential damage and/or loss of structures.

Ideally the roadway and buildings should be removed from the floodplain in this area, however if this is not feasible, set back, buried stabilization should be included to protect existing infrastructure in the right floodplain.

There is significant opportunity in this reach to restore both the aquatic habitat and riparian habitat in the floodplain. The channel needs more variability in the form of pools and riffles and large boulders. There is little to no riparian vegetation throughout this reach, so restoration efforts should include revegetation of the entire reach. There is significant potential to create lowered inset floodplains within this reach. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

Reach 58 - Fish Hatchery (North Fork). Reach 58 begins at Galuchie Gulch and continues downstream to Storm Mt. Road Bridge. The reach begins in a very narrow valley then quickly transitions to a wide valley with a slightly meandering channel. This reach experienced erosion, deposition, and channel migration. The CR 43 roadway was damaged and/or destroyed at multiple locations throughout this reach, though it is also located outside of the floodplain and was untouched by the flood at other locations. Several local access roads and bridges were destroyed during the flood. The abandoned Department of Wildlife fish hatchery is located along the north edge of the floodplain near the downstream end of the reach.

The wide undeveloped valley floor provides much potential for aquatic and riparian restoration. Inset floodplains may be incorporated to reduce pressure on CR 43 from future flooding while improving the riparian habitat. There is sufficient room to include a high flow channel within the floodplain areas. The upper portion of the reach needs some aquatic and riparian restoration; however the lower half needs the most attention. The channel needs more variability in the form of pools, riffles, and large boulders. The channel should include more variation in its alignment. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

Where needed CR 43 roadway embankment needs to be stabilized.

Reach 57 - Crosier Mt. Trail (North Fork). Reach 56 begins at the Crosier Mt. Trailhead and continues downstream to Galuchie Gulch. This reach has a wide valley width compared to most of the North Fork, though the very end of the reach narrows significantly. CR 43 parallels the channel through the whole reach, and is completely out of the floodplain at a few locations. The roadway was destroyed and/or damaged at three locations. Due to the flood and post-flood repair work the aquatic habitat was impacted for most of this reach.

The CR 43 roadway embankment should be set back where feasible and the embankment stabilized and revegetated. There is significant opportunity in this reach to restore both the aquatic habitat and riparian habitat in the floodplain. The channel needs more variability in the form of pools and riffles and large boulders. Restoration efforts should include revegetation of areas with little to no riparian vegetation. Inset floodplain benches should be incorporated into the wider areas throughout the reach. LWM could be located within the floodplain and the channel to add complexity and additional organic matter. LWM should be anchored in order to minimize transport during flooding.

5. CONCEPTUAL PLANS

The assessments completed for the MCDA were also used to guide the development of the proposed plans. The proposed plans are an attempt to meet the goals of the master plan while addressing the risks and needs of the corridor. By their nature, master plans are created at a conceptual level. As stated earlier, the plans provided here are not intended to be used for final design purposes. Many assumptions have been made during the plan development and we acknowledge there are potential unknown constraints that will ultimately impact final designs.

Maps of the conceptual plans are provided in Appendix C. The conceptual plans include ten different treatments that will help create a more resilient and healthy river corridor. Each design treatment is explained below.

The approach recommended in this master plan involves giving the river as much space as possible, setting back and burying bank stabilization, and rehabilitating and/or enhancing the channel, riparian fringe, and available floodplain. The first recommendation of the BTRRMP is to remove infrastructure from the floodplain and/or erosion risk zone (currently not mapped). The treatments provided in this master plan assume that most of the infrastructure will remain in its existing location. Future decisions made about final designs of roadway alignments, possible relocation of homes and businesses, and any change in land use may change the potential for restoration, the need for bank stabilization, and/or present new opportunities. The recommended treatments will need to be reassessed as to their need and applicability based on possibly different future conditions.

Central Federal Lands in coordination with Larimer County have begun work on the permanent repairs on some sections of CR 43 along the North Fork. Some of their treatments include setting the roadway back from the river to provide more space, swapping the river and road locations to remove the roadway from outside bends, and incorporating more vertical bank slopes to provide additional room for the river corridor. The remaining river corridor will then be restored and revegetated. These permanent repairs are one example of how the treatments recommended below can be applied.

5.1 Aquatic Restoration

Aquatic habitat restoration is aimed at creating, or rehabilitating, the appropriate in-stream structure (habitat) for the desired species. The specific type of habitat to be restored will vary depending on where it will occur within the corridor. Aquatic restoration should be designed to create ideal habitat, that allows full connectivity for aquatic biota, at the low winter flows and typical spring/summer high flows. Aquatic biota will also benefit from the restoration of the riparian vegetation and floodplain benches. The near shore vegetation provides cover for aquatic biota and a well-vegetated floodplain provides shelter during higher flood flows.

LWM should be used where appropriate. The lower order streams such as West Creek, Fox Creek, and the upper North Fork would naturally have a higher amount of LWM. However, it may be difficult to place a large amount of LWM into these channels due to the amount of infrastructure located in the river corridor, and the potential increase in the water level during floods that LWM may cause. The Lower North Fork and the main stem of the Big Thompson within the canyon typically transport LWM downstream. It is recommended to place LWM on floodplain benches in these reaches and some in channel LWM where appropriate.

All LWM placed in the canyon section is likely to become mobile in future large flood events. LWM should be anchored by burying it and if needed by other means. "Caution should be exercised when including LWM as a restoration component. Benefits should clearly outweigh risk" (Fischenich 2000). Two resources by the NRCS (NRCS 2007-a) and the USACE (Fischenich 2000) are provided in **Appendix D** for design guidance. LWM is not suited for situations where failure would endanger human life or critical infrastructure (NRCS 2007-a).

The Big Thompson River in the upper and lower canyons prior to the flood of September 2013 supported a robust aquatic ecosystem. The aquatic habitat conditions in the canyons consisted of high-gradient riffles, low-gradient riffles, pocket water (small pools formed downstream of large boulders) and pools, as depicted in **Figures 5.1** and **5.2**. More than 50% of the pre-flood habitat was high gradient riffles and pocket water (Miller 1993). These photographs show the generally large substrate present in the higher gradient areas and the abundance of riparian vegetation along the channel. These are two characteristics needed for aquatic habitat restoration. Areas with typical lower-gradient riffles are shown in **Figures 5.3** and **5.4**, and consist of large cobble substrate. Low-gradient channel types are less frequent due to the overall steep, canyon-bound river channel.

In the canyon reaches restoration efforts should use the pre-flood conditions as a template for desired future channel types. The instream aquatic habitat should take advantage of the large boulders to provide pocket water habitat similar to the pre-flood conditions. High-gradient riffles with a combination of large and small boulders are another habitat type that should be used in the canyon sections.

Figure 5.1. Big Thompson downstream of Waltonia Bridge, 9-24-2012.

Figure 5.2. Big Thompson River approximately ½ mile upstream of the mouth of the canyon, 9-24-2012.

Figure 5.3. Big Thompson River low gradient riffle near Drake, 9-12-2014.

Figure 5.4. Big Thompson River low gradient riffle near Cedar Cove, 9-12-2014.

The pre-flood low flow river width varied from approximately 20 feet in the narrow canyon sections to approximately 30-40 feet in the wider pocket water (Miller 1993). These widths could be used to guide channel widths at restoration areas. The restored channels should include a gradual bank slope to connect the channel with over bank floodplain habitat, where possible. The steep gradient within the canyon precludes this reconnection in many areas. Establishment of near-shore riparian vegetation is an important component for adequate function of the aquatic ecosystem (**Figure 5.5).**

The opportunities on the North Fork and tributaries are very similar to the canyon sections. These reaches are generally steep-gradient with large substrate forming small habitat features. The flood eroded and widened much of the river channel within this area. The channel should be resized to provide adequate function at low flow (e.g., pool habitat, narrowed riffles with adequate depth for fish movement). Where possible, the river channel should be connected to the adjacent floodplain to provide refuge habitat at high flows.

From the mouth of the canyon downstream to Glade Road the river transitions from the steeper mountain gradients dominated by pocket water and high-gradient riffles to a slightly meandering channel with low-gradient riffles, glides and pools. The aquatic biota in this section also transition from cold water mountain biota to cool water species. The main opportunities in this section include bank shaping and stabilization, reconnecting flood plains to the river channel and revegetation of near-shore riparian habitat.

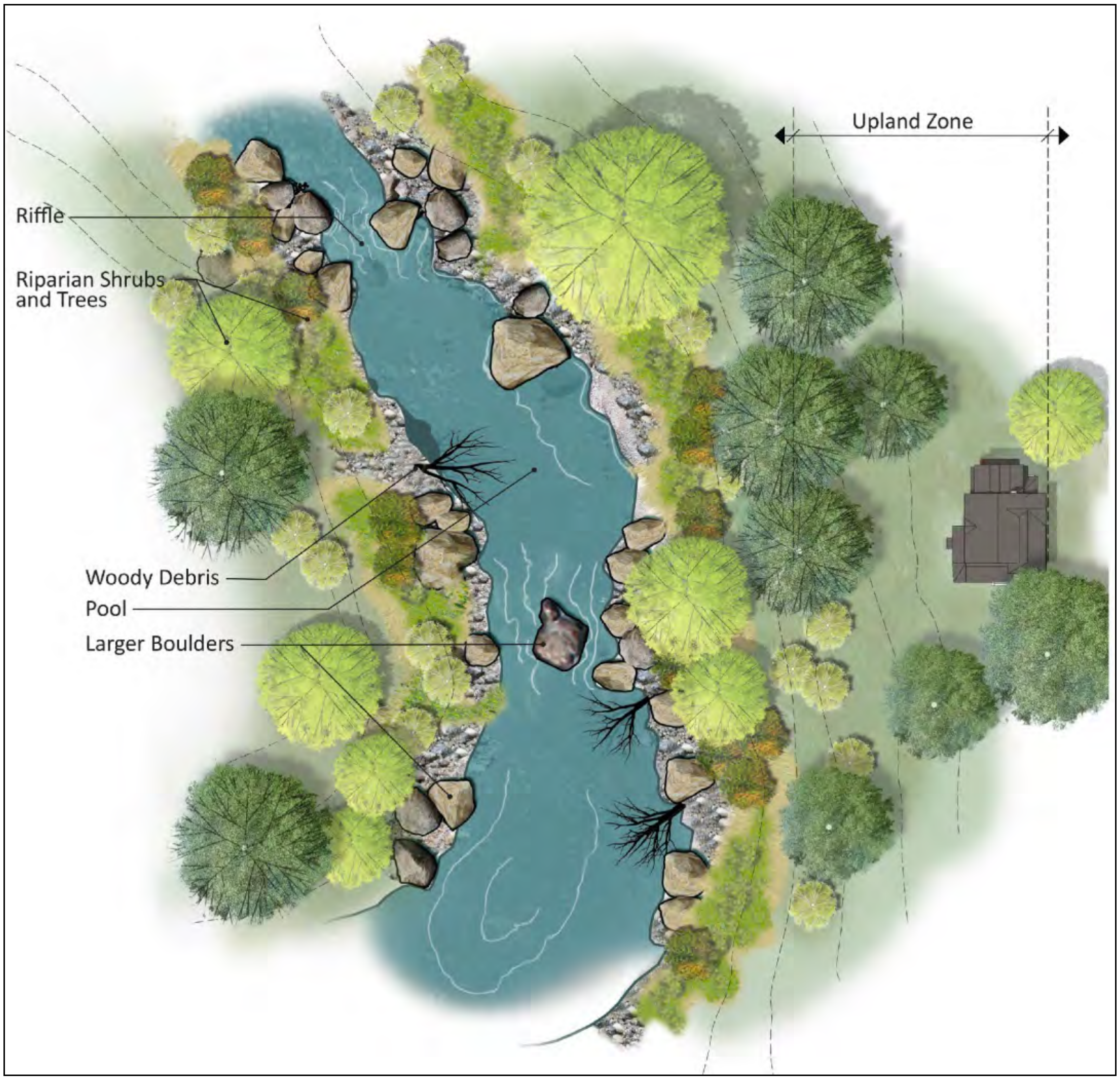


Figure 5.5. Restored Channel Prototype – Canyon Segments.

The reaches of river downstream of Glade Road to the confluence include rural and urban environments. Opportunities include channel reconfiguration (both width and cross section shape) and modification of fish passage impediments at existing diversions. This segment of river has cool water aquatic biota in the upstream section and warm water aquatic biota in the downstream section. The native species includes small minnows and darters without the capability to swim past many of the instream structures. These structures become impediments to upstream movement for native species, which is necessary for the species to maintain their populations in this river segment.

Several areas near bridges experienced channel widening and now have steep banks without a smooth transition from the channel to the floodplain. Regrading areas with steep banks to connect the low flow channel to the floodplain with a gradual sloping bank would benefit aquatic species. In addition to areas with steep banks, it appears that the flood removed some near channel vegetation. Restoration of the riparian area with appropriate planting would provide near shore cover for aquatic species. The plants in the riparian areas would also provide cover and refuge from high velocities during flood flows, (**Figure 5.6)**. Any redesigned channel should allow species to be able to access the floodplain as flows increase.

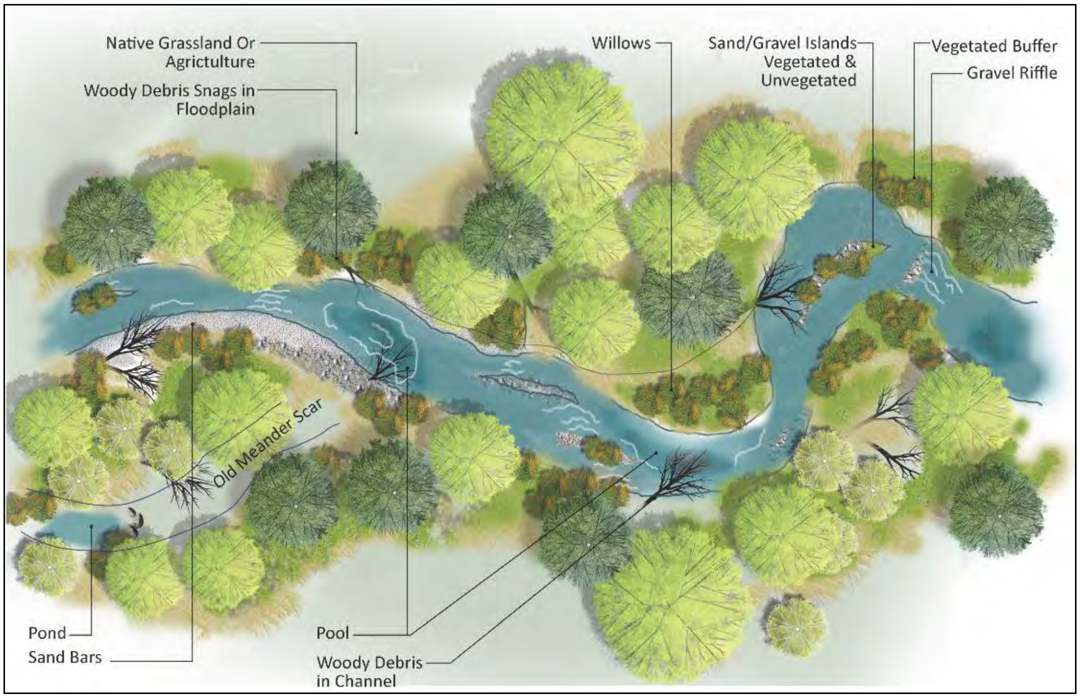


Figure 5.6. Restored Channel Prototype – Plains Segments.

5.2 Riparian Restoration

Riparian restoration refers to rehabilitating the vegetation that typically exists directly adjacent to the river and in the floodplain corridor up to the transition and upland zone, Figures 5.5 and 5.6 above and **Figure 5.7**. This includes wetlands and other vegetation that are dependent on a more consistent source of water. The vegetation directly adjacent to the river is also very important for the restoration of aquatic habitat since this vegetation is the primary source of organic matter.

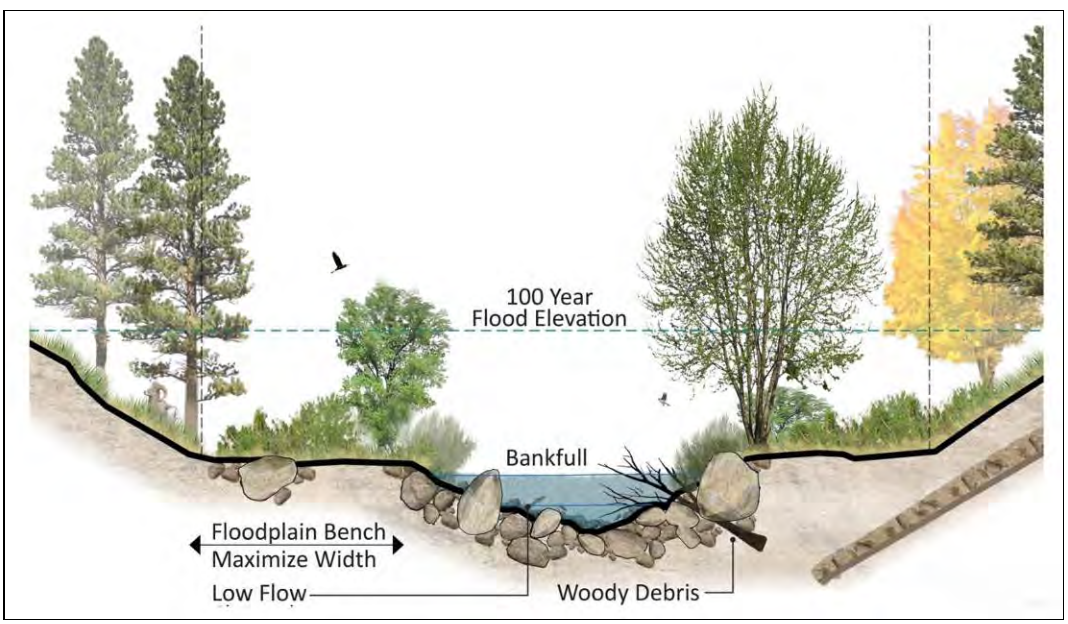


Figure 5.7. Typical restoration cross section showing aquatic habitat and riparian vegetation – Canyon Segments.

All restoration areas, both riparian and upland, should be planted with native riparian plants to expedite the formation of a healthy system. See Appendix D for general seed specifications, mixes, and vendors for Colorado.

In some locations the riparian restoration and bank stabilization measures can use the same treatment, **Figure 5.8**. Boulders and/or riprap planted with willows can increase the resiliency of the bank while improving the riparian and aquatic habitat as well. This approach may be useful in areas with no room for a floodplain bench. The left bank shown in **Figure 5.9** is a planted riprap bank protection used at Fairgrounds Park in Loveland. This treatment performed well during the 2013 flood event.

5.3 Bank Stabilization

Bank stabilization refers to a variety of stabilization measures used to protect infrastructure from high erosive forces during flood events. When possible, the bank stabilization recommended in this master plan should be set back, buried, and planted with vegetation.

Rivers naturally migrate and generate large erosive forces during high flow events. Infrastructure located in or near the main channel, floodplain, and sometimes outside of the floodplain will likely need either relocation or some type of protection from erosive forces during flooding in order to be resilient from future flood events. Some locations exist that will be difficult, if not completely infeasible, to protect infrastructure during large flood events.

There are a large variety of potential bank stabilization treatments that exist naturally or have been constructed. The specific type bank stabilization to use depends on a number of factors including amount of horizontal footprint available, velocity and depth of flooding, availability of materials, cost, constructability, maintenance, aesthetics, and potentially others. Bank stabilization treatments are often referred to as 'hard' or 'soft'. Hard bank stabilization treatments may include riprap, natural boulders, articulated concrete blocks (ACB), and soil cement. Soft bank stabilization includes vegetation plantings and large woody material, see Section 5.2. Multiple treatments can be used together including hard and soft treatments as noted in Section 6.2. For example a large boulder toe could be combined with a fully vegetated uppers slope. The boulders protect the slope from the high erosive forces that typically exist along the toe of slope and the vegetated slope may be sufficient if there are less erosive forces along the top of bank.

The options presented below are not intended to be exhaustive measures, but instead to provide potential solutions to use for various allowable slopes. A helpful resource produced by the USACE (Fischenich 2001) provides permissible shear stress and velocities for a variety of potential bank stabilization materials. This resource is also included in Appendix D. For reference, the shear stress and velocity that occurs in much of the canyon reaches during a 100-year flood is 8-12 lb/ft^2 and 15-20 ft/s or greater respectively.

Riprap has been the standard bank stabilization used for protecting highways, bridges, and other infrastructure that are subject to flooding. There are other types of bank stabilization that are also standard practice related to protecting transportation infrastructure. See Federal Highways HEC-20 (FHWA 2012) and HEC-23 (FHWA 2009) for more detailed information.

There is a demand for stream bank stabilization measures that provide enhanced aesthetics and more biologically diverse and ecologically compatible environments. While there are several naturalistic bank stabilization techniques (NRCS, 2007-b), the need exists for more research and design guidance for applying these treatments to protecting lives and property from large flood events. An ongoing research project by the National Cooperative Highway Research Program (NCHRP 24-39) will begin to help establish better guidelines for the use of environmentally sensitive bank protection measures.

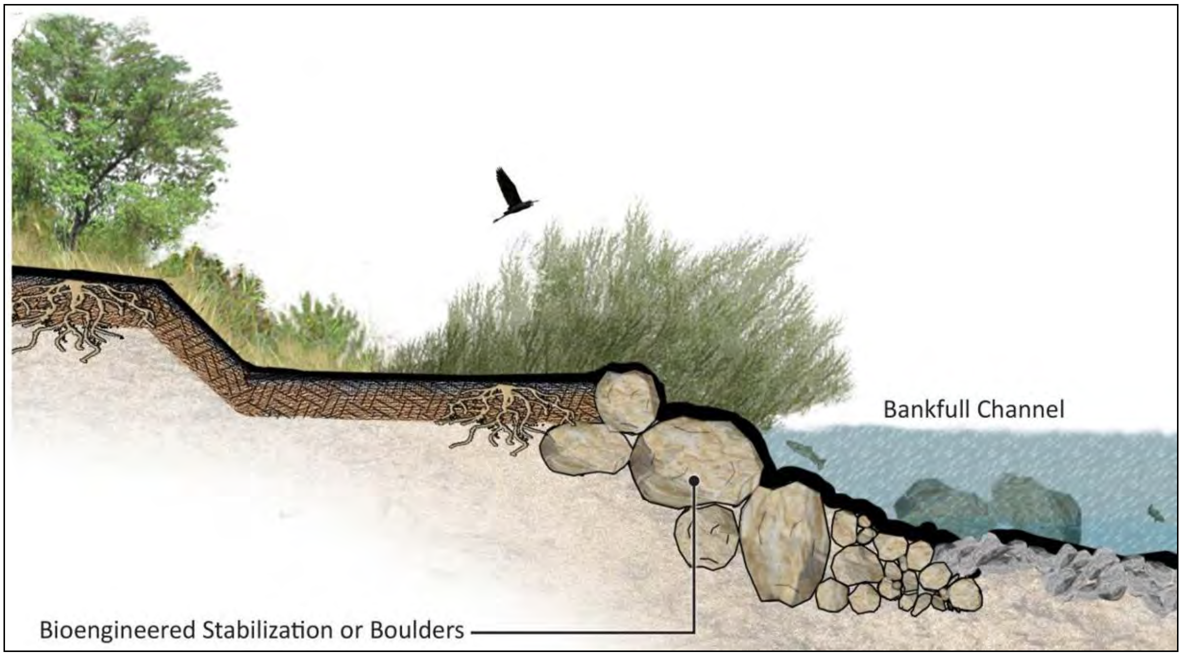


Figure 5.8. Willow planted boulders.

Figure 5.9. Planted riprap bank protection (left side), taken 8-29-2013, Fairgrounds Park, Loveland, CO.

Most of the canyon reaches will likely require more robust bank stabilization treatments if the intended goal is to protect infrastructure. The soft stabilization treatments such as vegetation and LWM are more suited for the Eastern Plains reaches, because of much lower energy during flooding. Hard stabilization treatments will still be required in areas with high energy like bridge crossings.

Riprap (**Figure 5.10**) can be constructed up to a slope of 1H (horizontal):1.5V (vertical). However steeper slopes require larger riprap sizes that may not be feasible. Riprap will be most effective at a 3H:1V slope or flatter. Riprap slopes require a filter and/or geotextile in order to be most effective. Due to the thickness of the filter and required riprap layers, the thickness of this type of protection can be quite large. It can be difficult to establish vegetation on top of riprap without sufficient soil cover. At a minimum, riprap adjacent to streams should be planted with willows. The upper slope should be designed and planted to establish upland vegetation as well.

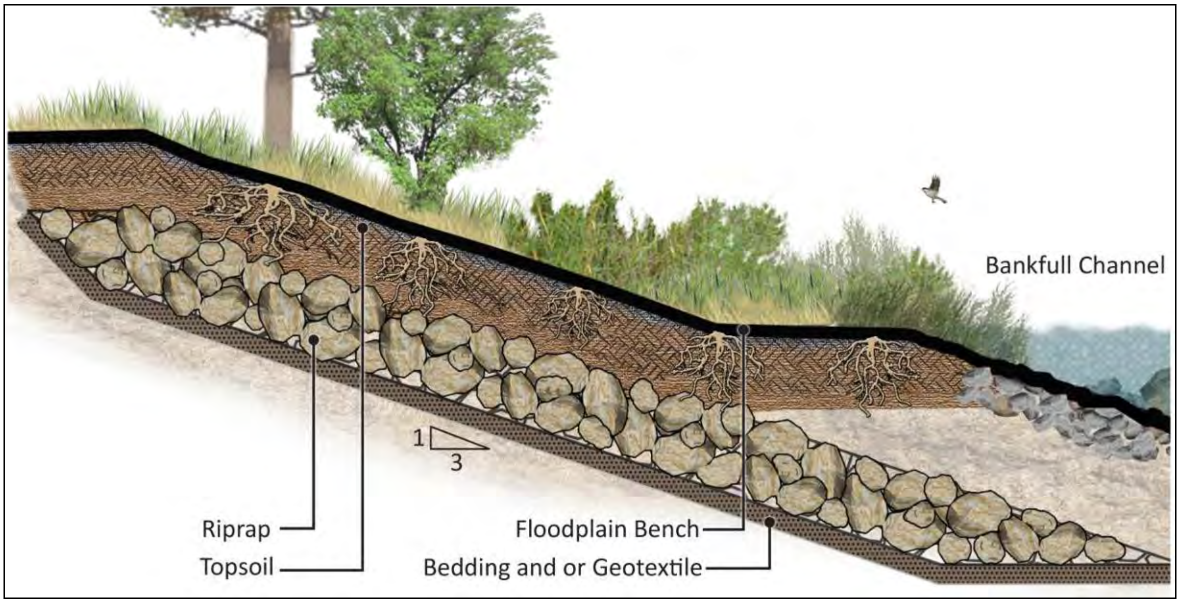


Figure 5.10. Bank Stabilization treatment, Riprap, 3H:1V slope.

Articulated concrete blocks (ACB) are a manufactured bank stabilization treatment (**Figure 5.11**). They can be installed at a 2H:1V slope or flatter. The benefit of ACBs compared to riprap is that they can provide similar protection to other treatments, but are not as thick and can allow vegetation to establish after installation. Even without significant soil cover, ACBs may allow sufficient vegetation to establish that they are completely covered (**Figure 5.12**).

Stacked boulders (**Figure 5.13**) essentially create a retaining wall, and may need to be partially grouted for structural stability. Due to the size of the boulders, they can be stacked to create a much steeper slope, approximately 1H:1V slopes. Central Federal Lands has been using this technique to reconstruct and stabilize portions of US 36 along St. Vrain Creek and plan to use it on CR 43 along the North Fork. They are using this treatment while also shifting the roadway away from the river and into the hillside more to create more space for the river. If large stone is not available locally the costs of this approach could be prohibitive. However, if sufficient quantities of large rock are available from blasting to widen roadways, this may be a good option for bank protection.

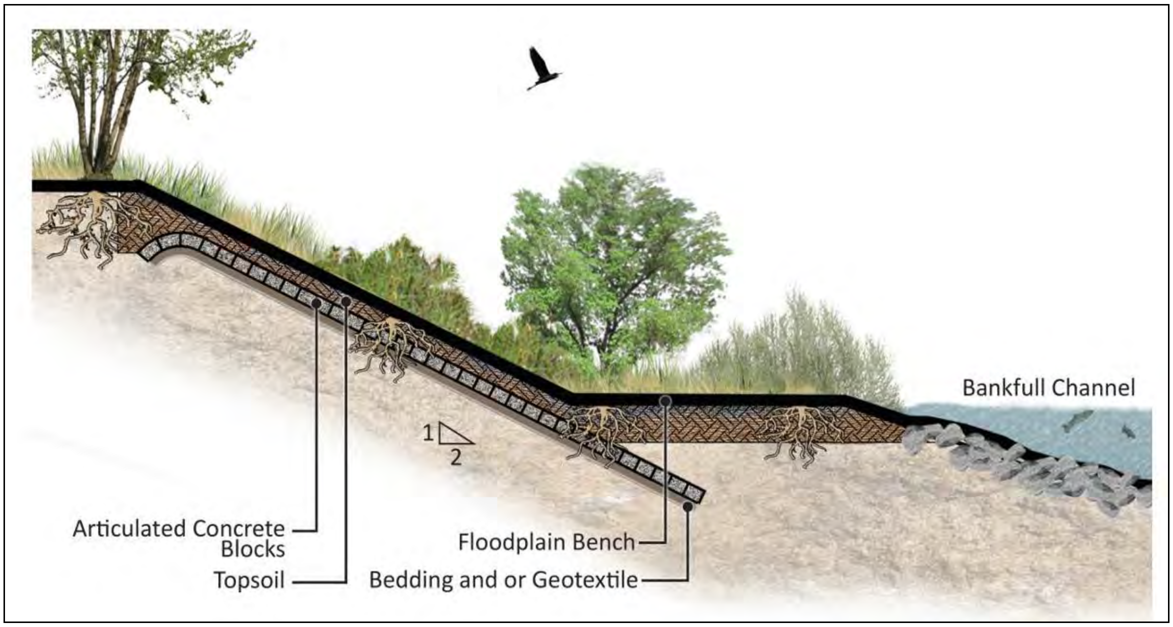


Figure 5.11. Bank Stabilization treatment, Articulated Concrete Blocks, 2H:1V slope.

Figure 5.12. ACBs at bridge abutment, vegetated area in foreground covers ACBs.

Soil cement (**Figure 5.14**), can be installed at slopes of 1H:1V and steeper. This is an unnatural treatment; however, if a location has insufficient space for other treatments accompanied by high shear stress during flooding, this may need to be considered if protecting infrastructure is the main priority.

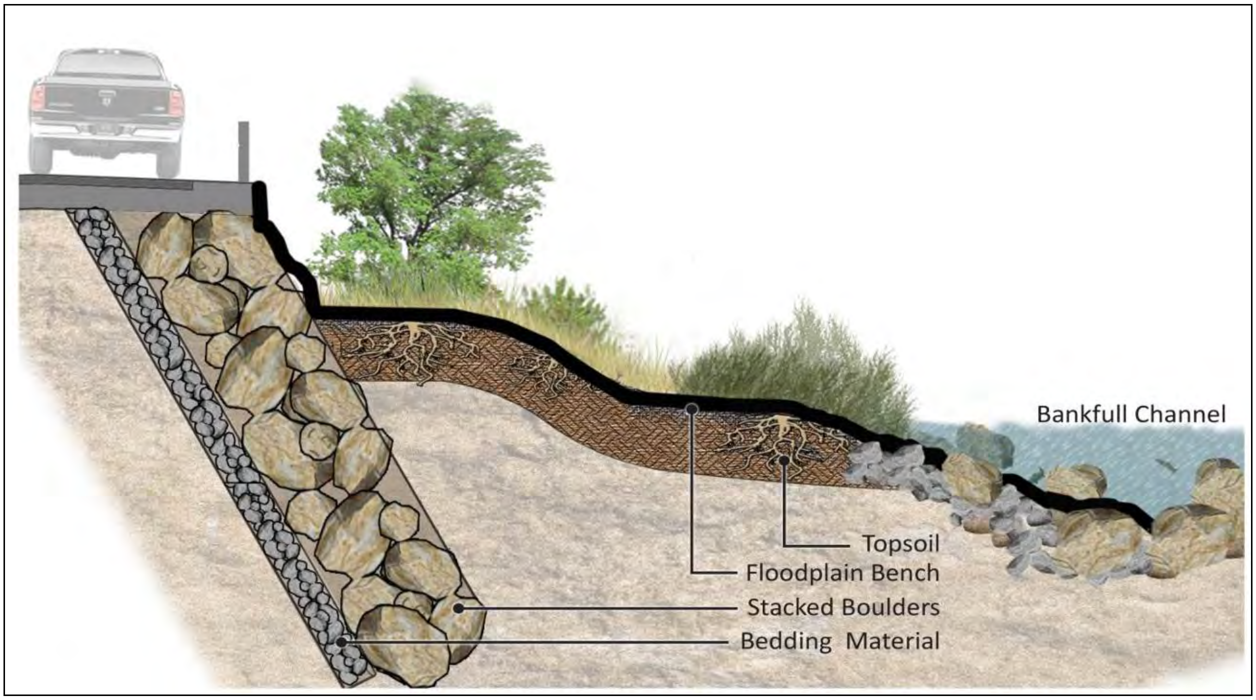


Figure 5.13. Bank Stabilization treatment, Stacked Boulders, 1H:1V slope or greater.

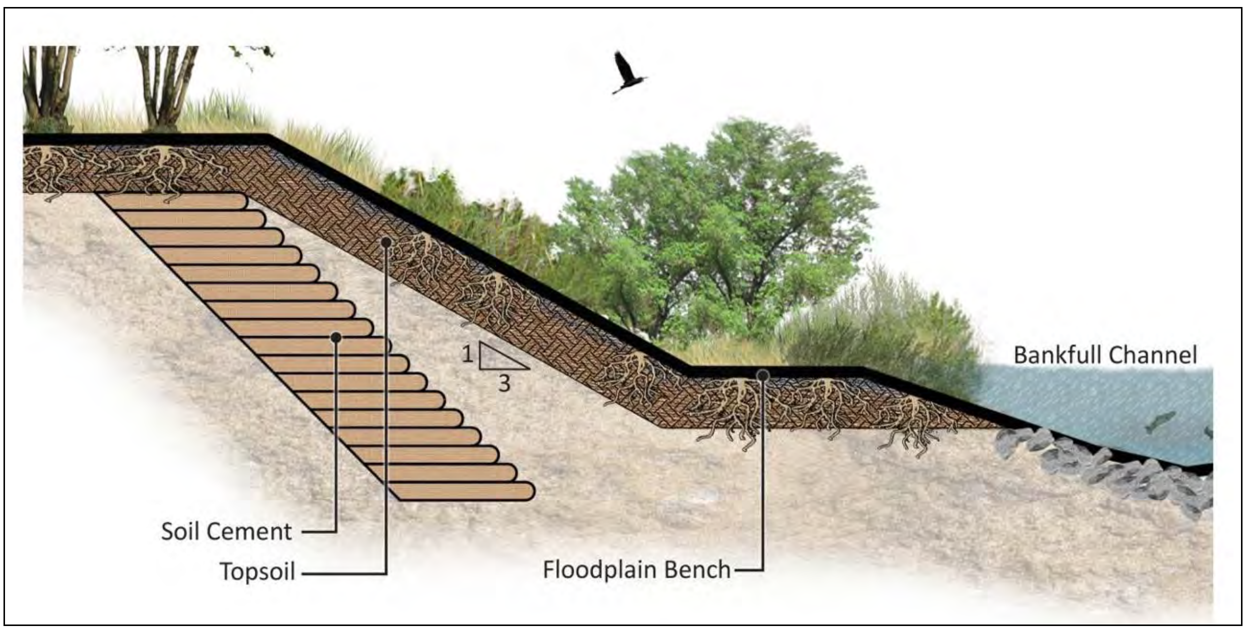


Figure 5.14. Bank Stabilization treatment, Soil Cement, 1H:1V and steeper.

Natural rock, LWM, and vegetated stabilization should be prioritized over hard stabilization treatments. However, shear stress and velocity during large flood events are high enough to preclude these treatments as an option when protecting infrastructure is a priority.

As long-term recovery projects are designed, it will be important to appropriately design bank stabilization to protect infrastructure without negatively impacting infrastructure located on the opposite bank. This will be particularly important in the canyon segments.

5.4 Walled or Elevated Road Section

These treatments are only recommended along sections of roadway. They are similar in purpose to bank stabilization and are recommended in locations where traditional bank stabilization may not be feasible. These include sections of roadway on the outside of bends in the river as well as severely constricted areas such as the Narrows. Vertical side walls, (**Figure 5.15**) do not require the typical roadway embankment fill on the river side of the road and therefore help increase the conveyance of water during floods which can also potentially lower the water surface elevation compared to typical stabilization treatments.

Elevated sections of roadway, **Figure 5.16**, similar to those in Glenwood Canyon provide the maximum amount of conveyance. However, both of these treatments are significantly more expensive than typical roadway construction with stabilized banks, and they may not be feasible due to budgetary limitations. Both the vertical walls and the elevated roadway treatments should include appropriate stabilization near the foundation or be anchored into bedrock to prevent failure due to erosion during flooding.

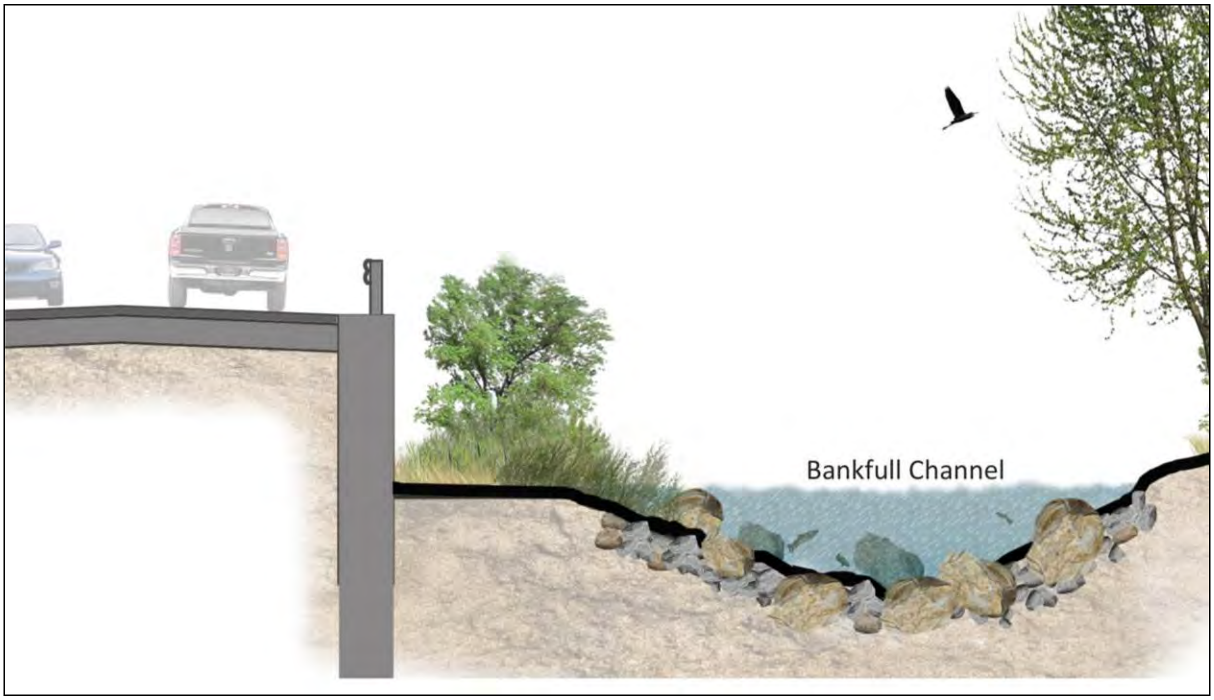


Figure 5.15. Vertical side wall treatment.

5.5 Proposed Channel

Channel migration occurred in most segments of the BTRRMP corridor. During the flood recovery phase channels were temporarily moved to enable the repair and reconstruction of roadways, bridges, and other infrastructure. In locations that experienced significant channel migration a proposed channel alignment is included in the conceptual plans. In each segment, the proposed channel location is one of several potential viable channel alignments. The proposed alignments were chosen based on observations from the 2013 and 1976 flooding, and take into account existing infrastructure. The alignments presented here may be suitable options; however a more thorough design process is needed to determine the ideal location.

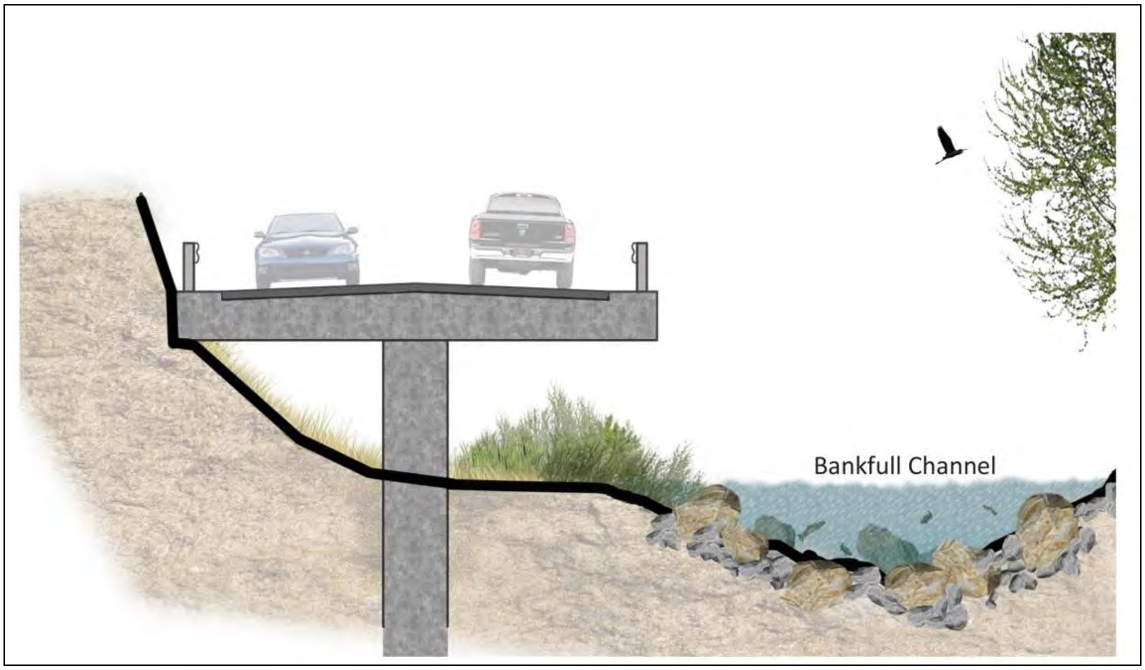


Figure 5.16. Elevated roadway treatment.

The 'correct' location of the channel could reasonably be anywhere within the active floodplain. The fact that the channel moved to a specific location during the 2013 flood does not mean that is the 'best' place for the river to be, though the post-flood channel may very well be an ideal location and alignment. In future flood events the river could move again to a previous location or an entirely new alignment. Rivers are dynamic and channels naturally move around in their floodplains. Typically the space available for channel migration is significantly less in the mountains than compared to the plains segments. However, there can still be areas of significant migration in the flatter open valleys that exist within the canyon segments such as near Drake and Cedar Cove.

Channel alignments should be chosen to function correctly from a geomorphic and hydraulic perspective, and attempt to meet the needs of the impacted stakeholders while not negatively impacting infrastructure.

Any new channels should be designed to recreate desired aquatic habitat features, as described in the aquatic habitat restoration treatment section. When viewing the conceptual plan maps keep in mind that any proposed channel locations assume that aquatic habitat would be restored in that location as well.

As permanent channel repairs are constructed within the canyon reaches the Master Plan recommends that in-channel features be designed with consideration for recreational boating safety. This includes channel design, placement of woody material, and large boulders. For further guidance see the related resource by American Whitewater (Colburn).

5.6 High Flow Channel

The high flow channel treatment is intended to provide a designated area within the floodplain for increased conveyance during flooding.

A high flow channel increases the capacity of a reach of river by creating a more efficient channel for flood flows to be conveyed within the floodplain, separate and higher than the main channel. They have been recommended in locations where small floodplains exist yet more conveyance is needed. They have also been recommended in locations to provide additional and/or improved habitat during high flows.

Where recommended near existing infrastructure, high flow channels should be appropriately stabilized so as not to increase erosion.

5.7 Increase Capacity

This treatment is applied to roadway crossings that experienced damage and/or closures during the 2013 flooding. In order to limit damage to roadways and bridges at river crossings due to overtopping and/or flanking, the capacity of the crossing must be increased to allow more flow under the bridge/roadway. This can be accomplished in multiple ways. The existing bridge can be left in place and a secondary relief structure can be incorporated into one or both of the bridge approach roadway embankments (**Figure 5.17**). This option is applicable to areas with larger floodplains east of the canyon mouth.

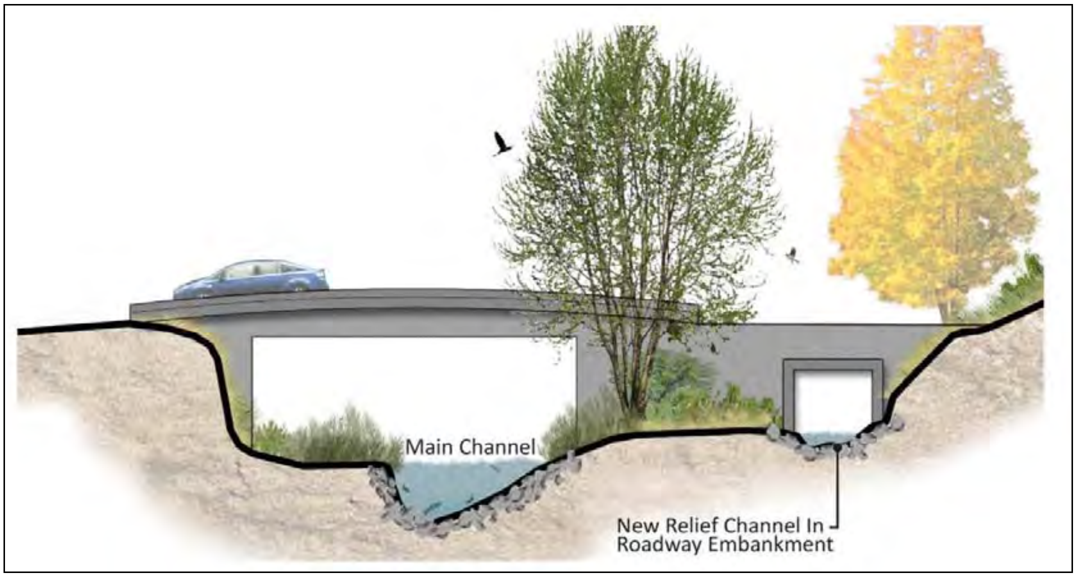


Figure 5.17. Relief structure in roadway embankment.

Another option is to replace the existing bridge structure and increase the opening width, height, or both in order to increase the flood flow capacity, as presented in **Figure 5.18**. There is also the possibility that existing bridges are not conveying flood flows as efficiently as possible due to upstream or downstream channel and floodplain configurations.

As structures are replaced the design process should aim to create the most efficient structure location, channel alignment, and floodplain grading. Bridge and/or culvert replacement also needs to take into account sediment and debris transport during flood events. Increasing the capacity of the bridge will help with debris, however the relief bridge option will likely not improve transport of debris unless the relief bridge is large and the top of the opening is well above the design flood elevation. All stream crossings should be designed for aquatic organism passaged so as not to create a barrier. This is particularly important if culverts are used at crossings. For additional recommendations specific to access bridges within the canyon see Section 7.4.

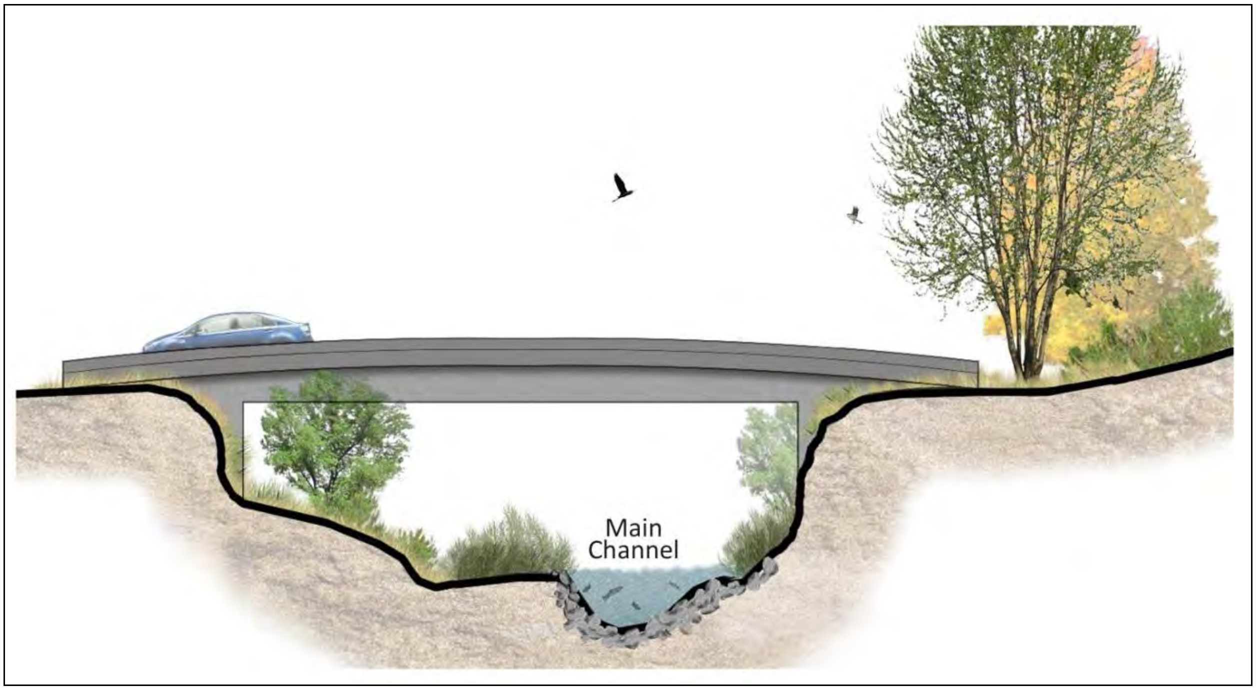


Figure 5.18. Increase width and/or height or existing bridge.

Two locations where this treatment is proposed are along roadways, not bridge crossings, CR 52 and CR 15.5, which significantly encroach on the floodplain. The recommendation of these locations is to realign the roadways away from the river.

It may not be feasible to increase the size of existing structures and/or add relief structures. Another consideration would be to stabilize the lowest sections of the approach roadway so that overtopping flows to not lead to the failure of the road embankment.

5.8 Lower/Regrade

The lower/regrade treatment involves excavating material and either regrading the material into surrounding lower ground or hauling it away. This treatment is recommended for locations within Loveland and areas downstream. Due to historic land use practices (primarily gravel pit mining) the main channel is mostly cut off from the historic floodplain. During a flood the water is confined to the main channel which increases the velocity and depth of flow compared to historic conditions. In addition to causing bank erosion and potential vertical erosion within the main channel, the primary issue is that the main channel will often avulse into abandoned gravel pits. This resulted in flood flows abandoning the main channel and creating new flow paths within the gravel pits and/or other locations within the floodplain. Which can cause additional and unexpected erosion, deposition, and damage to infrastructure.

The purpose of the proposed lower/regrade area is to direct future flood events to specific locations instead of the flood randomly 'choosing' where to go. There is significant opportunity to use the material to regrade the edges of the gravel ponds to improve the floodplain ecosystem.

5.9 Stabilized Overflow

This treatment will be used in conjunction with the regrading and restoration of select areas of the floodplain in and around Loveland. During the 2013 flood the river eroded sections of embankments separating the main channel from the floodplain. The stabilized overflow areas consist of a lowered embankment with a stabilized downstream face to prevent future floods from head cutting and eventually avulsing through these areas, **Figure 5.19**. These overflow locations allow flood flows to access the floodplain at designed locations in a more controlled manner. The downstream slope may be graded and planted or stabilized with treatments presented in Section 6.3. Hard stabilization may not be necessary to protect these areas from head cutting. Regrading and revegetation may be sufficient to stabilize the overflow locations. Providing designated locations to access floodplains will not only help alleviate some erosion and flooding issues, it is also a benefit to the ecological health of the river corridor.

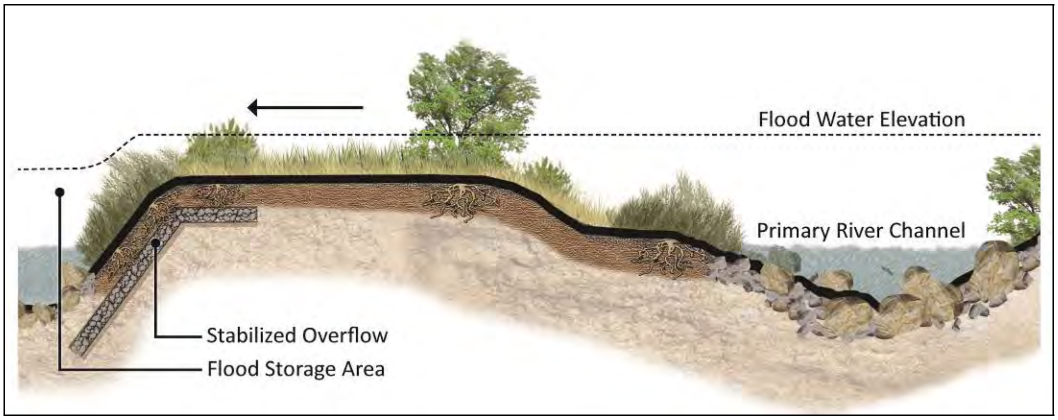


Figure 5.19. Stabilized overflow treatment.

5.10 Floodplain Bench

Floodplain benches, as shown in several of the previous figures, are intended to be a low bench above the ordinary high water line that will be inundated by floodwaters in higher flow events. Floodplain benches have the potential to provide multiple benefits in future flood events. They will provide additional area for flood conveyance, potentially reducing the velocity in the main channel as well as the water surface elevation across the floodplain. They will provide a larger area for riparian vegetation restoration. Vegetated floodplains also act as filters to help improve water quality during high flow events.

The floodplain through Loveland and east of I-25 has a high potential for improvement. These areas include old gravel pits, active gravel pits, agricultural fields, grazing pastures, etc. Due to the existing uses of the floodplain restoration of these areas will likely require the purchase of land and/or changing existing land use practices. Recommendations made in the master plan attempt to recognize existing land use practices while trying to restore some of the historic floodplain. Depending on land owner interest there may be significantly more opportunity to restore more floodplain area than is shown on the maps.

The areas designated as floodplain bench in the proposed plan maps may require excavation, regrading, vegetation seeding/planting, introduction of LWM, and/or bank stabilization features.

5.11 Improve Conveyance

This item is not a specific treatment, but will likely include a combination of some of the previously identified treatments. The only place this is designated is upstream of US 34 near Glade Road. This area contains a lot of infrastructure in the floodplain and experienced deposition during the 2013 flood event. To improve this area's flood resiliency, treatments that increase the conveyance of flood flows need to be incorporated into the floodplain. This may include lowering and regrading portions of the floodplain, potentially a high flow channel, as well as the removal and/or relocation of infrastructure including homes, roads, and utilities. Lowering the flood risk to existing properties is not likely without the removal of some homes or businesses. If a future project attempts to mitigate flooding in this area, there will need to be close collaboration from all potentially impacted stakeholders regarding the final mitigation solution. Any design treatments will be dependent on which, if any, properties would be available for removal and restoration.

5.12 Applied Treatments

All of the above treatments have been recommended for the BTRRMP corridor based on observations made during the assessments. The maps depicting the conceptual plans are included in Appendix C. The following illustrative sections are intended to help visualize how some of the treatment areas could be applied and work together at various locations throughout the corridor.

The upper canyon typically consists of a narrow corridor that includes the main channel, roadway, occasional areas of homes and a few small inset floodplains. The typical section shown in **Figure 5.20** is near Waltonia. The right bank includes buried bank stabilization planted with riparian vegetation. This section also includes a vertical wall along the left bank to protect the roadway. The vertical wall will provide more area for conveyance and allow a small inset floodplain along the toe for riparian vegetation.

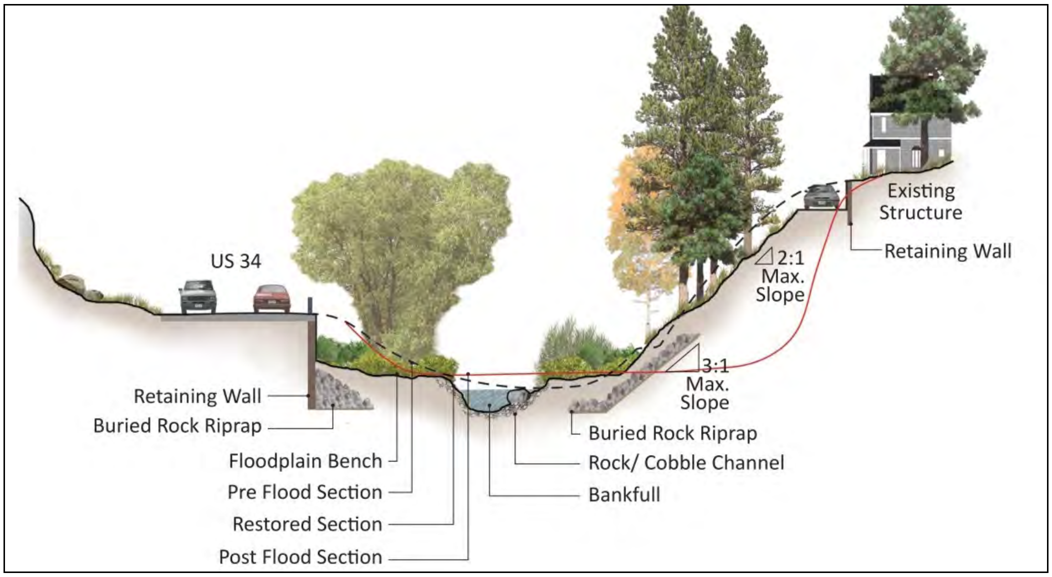


Figure 5.20. Illustrative section at Waltonia - view downstream.

The river corridor changes downstream near Drake. The river flattens some and the valley floor is wider with larger floodplains. During both the 1976 and 2013 floods this area experienced large amounts of sediment deposition. This results in an unstable river channel that can migrate during flood events. The recommended treatments in this location include buried bank stabilization set back as far as possible with inset floodplains and channel (**Figure 5.21**). This area will likely experience similar deposition in future flood events with unpredictable channel movements. The set back bank stabilization will help protect infrastructure on both sides of the river while giving the river as much space as possible for restoration and potential future channel migrations.

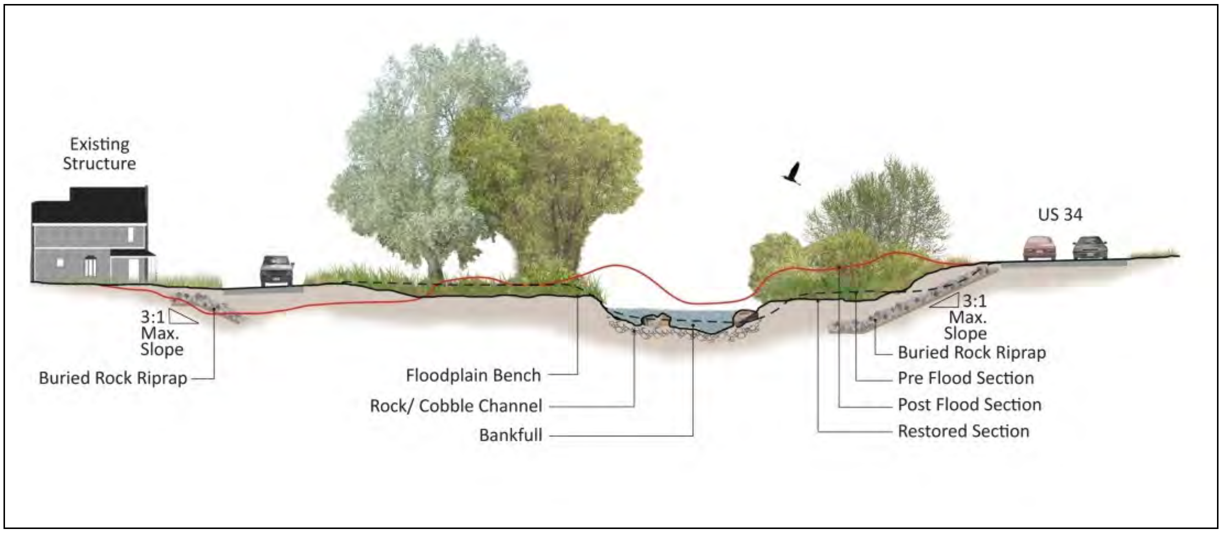


Figure 5.21. Illustrative section at Drake – view upstream.

Downstream of Drake the canyon narrows some, but has more room than the upper canyon. The typical section shown in **Figure 5.22** includes buried bank stabilization with a restored riparian corridor with as much floodplain bench as possible. Local access roads will have to be redesigned to work with the newly restored corridor. The section below shows a road on the upper slope with a small retaining wall. This is one of many options possible.

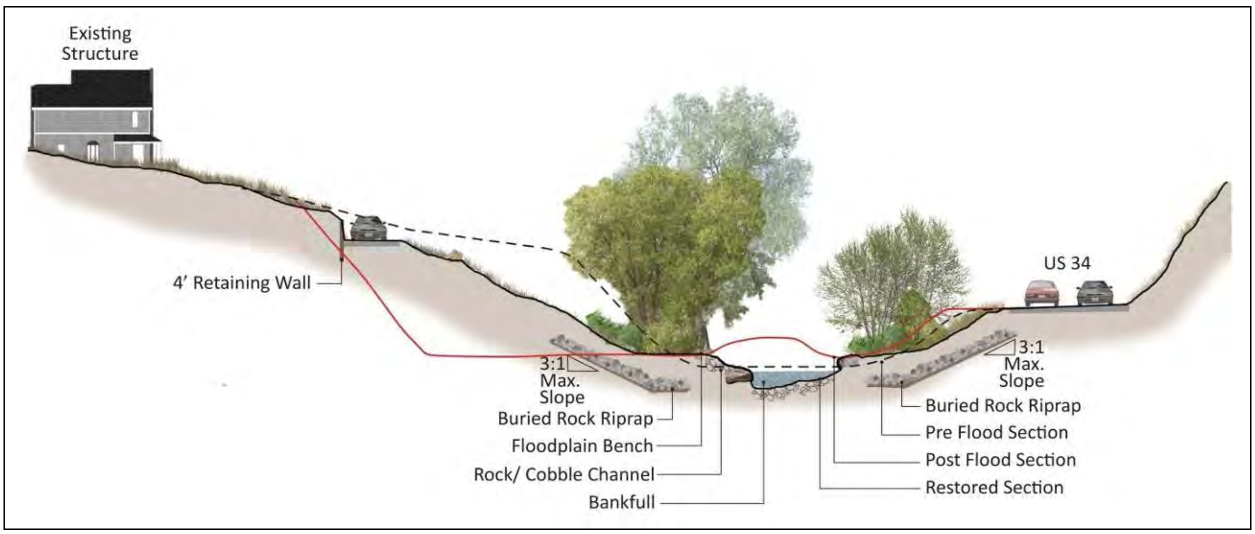


Figure 5.22. Illustrative section downstream of Drake – view upstream

The lower canyon contains more open valleys with larger floodplains compared to the upper canyon. Near Jasper Lake Road there are homes on both sides of the river on low and upper floodplains. The recommendation here is to include buried bank stabilization along the higher right bank, lower some of the existing inset floodplain, and add a high flow channel if feasible (**Figure 5.23**). Homes that exist on low floodplain benches through the master plan corridor are difficult to protect from flooding and erosion. The recommendations made at this location, and others, are an attempt to reduce flood damages by directing flows away from structures while increasing flood flow capacity where possible.

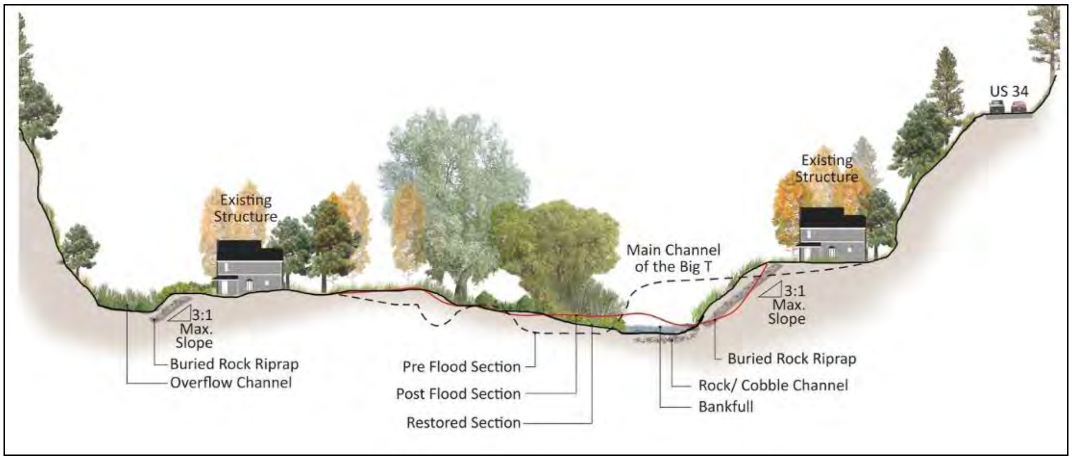


Figure 5.23. Illustrative section near Jasper Lake Road – view downstream.

Throughout the Loveland segment a common problem is a constricted channel disconnected from historic flood plains. This is often due to old gravel mining pits and associated berms. It is recommended that berms be lowered and stabilized to provide, and control, access to the floodplain (**Figure 5.24**). It is also recommended to regrade and restore these same areas where feasible to improve the health and function of the floodplain. Restoring floodplains and improving the conveyance of future flood events will be dependent on the ability to regrade portions of the floodplain, change land use types, and potential remove structures. Close coordination with landowners will be required to implement these recommendations.

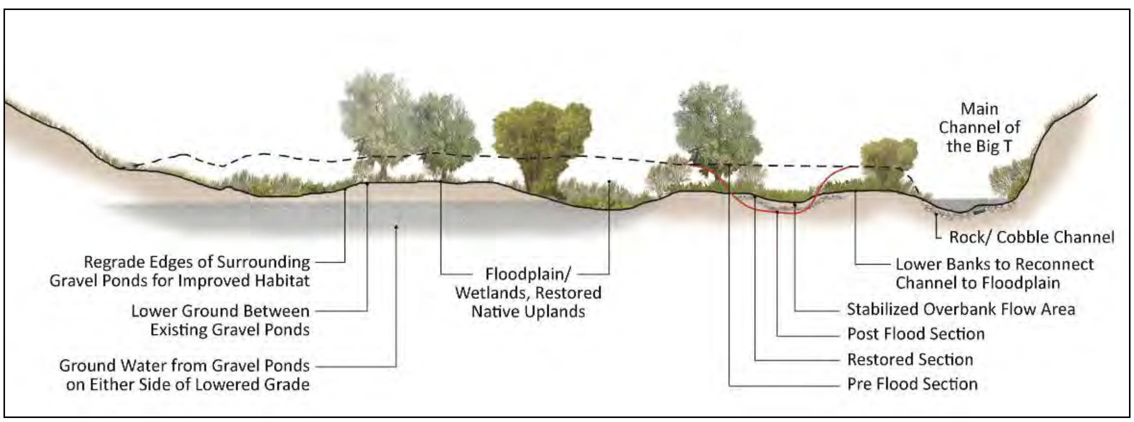


Figure 5.24. Illustrative section near Loveland – view downstream.

The Eastern Plains segment is similar to Loveland; however the primary land use within the historic floodplain in this segment is agricultural. The channel has become disconnected from its floodplain as a result of down-cutting, the presence of levees, the encroachment of agricultural or gravel mining activities, and/or changes in hydrology due to diversions upstream. It is recommended that some floodplain areas be lowered to allow for more inundation from regular high flow events (**Figure 5.25**). Several reaches need significant revegetation of the channel banks and floodplain and/or removal of invasive vegetation. LWM should be incorporated both in the channel and floodplain. There is very little bank stabilization recommended in the eastern segments. Restoring and maintaining a wide vegetated floodplain appears feasible throughout this area and will provide significant benefits during large flood events, as described in Section 2.2. Restoring floodplains will be dependent on the ability to regrade portions of the floodplain and change land use types. Close coordination with landowners will be required to implement these recommendations.

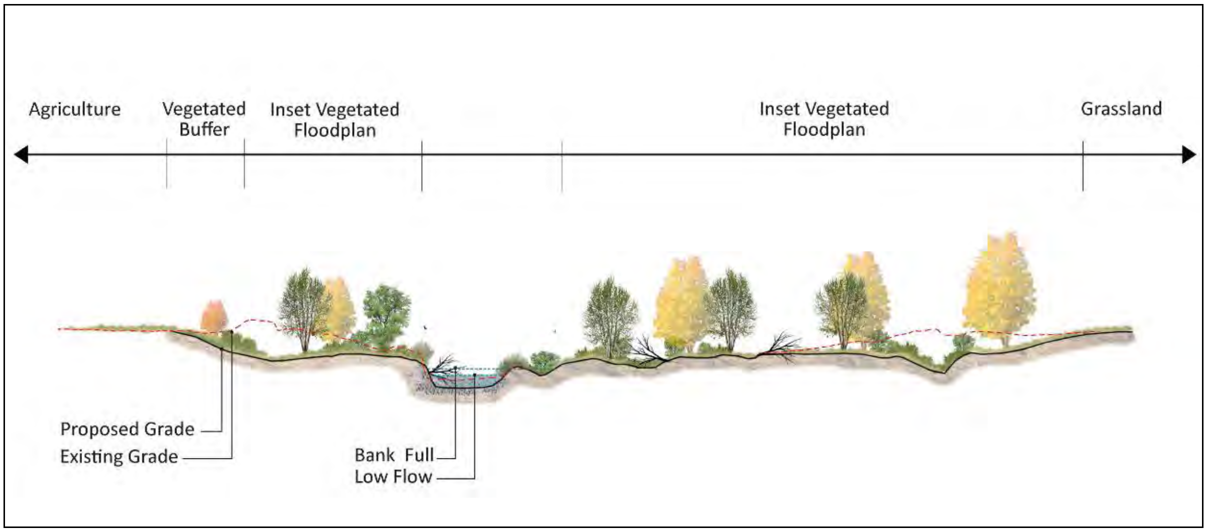


Figure 5.25. Illustrative section of Eastern Plains– view downstream.

The upper North Fork and tributaries are smaller creeks within a very small valley with homes and local access roads sharing the floodplain and sometimes built directly adjacent to creeks. Bank stabilization and vegetation are recommended as needed with small retaining walls as feasible, potentially using stacked boulders as depicted in **Figure 5.26**. The retaining walls would help provide bank protection, as well as provide additional space for future floods. It may be difficult and infeasible to provide flood protection to all structures as well as the roadways in these areas.

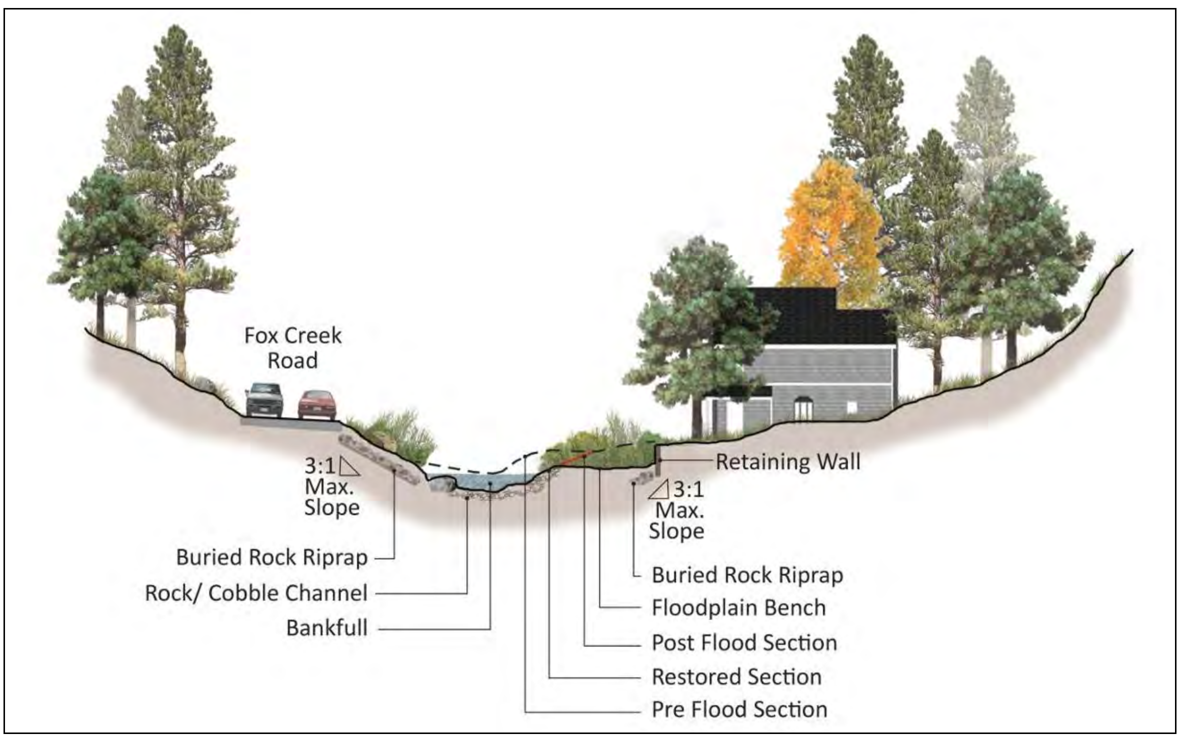


Figure 5.26. Illustrative section at Fox Creek – view downstream.

West Creek near Glen Haven has potential for a wider riparian corridor than the other upper tributaries. Recommendations in this reach include buried bank stabilization set back from the channel as far as possible to protect roads and buildings (**Figure 5.27**). This will provide the maximum amount of space to restore riparian ecology and to convey future flood flows.

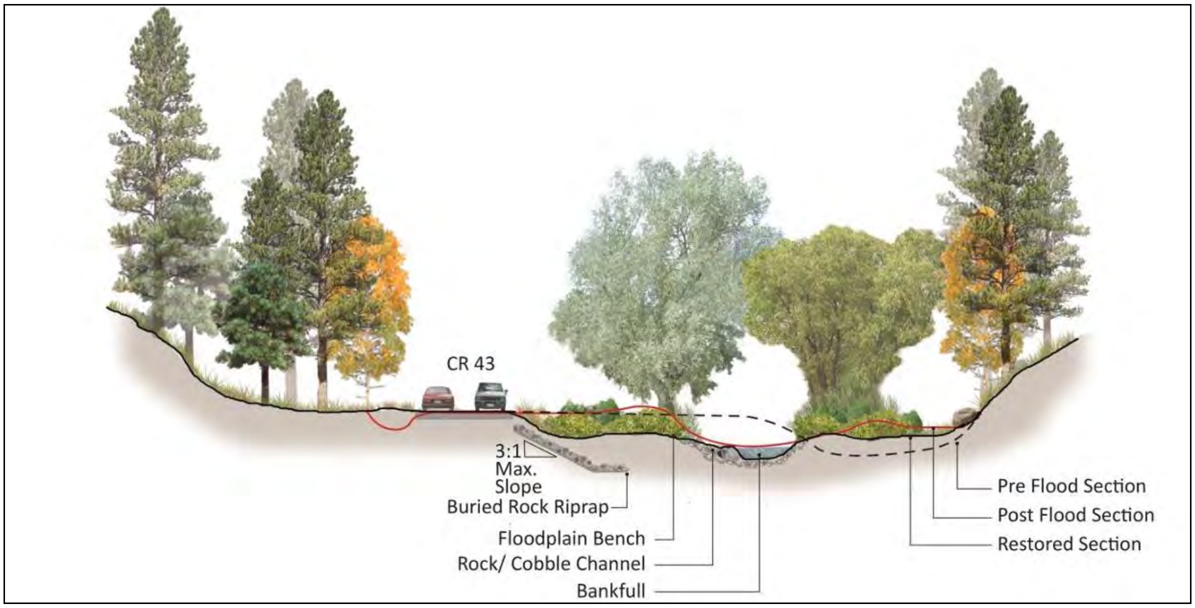


Figure 5.27. Illustrative section at Glen Haven – view upstream.

6. COSTS

Due to the conceptual nature of the proposed treatments of this master plan, the calculated costs are very approximate. Treatment costs were calculated for each reach based on per linear foot or acre of each treatment as well as lump sum costs for two treatments.

There are several variables that will impact the actual costs to implement the BTRRMP. These may include the actual length, height, width, and/or area of treatments, availability of material, construction methods, amount of material to import and/or export, amount of engineering design required, real estate needs, 404 and FEMA permitting requirements, and likely others. The size of each project will also impact the final costs due to economies of scale. Because of the unknowns the costs are presented as a low and high amount in order to show the potential range of costs that are possible.

The low and high unit costs for each treatment used for the BTRRMP are provided in **Table 6.1**. For the Wall or Elevated Roadway treatment, only the approximate costs for a wall are included. Elevated roadway sections will have a higher unit cost.

Table 6.1. Unit Costs.

Big Thompson River Restoration Master Plan Conceptual Plan Treatment Costs			
Treatment	**Cost Per Unit (low) ($)**	**Cost Per Unit (high) ($)**	**Unit Measure**
Aquatic Restoration	40	120	LF
Aquatic Restoration - Partial	20	60	LF
Riparian Restoration	100	250	LF
Riparian Restoration - Partial	50	125	LF
Bank Stabilization	300	600	LF
Bank Stabilization and Riparian - Partial	200	425	LF
Stabilized Overflow	400	800	LF
Wall or Elevated Roadway	2,000	3,000	LF
Proposed Channel	225	450	LF
High Flow Channel	150	225	LF
Increase Capacity	500,000	1,500,000	LS
Lower/Regrade	7,000	20,000	Acre
Floodplain Bench	5,000	15,000	Acre
Improve Conveyance	1,000,000	3,000,000	LS

*Partial is assumed to be half the total length of the proposed treatment
LF = Linear Foot
LS = Lump Sum

Sources used to create unit costs were obtained and checked using a variety of sources including the following:

- Urban Drainage and Flood Control District Cost Estimator for Master Planning
- Central Federal Lands cost estimates related to the reconstruction of CR 43
- NRCS exigent repairs cost estimates
- Ayres Associates past and recent project experience
- CDOT Cost Data Book, 2013 and 2012
- USDA Forest Service Stream Restoration Cost Estimates
- A variety of other related resources

Aquatic habitat costs were reduced to account for the reality that not all of the recommended areas will need complete restoration.

Additional costs, also provided as a low and high amount, include items that will likely be required during the design and construction phase of a project, **Table 6.2**. These include engineering design, management, construction related requirements, and a contingency for items to account for the unknowns at this point in the project process. The high amounts are recommended by the City of Denver's Urban Drainage and Flood Control District (UDFCD).

Table 6.2. Additional Costs.

Additional Costs		
Item	**Percent of Improvement Cost (low)**	**Percent of Improvement Cost (high)**
Engineering	5	15
Administrative/Legal	1	5
Construction Management	5	10
SWMP	2	5
Mobilization	2	5
Dewatering	0	5
Traffic Control	0	5
Contingency	10	25
Total	25	75

The total cost for each reach was computed by multiplying the unit costs by the quantity of each recommended treatment and then adding the additional cost. Total costs are provided in **Table 6.3**, and include a low and high cost for each. In locations that include major roadways paralleling rivers, the reach costs were separated into treatments assumed to be part of future roadway construction and those that are the responsibility of private individuals or agencies other than roadway construction. Digital versions of the information provided here and treatment quantities are provided in Appendix B.

Table 6.3. Total Costs.

Big Thompson River Restoration Master Plan Total Costs						
Stream	**#**	**Name**	**Reach Cost (low)**	**Reach Cost (high)**	**Roadway Cost (low)**	**Roadway Cost (high)**
Big Thompson River	1	Evergreen Point	$ 237,100	$ 875,070	$ 26,000	$ 91,000
	2	Rock Canyon	$ 827,063	$ 2,571,319	$ 244,431	$ 856,861
	3	Loveland Heights	$ 243,688	$ 788,069	$ 187,875	$ 657,563
	4	Bella Vista	$ 484,725	$ 1,489,451	$ 76,375	$ 267,313
	5	Glen Comfort	$ 426,938	$ 1,334,419	$ 130,188	$ 455,656
	6	Noels Draw	$ 651,625	$ 1,643,863	$ 207,688	$ 726,906
	7	USFS-1	$ 85,288	$ 320,101	$ 831,125	$ 2,520,700
	8	Seven Pines	$ 287,188	$ 1,005,156	$ 506,250	$ 1,569,488
	9	Oxbows	$ 808,250	$ 2,501,275	$ 767,313	$ 1,873,594
	10	USFS-2	$ 430,600	$ 1,246,770	$ 7,475,313	$ 15,929,594
	11	Waltonia	$ 1,598,125	$ 4,962,388	$ 11,644,500	$ 25,278,750
	12	Mountain Shadows	$ 393,625	$ 1,197,613	$ 30,347,681	$ 64,158,911
	13	West Drake	$ 692,375	$ 2,061,325	$ 6,979,750	$ 15,288,438
	14	Drake	$ 629,825	$ 1,779,540	$ 3,816,082	$ 8,566,900
	15	East Drake	$ 1,544,225	$ 4,410,683	$ 1,583,613	$ 4,581,360
	16	Midway	$ 1,146,525	$ 3,560,393	$ 523,750	$ 1,564,063
	17	Old Idlewild Dam	$ 335,750	$ 1,250,025	$ 876,538	$ 2,581,583
	18	Idlewild	$ 1,338,125	$ 3,920,613	$ 1,844,669	$ 5,445,221
	19	USFS-3	$ 45,750	$ 160,125	$ 520,875	$ 1,823,063
	20	V-Smith Mountain Park	$ 601,013	$ 1,729,665	$ -	$ -
	21	Cedar Cove	$ 2,155,856	$ 6,242,171	$ 365,850	$ 1,032,570
	22	Jasper Lake	$ 3,212,044	$ 8,958,084	$ -	$ -
	23	Narrows	$ -	$ -	$ 24,337,325	$ 51,984,590
	24	Sylvan Dale	$ 2,511,625	$ 7,134,225	$ 3,025,125	$ 6,590,938
	25	Loveland WTP	$ 569,950	$ 1,917,825	$ 625,000	$ 2,625,000
	26	River View	$ 487,813	$ 1,917,825	$ 1,036,125	$ 3,855,513
	27	Glade Road	$ 4,568,144	$ 7,966,035	$ 625,000	$ 2,625,000
	28	Whiteside	$ 585,669	$ 2,225,571	na	na
	29	Morey Open space	$ 1,297,244	$ 3,786,055	na	na
	30	Rossum - Namaqua	$ 2,043,485	$ 7,168,166	na	na
	31	Namaqua - Wilson	$ 1,703,018	$ 6,080,900	na	na
	32	Wilson - Taft	$ 2,256,754	$ 8,317,046	na	na
	33	Taft - Railroad	$ 1,414,616	$ 5,500,902	na	na
	34	Fairgrounds Park	$ 1,108,045	$ 4,591,773	na	na
	35	Lincoln - St. Louis	$ 1,046,245	$ 3,955,644	na	na
	36	St. Louis - Boise	$ 1,393,018	$ 5,040,989	na	na
	37	Boise - CR 9e	$ 3,032,483	$ 10,179,938	na	na
	38	Kauffman's	$ 1,370,953	$ 4,300,415	na	na
	39	I-25	$ 1,260,673	$ 5,230,348	na	na
	40	Thompson River Ranch	$ 1,437,138	$ 5,517,278	na	na
	41	County Line Road	$ 1,421,419	$ 5,491,596	na	na
	42	CR 54	$ 1,134,963	$ 4,766,843	na	na
	43	Great Western RR	$ 3,014,594	$ 12,642,394	na	na
	44	CR 48.5	$ 1,882,319	$ 7,896,131	na	na
	45	Milliken	$ 307,019	$ 1,289,479	na	na
	46	Milliken East	$ 468,881	$ 1,890,114	na	na
	47	CR 27.5	$ 324,963	$ 1,364,843	na	na
	48	Confluence	$ 331,094	$ 1,157,494	na	na
North Fork and Tributaries	49	Upper West Creek	$ 1,304,325	$ 3,968,703	$ 140,250	$ 392,700
	50	Glen Haven	$ 1,375,656	$ 4,290,169	$ 1,257,025	$ 3,590,755
	51	Fox Creek	$ 1,986,000	$ 5,908,350	$ -	$ -
	52	Upper North Fork	$ 2,195,500	$ 6,531,613	$ -	$ -
	53	NF - Canyon 1	$ 740,850	$ 2,424,345	$ 3,181,356	$ 9,249,546
	54	Dunraven	$ 408,056	$ 1,428,586	$ 2,782,571	$ 8,896,599
	55	NF-Canyon 2 upper	$ 557,775	$ 1,915,218	$ 2,716,400	$ 7,938,018
	56	NF-Canyon 2 lower	$ 945,150	$ 3,089,293	$ 1,722,625	$ 5,121,288
	57	Crosier Mt Trail	$ 400,513	$ 1,610,753	$ 884,688	$ 2,557,188
	58	Fish Hatchery	$ 2,271,313	$ 6,669,119	$ 1,936,625	$ 5,559,400
	59	North Drake	$ 1,801,675	$ 6,028,698	$ 155,688	$ 437,588
		Total	**$ 69,134,632**	**$ 225,202,785**	**$ 113,381,666**	**$ 266,693,652**

7. MANAGEMENT GUIDELINES

Besides the physical treatments described in the previous section, the long-term reduction of flood losses will require that the current floodplain management ordinances continue to be enforced and will also require a significant update and perhaps expansion of the technical data that support floodplain management.

7.1 Current Floodplain Management Context

This master plan encompasses unincorporated areas of Larimer and Weld Counties, as well as segments within the corporate limits of the City of Loveland and the Town of Milliken. All of these jurisdictions participate fully in the National Flood Insurance Program (NFIP), which is administered by FEMA and which makes flood insurance available for properties within participating communities. The federal regulations that form the foundation of the NFIP are found in Title 44, Part 60 of the Code of Federal Regulations.

In Colorado, the Colorado Water Conservation Board has a statewide technical oversight role in floodplain management and has promulgated Rules and Regulations for Regulatory Floodplains in Colorado. These rules for Colorado communities go beyond the requirements of the NFIP in several aspects.

The specific administrative procedures vary between communities, but in general the basis of floodplain management is that permits must be obtained to conduct certain activities and to construct buildings and infrastructure within regulated floodplains. The communities and jurisdictions along the Big Thompson River have been active and responsible in floodplain management since the 1980s, which is a contributing factor to the relatively low loss of life in the 2013 flood compared to the 1976 flood. In the City of Loveland, for instance, the floodplain administrator called for evacuation of the FEMA 100-year Big Thompson floodplain area well before the flood peak arrived. Additionally, some buildings in the Big Thompson Canyon that had been the site of loss of life during the 1976 flood were never rebuilt, in part due to floodplain management ordinances.

Obviously then, the affected jurisdictions should continue the practices of responsible floodplain management into the future. Significant obstacles exist, however, in the availability of technical data and tools to support floodplain management. Even before the 2013 flood, the enforcement of floodplain ordinances along the Big Thompson River was impaired by the following factors:

- Peak 100-year flood discharges that are from outdated hydrologic studies that were performed in the 1970s using data from the 1960s and earlier (affecting the entire Big Thompson below Olympus Dam)
- Hydraulic models from the 1970s with coarse resolution, incorporating old topographic data and using outdated computation techniques (from Olympus Dam to Buckhorn Creek)
- Inaccessibility of the digital hydraulic model files from which the effective mapping was derived (upstream of Buckhorn Creek and downstream of Thompson Ranch subdivision)
- Inaccurate digital mapping of the floodplain versus topography that existed just prior to the flood, as shown in **Figure 7.1** (in various locations, mostly in the unincorporated areas)
- Structures in the floodplain that cannot be protected by means other than elevation or other type of floodproofing

Figure 7.1. Illustration of inaccurate digital floodplain data.

Additional challenges have arisen as a result of the erosion and deposition, and lateral and vertical channel changes that occurred during the 2013 flood. These changes have complicated floodplain management in several ways, including the following:

- In many locations the current plan view mapping of the floodplain does not reflect large zones that were eroded to elevations below the flood level or that were raised by deposition to elevations above the flood level
- Much grading, bank protection and channelization work has already been done or will be done in the near and distant future to restore and protect damaged facilities, structures and properties
- For practical reasons the aforementioned work will not, in most cases, be designed to match the pre-flood line and grade, meaning that the floodplain mapping that was developed for pre-flood conditions will never again be accurate except in some locations in Loveland and farther east
- The aforementioned work will progress over a period of several years, meaning that floodplain conditions will be in a state of ongoing change at a scale and pace not normally encountered in floodplain management

7.2 Updating Technical Tools and Data for Future Floodplain Management

Much updating is needed to the technical tools and data that form the basis of floodplain management. Some of the required work is already underway or nearly complete.

Hydrology (Peak Flood Discharges). The CWCB and CDOT are working together to establish new design hydrology for the flood-affected stream reaches. This new hydrology, which has been completed for the Big Thompson as far downstream as Buckhorn Creek, incorporates a highly detailed and calibrated rainfall-runoff model, supplemented and verified with stream gage analysis (CDOT 2014). The hydrology has been widely reviewed and is still under review in certain aspects. It has not yet been adopted by FEMA. Moving forward the CWCB/CDOT hydrology (potentially revised and/or expanded from its current status) should be used for floodplain-related studies and designs because it represents the best available data.

Hydraulics (Flood Levels and Floodway Analysis). The official FEMA hydraulic models in the canyon reaches were rendered obsolete by the erosion, deposition and channel changes of the 2013 flood. For the interim, CWCB has commissioned approximate hydraulic analysis and floodplain mapping using Atkins' proprietary Rapid Floodplain Delineation technology. This hydraulic analysis and mapping is coarse and approximate and does not incorporate the new CWCB/CDOT hydrology but can be useful in estimating floodplain elevations for the canyon reaches of the Big Thompson River until more detailed and current hydraulic models have been developed. Downstream of Buckhorn Creek, the effective FEMA hydraulic models are still reasonably accurate in most locations, but have not been updated with the new CWCB/CDOT hydrology.

Ultimately it is essential that the floodplain hydraulic modeling be updated throughout the master plan area. CDOT and the FHWA Central Federal Lands Highways Division have indicated an intention to perform hydraulic modeling of both existing conditions and post-project conditions as part of their design and construction efforts for the permanent repairs to US Highway 34 and County Road 43 (along the North Fork of the Big Thompson), respectively. Those models, when available, will become very useful "best available data" tools for floodplain management during the flood recovery period. They should be used, along with the current models downstream of Buckhorn Creek updated with the new hydrology, for basic floodplain management and permitting activities. Additionally, it is necessary to establish accurate modeling of pre-flood conditions where such mapping didn't exist, such as in the canyon reaches. The pre-flood conditions should be used as the baseline for comparative analyses, such as no-rise studies to verify that a project will not create an adverse floodplain impact. A resource available for pre-flood conditions is a database of LiDAR mapping from May of 2013 that covers the entire Big Thompson River from Loveland to Olympus Dam and the North Fork from Drake to Glen Haven.

Mapping (Floodplain and Floodway Delineation). The mapping of the floodplain extent will need to be updated to reflect new topography, new hydrology, and new hydraulic modeling. In the canyon reaches, the inundation mapping from the Rapid Floodplain Delineation work referenced above is available but is coarse and approximate and also doesn't reflect changes made in the course of recent repair projects. The effective FEMA mapping downstream of Buckhorn Creek is available but doesn't reflect the latest hydrology.

Eventually it will also be necessary to establish new regulatory floodway limits. By Larimer County standards and by the CWCB Rules and Regulations, the minimum standard for floodway determination is for a 0.5-foot surcharge floodway. The currently effective floodway in the reaches upstream of Loveland is based not on the concept of encroaching into the floodplain until a certain surcharge is reached, but rather on the basis of depth and velocity. In these reaches, any area in which the anticipated velocity is greater than 3 feet per second or the anticipated water depth is greater than 1.5 feet is included in the floodway. In all locations this approach led to a wider (e.g., more restrictive to property owners) floodway delineation than a 0.5-foot surcharge would require. In fact, in many locations the floodway established under the depth/velocity criteria occupies nearly the entire floodplain.

7.3 Floodplain Management Moving Forward

The procedures used by the various affected floodplain administration jurisdictions have followed the federal regulations for the NFIP and the state's more stringent rules as well. The most pressing need for improvement is for the technical tools and data to be updated as described previously. The river changes caused by the flood have created complications in the details of certain evaluations and procedures for the floodplain permit process.

Floodplain Permits Needed Urgently. Since September 2013 there has been, understandably, a strong impetus from property owners and infrastructure agencies to perform repairs to prevent further property loss. These repairs are ongoing, often small in scope and typically are on an urgent timeline such that a drawn out floodplain permit process is untenable. In response to this situation Larimer County is issuing emergency floodplain permits that allow parties to carry out work that is truly of an emergency nature without going through the full process for a permanent floodplain development permit. The emergency permit is issued with the condition that at a later date the work will be subject to the full scope of floodplain development review and may, as a result, need to be altered to mitigate a violation of the regulations. These emergency permits have been, and will continue to be, very useful in carrying out necessary work, especially with the current status of obsolete technical data. The post-emergency review of projects built using these permits, however, may prove to be an overwhelming task in the future, just because of the number of such projects.

Appropriate Baseline for Floodplain Impact Evaluation. A very common engineering activity in the context of floodplain management is comparing proposed project conditions to a baseline condition to verify the project will not cause an adverse impact (no-rise analysis). Under normal circumstances the appropriate baseline for comparison is the best model of existing conditions. This concept is problematic for the reaches that experienced a great deal of erosion during the flood. In these reaches the existing channel capacity may be significantly greater than the pre-flood condition. Often the work that will be needed to restore the river, including the types of improvements recommended in this master plan, will by necessity reclaim some of the eroded area to establish an appropriately protected bank line, road embankment, etc. If the baseline for no-rise analysis is to be the existing post-flood conditions, it will often be impossible to show no-rise for the proposed work. A more fair and practical approach is to use the pre-flood conditions as the baseline. Pre-flood conditions may be defined as the current effective FEMA model in areas where that model is reasonably current and accurate. In other areas, such as the canyon reaches, it is advisable to use a new pre-flood model that will make use of the best pre-flood topographical information, such as the May 2013 LiDAR that exists for much of the master plan area.

Rapid Changes to Physical Channel and Floodplain Conditions. The flood recovery and repair work, and the implementation of this master plan, will take place over many years. Especially in the next five years, the changes in the physical features of the channel and floodplains will take place at a steadily rapid pace due to the permanent road repairs, various infrastructure protection projects, rebuilding of parks, and the property protection that will be implemented by land owners. During this time it will not be practical to officially update the FEMA maps through the map revision or restudy process. A more likely and practical approach will be to use the best available information (hydraulic modeling, topography and mapping) at the point in time that a permit is being sought. The available information will be changing rapidly as various modeling efforts are completed.

Existing Vulnerable Structures. Many structures remain in highly hazardous floodplain locations. The improvements recommended in this master plan, even when fully implemented, might mitigate the flood risk at these structures to some degree, but cannot be expected to eliminate the flood risk. Such structures can only be protected from flood risk by relocation or floodproofing/retrofitting. Guidance on floodproofing and retrofitting can be found in the documents listed below, among others:

- FEMA Technical Bulletin 3-93 Non-Residential Floodproofing: Requirements and Certification (FEMA 1993)
- FEMA 312: Homeowner's Guide to Retrofitting (FEMA 2014)

Erosion Hazards Beyond the Floodplain Limits. The federal and state floodplain management regulations, and the ordinances of the affected local jurisdictions, focus on flood inundation hazards, and to a very limited extent on erosion hazards that could affect properties within the floodplain limits, also known as the Special Flood Hazard Area. The 2013 flood, like many large past floods in the region, damaged and destroyed many structures that were located outside of the mapped Special Flood Hazard Area. This occurred primarily within the canyon reaches, where the steep slopes and high flow velocities acting over an extended period led to extensive erosion of hill slopes. At several locations, the hill slope erosion caused complete or partial undermining of homes that were at much higher elevations than the flood water surface.

The CWCB River Corridor Protection and Management Fact Sheet in Appendix D describes the concept of a fluvial zone erosion map or Erosion Hazard Zone. Many communities incorporate Erosion Hazard Zones, and building setbacks within those zones, into their zoning codes and ordinances. Erosion Hazard Zones could be a useful informational tool even if they aren't used for regulatory purposes.

The geomorphic assessment information presented in this master plan, along with other geomorphic documentation from the aftermath of the 2013 flood and the 1976 flood, would be useful data in the establishment and mapping of Erosion Hazard Zones.

Irrigation Canals. Some of the September 2013 flood damages were attributed to the effect of irrigation canals discharging flood flows in areas outside the river floodplain. The flows entered the canals either at their river diversions or by interception in overbank areas. A joint effort between floodplain management jurisdictions and irrigation companies to identify the most problematic canal segments and mitigate the risks is recommended. Mitigations could include verifying or increasing canal capacity, ditch bank stability enhancements, or establishing designated spill locations where excess flows are safely discharged to the river or a tributary.

Diversion Structures. There are seventeen diversion structures along the Big Thompson River within the BTRRMP corridor. Most of these structures received little damage during the 2013 flood; however, they do present a barrier to fish passage as noted in Section 5.1. It is recommended that these structures be replaced with fish passable diversions. The replacement structures should be designed to withstand large flood events so that the owners are not left with a structure with potentially higher maintenance and/or replacement costs. Agencies interested in improving the aquatic ecosystem within the BTRRMP will have to coordinate with willing diversion structure owners to design and construct suitable alternative structures. The type of replacement structure may vary depending on its location within the BTRRMP.

7.4 Access Bridges to Private Properties

In the canyon reaches of the Big Thompson River, several of the access bridges to private properties were damaged or destroyed in the September 2013 flood. Many of these structures were completely or partially blocked by debris, causing the flows to flank the bridge around one or both abutments. The flanking of the bridges destroyed their approaches, but also caused extensive damage to US Highway 34 and to properties on the opposite side of the river. At the bridge shown below (**Figure 7.2**), the flooding around the bridge formed a new channel and left a vertical cut bank over 100 feet south of the pre-flood channel bank location.

Figure 7.2. Flanked access bridge in Big Thompson Canyon.

Access has been temporarily restored to some, but not all of the private properties. The structures that caused collateral erosion damage due to blockage should be considered for removal and/or replacement. Certain principles should be considered in the establishment of permanent access crossings. From a flood risk perspective, the number of crossings should be minimized by combining existing crossing points wherever feasible. The locations of the crossing, wherever possible, should be selected with consideration to stream morphology and floodplain configuration. Narrow floodplain locations not subject to aggradation are favorable from the hydraulics standpoint. Any new access bridge should provide a hydraulic opening as wide and tall as possible. The bridges that suffered the least blockage during the flood where those that had the highest vertical clearance above the channel bed. It is acknowledged that often the vertical profile of the bridge will be controlled by the highway elevation on one side and the floodplain elevation on the other.

The use of breakaway bridges have been discussed in both the 1976 and then current recovery efforts. Breakaway bridges do exist for smaller types of bridges. However, it is difficult, if not impossible, to design access bridges to accommodate heavy vehicles and allow them to breakaway during high flow events.

Where a tall and wide opening cannot be provided, the crossing should be designed such that the bridge can be flanked without major erosion damage to either channel bank. This would be accomplished by making the approach profile as low as possible and stabilizing the channel banks upstream and downstream of the bridge.

8. DATA GAPS

Access to quality, up to date information is very important during the planning and design process. While we did have access to a sufficient amount of information for this master plan, we do have some recommendations for future data needs that will help with long-term recovery and restoration and management of the entire watershed. While expensive to collect, create, and maintain, quality up to date information can save significant money in the long-term by helping engineers and planners do their jobs more efficiently and accurately. This type of data can also be used by emergency personnel for disaster planning and response.

The types of information we recommend creating and/or improving upon will benefit many agencies and stakeholders and therefore the costs should be spread out among all benefited local, state, and federal entities. We recommend that a coordinated plan be created to maximize coordination between all benefited entities.

8.1 Geographic Information System (GIS) Data

Larimer County GIS information, including county-wide land parcels, is available online and was used during the master plan process. However, there are several locations where the geographic locations of the parcels were in error. These locations were primarily in the mountainous regions of the county. The county parcel data set is also not complete in regards to parcel ownership.

We would recommend that the County take measures to improve on the accuracy of their parcel dataset. As transportation corridors are redesigned and constructed, there may be sufficient survey information collected that could help improve the parcel locations along the these corridors.

We would also recommend that the attributes, such as property owner, be updated and verified. During planning and design work it is helpful to quickly be able to know which parcels are privately owned, City, County, State, Federal, etc.

In addition to accurate parcel information, we also recommend that the County create a dataset that includes the location and type of every structure within the County.

If not in place already, we would recommend regular collection of aerial imagery and topographic (LiDAR) data collection. These two pieces of data often form the foundation for planning and design and are also often the source of other GIS data as mentioned above.

8.2 Risk Assessments Improvements

All of the assessments conducted for this master plan would benefit from more detailed study and future updates. However, to best plan for and design a more flood resilient corridor we believe it is important to have a more complete and accurate understanding of all infrastructure at risk from flood risk and geomorphic risk.

The approach used to determine flood risk for this master plan was simplified and likely incomplete in regard to all infrastructure located within the floodplain. It was conducted with outdated floodplain maps. We recommend that a thorough risk assessment be completed at some point in the future when more complete and accurate information is available. This includes improved floodplain mapping, up-to-date and complete structure locations, delineation of potential riverine erosion hazard zones, and more complete utility information.

We would also recommend that a future flood risk assessment include a varied scale of infrastructure based on cost. This would provide a more complete view of the level of flood risk that exists throughout the corridor, and be a valuable tool for future restoration, mitigation, and disaster preparedness planning.

9. MOVING FORWARD

Permanent projects are beginning this fall with the reconstruction of portions of CR 43 by CFLHD. The remainder of CR 43 will be completed over the next few years. This fall, CDOT is beginning the design process for the reconstruction of US 34 along the Big Thompson River from Olympus Dam east to Loveland. The City of Loveland and Larimer County are both beginning to work on permanent repairs and restoration projects. They are also beginning an assessment of recreation and conservation opportunities along the Big Thompson River, including the North Fork. This assessment will create a regional vision for reconstructing and enhancing recreational opportunities via public property and conserving lands along the river corridor in order to prioritize strategic investment, coordinate funding strategies, and facilitate unified decision-making among stakeholders. Other federal agencies will also be completing work within the corridor including NRCS and USFS. The BTRRC is also beginning to pursue funding to begin work.

As long-term recovery begins, it is important to remember that typical Federal, State, and local regulations apply. Working along rivers can require multiple permits because of the potential local impacts to neighbors and larger impacts to the river throughout the corridor. It is not necessary for landowners to understand every nuance of each permitting process. It is important to understand what permits may be required before work begins. The BTRRC has put together helpful resources that provide a basic framework for river corridor projects as well as potentially required permits. These resources, and several others, are available in Appendix D and on their website (BTRRC-a). CWCB has also put together a helpful response to FAQs related to rebuilding and regulations (CWCB 2013-b).

As with all master plans the recommendations provided in this document will require further engineering, design, permitting, and stakeholder input before projects are constructed. If you own property along the river, the rehabilitation of that land is your responsibility. However, the amount of work proposed within this master plan is likely not feasible for individual homeowners. It will be most efficient if multiple restoration projects can be completed simultaneously and collaboratively. As CFLHD and CDOT begin the permanent repairs along both canyon roadways it would be most efficient to be constructing the roadway and restoring the adjacent reach of river, and the opposing bank at the same time. There are a variety of potential funding sources for private, and public, projects. Because of the constantly changing nature potential funding options and their requirements it is recommended to contact the BTRRC and/or visit their website.

If you are a private landowner along the Big Thompson River, your input and involvement in the restoration of this corridor is important. The BTRRC has created a neighborhood representative program similar to what existed on the Little Thompson River and it has proven successful during recovery. Please contact the BTRRC for more information and ways to get involved (BTRRC-b).

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