Post-Flood Recovery Assessment and Stream Restoration Guidelines for the Colorado Front Range

Eric E. Richer, Matt C. Kondratieff, and Benjamin D. Swigle
Colorado Parks and Wildlife, Fort Collins, Colorado
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Abstract

Severe flooding impacted rivers and streams in the Colorado Front Range during September 2013. The flooding had devastating effects on communities and infrastructure, but had many beneficial effects on river ecosystems and stream functions. Flooding is a natural component of river systems that is vital for many ecological and physical processes. Following the flood, rebuilding infrastructure was given top priority and permitting processes were suspended or expedited to facilitate reconstruction activities. In many cases, emergency reconstruction activities led to degradation of stream functions and aquatic habitat. Degradation was often associated with the creation of trapezoidal and armored channels. Initial monitoring following the flood showed variable impacts to fish populations, with changes in trout abundance ranging from -58% to +69% at sites that were severely impacted by the flood but not further altered during emergency reconstruction. Monitoring sites that underwent substantial channel alterations during emergency reconstruction had an average change in trout abundance of -95%. Floods may provide an opportunity to improve a variety of stream functions related to channel stability, flood conveyance, geomorphology, water quality, and habitat connectivity. However, programmatic constraints at both the state and federal level limit opportunities to improve rivers beyond their pre-flood condition. Addressing permitting and funding constraints prior to the next major flood could greatly improve the efficiency and effectiveness of emergency flood response while reducing long-term maintenance and stream restoration costs.

Introduction

The Colorado Front Range was impacted by severe flooding in September 2013 as a result of a 1000-year precipitation event. The intensity and duration of precipitation caused unprecedented runoff events in many rivers, which led to loss of life and substantial property damage. The Cache la Poudre, Big Thompson, St. Vrain, Left Hand, and Boulder watersheds experienced 25- to 500-year floods. Although the flood had devastating effects on infrastructure and daily life, it had many positive effects on natural stream functions. Flooding is a natural component of river ecology, and natural river systems not only benefit from, but are dependent upon, high flows for many ecological and physical processes. Given the devastating effects of floods on communities, it is not surprising that the functional benefits of floods on natural ecosystems are often misunderstood and understated.

Flooding has many unfortunate effects, the most tragic being the loss of life and property. Preliminary estimates from the Colorado Water Conservation Board (CWCB) included nine fatalities, 16,000 damaged homes, 1,800 destroyed homes, 750 damaged businesses, 200 destroyed businesses, and 200 miles of damaged state highways. Stream gauges and water delivery infrastructure also suffered severe damages with 207 dams impacted, nine low hazard dams lost, and over 160 water-diversion structures damaged or destroyed (Colorado Division of Water Resources). In addition, damage to oil and gas and wastewater treatment facilities may have impacted water quality. This devastation required a swift

and coordinated emergency response, and we are grateful to the emergency responders that saved lives and restored access to isolated communities.

Colorado Parks and Wildlife (CPW) is responsible for perpetuating the wildlife resources of the state (C.R.S.§ 33-9-101 (12) (b)). CPW also holds more individual water rights in Colorado than any other entity and owns or manages publically-accessible properties along many rivers impacted by the flood. When combined, these factors provide a unique perspective on the flood. Habitat conservation, connectivity, enhancement, and restoration are all vital components of fisheries management. Management goals include maintaining sport fish populations that provide recreational and economic benefits and long-term conservation of native fish populations. From a functional standpoint, it is important to note that most rivers in the Colorado Front Range were already in a severely degraded state prior to the flood. Some characteristics of healthy rivers include the ability to convey water and sediment, longitudinal connectivity between upstream and downstream reaches, functioning riparian corridors that mitigate flood impacts when inundated, and habitat complexity that supports aquatic and terrestrial wildlife. Many of these characteristics are missing from large portions of rivers along the Colorado Front Range.

Rivers and streams along the Colorado Front Range have experienced substantial anthropogenic changes over the past 200 years. These changes were largely due to historic land use activities and water development, such as beaver trapping, placer and gravel mining, flow regulation, timber harvest and tie drives, and construction of roads and railroads (Wohl, 2011). Most rivers in the Front Range are fragmented by numerous diversion structures that prevent upstream migration of fish, adversely affect sediment transport, entrain downstream migrating fish in irrigation ditches, and sporadically dry up river segments during periods of drought or baseflow. Roads have been constructed along many rivers in the Front Range, leaving little room to dissipate energy through the process of floodplain inundation during high flows. Many of these rivers and streams have also been channelized in an attempt to convey floods, protect infrastructure, and maximize crop production. However, experience has shown us that channelized, trapezoidal rivers experience massive channel adjustments during and immediately following floods while natural rivers with healthy and functioning floodplains do not. Yet channelization and armoring of rivers continues to be a common practice, despite the repeated failure of this approach during floods.

The response to the 2013 floods along the Colorado Front Range has many positive aspects, highlighted by promptly-restored access to isolated communities, emergency protection of property and infrastructure, moving highways farther away from river channels, and protecting livelihoods through reconstruction and repair of water delivery infrastructure. However, there are many ways in which our response to floods could be improved. There are valuable lessons from the 2013 flood response that should be addressed prior to the next flood event. Floods may provide opportunities to improve the health of our rivers for the benefit of both local communities and the wildlife that depend on them. With proper advance planning, protecting communities and river ecosystems do not need to be mutually exclusive. There are opportunities to coordinate stream reconstruction activities so that multiple goals and objectives can be achieved simultaneously in a more efficient manner. The objectives of this paper are to improve understanding of natural stream functions, discuss more comprehensive approaches to emergency flood response and reconstruction, and develop conceptual guidelines for post-flood stream restoration. The overarching goal is to be better prepared for the next flood.

Post-Flood Recovery Assessment

The flood recovery process was broken into two phases: (Phase I) emergency or exigent repairs and (Phase II) permanent repairs. Exigent repairs were focused on protecting life and property, and needed to be completed prior to snowmelt runoff in spring 2014. This exigent work consisted of rebuilding roads and water diversion structures, bank stabilization and armoring, and channel dredging to return rivers to their pre-existing condition. Permanent repairs were mostly delayed until after runoff and will focus on infrastructure protection, bank stabilization, and stream restoration. In-stream construction and stream restoration are challenging processes that often involve interdisciplinary teams of engineers, hydrologists, geomorphologists, and biologists. Because rivers are highly dynamic systems used by a variety of stakeholders, processes have been implemented at both the state and federal level to protect rivers and streams from activities that lead to habitat degradation and loss of function.

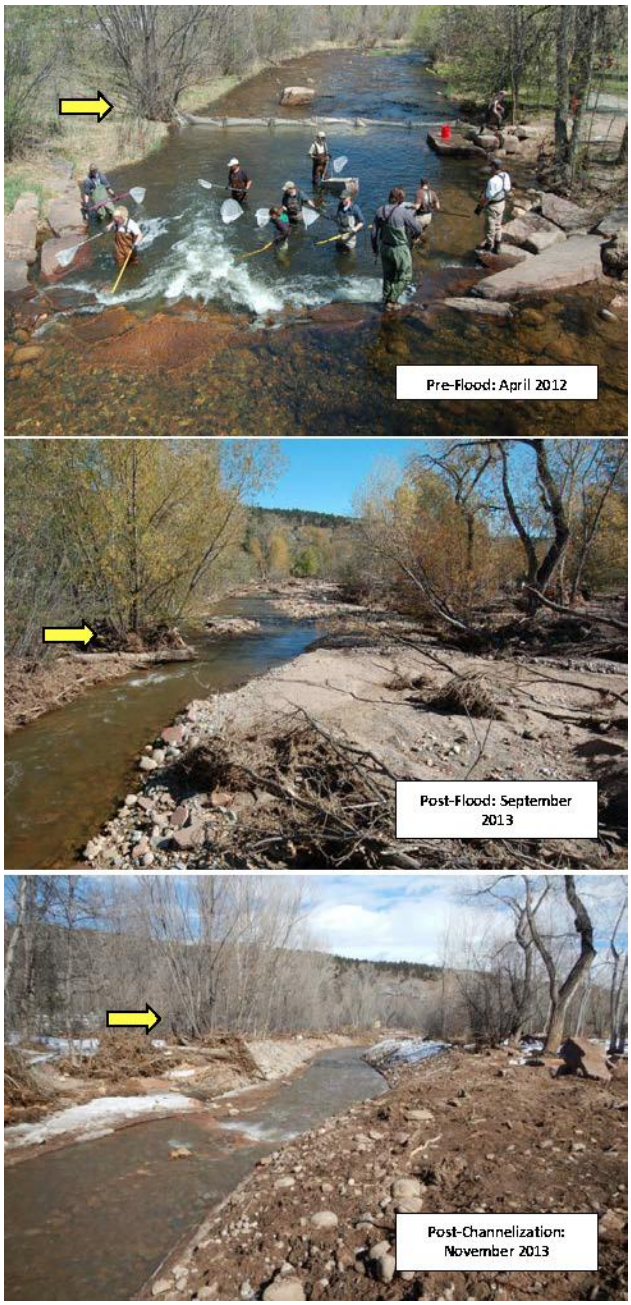


Figure 1. Pictures of the South Fork of St. Vrain Creek through Bohn Park showing pre-flood condition, post-flood condition, and post-channelization condition. The yellow arrow denotes the same river birch.

Colorado Senate Bill 40 (33-5-101-107, CRS 1973 as amended) exists to protect the state's fish and wildlife resources from actions that obstruct, damage, diminish, destroy, change, modify, or vary the natural existing shape and form of any stream or its banks or tributaries. Highway construction projects and maintenance activities that impact any stream or its banks or tributaries require formal application to CPW for Senate Bill 40 (SB40) Certification. This process was suspended immediately following the flood to streamline reconstruction efforts. Section 404 of the Clean Water Act established a program to regulate the discharge of dredged or fill material into the waters of the United States, including wetlands. The 404 permitting process was also expedited after the flood. Given the need for emergency reconstruction, expediting the SB40 and 404 processes was justifiable. However, these regulations exist to protect rivers from unnecessary degradation, and their absence likely contributed to degradation of aquatic resources during reconstruction in some areas.

River projects are increasingly challenging because they typically involve multiple stakeholders with diverse and often conflicting objectives. Projects that focus on a single goal, such as bank stabilization, can adversely affect physical processes and ecological functions, thereby degrading resources valued by other stakeholders. The total economic output from fishing in north central Colorado is $523 million annually (Southwick, 2014), which highlights the importance of fishing in the Colorado Front Range. River projects that focus only on the protection of infrastructure can result in degradation of a fishery and adversely impact those stakeholders that value fisheries. In addition to sport fish, there are many native fish species in the Colorado Front Range that are currently listed as state threatened or endangered due to habitat fragmentation and degradation. The flood recovery effort provided a rare opportunity to improve conditions for both sport fish and native species by elevating the ecological function of these river systems.

Funding for Phase I recovery efforts was primarily provided by the Federal Emergency Management Agency (FEMA) and Natural Resource Conservation Service (NRCS) Emergency Watershed Protection Program (EWP). Funding for Phase 2 "non-exigent" or permanent repairs was uncertain. Due to this uncertainty, many of the "temporary" fixes may become permanent features along rivers of the Front Range. Ecological lift and stream functions were not considered for most of these temporary or exigent projects. In many cases, the protection of property was the primary and only concern. We recognize the importance of protecting property and acknowledge the critical need for these efforts, but recommend alternative approaches to protecting property that minimize degradation of river ecosystems. It is possible to approach emergency flood response in a comprehensive manner that protects life and property as well as stream functions. Opportunities exist to incorporate principles of natural channel design into emergency flood response that will maximize the potential for post-flood stream recovery and stability. With some advance planning, overall project costs could be reduced, efficiency increased, and long-term river stability and function improved.

Some of the emergency work that was completed is concerning from an ecological standpoint. One of the major ecological concerns is related to "sweeping" the river to accommodate downstream construction. We understand this is a convenient means to work within the active channel, but diverting all of the flow has severe implications for all aquatic life downstream of the diversion point. CPW received numerous reports of dead or stranded fish during the peak of construction activities. We recommend using coffer dams and pumps to manage water in the immediate vicinity of construction as a means to accommodate in-stream construction while maintaining downstream flows. As a last resort, should a river need to be dried for in-stream construction, we recommend that water flows be reduced incrementally so that aquatic organisms can seek refuge in pools or other reaches with sufficient flow.

Sediment transport and geomorphology were not priorities during emergency reconstruction. Channelization, abrupt changes in channel width, and inappropriate use of in-stream treatments may lead to issues with post-flood channel stability. In many instances, rivers were "temporarily" channelized to achieve design dimensions that accommodate a 5-year or 25-year flood. These temporary channels were typically trapezoidal and designed with the objective to lower the 100-year flood stage (Figure 1). We feel this is one of the greatest challenges facing post-flood stream restoration efforts. Can we restore rivers to a more natural and sustainable condition when homes and businesses are built in the floodplain? Throughout history, we have attempted to modify and constrain rivers to achieve our engineering objectives. But the traditional approach to managing rivers, which focuses on containing all flows within engineered channels, not only leads to ecological degradation but also leads to severe channel adjustments during floods. Trapezoidal channels fail because they concentrate energy within the channel instead of dissipating energy on the floodplain.

This issue with trapezoidal channel failure is illustrated by two contrasting reaches on Left Hand Creek (Figure 2). The upstream reach is an urban site near Kanemoto Park with a trapezoidal and armored channel designed to convey floods. The Kanemoto reach experienced substantial bank erosion during the flood. Bank erosion was so severe that the park's swimming pool was undermined. The bank erosion observed at Kanemoto Park is a stark contrast to a downstream reach near Highway 119. The reach near Highway 119 was restored in 2002 using a multi-stage channel design with a functional floodplain, and almost no bank erosion was observed at this site during the flood (Figure 2). The stark contrast between these sites also extends to the cost of reconstruction and habitat restoration. The Kanemoto reach will require substantial investment to stabilize and restore the river channel, whereas the Highway 119 reach will require no funds for stabilization or restoration. This example illustrates the value of riparian floodplains for flood conveyance, channel stability, and protection of property and infrastructure.

Left Hand Creek at Kanemoto Park, February 2014. This urban reach was designed to convey flood flows, but bank erosion was so severe during the flood that the park's swimming pool was undermined.

Left Hand Creek at Upstream of HW 119, June 2014. This reach was restored in 2002 using a multistage channel design and riparian corridor. Almost no bank erosion was observed during the flood.

Figure 2. Pictures of the two locations on Left Hand Creek illustrating the value of multistage channel designs and functioning riparian corridors for flood conveyance and channel stability.

There is a new paradigm in river engineering that embraces riparian floodplains as the most effective and sustainable means to convey floods and dissipate energy. Natural channels typically contain multiple stages that are inundated at different flows. For example, a four-stage channel includes (1) a low flow channel that maintains habitat during baseflows, (2) the bankfull or active channel, (3) a riparian bench to convey frequent floods, and (4) a flood-prone area between terraces to convey infrequent floods (Figure 3). We commend emergency work conducted by the CWCB, Colorado Department of Transportation (CDOT), and Natural Resource Conservation Service (NRCS) that incorporated multi-stage channel designs, but there are also many examples of trapezoidal, single-stage channels constructed after the flood. These trapezoidal channels create over-wide conditions with poor habitat quality. In nature, the trapezoidal channel often appears as an intermediate step following a disturbance that serves as a transition toward a stable end point. The length of time needed to reach a stable form depends on a range of factors including geomorphic context, vegetation, and number of steps within a channel evolution sequence. During low flows, over-wide channels create shallow conditions that elevate water temperatures and decrease dissolved oxygen. In addition, over-wide conditions often induce aggradation of sediment because the channel lacks the capacity to transport the incoming sediment load. During floods, over-wide channels concentrate energy, which increases water velocity and accelerates bank erosion. Multi-stage, or nested, channel designs provide a means to create naturally stable channels that convey floods and provide quality habitat for aquatic

organisms. During emergency reconstruction, multi-stage dimensions can be "roughed-in" thereby reducing the cost of permanent stream restoration efforts.

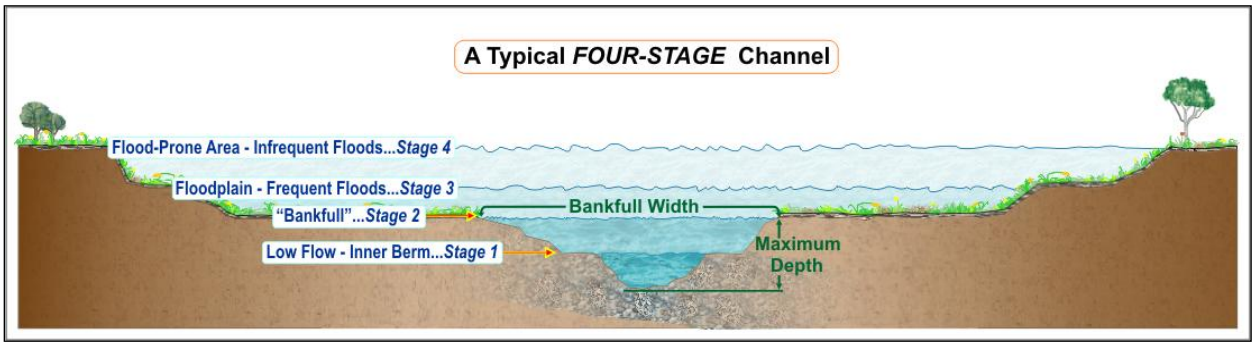


Figure 3. A typical four-stage channel design for a C4 stream type in a Valley Type VIII (Used with permission from D.L. Rosgen).

Fish Passage at Diversion Structures

Figure 4. Diversion structure at the Watson State Wildlife Area, Cache la Poudre River.

Over 160 diversion structures were damaged during the 2013 floods. These structures typically consist of concrete walls or grouted boulders that span the width of the channel (e.g., Figure 4). These structures were designed to create upstream backwater with enough differential head to maintain flows into irrigation ditches. Substantial investments have been made to develop the water delivery infrastructure that sustains the economy of the Colorado Front Range. Unfortunately, much of this infrastructure was developed decades ago without any consideration for dynamic river processes or ecological functions. The traditional diversion structure consisting of a low-head concrete dam and head-gate has many negative effects on stream functions. Diversion structures often create barriers to the upstream migration of fish. Upstream migration is a vital component of many species' life histories. Trout are known to migrate upstream to find ideal spawning habitat and then move back downstream to over-winter in warmer, lower-velocity, and more productive waters. Barriers to migration, such as diversion or grade-control structures, can adversely impact populations of many fish species.

Following the 2013 floods, CPW worked with the NRCS, CWCB, US Fish and Wildlife Service (USFWS), and FEMA to address issues with fish passage at diversion structures. These efforts culminated in a Fish Passage Workshop and Webinar that is hosted on the FEMA website at https://fema.connectsolutions.com/fishpassage/. This workshop provided information on different approaches to achieving fish passage at diversion structures, including design criteria for rock ramps, and alternative approaches to diversion structure design such as the cross-vane diversion structure (Figure 5). Hydraulic design criteria for fish passage structures are presented in Table 1. In addition to

design criteria, CPW developed maps that prioritized streams for fish passage in the South Platte basin for both native fish species and trout (Appendix A). These maps identified St. Vrain Creek, South Platte River, Left Hand Creek, Boulder Creek, and Cache la Poudre River as the highest priority streams for native fish passage in flood-impacted drainages. Transition zones that connect over-winter habitat at lower elevations to spawning and rearing habitat at higher elevations were identified as the highest priority reaches for trout passage.

Table 1. Hydraulic design criteria for fish passage structures in the Colorado Front Range.

Species Assemblage	Velocity (ft/s)	Minimum Depth (ft)	Vertical Drop (ft)	Turbulence (*EDF)
Native minnows and darters	1-2	0.5	0.0	<7
Native dace and suckers	3-4	0.5	0.0	<7
Trout	3-6	0.5-1.0	0.5-1.0	<7

* Energy Dissipation Factor (EDF) = (γQS)/A (Laiho, 2014)

St. Vrain Creek and Left Hand Creek are two of the last refuges for a number of state threatened and endangered fish species. Both of these streams were severely impacted by the flood, with devastating effects from Lyons through Longmont. Forty-three diversion structures were damaged on these two streams. As of March 2014, only two of the 43 damaged structures had incorporated fish passage during reconstruction efforts. Furthermore, fish passage designs for these structures were adapted from techniques used in the Pacific Northwest to pass salmon, such as the pool-weir fish ladder. The threatened and endangered native species in St. Vrain Creek and Left Hand Creek are adapted to the historical conditions in the rivers of the Colorado Front Range. As such, they can neither jump as high nor swim as fast as the salmon of the Pacific Northwest. Unfortunately, the two examples of fish passage on St. Vrain Creek are not ideal designs for passing small-bodied native fishes. Regardless, we commend the ditch companies that incorporated fish passage in the face of so many challenges.

Multiple obstacles to incorporating fish passage, including permitting, funding, and historical designation, led most ditch companies to abandon fish passage as a viable option during the emergency reconstruction period. We feel it is important to address these issues so that future fish passage efforts are better prepared for these obstacles and, hopefully, more successful. Perhaps the greatest obstacle was related to 404 permitting from the Army Corps of Engineers (ACOE). Given the magnitude of damage, the ACOE did not want to impede reconstruction efforts. Ditch companies needed to be operational by April 1, 2014, and most were granted agricultural exemptions from the 404 process. Two types of agricultural exemptions can be used to satisfy permitting requirements for diversion structure re-construction: (1) a maintenance exemption which requires the diversion structure be rebuilt to its pre-existing condition, and (2) an irrigation maintenance exemption, which allows repairs to be completed outside the footprint of the original structure, such as incorporation of a fish passage structure. Under the maintenance exemption, any modification that changed the character, scope, or size of the original design would require a permit.

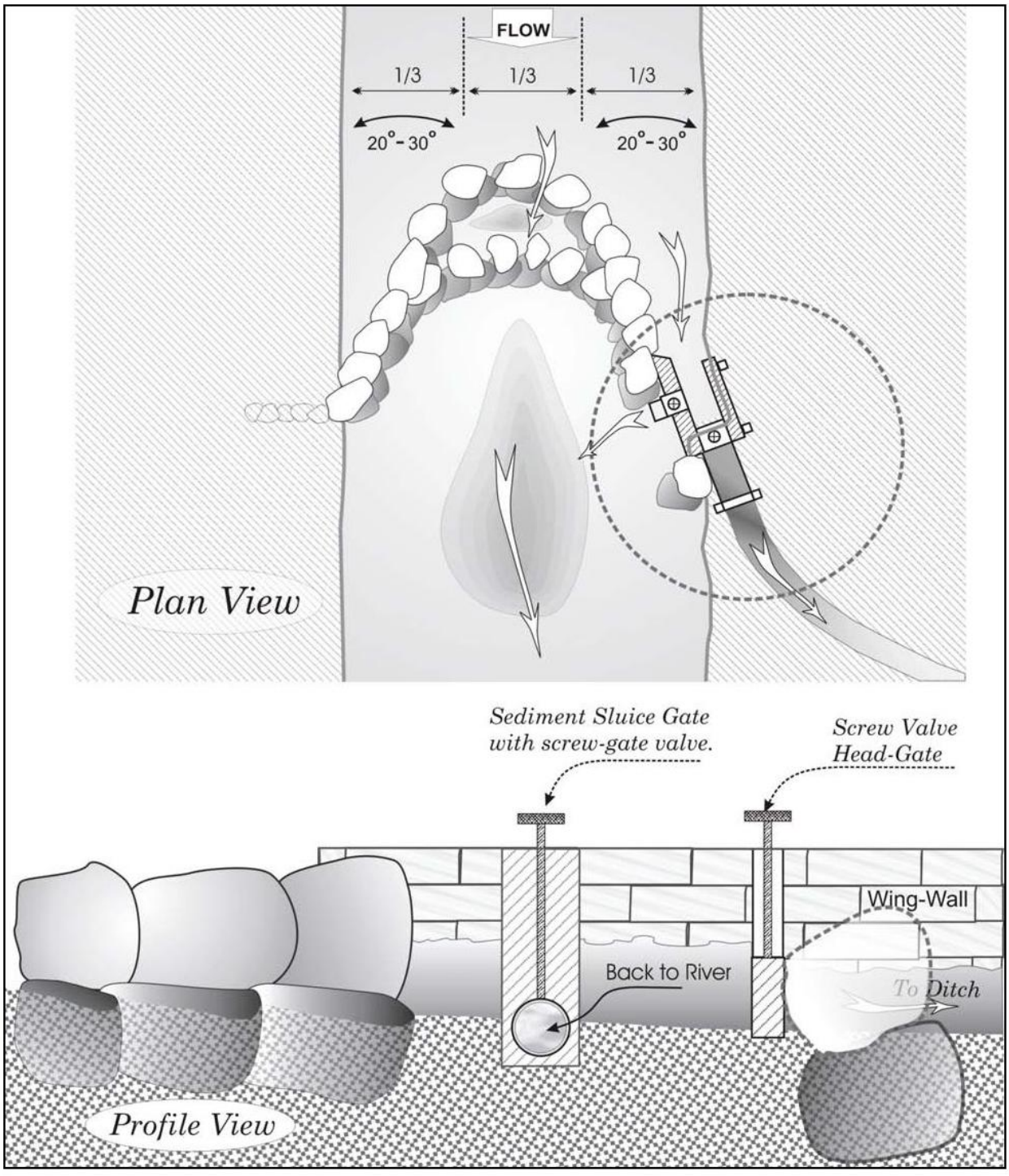


Figure 5. Conceptual example of a cross-vane diversion structure with irrigation head gate and sediment sluice (Rosgen, 2006).

Due to confusion regarding the two types of agricultural exemptions offered by the ACOE, many ditch companies and conservancy districts feared that incorporating fish passage into the diversion design would nullify their agricultural exemption and trigger the need for a nationwide or individual 404 permit. The ACOE Regional General Permit (RGP) No. 12 is a permit that explicitly applies to fish passage structures in Colorado. Unfortunately, RGP No. 12 was not utilized during post-flood reconstruction process. We recommend that state and federal agencies work with the ACOE to clarify permitting options for rebuilding damaged diversion structures in a manner that accommodates fish passage without delaying reconstruction efforts. We also recommend that RGP No. 12 be considered, possibly on a watershed scale, as a means to permit large scale fish passage efforts in a timely manner.

Funding concerns were the second major obstacle to building fish passable diversion structures. Due to programmatic constraints, FEMA would only fund the reconstruction of diversion structures to their pre-existing condition. Although it is more cost effective to incorporate fish passage during a major construction project, FEMA could not pay for fish passage if the structure did not have fish passage before the flood. This issue was further complicated because many threatened and endangered species in Colorado are not federally listed under the Endangered Species Act (ESA). If the brassy minnow or common shiner were federally listed as threatened or endangered, FEMA may have required that all diversion structures in priority reaches incorporate fish passage. Colorado's list of state threatened and endangered species is statutory in nature but lacks jurisdictional authority. Despite the lack of authority, we recommend that FEMA includes the conservation of state-listed species as a priority when responding to similar natural disasters. Furthermore, incentives could be used to address fish passage and habitat conservation for the preservation of state-listed species.

Based on our experience from the September 2013 flood, there is not a readily available source of funding for implementing fish passage at diversion structures. CWCB did offer low or no interest loans for ditch companies that wanted to incorporate fish passage into the design of their new structures. However, this incentive did not outweigh the permitting issues discussed above. To address limited funding for fish passage in Colorado, we recommend that an emergency flood response fund be established that could address fish passage and conservation of native species. Ideally, this fund would support design and implementation of fish passage projects, as well as monitoring and research activities to evaluate and improve effectiveness of fish passage designs.

These permitting and funding issues may have prevented ditch companies from considering alternative diversion designs recommended by the CWCB and CPW, such as the cross-vane diversion structure (Figure 5). These structures have not been widely used in the Colorado Front Range, but have been successfully and broadly applied in western Colorado to divert water and provide grade control while accommodating the passage of sediment, fish, and boats. Furthermore, these structures are often cheaper to build and repair than the traditional low-head concrete dam. These alternative structures may not have qualified for the agricultural exemption from the ACOE because they departed from the "character, scope, or size" of the original design under the maintenance exemption. However, the cross-vane structure is included under the Regional General Permit No. 12, which could expedite the permitting process for these structures in Colorado. We recommend that state and federal agencies work with the ACOE to identify permitting options for incorporating alternative diversion designs into emergency flood response.

The third issue that prevented a large scale effort to incorporate fish passage was related to the historical designation of diversion structures. Many diversion structures are considered "historical" by the State Historical Preservation Office (SHPO) due to the important role irrigation played in the

development of the Colorado Front Range. SHPO is committed to maintaining the historical nature of these diversion structures, such that repairs to damaged structures must use the same type of grout that was used when the structure was originally built. There were concerns that incorporating fish passage would alter the historical character of these diversion structures. SHPO's concerns about fish passage were acknowledged by FEMA and placed fish passage projects in a negative context. We recommend that issues with historical designation and fish passage at diversion structures be resolved in a way that incorporates fish passage without compromising historical integrity.

State of the Fishery

CPW is the lead agency responsible for fisheries management of public waters in Colorado. The primary tool that guides fisheries management in rivers is the multiple-pass electrofishing survey. Electrofishing is a common method used to sample fish populations and determine abundance, density, species composition, and fish condition. These surveys monitor fish populations and evaluate the impacts of flooding, wildfire, disease, and competition. Surveys are used to assess fishing regulations, the need for reintroduction via stocking, the need for habitat improvement, as well as the success of stream restoration projects. Electrofishing surveys are conducted regularly in all major rivers in the Colorado Front Range, and provide a valuable dataset for evaluating the effects of both the flood and emergency reconstruction efforts on these fisheries. In general, post-flood electrofishing surveys conducted in the Cache la Poudre River and Boulder Creek revealed limited impacts to the fishery and very limited channelization work. As a result, post-flood fishery assessments focused on the Big Thompson River and St. Vrain Creek, as large portions of these systems were physically altered and channelized to convey spring runoff and facilitate re-construction. Preliminary observations suggest that major river restoration would not be necessary in many locations had post-flood channels been left intact.

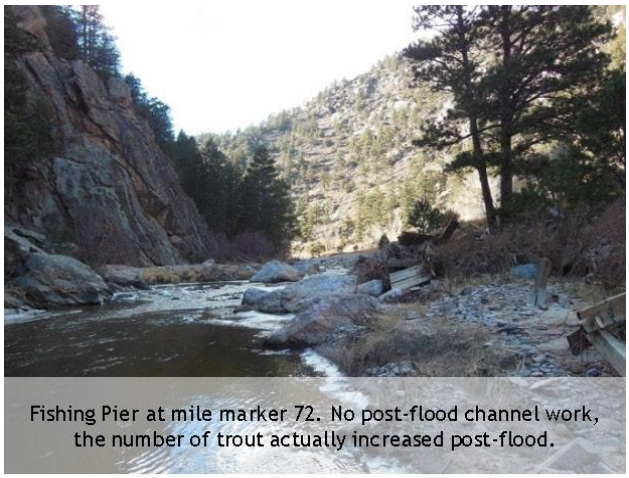
Big Thompson Fishery Assessment

CPW conducted a large-scale, pre-flood study of the Big Thompson River to document fishery resources for relicensing the Idlewilde Dam Hydroelectric Project with the Federal Energy Regulatory Commission (FERC). Following the September 2013 floods, the Idlewilde Dam, all turbines, and pipeline were damaged beyond repair which led to the complete removal of the dam. Although the fisheries data no longer applied to the relicensing process, they provided valuable baseline information for assessing post-flood damages to aquatic resources. A total of nine sites, five completed as part of the FERC study in 2012 and four historical sampling sites, were resurveyed following the flood. Results from the comparative surveys are presented in Table 2, and historical survey data are included in Appendix B. These data suggest that post-flood channelization activities conducted to rebuild Highway 34 between Loveland and Estes Park had a more devastating impact on the Big Thompson fishery than the flood itself. Sections of river that were undisturbed by post-flood reconstruction contained 7% more trout per mile, on average, relative to pre-flood estimates. Sections of river that were heavily channelized and armored during post-flood reconstruction contained 95% fewer trout, on average, relative to pre-flood conditions.

Channelization and armoring of the Big Thompson River reduced trout abundance by 90-100% at most locations surveyed (Table 2). For example, a section of the Big Thompson River at Drake contained 3,206 trout per river mile when surveyed in September 2012. No fish were found at this same location in November 2013 following channelization work (Figure 6). Farther upstream, near the Waltonia Bridge, trout abundance was reduced from 5,895 fish per mile in September 2012 to 130 fish per mile in October 2013. Sections of the Big Thompson River that were not artificially channelized fared much better in terms of trout abundance. The handicap fishing pier access site located near Highway 34 mile marker 72 yielded 3,769 trout per mile in October 2011. Following the 2013 flood, this same section contained 4,368 trout per mile, a 16% increase. Relatively little restoration work is needed for sections of the Big Thompson River where post-flood landscapes were not altered or channelized during post-flood reconstruction activities.

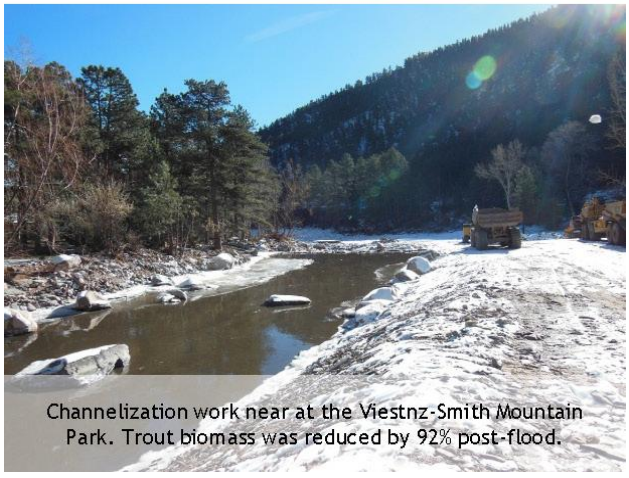
St. Vrain Fishery Assessment

In September 2013, the St. Vrain Watershed, including the North and South Forks of St. Vrain Creek, experienced a record flood event, reaching 100-year flood levels and surpassing 500-1000 year levels in certain areas. Stream flows below the town of Lyons were estimated at 19,600 cfs (Houck, 2014), easily surpassing the previous record set in 1941. CPW initially conducted post-flood electrofishing surveys at Bohn Park, South Fork St. Vrain Creek, and Meadow Park, North Fork St. Vrain Creek, during October 2013. The monitoring reach through Bohn Park was subsequently channelized during February 2014. Following this channelization work, CPW re-surveyed both Bohn Park and Meadow Park to evaluate the effects of channel alterations on the fishery.



Fishing Pier at mile marker 72. No post-flood channel work, the number of trout actually increased post-flood.

Channelization work near Drake. No fish were found at this location post-flood.



Channelization work near at the Viestnz-Smith Mountain Park. Trout biomass was reduced by 92% post-flood.

Figure 6. Post-flood photos of fish monitoring sites along the Big Thompson River showing the effects of channelization.

Table 2. Total trout abundance (brown trout and rainbow trout) prior to and after the September 2013 floods at monitoring locations along the Big Thompson River.

Location	Miles Downstream of Olympus Dam	Pre-Flood		Post-Flood			
		Sample Date	Abundance (trout/mile)	Sample Date	Abundance (trout/mile)	Abundance (% change)	Channel Alterations
Below Olympus Dam	0.3	10/18/11	3013	10/30/13	5092	69%	Minimal
Chucks Place	3.5	10/18/10	6805	11/07/13	4730	-30%	Minimal
Bridge at Glen Comfort	5.1	10/18/10	4358	11/08/13	3134	-28%	Minimal
Handicap Ramp	8.8	10/19/11	3769	11/07/13	4368	16%	Minimal
Waltonia Bridge	10.2	09/20/12	5895	10/08/13	130	-98%	Channelized
Drake	12.3	09/25/12	3206	11/07/13	0	-100%	Channelized
Upstream of Idlewilde Dam	13.7	09/17/12	5003	11/26/13	522	-90%	Channelized
Indian Meadow	14.8	09/25/12	2797	11/27/13	122	-96%	Channelized
Viestnz Smith Park	16.0	09/24/12	3104	11/27/13	243	-92%	Channelized

Decreased trout abundance was observed at both St. Vrain sites following the flood (Figure 7). Trout abundance at Bohn Park was previously estimated at 3,417 trout per mile in October 2005. Following the flood, trout abundance had decreased to 1,442 trout per mile in October 2013, representing a 58% decline for the previous estimate. Following post-flood channelization work, the electrofishing survey at Bohn Park yielded a single trout, or roughly nine trout per mile, representing a 99% decline in trout abundance between the post-flood and post-channelization surveys. Unlike Bohn Park, the historical survey site at Meadow Park on the North Fork St. Vrain was not channelized and remained relatively unaltered following the September 2013 flood. At this site, trout abundance decreased from 4,033 trout per mile in September 2009 to 1,659 trout per mile in October 2013, representing a 59% decline in the fishery due to the flood. However, survey results indicate that the fishery remained stable after the flood as 1,706 trout per mile were observed in February 2014. Although high flows observed during the flood impacted fisheries, these results suggest that drastic channel alterations during post-flood reconstruction further degraded fisheries in the Colorado Front Range. CPW will continue monitoring efforts to further evaluate the effects of both the 2013 floods and post-flood reconstruction on fishery resources in flood-impacted rivers.

Stream Restoration Guidelines

CPW recommends the following guidelines for stream restoration. These guidelines are general in nature, and may not be applicable in certain situations or appropriate for all stream reaches. The most important components of successful stream restoration projects are identification of appropriate goals, development of a design that addresses those goals, and selection of qualified and experienced contractors. The first step in any stream restoration project is identifying goals and objectives. Initial development of goals and objectives should involve all stakeholders affected by the project, although some goals may be weighted higher than others when finalizing a master plan for restoration. Identifying the condition to which the river will be restored is a vital step. Restoration implies returning a river to its pre-development condition, which is often not feasible or desired by all stakeholders. We recommend setting stream restoration goals that elevate the ecological function of rivers beyond their pre-flood condition in accordance with the Stream Functions Pyramid developed by the Environmental Protection Agency (EPA), USFWS, and ACOE (Harman et al., 2012).

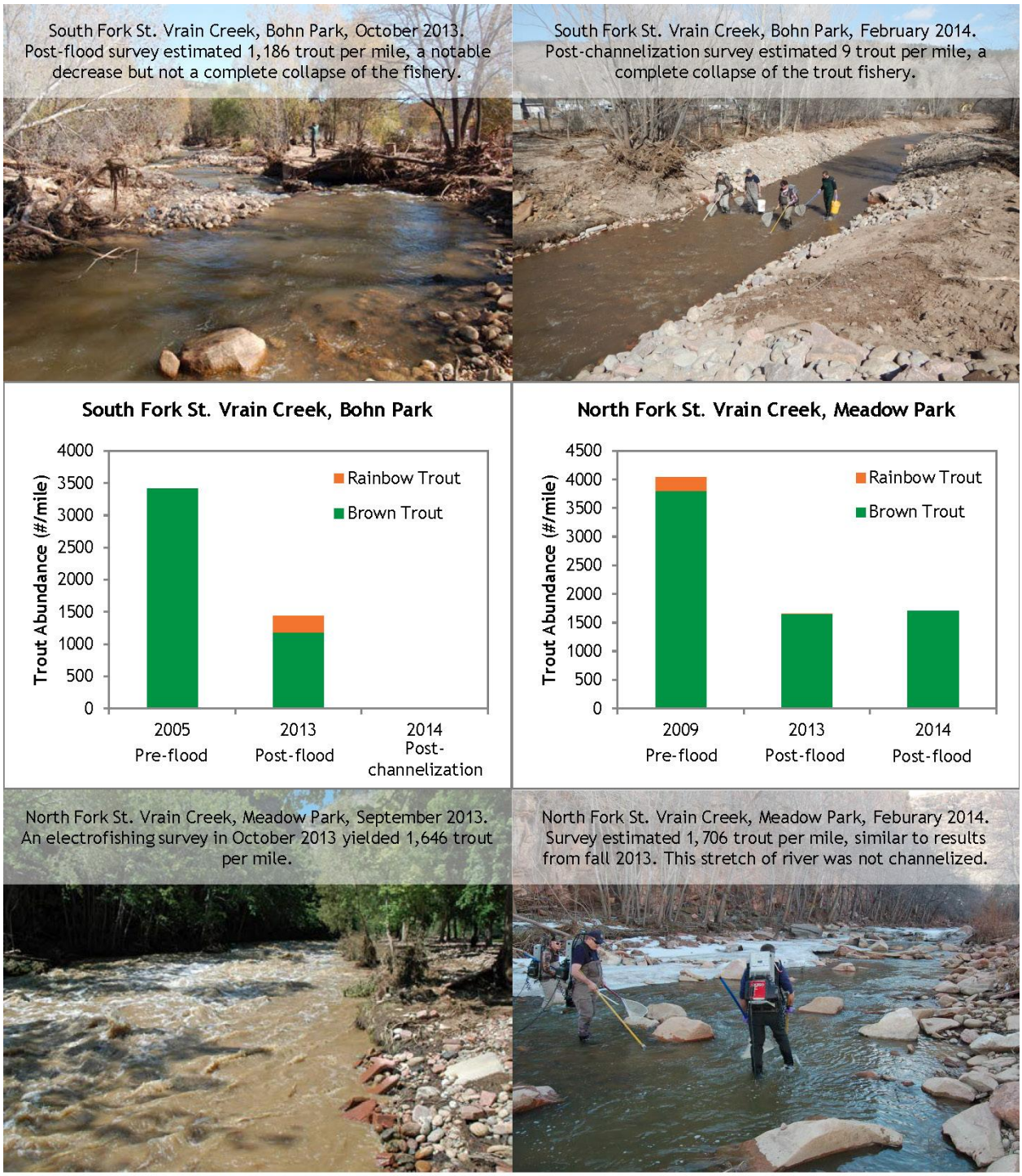


Figure 7. Changes in total trout abundance at Bohn Park, South Fork St. Vrain Creek, following the flood and subsequent channelization compared to Meadow Park, North Fork St. Vrain Creek, which was not channelized.

If restoration goals include enhancement of habitat for aquatic organisms, we recommend conducting a thorough analysis of potential factors that might be limiting populations (i.e., limiting factors analysis). Aquatic organisms are sensitive to a range of factors that are directly and indirectly linked to river hydrology, hydraulics, geomorphology, physiochemical processes, and biological interactions.

Therefore, restoration projects that address biological enhancement are inherently complex and should utilize monitoring and adaptive management to maximize effectiveness. Before-After/Control-Treatment (BACT) study designs are particularly useful for evaluating the effectiveness of stream restoration projects.

Stream Restoration Priorities: Protect

Trout Unlimited promotes one of the more common themes for habitat conservation and stream restoration, which is to ***protect***, ***reconnect***, and ***restore***. The most effective way to maintain functioning river systems is to protect streams or reaches that are not degraded. The 2013 flood improved stream functions in many locations. Examples of improved functions include: newly established point bars that support deep pools at low flows while dissipating energy at high flows; channel narrowing that improved width-to-depth ratios; improved hyporheic connectivity and interstitial habitat; increased bedform diversity; recruitment of large wood and boulders that enhanced instream habitat; increased sinuosity that improved form roughness to dissipate energy at high flows; improved floodplain connectivity that will dissipate energy at high flows; and improved connectivity between upstream and downstream reaches.

Flows of the magnitudes observed during the 2013 floods also provide flushing and channel maintenance benefits (Kondolf and Wilcock, 1996). Prior to the flood, many stream beds were severely armored due to decreased frequency of flushing flows, meaning there was impaired connectivity between the active channel and hyporheic zone, which is the area beneath and alongside the streambed. This embeddedness, or armoring, degraded habitat for aquatic insects, small bodied native fishes, and spawning sport fish. Unfortunately, much of the improved habitat that resulted from the flood was not protected. Rather, this newly formed habitat was removed during channelization and used for road base or armoring of stream banks. We understand that rebuilding infrastructure was the highest priority after the flood, but it is important to acknowledge the ecological benefits that result from floods and to preserve those to the fullest extent possible without endangering life or property.

Another common observation in the post-flood response was the removal of large woody debris (LWD). There are many studies that document the importance of wood in natural river channels. Some of the benefits of LWD include energy dissipation at the channel boundary, storage of sediment and organic matter on the streambed, increased habitat complexity, and retention of organic matter and nutrients (Wohl, 2011). We understand there are many instances in which large wood was intermingled with trash or hazardous materials, and we support the removal of this “debris”. Although the accumulation of LWD at bridges can create issues with flood conveyance, Johnson and Scheeder (2011) suggest that the best solution for debris management at bridges lies within stream restoration practices, particularly bank stabilization. However, many of the emergency bank stabilization techniques used after the flood, including rip-rap and Jersey barriers, adversely affect stream functions and may not be sustainable.

Channel evolution models demonstrate that channelized rivers are not stable and that channelization will lead to degradation and widening followed by aggradation and further widening (Figure 8). Rip-rap is commonly used in an attempt to prevent the natural evolution of channel morphology, but rip-rap can become mobilized or undermined during floods, as observed during the 2013 floods. We hope that bank stabilization measures can be utilized in a manner that supports stream functions, while both creating quality habitat and reducing debris accumulation at bridges. There are many stream restoration techniques, such as toe-wood or log-vanes, that utilize LWD to stabilize banks and create

habitat. It is vital that these techniques be used in the appropriate geomorphic context and meet design specifications. Examples of these techniques can be found at the ACOE website under Regional General Permit No. 12. Abbe and Brooks (2011) is another resource on geomorphic, engineering, and ecological considerations for using LWD in river restoration. Wohl et al. (in preparation) is also a valuable resource for analyzing the risk associated with large wood in streams of the Colorado Front Range.

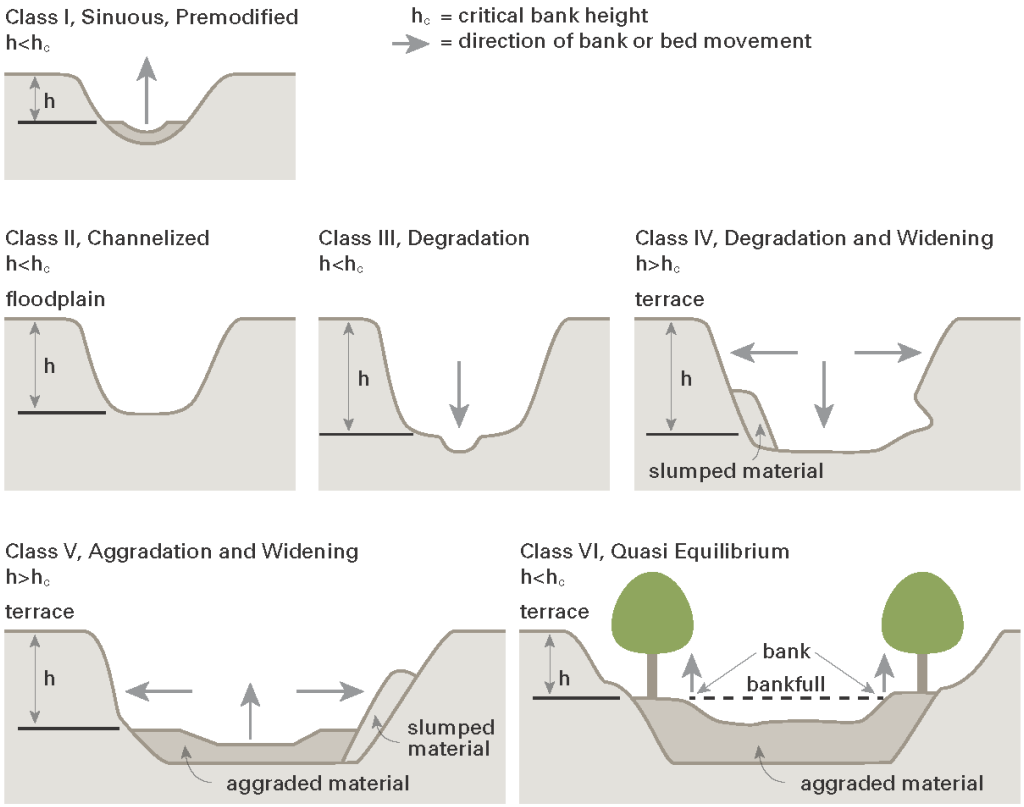


Figure 8. The Simon channel evolution model (Harman et al., 2012).

Stream Restoration Priorities: Reconnect

Habitat connectivity is vital component of a functioning river or stream. There are three dimensions of habitat connectivity: longitudinal, lateral, and vertical (Figure 9). Longitudinal connectivity relates to connectivity between upstream and downstream reaches, lateral connectivity implies connectivity between the active channel and floodplain, and vertical connectivity pertains to connectivity between the active channel and hyporheic zone. Despite aforementioned issues with fish passage, re-connecting upstream and downstream reaches should remain an important goal for stream restoration along the Colorado Front Range. Longitudinal connectivity allows fish and other organisms to migrate upstream or downstream. Migration is a vital component of many species life cycle. Over a typical life cycle, fish seek out a variety of habitat conditions depending on their life stage, season, and environmental variability, among other factors. Should their local habitat patch become degraded from land use, point-source pollution, or climate change, fish and other organisms require access to habitat conditions found upstream or downstream. Lateral connectivity is also important for fish, as many species utilize the low velocities found on inundated floodplains for both refuge and migration. Therefore, it is

important to design channels that inundate their floodplains on a frequent basis, every 1-2 years. This multi-stage channel design supports a variety of river functions, including channel maintenance, exchange of nutrients and sediment, healthy riparian corridors, groundwater recharge, and energy dissipation during floods.

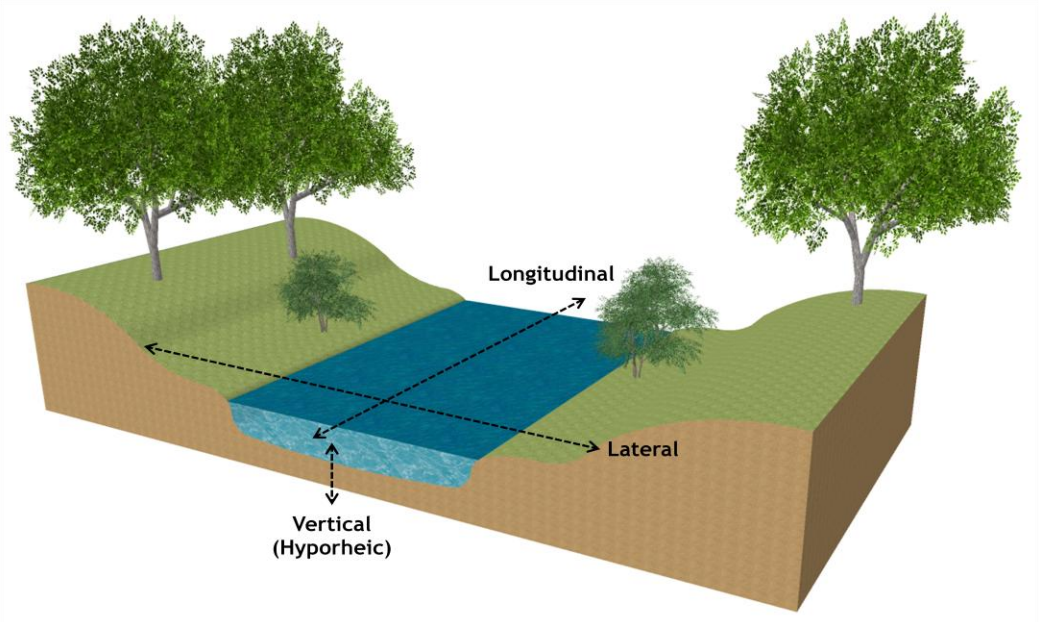


Figure 9. The three dimensions of habitat connectivity in a functioning river system.

Stream Restoration Priorities: Restore

Guidelines for improving stream functions are detailed in the Stream Functions Pyramid (Figure 10; Harman et al., 2012). The Stream Functions Pyramid is a simple, conceptual framework based on the premise that all streams share common characteristics and functions. Hydrology and hydraulic processes provide the foundation for all stream functions, followed by geomorphologic, physiochemical, and biological functions. The pyramid captures the hierarchical nature of these functions and is a valuable tool for conducting stream assessments, developing project goals and objectives, and identifying approaches to restoration. We encourage state and federal agencies that are responsible for emergency reconstruction to consider the Stream Functions Pyramid when conducting exigent repairs after a major flood. By utilizing approaches to emergency flood response that support stream functions and ecological lift, we could not only improve the condition of our rivers, but also reduce costs associated with "permanent" stream restoration efforts following a major flood.

Appendix C provides a general assessment of function-based parameters prior to the flood, after the flood, and following emergency reconstruction. This assessment was based on site visits to the Cache la Poudre River, Big Thompson River, St. Vrain Creek, Left Hand Creek, and South Boulder Creek. Although quantitative metrics were not used for this assessment, this qualitative assessment is representative of post-flood changes to function-based parameters in the Colorado Front Range. To summarize, the following parameters were improved by the flood: floodplain connectivity, flow dynamics, groundwater/surface water exchange, sediment transport capacity, large woody debris

transport and storage, channel evolution, bedform diversity, bed material characterization, water temperature and dissolved oxygen, nutrients and organic carbon, and landscape connectivity. All of these parameters were subsequently degraded to a lower functioning state in reaches where emergency reconstruction took place. We encourage restoration programs and grants to utilize a function-based approach for stream restoration projects that will improve conditions beyond their pre-flood, degraded condition. If streams must be returned to a pre-existing condition, we recommend that they be returned to their post-flood condition rather than their pre-flood condition.

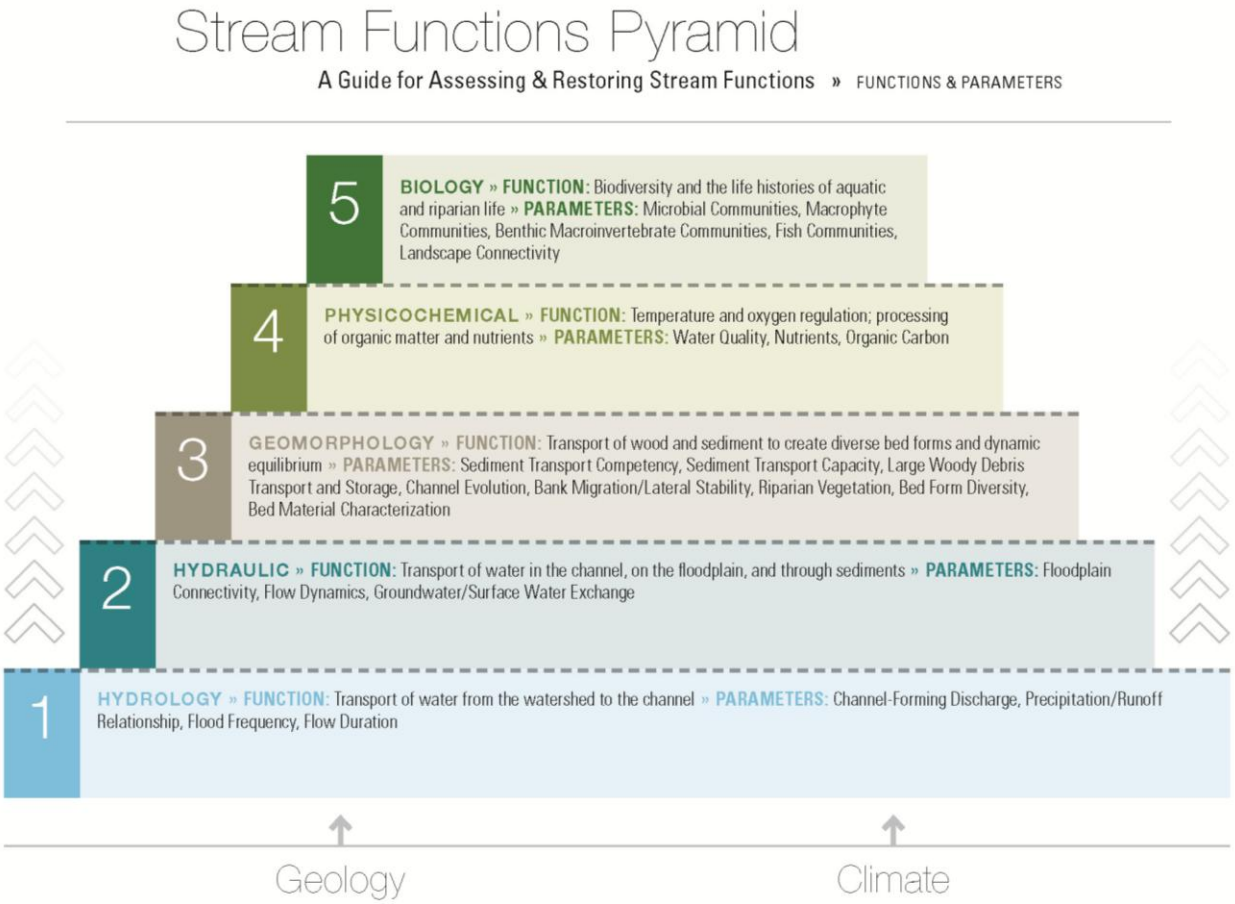


Figure 10. Functions and parameters associated with the each level of the Stream Functions Pyramid (Harman et al., 2012).

Although funding and programmatic constraints could impact the extent of post-flood stream restoration, permitting should not be a major obstacle for stream restoration because CPW has worked with the ACOE to develop Regional General Permit No. 12. This permit addresses aquatic habitat improvement for stream channels in Colorado, including a list of authorized activities and examples of in-stream structural designs. The permit also includes a list of general conditions and best management practices. We recommend that Regional General Permit No. 12 be utilized for post-flood stream restoration projects, and hope that it provides a means to expedite the 404 permitting process while maximizing the benefits of stream restoration projects.

Summary of Recommendations

We recommend that the following points be addressed or incorporated into future flood responses. The points are divided by topic, including recommendations for emergency in-stream construction, fish passage, and stream restoration.

Recommendations for Post-Flood Emergency Reconstruction

- Utilize coffer dams and pumps to manage water in the vicinity of in-stream construction activities instead of drying long segments of river.
- If the entire river must be dried prior to in-stream construction, gradually decrease flows so that aquatic organisms can seek refuge in pools or downstream reaches.
- Develop or utilize existing criteria for identifying large woody debris that can be left in the channel.
- If large woody debris must be removed from the channel, stockpile the wood nearby for use in future stream restoration projects.
- Clarify definitions of "debris" so that large wood and boulders are not included under the same category as hazardous materials, building materials, or trash.
- Work with FEMA and NRCS to indentify efficient means to fund exigent projects that improve stream function over the pre-existing condition.
- Extend the length of service for emergency FEMA employees beyond 120 days to minimize inconsistent priorities and processing of information due to high-turnover rates.
- Reduce stream restoration costs by approaching emergency construction efforts in a comprehensive manner that minimizes disturbances to geomorphology and ecology.
- Develop conceptual channel dimensions based on hydrologic analysis, such as regional curves, prior to the next flood to expedite restoration designs.
- Incorporate multi-stage channel dimensions and bedform-spacing into post-flood channel work to place the river on a trajectory towards dynamic equilibrium between sediment supply and stream flows.
- Improve understanding of river ecology and stream functions among federal agencies, state agencies, and contractors working on emergency reconstruction projects.
- Develop a central "clearing house" for information pertinent to reconstruction efforts that allows for streamlined communications between multiple agencies, contractors, and stakeholders.
- Organize a workshop or symposium with state and federal agencies, municipalities, water users, and other stakeholders to discuss lessons learned and begin planning for the next flood response.

Recommendation for Incorporating Fish Passage into Emergency Flood Response

- Identify priority streams for fish passage prior to the next flood.
- Develop fish passage design criteria for priority streams.
- Develop a process for addressing fish passage at diversion structures that is endorsed by the ACOE, FEMA, and SHPO. This process should address funding and permitting constraints, including the historical designation of diversion structures.
- Establish an emergency flood-response fund that could be used for fish passage and post-flood habitat conservation.

- Improve awareness of alternative diversion structure designs that accommodate fish passage and improve stream functions, such as the cross-vane diversion structure.
- Incorporate fish screens into diversion designs to reduce the frequency of fish entrainment in irrigation ditches. This will require addressing funding issues related to pre-existing conditions.
- Improve understanding among stakeholders of aquatic organisms found in Colorado streams and rivers, including the economic value of sport fish populations and ecological significance of native species.
- Utilize Regional General Permit No. 12 for permitting fish passage projects in Colorado.

Recommendations for Stream Restoration

- Protect functioning stream reaches, improve habitat connectivity, and restore degraded streams to a higher functioning state.
- Utilize the Stream Functions Pyramid to develop project goals and objectives.
- Conduct a limiting factors analysis to evaluate project goals and objectives and inform selection of habitat treatments.
- Utilize functional floodplains to convey flows and dissipate energy during floods.
- Develop multi-stage channel designs based on the current hydrologic and sediment regimes.
- Design channels to achieve sediment continuity.
- Incorporate large woody materials into stream restoration designs to improve geomorphic function.
- Utilize post-restoration monitoring to evaluate the effectiveness of stream restoration and habitat enhancement projects.
- Utilize the ACOE Regional General Permit No. 12 for permitting post-flood stream restoration projects in Colorado.

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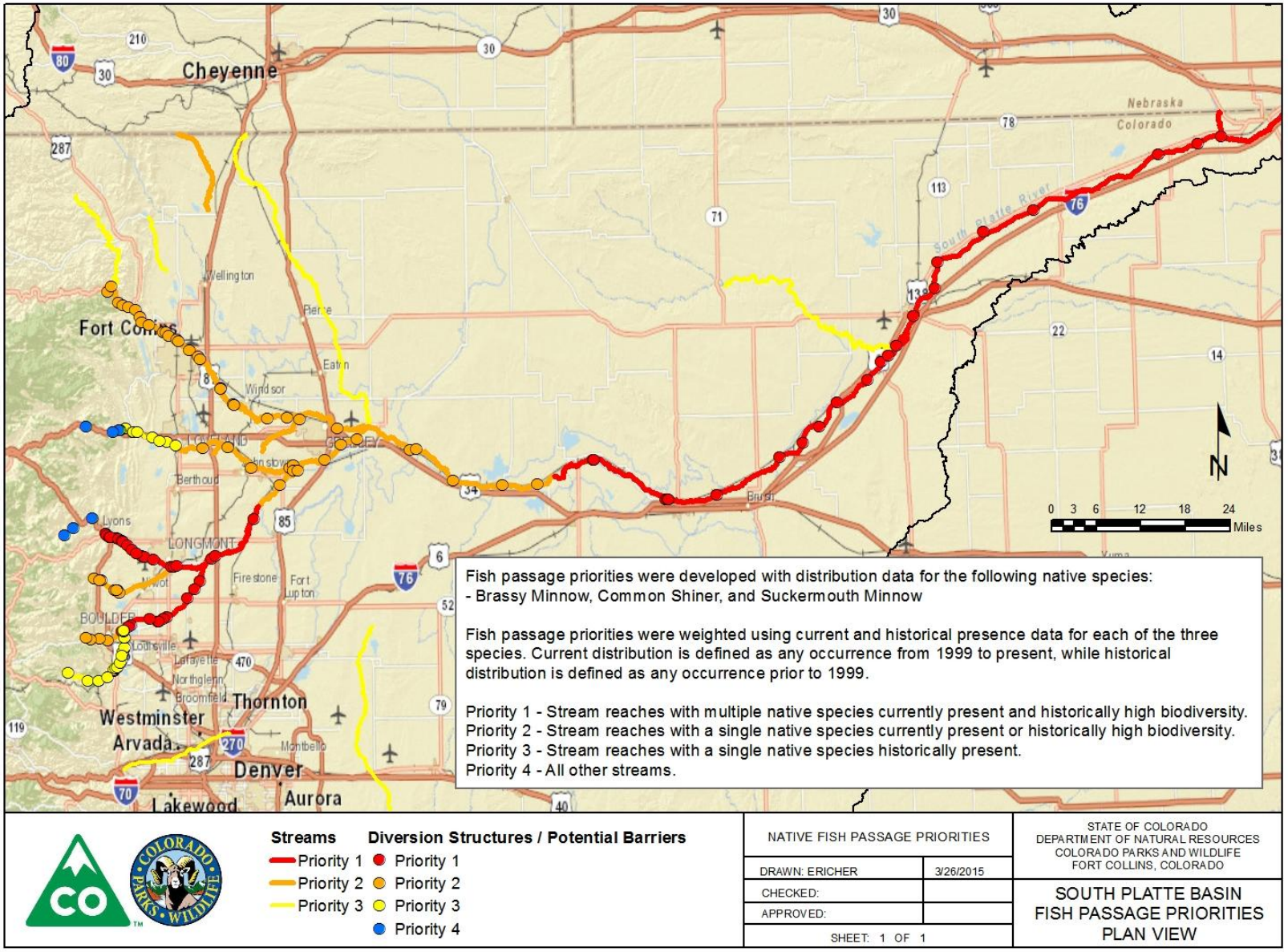
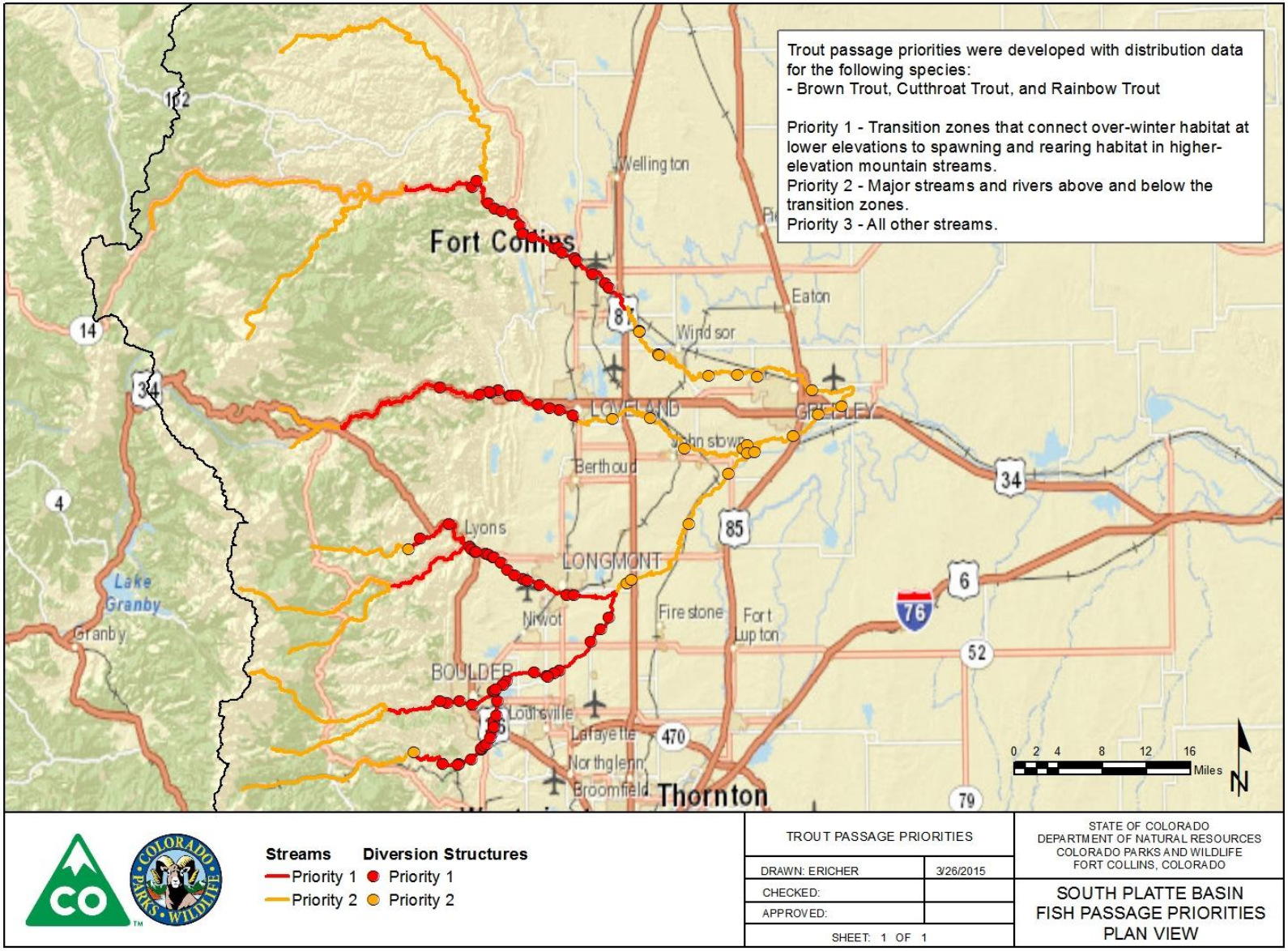
Appendix A


Cheyenne
Fort Collins
Wellington
Windsor
Eaton
Berthoud
Lyons
LONGMONT
Firestone
Fort Lupton
BOULDER
Louisville
Lafayette
Northglenn
Broomfield
Thornton
Westminster
Arvada
Montbello
Denver
Aurora
Lakewood
Brush
Nebraska
Colorado
South Platte River
0 3 6 12 18 24
Miles
N
Fish passage priorities were developed with distribution data for the following native species:
- Brassy Minnow, Common Shiner, and Suckermouth Minnow
Fish passage priorities were weighted using current and historical presence data for each of the three species. Current distribution is defined as any occurrence from 1999 to present, while historical distribution is defined as any occurrence prior to 1999.
Priority 1 - Stream reaches with multiple native species currently present and historically high biodiversity.
Priority 2 - Stream reaches with a single native species currently present or historically high biodiversity.
Priority 3 - Stream reaches with a single native species historically present.
Priority 4 - All other streams.
Streams
Priority 1
Priority 2
Priority 3
Diversion Structures / Potential Barriers
Priority 1
Priority 2
Priority 3
Priority 4
NATIVE FISH PASSAGE PRIORITIES
DRAWN: ERICHER
3/26/2015
CHECKED:
APPROVED:
SHEET: 1 OF 1
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO
SOUTH PLATTE BASIN
FISH PASSAGE PRIORITIES
PLAN VIEW


Trout passage priorities were developed with distribution data for the following species:
- Brown Trout, Cutthroat Trout, and Rainbow Trout
Priority 1 - Transition zones that connect over-winter habitat at lower elevations to spawning and rearing habitat in higher-elevation mountain streams.
Priority 2 - Major streams and rivers above and below the transition zones.
Priority 3 - All other streams.
Fort Collins
Wellington
Eaton
Windsor
LOVELAND
GREELEY
Johnstown
Berthoud
Lyons
LONGMONT
Lake Granby
Granby
Niwot
Firestone
Fort Lupton
BOULDER
Louisville
Lafayette
Northglenn
Broomfield
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Priority 1
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Diversion Structures
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Priority 2
TROUT PASSAGE PRIORITIES
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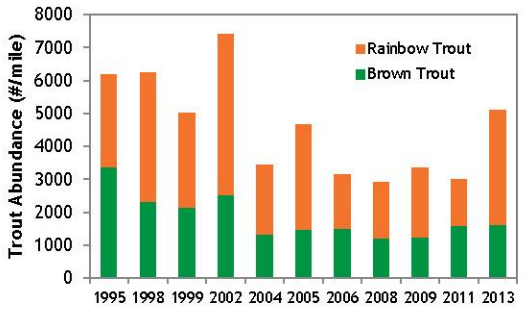
STATE OF COLORADO
DEPARTMENT OF NATURAL RESOURCES
COLORADO PARKS AND WILDLIFE
FORT COLLINS, COLORADO
SOUTH PLATTE BASIN
FISH PASSAGE PRIORITIES
PLAN VIEW

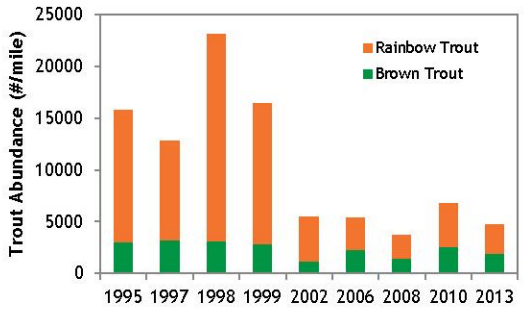
Appendix B

Trout abundance data (#/mile) for monitoring sites along the Big Thompson River. Notes: * denotes locations where post-flood channelization occurred in 2013; scale for abundance varies among sites.

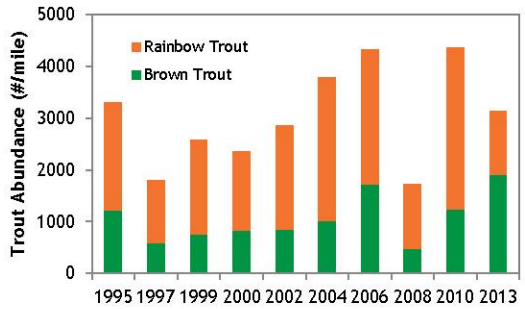
Big Thompson River, Below Olympus Dam



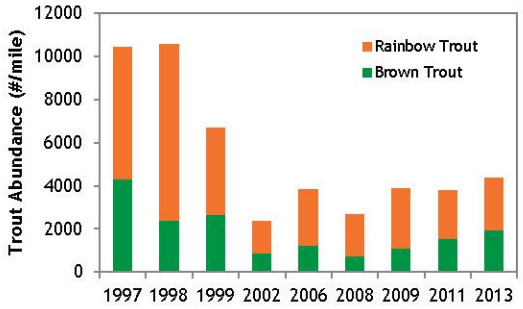
Big Thompson River, Chuck's Place



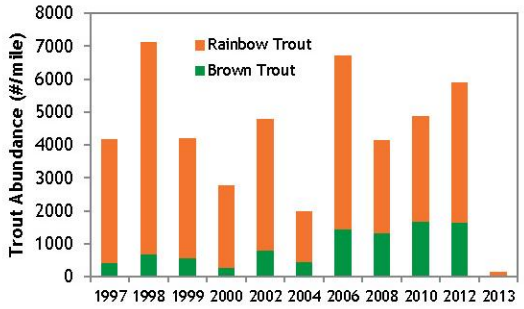
Big Thompson River, Bridge at Glen Comfort



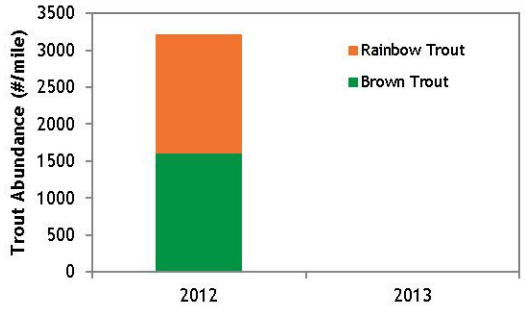
Big Thompson River, Handicap Ramp



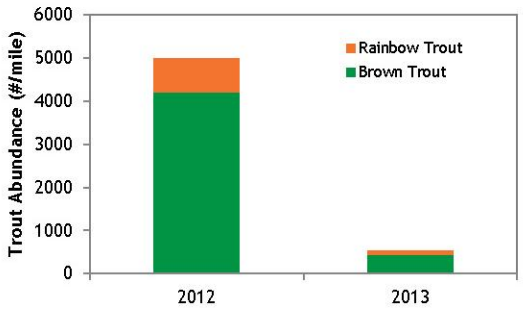
*** Big Thompson River, Waltonia Bridge**



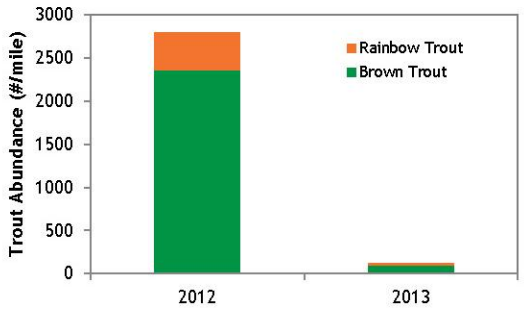
*** Big Thompson River, Drake**



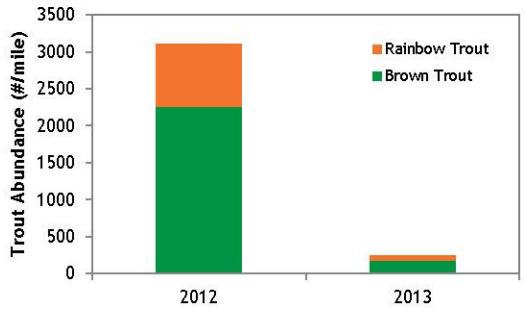
*** Big Thompson River, Upstream Idlewilde Dam**



*** Big Thompson River, Indian Meadows**



*** Big Thompson River, Viestnz Mountain Park**



Appendix C

Comparison of function-based parameters prior to the 2013 flood, after the flood, and after emergency reconstruction.

Level & Category	Parameters	Pre-flood condition	Post-flood condition	Post-emergency reconstruction
1 - Hydrology	Channel-forming discharge	Significant decrease from historic range	Not affected	Not affected
	Flood frequency	Magnitude of floods has decreased from historic range	Not affected	Not affected
	Flow duration	Duration of flows has decreased from historic range	Not affected	Not affected
2 - Hydraulics	Floodplain connectivity	Reduced connectivity from past channelization	Improved connectivity due to channel forming flows during the flood	Degraded connectivity from channelization and streambank armoring
	Flow dynamics	Velocity, shear stress, and stream power decreased from hydrologic alteration	Improved flow dynamics due to more natural channel morphology	Degraded flow dynamics from channelization
	Groundwater/surface water exchange	Reduced exchange due to water development & channelization	Substantial exchange of groundwater and surface water from floodplain inundation	Degraded exchange of groundwater and surface water from channelization and streambank armoring
3 - Geomorphology	Sediment transport capacity	Reduced capacity from water development	Improved capacity from lower width-to-depth ratio, improved flow dynamics, and removal of low-head dams	Degraded capacity from reconstruction of low-head dams and channelization
	Large woody debris transport and storage	Reduced transport capacity and storage	Significant increase in storage and potential for future transport	Significant decrease in storage and potential for future transport
	Channel evolution	Ongoing degradation and widening	Improved sinuosity, width-to-depth ratios, and floodplain connectivity	Returned to degraded, channelized stage of channel evolution
	Bank migration/lateral stability	Prevalence of armored streambanks	Substantial bank erosion and channel avulsion	Eroding banks stabilized with rip-rap and grout
	Riparian vegetation	Reduced cottonwood recruitment and overall function	Scoured or buried vegetation in many locations. Sediment deposition created favorable conditions to re-establishing riparian vegetation.	Channelization degraded lateral connectivity, which adversely affected riparian vegetation.
	Bed form diversity	Degraded from reduced frequency of channel maintenance flows	Improved diversity from channel maintenance flows	Reduced diversity from channelization and in-stream construction

	Bed material characterization	Increasing presence of fines and embeddedness	Reduced embeddedness and improved hyporheic conditions	Instream construction likely impacted stream bed and degraded hyporheic zone
4 - Physiochemical	Water quality - toxicants	Degraded from land use and emerging contaminates of concern	Sewage and hazardous materials introduced to channel	Sewage lines repaired and hazardous materials removed
	Water quality - temperature	Increased temperatures from water development and over-wide conditions	Newly scoured pools and narrower channels likely to reduce water temperatures	Channelization created over-wide, shallow conditions that elevate water temperatures. Poor floodplain connectivity reduces riparian water storage and return flows.
	Water quality - dissolved oxygen	Decreased DO from increased temperatures	Reduced temperatures (see above) and improved bedform diversity likely to increase DO	Elevated temperatures from channelization likely to reduce DO
	Nutrients	Elevated nutrients from wastewater treatment facilities, agricultural fertilizers, and atmospheric deposition	Nutrient exchange with floodplain	Channelization reduces floodplain connectivity and subsequent nutrient exchange between riparian areas and the active channel
	Organic carbon	Removal of LWD likely reduced amount of organic carbon	Improved carbon exchange with floodplain and recruitment of wood	Removal of wood from the channel reduces the amount of available organic carbon
5 - Biology	Microbial communities	Uncertain	Uncertain	Removal of large wood decreased available nutrients and organic carbon which adversely impacts primary production
	Macrophyte communities	Uncertain	Likely scoured	Removal of large wood decreased available nutrients which adversely impacts primary production
	Benthic macroinvertebrate communities	Negatively impacted by streambed armoring	Improved hyporheic connectivity, but populations likely decreased due to streambed disturbance	Instream construction likely impacted stream bed which degraded hyporheic connectivity. Removal of large wood decreased available nutrients and organic carbon which adversely impacts primary production

	Fish communities	Impaired due to altered hydrology, whirling disease, in-stream barriers, and channelization	Decreased abundance was observed at most sites, although some sites exhibited increased abundance. The highest observed decline was -59%.	Dramatically decreased abundance (-90 to -100%) was observed in channelized reaches. Widespread reports of fish mortality during the peak of construction activities
	Landscape connectivity	Disconnected stream reaches in the longitudinal, lateral, and vertical dimensions.	Improved connectivity in the longitudinal, lateral, and vertical dimensions.	Degraded connectivity in the longitudinal, lateral, and vertical dimensions