Cache La Poudre River

RIVER HEALTH ASSESSMENT FRAMEWORK

2019 Methods and Application

City of Fort Collins

Contents

Acronyms

303(d)	The 303(d) list of impaired waters in Colorado as defined by Colorado Department of Health and Environment
cfs	cubic feet per second
CDPHE	Colorado Department of Public Health and Environment
CPW	Colorado Parks and Wildlife
CSU	Colorado State University
CSU-LFL	Larval Fish Laboratory at CSU
EP	Ephemeroptera and Plecoptera (mayfly and stonefly; sensitive taxa)
ELC	Environmental Learning Center
ERM	Ecological Response Model
FACStream	Functional Assessment of Colorado Streams method
HEC-RAS	Hydraulic Engineering Center— River Analysis System
LiDAR	Light Detection and Ranging (a remote sensing method)
m	meters
MMI	Multi-Metric Index (used for aquatic insects)
MWAT	Maximum weekly average temperature
RHAF	River Health Assessment Framework
SOPR	State of the Poudre River

Preface: Purpose of this document

In 2017, the first State of the Poudre Report (SOPR) was released by the City of Fort Collins. The SOPR is a holistic, integrated assessment of river health for 26 miles of the Cache la Poudre River from the Munroe Diversion in the Poudre Canyon to the point where the Poudre crosses Interstate 25.

The project which culminated with the publication of the SOPR was developed in two phases. The first phase is described in the 2015 River Health Assessment Framework (RHAF), which laid out the overall framework and methods for assessment. In the second phase, the RHAF was used to conduct an assessment of the current state of the health of the Poudre River, using primarily 2015-2016 data. The results of this assessment were reported in the SOPR (City of Fort Collins, 2017).

Owing to the two-phased river assessment process and the complex, multifaceted nature of this project, the documentation of methods became fragmented across reports and appendices and thus perhaps difficult to follow for someone interested in repeating the assessment. Also, in the process of moving between phases from development of the framework (the RHAF) through to its first application (the SOPR), various degrees of adaptation and further methods development were needed. In the 2017 SOPR report, methods modifications and field applications were documented in the body of the report and/or the appendices. **Therefore, the purpose of this document- which stands in lieu of the methods and some portions of the appendices of the RHAF and SOPR - is to represent the most up to date version of the assessment framework methods and application details in one single location to maximize their usefulness for interested parties and future users.**

This document is primarily developed and written for the practitioner, whether it is the team that will conduct the second State of the Poudre (anticipated for 2021) or teams from beyond this geographic area who may be interested in applying parts or all of this methodology to their river. This methods compilation follows the same general format as the RHAF and the SOPR. Chapter 1 presents an overview of the overall assessment framework and geographic scope of the project. Chapters 2-10 present the indicators (in the same order as the other documents) and include the basic descriptions of the indicator and its metrics, the grading guidelines, the specific methods and analysis for each metric and brief descriptions of the relative contributions of each metric to the indicator. The final chapter (11) explains how the indicators were rolled up into health scores for the reaches, zones, and the entire Poudre River study area.

Chapter 1: Organizing framework and geographic scope

Approach to grading river health

In taking a functional approach to understanding river health, the underlying question is not how the ecosystem looks, but rather, how well the system is functioning. A functional assessment conveys information about the condition of, and inter-dependencies between, many different components of the river ecosystem. It affords the advantage of not only revealing the current stressors (human impacts- past or present- that impair river health), but also how management actions and other changes may affect the future health and resilience of the river. The methods used herein are adapted from the Functional Assessment of Colorado Streams (FACStream) protocol (Beardsley, et al. 2015) and were first fully documented in the City's "River Health Assessment Framework" (City of Fort Collins, 2015).

Following the FACStream framework and numerous other ecological assessment methods, the River Health Assessment Framework (RHAF) uses an academic grading scale (A-F) to relate the state of health or impairment. Grading guidelines provide the criteria for the conditions or magnitude of impairment warranting a given grade. Table 1.1 below describes the general functional river health condition embodied by each grade category.

Table 1.1: General functional conditions corresponding to indicator and metric grades and numerical scores in the Poudre River Health Assessment Framework.

Grade	Score	Descriptor	Explanation
A	90 – 100	Reference standard	Condition of the indicator or metric is self-sustaining and supports functional characteristics appropriate to sustain river health. Little or no management is needed to sustain and protect this level of function, given the minimal stressors from the modern landscape.
B	80 – 89	Highly functional	Condition maintains essential qualities that support a high level of function, but there is some influence of stressors at a detectable, yet minor, level. Requires limited management to sustain and protect against stressors.
C	70 - 79	Functional	Condition is altered by stressors that substantially impair functionality, but basic natural river functions are still sustained. Periodic, and at times intensive, management is required to maintain the river's functional role.
D	60 - 69	Functionally impaired	Condition is severely altered by stressors that impair basic natural river functions and the overall health of the river. Active management is required to maintain the river's functional role.
F	50 - 59	Non-functional	Condition is profoundly impaired by massive or overwhelming stressors that render it incapable of supporting basic natural river functions or it is otherwise unable to sustain biological river communities.

Within a given grade category, the range of condition varies within the bounds of the grading criteria. The variation in condition within grade categories is conveyed by adding pluses or minuses to the letter grades (*e.g.*, B+ or B-). Grading criteria are based on characteristics that indicate function, the severity of stressors degrading the indicator, and on the amount of maintenance required to sustain or improve habitat conditions.

Required maintenance (costly and challenging river management) is useful to consider in the context of river health grades as it can help guide and prioritize future management decisions. A lack of required maintenance implies a sustainable, dynamic equilibrium in the system. Active maintenance is required to set various components of the natural system back on track when disequilibrium threatens system stability. The maintenance required to sustain a dysfunctional river system has both direct and intrinsic costs to the residents of Fort Collins.

River Health Assessment Framework

The framework consists of nine indicators and 25 metrics (Table 1.2). Some refinements of the original RHAF were implemented during the SOPR assessment in response to data availability and field trials.

Table 1.2: Summary of indicators and metrics included in the State of the Poudre River baseline assessment.

Indicator	Metrics
Flow Regime	Peak flow, base flow, rate of change
Sediment Regime	Land erosion, channel erosion, continuity
Water Quality	Temperature, pH, nutrients, dissolved oxygen
Floodplain Connectivity	Floodplain extent
Riparian Condition	Vegetation structure, habitat connectivity, contributing area
River Form	Planform, dimension, profile
Resilience	Dynamic equilibrium, recovery potential
Physical Structure	Coarse-scale structure, fine-scale structure
Aquatic Life	Aquatic insects, aquatic habitat connectivity, native fish, trout

The RHAF indicators serve as the framework to organize information from river-related scientific disciplines and to make it easier to understand the ramifications for river health. The metrics are the backbone of the RHAF and represent aspects of the river ecosystem which can be practically measured and assigned a numerical score. The grading guidelines for each metric are provided in the following chapters.

Incorporating multiple methods within the assessment framework

FACStream's grading guidelines apply broadly to all Colorado streams and rivers and are written to guide rapid functional assessment. However, the FACstream structure is intended to be adaptable to accommodate methods beyond the rapid assessment approach and refine the grading criteria to best suit the local context. So, given the Poudre River has been the subject of long-standing and intensive study that has resulted in a considerable amount of information that can further inform the assessment, many of the FACStream grading guidelines have been customized and/or quantified specifically to the

Poudre River. The specificity or degree of customization for each metric varied based on availability and applicability of existing data, and potential to collect new information within the scope of this project.

Throughout chapters 2-10 a grading guideline table is presented for each metric that was derived from the guiding principles described in Table 1.1 and by the original underlying concepts of FACstream. Taking advantage of the flexibility to adapt FACstream, the local context, available data, and the project's scope and management priorities, a spectrum of approaches was used across the indicators/metrics. For any given metric, the grading guidelines may closely resemble the original qualitative FACstream criteria (which are primarily stressor-based) or the guidelines might define a more explicit quantitative set of criteria, or a combination of both. Thus, throughout this document, one may find a merging of both approaches.

Given this multi-faceted approach, metric scores are determined by the practitioner first through the indicated approach (which may range from quantitative to desktop analysis to rapid assessment style observations). However, applying multiple lines of evidence was always a second option for scoring under the following types of circumstances:

- If the primary assessment approach was not possible for all reaches due to data limitations or circumstances that prevented consistent data application;
- Limitations on project budget and scope of field assessments or land access constraints; or
- The grading guidelines provide thresholds only for some grade levels and not for the extremes (for example, see the A and F grading definitions for peak flows).

Thus, the grading guidelines and related discussions presented in this document help the practitioner understand the primary methods for evaluation while often also referring to other possible considerations such as stressors as guides to determine the numeric score. A comprehensive list of stressors for each metric is presented in chapter 3 of the SOPR (2017). Where a strict quantitative approach was not used, the assessors often brought multiple lines of evidence to bear by integrating information from various sources including the relative severity of stressors, local observations and context, and expert ecological knowledge and judgement.

For this project, all metrics received <u>numeric scores</u> first which were translated into <u>letter grades</u> at the end of the assessment.

Recommended Ranges

The final step in development of the City of Fort Collins RHAF was to determine a recommended range for each metric that, if achieved, would contribute to an overall healthy and functioning system. These recommended ranges are not a factor in scoring and grading the metrics and indicators, but rather represent a goal to work *towards,* and are specific to the contemporary circumstances on the Poudre as determined by the City of Fort Collins. The recommended ranges are a guide rather than an edict or mandate for the City. Initiatives aimed at improving scores for any specific metric must be considered within the context of other City goals, as well as legal and jurisdictional limitations. River health goals can at times or in specific places conflict with other City goals which may take priority, particularly for the provision of essential services such as drinking water, public safety, and protection of infrastructure.

After establishing the above grading guidelines, recommended ranges were established for each metric. The recommendations describe the range of conditions necessary and desired to support varying degrees of river health. Recommended ranges consider not only the metric's direct support of river functioning but also the way it indirectly affects or suggests the condition of other health indicators. For example, aquatic insect populations not only perform intrinsic functions such as organic matter cycling, but they support fisheries and are indicative of water quality. The recommended ranges show the span of metric condition that would support ecosystem function and is potentially attainable. While the recommended ranges suggest aspirational yet realistic upper limits for each metric, a better grade is always acceptable.

Figure 1.1 provides a snapshot of the recommended ranges for each metric. In keeping with the goal of developing aspirational but reasonable recommendations for river health the framework recommends most metrics should fall in the B range or higher (with a few exceptions) (City of Fort Collins, 2015).

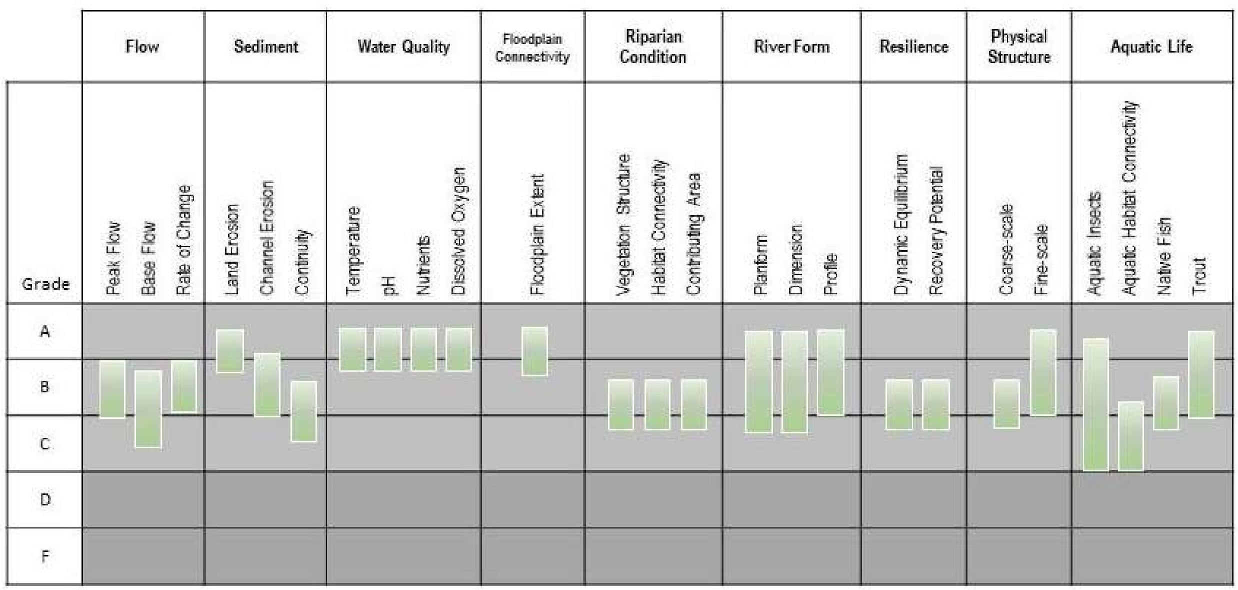

Figure 1.1: A summary of the RHAF's grade recommendations for each river health metric.

At-a-glance tables

Given the spectrum of methodological approaches (from desktop analyses to field based rapid assessment to quantitative analyses), an at-a-glance table is provided at the beginning of each chapter as a quick overview of the metrics and associated methods for each river health indicator. The associated data sources, period of record/observation, and geographic scales are also included.

The SOPR baseline assessment is the first application of the Poudre RHAF and it represents a snapshot of the river's health in 2015–2016. However, because of the inherent differences across disciplines and assessment approaches each metric pulls data from a distinct and possibly unique time period to inform results. For example, for all the metrics informed through rapid assessment, field work was completed in 2016. For water quality, aquatic insects and fish, because of the time lag in data collection and processing as it overlapped with the completion of this project, the data sourced was from 2015.   On the other end of the spectrum, the peak flows analysis requires a return interval statistic, and thus draws data from a multi-decadal period (specific time period is unique to each gage).

The at-a-glance tables also include the relative contribution (or weight) each metric was given when the numeric scores were rolled up to calculate the final overall numeric scores (and associated letter grade) for each indicator.   The relative proportions were determined based on foundational principles and well-accepted paradigms of stream ecosystem theory (e.g., Harman et al. 2012, Wohl 2004, Knighton 1998, Minshall et al. 1985, Knight and Bottorff 1984, Hynes 1970, Leopold et al. 1964), as well as the SOPR team members' expert knowledge of the Poudre River and similar streams along Colorado's Front Range.

Study area

The SOPR study area encompasses the Poudre River and its associated riparian area from just upstream of the Munroe Diversion (above Gateway Natural Area in the Poudre canyon) to Interstate 25 (Figure 1.2). The river varies greatly through the study area with a range of geologic and ecological settings and different types of human influence. To account for this variability and meaningfully convey the state of the Poudre River, the study area was divided into four zones: Canyon, Rural, Urban, and Plains. These four zones were further subdivided into a total of 18 reaches to define relatively homogenous assessment units (Figures 1.2 and 1.3a-d, Table 1.3).

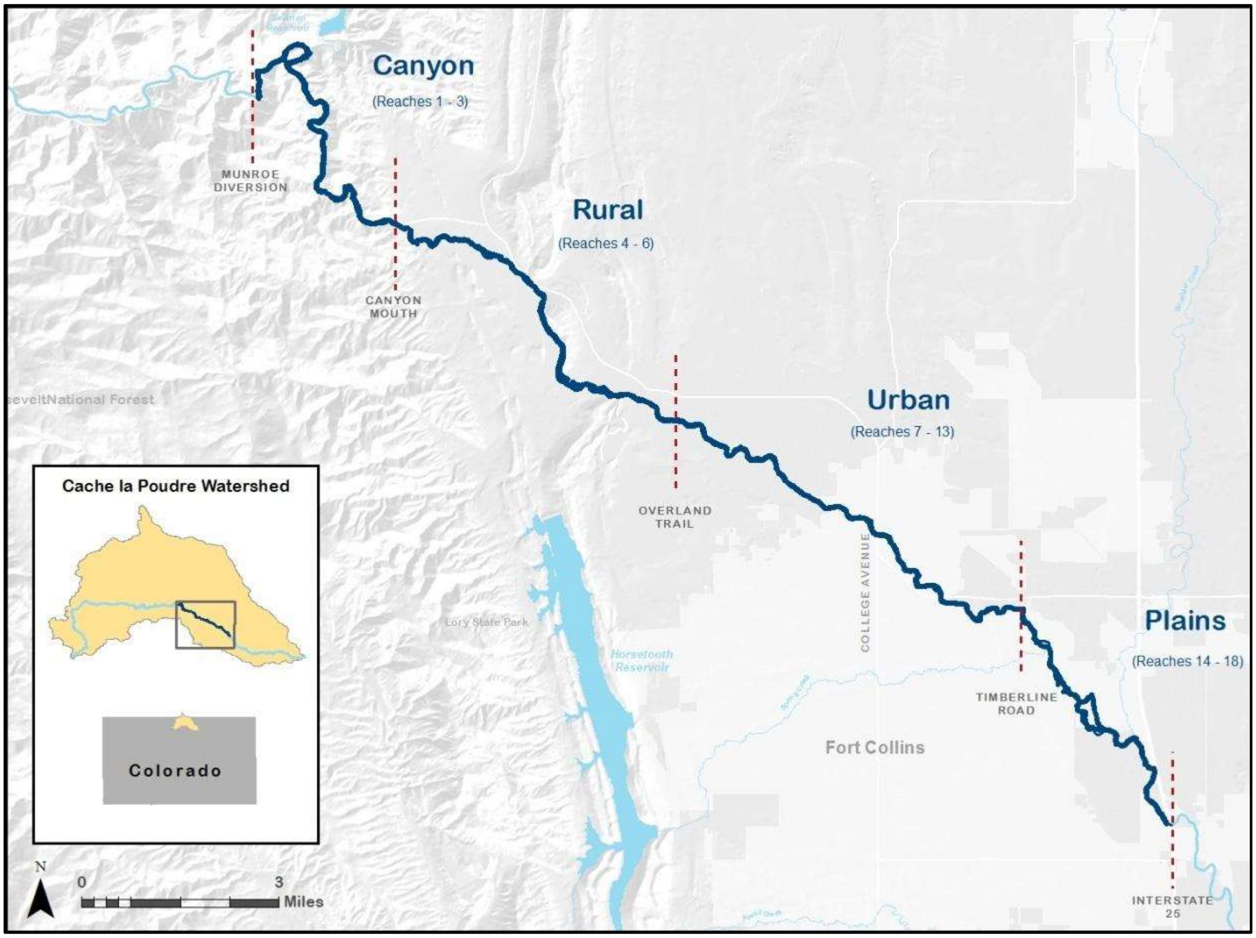

Figure 1.2: Map of the SOPR study area depicting the four study zones (City of Fort Collins, 2017).

As a natural ecological transition zone, the changes that occur to the river through the SOPR study area are extensive and even greater changes are brought by anthropogenic impacts (Figure 1.3a-d). The Canyon zone is relatively steep (average slope of 0.65%) and forested, and the river corridor is geologically confined. It is mostly unaltered except for several diversion dams and Colorado Highway 14, which parallels the river. The Rural zone, stretching from the canyon mouth to Overland Trail, is on the upper piedmont which remains relatively steep (average slope of 0.55%). Here, the floodplain opens up and the river is mostly unconfined, except for a few points where it flows through water gaps in the hogbacks. Rural land uses dominate the landscape, but some higher-density residential development is situated adjacent to the river in the town of Laporte and diversion dams segment the river.

In the Urban zone, the river flows through Fort Collins where there is a high level of residential, commercial, and industrial development, along with many bridges and diversion dams. The river is less steep in this zone (with an average slope of 0.40%) and is naturally unconfined. However, floodplain encroachment, channelization, and artificial stabilization have confined the river through most of this zone. Below Fort Collins, the Poudre exits the piedmont to flow into the plains. Average river slope in the Plains zone is 0.27%, but there is an abrupt change from 0.35% to 0.15% at the toe of the piedmont near the Environmental Learning Center (ELC). The natural geologic channel confinements in this zone are few, and the historical valley bottom would have been at its widest here. Even though the dominant land uses on the Plains zone are rural and industrial, the legacy of gravel mining has resulted in a floodplain that is tightly confined by artificial features such as berms (to protect the ponds left from gravel mining), roads, and bridges.

Table 1.3: A list of the landmarks used to define the upper and lower end of each of the 18 study reaches.

Location descriptions for each SOPR study reach
1. Munroe Canal Diversion to North Fork Poudre River
2. North Fork Poudre River to Poudre Valley Canal
3. Poudre Valley Canal to Greeley Diversion
4. Greeley Diversion to County Road 54
5. County Road 54 to Rist Canyon Road
6. Rist Canyon Road to just below Overland Trail*
7. Just below Overland Trail to Larimer Weld Canal
8. Larimer Weld Canal to Shields Street
9. Shields Street to College Avenue
10. College Avenue to Lincoln Street
11. Lincoln Street to Mulberry Street
12. Mulberry Street to Timnath Reservoir Inlet Canal
13. Timnath Reservoir Inlet Canal to Timberline Road
14. Timberline Road to Prospect Road
15. Prospect Road to Fossil Creek Reservoir Inlet Diversion
16. Fossil Creek Reservoir Inlet Diversion to Boxelder Creek
17. Boxelder Creek to Rail Road Bridge
18. Rail Road Bridge to Interstate-25

*The break point for this reach is at the downstream end of Butterfly Woods Natural area, which is located just downstream of Overland Trail.

Figure 1.3a and b: Each zone in the SOPR study area and their corresponding reach breaks shown on land imagery.

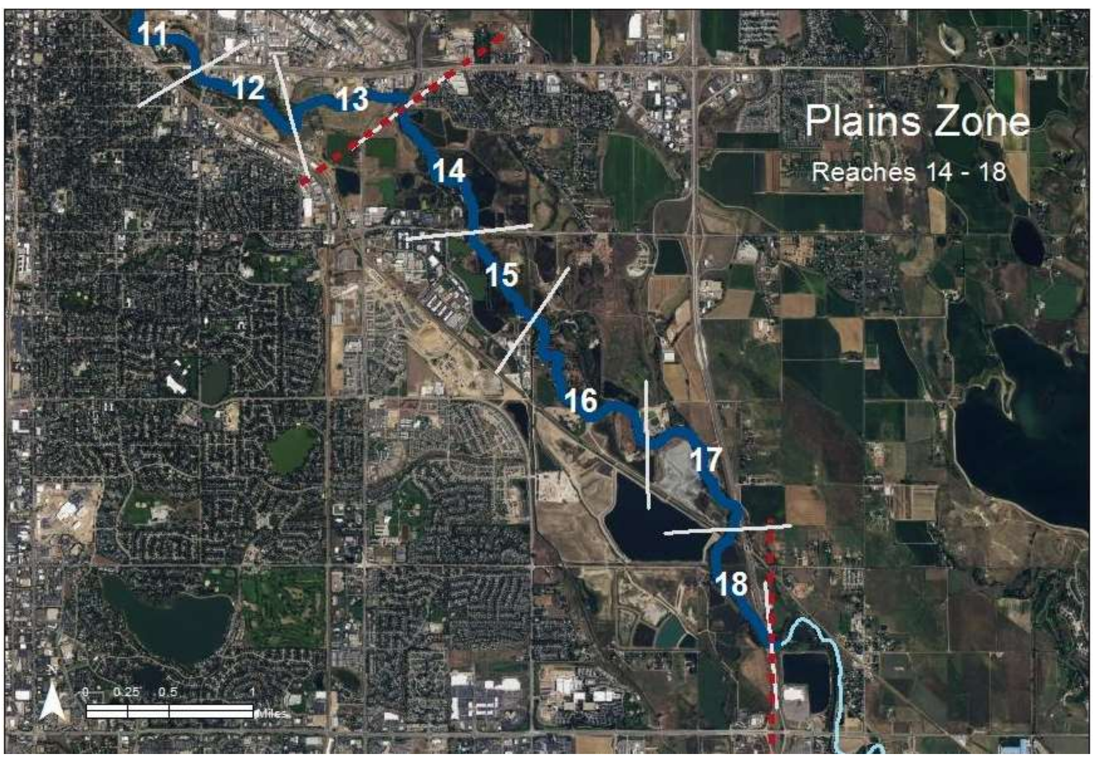

Figure 1.3c and d: Each zone in the SOPR study area and their corresponding reach breaks shown on land imagery.

RHAF study reaches and subject-specific study reaches or sample sites

Reach breaks mark important changes in river form, land use or water use (Figures 1.3 a-d). However, in some cases indicator-specific sub-reaches were established to better reflect appropriate scales of analysis and data availability. All assessment results were then translated to the 18 main study reaches during analysis and reporting.

For the Flow Regime indicator, analysis is based on the City of Fort Collins Ecological Response Model (ERM) (City of Fort Collins, 2014) which has its own defined sections and reaches. The critical demarcation with respect to ERM is the change from the *transition section* to the *warm section* at Boxelder Gage since standards for peak flow change abruptly at this point. The peak flow metric is also intrinsically tied to the three flow gages within this study area located at the canyon mouth, Lincoln Street and just upstream of the confluence with Boxelder Creek.

The river was broken into 99 sub-reaches while evaluating geomorphic indicators of River Form, Resilience, and Physical Structure. Sub-reach breaks were made anywhere there was enough change in physical condition for one or more of the geomorphic metrics to differ by at least one full letter grade from adjacent areas. Since the geomorphic impacts of river crossings and diversion structures tend to be more pronounced upstream of these features, the reach breaks were generally made right at the crossing/structure.

The Water Quality indicator incorporates data from the Colorado Department of Public Health and Environment (CDPHE) and the City of Fort Collins. CDPHE monitors and regulates water quality by river segments. All or some of three CDPHE-defined Poudre River Segments (10, 11, and 12) fall within the SOPR study area. The City of Fort Collins also has defined river sections for monitoring and regulating water quality. Eight water quality study sections fall within the study area, each with a representative sampling location.

The Aquatic Life indicator uses data from Colorado Parks and Wildlife (CPW) and Colorado State University (CSU), which conduct regular sampling of fish and aquatic insects at sites that characterize the river segments, inform management objectives, and monitor influence of known potential stressors. In 2016, the City of Fort Collins supplemented these data collection efforts with 10 additional aquatic insect monitoring sites, located upstream of Lincoln Street, in the upper Urban and Canyon zones.

Chapter 2: Flow Regime

Table 2.1: Flow Regime Metrics at a glance.

Flow Regime Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Peak flows	Quantitative: based on discharge magnitude, frequency, and duration thresholds for river bed mobilization (except for the Canyon zone- see text)	Historical discharge data collected near the canyon mouth, Lincoln Street in Fort Collins and near the confluence with Boxelder Creek; entire gage record was used (unique to each gage).	Defined by three existing stream gages	50%
Base flows	Quantitative: based on mean and minimum winter daily average discharge values (except for the Canyon zone-see text)	Data sources were the same gages as mentions above, along with consideration of modelled flows (Bishop-Brogden Associates, 2015)		25%
Rate of change	Qualitative: based on observed patterns in the daily hydrographs during the period of analysis			25%

Introduction

Water is widely understood to be the master variable of a river's condition. Similarly, for this assessment the Flow Regime is a fundamentally important indicator and contributor to the overall river health grade. The magnitude, duration, frequency, timing, and rate of change of river flow interact with the landscape to determine the types and levels of functions that the river performs. Three metrics are used to describe the condition of the river's Flow Regime: **peak flows**, **base flows**, and flow **rate of change**.

- Adequate **peak flows** are essential to river health and functioning. Spring snowmelt-driven peak flows drive the production of many watershed services including water quality maintenance, support of fisheries and riparian habitats, recreation and aesthetics. High flows flush accumulated sediment and algae from the system, leaving the substrate clean and increasing the oxygen in the water. They also maintain the shape of the channel, facilitate forest reproduction, and sustain groundwater connections that moderate stream temperatures.

- **Base flows**, on the other hand, are the low flows that occur during drier times of the year. They support aquatic life and habitat connectivity after the seasonal snows have melted. Base flows are generally comprised of rainfall in the watershed and slowly percolating groundwater. In more managed systems, flows may be augmented with reservoir releases, exchanges and water administration and groundwater returning from urban land uses. Base flows are critically important to river health since the raw material for aquatic life support – water – is at its lowest supply.
- The **rate of change** of flows over relatively short time frames (*e.g.,* hours) has an influence on aquatic and riparian species. On the Poudre River, rapid fluctuations in river flow, especially in the low flow months, create a highly unnatural environment that is a significant stressor on aquatic insects and fish.

Flow Regime methods, analysis, and grading guidelines

Flow regime metrics were evaluated at the reach scale. A combination of gage data, diversions records, flushing flow criteria and operational knowledge of the system were used to inform these metrics.

All three metrics used data from three gages within this study area but the use of this data was unique for each metric. In general, gage data was applied to all the reaches downstream of a given gage. An exception was made for the Canyon zone because no proximate upstream gage data was available. Therefore, data from the gage downstream (located at the canyon mouth- the end of the Canyon zone) was applied to the three reaches upstream in the canyon zone. Also, because the canyon zone is a different type of river system, and because fewer data are available to describe conditions in this zone than in reaches downstream, the approach and/or degree of specificity for evaluating and scoring the canyon zone was either slightly or entirely different (depending on the metric) as compared to the approach used to the Rural, Urban, Plains zones. In short, Canyon zone reaches were largely scored qualitatively based on the gage at the canyon mouth (located at the downstream end of the Canyon zone) and a general understanding of water diversion patterns.

By design, the Flow Regime metrics and grading guidelines were based upon the flows needed to meet specific criteria identified to support functionality of other metrics. Because few empirical relationships were available linking RHAF metrics and flows, the numeric criteria for peak and base flow metrics were based upon thresholds identified in the Ecological Response Model (ERM)[1] that were developed in a partnership led by the City of Fort Collins Natural Areas department (City of Fort Collins, 2014).

The metrics were assessed using historical discharge data collected at three gages along the Poudre located at: the canyon mouth (Gage CLAFTCCO, representing reaches 3-10), Lincoln Street (Gage CLAFORCO, representing reaches 11-16), and near the confluence with Boxelder Creek (Gage CLABOXCO, representing reaches 17-18). Each gage represents a section of the river, and the 2017 SOPR reports employed the assumption that peak flow conditions are uniform between gages. Reaches

[1] The ERM full report, appendices, and flow data are available online http://www.fcgov.com/naturalareas/eco-response.php

represented by each gage section were assigned a grade based on conditions measured at the gage. No attempt was made in this study to interpret impacts to flow patterns, such as diversions, at a finer scale within these three sections because this would be an extensive effort and thus was beyond the scope of this project.

When considering the results for all three flow metrics, note that there are various degrees of uncertainty in the results across the zones corresponding to data availability or lack thereof. For example, for the peak flow metric the Canyon zone was evaluated using the general qualitative grading guideline descriptions and a general high-level evaluation of alterations to flows, in contrast to the lower three zones that were assessed quantitatively. Also, with regard to uncertainty, the quantitative assessment for the lower three zones was conducted using gage data and grading guideline thresholds developed in the ERM that originate from specific locations on the river. Therefore, the further one moves from these gage locations, the greater the uncertainty.

Peak Flows

The grading guidelines for the peak flows metric are based in part on the thresholds for river bed mobilization modeled in the ERM. Bed mobilization is critical for maintaining habitat and the life cycle needs of aquatic insects and fish that rely on clean interstitial spaces between coarse bed materials. Another important role of bed mobilization is to prevent armoring (winnowing of fine sediments resulting in a predominance of coarse bed particles), or conversely, sedimentation (excessive deposition of fine sediment resulting in burial of coarser bed particles and filling of the space between them). These processes can have a cascading effect on a spectrum of other important functions associated with a healthy river. Bed mobilization occurs when shear stress, or the amount of force exerted by the flowing water on the bed sediment particles, exceeds a critical threshold value. The peak flow thresholds needed to perform other functions such as algae scour, channel maintenance and certain riparian processes may correlate to (but are unlikely to be the same as) the bed mobilization thresholds. Flows required to perform these other important functions were not explicitly analyzed for this metric.

The qualitative grading guidelines for peak flows were developed using the FACStream framework (Johnson, et al. 2016) as a guide and refined with site-specific information on the associated ecological functions (Table 2.2). Numeric criteria, used to assign B, C, and D grades for peak flows, are based upon the channel structure indicator in the ERM, which in turn is based upon the shear stress necessary to mobilize the channel substrate and to flush fine sediment from the river bed (Table 2.3). The A and F grades were assigned qualitatively, as described below.

There are three aspects of peak flows:

- **magnitude**: the volumetric discharge of the peak flow (reported daily average discharge in cubic feet per second [cfs])[2]
- **frequency**: how often peak flows of a desired magnitude occur (reported as a return interval in years)

[2] Daily average discharge is the most commonly-available discharge data type from the USGS and other sources, thus all criteria were based upon daily average discharge

- **duration**: the length of time discharge is above a desired magnitude, reported as number of days the daily average discharge exceeds that magnitude during the water year).

Peak flow grading guidelines

Table 2.2 provides a qualitative description of peak flow grading guidelines for all grades (A–F) and Table 2.3 presents quantitative magnitude, duration and frequency thresholds for B, C, and D grades. For grades B, C, and D the grading guidelines include numeric values where the narrative thresholds are supported by research specific to the Poudre River at given locations.

Table 2.2: Qualitative description of peak flow grading guidelines.

Grade	Description
A	Peak flows provide all the functions necessary for a healthy and resilient river ecosystem. Hence, other metrics require no additional management on account of flow functions, but they may require management on account of other urban/anthropogenic stressors. Peak flows that meet the A would drive the function of natural lateral river movement essential for large scale regeneration of riparian habitats. Flow at this level may not actually affect such outcomes in anthropogenically constrained river systems.
B	Peak flows have been reduced or re-timed such that the function of full (natural) lateral river movement may not be supported but other essential function continue to be supported. Peak flows support the 'B' grade for dependent metrics such as: largely natural coarse and fine scale physical structure to support aquatic habitat, long-term dynamic equilibrium with occasional management support, maintenance of river form with occasional management support, and inundation of riparian forests and wetlands. Mobilization of the riverbed, including coarse and fine sediments, which creates and maintains many of these processes and conditions, should occur (though with less certainty than at the A level) at discharges equal to or greater than those shown in Table 2.3 for the B grade.
C	Peak flows have been reduced or retimed such that there is an increased risk of having an adverse effect on associated functions. Bed mobility, including coarse and fine sediments) should occur (though with less certainty than at the B level) at discharges equal to or greater than those shown in Table 2.3 for the C grade.
D	Peak flows have been significantly reduced or retimed past critical system thresholds, having a cascading deleterious effect on associated functions and dependent metrics. Examples include reaches below diversions that have fluctuating low regimes but severely attenuated peaks, flashy urban watersheds, or watersheds with major augmentation or withdrawal. At discharges equal to or greater than those shown in Table 2.3 for the D grade, peak flows reach desired magnitude for bed mobility but occur too infrequently to provide required bed mobility and fine sediment flushing.
F	Peak flow patterns do not resemble the natural hydrograph resulting in the near elimination of natural stream functions and likely require high levels of management in order to maintain a river minimally acceptable to the public and resource managers. Examples include rivers with overwhelming augmentation or withdrawal of water. Peak flows fall below the D grade thresholds for magnitude, frequency and duration (Table 2.3).

The values for the magnitude, frequency, and duration of desired peak flows are based upon flushing and mobility conditions suggested by available literature (Wilcock *et al.*, 1996; Milhous, 2009; Milhous, 2012). To quantitatively relate flows to the goal of achieving bed mobility the RHAF relied on the analysis from the ERM, which can be summarized as follows. The ERM team modeled 53 different river flows ranging from 50 cfs up to 9,000 cfs using the HEC-RAS 1-D hydraulic model to develop piecewise, at-a-station hydraulic geometry relationships for hydraulic radius, friction slope, shear stress, and dimensionless shear stress as functions of discharge for representative cross sections in each reach. Dimensional shear stress from HEC-RAS was then converted to dimensionless shear stress (τ*) which is referenced to the median grain size (d_{50}) of the river bed.

The body of scientific literature presents a spectrum of dimensionless shear stress values. In general, lower values represent lower certainty that the function (e.g., mobilization of the stream bed) will be performed and the higher values offer conservative or most likely chances the function will be performed. This range of values was used to inform the B, C, and D threshold criteria for shear stress values ranging from 0.021 (D criterion), to 0.03 (C criterion) to 0.035 (B criterion). The flow thresholds presented in Table 2.3 correspond to the shear stress values required for mobilizing the average bed grain size for a given location, as determined by the aforementioned ERM analysis.

The target frequency for bed mobility is 1 in 3 years and sediment flushing is 2 in 3 years. A target peak flow duration of 1 to 5 days is suggested to achieve desired bed mobility and sediment flushing functions that support river-riparian health. The RHAF uses a required duration of 3 days above the desired flow magnitudes in Table 2.3, which is the midpoint of the suggested range of 1 to 5 days.

Table 2.3: Quantitative criteria for B, C and D grade levels for the peak flow metric. The table indicates for each reach the gage from which to pull data and the thresholds against which the data should be measured.

Zone	**Canyon**			**Rural**			**Urban**							**Rural**				
Reach	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Gage	Canyon mouth			Canyon mouth						Lincoln Street							Boxelder	
A (90-100)	No thresholds established																	
B (80-89)	Evaluated qualitatively with consideration of gage data and known diversions			3300 cfs													2100 cfs	
C (70-79)				2700 cfs													1550 cfs	
D (60-69)				1750 cfs													900 cfs	
F (50-59)				Less than D thresholds														

The steps for using this table to conduct a peak flow analysis for a given reach are as follows.

1. Determine which gage will be used for the reach being analyzed.
2. Run statistics first to evaluate if the data indicates the required peak flow magnitude threshold for the B grade (Table 2.3) is met for 3 days in a water year. The 3 days do not need to be continuous.
3. If the return interval is greater than 4.5 years move down one row in Table 2.3 and run the same test for the C grade threshold. If the return interval is less than 4.5 then move to step 4.
4. Consider the return interval again to determine if the scores should be adjusted with a "+" or "-."

- If the return interval was less than 2.5 years, three points were added to the score to make the grade a '+' (i.e., B+=88, C+=78, D+=68).
- If return interval was between 2.5 and 3.5 years, the score was left as the midpoint of the assigned grade (i.e., B=85, C=75, D=65).
- If the return interval was between 3.5 and 4.5 years, three points were subtracted from the score to make the grade a '-' (i.e., B-=82, C-=72, D-=62).

Other considerations for interpretation of peak flow function

Flows that mobilize the median-sized bed material for a given reach do not occur every year, nor must they to maintain river health. Peak flows must be analyzed over various time scales to determine whether flushing thresholds are exceeded often enough (referred to as the "return interval"), and for enough duration, to maintain river health. For this analysis of peak flows, the period of record from 1976-2016 for each of the three gages was analyzed for peak flow magnitude, duration, and frequency thresholds (Figure 2.1). Such a long-term record is needed to compute a return interval and to characterize ecological processes and cycles that occur over long periods (decades to centuries).

However, long-term patterns do not provide information on the possible occurrence of recent river bed mobilization in the 2017 SOPR report study period (*i.e*., 2015-2016). Therefore, a second line of evidence helped convey the current condition of the critical ecological functions driven by the peak flows. The embeddedness of riffles, as measured in the fine-scale physical structure metric (see Chapter 9) provides field-based evidence indicating the degree of bed flushing that has occurred recently. The riffle embeddedness factor, as reported through the fine-scale physical structure metric, is not intended to influence or be combined with the peak flow metric, but instead can be used to provide complimentary evidence of recent flow patterns affecting river health.

Using the fine-scale structure metric alone, without analysis of the longer flow record, could be misleading, since rivers naturally experience climate-driven wet-dry cycles that span years to decades. For instance, during a dry period, when flushing has not occurred for several years, the riffles may appear more embedded with fines. Therefore, multiple lines of evidence were assembled for the 2017 SOPR report, covering multiple time scales, to produce a better understanding of flow patterns, which are arguably the largest driving factor in maintaining Poudre River health. Thus, the near-term flow patterns and the grade for the fine-scale physical structure metric for embeddedness can be an important complement to the peak flow grades to produce a more complete picture for interpretation of any given year's assessment (Figure 2.1). In other words, this additional information on fine scale response to recent flow patterns was used to understand and communicate more a complete story of the current condition of the riverbed, but was not part of the actual scoring process.

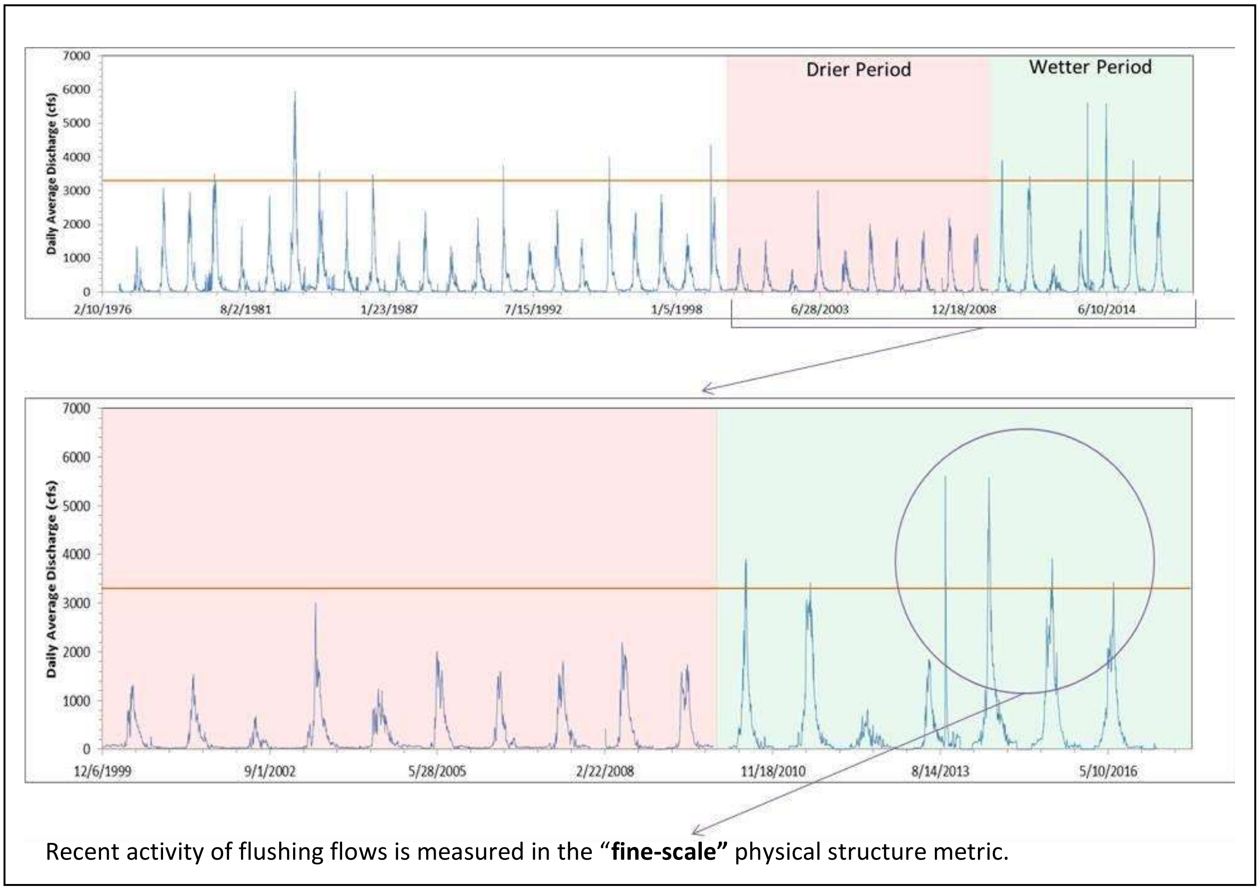

Figure 2.1: Daily average discharge at the canyon mouth gage (1976-2016) was analyzed for peak flow magnitude, duration, and frequency thresholds. The horizontal orange line indicates flow of 3300 cfs which was calculated in the ERM as the threshold required to mobilize the median grain size in the Rural and Urban zones. Long, medium, and short time scales are considered in the comprehensive interpretation of flushing flow functions. The fine-scale physical structure metric provides another line of evidence to determine whether flushing has occurred in the past few years.

Base Flows

The base flow metric rates impairment to the magnitude and frequency of low-flow discharge events in a reach based on how often discharge typically drops below ecologically relevant thresholds on an annual basis. Numeric criteria for base flows are based upon the low-flow needs of juvenile (young-of-year) brown trout. The ERM report suggests that numbers of young brown trout are higher when Poudre River flows average 35 cfs or higher in the period between November and March, reflecting good conditions for incubation of embryos (*i.e.,* adequate flow of water through gravel riffles where eggs are deposited), and a subsequent higher relative survival through to the following autumn. A discharge of 10 cfs was presented in the ERM, and incorporated into these grading guidelines, as a minimum base flow based on expert knowledge and familiarity with the river by experts.

Trends in base flow magnitude, duration, and timing observed on plotted hydrographs for each gage were considered when scoring the base flow metric. To score and assign grades for the base flow metric, mean and minimum winter daily average discharge values were calculated for the period of record at each gage and compared to numerical standards according to the guidelines in Table 2.4.

An additional step was then taken to refine reach-scale scores to the degree possible. The City previously conducted an analysis to better understand locations below diversion points where critical low flow events are common (Bishop-Brogden Associates, 2015). The results of this report were reviewed and reach-scale base flow scores were adjusted accordingly (Tables 3.2 and 3.3 in the SOPR, 2017).

Table 2.4: Base flow grading guidelines.

Grade	Description
A	Base flow magnitude is ample to provide all the functions necessary for a healthy and resilient river ecosystem. There are no dry-ups or other significant stressors and aquatic life is never stressed by altered base flow.
B	Base flow magnitude is less than optimal but with minimal effects on stream function. Aquatic life is never critically stressed by altered base flow. Base flows support habitat availability, connectivity, and functional needs of aquatic life. Flows less than 35 CFS occur less than 50 days per year and on less than 50% of days in winter on average. Flows less than 10 CFS occur less than 5 days per year and on less than 10% of days in winter on average. There are no periods of no flow.
C	Base flow alterations are short in duration or are during times of the season when stream functions are minimally stressed. Base flows support aquatic life needs most of the time, but poor habitat availability, connectivity, and water quality may occur intermittently. Flows less than 35 CFS occur less than 100 days per year and on less than 50% of days in winter on average. Flows less than 10 CFS occur less than 10 days per year and on less than 10% of days in winter on average. There are no periods of no flow.
D	Altered base flow patterns are common and measurably affect stream function. Flows less than 35 CFS occur less than 150 days per year on average. Flows less than 10 CFS occur less than 100 days per year and on less than 60% of days in winter on average. There are less than 20 days per year with no flow on average.
F	Altered base flow patterns have critically reduced stream function, including eliminating native or desired species, violating water quality standards, and/or other irreversible changes. Flows less than 10 CFS occur more than 100 days per year and on less than 60% of days in winter on average. There are 20 or more days per year with no flow on average.

Rate of Change

The rate of change metric evaluates impairment to the rate that discharge changes over time, based on the degree to which rate of change is likely to stress plants and animals during critical life stages. The rate of change metric also considers the rate at which flows increase and decrease between the base and peak flows. The characteristics of the ascending and descending limb of the river's hydrograph have significant influence on critical life stages for riverine species such as the spawning and incubation period for native fish and the seedling establishment period for riparian trees.

In the process of adapting the FACstream for the Poudre, the rate of change metric was added because rapid rates of change in flow within short time periods (*i.e.,* hours) are a well-recognized concern on the Poudre River through Fort Collins. The grading guidelines for this metric (Table 2.5) are based on the general understanding of impacts of rapid changes in flow rates to aquatic species (Cushman, 1985; Bunn and Arthington, 2002). However, little data is available specifically describing effects of rapid, short-term changes in river discharge on stress and survival of aquatic species for this particular system. Consequently, this metric is rated qualitatively based on observed patterns in the daily hydrographs during the period of analysis for the 2017 SOPR report (i.e., 2016).

Table 2.5: Rate of change grading guidelines.

Grade	Description
A	Flow rate of change equal to or less than that caused by natural weather patterns and seasonal trends. Rate of change is within the tolerance of native and desired biota.
B	Flow rate of change is somewhat altered but change over hours is slow enough to support highly functional aquatic life and abundant ecological diversity. This includes rate of change from peak flows (the descending limb of the hydrograph) as well as base flows.
C	Flow rate of change is moderately altered and stresses native and desired plants and animals. Daily flow change needs to be less than an order of magnitude per day to maintain this level of function.
D/F	Daily and hourly variability are erratic and independent of season or climate. Aquatic life is still able to exist, but only the most resilient species survive.

A note on analytical approaches for assessing flow condition

There are a variety of possible analytical approaches for measuring river flows. Elements to consider within this study area include modeling the natural flow regime, climatic cycles, frequent diversions along the river, and gage data with distinct periods of record. The analytical approach selected must meet project objectives and scope. Thus, for this study, the gage data and thresholds established in the ERM were the primary tools for assessment.

Using gage records to calculate metric scores at three stations and extrapolating results over all the reaches in each gage section, as was done in this study, provides one level of assessment of flow regime impairment by averaging the effects of multiple diversions between gages. Since many important flow management impacts occur at discrete points, sometimes affecting changes in flow volume across shorter river segments between structures within each gage section, a finer resolution analysis would give more accurate results. Flow records exist for most of the structures, which would enable finer-scale analysis using a point-flow model or reach-specific discharge accounting system. This could provide a more accurate (on a finer spatial scale) account of the effects of each diversion at a resolution sufficient to identify reaches with critical flow issues.

Chapter 3: Sediment Regime

Table 3.1: Sediment Regime metrics at a glance.

Sediment Regime Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Land erosion	Semi-quantitative: based on evidence of land disturbance that is visible on current aerial imagery	Aerial imagery, GIS spatial data, and field observations	Watershed scale	Average of metric scores
Channel erosion	Semi-quantitative: based on evidence of channel erosion identified on current aerial imagery and knowledge gained through field-based observations		Sub-reach scale; defined by changes in geomorphic conditions (see Chapter 1)	
Continuity	Semi-quantitative: based on the proportion of contributing watershed retaining sediment and knowledge gained through field-based observations		Watershed scale	

Introduction

Sediment is soil, sand, and rock that is washed from the watershed slopes into the river. Fine sediments can be suspended in the water or larger particles can move along the river bed. Sediment is a natural component of the Poudre River ecosystem, but too much or too little will throw the river's physical processes out of balance. When sediment is in excess it builds up on river bottoms or floodplains, buries fish spawning habitat, and suffocates aquatic insects. A shortage of sediment can be equally detrimental for river health. The river is always trying to balance its energy inputs and outputs. When a river reach is deprived of sediment, the imbalance between sediment supply and the water's energy is expressed through down-cutting into the bed or erosion of banks. In this way, a sediment-starved river finds its own sediment sources, but at a cost.

The Sediment Regime indicator is described with three metrics: **land erosion**, **channel erosion** and sediment **continuity**.

- **Land erosion** considers the amount of sediment produced in the watershed by hillslope processes and land uses resulting in exposed soils.

- **Channel erosion** evaluates sediment production caused by erosion of the channels of the river and its tributaries. While erosion is a natural process, the rates of erosion can be elevated by human activities, such as when alluvial streams incise to form gullies.
- Reductions in sediment **continuity** (supply) cause downstream areas to either become unstable due to bed and bank erosion or the sediments to armor the bed (degrading fish and insect habitats). Watershed contributions to sediment starvation include diversions, dams, excessive imperviousness in the watershed, or upstream channels and banks being lined with unnatural impervious material or buried in culverts.

Sediment regime methods, analysis, and grading guidelines

Sediment regime was evaluated at the watershed scale (land erosion and sediment continuity metrics) and the sub-reach scale (channel erosion metric) using a combination of desktop analysis and information obtained from field observations. The Sediment Regime indicator score for each reach was calculated by averaging the reach-scale scores for all three metrics.

Land Erosion

Land erosion rates impairment to the amount of sediment produced via land erosion in the contributing watershed of a reach, based on the extent of land use and unnatural bare ground in the watershed. The land erosion metric was graded according to the guidelines in Table 3.2, based on evidence of land disturbance that is visible on current aerial imagery, including: road density, unvegetated slopes, clear-cuts, and human-caused mass erosion such as landslides associated with roads, construction, or logging.

The greatest land disturbance in the watershed for the 2017 SOPR report was the burn scar left behind by recent wildfires. GIS layers outlining the burn scars by degree of intensity were used to calculate the percentage of burned area in the contributing watershed for each reach as part of the scoring for this metric. Land erosion metric scores in the Canyon and Rural zones are, therefore, closely tied to the proportion of burned area in the contributing watershed. In the Urban and Plains zones, sediment from other land uses and outfalls becomes more important.

Table 3.2: Land Erosion grading guidelines.

Grade	Description
A	The amount and rate of sediment production from land erosion is relatively unaffected by human land use. There are no significant stressors.
B	Stressors are present but rates of surface erosion and mass erosion events appear to be mostly natural. Examples include watersheds with low road or development density or grazing practices that do not deplete vegetation cover. There is no visible discharge of sediment or evidence of sediment deposition from outfalls.
C	Land uses in the watershed are causing significant changes to the amount of land erosion. Examples include overgrazed slopes with increased bare ground, high density of unimproved roads, or evidence of past human-caused mass erosion. If present, visible discharge of sediment or evidence of sediment deposition from outfalls is minimal.

D	Greatly increased land erosion caused by human activity or land use is evident. Examples include widespread overgrazed or clear-cut slopes, erosion associated with roads adjacent to the stream, or evidence of recent human-caused mass erosion. Visible discharge of sediment or evidence of sediment deposition from outfalls indicates unprotected exposed soil in the contributing watershed.
F	Land uses in the watershed are causing an overwhelming amount of sediment from land erosion. Examples include widespread loss of ground cover on adjacent slopes with rill or gully formation or very large or frequent human-caused mass erosion. Visible discharge of sediment or evidence of sediment deposition from outfalls indicates a significant proportion of unprotected exposed soil in the contributing watershed.

Channel Erosion

Channel erosion rates impairment to the amount of sediment produced via channel erosion on the main stem and tributary rivers upstream of a reach based on the extent of human-induced channel erosion and incision in tributary reaches. Natural channel erosion can vary greatly depending on a variety of interrelated factors including position in the watershed, channel gradient, and dominant bed material.

Depending on the context, erosion of a river channel's banks may be viewed either positively or negatively. Bank erosion is a normal process that occurs when rivers need to adjust their planform, profile, or channel dimension to deal with changes in sediment and flow regime or during large flood events. Accelerated bank erosion can be identified in the field in pool-riffle systems by the presence of large unvegetated point bars opposite of the eroding bank which can indicate that erosion and subsequent deposition of the eroded sediment is occurring at a faster rate than the vegetation can establish on the point bar. Furthermore, bank erosion occurring not just in the outside bends but in straight sections can also be indicative of accelerated bank erosion.

Bank armor in the form of riprap is often used to stop bank erosion in areas where nearby assets need protecting. The use of riprap on a large enough scale can actually have the opposite effect of accelerated bank erosion and limit the amount of sediment to the river to a point where the river has more energy to move sediment which can potentially cause channel degradation downstream and/or channel bed armoring as the system potentially becomes more (unnaturally) sediment supply limited.

A grade for channel erosion was applied to each of the 99 Poudre River sub-reaches according to the guidelines in Table 3.3, based on evidence of channel erosion on current aerial imagery, and knowledge gained through field-based observations which included a foot survey of most of the river in the project area in Fort Collins. Remotely assigned grades were then re-evaluated during field surveys performed when scoring the geomorphic indicators. Sub-reach scores were weight-averaged by length to calculate grades for the respective reaches.

Table 3.3: Channel Erosion grading guidelines.

Grade	Description
A	Tributaries and main-stem rivers in the watershed show natural levels of erosion. There are no significant stressors.

B	Some tributaries and main-stem rivers in the watershed may have isolated areas of accelerated bank erosion, but channel-scale instability is not present. Or the use of bank armor is isolated. Stressors are present but the combined effects are minimal.
C	Accelerated bank erosion in tributaries and main-stem rivers is common in the watershed. Localized areas with major instability, incision, and/or gully formation are present. Or the use of bank armor is commonplace. The combined effects of stressors cause reach-scale instability which is moving through the watershed.
D	Accelerated bank erosion in tributaries and main-stem rivers is widespread in the watershed. Human-induced channel erosion is a major source of sediment to the reach. Adjacent contributing reaches are incised and some of the contributing tributaries are unstable gullies, or bank armor is widespread in the reach and limiting sediment supply to the watershed.
F	Human-induced channel erosion is an overwhelming source of sediment to the reach. Stream and river reaches are unstable and many of the contributing tributaries are unstable incised channels or eroding gullies, or bank armor is placed in every outside bend and in straight reaches limiting the supply of sediment and causing increased channel instability downstream.

Sediment Continuity

Continuity rates impairment to the natural transport of sediment from its sources in the contributing watershed to the reach based on the number and size of unnatural impediments to sediment transport in the contributing watershed and on the proportion of the watershed from which sediment transport is blocked by large dams and reservoirs. In-line dams affect sediment continuity, and the proportion of the contributing watershed from which sediment is retained was a primary basis for grading.

Additional impacts to sediment continuity by smaller in-line diversion dams and transport limitations caused by flow regime and river form impairment were considered secondarily. Evidence of sediment-continuity impairment from these secondary sources was evaluated during field surveys.

The occurrence of these features in the contributing watershed area (i.e., upstream of a reach) was used to assign reach-scale sediment continuity grades according to the guidelines in Table 3.4.

Table 3.4: Sediment Continuity grading guidelines.

Grade	Description
A	The amount of sediment delivered to the reach is at natural levels. Small impediments to sediment continuity exist, but they are either insignificant or they block sediment from less than 10% of the contributing area.
B	Impediments to sediment continuity block sediment from 10-20% of the watershed. Examples include small dams higher on the main stem or major dams on tributaries.
C	There are major impediments to sediment continuity in the watershed, but these impediments either pass a portion of sediment or block sediment from 20- 60% of the contributing area. Reaches far below major dams are an example.
D	Major impediments to sediment delivery block sediment from more than 60% of the contributing area.
F	Major impediments to sediment delivery trap most or all incoming sediment, supplying the downstream reach with clear-water discharge. Examples include tail waters directly below major dams.

Chapter 4: Water Quality

Table 4.1: Water Quality metrics at a glance.

Water Quality Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Temperature	Quantitative: based on routine water quality data collected by the City of Fort Collins Utilities	Fort Collins Utilities' Source Water Quality Monitoring Program, Lower Poudre River Monitoring Alliance (2015), and CDPHE's Section 303(d) List of Impaired Waters (Reg. 93, 2016)	Defined by 7 long-term water quality monitoring sites and 8 water quality sections	50% (average of metric grades) + 50% (minimum metric grade)[1]
Nutrients				
pH				
Dissolved Oxygen				

[1]The overall Water Quality indicator grade for each reach was calculated using a formula that equally weights the average of the metric scores and the lowest of the metric scores [*water quality = 50% (average of metric scores) + 50% (minimum metric score)*]. This method recognizes the cumulative effects of multiple water quality factors and also that one factor may serve as a limit to water quality. Water quality reach grades were then translated to the 18 SOPR reaches for consistency with other indicators and to be included in the calculation of the overall river health grade.

Introduction

Water Quality describes the ability of water to support life, including the plants and animals that live in it and those that depend on it, including humans. The notion of water quality encompasses element levels, such as those of lead or mercury, but it also refers to nutrient concentrations, pathogen concentrations, the amount of oxygen present, and the physical properties of water such as its temperature and pH. Four metrics are used to inform the Water Quality indicator: **water temperature**, **nutrients**, **pH**, and **dissolved oxygen**.

- **Water temperature** is a critical abiotic habitat factor that is inversely proportional to the concentration of dissolved oxygen in the water and has a strong control on what types of organisms can inhabit a river reach. For instance, trout are considered "cold water" fish and viable populations cannot typically be sustained above a given temperature threshold.
- **Nutrients** in the water are necessary to support aquatic life, but when nutrients are supplied in excess, water quality suffers through algal blooms, decreased clarity, and bad odor.

- The **pH** of water is a measure of its acidity or alkalinity, which can be affected by the natural geology underlying a stream, the amount of plant growth and organic material, chemical contaminants, and certain types of mine drainage. Aquatic organisms react strongly to gradients in pH and it sets the context of the chemical environment mediating the types and rates of a host of bio-geochemical processes and reactions.
- The **Dissolved oxygen** content is generally high in steep mountain streams, where the relatively cold water can accommodate a higher dissolved oxygen concentration and turbulent flows engulf "pockets" of air, allowing the gas to dissipate in the water. All other things being equal, dissolved oxygen content tends to decrease as flow rate decreases and water temperature increases. Dissolved oxygen content is most commonly impacted by the elevated microbial respiration resulting from the decomposition of organic matter, such as over-growth of algae and aquatic plants. Like the air we breathe, the oxygen dissolved in water is essential to aquatic life.

Water quality methods, analysis, and grading guidelines

Spatial Organization

The water quality data used to grade the Water Quality indicator metrics for the SOPR (2017) were collected in 2015 from seven monitoring sites associated with the Upper Cache la Poudre (CLP) Collaborative Water Quality Monitoring Program and the Lower CLP Water Quality Monitoring Program. Each of the seven monitoring sites is shown in Figure 4.1 and described in Table 4.2. Water quality data collected in 2015 were used because the current year's data (2016) were still under review and not yet finalized for public use at the time the analysis was conducted.

The Poudre River was divided into eight sections for the water quality assessment to evaluate impacts of potential stressors on water quality through the project extent (see Figure 4.1). Section breaks were established based on contributions from major tributaries and reservoirs, changes in Colorado Department of Public Health and Environment (CDPHE) Stream Segment and Classification, known dischargers to the Poudre River, and the location of water quality monitoring sites (Table 4.2). Water quality data collected at monitoring sites located within a specified section were used to grade the entire section. In the one circumstance where a water quality monitoring site was not located within the section (WQ3), data collected from the nearest downstream site (PLNC) were used to grade the upstream section (WQ3). The lowest elevation water quality section (WQ8) was downstream of the end of the SOPR study area. This section was not included in the grading assessment for water quality but was discussed in the results because the City's water treatment operations extend downstream of I-25.

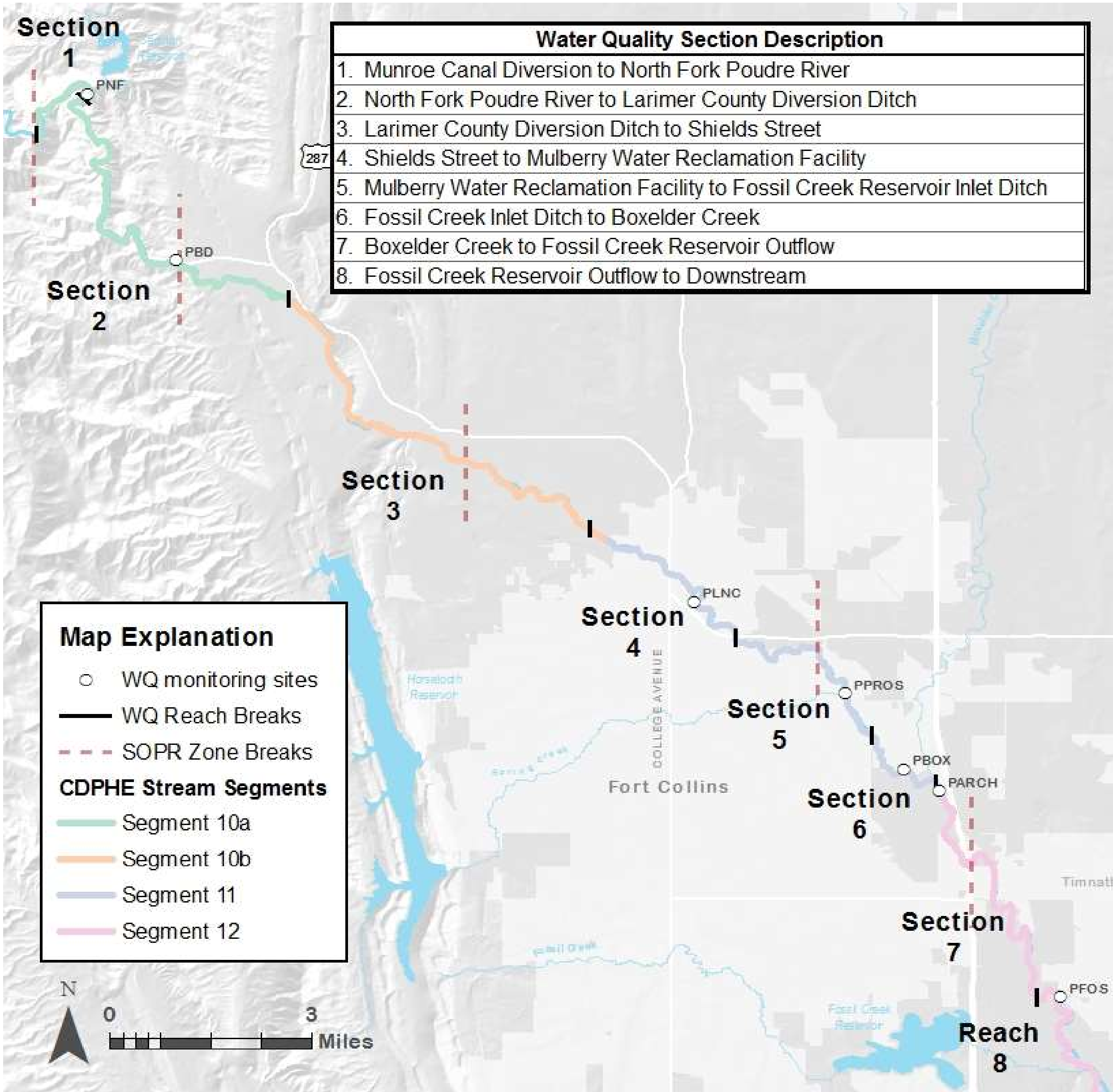

Figure 4.1: Water quality monitoring locations, water quality section breaks, and Colorado Department of Public Health and Environment (CDPHE) Stream Segments used to grade the Water Quality indicator for the State of the Poudre River 2017 report. CDPHE Stream Segments were used to identify appropriate water quality standards based on the State's stream segment classification for aquatic life (i.e. "cold aquatic life" or "warm aquatic life").

Table 4.2: Water quality monitoring locations (sites) and sections, with corresponding SOPR (2017) water quality reaches and zones and Colorado Department of Public Health and Environment (CDPHE) Stream Segments.

WQ Monitoring Location (Site)	WQ Section	Represented Reaches	Zone	CDPHE Segment
PNF	WQ1	1. Munroe to North Fork	Canyon	Segment 10
	WQ2	2. North Fork to PV Canal		
PBD		3. PV Canal to Greeley Div.		
		4. Greeley Div. to CR 54	Rural	
	WQ3	5. CR 54 to Rist		
		6. Rist to Overland		
		7. Overland to Larimer-Weld	Urban	
		8. Larimer-Weld to Shields		
	WQ4	9. Shields to College		Segment 11
		10. College to Lincoln		
PLINC		11. Lincoln to Mulberry		
	WQ5	12. Mulberry to Timnath		
		13. Timnath to Timberline		
PPROS		14. Timberline to Prospect	Plains	
		15. Prospect to FCRID		
PBOX	WQ6	16. FCRID to Boxelder		
PARCH	WQ7	17. Boxelder to Railroad		Segment 12
		18. Railroad to I-25		

Development of grading guidelines using historical data and CDPHE water quality standards

The grading guidelines were developed using historical data collected by the City of Fort Collins Utilities' water quality monitoring programs and CDPHE water quality standards. Two monitoring locations were identified as reference sites for the "cold" and "warm" water stream segments. Water quality data from the Source Water Monitoring Program's mid-elevation monitoring site (PSF - Poudre below the South Fork) was used as a reference site for the "cold" water stream segments because water quality is subject to limited land use influence with the exception of high elevation water storage reservoirs and headwater diversions. This monitoring site, which is not shown in Figure 4.1 or in Table 4.2, is located upstream of Stream Segment 10a and represents cold water conditions generally found in the upper watershed. The Lower Poudre River Water Monitoring Program's highest elevation monitoring site (PLNC – Poudre at Lincoln Street Bridge) represents warm water conditions influenced by the lower watershed. This monitoring site is the highest elevation monitoring site located within Stream Segment 11 where the aquatic life classification changes from "cold" to "warm." The PLNC monitoring site is located upstream of all wastewater reclamation facilities that discharge to the Poudre River and conditions at this site were used as reference for the Urban and Plains zone (Figure 4.1).

Statistical analyses were performed on data from these two monitoring sites using box-and-whisker plots to assess and compare data distributions over the historical period of record defined as 2009 to 2013. A 5-year period of record was selected because this amount of time is generally accepted as adequate to evaluate trends and capture annual and seasonal variability. The general approach to the development of grading guidelines was to subdivide the range of data into categories for A-C grades using percentiles of the data distribution as well as water quality standard values for each specific metric. In general, the nth percentile has n% of the observations below it, and (100-n)% of observations above it. The 50th percentile, for example, represents the median of the data, in which half the observations fall above and half fall below. In general, "A" and "B" grades represent acceptable water quality conditions with minimal effects from stressors and require little to no management or current management practices to sustain the metric.

The CDPHE water quality standards were incorporated at the "C" grade and lower (D and F). For nutrients (N & P), the CDPHE's proposed interim values were used in the absence of adopted standards. As water quality indicators approach the water quality standard there is a higher risk of exceeding the State's standard and management may be required to avoid exceedance and listing under Section 303(d) of the federal Clean Water Act and listing on Colorado's Monitoring and Evaluation (M&E) List. At the "C" grade the water quality standard (or proposed standard) has not yet been exceeded, but the water quality metric is at higher risk of exceedance. If the water quality standard has been exceeded then the indicator receives a "D" grade, and if the standard is consistently exceeded an "F" grade. In most cases, stream segments that exceed the water quality standard are listed on Colorado's Section 303(d) List and Monitoring and Evaluation (M&E) List. Colorado's Section 303(d) List and Monitoring and Evaluation (M&E) List establishes Colorado's list of impaired waters and list of waters suspect of water quality problems (5 CCR 1002-93 (2012). A water body or segment is placed on the M&E List when water quality standard exceedances are suspected, but uncertainty exists regarding one or more factors (such as the representative nature of data used in the evaluation).

The procedure used to establish grading guidelines for each of the four Water Quality metrics is described below.

Water Temperature

The water temperature metric rates impairment to the water temperature regime in a section based on biologically relevant water temperature standards and identification of impairment by the Colorado Water Quality Control Division (303d listing).

Water temperature data analyzed over the historical period of record did not show normal symmetry for either reference site. As a result, the 50th percentile for water temperature was used to differentiate between an "A" and "B" grade (Figure 4.2). The "B" and "C" grade were separated by equally dividing the temperature range between the 50th percentile and the water temperature value listed for the stream segment's respective daily maximum (DM) water quality standard (i.e., 23.9°C for Stream Segments 10a and 10b [see Figure 4.1]). The DM temperature standard value was used to define the low end of the "C" grade (i.e., threshold between a "C" and "D" grade) because it is the higher temperature value of the two temperature standards used in Colorado, the other standard being the maximum weekly average temperature (MWAT)[3] (CDPHE WQCC Regulation No. 38). The "D" and "F" grades were defined as stream segments listed on the 303(d) List of Impaired Waters for temperature. Stream segments listed for more than one listing cycle are assigned an "F" grade.

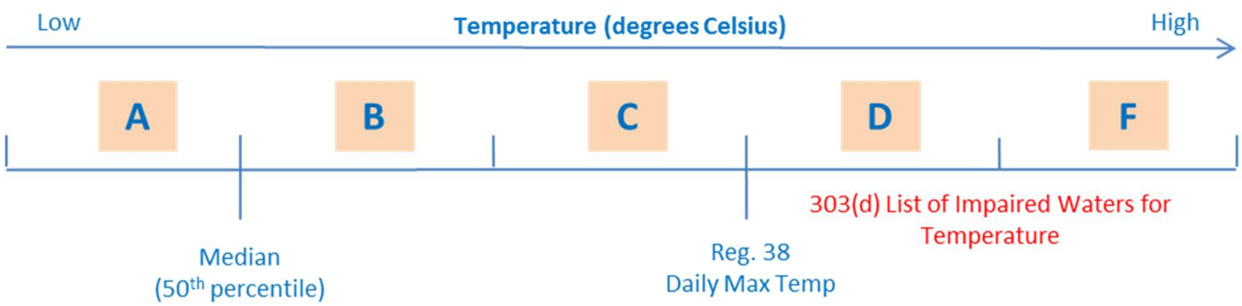

Figure 4.2: Illustration of the method used to develop grading guidelines for the water temperature metric.

Nutrients

The nutrients metric rates impairment to the concentration of nutrients in the water in a reach. Grading criteria are based on biologically-relevant standards for total nitrogen and total phosphorus concentrations and identification of impairment by the Colorado WQCD (303d listing), as below.

Total nitrogen concentrations were calculated as the sum of nitrate as nitrogen, nitrite as nitrogen and total Kjeldahl nitrogen. Concentrations, for both total phosphorus and nitrogen constituents, measured below the reporting limit were estimated at half of the reporting limit. Total phosphorus and total nitrogen data analyzed over the historical period of record did not show normal symmetry for either reference site. Because these data exhibited a positively skewed distribution and nutrient levels were relatively low over the time period (near the reporting limit or below), the 75th percentile for nutrients was used to differentiate between an "A" and "B" grade (Figure 4.3). Using the 75th percentile also allowed for nearly equal concentration ranges for "A", "B" and "C" grades. The "B" and "C" grade were separated by equally dividing the nutrient concentration range between the 75th percentile and the numeric water quality standard for the respective stream segment and classification. The "D" and "F" grades incorporate the state of Colorado's interim nutrient water quality standard guidelines. Stream segments that exceed the numeric standard value more than two times in a five year period or stream segments that are listed on the 303(d) for more than one listing cycle are assigned an "F" grade.

[3] MWAT, or maximum weekly average temperature, was not evaluated or used for water temperature grading for the SOPR project. The temporal resolution of the water temperature data evaluated for the SOPR was insufficient to calculate MWAT.

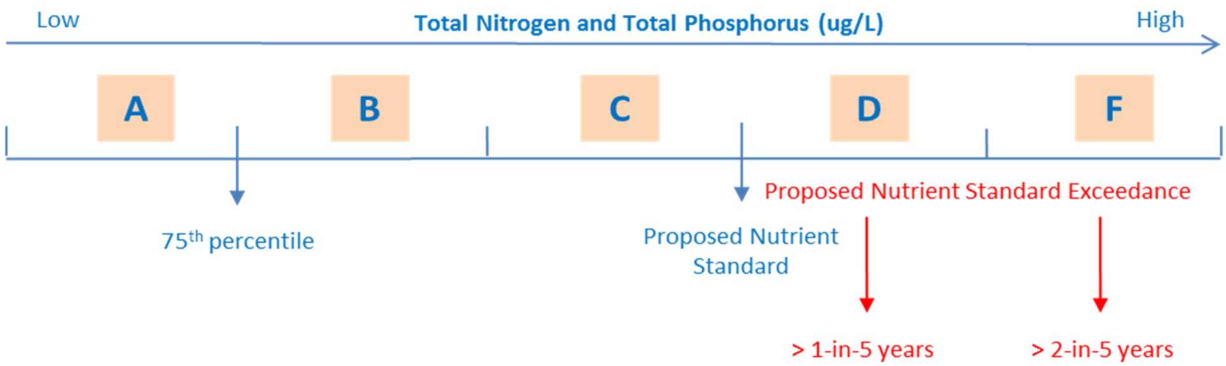

Figure 4.3: Illustration of the method used to develop grading guidelines (Table 4.2) for the nutrients metric.

pH

The pH water quality metric rates impairment to the concentration of hydrogen ions (acidity or alkalinity) in the water in a reach based on biologically relevant pH standards and identification of impairment by the Colorado WQCD (303d listing).

Unlike other parameters the pH grading guideline was not developed based on 5-year data record, but rather by using only the water quality standard. The “A”, “B” and “C” grades were normally distributed by dividing the wider pH range of the water quality standard (6.5 to 9.0) into six equally divided smaller ranges (Figure 4.4). As the pH diverges from the center value in either direction on the scale towards exceeding the water quality standard the grade gets progressively lower. The “D” and “F” grades were defined as stream segments listed on the 303(d) List of Impaired Waters for pH. Stream segments that are listed on the 303(d) List of Impaired Waters for more than one listing cycle are assigned an “F” grade.

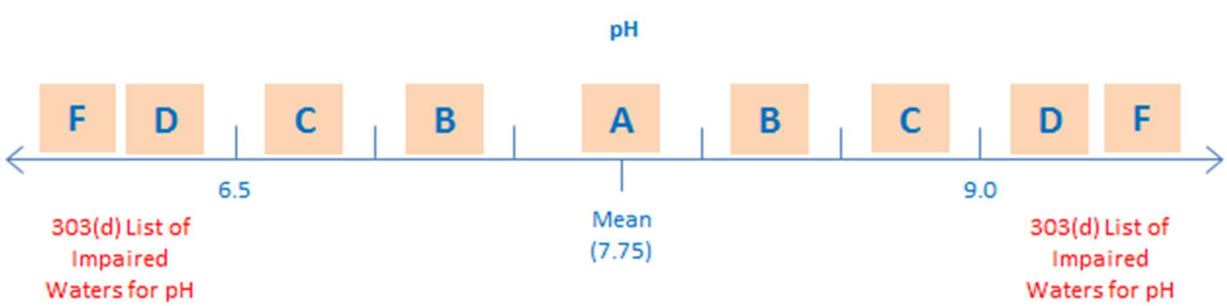

Figure 4.4: Illustration of the method used to develop grading guidelines for the pH metric.

Dissolved Oxygen

The dissolved oxygen water quality metric rates impairment to the concentration of dissolved oxygen in the water in a reach based on biologically relevant standards for dissolved oxygen concentration and identification of impairment by the Colorado WQCD (303d listing).

Dissolved oxygen data were not collected by the Source Water Monitoring Program (PSF) prior to 2014, so the grading guidelines for dissolved oxygen were established using data collected from the PLNC monitoring site (Figure 4.1). Dissolved oxygen data from this reference site did not show normal symmetry over the historical period of record. The 15th percentile for dissolved oxygen was used to differentiate between an "A" and "B" grade because this statistic is commonly used by the CDPHE to evaluate attainment of the dissolved oxygen standard (CDPHE WQCD, 2015) (Figure 4.5). The "B" and "C" grade were separated by equally dividing the dissolved oxygen range between the 15th percentile and the chronic dissolved oxygen water quality standard listed for the "Aquatic Life Cold" stream segment classification (6.0 mg/L). This value was used because the "Aquatic Life Cold" stream segment has more stringent values required to sustain aquatic life. The "D" and "F" grades were defined as stream segments listed on the 303(d) List of Impaired Waters for dissolved oxygen and for "Aquatic Life Cold" stream segments that do not meet the dissolved oxygen standard for the spawning season. Stream segments that are listed on the 303(d) List of Impaired Waters for more than one listing cycle are assigned an "F" grade.

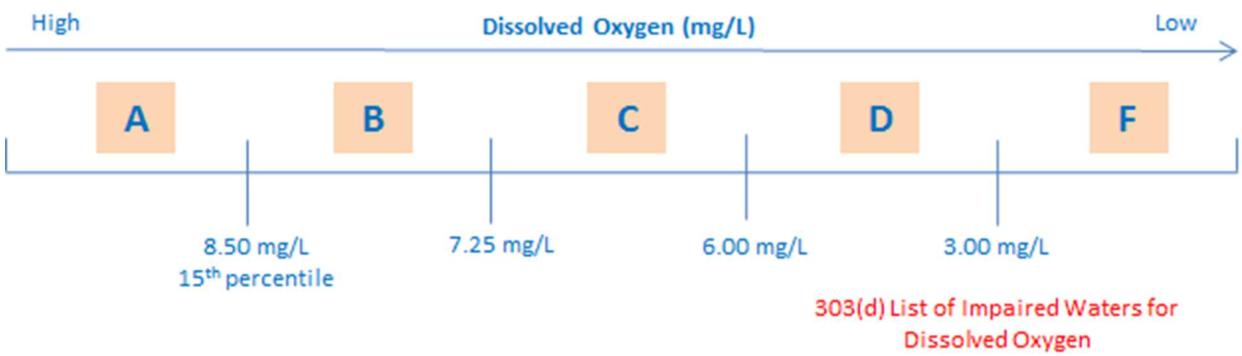

Figure 4.5: Illustration of the method used to develop grading guidelines for the dissolved oxygen metric.

Water Quality grading methodology

The first step in grading water quality was reviewing Colorado's Section 303(d) List of Impaired Waters (Regulation 93) for the four water quality metrics used in the SOPR's River Health Assessment Framework (RHAF). Any SOPR water quality section within a CDPHE stream segment listed for impairment received a "D" or "F" grade unless additional data demonstrated attainment of the water quality standard (i.e., impairment was no longer occurring).

The next step for grading water quality sections within 303(d) listed stream segments was conducting additional analysis to better understand the spatial extent of the impairment using the best available data. For example, Cache la Poudre Stream Segment 10a was listed on the 303(d) list for temperature resulting in a "D" grade for sections WQ1 and WQ2. The 303(d) listing was based on continuous temperature data collected from the Cache la Poudre at Canyon Mouth near Fort Collins (CLAFTCCO) gaging station located within section WQ2 (Figure 4.1). Continuous water temperature data were available from the City of Fort Collins Poudre River Intake located within section WQ1 (Figure 4.1). Interpretation and comparison of these data to the numeric water quality standard showed attainment of the water temperature standard in section WQ1, thereby suggesting a better grade.

Water quality sections that were not on the 303(d) list for RHAF specific water quality metrics and water quality sections proven to be in attainment with the water quality standard were graded by comparing the respective water quality metric grading statistic against the grading guidelines, described below. The criteria used for grading each specific water quality metric are defined in Table 4.3.

Table 4.3: Grading guidelines and data interpretation for the four water quality metrics: Temperature, Nutrients, pH and Dissolved Oxygen. Numeric values for "D" and "F" grades were adopted from the CDPHE WQCC Regulation No. 31, The Basic Standards and Methodologies for Surface Water. Numeric values for "A" grades correspond to empirically-derived values from reference sites, as described in the text. Values for "B" and "C" grades were derived for this study based on approximately equal partitioning of values from empirical data, as described in the text.

Metric	CDPHE Stream Classification for Aquatic Life	Grading Statistic	Grades and Corresponding Water Quality Criteria				
			A	B	C	D	F
TEMP (deg C)	Cold	Seasonal average (Apr-Oct)	<8.4	8.4-16.1	16.2-23.9	>23.9	
	Warm	Seasonal average (Mar-Nov)	<11.8	11.8-20.4	20.5-29.0	>29.0	
		Seasonal average (Dec-Feb)	0.2-1.0	1.1-6.8	6.9-14.5	>14.5	
TPHOS (ug/l)	Cold	Annual median	<23	23-66	67-110	>110	
	Warm	Annual median	<55	55-112	113-170	>170	
TN (ug/l)	Cold	Annual median	<448	448-849	850-1,250	>1,250	
	Warm	Annual median	<602	602-1,306	1,307-2,010	>2,010	
pH	Cold and Warm	15th percentile	7.75-7.33	7.33-6.92	6.92-6.50	<6.50	
		85th percentile	7.75-8.16	8.16-8.58	8.58-9.00	>9.00	
DO (mg/L)	Cold and Warm	15th percentile	>8.5	8.5-7.25	7.25-6.0	6.0-3.0	<3.0

Water Temperature grading

The water temperature metric was evaluated by comparing average water temperatures over the 2015 monitoring season to the RHAF water quality grading guideline shown in Table 4.3. The average water temperature for water quality reaches located within Cache la Poudre Stream Segments 10a and 10b (Aquatic Life Cold) was calculated from data collected over the months of April through October. The average water temperature for water quality reaches located within Cache la Poudre Stream Segments 11 and 12 (Aquatic Life Warm) was calculated from data collected over the months of March through November (warm season) and December through February (cold season). These seasons were defined based on the CDPHE Water Quality Control Commission's (WQCC) water quality standard for temperature. A cold season temperature grade was not assigned to water quality reaches located within Cache la Poudre Stream Segments 10a and 10b because the Upper CLP Water Quality Monitoring Program does not collect monitoring data from December through March. A single numeric temperature grade for water quality reaches located within Cache la Poudre Stream Segments 11 and 12 was calculated by averaging warm and cold season numeric grades.

Nutrient grading

Nutrient grades were assigned to each water quality reach by evaluating annual median total nitrogen (TN) and total phosphorus (TP) concentrations measured over the past five years (2011-2015). A five-year period was selected because the interim water quality standard allows a 1-in-5-year exceedance frequency. Since the interim nutrient standards have not yet been adopted the five-year period of record was evaluated to determine attainment with the interim nutrient standards. There are specific circumstances outlined in CDPHE WQCC Regulation 31.17 that will be considered once these standards are adopted, but for the purpose of the SOPR baseline assessment all water quality reaches were evaluated against the specified numeric values defined in Regulation 31.17 (Table 4.3). Water quality reaches with more than one exceedance over the five-year period were automatically assigned a "D" or "F" grade. If the water quality reach was in attainment with the standard then the annual median concentration from the 2015 monitoring season was evaluated against the RHAF water quality grading guideline (Table 4.3). Water quality reaches located within Cache la Poudre Stream Segments 10a and 10b were compared with the "cold" segment grading guidelines and water quality reaches located within Cache la Poudre Stream Segments 11 and 12 were compared with the "warm" segment grading guidelines. Total nitrogen was calculated as the sum of nitrate as nitrogen, nitrite as nitrogen and total Kjeldahl nitrogen. Concentrations that were measured below the reporting limit were estimated at half the detection limit.

pH grading

The pH metric was evaluated by comparing the 15^{th} and 85^{th} percentiles measured over the 2015 monitoring season against the RHAF water quality grading guideline (Table 4.3). The 15^{th} percentile was compared to the minima pH water quality standard value (6.5) and the 85^{th} percentile was compared to the maxima pH water quality standard value (9.0). Data interpretation and statistics for pH were adopted from the CDPHE Water Quality Control Division (CDPHE WQCD, 2015). For the purpose of the State of Poudre River baseline assessment, the two numeric grades assigned for the 15^{th} and 85^{th} percentiles were averaged to obtain an overall pH metric grade for the water quality reach.

Dissolved oxygen grading

The dissolved oxygen metric was evaluated by comparing the 15th percentile measured over the 2015 monitoring season against the RHAF water quality grading guideline (Table 4.3). This statistic is used by the WQCD when evaluating attainment of the chronic water quality standard for dissolved oxygen. If the 15th percentile value for the annual dataset was less than the trout spawning season dissolved oxygen criteria (7.0 mg/L; CDPHE WQCD, 2015) then the 15th percentile was re-evaluated for spawning season data. The spawning season was determined based on the best available information. Data interpretation and statistics for dissolved oxygen were adopted from the CDPHE WQCD (CDPHE WQCD, 2015).

Chapter 5: Floodplain Connectivity

Table 5.1: Floodplain Connectivity metrics at a glance.

Floodplain Connectivity Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Floodplain extent	Quantitative: based on the extent of the modeled five-year return interval floodplain, or estimated width of five-year floodplain using aerial imagery where model results were unavailable	HEC-RAS model provided by the City of Fort Collins, 2014 LiDAR survey and channel cross section data, and aerial imagery	Defined by HEC-RAS model	100%

Introduction

The river's access or connection to its floodplain affects river health as much as it does the riparian ecosystem. When flows are higher than the channel can contain, the floodplain provides relief. The floodplain allows excess water to spread across the land. Vegetation, woody debris and complexity in the floodplain's topography help absorb the energy of rushing water. This allows the channel to maintain a stable shape and habitat features, while also providing a buffer to human infrastructure. At the same time, overbank flood flows nourish the riparian zone, replenishing nutrients, recharging the aquifer, and rejuvenating the forest.

A healthy floodplain harnesses the power of flood flows. It allows water to wander through a defined habitat zone where its abundant energy can not only dissipate but also bring forth new life.
Where floodplains are narrow, communities can expect that the river and associated infrastructure will require routine maintenance and substantial reconstructing following large flows.

Floodplain Connectivity methods, analysis, and grading guidelines

The Floodplain Connectivity indicator is described with a single metric: **floodplain extent**. Floodplain extent rates impairment to the width of the active floodplain in a reach based on the percentage of the historical 5-year floodplain that still exists. The 5-year floodplain is defined as the width of the floodplain that is inundated by flows occurring 1 in 5 years. This "5-year floodplain" helps the system maintain year-to-year dynamic equilibrium, and this is the zone where most of the river's forests and wetlands are created and sustained.
The extent of the 5-year floodplain was mapped using a Hydraulic Engineering Center – River Analysis System (HEC-RAS) model provided by the City of Fort Collins. Digital terrain data for the model came

from a 2014 LiDAR survey and additional channel cross-section data from land surveys (King Surveyors, Spring 2013 and Spring 2014). The model covered the river reach from just upstream of Shields Street to just downstream of I-25 (the Rural, Urban, and Plains zones of the SOPR study area). Channel widths were manually measured using aerial imagery at each modeled cross-section and then subtracted from the modeled water surface width to get the resulting floodplain width. These modeled widths were then used to assign grades for each reach according to the guidelines in Table 5.2.

For reaches upstream of where HEC-RAS model results were available (the Canyon zone of the SOPR study area), current aerial imagery was used to estimate the width of the 5-year floodplain. The degree of floodplain encroachment was then estimated by evaluating evidence of land-use change and comparison to similar reaches for which modeled results are available. The degree of floodplain encroachment, defined as the percentage by which the width of the 5-year floodplain was diminished, was then used to assign grades for reaches in the Canyon zone according to the guidelines in Table 5.3.

Table 5.2: Floodplain Extent grading guidelines for Rural, Urban, and Plains zones of the SOPR study area.[1]

Grade	Description
A	No significant stressors. The width of the 5-year floodplain is greater than 100 m
B	The width of the 5-year floodplain width is between 75 to 100 m
C	The width of the 5-year floodplain width is between 50 to 75 m
D	The width of the 5- year floodplain width is between 25 to 50 m
F	The width of the 5-year floodplain width less than less than 25m

[1]The 5-year floodplain width includes both sides of the channel but excludes the channel itself. The width categories are based on expected average widths for river reaches in the Rural, Urban, and Plains zones and were derived from HEC-RAS modeling using historical and current river flows corresponding to the 5-year recurrence interval. Each river reach is characterized by a large degree of variation including long reaches with narrow to non-existent floodplains and intermittent wider reaches.

Table 5.3: Floodplain Extent grading guidelines for the Canyon zone of the SOPR study area.

Grade	Description
A	Floodplain extent is diminished less than 10% (> 90% intact)
B	Floodplain extent is diminished 10 - 30% (70 - 90% intact)
C	Floodplain extent is diminished 30 - 50% (50 - 70% intact)
D	Floodplain extent is diminished 50 - 70% (30 - 50% intact)
F	Floodplain extent is diminished more than 70% (< 30% intact)

Chapter 6: Riparian Condition

Table 6.1. Riparian Condition Metrics at a glance.

Riparian Condition Metrics	Analysis type	Data Source and Period of Record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Habitat connectivity	Qualitative	Historical and current (2016) aerial imagery	Reach scale (see Table 1.3 and Figures 1.3a-d)	10%
Contributing area	Qualitative		Reach scale (see Table 1.3 and Figures 1.3a-d)	10%
Vegetation structure	Qualitative	U.S. Fish and Wildlife Service, National Wetlands Inventory (NWI) data, City of Fort Collins Natural Areas habitat mapping (2009), aerial imagery and GIS spatial data	Cover type patch (polygon) 190 of 500 polygons assessed in the field, remainder assessed and calibrated remotely	80%

Introduction

The riparian zone is the area adjacent to and influenced by the river, forming a biological transition zone or "ecotone" between aquatic and terrestrial ecosystems. The riparian zone can be very narrow in canyon reaches or extend laterally for miles when unconfined. The native riparian zone of plains rivers is characterized by a gallery forest of cottonwood, intermixed with meadows and shrublands. The ribbon of riparian habitat found along rivers forms a virtual highway for wildlife and birds. Roughly 80% of Colorado's species are dependent on riparian areas for food, water and refuge. Riparian habitats flood at varying intervals depending on topography, flow regime and channel shape. While high flows cause disturbance to the habitat by uprooting trees, removing vegetation and burying plants with sediment, this disturbance also redistributes nutrients and sediment and provides conditions needed for the establishment of new plants and is thus required for the long-term persistence of the riparian ecosystem.

The condition of the riparian zone is described using three metrics: **habitat connectivity**, **contributing area**, and **vegetation structure**.

- **Habitat connectivity**: The opportunity for animals and seeds to move unimpeded through the riparian corridor is fundamentally important to the maintenance of biotic functioning of the riparian zone. If riparian habitat is functionally isolated, its value to wildlife is greatly diminished and floral and faunal biodiversity will decline. The habitat connectivity metric describes the apparent ability of wildlife to move between habitat patches and up and down the riparian corridor.

- **Contributing area**: The contributing area metric describes the landscape surrounding the riparian zone and its ability to support or degrade river health.
- **Vegetation structure**: The vegetation structure metric describes riparian vegetation and its ability to support characteristic riparian functions. Healthy riparian zones are characterized by a high level of vertical and horizontal complexity, including a mosaic of habitat types and multiple vegetation layers. The character and complexity of riparian vegetation are primarily driven by above ground saturation and the associated disturbance caused by seasonal flooding and alluvial groundwater. The vegetation character and complexity in turn affects a spectrum of physical functions in the river ecosystem while providing critical wildlife habitat.

Riparian Condition methods, analysis, and grading guidelines

The lateral extent of the “SOPR riparian zone” was defined as the edge of the natural floodplain or 100 meters from each river bank (200 meters combined terrestrial width), whichever was narrower. A riparian zone width of 100 meters on each side of the river was selected for the SOPR based on professional experience and judgment derived from technical team members’ previous work in the Poudre River and other similar Colorado watersheds. This spatial extent was applied for evaluation and grading of the habitat connectivity and riparian condition metrics, and for delineation, assessment (field or desktop), and grading of vegetation polygons for the vegetation structure metric.

Habitat Connectivity

Habitat connectivity rates impairment to the connectivity of riparian habitat in a reach based on the width of continuous functional riparian habitat and on the degree to which riparian area is isolated from laterally- and longitudinally-adjacent habitat by barriers that limit migration and dispersal of terrestrial organisms. The habitat connectivity metric was evaluated by visually estimating the amount of continuous riparian habitat remaining within the SOPR riparian corridor using aerial photography and assigning a grade for each reach according to the guidelines in Table 6.2. Lateral or longitudinal breaks in habitat caused by development and infrastructure, such as roads, were considered migration and dispersal barriers. Where barriers were present, grades were lowered to reflect the degree of habitat isolation or interrupted connectivity. The habitat connectivity metric composes 10% of the overall score for the Riparian Condition indicator.

Table 6.2. Habitat Connectivity grading guidelines.

Grade	Habitat patch size	Types and degree of barriers
A	A continuous corridor of functional riparian habitat > 100 m wide is present within the reach.	No appreciable barriers exist within the assessment reach or between the assessment reach and adjacent wetland and riparian habitats
B	A continuous corridor of functional riparian habitat 50 - 100 m wide is present within the reach.	Barriers impeding migration or dispersal within the assessment reach or between the assessment reach and adjacent wetland/riparian habitat are permeable and easily passed by most organisms. Examples could include gravel roads, minor berms, ditches or barbed-wire fences. More significant barriers (see "D" grading guidelines below) could affect migration of plant and animal species in the assessment reach to up to 10% of the surrounding wetland/riparian habitat.
C	A continuous corridor of functional riparian habitat 15 - 49 m wide is present within the reach.	Barriers to migration and dispersal retard the ability of many species to move within the assessment reach or pass between the assessment reach and adjacent wetland/riparian habitat. Passage of species through such barriers is still possible, but it may be slowed down, constrained to certain times of day, increasingly dangerous or require additional travel. Busy two-lane roads, rail lines, small-to-medium artificial water bodies or widely scattered residential development would commonly result in a score in this range. More significant barriers (see "D" grading guidelines below) could affect movement to up to 10% of the surrounding wetland/riparian habitat.
D	A continuous corridor of functional riparian habitat 15 - 49 m wide is present within the reach.	Barriers to migration and dispersal preclude the passage of many types of species within the assessment reach and between the assessment reach and up to 66% of surrounding wetland and riparian habitat. Travel by those animals which can potentially negotiate the barrier is strongly restricted and may include a high chance of mortality. Up to 33% of surrounding wetland/riparian habitat could be functionally isolated from the assessment reach.
F	A continuous corridor of functional riparian habitat within the reach is less than 5 m wide or absent altogether.	The assessment reach is essentially isolated from the surrounding wetland/riparian habitat by impermeable migration and dispersal barriers. An interstate highway or concrete-lined water conveyance canal are examples of barriers that would generally create functional isolation.

Contributing Area

Contributing area rates impairment to the buffering capacity and supportive role of surrounding land area in a reach based on the types and extent of land use within 200 meters of the delineated riparian zone. The contributing area metric was evaluated in the 200 meter-wide area flanking the SOPR riparian zone. The 200 meter width is the area in which adjacent land uses have the highest capacity to influence riparian condition and river health, and was modified from the contributing area width used in other riparian and wetland assessment methodologies (FACWet [Johnson et al. 2013]; CRAM [California Wetlands Monitoring Workgroup 2012]). Using aerial imagery, the ability of the reach's contributing area to support or degrade river health was visually estimated based on land use and a grade was assigned according to the guidelines in Table 6.3. The contributing area metric composes 10% of the overall score for the Riparian Condition indicator.

Table 6.3. Contributing Area grading guidelines.

Grade	Description
A	No appreciable land use change has occurred on the surrounding landscape.
B	Some land use change has occurred in the surrounding landscape, but changes have minimal effect on the landscape's capacity to support characteristic riparian and aquatic functioning. This may be because the land use changes are not intensive, *e.g.*, haying, light grazing, or low intensity silviculture, or because more substantial changes have occurred in less than roughly 10% of the area.
C	The surrounding landscape has been subject to a marked shift in land use; however, the land retains much of its capacity to support natural riparian function and is not an overt source of pollutants or sediment. Moderate-intensity land uses such as dry-land farming, urban "green" corridors, or moderate cattle grazing would commonly fall within this scoring range.
D	Land use changes in the surrounding landscape have been substantial, including a moderate-to-high coverage (up to 50%) of impermeable surfaces, bare soil, or other artificial surfaces. Considerable in-flow of urban runoff or fertilizer-rich waters are common. The supportive capacity of the land has been greatly diminished but not totally eliminated. Intensively logged areas, low-density urban developments, some urban parklands, and many cropping situations would commonly result in a score within this range.
F	The surrounding landscape is more or less completely developed or is otherwise a cause of severe ecological stress on riparian and aquatic habitats. Commercial developments or highly urban landscapes generally result in a score of less than 0.6.

Vegetation Structure

Vegetation structure rates impairment to the riparian vegetation structure and complexity. The vegetation structure metric was evaluated using a multi-step approach that entailed classifying vegetation polygons, initial desktop grading, field assessment, and calibrated desktop grading. This process resulted in grades, and corresponding numerical scores, for each vegetation polygon. The scores for all polygons within a reach were then averaged using a weighted approach based on the total area of each polygon and the reach-average score was used to assign a grade for the reach according to the guidelines in Table 6.4. The vegetation structure metric composes 80% of the overall score for the Riparian Condition indicator.

Table 6.4. Vegetation Structure grading guidelines.

Grade	Description
A	The structure, complexity and species composition of the riparian vegetation resemble native conditions. The weighted average score is 90–100, indicating that vegetation is self-sustaining with an absence or trivial presence of exotic or noxious species, a strong predominance of native species without spread of aggressive native species (e.g., cattails), and characteristic habitat patchiness and interspersion.
B	The structure, complexity and species composition of the riparian vegetation still resemble native conditions but with mild detectable changes. The weighted metric score is 80–89, indicating that vegetation is largely self-sustaining, requiring little maintenance to preserve habitat vegetation quality. Noxious species may be present but at very low densities that do not threaten functioning. Desirable native species predominate but minor invasion by aggressive native species

	(e.g., cattails) may be present. Vegetation maintains a high degree of patchiness and interspersion, but some minor homogenization through land use has occurred.
C	Substantial changes in the character of the vegetation are evident, including alteration of layer coverage, structural complexity and species composition; but the vegetation retains its essential character. The weighted metric score ranges from 70–79, indicating that regular minor management, such as weed spraying, is required to maintain vegetation condition. Minor populations of noxious species may occur, and a larger proportion of the species are exotic or aggressive native species (e.g., cattails). Homogenization of the riparian vegetation is common in terms of vertical structure or habitat interspersion.
D	The vegetation structure, complexity and species composition have been profoundly impacted. The weighted metric score is 60–69, indicating that significant patches of noxious weeds may be present, along with a preponderance of exotic species. Aggressive native species (e.g., cattails) may wholly dominate the vegetation, substantially reducing vertical and horizontal vegetation complexity.
F	The vegetation layer has been completely removed or altered to the extent that it is no longer comparable to the natural structure, diversity and composition. The weighted metric score is 50–59.

The multi-step approach used to evaluate and score the Vegetation Structure metric is outlined below.

Vegetation Classification:

Vegetation classification was a GIS exercise which began by merging and intersecting two existing data sets: 1) U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) Data; and 2) City of Fort Collins (2009) Natural Areas (NAD) habitat mapping. The NWI data layer covered the entire SOPR study area, but it only mapped wetland and some riparian habitats. The NAD mapping was comprehensive and included habitats beyond wetlands but data were only available for City properties. Where the two datasets overlapped, the NAD data was used since it covered non-wetland areas and was more accurate and informative than NWI due to its better spatial resolution and more rigorous mapping methodology.

After joining the datasets and clipping them to the SOPR riparian zone, the remaining unmapped cover types were then mapped using 2015 aerial imagery. All polygons were classified as one of 10 possible cover types: native montane mesic, canopy forest, sub-canopy forest, scrub-shrub, herbaceous, emergent wetland, urban, developed, bare ground, or lentic open water. Patches were also classified by land use type (e.g., Light Agriculture, Transportation Corridor or Naturalized Open Space), development level (high, medium, low) and floodplain position (riverine, terrestrial, depressional [usually gravel ponds]).

Initial Desktop Grading:

All polygons with urban, developed, open water, or bare ground cover types were assigned metric grades based solely on desktop analysis (i.e., U.S. EPA Level 1 assessment) and most of those grades were in the D or F range. Features such as remnant oxbows created by riverine processes were not categorized with other "open water" polygons and thus were not automatically graded as a "D" or "F." Polygons with natural-looking riparian vegetation were not initially graded but selected as candidates for field assessment.

Field Assessment:

As many riparian sites were evaluated in the field as possible, using rapid assessment (i.e., U.S. EPA Level 2). Riparian habitat polygons on City of Fort Collins and publicly accessible properties were considered priority for sampling. Other riparian habitat polygons were included as access, vantage, time and resources would allow. Field assessment occurred in about 38% of natural or semi-natural riparian polygons. Grading guidelines for the sub-metrics used in the field assessment are described in Table 6.5.

Table 6.5. Vegetation Structure sub-metric scoring guidelines.

Canopy Composition	
A (93)	Natives dominate
B (83)	Natives dominate/some exotics.
C (77)	Natives and exotics Co-dominate
C- (71)	Exotics dominate
Sub-canopy Composition	
A (93)	Natives dominate.
B (83)	Natives dominate/some exotics
C (77)	Natives and exotics Co-dominate
C- (71)	Exotics dominate
Shrub Presence	
A (90-100) Shrubs are present and common, commonly scattered and/or patchy and often dense near banks. Shrub distribution characteristic of native habitats	
B (80-89) As above, except shrub layer is showing signs of stress or mild clearing.	
C (70-79) Shrubs are present and not uncommon, but often widely dispersed. Shrubs showing notable stress, die off or widespread-clearing apparent or probable	
D (60-69) Shrub were likely naturally are present and/or shrub habitat exists, but shrub layer is reduced to scattered individuals	
F (50-59) Virtually no shrubs present as a result of clearing, land uses or water management	
Structural Diversity	
A (90-100) Three or more vegetation layers distributed as characteristic in native habitat	
B (80-89) Minor clearing or probable reduction of one or more vegetation layers	
C (70-79) Two to three layers are present but the amount of single layer habitat has been substantially increased through land use and or water management	
D (60-69) Only 1 vegetation layer present apparently as the result of land use or water management and there is a marked lack of vertical structure	
F (50-59) Vegetation sparse or lacking	
Problem Herbaceous Species[4]	
A (90-100) Present, but widely scattered individuals; vegetation is essentially in natural condition although some exotic species may be present	
B (80-89) Present, and more abundant than the above. Small patches of domination by problem species, may be present, but they represent a small fraction of overall herbaceous species coverage	
C (70-79) Fairly abundant and may dominate large proportions of the habitat	
D (60-69) Generally dominant and greatly suppressing species diversity and the coverage of native species	
F (50-59) Dominant and vegetation highly altered. Including row crops and landscaped areas	
Problem Woody Species[5]	
A (90-100) Present, but widely scattered individuals; vegetation is essentially in natural condition	

[4] Problem herbaceous species include noxious species, and aggressive exotics. Examples include cattails, reed canary grass, and smooth brome.

[5] Problem woody species include noxious species, and aggressive exotics. Examples include crack willow and Russian olive.

B (80-89) Present, and more abundant than the above. Small patches of domination by problem species may be present, but they represent a small fraction of the woody species coverage
C (70-79) Fairly abundant and may dominate large proportions of the habitat
D (60-69) Generally dominant and greatly suppressing species diversity and the coverage of native species
F (50-59) Dominant and vegetation highly altered. Including row crops and landscaped areas
Problem Woody Species[6]
A (90-100) Present, but widely scattered individuals; vegetation is essentially in natural condition
B (80-89) Present, and more abundant than the above. Small patches of domination by problem species may be present, but they represent a small fraction of the woody species coverage
C (70-79) Fairly abundant and may dominate large proportions of the habitat
D (60-69) Generally dominant and greatly suppressing species diversity and the coverage of native species
F (50-59) Dominant and vegetation highly altered. Including row crops and landscaped areas
Patchiness and Habitat Interspersion[7]
A (90-100) Complex mosaic of habitat patches or plant communities resembling native conditions; no single dominant zone.
B (80-89) Coarse mosaic of nested or interspersed habitat patches or plant communities; usually no single dominant habitat or community but minor homogenization of habitat has occurred as the result of land use or water management
C (70-79) Low level of patchiness and interspersion as the result of land use or water management; habitat patches exist but one type may dominate.
D (60-69) Habitat is essentially one homogeneous type of vegetation
F (50-59) Vegetation absent or row crops
Native Tree Species Regeneration
A (90-100) A complex age/size class structure of native riparian tree species present
B (80-89) Two or three age/size classes dominate, usually comprised by mature to decadent individuals and saplings or small trees. Re-establishment occurs on a reliable but episodic level.
C (70-79) Mainly mature or evenly aged native trees but at least some members of two age/size classes are present indicating that natural recruitment can still occur even if in frequently
D (60-69) Mainly very mature, decadent or dying individuals; or mainly exotic woody species
F (50-59) Canopy artificially removed or complete domination by exotic species with no native tree species in the understory.
N/A Native tree species naturally uncommon or absent

[6] Problem woody species include noxious species, and aggressive exotics. Examples include crack willow and Russian olive.
[7] Interspersion is a measure of the number of distinct patches (as in plant zones) and the amount of edge between them (California Wetlands Monitoring Workgroup 2012).

Calibrated Desktop Grading:

The remaining unassessed polygons (those not evaluated using initial desktop grading or field assessment) were evaluated using desktop analysis and grades were assigned by visually assessing similarity to field-validated polygons using the following procedure.

1. First, the median Vegetation Structure metric score for each cover type and land use was calculated from field data.
2. Median metric scores for the various natural cover types were used to assign initial grades to the remaining remotely unassessed polygons.
3. The initial grade was then adjusted based on the land use. For instance, a cottonwood forest polygon might receive an initial grade of B, based on cover type. If the Land Use was determined to be protected naturalized open space with rural surroundings, the grade might be elevated to a B+. One the other hand, the grade for this same polygon might be lowered to a B- if the Land Use is light agriculture adjacent to an area of intensive agriculture. In this case the grade reduction reflects the probable stress placed on riparian habitats by grazing and runoff from fields.
4. Polygon scores corresponding to the adjusted grades assigned in Step 3, above, were revised a final time taking into account floodplain position. Scores for terrestrial and depressional polygons isolated from the majority of river processes were reduced by 7% (approximately half a letter grade) to account for their reduced ability to support river health compared to similar riverine habitats.

Reach-scale Scoring:

Once all the polygon mapping and grading was complete, reach scores were calculated for the Vegetation Structure metric. Reach scores were calculated by weighting each polygon score by the polygon's size (i.e., area; in acres or other measure of area) to create a weighted average using the following formula:

$$\frac{(\text{Size}_{\text{PolyA}} \times \text{Veg Structure Score}_{\text{PolyA}}) + (\text{Size}_{\text{PolyB}} \times \text{Veg Structure Score}_{\text{PolyB}}) + \ldots(\text{Size}_{\text{Poly n}} \times \text{Veg Structure Score}_{\text{Poly n}})}{\text{Total Reach Area within the SOPR Riparian Zone}} = \text{Reach Score for Vegetation Structure}$$

The weighted average reach score derived from this calculation was then used to assign a grade for the reach according to the grading guidelines in Table 6.4.

Chapter 7: River Form

Table 7.1: River Form metrics at a glance.

River Form Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Planform	Qualitative: based on field observations and aerial imagery when field access was restricted	Historical aerial photos, field surveys in 2016, and current aerial imagery	Sub-reach scale	Average of metric scores
Channel dimension				
Channel profile				

Introduction

Understanding how the river form responds to human-caused and natural stressors is important for effective management, conservation, and rehabilitation of rivers and streams. For example, channel change may have implications for the protection of property and structures, water supply, navigation, and aquatic and riparian habitat. Geomorphic responses to disturbances include changes to the channel bed elevation (erosion or deposition), channel width, channel form (*e.g.*, braided, plane bed, riffle-pool) and/or the size of channel bed materials. While most channels tend towards an equilibrium state, it could be argued that no channel is truly in equilibrium and that channels are always adjusting to some short- or long-term influence. Fortunately, this tendency toward equilibrium is intrinsic to river systems when the necessary building blocks of space, water, and sediment are present.

The River Form indicator was evaluated based on three metrics: channel **planform**, **channel dimensions**, and **channel profile**.

- **Channel planform** refers to the 'bird's eye' view of the river and describes the degree of branching and sinuosity.
- The **channel dimension** focuses on the cross-sectional condition that can be altered by the processes of degradation, enlargement, and widening.
- **Channel profile** describes a river's bed grade, or longitudinal slope, including any abrupt drops caused by dams or other grade control structures.

River Form methods, analysis, and grading guidelines

All three of the River Form metrics were graded at the sub-reach scale during field surveys by fluvial geomorphologists with experience on the Poudre and other Front Range rivers. Nearly all (22.6 miles) of the 23.9-mile study area was assessed in the field. The remaining 1.3 miles (on private land with no access) were scored using remotely-derived data such as aerial imagery. Scores reflect the degree of departure from a natural reference river form for the respective reach using evidence of anthropogenic impacts, or stressors in combination with reflection on the degree of change compared to the natural geomorphic context for this particular system. The native or reference system was qualitatively determined through use of historic aerials and local historical descriptions, and basic ecological concepts underpinning this type of system. Reach scores were then calculated as the average of the component sub-reach's scores, weighted by length.

Channel Planform

Channel planform rates impairment to the lateral configuration of a river reach, including patterns of branching, sinuosity, and curvature based on the extent of artificial impacts such floodplain encroachment, channelization, straightening, and bank armoring. The channel planform metric was assessed using aerial imagery and later validated through field observations to identify changes to river branching and braiding patterns, sinuosity, belt width, meander length and width, amplitude, and bend radius of curvature. Direct evidence of planform impairment was documented during field visits by noting areas of floodplain encroachment, channelization, realignment, and bank or channel armoring. The information from aerial imagery and field observations was used to assign a channel planform grade for each sub-reach according to the guidelines in Table 7.2.

Table 7.2: Channel planform grading guidelines.

Grade	Description
A	Planform and variation is appropriate for a well-functioning river of this flow/sediment regime and landscape position. There are no significant constraints (such as physical constraints) to the river planform.
B	Planform and variation is largely appropriate for a river of this flow/sediment regime and landscape position. Stressors are evident, but with minimal effect on the river planform.
C	There are localized constraints to the river planform, possibly from floodplain encroachment or hardened banks.
D	There are widespread constraints to the river planform, from floodplain encroachment, hardened banks, or planform straightening.
F	Severe changes to the planform are evident. Examples include reaches where the channel was naturally braided or meandering but has been artificially straightened, channelized, and/or armored.

Channel Dimension

Channel dimension rates impairment to the cross-sectional shape and size of a river reach, including the channel, floodplain, and flood-prone area[8], based on the degree of channel entrenchment and alterations to the channel cross-sectional area and width-depth ratio. It is evaluated using three sub-metrics:

- *Entrenchment* – Degree to which the river channel is artificially confined or isolated from the floodplain. It is scored by evaluating criteria for the width of flood-prone area and the ratio of bank height to the height of water surface at bankfull discharge, or "bank height ratio". Entrenchment was not used to evaluate dimension in the Canyon zone since the river in that zone is naturally entrenched.

[8] In fluvial geomorphology, the flood-prone area is the area bordering a river that will be covered by water at a flood stage of twice the maximum bankfull depth, where bankfull depth is defined as the water's depth when the river is at bankfull stage. Bankfull stage is the average water surface elevation at which the river begins to overtop its banks, typically occurring once every 1-2 years.

- *Cross-sectional area* – Assessing that the shape and area of the active bankfull channel is appropriate for its geomorphic and hydrologic setting and not reduced or enlarged.
- *Width-depth ratio* - Degree to which the channel top width is has become wider or narrower relative to mean depth at bankfull discharge.

In the Rural, Urban, and Plains zones of the Poudre River in the study area, each of the three sub-metrics for channel dimension were assigned grades according to the guidelines in Table 7.3. In the Canyon zone, the cross-sectional area and width-depth ratio sub-metrics were assigned grades according to the guidelines in Table 7.4.

Table 7.3: Channel dimension sub-metric grading guidelines for the Rural, Urban, and Plains zones.

Grade	Entrenchment	Channel Cross Sectional Area	Width to Depth ratio
A	Not entrenched, flood-prone area is greater than 7 times bankfull width[9] and bank height ratio is less than 1.0	Appropriate with no significant stressors	Appropriate with no significant stressors
B	Minimal entrenchment, flood-prone area is greater than 7 times bankfull width	Stressors present, but effects are minimal	Stressors present, but effects are minimal
C	Slight entrenchment, flood-prone area is less than 7 times bankfull width	Slightly enlarged or reduced	Slight overwidth or overdepth
D	Moderate entrenchment, flood-prone area is 2-7 times bankfull width	Enlarged or reduced	Overwidth or overdepth
F	Fully Entrenched, flood-prone area is less than 2 times bankfull width	Extremely enlarged or reduced	Extreme overwidth or overdepth

Table 7.4: Channel dimension sub-metric grading guidelines for the Canyon zone.

Grade	Channel Cross Sectional Area	Width to Depth ratio
A	Appropriate with no significant stressors	Appropriate with no significant stressors
B	Stressors present, but effects are minimal	Stressors present, but effects are minimal
C	Slightly enlarged or reduced	Slight overwidth or overdepth
D	Enlarged or reduced	Overwidth or overdepth
F	Extremely enlarged or reduced	Extreme overwidth or overdepth

[9] Bankfull width is the width of the inundated channel when the river is at bankfull stage. Bankfull stage, or discharge, is the dominant channel-forming flow typically occurring once every 1-2 years.

Channel Profile

The channel profile metric rates impairment to the longitudinal shape (gradient or slope) of a river reach based on the degree to which river bed profile and slope is altered. It is evaluated by documenting changes to overall slope, usually due to altered planform, and to localized changes caused by dams, grade control structures, or geomorphic responses such as aggradation zones or head-cuts. The channel profile metric was graded for each sub-reach according to the guidelines in Table 7.5.

Table 7.5: Channel profile grading guidelines.

Grade	Description
A	Water surface slope and bed profile variation are appropriate for a well-functioning river of this flow/sediment regime and landscape position. There are no artificial changes in slope (e.g., dams, grade control structures, channelization) or other significant modifications to the channel profile.
B	Overall water surface slope and bed profile variation are appropriate for a well-functioning river of this flow/sediment regime and landscape position. Modifications to the channel slope or profile are evident but with minimal effect.
C	There are changes to the localized bed profile and/or the water surface slope is impacted to a small degree. Examples include reaches with small grade control structures (decreased slope) or reaches that have been slightly straightened (increased slope).
D	There are major local gradient impacts at low flow and/or significant changes to the slope of the water surface. Examples include reaches with large grade control structures and moderate planform changes.
F	Severe changes to slope are evident at all flows.

Chapter 8: Channel Resilience

Table 8.1: Channel Resilience metrics at a glance.

Channel Resilience Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Dynamic equilibrium	Qualitative: based on review of historical aerial photographs and field observations	Historical aerial photographs, field surveys in 2016, and current aerial imagery	Sub-reach scale	Distance weighted average of metric scores
Recovery potential				

Introduction

Like all rivers, the Poudre River faces major disturbance events including floods, droughts, and fires. To recover from these disturbances, rivers must rely on their built-in resilience. This resilience is a direct function of the availability of appropriate flow and sediment regimes, ample lateral floodplain space, connectivity to adjacent ecosystems, and the pre-disturbance condition of the system. The more rivers can be managed for resilience, the healthier they will be under common conditions, and recovery from major disturbances will be faster.

The Channel Resilience indicator was evaluated using two metrics: **dynamic equilibrium** and **recovery potential**.

- **Dynamic equilibrium** is the long-term (decadal) tendency for a river to maintain its form or character under a characteristic flow and sediment regime. The definition of dynamic equilibrium varies for different river types. In channels where sediment does not tend to move, stability is a function of both the channel bed and the banks being stronger than the forces acting upon them. In other channel types, in which there is a balance of incoming and outgoing sediment, stability is maintained through a complex state of dynamic equilibrium between sediment supply and flow energy.
- **Recovery potential** describes the ability of a river system to rapidly recover from changes arising from singular extreme events or disturbance (*e.g.*, floods, fires, landslides) in an acceptable length of time without significant costly human intervention.

Channel Resilience methods, analysis, and grading guidelines

Both metrics were first remotely evaluated using historical aerial photos to document stability trends, changes to river form, lateral migration, avulsions, and erosion. Field observations were then made during site visits to observe stressors and direct signs of instability.

Dynamic Equilibrium

Dynamic equilibrium rates impairment to the long-term tendency of a reach to maintain its form under a characteristic flow and sediment regime. Using the guidelines in Table 8.2, this metric is graded based on the presence and degree of impacts that indicate instability, including excess deposition, scour, bank erosion, accelerated migration, pool-filling, unnatural bars, over-widening, enlargement of the channel's cross-sectional area, or incision.

For the dynamic equilibrium metric, stressors such as altered peak flow and sediment regimes, channel evolution stage, changes to stream form, and direct impacts such as channel and bank hardening were all considered. However, if the channel instability was mitigated, the reach scored higher. The use of bank armoring to stop erosion can help channel stability in the short-term but long-term resilience would not score well, which is why the recovery potential metric scores would be lower with the presence of bank armoring. In the field, signs of channel instability included excess deposition, scour, or bank erosion, pool filling, unnatural bar development, and severely over-widened or entrenched channel form.

Table 8.2: Dynamic equilibrium grading guidelines.

Grade	Description
A	Stressors are minimal. Patterns, levels, and rates of dynamic processes (erosion, deposition, and channel migration) are appropriate for the river in light of its landscape setting.
B	Moderate stressors are present but partially mitigated. Patterns of erosion, deposition, and channel migration are within the natural range for this river type.
C	Moderate stressors are present and largely unmitigated. Notable impacts to stability are evident but not widespread. Examples of impacts include excess sediment deposition, scour, bank erosion, accelerated channel migration, pool filling, unnatural bars, over-widening, enlargement of the channel's cross-sectional area, or mild incision.
D	Significant stressors are present and unmitigated. Excess sediment deposition, scour, or widespread bank erosion are common., along with common avulsions on meandering streams, complete pool filling, reach wide aggradation, recent head cuts, or artificially hardened channels in unconfined alluvial valleys.
F	Streams have visible and rapid aggradation, incision, or channel migration. Stressors need to be identified and mitigated rapidly or the instability will worsen and spread.

Recovery Potential

Recovery potential rates impairment to the ability of a reach to recover its functional potential after disturbance. Using the guidelines in Table 8.3, this metric is graded based on the current extent of the historical channel migration zone, the potential for natural riparian recovery, the need for reliance on artificial stabilization to aid recovery, risks to public safety, and the potential for infrastructure damage.

The grading guidelines for this metric take into consideration the apparent potential for the reach to recover characteristic functioning after disturbance, while also considering risks to public safety and infrastructure damage. Two general criteria guided grading:

- *Channel migration zone* is the width of the corridor in which the river can freely migrate, unconstrained by artificial structures and without causing significant infrastructure damage. The width of the existing channel migration zone was compared to the historical condition, using evidence of past fluvial features and human impacts that restrict lateral movement of the river.
- *Reliance on artificial stabilization* measures was rated as the degree to which channel stability depends on artificial stabilization, such as engineered structures or routine maintenance.

Table 8.3: Recovery potential grading guidelines.

Grade	Description
A	The reach is fully resilient and capable of rapid recovery. There are no significant stressors that obstruct the physical movement or adjustment of the river within its historical migration zone, and no impediments to native plant source, dispersal, and establishment of critical components.
B	The reach is resilient to moderate events but may be slow to recover its functional potential from major disturbance. There are few risks to infrastructure or public safety. It retains most of its historical channel migration zone, few obstructions to movement and adjustment, and mostly native riparian vegetation.
C	The reach can likely recover its functional potential after moderate disturbance but may not recover from major disturbance without direct intervention. Infrastructure and human safety is at risk in major events. It has a significantly diminished channel migration zone, obstructions to physical movement and adjustment, or vegetation that is limited due to a lack of local source material, dispersal barriers, impediments to establishment, or exotics.
D	The reach is unlikely to recover its functional potential after moderate disturbance without direct intervention. Stability depends on artificial stabilization or structures, and infrastructure or human safety are at risk when these fail. The reach has a severely limited channel migration zone. Natural recolonization and recovery of the riparian zone is improbable.
F	The reach depends entirely on artificial stabilization, engineered structures, or routine maintenance to maintain functional condition, and has no capacity to recover naturally if these fail. Severe infrastructure damage or safety risks are probable in the event of failure. Channel migration zone and the potential for natural vegetation recovery are nonexistent.

Chapter 9: Physical Structure

Table 9.1: Physical Structure metrics at a glance.

Physical Structure Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Coarse-scale	Qualitative: based on field observations of the diversity of water depth/velocity combinations, topographic complexity of the bed and banks, and physical structure of the reach	Field observations in 2016, supplemented by most recent aerial imagery	Sub-reach scale	Distance weighted average of metric scores
Fine-scale	Qualitative: based on field observations of interstitial space availability, bed armoring, embeddedness, and algae in riffles			

Introduction

Physical structure in streams and riparian areas is the product of channel change, hydraulics, biological processes, and the work of natural ecosystem engineers such as beavers. As we alter the inputs or form of a stream corridor through land and water use changes, these actions have direct effects on the physical structure within that system. The required physical structure is often dictated by the habitat needs of native (or desired) species. Habitat needs vary widely by species and life stage. Diversity in physical structure supports a wider variety of species and/or life stages and provides places for aquatic species to rest or hide in times of stress. Diversity in physical structure tends to be difficult to maintain in highly static systems.

The Physical Structure indicator was evaluated based on metrics describing the physical structure at two scales: **coarse-scale physical structure** and **fine-scale physical structure**.

- **Coarse-scale physical structure** includes the characteristic diversity of different water velocity conditions (fast versus still water), depth, and physical cover such as structural elements (*e.g.,* large wood jams or rocks), overhanging banks, and vegetation for the selected reference condition. Factors affecting coarse-scale physical structure include habitat types and distribution (*e.g.*, pool spacing, pool-riffle ratios) and velocity/depth ratios.
- **Fine-scale physical structure** evaluates the amount and diversity of microhabitats within the reach, primarily bed materials and algae. Typical factors affecting fine-scale physical structure include bed material size distribution, fine sediment deposition and scour, embeddedness,

compaction, and algae type/cover. Signs of degradation can include channel bed armoring, elevated fine sediment deposition, or excessive algae.

Physical Structure methods, analysis, and grading guidelines

The physical structure indicator grade is the average of two metrics that consider different scales of river structural diversity. The **coarse-scale** and **fine-scale physical structure** metrics were both graded based on field observations of the 22.6 river miles that were visited. Grades for the reaches in the 1.3 miles that were not observed in the field were extrapolated from similar reaches, guided by examination of recent aerial imagery.

Coarse-scale physical structure

Coarse-scale physical structure rates impairment to the physical habitat diversity relevant to aquatic organisms the size of adult fish and amphibians in a reach, based on the diversity and distribution of water depth, velocity, and physical cover. Coarse-scale physical structure grades were based on qualitative estimates of the diversity of water depth/velocity combinations, topographic complexity of the bed and banks, and physical structure of the reach compared to the natural reference condition. Using this information, grades were assigned according to the guidelines in Table 9.2.

Table 9.2: Coarse-scale physical structure grading guidelines.

Grade	Description
A	Natural coarse-scale structural heterogeneity in the reach is characteristic of the reference stream type. There are no significant stressors.
B	Mostly natural coarse scale physical structure is present. Examples include reaches with slightly altered physical structure arising from dispersed stressors or minimal direct impacts. Stressors are present but the combined effects are minimal.
C	Most typical velocity-depth combinations are present, but distribution of features is skewed. Examples include reaches with increased pool/run habitat or lack of off-channel habitat.
D	Most typical velocity-depth combinations or characteristic structural elements are absent, making the reach uncharacteristically homogenous. Examples include reaches with graded or heavily armored banks, or with features that are frequently limited by inundation or low flow.
F	Coarse-scale structural diversity is severely altered. Examples include reaches with severely homogenized physical characteristics such as unnatural plain-bed morphology.

Fine-scale physical structure

Fine-scale physical structure rates impairment to the physical habitat relevant to aquatic organisms the size of macroinvertebrates or fish larvae in a reach, particularly the availability of interstitial space within the river bed substrate, based on the degree of embeddedness, armoring, proportion of fine sediment, and presence of algae. Fine-scale physical structure grades relied heavily on qualitative field observations of interstitial space availability, bed armoring, embeddedness, and algae in riffles. This information was used to assign grades according to the guidelines in Table 9.3.

Table 9.3: Fine-scale physical structure grading guidelines.

Grade	Description
A	Substrate is clean on the surface and interstitial spaces are open. Algae exists but is limited. Stressors are minimal.
B	Interstitial space in riffles and other high-energy zones is open but showing some evidence of degradation. Stressors are present but the combined effects are minimal.
C	Fine sediment/algae cover is elevated. Patches of armoring, embeddedness, or algae persist in riffles.
D	The reach is characterized by bimodal materials distribution, increased embeddedness, and presence of excessive algae.
F	Completely static armored conditions exist. Substrate is choked with fine sediment and/or algae.

Chapter 10: Aquatic Life

Table 10.1: Aquatic Life metrics at a glance.

Aquatic Life Metrics	Analysis type	Data source and period of record	Finest scale of resolution for data collection	Relative scoring contribution to indicator score
Aquatic insects	Quantitative: based on six sub-metrics used to calculate a single index score for each site using the CDPHE Multi-Metric Index tool	Aquatic insect community data from samples collected in 2015 and 2016	13 monitoring sites	70%
Native fish	Quantitative: based on CPW and/or CSU Larval Fish surveys	CPW or Colorado State University Larval Fish Laboratory data from 2015	Five stations between College Avenue and I-25	Not included due to lack of sufficient data across study area
Trout	Quantitative: based on CPW fish surveys	CPW fish survey at in 2016	Two sampling stations at Gateway Park and Lee Martinez Park	Not included due to lack of sufficient data across study area
Aquatic habitat connectivity	Quantitative: based on the length of the habitat connectivity segment between successive barriers	Current aerial imagery	Reach scale	30%

Introduction

The Aquatic Life indicator uses the community composition of animal species that depend on the river and its riparian forests. The structure of the aquatic community can be conceptualized as a “trophic” or feeding pyramid. Within this concept, animals at a lower trophic level, such as aquatic macroinvertebrates, form the base of the pyramid, while predatory animals such as trout are closer to the top of the pyramid. Four metrics can be used to assess this indicator: **aquatic insects**, **native fish**, **trout**, and **aquatic habitat connectivity**. For the SOPR assessment, only the aquatic insects and aquatic habitat connectivity metrics were used for scoring and grading the Aquatic Life indicator. This approach was decided simply because the trout and native fish metrics were lacking enough sampling sites from which to draw conclusions across the study area. The importance of each metric to river health and the Aquatic Life indicator is described below.

- **Aquatic insects** are an essential component of the river ecosystem, performing numerous critical functions. Aquatic insects can also act as an important indicator of water quality, at times providing pollutant-specific information about stressors.
- The **native fish** metric focuses on the small-bodied, warm-water species common to the eastern Colorado plains. These fishes avoid colder mountain waters and therefore most species are observed primarily downstream of Shields Street in Fort Collins.
- **Trout** are a hallmark of Colorado's streams and are a valued recreational resource. They are also often associated with good water quality and colder water temperatures.
- Poor **aquatic habitat connectivity** is one potential stressor on the health of aquatic life. Aquatic species must be able to move among habitats to feed, avoid stressors, and breed. Barriers, such as grade control structures and cross-channel agricultural diversions, can restrict the movement of aquatic species, causing communities to degrade and disrupting food webs.

The development of these aquatic life metrics was informed by existing monitoring programs that provide data for a portion of the study area. Therefore, they are written with a focus on quantitative rather than narrative descriptions and each grade was developed to reflect the function-based grading guidelines as presented below.

Aquatic Life methods, analysis, and grading guidelines

Indicator-specific study areas for Aquatic Life

Colorado Parks and Wildlife (CPW) and Colorado State University (CSU) conduct regular sampling of fish and aquatic insects at sites that characterize the reaches, inform management objectives and monitor influence of known potential stressors. In 2016, the City of Fort Collins supplemented these data collection efforts with 10 additional aquatic insect monitoring sites, located upstream of Lincoln Street, in the upper Urban and Canyon zones (Table 10.2 and Figure 10.1).

Table 10.2: Aquatic insect sampling sites for the 2017 SOPR report.

Site Name	Sample Year	Site Description	Represented Reaches	Zone
PRbRB	2016	below Rustic Bridge	Upstream of study area	
PRbLSF	2016	below the Little South Fork	Upstream of study area	
PRabvMD	2016	above Munroe Diversion	Upstream of study area	
PRabvNF	2016	above North Fork confluence	1. Munroe to North Fork	Canyon
PRbNF	2016	below the North Fork	2. North Fork to PV Canal	
PRbPVC	2016	below the Poudre Valley Canal	3. PV Canal to Greeley Div.	
PRbHSC	2016	below Hansen Supply Canal	4. Greeley Div. to CR 54	Rural
			5. CR 54 to Rist	
PRaLP	2016	at Lyons Park	6. Rist to Overland	
			7. Overland to Larimer-Weld	Urban
PRabvSSB	2016	above the Shields St. Bridge	8. Larimer-Weld to Shields	
PRaLM	2016	at Lee Martinez Park	9. Shields to College	
			10. College to Lincoln	
PLINC	2015	at Lincoln Street Bridge	11. Lincoln to Mulberry	
			12. Mulberry to Timnath	
			13. Timnath to Timberline	
PROS	2015	at Prospect Street Bridge	14. Timberline to Prospect	Plains
			15. Prospect to FCRID	
PBOX	2015	at Nature Center Gage	16. FCRID to Boxelder	
			17. Boxelder to Railroad	
			18. Railroad to I-25	

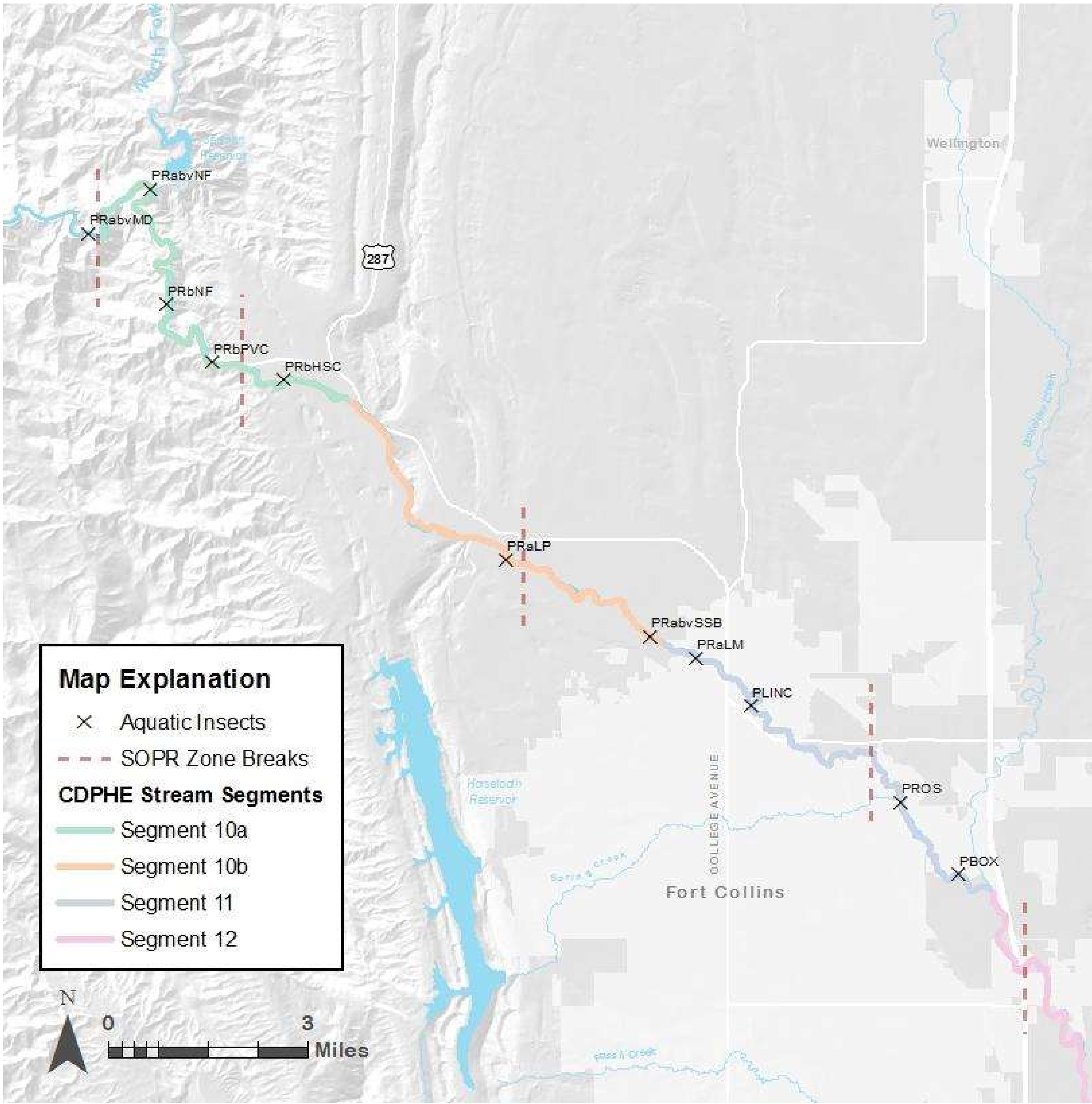

Figure 10.1: Aquatic insect sampling sites used to calculate MMI scores and grade the aquatic insects metric for the SOPR 2017 report. Also shown are the SOPR zone breaks, and Colorado Department of Health and Environment (CDPHE) Stream Segments. Two upstream most sites are not depicted in this map.

Aquatic insects and aquatic habitat connectivity

The aquatic insects and habitat connectivity metrics were used to score and assign grades for the Aquatic LIfe indicator. The analysis methods and grading guidelines for these two metrics are described below.

Aquatic insects

The aquatic insects metric rates the health of the aquatic insect community based on diversity and relative abundance of certain taxonomic groups and functional feeding groups, including groups that are sensitive to ecological stressors. This metric was evaluated using aquatic insect community data from samples taken from 13 sites in 2015 and 2016 (Table 10.1). One sample was collected at each site, analyzed in the lab, and the results were used to calculate scores for each of six sub-metrics using the CDPHE Multi-Metric Index (MMI) tool[10] as described in the CDPHE Water Quality Control Commission's Policy Statement 10-1 for Aquatic Life Use Attainment (CDPHE 2010). Specific sub-metrics used in the MMI are specified in Policy Statement 10-1 for each Biotype[11]. All SOPR aquatic insect sites are located in Biotype 1 (Transition), which requires the use of the following six sub-metrics for the MMI:

- EP taxa – a measure of community richness based on the number of Ephemeroptera and Plecoptera (mayfly and stonefly) taxa present
- Chironomidae – relative abundance of the family Chironomidae (non-biting midges)
- "Sensitive plains" families – percentage of certain sensitive taxa identified by CDPHE to be common on healthy Colorado plains' rivers
- Predator/Shredder taxa – relative abundance of taxa in the predator and shredder feeding groups
- Clinger taxa – relative abundance of taxa classified as clingers
- Non-insect taxa – relative abundance of non-insect taxa

A single MMI score was calculated for each site as the average of the six sub-metric scores. The MMI values were then converted to aquatic insect metric grades for each reach using the grading guidelines in Table 10.3. All reaches represented by a site were scored the same. The aquatic insects metric composes 70% of the overall score for the Aquatic Life indicator.

Table 10.3. Aquatic insects grading guidelines.

Grade	Description
A	The reach is considered to be representative of the reference condition for aquatic insect communities and aquatic life use. No management is needed other than protection of existing conditions. Multi-metric index (MMI) score is 80-100. The reach is in attainment for aquatic life use (CDPHE 2010)[12].
B	Some detectable stressors are evident with minor alterations to aquatic insect communities. The ecological system retains its overall structure and supports a high level of function. Some management may be required to sustain or improve this condition. MMI score is 65-79. The reach is in attainment for aquatic life use (CDPHE 2010).
C	The reach supports and maintains essential components of the unimpaired aquatic insect community, but exhibits measurable signs of degradation and less than optimal community parameters. The reach has a MMI score of 52-64 and meets the CDPHE (2010) attainment threshold for aquatic life use.

[10] The SOPR used the 2010 version of the CDPHE Multi Metric Index (MMI) tool as described in CDPHE (2010) Policy 10-1. The MMI tool and Policy 10-1 have since been revised, as described in CDPHE (2017).
[11] A Biotype is a geographic region defined by elevation, stream gradient, and ecoregion (CDPHE 2010). Macroinvertebrate community composition is expected to be similar at sites within a Biotype.
[12] A MMI score of 52 or greater meets the aquatic life use attainment threshold for streams and rivers in Biotype 1 (Transition) (CDPHE 2010; Policy 10-1).

D	There are detectable alterations or degradation of aquatic life use, but the system still supports a fundamental aquatic insect community structure and function. Active management is required (or at least recommended) to maintain and improve characteristic functional support. The MMI score is 42-51 and is considered to be in the "gray area" between aquatic life use attainment and impairment (CDPHE 2010).
F	There is clear impairment to the aquatic insect community and aquatic life. This level of alteration generally results in an inability to support characteristic aquatic organisms, or makes the stream segment biologically unsuitable. The reach has an MMI score of < 42 and aquatic life use is thus considered "impaired" (CDPHE 2010)[13].

Aquatic habitat connectivity

Aquatic habitat connectivity rates longitudinal connectivity of a reach to adjacent reaches of the river based on the average distance between fish passage barriers. Grading involved mapping and evaluating structures along the Poudre River, primarily diversion dams, to determine whether structures should be classified as barriers and to calculate the distance between them. A structure is considered a barrier if it prevents fish from moving past (up) it for the majority of the year. All structures are passable in the downstream direction during the highest flows but currents under these flow conditions are too swift for upstream movement.

The length of the habitat connectivity segment between successive barriers was measured and scores were assigned according to the guidelines in Table 10.4. The aquatic habitat connectivity segment scores were overlaid on the 18-reach scale and then weight-averaged to determine final scores for each reach. The score for the most downstream reach is based on the distance to the Greeley Canal #2 diversion structure, which is the next significant barrier downstream, even though it is outside the study area. The aquatic habitat connectivity metric composes 30% of the overall score for the Aquatic Life indicator.

Table 10.4: Aquatic habitat connectivity grading guidelines.

Grade	Description
A	Average distance between barriers is 20 miles or more
B	Average distance between barriers is 10-19.9 miles
C	Average distance between barriers is 5-9.9 miles
D	Average distance between barriers is 2-4.9 miles
F	Average distance between barriers 1.9 miles or less

Native fish and trout

Native fish and trout scores were not included in scoring the Aquatic Life indicator since fish data for the SOPR (2017) were not available for the Rural zone and broad extrapolation of site-specific data to the zone as a whole would have increased inconsistencies. Trout populations and native fish community structure mainly represent ecosystem response variables, rather than drivers of overall river health. Therefore, for the 2017 SOPR report, fish grades were only provided where data were directly available.

[13] A MMI score < 42 indicates aquatic life use impairment for streams and rivers in Biotype 1 (Transition) (CDPHE 2010; Policy 10-1).

The grading guidelines are provided here to facilitate inclusion of these metrics in future River Health Assessment efforts on the Poudre River or elsewhere.

Native fish

The native fish metric rates impairment to the native fish community in a reach based on the number of species and age classes present (Table 10.5) based on CPW knowledge of recent and historical fish populations.

Five stations were sampled in 2015 between College Avenue and I-25 by either CPW or the Colorado State University Larval Fish Laboratory (CSU-LFL) to assess **native fish** species composition. Seine nets and electrofishing methods were used at each station to capture live fish and determine the presence or absence of multiple life stages of native fish species. Metric grades were assigned based on two sub-metrics:

- *Number of native species* – Number of native fish species captured in sample efforts
- *Number of species with multiple life stages* – Number of species for which fish of multiple life stages were captured

Only reaches with sampling stations with data from 2015 were graded.

Table 10.5: Native fish grading guidelines.

Grade	Description
A	12 or more taxa, multiple life stages for most species
B	9-12 taxa, multiple life stages for most species
C	7-8 taxa, multiple life stages for half of species
D	5-6 taxa, single life stage for most species
F	4 or fewer taxa, single life stage for most species

Trout

The Trout metric rates the condition and viability of the trout fishery within a reach based on trout population characteristics (Table 10.6).

Trout are expected on the Poudre upstream from approximately the mid-point of the Urban zone. The **trout** metric was evaluated on these reaches by Colorado Parks and Wildlife (CPW) biologists who used two-pass electrofishing sample methods to monitor trout populations at several stations along the Poudre River annually. One station is at Gateway Park on Reach 1 (Munroe Diversion to North Fork) in the Canyon zone. Another is at Lee Martinez Park on Reach 9 (Shields to College) in the Urban zone. Results from these two stations, sampled in 2016, were used to grade the trout metric based on six sub-metrics:

- *Age classes* – Number of age classes of brown trout
- *Recruitment* – Number of Age-0 brown trout, assessed as low, medium, or high
- *Recreation potential* – Number of catchable-size (> 9 inches) brown trout, assessed as low, medium, or high

- *Relative weight* – Average relative weight for stock-sized (> 6 inches) brown trout. Relative weight – the ratio of actual fish weight to the weight of a healthy fish of the same length – is a measure of fish health
- *Biomass*– Biomass of stock-size (> 6 inches) brown trout, in pounds per acre.
- *Population number* – Number of stock-size brown trout per mile of stream, assessed as low, medium, or high

Table 10.6. Trout grading guidelines.

Grade	Description
A	Four or more age classes are present; high levels of natural reproduction and age 0 fish are present; trout biomass exceeds 60 lbs/acre-(gold medal standard); population has a better than average relative weight; high population estimates of catchable-size trout indicates a viable recreational fishery.
B	At least three age classes are present; medium levels of natural reproduction and age 0 fish are present; trout biomass is 40-59 lbs/acre; population has an average relative weight; moderate population estimates of catchable-size trout indicates a mediocre recreational fishery.
C	At least two age classes are present; low levels of natural reproduction and age 0 fish are present; trout biomass is 20-39 lbs/acre; population has a below average relative weight; fluctuating population estimates of catchable-size trout indicate an inconsistent recreational fishery.
D	The trout population is dominated by a single age class; very sporadic natural reproduction and few age 0 fish are present; trout biomass is 0-19 lbs/acre; population has a below average relative weight; low population estimate of catchable-size trout indicates a poor recreational fishery.
F	No trout present; no natural reproduction; no biomass; no recreational fishery

Chapter 11: Calculating reach, zone and overall grades

In the RHAF, metric scores are combined to produce indicator scores, and then the indicator scores are rolled up into a single rating of river health using a weighted average. The rolled up river health rating, or grade, can be calculated for each reach, for each zone, and for the entire area of analysis by rolling up the scores at each successive level of spatial resolution using the weighting factors described below. Table 11.1 provides a summary of the metric and indicator weightings used in the SOPR.

Table 11.1: Weighting of indicator and metric scores used in the State of the Poudre River report (City of Fort Collins, 2017)

Weighting of indicator scores (to create overall grade)	Weighting of metrics to create indicator scores
Flow Regime (20%)	= 50%(peak flow) + 25%(base flow) + 25%(rate of change)
Sediment Regime (5%)	= average of metric grades
Water Quality (10%)	= 50%(average of metric grades) + 50%(minimum metric grade)[1]
Floodplain Connectivity (10%)	= 100% floodplain extent
Riparian Condition (20%)	= 80%(riparian vegetation structure) + 10%(contributing area) + 10%(habitat connectivity)[2]
River Form (10%)	= average of metric grades
Resilience (10%)	= average of metric grades
Physical Structure (10%)	= average of metric grades
Aquatic Life (5%)	= 70%(aquatic insects) + 30%(aquatic habitat connectivity)[3]

1. The nutrient metric grade as a component of water quality is = 50%(TN) + 50%(TP).
2. The riparian condition score is disproportionately weighted with the riparian vegetation structure metric because it represents the majority of the data collected and evaluated.
3. The native fish and trout metrics are not considered in the calculation of this indicator grade because these data are not available except on a few reaches and experts cannot make informed estimates of these metrics on reaches without sampled data.

Grades were calculated for each of the 18 reaches using the weightings as shown in Table 11.1. Reach grades were then combined within a given zone using an average weighted by the length of each reach to produce a zone level grading of river health. The four zones were then combined in a similar fashion to produce the overall rating of river health within the SOPR study area.

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