DRAFT

MEMORANDUM

DATE: August 8, 2023

TO: Mary Powell, Environmental Manager

FROM: Brian Murphy, PhD, PE, River Works Ltd

SUBJECT: Urban Stream Assessment Procedure: Overview and Interim User Guidelines

Introduction

This memorandum provides information and guidance for Mile High Flood District's (MHFD or District) watershed managers, practitioners, local government staff, developers, and private property owners involved in assessing the condition of streams in the District's service area. MHFD is committed to improving and preserving stream corridors that provide value to the community and benefit the environment. Its Urban Stream Framework (MHFD 2023) supports that mission and their stewardship core value: "Be Stewards of Watersheds and Streams by promoting natural and beneficial functions of floodplains and responsible watershed management." The adoption of the Urban Stream Framework by MHFD represents a planning and management shift for the District, which in turn highlights the need for a science-based stream assessment procedure that can better capture the balance between protecting and restoring urban streams and improving overall benefits with other stream uses and values.

The area's varied climate, hydrology, geology, and development patterns result in a broad range of stream and watershed environments. Given this extensive variety, and the Districts' aim to develop an assessment method that supports their mission to "protect people, property, and our environment" across the entirety of the District, it must be applicable across a broad range of stream types and scales. With this in mind, MHFD created the urban stream assessment procedure (USAP) in order to assess the physical condition and community values of urban streams in the Denver metropolitan area. USAP's primary application is assessing the physical condition of streams (i.e., creeks, gulches, drainages) and the South Platte River in the Denver metropolitan area. USAP applies the term "condition" purposefully, to highlight the management of physical conditions characteristically employed by MHFD.

This document is primarily written for a multi-disciplinary team, whether it is a team that will conduct a comprehensive assessment for a watershed master plan or a team that is studying and designing stream improvement measures. Section 1 describes the development of USAP, including a description of the five elements – community values, hydrologic processes, hydraulic characteristics, geomorphic forms and processes, and vegetation structure and processes – and assessment strategies and types. Section 2 summarizes the USAP methods outlining the step-by-step process of the assessment while Section 3 explains the USAP indicators and their associated metrics and their connection to the five elements. Section 4 describes the USAP workbook and scoring approach. The workbook is a spreadsheet -based tool that guides indicator and metric selection across all elements and summarizes the functional characteristics associated with each metric. **Appendices A through E** include the method sheets associated with each element with a detailed description of the indicators, metrics, scoring guidelines, and the specific analysis for each metric.

Note MHFD is developing a watershed-scale USAP dataset, which provides practitioners and watershed managers a high-level overview of stream conditions across the five elements. The watershed-scale dataset leverages MHFD's stream network with existing conditions scores for all reaches based on publicly available data such as DRCOG topography and land use land cover. Contact Mary Powell for more information on the USAP watershed-scale dataset.

Limitations of Use

While any assessment procedure has its limitations, MHFD intentionally designed USAP with a flexibility that allows stream managers to apply it to a variety of watershed contexts, tailoring the assessment to the specifics of each. The intention is that USAP is widely applicable across the District's approximately 1,700 square miles of watershed and 3,000 miles of streams, and potentially beyond the District as well. However, USAP exhibits a few limitations. For example, in designing the procedure, the MHFD chose not to incorporate assessment of a watershed's water quality or aquatic habitat. These functions of stream "health" are well covered by many pre-existing assessment frameworks.

The use of USAP requires well-experienced practitioners. While reducing subjectivity was a goal during the development of USAP, some assessment parameters require skilled practitioners to assess correctly. Assessors must be knowledgeable in hydrologic and hydraulic properties, fluvial geomorphic and watershed processes, and riparian ecology; and be well trained and experienced in collecting geomorphic and vegetation data. And finally, indicators that reflect human connections and values are inherently difficult to ascertain. USAP relies on publicly available datasets, as well as dialogue with stakeholders, to define and assess community values. Yet, the linkage between data and stakeholder values is somewhat limited and will require refinement over time.

1. Development of the Urban Stream Assessment Procedure

Many previous stream assessment frameworks and methods informed the creation of USAP. Most assessments were designed for a broad range of predominantly undisturbed "natural" streams that focus on overall stream "health" by evaluating, for example, biologic and water quality parameters or by conducting an audit of stream features such as physical habitats and their characteristics. The lack of a consistent physically-based assessment approach for urban streams is also due in part to insufficient broad-scale data and the logistical difficulty of investigating stressors such as hydrologic conditions, ecological interplay, socio-ecological values on stream condition. MHFD developed USAP to address these limitations and to improve the management of streams in the urban environment using a new set of integrated methods and more robust data collection and evaluation techniques. USAP exhibits several defining properties to ensure that it is well-suited to application in the urban environment for which it was developed. Among these unique features are:

- A multi-scale approach captures the context of watershed-wide processes.
- A focus on the physical condition—structure and function—of urban streams and on the forms and processes that create these physical conditions.
- A framework that accounts for the human connections and values to waterways and how they affect management.
- A tailored approach to assessing the relevant metrics in each unique context.
- A foundation for collecting quantitative and qualitative information to inform the results of the assessment.

- Situating the assessment results within the context of the stream to guide realistic and efficient management.

USAP provides a structure that embraces the complexities prevalent in urban streams by integrating community values (such as health and wellness, public safety, and recreation) with physical elements (including flow regime, geomorphic processes, and vegetation structure). These features allow USAP to fill a gap among stream assessment frameworks when applied to urban watersheds.

1.1 Overview of the Urban Stream Assessment Procedure

USAP encapsulates new ideas of social–ecological systems that are at the forefront of urban stream planning and management. The many socio-ecological complexities of urban streams confound their management, particularly when it comes to determining the appropriate interventions to improve their physical condition. By assessing physical processes against an understanding of community values, USAP can inform urban planning, stream management, and restoration that better supports the benefits streams provide to humans, which in turn bodes well for their success. The process can be conceptualized by three questions:

- Why do we need to assess conditions of this urban stream or watershed?
- What functions and values determine the ability of the stream to perform its natural processes, given its context?
- How should we assess the functions and values of this urban stream or watershed?

The first question helps hone the intent of the assessment before identifying the values and functions to assess. The questions frames the social-ecological values and urban stream physical functions to include in the assessment while the answer to the third question describes how to measure the specific attributes of functions and values. The overall framework is illustrated in Figure 1.

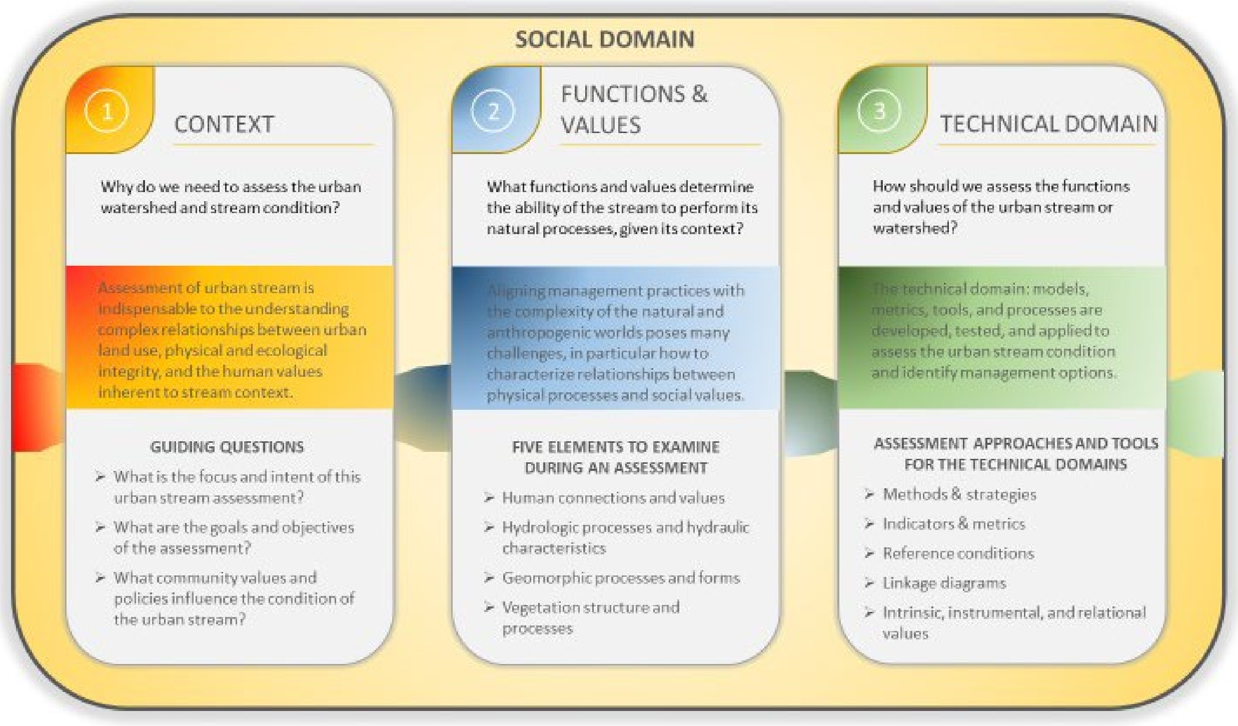
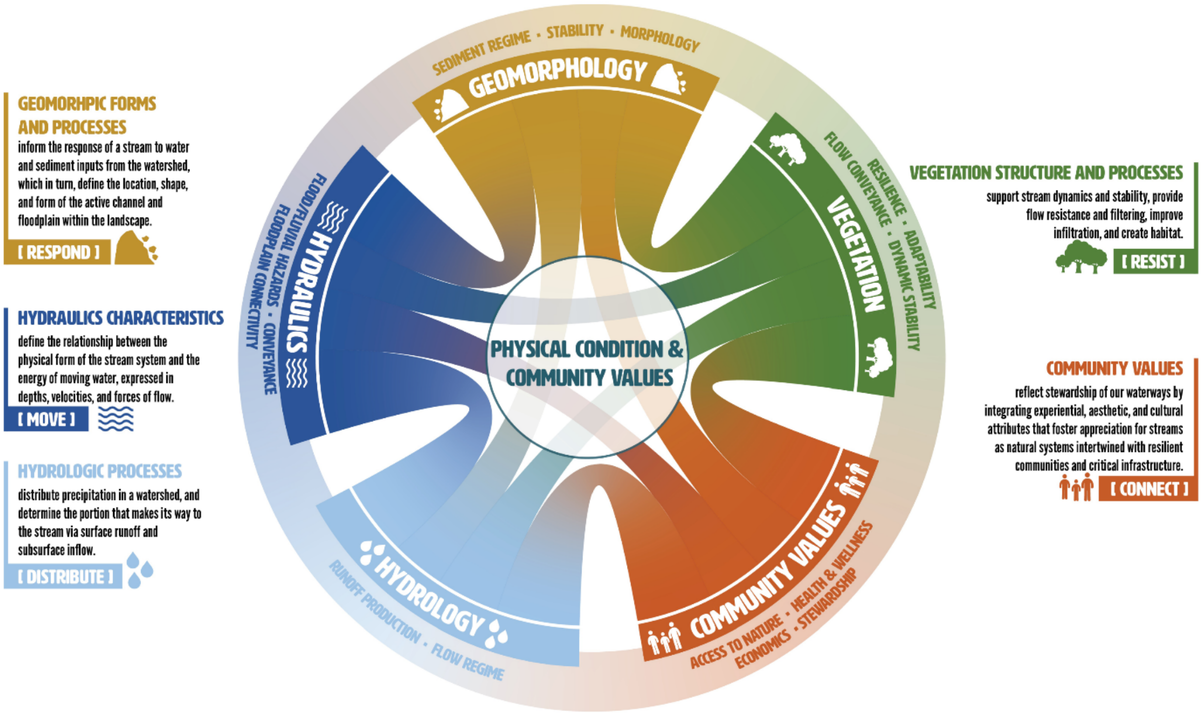


Figure 1: A tiered framework for urban riverscape stream assessment that incorporates social-ecological values. When devising measures, the process works from left to right. When assessing and drawing conclusions, the process works from right to left.

1.2 The Five Elements

Given that USAP evaluates stream character and behavior based on physical and social-ecological indicators and metrics, MHFD determined a series of five core elements at play in the urban setting to assess: community values, hydrologic processes, hydraulic characteristics, geomorphic forms and processes, and vegetation structure and function (Figure 2).



GEOMORHPIC FORMS AND PROCESSES
inform the response of a stream to water and sediment inputs from the watershed, which in turn, define the location, shape, and form of the active channel and floodplain within the landscape.
[RESPOND]

HYDRAULICS CHARACTERISTICS
define the relationship between the physical form of the stream system and the energy of moving water, expressed in depths, velocities, and forces of flow.
[MOVE]

HYDROLOGIC PROCESSES
distribute precipitation in a watershed, and determine the portion that makes its way to the stream via surface runoff and subsurface inflow.
[DISTRIBUTE]

VEGETATION STRUCTURE AND PROCESSES
support stream dynamics and stability, provide flow resistance and filtering, improve infiltration, and create habitat.
[RESIST]

COMMUNITY VALUES
reflect stewardship of our waterways by integrating experiential, aesthetic, and cultural attributes that foster appreciation for streams as natural systems intertwined with resilient communities and critical infrastructure.
[CONNECT]

Colors represent each of the five elements of urban stream function and maintenance. Colored bands reflect the connections between these elements and that each element influences, and is influenced by, the other elements.

Figure 2: Five elements of the urban stream assessment procedure

These core elements provide insights into the processes occurring along the stream and the anthropogenic stressors influencing the physical condition of the stream. They serve to guide the collection of data that informs the assessment across five key interconnected facets. See below for further information on the five elements.

1.2.1 Human connections and values

Communities greatly value streams and exhibit a strong sense of place associated with flowing water (e.g. Kendal and Farrar, 2016). The importance of streams to communities provides waterway managers with license to restore stream health (Boyd 2021). Thus, understanding a community's specific values, including determining the anticipated social benefits of restoration as well as the potential concerns, in order to identify community-valued attributes and amenities can guide the selection of assessment metrics for urban streams. Ignoring social-ecological connections, on the other hand, can lead to assessment and management outcomes that provide little value to people, or even conflict with community benefits. Unless eco-centric projects reinforce some high-level, broadly-supported strategic goal, such as the protection of an endangered species or creating landscape-scale connectivity, they are unlikely to be successful. When communities are invited to co-design the future of urban waterways, they center themselves in the landscape, with their aspirations for better ecological health going hand in hand with better access and amenities for the community (e.g. McAuley and Knights, 2021).

Identifying community-valued attributes requires practitioners to consider the range of values that make streams important to communities and to produce a conceptualization of value that is inclusive. These complexities convey that USAP benefit from social science expertise in order to devise community engagement strategies, questionnaires, or other means of identifying valued attributes (e.g. Kendal et al., 2015). A unique and vital case exists in newly developing areas where the community does not yet exist (Sammonds and Vietz, 2015; Birtles et al., 2015); in such scenarios project stakeholders must advocate for the rights of the future community to form the kinds of relationships with streams that they wish, while ensuring that those relationships are compatible with a functioning systems.

1.2.2 Hydrologic Process

It is well known that runoff is a master variable that controls many aspects of hydraulic and geomorphic conditions as well as ecological processes (Poff et al., 1997; Doyle et al., 2005; Bunn and Arthington, 2002, Vietz et al., 2017). Thus, USAP includes evaluation of aspects of the hydrologic processes that maintain resilient physical form, sustain in-stream biota and riparian vegetation, and support human uses and benefits provided by streams (Fletcher et al., 2014). For example, overbank flows are critical to watering floodplain vegetation (Piegay, 1997), moderate peak flows can be important for flushing fine sediment and channel maintenance (Poff et al., 2010; Piegay, 1997), and baseflows are essential to providing persistent in-stream physical habitat (Smakhtin, 2001) and in some cases an environment for recreation (e.g. Willis and Garrod, 1999).

Urbanization can have varying impacts on hydrology (Booth et al., 2016; Brown et al., 2009), depending on urban design and the pre-development hydrologic regime. Most commonly, in urban areas peak flows increase in magnitude and frequency due to elevated runoff from impervious surfaces through efficient drainage pathways (Fletcher et al., 2013) and/or combined sewer overflows (Tetzlaff et al., 2005). Effects on low flows can be highly variable (Bhaskar et al., 2016): they can decrease because water is diverted to surface runoff rather than recharging groundwater, or they can increase due to leaks in water supply infrastructure, increased dry-weather irrigation, and wastewater discharges. Thus, overall flow volumes in urban streams are quite variable (Konrad and Booth, 2005). And while they commonly become more flashy, this pattern is not necessarily the case in naturally flashy systems such as arid lands (McPhillips et al., 2019).

1.2.3 Hydraulic characteristics

“Hydraulics” refers to the movement of water through the channels and floodplains, as expressed in depths, velocities, and forces of flows (i.e., stream power, shear stress), as well as the interactions between sediment, water, and wood (Niezgoda and Johnson, 2005; Anim and Banahene, 2021). The hydrological processes of a streams, specifically alterations to flows, create changes to the hydraulic processes. The movement of water through the landscape influences the geomorphology and vegetation of streams across a broad range of spatial and temporal scales. The shape and size of stream channels, the distribution of vegetation, the stability of channel bed and banks, and the physical in-stream habitat for aquatic biota are all largely determined by the interaction between the flow regime, local geology, and physical features. It is these relationships that USAP helps practitioners understand in order to define flow requirements for an urban streams. In doing so, relevant flow metrics can be defined, assessed, and used to guide policy towards more functional flow regimes.

1.2.4 Geomorphic forms and processes

The location, shape, and form of a streams is determined by geomorphic processes, such as erosion, sediment transport, and large wood dynamics produced by water and sediment moving through the system. But these physical elements can also be constrained or even defined by direct modification, like constructed channels or rock protection. Adjustments to bed, bank, and channel morphology have important implications for ecosystem functioning and hazards associated with streams dynamics (Bollati et al., 2014). Development has altered physical habitat (Violin et al., 2011) and sediment transport rates (Papangelakis et al., 2019, Russell et al., 2020), which contribute to the degradation of stream ecosystems (Vietz et al., 2016a; Hawley et al., 2013; Vietz et al., 2014).

Assessment of the geomorphology of urban streams typically focuses on the channel due to the encroachment of human development on parts of the stream corridor that would, under more natural circumstances, be more fully connected with the channel, including floodplains. Connectivity between the channel and its floodplain reflects the two-way transfer of water, sediment, and nutrients between them, and is critical for maintaining riparian vegetation and habitat and creating flow inefficiencies and a resilient river system (Brierley and Fryirs, 2005). Poorly connected floodplains often reflect impairments to stream health and function due to hydromodifications, channel modifications, and/or anthropogenic land uses within the floodplain, which limit hydrogeomorphic processes and biologic interactions between the channel and its floodplain. These anthropogenic stressors create constraints and evolutionary trajectories that can hamper or preclude re-connection in urban environments so that investigating those stressors and their associated impacts is central to assessing urban streams.

The simplification of stream geomorphic processes that are inherent to urbanization causes erosion, sedimentation, and direct channel modification that reduces the geomorphic complexity and alters channel-floodplain connectivity. These important processes, and the associated spatial and temporal variability, are the focus of USAP because they are now recognized as fundamental to stream management strategies (Kline, 2010; Wohl, 2016; Blazewicz et al., 2020, Melbourne Water, 2018). Assessing at various scales the physical attributes, such as connectivity, stability, dimensions, and physical complexity, will help to illustrate relevant aspects of morphologic character, their importance in supporting human values and benefits, and their sensitivity to degradation or management influences.

1.2.5 Vegetation structure and processes

The ecological condition of urban streams affects the value they provide to society (Gonzalez del Tango and Garcia de Jalon, 2013). In turn, changes in flow and sediment regimes and channel and riparian zone characteristics affect the ecology (Gurnell et al., 2007). Hydrologic changes, in particular, significantly influence the vegetation of urban streams, and their significance depends on the context, and spatial and temporal patterns of urban development. In urban streams with altered hydrology, the benefits of improving riparian or wetland vegetation may be tempered by the persistent effects of altered streamflow. Thus, identifying the primary mechanisms of physical degradation of vegetation requires rethinking how we assess urban streams.

The interactions between vegetation structure and processes and hydrogeomorphic processes are an important component of assessing a stream. Riparian vegetation, for example, supports stream dynamics and stability, provides flow resistance and filtering, improves sediment and organic matter retention, and provides large wood which fosters structural complexity (Gurnell, 2014). Urban streams not only deliver these ecological functions, but and also support the social values that underpin communities that rely on those ecological functions. Thus, assessing those functions is paramount to identifying and deploying management actions to address the stressors degrading them.

1.3 Spatial Scales

USAP implements a multi-scale schema incorporating spatial scales from watershed to corridor to reach, linking the hierarchical processes between these spatial units (Figure 3). Assessments at the watershed, corridor, and reach scales identify needs related to hazard risk reduction, structure maintenance, and stream function.

USAP is designed to allow practitioners to assess the functionality of streams at multiple scales. Practitioners can implement the assessment at any of the three scales or a combination of them, depending on the objectives set forth by stakeholders at the outset of the process. The desired level of effort and available funding can often drive this decision. For example, an assessment undertaken at the watershed scale relies predominately on desktop analyses, while reach scale assessments often require field measurements. Most indicators can be evaluated at all three scales. However, the objectives within each element vary depending on the scale.

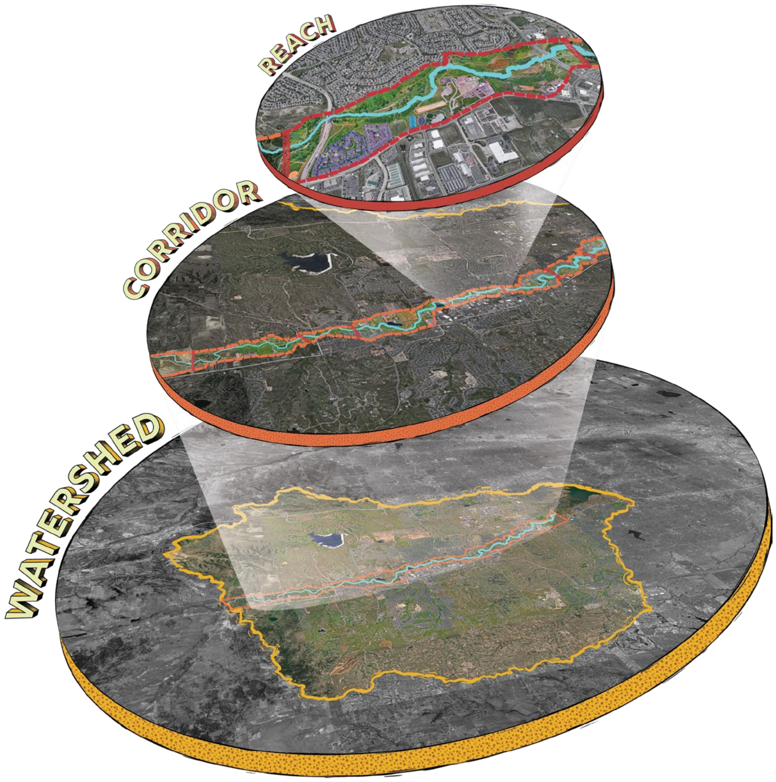


Figure 3: Spatial scales of the urban stream assessment procedure

A **watershed** is the geographic area within the boundary of a drainage divide that drains all the streams, rainfall, and tributary groundwater to a common point such as a confluence with another stream. Larger watersheds may contain smaller watersheds along with other tributaries. The word "watershed" is often used interchangeably with drainage basin or catchment.

A **stream corridor** (also referred to as a riverscape) is the area of land adjacent to and along the length of a stream, including a stream channel, its floodplain, and riparian zone, typically up to the margins of nearby hillslopes or any confining terraces. The stream corridor often encompass multiple reaches and are generally delineated according to upstream and downstream points at which the hydraulic, geomorphic, and/or vegetation characteristics of a stream or river change such that the physical characteristics are noticeably different.

A **reach** is a section of a stream or river, typically less than one-mile long, with a defined upstream and downstream boundary, for example a confluence, a bridge, or a diversion structure, along which similar geomorphic and hydrologic conditions exist, such as discharge, depth, and slope. The characteristics of a reach are sufficiently uniform such that the stream or river maintains a consistent set of physical process-form interactions along it. The reach is also the scale at which humans view and interact with a stream or riverscape.

Selection of a study scale relies on previous planning studies, desktop review, local knowledge, and should include a site visit with all stakeholders.

1.4 Assessment Strategies

The primary objective of USAP is to provide watershed managers and practitioners with a tool to improve understanding of the physical condition of urban streams as well as support future vision(s) for the watershed on a localized and regional scale. The strategies described in Table 1 are provided at the three scales (watershed, stream corridor, and reach) for all five elements. Those strategies influence the selection of indicators and metrics.

Table 1: Reach, corridor, and watershed-scale strategies for the assessment of the five elements.

Element	**Spatial Scale**		
	Reach	Corridor	Watershed
Community values	• Consider social-ecological aspects such as equitable access to nature, enhanced health & wellbeing, safety and security, First Nations cultural value, stewardship of natural resources. • Evaluate local attributes that are significant to human communities (e.g. waterholes, fishing spots, cultural sites, habitat for iconic species) • Consider the adjacent context, such as neighborhood values, aesthetic and experiential characteristics, and historical management practices.	• Evaluate interactions of reaches with regional plans for transportation, trails, open space, land-use, and associated risks to life and property from flood and fluvial hazards. • Assess current maintenance regime and legacies of past management (e.g. concrete-lining/rock armoring) • Assess community wants and needs with regard to functional, connected streams. • Evaluate local communities' understanding of stream corridor condition and hazards.	• Understand and respond to current conditions and support future vision(s) on a regional scale • Consider regional strategic priorities for environmental protection/improvement (e.g. iconic, endangered and keystone species) that are supported by the broader community. • Identify education and outreach programs for undervalued keystone community relational values tied to the watershed
Hydrologic process and hydraulic characteristics	• Evaluate the full spectrum of flows, including including low flows. • Identify discharge points into the reach (stormwater inflows, tributaries) as well as diversion structures. • Evaluate how flow regime changes manifest at the reach scale. • Determine hydraulic characteristics for various runoff events to establish depths, velocities, and shear stress and evaluate associated impacts to reach morphology. • Determine if restoration or renovation strategies can affect quantity or quality of flows through the reach.	• Consider how high and low flows provide lateral connectivity with groundwater and floodplains. • Evaluate impacts of past and future hydrologic changes to the stream function (e.g. flood attenuation). • Determine areas of high and low flood and fluvial hazard and evaluate risks to ecological/hydromorphic floodplain function (e.g. loss of riparian vegetation to bank erosion, change in floodplain vegetation watering regime).	• Delineate the stream network and opportunities to preserve /recreate /mimic headwater streams • Identify impacts to the stream network due to changes in hydrology • Identify watershed-scale factors and management measures (regional detention, stream network, land use patterns, etc.) that influence the hydrologic regime. • Evaluate how existing and future flow storage/detention is distributed across the watershed. • Evaluate the energy spectrum (i.e. stream power/shear stress) along the stream network.

Geomorphic forms & processes	• Place reach-scale geomorphology in context of processes occurring along the stream to identify larger-scale/offsite drivers of change • Evaluate processes observed at the reach scale (e.g. local erosion). • Determine sediment transport capacity of the flow regime to identify erosion/deposition hotspots. • Determine if the reach is stable or trending towards aggradation/ degradation and the factors that contribute to anticipated future changes. • Understand geomorphic hazards and determine whether instability may threaten infrastructure, property, or public safety.	• Identify dominant geomorphic landscapes along the stream corridor to understand the influences that shape the stream. • Determine locations where the channel's ability to adjust is limited through constraints and areas where adjustment is incompatible with land use. • Evaluate the geomorphic function of the reaches including. • Analyze geomorphic trajectory and evaluate likely future responses given flow alteration and land use practices. • Consider context of processes occurring to identify larger-scale/offsite drivers of change	• Identify dominant landscapes in the watershed to understand influences that shape the land and the stream network. • Determine areas within a watershed where the sediment supply/ transport regime is changing or is out of balance due to natural and/or anthropogenic stressors or anticipated future flow conditions. • Understand sediment continuity along the stream network, including significant sediment sources/sinks. • Place watershed-scale geomorphology in context of natural and anthropogenic constraints (climate, geology, urban infrastructure, etc.)
Vegetation structure & processes	• Understand the existing in-stream and bank vegetation communities and species. • Identify hydrogeomorphic functions of vegetation (e.g. erosion resistance). • Evaluate the quantity and function of large wood.	• Understand the existing vegetation communities • Understand the ecological resilience of the existing vegetation communities. • Identify areas of vegetation with invasive, sparse, or stressed vegetation; investigate causes.	• Understand landscape-scale riparian vegetation communities and connectivity. • Determine existing or potential future gaps in, or encroachments on, riparian vegetation. • Determine network-scale impacts of vegetation on flood conveyance.

1.5 Assessment Levels of Detail

USAP includes three "levels of detail" or tiers that are associated with differing levels of effort to gather information for each level through a multi-disciplinary approach. The information allows the user to proceed to the level of specificity needed for any area. The process can be cumulative or independent at each tier; however, each tier builds on the previous one and provides a basic framework of knowledge about a given Element. The various levels of assessment are displayed and characterized in Figure 4 and Table 2.

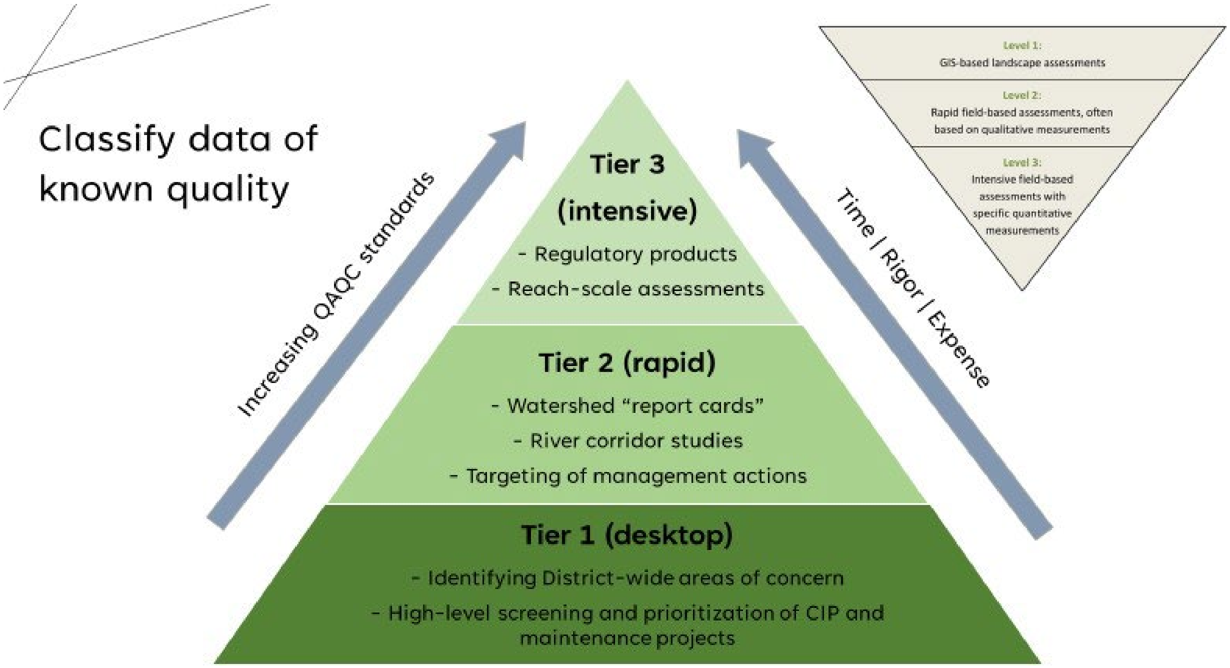


Figure 4: USAP tiers of data collection

Tier 1 is a desktop procedure that begins by assembling and interpreting existing maps, publicly data, and stream classification information. The intended use of the desktop assessment is to (1) determine context, (2) delineation of stream reaches; (3) identification of management strategies (see Section 2.3); and (4) prioritize reaches for which more detailed information is required. Reach delineation is based on geomorphic landforms, stream classification, stream gradient, and other factors, including roadway crossings. Watershed-scale management strategies summarize the measurable objectives for the assessment based on scale and Element.

Tier 2 is a rapid field procedure that identifies and maps observable physical features using qualitative measures. Physical features are delineated on the basis of easily identifiable characteristics and correspond to the corridor-scale strategies (see Table 1). The intended use of the rapid assessment is to verify results from Level I or to quickly measure and document conditions on the field.

Tier 3 involves more intensive, site-specific field data collection to address specific questions, issues, or needs. Quantitative data are collected to: (1) characterize existing and potential stream conditions; and (2) to monitor changes in those conditions. Information from Level lll surveys is used to assess impacts of land use changes, hydromodification, and management activities, and for project design.

Table 2: USAP Level of Assessment Summary

Evaluation Level	Description	Kinds of Data Curated	Management Applications
Tier 1	Desktop analyses using existing publicly available data	• Land use changes Natural space opportunities • Urban heat island index • Environmental and health hazards • Social vulnerability index • Infrastructure risk • Structures in floodplain and/or FHZ • Channel and floodplain capacity • Stream type(s) • Vegetation cover types • Geomorphic character (e.g., valley bottom type) • Floodplain connectivity	• Documents existing information • Displays resource values and management gaps • Results in mapping of functional areas • Provides basis for prioritization for higher level evaluation (II or III) • Provides high-level indication of stream condition
Tier 2	Rapid field work curating new data	• Universal access • Maintenance requirements • Flow regime type • Flow alterations due to diversions • Entrenchment ratio • Sediment sources • Geomorphic properties (e.g., depositional reachs) • Bank stability • Vegetation community type and diversity • Vegetation structural layers	• Identifies and maps geomorphic properties and riparian condition • Verifies resource values and management/maintenance gaps • Characterizes existing stream condition in relation to functional characteristics • Identifies areas for Level III assessment • Evaluations current management/maintenance effects • Provides a basis for management decisions
Tier 3	Detailed field investigation, reach or site specific	• User experience • Neighborhood identify and placemaking • Community stewardship efforts • Location of stormwater control measures • Flow regime analysis • Channel and crossing structure capacity • Channel stability index • Mapping and analysis of Channel adjustments • Bank protection locations • SEM stages • Foliage height/volume • Vegetation community assemblages and composition • Dominant plant associations	• Monitoring procedures • Identifies “watch” zones • Refines the relationship between natural processes and land use changes or management activities • Quantifies current status and potential recovery • Quantifies/validates resource values • Identifies limiting factors • Provides detailed project design criteria based on site characteristics • Quantitatively validates Level I or Level II assessment results

1.6 Context

Under a values-based paradigm, assessment is conducted to ascertain the physical condition and stream values given the context, which leverages both social and physical indicators. Context refers to the hydrologic, geomorphic, ecological, and social setting of the watershed, corridor, and/or reach. It includes the spatial and temporal dimensions of the “frequency and duration of specific processes” influencing the stream (Wohl, 2018), as well as the social-ecological processes that underpin management and maintenance decisions in the study area. These physical and social characteristics interact to create a context that governs the process of defining a problem statement and identifying solutions. In short, context underpins assessing urban streams.

While the context for every project will be different, every project has a context (see Table 3). Further, some aspects of context might be viewed positively by one stakeholder group and negatively by another. For example, a concrete channel might be a positive for the owner of a homeowner adjacent to a stream and a negative for a local watershed group. Thus, descriptions of the context should use objective, value-neutral language to reflect the perspectives of all stakeholders without judging which aspects are good or bad.

Table 3: Examples of context and types of inventory to define the project area's context

Context examples	Type of inventory
The area's natural environment	• Does the project area include natural features such as a park, open space, or riparian area? • Is there a connection to the stream for fishing, walking, or boating? • What are the land uses in the area?
The area's social environment	• How do stakeholders perceive the community and its strengths and weaknesses? • Are there major gathering places in the project area? • What are the area's demographics? • Are there elderly, low-income, or minority communities in the area?
The function and design of in-stream recreational amenities	• What types of users and trips does the recreation feature need to accommodate? • How does the recreation feature affect businesses and residents?
The mobility behavior in the area	• Who is traveling in the area? • What modes are they using?
The area's cultural characteristics	• What aspects of the community are important to stakeholders? • What significant features define the community?

** Modified from FHWA Context Sensitive Solutions (CSS)*

Recognizing that the specific methods used in developing an assessment approach will be dependent on the socio-political context in which assessors are working, we propose several general principles that can underpin this work (see Table 4).

Table 4: Principles for incorporating context into USAP

Focus on building trust between participants by adopting a transparent approach to defining values and linking them to appropriate indicators and measures. Collaborative mapping of these relationship avoids the problem of a 'black box' when designing river management projects, and provides a shared basis for input into decision-making.
Prioritize dialogue in gathering technical and non-technical input into the development of goals and assessment criteria, and involve communities, where possible, in the selection of methods that will be used to investigate their values and understand their connections to place.
Recognize that values are dynamic and can change over time, through shared learning when participants share knowledge.
Recognize relational values alongside more traditional conceptualizations of values, such as intrinsic or instrumental. While relational values can be more difficult to define, they tend to be powerful motivators driving people to action. Their recognition allows for a more complete articulation of the elements of a stream that contribute to a sense of place (Tadaki et al., 2017, West et al., 2018, Mould et al., 2020a).

These principles are intended to create spaces for collaboration between assessors, resource managers, and communities, through which participants can share knowledge, learn from each other, and construct logic that reflects a broad range of values.

2. Methods

In its simplest form, the roadmap to USAP's assessment framework can be subdivided into two sections: what is assessed and how it is assessed. Thus, implementing USAP across the watershed, corridor, or study reach, requires applying methods separated into three steps, as described below, with the main tasks of each step schematically shown in Figure 5.

Figure 5: Flow chart of the three steps and associated tasks in the application of USAP

2.1 Characterization of watershed or stream

Step 1 relies on a multi-scale delineation and classification of spatial, geomorphological, organizational hierarchy, for example drainage basin, functional process zones, reaches, and geomorphic units. The characterization of the stream system in its current condition at the landscape scale focuses on watershed processes, causes of degradation (drivers, pressures/stressors), and flow regime modifications. Identifying the study area's spatial extent, describing the setting, and building relationships to establish a common vision with the relevant institutions and community stakeholders are the inaugural steps of the USAP process. This requires developing an understanding of the physical and social context of the study area, for example the geology, topography, climate, land use, development patterns, and political and economic mandates, in order to determine appropriate goals and to draft a problem statement that will drive the assessment itself, undertaken in Step 2.

This step also requires preparing spatial data to develop an understanding of the physical characteristics and the social-ecological context of the study area. This desktop analysis leverages historical information, publicly available geospatial datasets, and curated data from GIS tools. It may be the case for a given stream that data relating to the impacts on stream processes or vegetation communities is sparse or absent. When this is the case, stressors or regional factors known to be critical to the viability of processes and vegetation communities in like environments may be used as surrogates to extrapolate predicted impacts on identified stream values (Step 3). Available data can also be used for interpreting and assessing the present stream conditions, with regards to physical changes and variability from historic conditions. For example, a comparison of channel bank positions recorded in the oldest to most recent photographs can reveal channel narrowing, thereby complementing the hydraulic and geomorphic indicators of floodplain connectivity and channel adjustments. Any reconstruction of historical changes; however, is highly subject to the quality, quantity, and type of data that is available.

Uncovering existing information is pertinent to the description of physical conditions and community values of the area. The information and data catalogue should emphasize related or relevant aspects of stream physical condition, although water quality or aquatic life data may also be useful. The literature review and desktop analysis of available data sets accompanying the assessment in Step 1 serve to uncover stressors, historical changes (natural or anthropogenic), and possible thresholds at which point the onset of stream degradation or vegetation loss occurred. For example, this may require query of regional data sets to determine how land use has changed or is predicted to change in an urbanizing watershed.

Once the context has been set, stakeholders work together to determine an understanding of the study area and the key values provided by it. This includes identifying community values—historical, current, and potential—whether they are defined as important physical processes, recreational activities, or stream features, which are linked to wider community aspirations and ecosystem services. Stakeholders use the community values and their vision for the watershed or stream to develop an integrated approach to assessing watershed, stream corridor, or reach conditions. Values may be regional or local, as well as dependent on the social and economic context in which they exist.

2.2 Assessment of current conditions

Step 2 involves the assessment of current conditions at the watershed, stream corridor, and reach levels (see Figure 3). First, **step 2a** requires defining the indicators. The assessment should include all the relevant indicators noted in Section 3 to the degree supported by the project goals and available data. The suite of chosen indicators describes the physical conditions and social-ecological values across the study area as well as upstream and downstream in a way that is relevant to the information needs of the assessment, which is determined in **Step 2b**. The intent is that the assessment provides a foundational context and answers key questions such as: What specifically will the assessment be used for? What questions will it seek to answer? The responses to these questions, established in step 2b, guide the vision and outcome of the assessment.

In **Step 2c**, the assessment focuses on prioritizing data and determining data gaps using a combination of data examination, reviewing project purpose, and expert opinion. **Step 2d** is the crux of the assessment due to the selection of metrics, measurements, and data collection methods. This step also includes determining whether a metric will be evaluated remotely or in the field (see Section 1.5). The assessment should include the relevant metrics noted in Section 3 and Appendix A, however, USAP does not mandate including all metrics across each scale. As a part of **Step 2e**, functional characteristics and qualities and maintenance requirements for each metric are determined as well as scoring guidelines. Scores will either be based on discrete criteria or on expert opinion, calibrated by scoring guidelines, and supported by the best available evidence, including professional judgment.

The functional characteristics follow a simple scoring scheme of “fully functional” (3 points), “functional” (2 points), “partly functional” (1 point), or “not functional” (0 points) condition (see Table 5). The scoring scheme for the community values element is similar, although functional qualities and values are scored, rather than condition. The assumption driving this aspect of the assessment is that functional degradation brings about a corresponding reduction in community values and increase in maintenance.

Table 5: Reference condition guidelines used to calibrate the criteria of USAP indicators and metrics

Guideline	Score	Description
Fully functional stream system	3	The condition of the indicator is self-sustaining and supports functional characteristics appropriate to sustain stream physical condition. Minimal, if any, management is required to sustain and protect this level of function given stressors from the modern riverscape/landscape and climate. The variable retains its essential qualities and fully supports physical and social-ecological function.
Functional with moderate maintenance	2	The condition of the indicator is moderately altered and/or degraded by stressors that substantially influence the variable's functionality. The variable still supports natural physical and social-ecological functioning. Frequent management and maintenance are required to sustain the characteristic functional role of the variable.
Partly Functional with active maintenance	1	The condition of the indicator is significantly altered by stressors that impair the indicator variables' ability to support characteristic function and the overall physical condition of the stream. Extensive, consistent active management and maintenance is required are required to sustain the characteristic functional role of the variable.
Not functional with intensive maintenance	0	The condition of the variable is under the influence of severe adverse alterations/stressors. The level of alteration generally results in an inability of the indicator variable to support characteristic functions and/or it otherwise makes the area physically and social-ecologically unsuitable.

Step 2f is the implementation of USAP on a watershed, corridor, and/or stream to evaluate the assessment process, including the application of indicators, metrics, and scoring guidelines. As discussed in Section 1.5, measurement of metrics is based on an integration of GIS and field data field (including rapid or detailed methods). The data should be stored in relational databases that allow for the application of classification, prioritization, and monitoring screening tools. Once the assessment is complete, the data is synthesized and interpreted geospatially in **Step 2g** in order to score the physical condition and social-ecological values in **Step 2h**.

2.3 Diagnostics, Analysis, and Mapping

The final step is summarizing the scoring results and using those results to evaluate risks and to support decision-making efforts. By grouping the metric scores for the indicators under each element, a composite score defines the evidence of current physical function and human alteration. The assessment is then used to indicate the physical condition and social-ecological quality of the study area following the "fully functional," "functional," "partly functional," or "not functional" condition scoring scheme. Step 3 includes a discussion of the study area's characteristics and the limiting factors that overwhelm the functional conditions of the five elements. For example, do reaches show moderate geomorphic function as a result of downcutting, or good lateral migration as a result of very limited channel reinforcement and a wide erodible corridor? In combination, such conclusions can lead to problem identification and an understanding of the risks and a diagnosis of the stressors influencing the morphology indicator under the geomorphology element.

The methods used to implement the mapping generally follow O'Brien and others' 2017 data visualization and condition ranking scheme. The network-based status maps display the scoring results of the metrics, indicators, or elements (see Figure 6). The four colors correspond to the level of functionality following the "fully functional," "functional," "partly functional," or "not functional" condition scoring scheme. The maps help establish a physically realistic understanding of the functional characteristics. They provide consistent, study area-wide visual representations of the assessments to inform strategic stream management practice. The communication of findings using maps is intuitive and simplifies outputs from the assessment of all five elements.

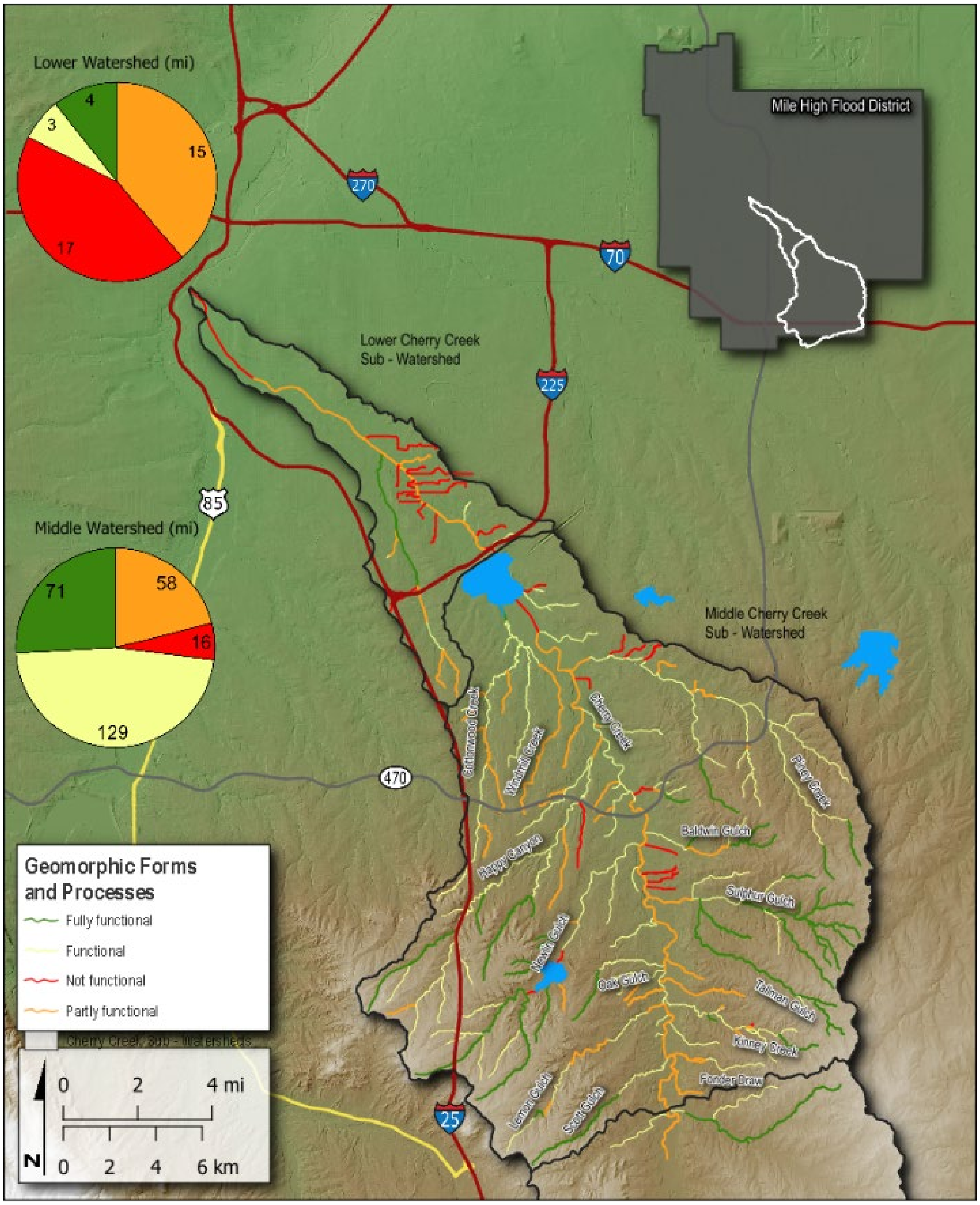


Figure 6: Example network-based status map displaying the scoring results of the geomorphic element in the Cherry Creek middle and lower sub-watersheds.

Following completion of the assessment, practitioners and watershed managers synthesize spatiotemporal data across study sites to interpret trends and determine likely trajectories for watershed or stream changes. The diagnosis and mapping results from Step 2, and any field data and projected trajectories, provide the input for acutely evaluating and interpreting a watershed or a stream's condition. The summation and averaging of scoring results from Step 2 provide a concise synthesis of the overall watershed or riverscape score across all five elements (see Figure 7). The four colors correspond to the level of functionality following the same condition scoring scheme as the individual five elements. This visualization allows quick interpretation of the lowest scoring element (or indicator) as well as the overall condition.

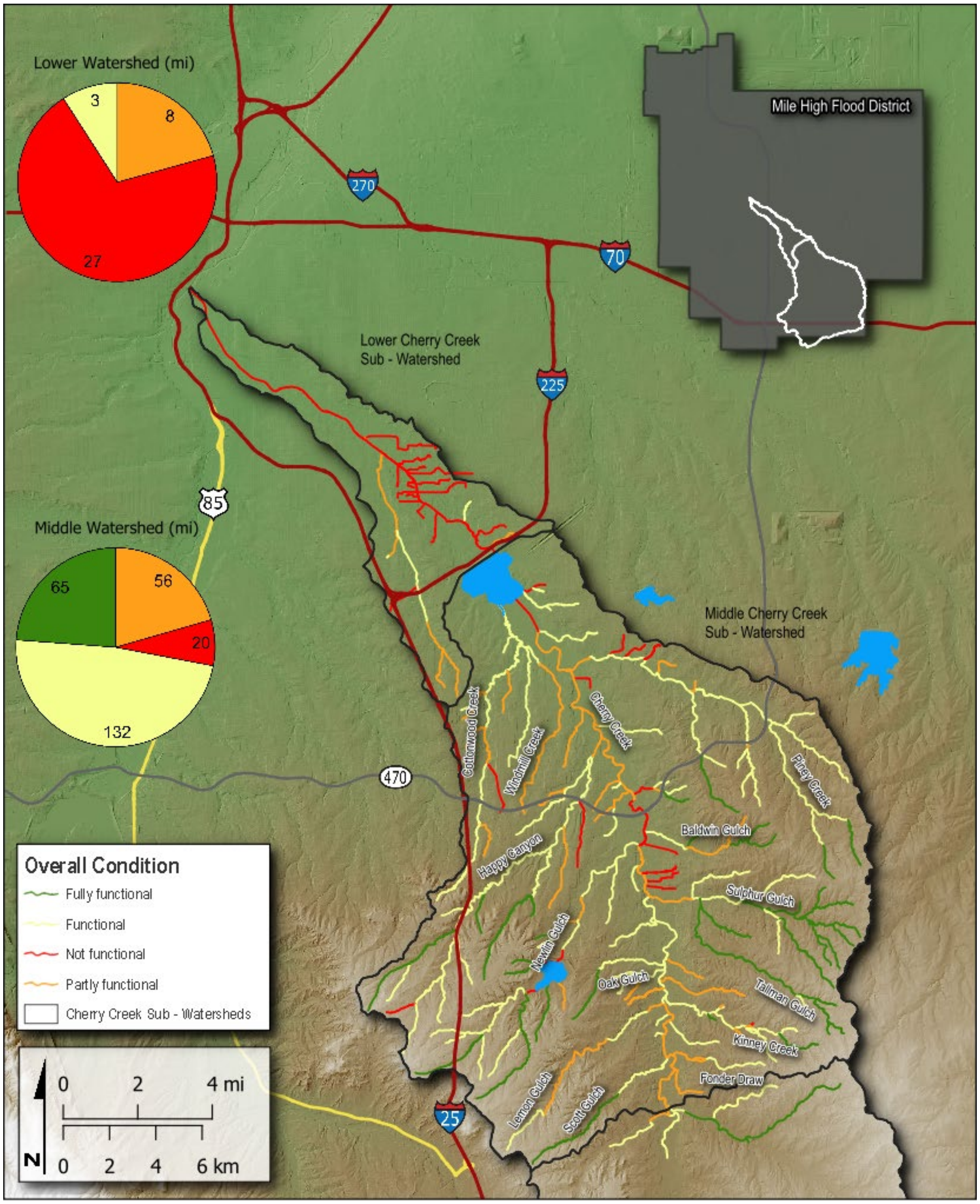


Figure 7: Example network-based status map displaying the scoring results of the overall condition in the Cherry Creek middle and lower sub-watersheds.

2.4 Connection between USAP indicators and stressors

Stressors are human activities (historical or present-day) that impact river health and contribute to impairment. Identifying stressors—the causes of impairment—is a critical first step to understanding which aspects of stream function local stakeholders can feasibly and practically address (see Table 6). While it is understood that adjustments in stream function arise from the influence of numerous 'drivers for change' (i.e., stressors) operating at multiple spatial and temporal scales, causal understanding requires knowledge of a suite of drivers for change rather than a focus on a single causal influence, whether natural or human in origin (Fitzpatrick and Knox, 2000).

Table 6: Stressors on watershed and stream processes and the associated USAP indicators and metrics

	Stressor	Description	Pressures (Problems)	USAP Indicator	USAP Metric
Watershed	Urbanization	Vegetated land converted for commercial/industrial, infrastructure, transportation, or residential use	Flow regime changes	Flow regime	Rate/magnitude, volume, timing
			Sediment loading changes	Sediment regime	Sediment delivery, land-use gradient
	Land use changes	Development and land use changes in the watershed	Increased runoff	Flow regime	Rate/magnitude, volume, timing
			Sediment imbalances	Sediment regime	Sediment delivery potential, land-use gradient
	Hillslope erosion	Sediment supply from eroding hillslopes	Increased runoff	Flow regime	Rate/magnitude, volume, timing
			Sediment imbalances	Sediment regime	Sediment delivery potential
	Dam and reservoir operations	Peak flow reduction and baseflow augmentation caused by normal reservoir operations	Flow and sediment regime changes	Flow regime	Rate/magnitude, volume, timing
				Sediment regime	Sediment continuity
	Surface water diversions	Flow diversions to support agricultural and municipal needs	Flow and sediment regime changes, dry up points, fish passage barriers, Irrigation return flows	Flow regime	Rate/magnitude, volume, timing
				Sediment regime	Sediment continuity
Corridor/Reach	Urbanization	Riparian land converted for commercial, transportation, or residential use	Artificial bank erosion, fine sediment entrainment	Sediment regime	Sediment delivery potential, land-use gradient
	Infrastructure	Roads, railroad, trails and bridges in riparian and channel area	Roads, railroads, trails and bridges disconnect riparian and channel areas	Stream Dynamics	Artificiality
				Sediment regime	Sediment continuity
	Levees	Levees, high banks, raised parallel roads, and/or artificial embankments	Disconnect streams, loss of riparian vegetation	Floodplain connectivity	Floodplain connectivity ratio
				Stream Dynamics	Artificiality
	Channelization	Modified stream planform and geometry with decreased sinuosity and stream length to improve flow conveyance	Straightening and dredging channels increases flow and sediment transport	Stream Dynamics	Planform, profile, confinement
	Bank/channel armoring	Stream segments stabilized with engineered structures, armored banks (e.g. riprap)	Increased flow and reduced sediment input	Stability	Channel stability index
	Channel spanning structures	Diversion structures, dams, weirs, vanes, spurs	Fish passage barriers, sediment continuity	Stream Dynamics	Geomorphic functionality
	Aggregate mining	In-channel or floodplain aggregate mining and largescale excavation, gravel pits/ponds	Channel bed degradation, increased sediment loading, sediment transfer downstream	Stability	Channel stability index
	Riparian vegetation removal	Riparian land altered to support agricultural or urban uses	Hillslope, bank, and channel erosion; localized channel adjustment; reduced diversity and resilience	Resiliency	Composition

	Woody material removal	Channel/floodplain debris removal or diminished wood recruitment	Localized bank and channel erosion, localized channel adjustment, limited flow attenuation, limited structural diversity	Stability	Channel stability index
				Resiliency	Diversity
	Exotic plant species/weeds	Exotic plants present in riparian area	Limited diversity, non-resilient plants, decreased riparian habitat	Dynamic stability	Cover
	Unknown stressor(s)	The dominant source of the impairment is unknown or not listed	Non-point source runoff/sediment		

3. Indicators and Metrics

The assessment of the five elements includes selecting a diverse set of indicators and metrics for every element. Indicators are summary variables that provide a gauge or meter, and often they are indicative of a suite of more complicated, interactive processes, patterns, or conditions. Indicators are useful because they offer a simpler way to communicate and describe overall trends or levels. They also serve to foster an understanding of cause-and-response relationships at and between the various scales present in complex urban stream systems. In this way, indicators provide comprehensive baseline data from which to assess a stream's physical condition and its potential trajectories, and to develop a clear understanding of stressor-impairment (i.e., cause-effect) relationships. When evaluated collectively, these indicators comprehensively describe stream condition by diagnosing the severity, extent, and causes of impairment. This in turn provides insight into a stream's performance and maintenance requirements.

USAP includes 16 indicators that influence stream condition, which together cover the spectrum of USAP's five core elements (see Figure 8 and Table 7). The metrics associated with each indicator, detailed below and in Appendix A, are measurable features or attributes that allow for a reasonable and practical means of identifying the presence or absence of a particular function (Fischenich 2006). For example, in an assessment of a stream's hydraulic characteristics, the stream's ability to convey the full spectrum of flows accessing the floodplain can be measured and graded. In this process, it is also important to balance the need to incorporate relevant and valuable data into indicators and metrics with the level of effort required to review and compile those data and its relative value to accurately assessing the conditions and values. Thus, the selection of indicators and metrics accounts for project proponents and community priorities, difficulty of associated methods, data availability, and scoring usefulness. **To the extent practical, all indicators in the assessment procedure should be evaluated to obtain a relative measure of functionality**.

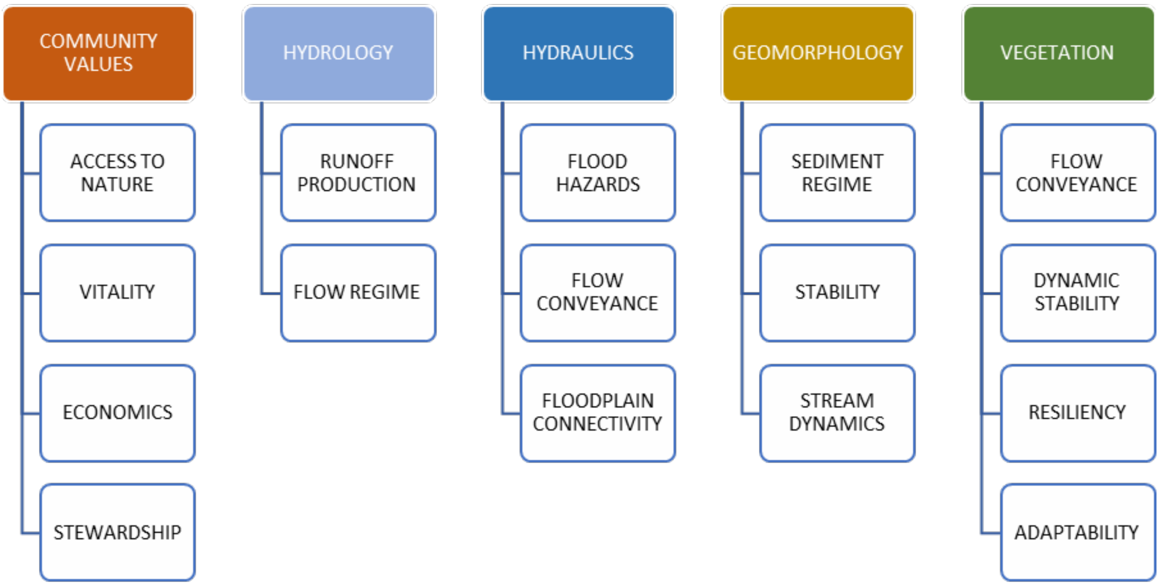


Figure 8: USAP five elements and indicators

Of note, some indicators are measured across multiple spatial scales, for example at watershed, corridor, and reach scales, whle others are only relevant to specific spatial scales. This is noted with the descriptions of each indicator in the sections below.

Table 7: Summary table of USAP's indicators and metrics that are applied across multiple scales to assess stream physical conditions and community values

Element	Indicators	Metrics	Scale	Assessment methods	Description	Example references
Community values	Access to nature	Gaps in natural space availability	Watershed	• Remote sensing: identification natural areas	Identifying gaps in public park availability across the watershed or corrdior using a demographic profile to identify gaps with the most urgent need for public parkland and natural space opportunities. Determining access to nature (parks, open space, river corridors, etc.) via multi-modal transit.	TPL 2017
		Natural space opportunities**	Corridor & reach	Field observations: proximity to natural areas		TPL 2017
		Universal access				TPL 2017
	Vitality (health, comfort, & wellbeing)	Safety and security	Watershed, corridor, & reach	• Remote sensing: identification and measurement of demographics and environmental and health hazards • SVI and UHI indices data:	Evaluating perceived safety considering health, birth, death, and crime data. Mapping locations of environmental and health hazards, social vulnerability index, and urban heat island (UHI) index data. Understanding aesthetic and experiential conditions.	COEPHT 2021
		Environmental and health hazards				COEPHT 2021
		Social vulnerability index**				CDC/ATSDR 2018
		Urban Heat Island Index	Corridor & reach			TPL 2018
		User experience				
	Economics	Maintenance costs**	Corridor & reach	• Desktop analysis, remote sensing-GIS, and database review	Evaluating infrastructure operation and maintenance costs; supporting/recognizing local government economic plans and development goals	
		Community development				SDO 2021; DOLA 2021
	Stewardship of natural resources	Water quality compliance**	Watershed, corridor, & reach	• Desktop analysis, remote sensing, and databases • Community interviews • Field observations	Compliance with local, state, and federal WQ standards; community involvement and activities that support watershed stewardship efforts and management; conservation/preservation measures to protect and enhance natural resources.	CDPHE 2020
		Community stewardship efforts				PPS 2012
		Watershed or stream protection				TPL 2017
Hydrologic processes	Runoff production	Land-use gradient	Watershed	• Remote sensing: hydrologic data and analyses • Database of SCMs	Refers to departure from historical LULC and the associated change in quantity of water supplied to urban streams from the surrounding landscape that is influenced by land use and stormwater control measures (SCMS).	Brown and Vivas 2005
		Flow alteration	Corridor			Poff et al. 2010
		Flow attenuation**	Reach			MHFD 2017
	Flow regime	Flow regime change**	Corridor	• Hydrologic data and analyses	Evaluation of changes in flow regime along the stream corridor under existing conditions. Evaluation of the pattern of peaks in the hydrograph and deviation of annual net rate, volume, and frequency using multi-spectrum flows (base flow, 2-year, 5-year, 10-year, 50-year, and 100-year). Flashiness considers impacts to the rate at which discharge varies over time while variability anticipates the seasonal changes in streamflow.	Poff et al. 2010
		Rate/magnitude	Reach			USGS 2019
		Volume				MHFD 2017
		Frequency				USGS 2019
		Flashiness (rate of change)				Baker et al. 2004
		Flow variability (timing /seasonality)				Poff et al. 2010
Hydraulic characteristics	Flood/fluvial hazards	Structures in broad floodplain	Watershed	• Remote sensing: flood and fluvial hazard data • Hydraulic analyses • FHZ protocol	Refers to structures and infrastructure within the floodplain, stream management corridor, and fluvial hazard zone that has the potential to be harmed by the present flow regime.	MHFD 2021
		Structures in stream mgmt. corridor	Corridor			MHFD 2020
		Structures in regulatory floodplain**	Reach			MHFD 2021
		Structures in fluvial hazard zone**				Blazewicz et al. 2020
	Flow conveyance	Channel and floodplain capacity**	Reach	• Field observations • Hydraulic data and analyses • Database of CS structures	Evaluation of the capacity and space available for a channel and floodplain to convey the full spectrum of flows. Presence of crossing structures that restrict conveyance of flows.	MHFD 2017
		Crossing structure capacity				MHFD 2017
	Floodplain connectivity	Floodplain connectivity ratio**	Reach	• Remote sensing: hydraulic data and modeling • Field survey	Refers to the degree to which water inundates and activates the adjacent riparian corridor.	Macfarlane et al. 2018
		Overbank return interval				MHFD 2017
		Entrenchment ratio				Rosgen 1994

Element	Indicators	Metrics	Scale	Assessment methods	Description	Example references
Geomorphic forms & processes	Sediment regime	Sediment delivery potential	Watershed	Remote sensing, geospatial analyses	Refers to the timing, and magnitude, of sediment entering and moving through the fluvial system.	NRCS 2008
		Sediment supply (land-use gradient)				Brown and Vivas 2005
		Corridor sources	Corridor	Field survey		Fryirs 2017
		Sediment continuity		Database of CS structures		USACE 2021
		Sediment transport capacity**	Reach	Modeling		Stroth et al. 2017
	Stability	Resilience	Watershed	Remote sensing, database of stressors	Refers to balance between fluvial processes and channel form. Identifying stressors that would impede the physical movement/ adjustment of the stream or the recovery of critical components. Patterns, levels, and rates of dynamic processes considering landscape setting, including lateral migration and bank stability.	Parsons & Thoms 2018
		Stream power gradient	Corridor	Modeling		Yochum et al. 2017
		Lateral migration		Field survey		O'Brien et al. 2019
		Channel stability index**	Reach	Field survey		Simon and Downs 1995
	Stream Dynamics (Morphology)	Floodplain fragmentation	Corridor	Geospatial analyses	The geologic and topographic influences and anthropogenic stressors from the watershed. Define and evaluate process domains that influence stream shape at the watershed scale. Evaluation of the existing physical template both within the channel margins and the channel corridor.	Macfarlane et al. 2018
		Profile		Historical long. profiles		USGS 1998
		Geomorphic functionality (continuity, bed forms, cross-section)	Reach	Field survey Historical cross sections		Rinaldi et al. 2013
		Artificiality (bank protection, stream planform, levees/embankments)**		As-built plans, database of structures		Rinaldi et al. 2013
		Channel adjustments (pattern, width, bed, SEM stage)**		Historical information, cross sections, pebble counts		Rinaldi et al. 2013; Cluer & Thorne 2014
Vegetation structure & processes	Flow conveyance	Riparian zone woody cover	Watershed	Remote sensing	Vegetative encroachment that could adversely raise surface water elevations during flood events. Defines the composition, cover, and structure of vegetation that can impede conveyance within the channel and under infrastructure (culverts, etc.) potentially resulting in large increases in water surface elevations within the riparian corridor during flood events.	DRCOG
		Clogging of crossing structures	Corridor & reach	Field survey and/or observations Hydraulic data		
		Floodplain roughness value consistency				RESPEC 2021; USGS1989
		Vegetation cover in the channel**				
	Dynamic stability	Vegetation cover	Watershed	Remote sensing	Vegetation composition and cover along streambanks influence erosional processes and sediment supplies. Characterize existing vegetation communities and cover to illustrate the balance between channel and floodplain processes.	
		Riparian extent				
		Vegetation cover**	Corridor & Reach	Field survey and/or observations		
		Woody vegetation cover**				
		Wetland community cover				
		Vegetation vigor				
		Bank stability				
		Streamside buffer width				
		Riparian extent**				
	Resiliency	Noxious weed cover**	Corridor & Reach	Remote sensing Field survey and/or observations	Changes in flow regimes and surrounding land use can lead to shifts in plant communities and upland plant encroachment into riparian zones. Identify areas with sparse or stressed vegetation that may lack erosion resistance.	
		Riparian functional traits				
		Riparian plant richness				
		Wetland plant richness				
	Adaptability	Number of plant communities**	Corridor & Reach	Remote sensing Field survey and/or observations	The ability of riparian ecosystems to adapt to changing environmental conditions. Determine areas of vegetation not dominated by native, riparian-adapted communities.	
		Number of structural layers				
		Riparian woody recruitment**				

** Indicates core metrics that should be quantified for reach-scale assessments

3.1 Community Values Indicators and Metrics

Community values, which include the built environment and social-ecological systems, encourage stewardship of our waterways by integrating experiential, aesthetic, and cultural attributes that foster appreciation for streams as natural systems in the built environment. This human connections and values element consists of four indicators: **access to nature, vitality, economics**, and **stewardship of natural resources**. See the community values methods sheet in **Appendix A** for further information. Each of these metrics can be assessed at all three spatial scales: watershed, stream corridor, and reach.

3.1.1 "Access to Nature" Indicator

The presence of and universal access to green spaces, natural areas, parks, trails, and waterways is a value that the District and local governments value and integrate into projects when supported by the community. The access to nature indicator is described by three metrics: **Gaps in natural space availability, natural space opportunities, and universal access.** Those three metrics can be evaluated at the watershed, stream corridor, or reach scales. The "gaps in park and open space availability" metric considers the equity of services and experiences associated with a stream. Are there trails, and other means of accessing natural spaces, reasonably spaced throughout the watershed, and if not, what gaps can be identified across the landscape? The "natural space opportunities" metric evaluates the mapped locations of proposed parks and open spaces, vacant lands, natural land cover, and riparian corridor in an effort to identify potential natural space opportunities for land use. The "universal access" metric measures the composition of a watershed or stream to understand how it can be accessed, understood, and used to the greatest extent possible by all people regardless of their age, size, or ability.

3.1.2 "Vitality" Indicator

The vitality indicator is a gage of the health, comfort, and wellbeing afforded by a watershed to the public. Urban streams provide a means of promoting the physical, mental, emotional health of people within their communities. At the same time, these natural areas work to encourage a positive public mindset for outdoor spaces. Encourages Environmental Justice Positive public mindset of area Aesthetic/experience (i.e. people want to be there because it's a nice place)

The vitality indicator is described by five metrics: **safety and security, environmental and health hazards, social vulnerability index, urban heat island (UHI) index, and user experience**. The first three metrics can be evaluated at the watershed, stream corridor, or reach scales. The urban heat island index and user experience metric are considered at the corridor or reach scale. "Safety and security" evaluates the perceived safety of a stream-adjacent area, considering data on health, birth, death, and crime at the watershed-scale to neighborhood scale. The "environmental and health hazard" metric leverages mapped locations and severity of hazards, including such things as toxic elements or mosquito or other vector sites.

The "Social Vulnerability Index" (SVI) metric uses from demographic data from the U.S. Census to map an understanding of the relative vulnerability of communities in an area and the level of need for assistance that would result in the event of a natural or man-made disaster, by utilizing such information as distances to public services. The "Urban Heat Island Index" (UHI) is a measure of heat absorbing surfaces, heat- generating activities, and the absence of natural elements such as trees to provide shade. Accordingly, the risk of heat-related mortality is higher in dense urban areas. This metric assesses the natural shade density of an area via tree coverage, the percentage of impervious surfaces along a stream corridor in comparison to rural areas, and leverages the Urban Heat Indices.

The "user experience" metric is a reach-scale evaluation of the aesthetic experience and perception of a stream and it's adjacent land. Through field observation and remote sensing-GIS, this metric examines the land use and zoning for adjacent areas, the presence of desirable amenities and services in those areas, the sightlines offered, and the balance of maintaining appropriate natural river edge types that also facilitate access to the river and river condition.

3.1.3 "Economics" Indicator

The economics indicator, which can be assessed at all three spatial scales, involves evaluating the costs of infrastructure and maintenance along a watershed, and assessing plans for community development. It incorporates two metrics: **maintenance costs** and **community development**.

The "maintenance costs" metric relies on reviewing precedence project comps (i.e., similar projects costs), projected operation costs (evidence-based projection), order-of-magnitude maintenance and operation costs, staff interviews and maintenance records and documentation. This metric can also consider infrastructure condition assessments, cost/benefit analysis and consultant expert opinions and cost estimates.

The "community development" uses historical and present-day information to study property values and trends and remote sensing to evaluate equity mapping along the corridor based on equity index and demographics, economic conditions. Local government planning records, such as city long range development plans, can also be reviewed to identify recent developments or upcoming development plans, future redevelopment, economic development districts, and brownfield redevelopment.

3.1.4 "Stewardship of Natural Resources" Indicator

The Stewardship and natural resources indicator is a measure of … it is made up of several metrics: **compliance with water quality standards, community stewardship efforts, watershed, stream corridor, or reach protection and management.**

The metrics for "compliance with water quality standards" and "community stewardship efforts" can be assessed at the watershed, stream corridor, and reach scales. The former examines whether the watershed meets or exceeds federal, state, or local water quality-based regulatory standards for the area, while the latter utilizes outreach to community members to assess the level of stewardship geared toward to positive change for the watershed, corridor, or reach.

The watershed, stream corridor, or reach protection and management metric considers stewardship practices that preserve or enhance stream systems and development patterns that encourage sustained 'natural function'. The metric includes accounting for development criteria that encourages green space, floodplain preservation, natural infrastructure and monitoring/reporting for air/water/soils quality and recent development or upcoming development plans such as SDPs that encourage or require preservation or enhancement of upland and/or riparian habitat areas.

3.2 Hydrologic Processes Indicators and Metrics

Hydrologic processes are responsible for the distribution of precipitation throughout the watershed. These processes determine the ratio of precipitation that reaches the stream through surface runoff and subsurface inflow, after losses due to interception and depression storage on the surface and infiltration into the subsurface. Assessing the function of hydrologic processes, we look to two main indicators: runoff production and flow regime. See the hydrology methods sheet in **Appendix B** for further information.

3.2.1 "Runoff Production" Indicator

Land and water use in a watershed may adversely affect runoff production and the associated total net volume of water supplied to a stream corridor and its reaches, or alter the pattern of the hydrograph by impacting peak flows, low flows, and rates of change. The runoff production indicator is described by three metrics: **land-use gradient, flow alteration**, and **flow attenuation**.

The methods applied to the land-use gradient (landscape and riverscape attributes) metric includes identifying and quantifying land use cover types using the land development index (LDI) and/or impervious cover. The analysis should leverage mapping of watershed (and sub-watershed) geospatial characteristics, such as land-use land-cover (LULC) and soil types, and measuring changes in stream density through stream order. Flow alteration is evaluated at the corridor scale to account for changes in runoff production caused by interventions such as dams, diversions, storm drains, spillways, retention basins, etc. The methods applied to the flow alteration metric include the quantitative evaluation of reduced/increased runoff caused by interventions, or the qualitative assessment of interventions in the absence of adequate data.

The methods applied to the flow attenuation metric include a qualitative evaluation of the effectiveness caused by stormwater control measures (SCMs) to preserve the natural flow regime or a qualitative assessment based on the presence of SCMs and their use(s). The analysis should consider management practices that both infiltrate and attenuate flows (e.g., grass swales, local detention facilities, increasing pervious surfaces) and identifying existing regional detention facilities.

3.2.2 “Flow Regime” Indicator

Changes in hydrologic processes resulting from urbanization influence the levels of discharge to the stream network. This can include upstream development, water use changes, or changes to regional storage facilities. Flow featuring different recurrence intervals can shape various aspects of the channel morphology and vegetation structure. At the stream corridor scale, one metric is applied to describe the flow regime indicator: **change in flow regime**. Change in flow regime is the evaluation of changes in flow regime along the stream corridor under existing conditions, including anthropogenic impacts such as diversions, groundwater wells, and unnatural inflow (e.g., urban drool).

At the reach scale, five metrics are used: **rate/magnitude, volume, frequency, rate of change (flashiness), and timing (seasonality)**. The “magnitude” (or, “peak flow”) metric rates impairment to the magnitude, timing, and duration of low- and high-flow events. The method assesses changes to the pattern of peaks in the hydrograph and deviation from the annual net peak flow discharge compared to geomorphically relevant thresholds. The “total volume” metric rates the net annual change in water volume caused by depletion and/or augmentation as a percentage of natural flows. The “frequency” metric takes account of number of times in a given period that peak flow is exceeded. “Rate of change” considers impacts to the rate at which discharge varies over time, with the method based on the “flashiness index” such as Richards-Baker Flashiness Index, while the “seasonality” metric assesses the start and end dates of certain flows (e.g., fall pulse, base flow, spring recession) due to various inputs including snow, snowmelt, heavy rainfall, or dry periods, compared to baseline seasonal variability of streamflow.

3.3 Hydraulic Characteristics Indicators and Metrics

Hydraulic characteristics are the influences that streamflow behavior has at specific locations that typically originate from human impact. The mechanics of streamflow and the power of flowing water cause fluvial and floodplain hazards and effect the connection to the riverscape extent. Assessing the function of hydraulic characteristics, USAP includes three indicators: flood/fluvial hazards, flow conveyance, and floodplain connectivity. See the hydraulics methods sheet in **Appendix C** for further information.

3.3.1 “Fluvial and/or Pluvial Flooding” Indicator

Urban flooding is becoming more frequent and persistent, with increasingly serious physical, economic, and social impacts (ASFPM Foundation 2019). The “flood/fluvial hazards” indicator accounts for the hazards associated with urban flooding and fluvial processes by identifying high risk areas. It does so by assessing the number of structures located within high-risk flood zones at all three spatial scales. At the watershed scale, "**structures in the broad floodplain**" are identified by remote sensing-GIS or through a hydraulic model. Likewise, within the stream corridor, "**structures in the stream management corridor**" are measured through remote sensing-GIS or desktop analysis, as are "**structures in the regulatory floodplain**" and/or "**structures in fluvial hazard zone (FHZ)**" at the reach scale. Each of these metrics give a relative sense of increases in flood or fluvial hazards in these zones.

3.3.2 "Flow Conveyance" Indicator

Healthy streams and floodplains provide several important functions and benefits, including the conveyance of baseflows and storm runoff. Stream corridors often provide an important service in flood conveyance in urban areas. As a public safety issue, the conveyance capacity of a stream should be maintained for the various flows described under the flow regime indicator. A reach-scale assessment of the "flow conveyance" indicator is most useful, and it is described by two metrics: **riverscape (channel and floodplain) capacity** and **crossing structure capacity**. The riverscape capacity is an evaluation of the capacity and space available for a riverscape to convey the full spectrum of flows, which can be assessed through hydraulic models or by remote sensing-GIS. Crossing structure capacity is a measurement of level of service of flow through constrictions; a hydraulic model can illuminate to what extent a stream is capable of conveying the full spectrum of flows given the degree of transverse structures present.

3.3.3 "Floodplain Connectivity" Indicator

An assessment of floodplain connectivity characterizes the degree to which water inundates and activates the adjacent riparian corridor. The "Floodplain Connectivity" indicator is a proxy measure of the extent and frequency with which flows interact with the channel and adjacent floodplain. This interaction is critical for creating and maintaining a healthy stream corridor because riparian vegetation throughout the floodplain can extend inundation residence times by attenuating and slowing flows through the system. Floodplain connectivity varies naturally based on geology, topography, hydrology, and the sediment regime. It also reflects impediments due to hydromodifications, channel modifications (e.g. enlargement, entrenchment, or channelization), and/or anthropogenic land uses within the floodplain (e.g. levees, drainage ditches, development, or fill) that limit hydrogeomorphic interactions between the channel and its floodplain.

The floodplain connectivity indicator is evaluated at the reach scale only and is described by two metrics: **floodplain connectivity ratio** and **entrenchment ratio**. When modeling data is available, the overbank return interval can also be used to measure floodplain connectivity. The floodplain connectivity ratio is an evaluation of the presence (or absence) of a modern floodplain and hillslope–stream corridor connectivity presence and length of any elements of disconnection (e.g., roads) along each stream side. It rates the accessible extent of the active floodplain relative to the maximum potential accessible floodplain. The active floodplain is defined as the extent to which flows can access the land adjacent to the river, whereas the maximum potential accessible floodplain can be determined using the Valley Bottom Extraction Tool (VBET; Gilbert et al., 2016), with the assumption that without impairments, the floodplain would occupy the entire valley floor. The entrenchment ratio measures the vertical containment of the stream. It is the ratio of the width of the flood-prone area to the surface width of the bankfull channel (flows > Q2 overtop low flow channel).

3.4 Geomorphic Forms and Processes Indicators and Metrics

Geomorphic processes inform the response of a stream to water and to sediment inputs from the watershed, which in turn, define the location, shape, and form of the active channel and floodplain within the landscape. USAP suggests three indicators to evaluate the geomorphic character of a stream: **sediment regime, stability**, and **stream dynamics** (or morphology). See the geomorphic methods sheet in **Appendix D** for further information.

3.4.1 "Sediment Regime" Indicator

Sediment is a natural component of the river and stream systems. Too much or too little will cause an imbalance in a stream's physical processes – a stream is always trying to balance its energy inputs and outputs. When a stream 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 stream finds its own sediment sources. When sediment is in excess it builds up on stream bottoms or floodplains, buries geomorphic features, and increases flood hazards.

The sediment regime indicator describes the timing and magnitude of sediment entering and moving through the fluvial system. In other words, the sediment regime describes how sediment is produced, how it enters the stream, and how it is subsequently transported and deposited. When the processes that influence the sediment regime are altered, the geomorphology of the stream may be adversely impacted. The sediment regime indicator is described by five parameters: **sediment delivery potential, sediment supply, corridor sources, sediment continuity**, and **sediment transport capacity**. "Sediment delivery potential," a measure of prospective erosion, and "sediment supply," a measure of changes to sediment sources over time, are assessed at the watershed scale, and rely on analyzing the geology, soils, and land use. "Corridor sources," a measure of how much the amount of sediment produced by channel erosion and incision has changed over time, and "sediment continuity," a measure of the density of unnatural impediments to sediment transport and the proportion of the watershed in which sediment transport is unnaturally blocked, are assessed at the stream corridor scale through remote sensing-GIS, desktop analysis, and field survey. And finally, "sediment transport capacity," a measure of the trends of erosion and sedimentation and local zones of erosion within a channel, is assessed at the reach scale through modeling and analysis.

3.4.2 "Stability" Indicator

The stability indicator refers to a balance between fluvial processes and channel form, for example, does the channel have a suitable width, depth, and slope to accommodate the water and sediment discharges characteristic of the stream? While channels continuously change, this indicator analyzes whether the system is trending towards equilibrium. The stability indicator is described by four metrics: **resilience, stream power gradient, lateral migration**, and the **channel stability index**. The "resilience metric," assessed at the watershed scale, examines stressors that impede a stream's ability to physically adjust to changes and might hinder the recovery of critical components. "Stream power gradient" and "lateral migration," assessed at the corridor scale, evaluate potential hotspots of erosion or sedimentation via changes in stream power and by looking at the extent to which the margins of the stream corridor prevent the channel from lateral adjustments. Finally, the "channel stability index," assessed at the reach scale, is a ranking scheme that follows the rapid geomorphic assessment (RGA) methods (Simon and Downs 1995, Kline 2010), which examines several factors relevant to stability, like bed material, bed/bank protection, degree of incision, bank erosion, bank instability, and bank accretion.

3.4.3 "Stream Dynamics" Indicator

The stream dynamics (also referred to as morphology) indicator analyzes the historic and existing morphology of streams, as well as the geologic and anthropogenic controls on the stream. It assesses the underlying processes of the channel to determine if the existing physical template is conducive for geomorphic functionality. The stream dynamics indicator is described by five metrics:, **floodplain fragmentation, profile, geomorphic functionality, artificiality**, and **channel adjustments**. Floodplain fragmentation and profile are assessed at the stream corridor scale, and geomorphic functionality, artificiality, and channel adjustments are assessed at the reach scale.

Metrics at the stream corridor scale assess geomorphic variables such as hillslope–corridor connectivity and quantification of the channel's ability to access its floodplain, in addition to tracking profile changes to identify the existing conditions and how the channel has adjusted in the past. Measuring the stream dynamics metrics at the reach scale can be done by applying multiple sub-metrics for each of the three metrics.

> Geomorphic functionality includes measuring three geomorphic properties: **continuity, channel bed forms**, and **geometry** (i.e., **cross section)**. The continuity metric accounts for the presence of longitudinal crossing structures that potentially alter natural flux of sediment along the reach while the bed forms and cross section metrics evaluate the channel forms and processes that inform planform and cross-sectional shape expected for that stream type and alteration of its natural heterogeneity.
>
> The artificiality metric includes three sub-metrics: **bank protection, stream planform**, and **levees/embankments**. The bank protection sub-metric measures the length of protected banks (walls, riprap, gabions, spur dikes, bioengineering measures, etc.) that prevent lateral migration. The stream planform sub-metric describes the artificial changes of a stream or river course due to anthropogenic modifications such as meander cutoffs, relocation of stream channel, or straightening of the stream channel. The levee and embankment sub-metric accounts for the presence of manmade levees and/or embankments close or in contact with the active stream corridor or floodplain.
>
> The channel adjustments metric includes four sub-metrics: **pattern, width, bed**, and **SEM stage**. The pattern sub-metric measures the adjustments in channel pattern from a historical reference point while the width sub-metric measures the average change in channel top width, bankfull or active channel widths. The bed sub-metric measures channel bed-level adjustments from a reference point. The SEM stage sub-metric accounts for the evolutionary stage and trajectory of stream adjustment to hydrogeomorphic attributes.

3.5 Vegetation Structure and Processes Indicators and Metrics

Vegetation structure and processes within a watershed support stream dynamics and stability, provide flow resistance and filtering, improve infiltration, and create habitat. To understand and evaluate the structure and processes of riparian and upland vegetation, USAP has identified four indicators: **flow conveyance, dynamic stability, resilience**, and **adaptability**, each of which can be assessed at all three spatial scales. See the vegetation methods sheet in **Appendix E** for further information.

3.5.1 "Flow Conveyance" indicator

Vegetation density and structure can impede the conveyance of a diversity of flows if not actively managed. The flow conveyance indicator reflects the influence of woody vegetation on stream hydraulics via roughness. Roughness in urban streams is often measured by Manning n-value. USAP considers the n-value range prior to any increase in water surface elevation for both existing and planned (or future) conditions. Openings to bridges and culverts are also an important metric to consider due to encroaching trees and shrubs. Woody cover is measured to determine if trees and woody vegetation bring the n-value below the desired threshold.

The flow conveyance indicator is described by four metrics: **riparian woody cover, clogging of crossing structures, floodplain roughness value consistency**, and **vegetation cover in the channel**. The "riparian woody cover" metric is assessed at the watershed scale by analyzing the percentage of riparian corridor occupied by woody vegetation. The "clogging of crossing structures" is assessed at the reach scale by measuring the number of structures such as bridges and culverts that are blocked by encroaching trees and shrubs as well as sediment deposition. The "floodplain roughness value consistency" is assessed at the reach scale by evaluating the existing or future conditions roughness value ranges before causing a rise in water surface elevation as compared to modeled or historical conditions. The "vegetation along the channel" is assessed at the reach scale by measuring the vegetation composition, density, and height.

3.5.2 “Dynamic Stability” indicator

Riparian vegetation’s potential to increase bank stability can have profound impacts on channel morphology and dynamics, particularly in low-energy systems (Gran et al. 2015). The net effect of vegetation on channel dynamics depends on both the energy of the system and the strength of vegetation (Gurnell et al., 2012). When riparian vegetation is in an early-life state, before it has a chance to develop a root network and become more resistant to flows, it has a higher likelihood of being destroyed. Once vegetation is well-established, its chances of survival are much higher and the channel and flows must work harder to remove it, slowing lateral migration and potentially affecting channel planform (Corenblit et al., 2009). In a system where hydrology or sediment loads are changing, the relationship between vegetation and channel dynamics should evolve with time as well (Gran et al., 2015). When riparian vegetation extends from stream edges to overbank areas (also known as the “floodfringe”) it stabilizes soil during flood events. The width of the riparian vegetation (in contrast to upland grassland) within a corridor is a reasonable metric through which to approximate stability when compared to its the potential width. Areas of encroachment that have narrowed the riparian corridor are also a measure of stability. Other measurements include vegetation vigor, root depths exceeding bed erosion (inferred by noting species), and appropriate cover of diverse, native vegetation communities.

The dynamic stability indicator is described by eight metrics: **vegetation cover, woody vegetation cover, wetland community cover, vegetation vigor, bank stability, streamside buffer width,** and **riparian extent**. The “riparian extent” and “woody vegetation cover” are measured at the watershed scale through remote sensing and GIS analyses to assess to what extent a watershed exhibits a wide, connected, functional riparian vegetation zone with a cover and composition of shrub and tree vegetation in the riparian zone. The other metrics are all assessed at the corridor and reach scale. “Vegetation vigor” assesses the degree of vegetation senescence either stress or age-induced while the “bank stability” metric defines the ability of vegetation along the channel banks to withstand erosional forces. The “streamside buffer width” metric describes the width of the wetland and riparian plant communities within the valley bottom. The width of the valley bottom that includes connected wetland, riparian, and upland plant communities is measured via the field-based “riparian extent” metric.

3.5.3 “Resiliency” Indicator

Riparian vegetation provides elastic structural support against erosive forces and improves infiltration and filtering. Vegetation along urban streams is considered resilient when it is capable of withstanding typical high annual peak flows and bouncing back. Resilient riparian vegetation is typically dominated by native, riparian-adapted assemblages or vegetation such that vegetation has adequate cover and deep root structure. Metrics for this indicator include **noxious weed cover**, **riparian functional trait, riparian plan richness,** and **wetland plant traits**; and are all measured at the corridor and reach scale. Through field observations and remote sensing, practitioners measure the absolute cover of noxious weeds in vegetation communities. The “riparian functional trait” metric defines the presence and cover of vegetation with traits adapted to withstand flood disturbance, inundation, and shallow groundwater tables while the “riparian plant richness” metric defines the number of different individual species that occur in the wetland, riparian, and upland communities in the valley bottom. The “wetland plant richness” metric defines the number of different individual species occurring in the wetland community only.

3.5.4 “Adaptability” Indicator

Riparian vegetation communities can adapt to changes in physical processes, like hydrology, as well as biological and chemical inputs. Assessing a vegetation community’s adaptability involves determining whether it has enough amplitude to adjust to the typical array of long-lasting chronic changes over time. Metrics such as **number of plant communities, number of structural layers,** and **riparian woody recruitment** provide responses to that question. All three metrics are measured at the corridor and reach scales.

The “number of plant communities” metric defines the number of distinct plant communities present in the riparian zone including wetland, riparian, and upland while the “number of structural layers” metric defines the vertical structural layers present at the reach scale. The riparian woody recruitment metric identifies whether native woody recruitment is present to replace aging shrubs and trees.

4. The Urban Stream Assessment Procedure Workbook

MHFD developed a Microsoft Excel Workbook to document the multiple parts of USAP. The USAP workbook (MHFD_USAP Workbook_v15 for distribution.xlsx) is comprised of 10 worksheets (tabs). The USAP workbook includes a tab for each element – Community values, Hydrology, Hydraulics, Geomorphology, and Vegetation. This workbook can be used to guide the selection of indicators and metrics to obtain a relative measure of functionality, which in turn, provides insight into a stream's performance and maintenance requirements. There are no macros in the workbook and all formulas are visible, though some worksheets are locked to prevent editing. The workbook can be used for a single project with multiple reaches within a project area.

The USAP worksheets includes the following tabs:

- Read me: guide that gives users a detailed description of the USAP workbook. It also describes the scales and .
- Urban Stream Process: Flow chart with the process to consider function and maintenance given the stream's context.
- 5 Elements: Figure explaining the five elements with brief descriptions of each element
- Urban Stream Matrix: Table with urban stream functions and elements (formerly titled HFLMS Framework).
- Assessment strategies: A table with assessment strategies at the three scales (watershed, stream corridor, and reach) for all five elements. Those strategies influence the selection of indicators and metrics.
- USAP_Community Values: A matrix with descriptions of the community values indicators, metrics, measurement, assessment methods, and analyses across the watershed, corridor, and reach scales.
- USAP_Hydrology: A matrix with descriptions of the hydrology indicators, metrics, measurement, assessment methods, and analyses across the watershed, corridor, and reach scales.
- USAP_Hydraulics: A matrix with descriptions of the hydraulic indicators, metrics, measurement, assessment methods, and analyses across the watershed, corridor, and reach scales.
- USAP_Geomrophology: A matrix with descriptions of the geomorphic indicators, metrics, measurement, assessment methods, and analyses across the watershed, corridor, and reach scales.
- USAP_Vegetation: A matrix with descriptions of the vegetation indicators, metrics, measurement, assessment methods, and analyses across the watershed, corridor, and reach scales.
- ExampleScoring Matrix_Indicator: An example scoring matrix for indicators and metrics across all five elements that can be leveraged for projects at the corridor and reach scale.

The workbook also includes a “sunburst” tab that can be used to illustrate the various indicators and metrics applied for a project.

5. Pilot Projects and Next Steps

MHFD is currently piloting USAP to test its application at different scales and on varying stream types. Pilot studies to date include:

- Cherry Creek Major Drainageway Plan (Muller Engineering) – Upstream of Cherry Creek Reservoir. The StoryMap is available at this link.

- Big Dry Creek at South Suburban Golf Course (ICON) – Phase 1: Stream assessment and Phase 2: Alternatives analysis. The StoryMap is available at this link.
- Willow Creek upstream of Quebec (ICON) – Phase 1: Stream assessment. The technical StoryMap is available at this link.
- Boulder Urban Stream Condition Assessment (Enginuity-Olsson) – Assessment for 16 major drainageways (~47 miles) within the City of Boulder. The GIS Explorer is available at this link.

USAP continues to evolve as the piloting process provides input and anchor points for verifying and revising the methods and output data (e.g., scores, results, etc.). MHFD is also producing a watershed-scale USAP dataset, which provides practitioners and watershed managers a high-level overview of stream conditions. The watershed-scale dataset leverages MHFD's stream network with existing conditions scores for all reaches based on publicly available data such as DRCOG topography and land use land cover. MHFD will provide periodic updates to USAP products and make the data available via their website and Confluence portal.

6. References

Anim and Banahene, 2021

Bhaskar et al., 2016

Birtles et al., 2015

Blazewicz et al., 2020

Bollati et al., 2014

Booth et al., 2016

Boyd 2021

Brierley and Fryirs, 2005

Brown et al., 2009

Bunn and Arthington, 2002

Doyle et al., 2005

Fischenich 2006

Fletcher et al., 2013

Gonzalez del Tango and Garcia de Jalon, 2013

Gurnell, 2014

Gurnell et al., 2007

Hawley et al., 2013

Kendal et al., 2015

Kendal and Farrar, 2016

Kline, 2010

Konrad and Booth, 2005

McAuley and Knights, 2021

McPhillips et al., 2019

Melbourne Water, 2018

Niezgoda and Johnson, 2005

O’Brien and others’ 2017

Papangelakis et al., 2019

Piegay, 1997

Poff et al., 2010

Poff et al., 1997

Russell et al., 2020

Sammonds and Vietz, 2015

Smakhtin, 2001

Tetzlaff et al., 2005

Vietz et al., 2017

Vietz et al., 2016a

Vietz et al., 2014

Violin et al., 2011

Willis and Garrod, 1999

Wohl, 2016