Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Subject:

Colorado Environmental Flow Tool Documentation

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Section 1: Introduction

The Colorado Environmental Flow Tool (Flow Tool) was designed to serve as a resource to help Basin Roundtables (BRTs) refine, categorize, and prioritize their portfolio of environmental and recreational (E&R) projects and methods through an improved understanding of flow needs and potential flow impairments, both existing and projected. The Flow Tool uses hydrologic data from Colorado's Decision Support System (CDSS), additional modeled hydrologic data for various planning scenarios, and established flow-ecology relationships to assess risks to flows and E&R attribute categories at pre-selected gages across the state. The Flow Tool is a high-level tool that is intended to provide guidance during Stream Management Plan development and Basin Implementation Plan (BIP) development. Note that in the past, the term "nonconsumptive" has also been used in the place of "E&R". For the purposes of this memorandum, these two terms should be viewed as interchangeable.

1.1   BACKGROUND AND PREVIOUS TOOLS

In 2005, the Colorado legislature established the Water for the 21st Century Act. This act established the Interbasin Compact Process that provided a forum for broad-based water discussions in the state. It created two new structures: (1) the Interbasin Compact Committee (IBCC), and (2) the BRTs. As part of the Interbasin Compact Process, the BRTs were required to complete basinwide needs assessments, including an assessment of nonconsumptive water needs. The nonconsumptive needs assessment (NCNA) process included mapping E&R attributes to create a statewide technical platform and developing tools to identify and quantify nonconsumptive water needs. The Flow Tool builds on the groundwork completed to support the NCNAs by the BRTs and other stakeholders.

1.1.1   NCNA FOCUS AREA MAPPING

During the Statewide Water Supply Initiative (SWSI) 2010 update, the BRTs utilized E&R mapping tools as a common technical platform to identify nonconsumptive focus areas within their basins. Each BRT used one of three methods to develop a summary map that highlighted E&R focus areas within their basin:

- Method 1: E&R focus areas in each basin were aggregated to the watershed level (USGS 12-digit Hydrological Unit Code [HUC]).
- Method 2: E&R focus areas in each basin were aggregated to the stream level using USGS information for stream segments provided by the National Hydrography Dataset (NHD).
- Method 3: Stream reaches were selected that represented most of the E&R activity within the basin. These stream reaches were selected based on a review of all available data layers and feedback from stakeholders and public outreach efforts.

The output of this process included a map for each basin showing NCNA focus areas. As shown in **Figure 1-1**, the various approaches resulted in different spatial units and scales.
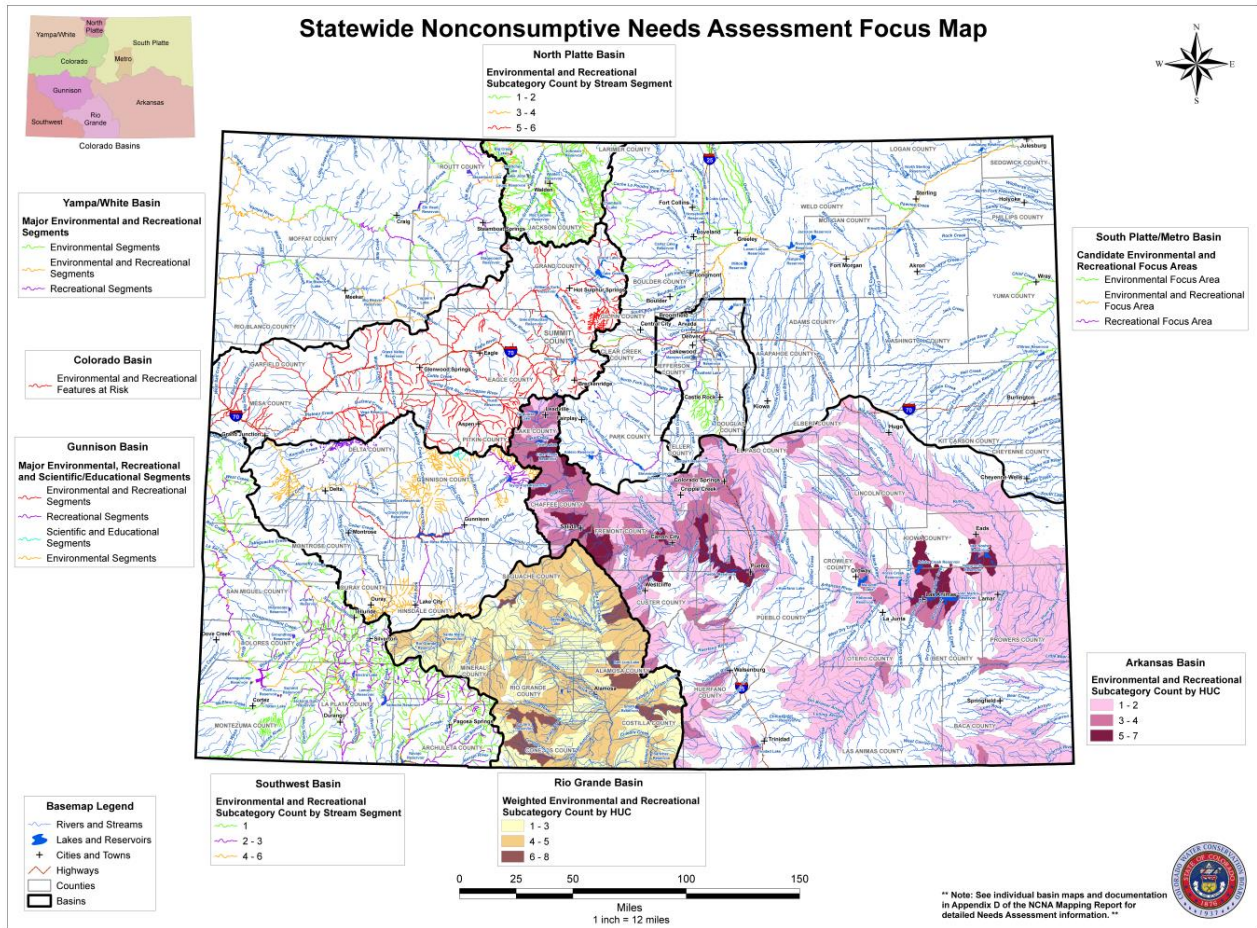
Figure 1-1. Statewide Nonconsumptive Needs Assessment Focus Area Map

1.1.2 NONCONSUMPTIVE PROJECTS AND METHODS

The BRTs also identified projects and methods required to meet the nonconsumptive needs identified as part of the NCNA focus area development process described above. The output of the Nonconsumptive Projects and Methods efforts included four maps that provided information on the location of projects and methods, the status of these projects and methods, and NCNA focus areas that had identified projects and methods completed or in progress.

1.1.3 NCNA DATABASE

From this exercise, the NCNA database (NCNAdb) was developed to help manage the nonconsumptive data received from the BRTs. The NCNAdb contained key information related to nonconsumptive attributes, projects, and associated protections. The content of the database was developed by a stakeholder-driven process that included members of the nine BRTs and statewide technical committees. Note that the database, now referred to as the E&Rdb, has also been updated, and will continue to be a tool as the BRTs work on their BIPs.

1.1.4 WATERSHED FLOW EVALUATION TOOL

CWCB also funded the development and testing of a tool known as the Watershed Flow Evaluation Tool (WFET). To date, the WFET has been applied in the Colorado and Yampa/White Basins. The WFET offers an approach to conducting a watershed-scale, science-based assessment of flow-related ecological risk throughout a basin, particularly when site-specific studies are sparse. The WFET assesses the risk that shifts in flow regimes pose to specific attributes, such as coldwater fish, warmwater fish, and riparian plant communities. The WFET was developed to identify areas that needed further site-specific studies, to support basin-wide assessments of project location and potential impacts, and to support strategic decision making about the system-wide operations of water systems to provide better ecological outcomes. The WFET was intended for additional studies on a watershed-scale. The Flow Tool described in this report provides analysis and results statewide at preselected gages.

1.1.5 HISTORICAL STREAMFLOW ANALYSIS TOOL

The Historical Streamflow Analysis Tool (HSAT) was developed and made available for use in the first round of BIPs and emphasized the evaluation of hydrologic variability at gage locations across Colorado. The user interface included a simple dropdown menu and the output included automatically generated tables and plots. Many of the basic flow summaries included in the HSAT were carried forward into the Flow Tool.

1.2 INTENDED USE OF THE FLOW TOOL

The Flow Tool is built on a legacy of stakeholder involvement and was created through a methodology that was developed collaboratively with a Technical Advisory Group and builds on the previous NCNA efforts described above. The Flow Tool, as developed for this Technical Update, can be used to assess the risk that stream-based ecological resources may change as a result of climate change, human uses, and/or the diversion of water. The Flow Tool is intended to be a high-level planning tool that:

- Uses the foundations of the HSAT and WFET to scale to a statewide platform;
- Post-processes CDSS projections to provide summaries of changes in monthly flow regime at pre-selected locations under different planning horizons;
- Identifies potential risks to E&R attribute categories through flow-ecology calculation projections;
- Serves as a complementary tool to the CDSS to refine, categorize, and prioritize projects; and
- Provides guidance during Stream Management Plan development and BIP development.

1.3 LIMITATIONS OF THE FLOW TOOL

While the Flow Tool is intended to inform and provide data for use in planning E&R projects and methods, it should be noted that it is NOT prescriptive. The Flow Tool does not:

- Designate any gap values. The Flow Tool does not identify flow deficiencies or gaps associated with the flow needs of E&R attributes. The Flow Tool analyzes where projected changes in monthly streamflow may increase risks to ecological resources based on reference conditions.
- Provide the basis for any regulatory actions. Because the Flow Tool does not require site-specific ecological data to identify the potential risk of ecological change and calculates risk using a monthly timestep, it should not serve as the basis for reach specific flow prescriptions in administrative or judicial processes.
- Identify areas where ecological change may be associated with factors other than streamflow. The Flow Tool does not explicitly evaluate or consider these additional factors that influence E&R attributes, although some of these factors are implicitly considered in the flow-ecology relationships.
- Provide results as detailed or as accurate as a site-specific analysis.

1.4 REPORT OVERVIEW

The remainder of this technical memorandum includes the following:

- ***Section 2: Tool Construction*** provides information on the software platform and inputs used to build the Flow Tool;
- ***Section 3: Results*** summarizes and discusses the Flow Tool outputs for each basin along with general statewide observations; and
- ***Section 4: Future Tool Enhancements*** discusses potential future updates to the Flow Tool.

Section 2: Tool Construction

The Flow Tool was constructed in Microsoft Excel by combining components of the HSAT and the WFET. The Flow Tool relies on modeled hydrologic data from the CDSS for "historical" and "future" flow regimes and established flow-ecology relationships to summarize flow statistics and potential risks to E&R attribute categories under each planning scenario. Detailed instructions for the use of the Flow Tool can be found in **Appendix A: User Guide**.

2.1 SOFTWARE PLATFORM AND INTERFACE

Figure 2-1. Flow Tool User Input Form

The Flow Tool was developed in Microsoft Excel using Visual Basic for Applications (VBA) programming. The Excel platform provides a familiar, and portable, working space for the tool user, as well as offers standard spreadsheet pre- and post-processing capabilities. User inputs specific to the application of the tool are provided via a user-friendly input form (**Figure 2-1**). The actual hydrologic and environmental flow metrics are calculated with underlying Visual Basic code. The tool graphical and tabular outputs are also generated with VBA code.

2.2 NODE SELECTION

The Flow Tool analyzes and produces data for 54 pre-selected Flow Tool nodes (**Figure 2-2**). The gages included in the Flow Tool were selected for inclusion based on a number of factors. Gages were reviewed collaboratively with key staff from The Nature Conservancy (TNC), the Colorado Water Conservation Board (CWCB), and Wilson Water Group (WWG) to determine available attribute data (where key E&R attributes were located and concentrated within a basin), consider spatial coverage across basins, and assess data availability. Some sites that were initially selected were eliminated due to data gaps, an insufficient period of record, and/or poor data quality. Additional detail for each Flow Tool node (gage name and number, HUC, E&R attribute categories present within the HUC, period of record) are available in **Appendix B**.
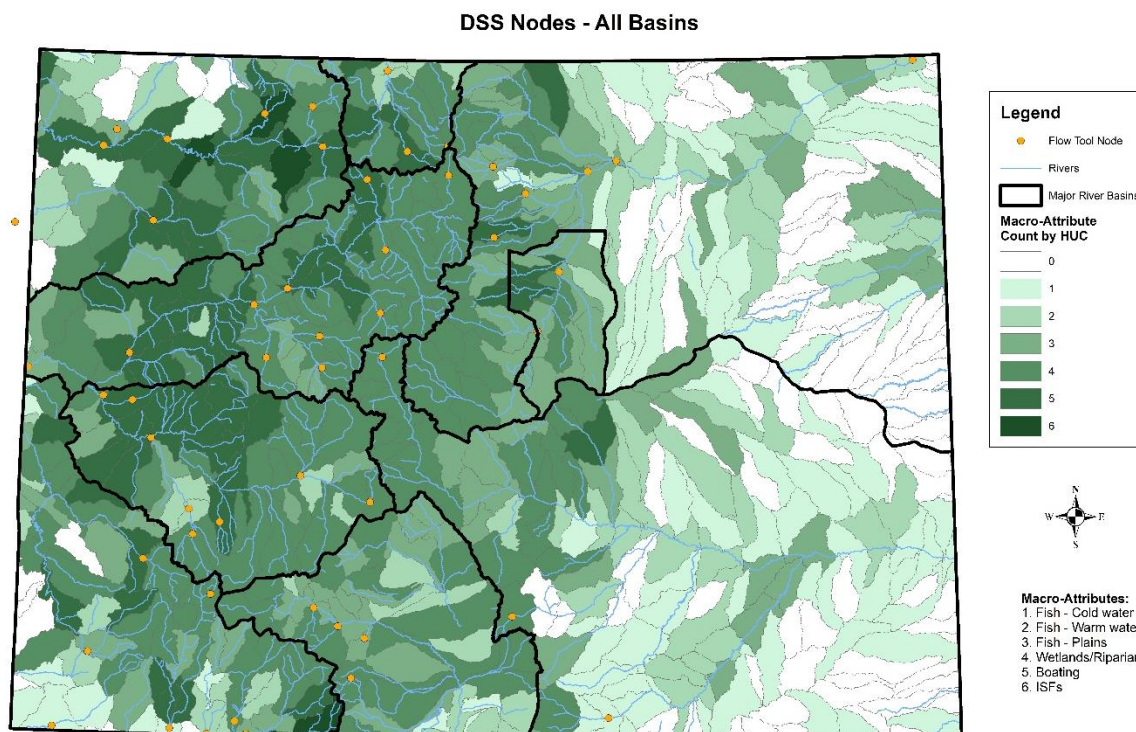
Figure 2-2. Flow Tool Nodes

2.3 DATA INPUTS

2.3.1 HYDROLOGIC DATA

The Flow Tool relies on hydrologic data from the CDSS and modeled data provided by WWG for each of the planning scenarios. Detailed analyses associated with the modeling efforts can be found in *Volume 2 of the Technical Update*. "Historical" hydrologic data loaded into the Flow Tool includes:

- Naturalized flows which represent "unimpaired" flows at the selected node, as modelled, without the impacts of water use, discharges, diversions, or storage. In other words, it is an estimate of "natural" river flows without anthropogenic impacts.
- Baseline flows that were developed (modelled) by pairing estimates of current water use and impairment with historical variable hydrology. In other words, it represents current activity in the basin, superimposed on an extended variable hydrologic profile.

While the naturalized flow data set is the default "historical" reference within the Flow Tool, the baseline data are also available and can be referenced for comparison to "future" data sets.

"Future" hydrologic data sets were provided by WWG for the following planning scenarios:

- Business as Usual;
- Weak Economy;
- Cooperative Growth;
- Adaptive Innovation; and
- Hot Growth

Figure 2-3 provides additional detail for each of the planning scenarios for which hydrologic data sets were modeled.

Drivers	A Business as Usual	B Weak Economy	C Cooperative Growth	D Adaptive Innovation	E Hot Growth
A. Economy/ Population					
B. Urban Land use	No change	No change	Higher density	Higher density	Lower density
C. Climate Status/ Water Supply	Same as 20th century observed	Same as 20th century observed	Between hot and dry and 20th century observed	Hot and dry	Hot and dry
D. Energy Water Needs	Low (no oil shale)	Moderate (no oil shale)	Low (no oil shale)	Low (no oil shale)	High (oil shale)
E. Agricultural Conditions	Total ag water demands slightly higher • Decrease in irrigated acres due to urbanization • Ag exports and demands lower • Ag is less able to compete with urban areas for water	Total ag water demands decrease • Decrease in irrigated acres due to urbanization • Ag exports and demands constant • Ag is less able to compete with urban areas for water	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands higher • Significant decrease in irrigated acres due to urbanization • Ag exports and demands high • Ag is better able to compete with urban areas for water • Increased ET due to climate change
F. Availability of New Water Efficiency Technology	• M&I Moderate • Ag: Efficiencies are increased	• M&I Moderate • Ag: Efficiencies are increased	• M&I High • Ag: Efficiencies are increased	• M&I High • Ag: Much higher efficiencies are implimented	• M&I Moderate • Ag: Efficiencies are increased
G. Social/ Environmental Values	No change	No change	• Increased awareness • Increased willingness to protect environment and stream recreation	• Increased awareness • Increased willingness to protect environment and stream recreation	• Full use of resources • Low willingness to protect environment and stream recreation
H. Regulatory Constraints	Regulation / Deregulation No change	Regulation / Deregulation No change	Regulation / Deregulation Increased	Regulation / Deregulation Increased but expedited	Regulation / Deregulation Reduced
I. M&I Water Demands	Lowest of the five scenarios	Middle of the five scenarios	Second lowest of the five scenaios	Second highest of the five scenarios	Highest of the five scnarios

Figure 2-3. Technical Update Planning Scenarios

Hydrologic data sets for each planning scenario were developed based on projected changes in supplies and demands and application of climate change factors. **Table 2-1** provides information on the climate factor applied to each planning scenario.

Table 2-1. Climate Adjustments by Planning Scenario

Planning Scenario	Baseline	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Climate Factor	Historical	Historical	Historical	In-Between	Hot and Dry	Hot and Dry

Note that the Rio Grande and Arkansas Basins do not currently have surface water supply models in the CDSS. As such, the nodes currently included in the tool for these basins are high enough in the basins to be "unimpaired". In other words, they are free of any anthropogenic water use impacts, either current or future. Therefore, the future scenario modeled flow changes reflect those associated with climate change only and, in fact, exactly match the corresponding climate change scenario output.

2.3.2 FLOW ECOLOGY RELATIONSHIPS

The flow tool estimates the response of E&R attributes in rivers under various hydrologic scenarios. The flow-ecology relationships in the Flow Tool were first developed as part of the WFET and were patterned after similar relationships that have been developed across the globe (Poff and Zimmerman, 2009) to inform water management. Flow-ecology quantifies the relationship between specific flow statistics (e.g., average magnitude of peak flow, the ratio of flow in August and September to mean annual flow) and the risk status (low to very high) for environmental attribute under the flow scenario being analyzed. Data-derived relationships have been developed for riparian/wetland plants (cottonwoods), coldwater fish (trout), warmwater fish (bluehead sucker, flannelmouth sucker, and roundtail chub), and Plains fish. Other metrics were developed with basic, well-established relationships between hydrology and stream ecology. Lastly, relationships for recreational boating were developed with stakeholders during WFET development.

Flow-ecology relationships, relevant equations, descriptions of risk classes, and references that informed the relationship are described in **Appendix C.** Development of the flow-ecology relationships, including statistical analyses are described in the WFET reports for the Colorado and Yampa/White/Green basins. Flow-ecology relationships vary across the state and were applied only where a relevant species or ecosystem would be expected to occur, e.g., risk for cottonwood-dominated riparian areas was estimated only for nodes mapped below 9,500 feet, and risk for Plains fishes was applied only below 5,500 feet and east of the Continental Divide.

2.4 TOOL OUTPUTS

The flow tool provides the following outputs:

- Monthly and annual timeseries plots;
- 3 and 10-year rolling average timeseries plots;
- Plot of monthly means;
- Monthly flow percentile plots;
- A tabular summary of annual hydrologic classifications;
- A tabular summary of statistical low flows; and
- A tabular summary of the calculated environmental flow metrics.

2.4.1 FLOW STATISTICS

Flow statistics are calculated and presented in graphical form (and are available in tabular form) on separate tabs within the Flow Tool. Monthly and annual timeseries plots are intended to provide concise summaries and comparisons of the underlying flow data sets and their associated temporal variability. The rolling average plots are provided to remove some of the year-to-year variability "noise" and help identify and compare larger timescale patterns and trends. Monthly mean plots highlight differences (and projected changes) in hydrologic seasonality, while the percentile plots highlight the modelled range of variability in the data sets and particularly the frequency of flow extremes.

2.4.2 HYDROLOGIC CLASSIFICATION

Within a designated tab in the Flow Tool, each water year included in the specified calculation period is assigned to one of five hydrologic classes: drought, dry, average, wet, or flood. Classifications are based on the total annual flow (AFY) in the given water year, compared to category threshold values. Classification thresholds are based on the selected reference flow data set (naturalized or baseline) for the given stream node and calculated according to the flow percentile values summarized in **Table 2-2**. For example, the annual flow threshold for classifying as a drought year is defined as the 5th percentile naturalized flow (exceeded 95% of the time in the naturalized record); while flood years are classified according to the 94th percentile naturalized flow (exceeded 6% of the time in the naturalized record).

Table 2-2. Hydrologic Classification Thresholds

Annual Flow Percentile (upper limit)	Hydrologic Category
5th	Drought
24th	Dry
75th	Average
94th	Wet
100th	Flood

2.4.3 STATISTICAL LOW FLOWS

Statistical low flows of a monthly duration are calculated in the tool for reference to common water quality metrics. Monthly low flows are calculated for recurrence intervals of: 2, 5, 10, 25, 50, and 100 years. Calculations are performed generally following the USEPA's DFLOW (Rossman, 1990) methodology, assuming a Log Pearson Type 3 distribution to the underlying data. These values are calculated for reference only, particularly with respect to relative changes in low flow rates under the simulated scenarios. The calculated values themselves are not intended to be used for regulatory purposes.

2.4.4 ENVIRONMENTAL FLOWS TABLE

The Environmental Flows table is generated using the flow-ecology relationships described in **Section 2.3.2** and **Appendix C**. Numeric output is presented as percent departure from reference flows. Reference flows can be specified as either the naturalized flow data set (default) or the baseline flow data set. See **Appendix A** for further details on this option. The table is also color coded based on risk category (from "low risk" to "very high risk") (**Table 2-3**). Risk categories were developed by numerous academics, agency staff, and consultants during development of the WFET according to percent departure threshold values (compared to reference condition). Risk category thresholds differ for each metric.

Table 2-3. Environmental Flow Risk Categories

Color Key:

	= low ecological risk
	= moderate ecological risk
	= less moderate ecological risk (cold water baseflow only)
	= high ecological risk
	= very high ecological risk

2.4.5 IMPAIRMENT ANOMALIES CHART

Also included in the tool output is a chart of "impairment anomalies". Two metrics are calculated for this plot: (1) annual average flow anomaly and (2) the standard deviation of monthly flow anomalies. The former is calculated as the percent difference between annual average scenario flow and annual average reference flow (Naturalized or Baseline) and is intended to reflect the change in long-term physical flow availability. The latter is calculated as the standard deviation of the percent changes in monthly mean flow rates, compared to reference, and is intended to reflect changes in the *timing* (rather than magnitude) of flow rates. The relative positioning of each scenario plotted by these metrics provides useful information with respect to the drivers of impairment. Large negative percent changes in annual average flow indicate a depletion impairment (consumptive use and/or climate change); while high standard deviations of monthly anomalies indicate a timing impairment (storage, water transfers, or return flows). The plotting area is divided into four quadrants reflecting four possible combinations of impairment: (1) no impairment, (2) timing impairment only, (3) timing and depletion impairment, and (4) depletion impairment only. Quadrant threshold values have been predefined, based on a coarse review of the datasets, as 10% for annual average anomalies and 20% for the standard deviation of monthly anomalies.

Section 3: Results

Flow Tool outputs for all 54 nodes across each of the nine basins were reviewed and considered for the discussion below. Flow statistics under "future" planning scenarios were compared to the timing and magnitude of "historical" peak and low flows. Risk categories identified through analysis of the environmental flow metrics were also reviewed and have informed the summaries presented for each basin.

Future risks to E&R attributes vary across the state depending on location and planning scenario. The risk to E&R attributes is influenced by basin-specific hydrology, water uses, and geographic location within basins. As a result, it is difficult to precisely characterize risks on a statewide basis (basin-specific observations are included in the summaries for individual basins below). However, several general observations can be made:

- Climate change and its impact on streamflow will be a primary driver of risk to E&R attributes.
- Projected future streamflow hydrographs, in most locations across the state, show earlier peaks and potentially drier conditions in the late summer months under scenarios with climate change.
- Under climate change scenarios, runoff and peak flows may occur earlier, resulting in possible mis-matches between peak flow timing and species' needs.
- Drier conditions in late summer months could increase risk to coldwater and warmwater fish due to higher water temperatures and reduced habitat. The degree of increased risk is related to the percent departure from reference conditions.
- In many mountainous regions without significant influence of infrastructure, peak flow and low flows are projected to be sufficient to sustain low to moderate risk for riparian plants and fish, but risks are projected to increase in scenarios with climate change.
- In mountainous regions with infrastructure, risks to E&R attributes vary. Streams that are already depleted may see increased risks in scenarios with climate change. However, some streams may be sustained by reservoir releases, which will help moderate risks for some E&R attributes in scenarios with climate change.
- Instream flow rights (ISFs) and recreational in-channel diversion water rights (RICDs) may be met less often in climate-impacted scenarios.

3.1 ARKANSAS BASIN

The Arkansas Basin is somewhat unique in that a surface water allocation model is not currently available. Hydrologic data sets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate change. A total of three nodes were selected for the Flow Tool within the Arkansas Basin (**Figure 3-1**):

- Arkansas River near Leadville, Colorado (07081200)
- Huerfano River at Manzanares Crossing, near Redwing, Colorado (07111000)
- Purgatoire River at Madrid, Colorado (07124200)

These sites were selected due to the location within the basin above major supply and demand drivers where impacts would likely be associated only with climate change factors. Management drivers impact river flows on the eastern plains. Because a water allocation model that incorporates management is not available, no data-based insights into flow change and risk to E&R attributes could be developed within this tool. The Flow Tool results for the Arkansas Basin include only Naturalized flows and Naturalized flows as impacted by climate change factors (In-Between and Hot and Dry climate factors). These data do not represent changes in flow due to irrigation, transmountain imports, and/or storage.
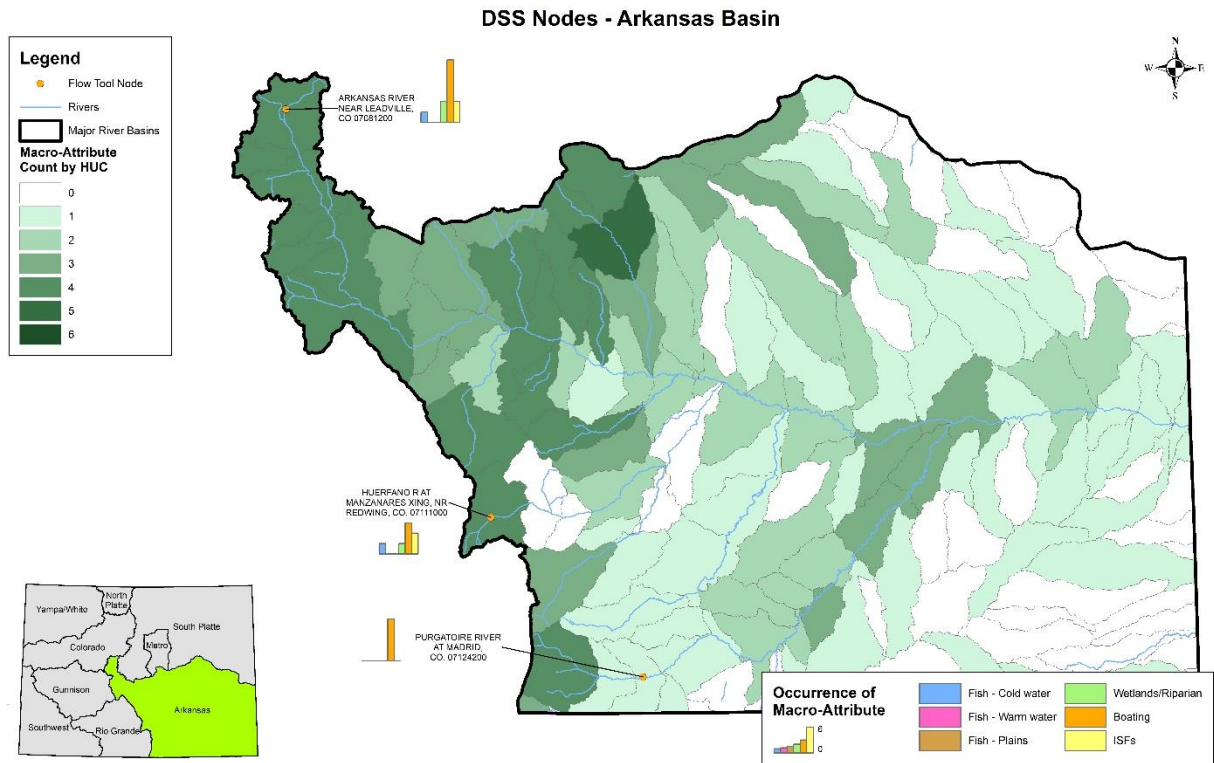
Figure 3-1. Arkansas Basin Nodes

At high elevation locations (e.g., near Leadville), peak flow magnitude does not change substantially. However, the timing of peak flow shifts to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the In-Between and Hot and Dry climate change scenarios. At montane and foothills locations (elevation range from approximately 5,500 feet to 8500 feet), peak flow magnitude drops under the In-Between and Hot and Dry climate change scenarios. Across all locations, mid- and late-summer streamflow is projected to decrease due to climate change.

At high elevations, peak-flow related risk for riparian/wetland plants and fish habitat remains low or moderate under future climate change scenarios. At lower elevations, the decline in peak flow magnitude increases the risk status for riparian/wetland plants and fish habitat. The reduction in peak flow may also adversely affect recreational boating. Metrics for coldwater fish (trout) indicate that even with climate induced changes to mid- and late-summer flows, flows are sufficient to keep risk low or moderate, although, risk may be higher in July and/or during dry years.

For the Arkansas Basin, because future flows under the five scenarios were not modeled, projected changes to flow at the selected nodes and the associated changes in risk to E&R attributes are entirely attributable to projected changes in climate. These climate-induced changes are similar to the general pattern seen in many parts of Colorado: earlier peak flow and reduced mid- and late-summer flows, with reduced peak flow magnitudes in some locations.

3.2   COLORADO BASIN

A total of eleven nodes were selected for the Flow Tool within the Colorado Basin (**Figure 3-2**):

- Colorado River below Baker Gulch near Grand Lake, Colorado (09010500)
- Muddy Creek near Kremmling, Colorado (09041000)

- Blue River below Green Mountain Reservoir, Colorado (09057500)
- Eagle River at Red Cliff, Colorado (09063000)
- Colorado River near Dotsero, Colorado (09070500)
- Roaring Fork River near Aspen, Colorado (09073400)
- Fryingpan River near Ruedi, Colorado (09080400)
- Crystal River above Avalanche Creek, near Redstone, Colorado (09081600)
- Roaring Fork River at Glenwood Springs, Colorado (09085000)
- Colorado River near Cameo, Colorado (09095500)
- Colorado River near Colorado-Utah State Line (09163500)
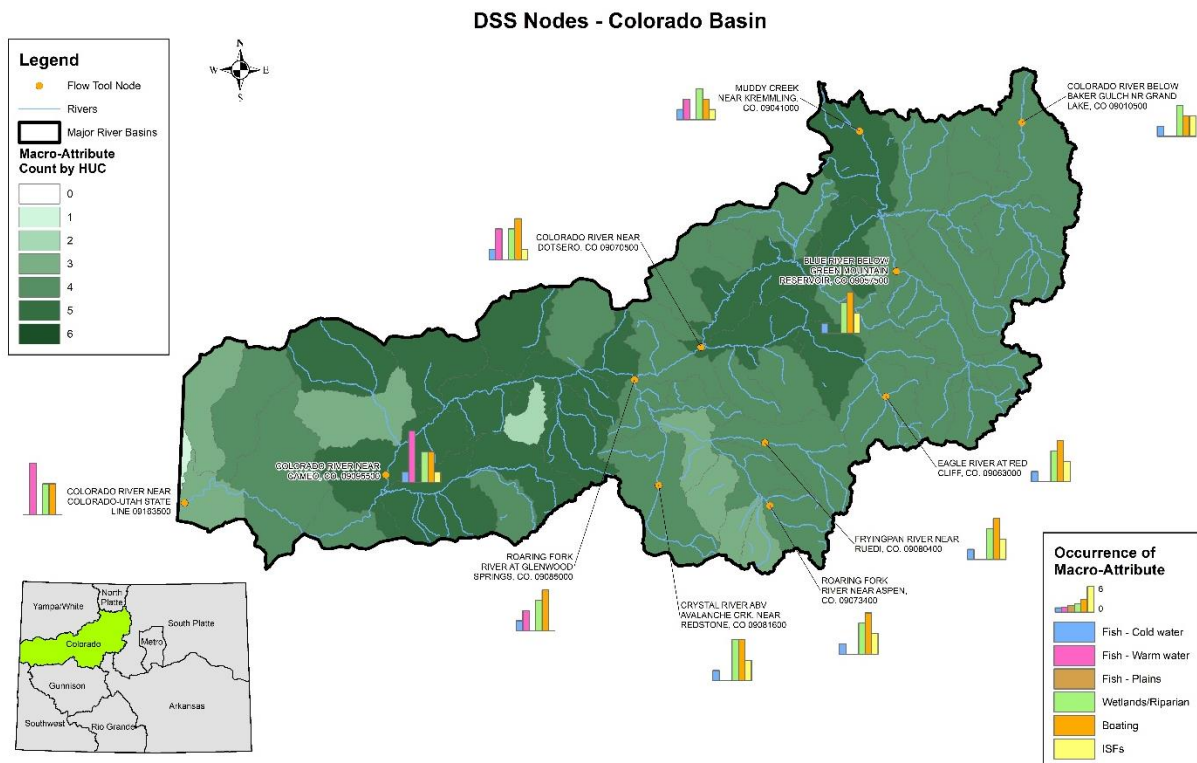
Figure 3-2. Colorado Basin Nodes

In the Colorado Basin, pattern of flow (both peak flows and low flows) are variable across the basin depending on several factors including elevation, storage, and transbasin diversions. The Colorado River usefully illustrates patterns that are present in numerous locations across the basin. Annual flow in headwaters (e.g., Colorado River below Baker's Gulch) under Baseline (Existing) conditions is currently below Natural conditions; this departure increases under climate change scenarios. Moving downstream through Dotsero, Cameo, and to the State Line, annual flow under Baseline conditions rebounds slightly closer to Naturalized conditions. Under climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot Growth), annual depletions increase from headwaters to the State Line.

Similar to the alterations in annual flows, peak flow magnitudes on the Colorado River under Baseline conditions are below Natural conditions from the headwaters through Dotsero and are closer to Natural conditions at lower elevations (Cameo and State Line). Under climate change scenarios (Collaborative Growth, Adaptive Innovation, and Hot Growth), peak flow magnitudes on the Colorado River decrease

further below Natural conditions. Decreases in peak flows (from Naturalized to Baseline) are more pronounced at locations below large reservoirs (e.g., Blue River below Green Mountain Reservoir, Fryingpan River below Reudi Reservoir. This dampening of peak flows is projected to worsen under climate driven scenarios. In some locations (notably, Crystal River above Avalanche Creek), peak flow magnitude is projected to increase under some scenarios. Under the scenarios with climate change factors applied, snowmelt and timing of peak flow shifts earlier in the year. In many areas from headwaters to lower elevations, June flows decrease well below Naturalized conditions, while April and May flows remain similar to Baseline or increase slightly.

Under Baseline conditions, mid- and late-summer flows in headwaters subject to transmountain diversions currently depleted compared to Naturalized conditions. The gap between Baseline and Naturalized conditions lessens farther downstream. Under climate change scenarios, mid- and late-summer flows in headwaters drop well below Naturalized; farther downstream, this drop is less pronounced. In many locations, mid- and late-summer flows under climate change scenarios are projected to be well below Naturalized. The Fryingpan below Reudi Reservoir is an exception to the large decreases in mid- and late-summer flows, because releases are made steadily from the reservoir.

Decreased peak flows that are prevalent across the basin under Baseline conditions create risk for riparian/wetland plants and fish habitat. This risk increases under climate change scenarios. Decreases in mid- and late-summer flows create risk for fish from loss of habitat and, in trout regions, increased water temperatures. Downstream from major reservoirs (e.g., Fryingpan, Green Mountain), diminished peak flows create increase risk for riparian/wetland vegetation and fish habitat if sediment is not flushed, while consistent mid- and late-summer flows keep risk to fish low to moderate.

ISFs throughout the basin and RICDs are likely to be regularly unmet if June-August flows decrease as projected under climate change scenarios.

In critical habitat for endangered species, reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations. For example, projected August flows under climate change scenarios on the Colorado River at Cameo suggest that flow recommendations for endangered fish will not be met during August in approximately one-third of years.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow issues related to E&R attributes arise from timing/water delivery issues. Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing demands for consumptive uses contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program (e.g., Coordinated Reservoir Operations Program) have demonstrated that flow timing and magnitude, and stream temperature can be improved through water management that explicitly considers the needs of E&R attributes.

3.3 GUNNISON BASIN

A total of eight CDSS nodes were selected for the Environmental Flow Tool within the Gunnison Basin (Figure 3-3):

- Gunnison River near Gunnison, Colorado (09114500)
- Tomichi Creek at Sargents, Colorado (09115500)
- Cimarron River near Cimarron, Colorado (09126000)
- Uncompahgre River near Ridgway, Colorado (09146200)
- Uncompahgre River at Colona, Colorado (09147500)
- Uncompahgre River at Delta, Colorado (09149500)

- Kannah Creek near Whitewater, Colorado (09152000)
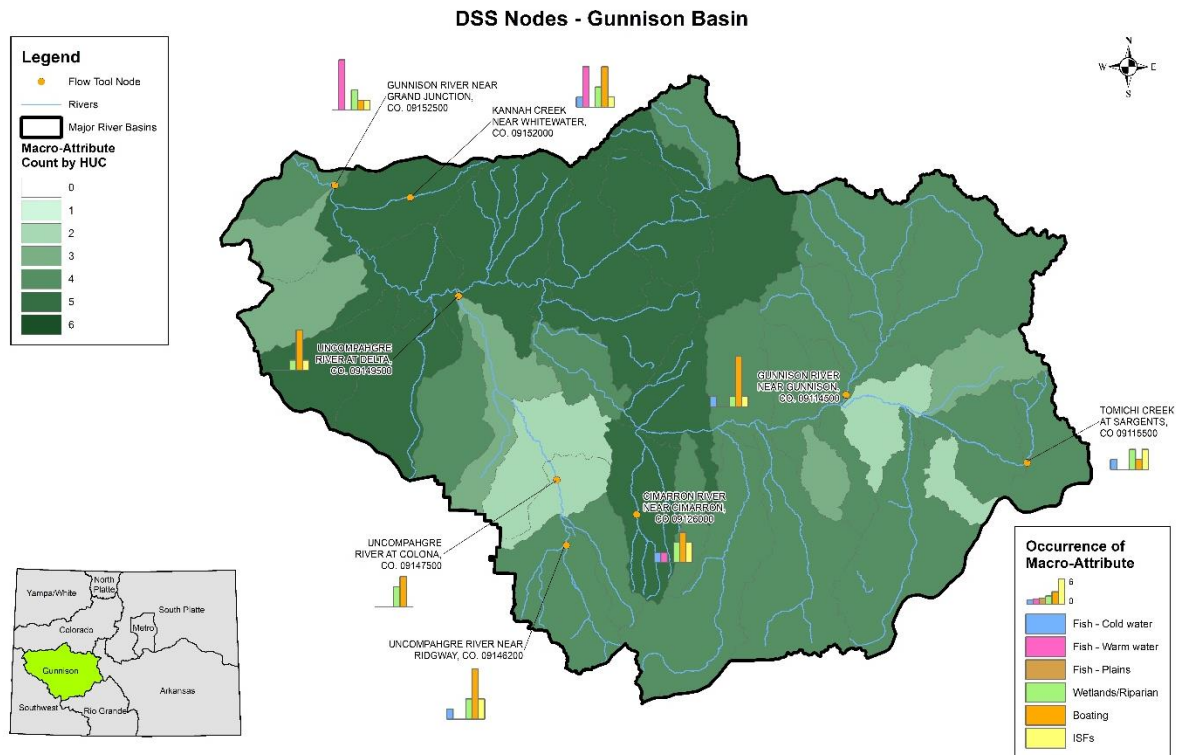- Gunnison River near Grand Junction, Colorado (90152500)

Figure 3-3. Gunnison Basin Nodes

In the Gunnison Basin, pattern of flow varies as a function of elevation, major diversions, and location relative to reservoir storage. At higher elevations (e.g., Gunnison River at Gunnison), mean annual flow under Baseline conditions is close to Naturalized conditions; under climate change scenarios (Cooperative Growth, Adaptive Innovation, Hot Growth), the gap between Natural and Baseline increases to about 20%. At locations lower in the basin (e.g., Gunnison River near Grand Junction), Baseline annual flows are further depleted; under climate change scenarios, depletions continue to grow.

In some locations (e.g., Gunnison River at Gunnison), peak flow magnitude under Baseline conditions is below Naturalized conditions, but under climate change scenarios, peak flow magnitudes increase. As a general rule, however, peak flows change little from Baseline under Business as Usual and Weak Economy scenarios, but decrease more substantially under climate change scenarios. Below major reservoirs on the Uncompahgre and Gunnison mainstems, peak flow under Baseline conditions can be half of the Naturalized condition. Peak flows continue to decrease further from Naturalized under climate change scenarios. Under all climate change scenarios in all locations, runoff and peak flows occur earlier, with June flows decreasing and April and May flows increasing. This change in peak flow timing may cause mis-matches between flow dynamics and the flows needed to support species.

At higher locations in the Gunnison Basin, mid- and late-summer flows under Baseline conditions are 0-20% depleted from Naturalized conditions; under climate change scenarios, these flows drop further below Naturalized. At lower elevations on mainstem rivers (e.g., Uncompahgre at Delta; Gunnison River near Grand Junction), mid- and late-summer flows under Baseline conditions are 30-50% below Naturalized; under climate change scenarios, these flows are also projected to fall further below Naturalized.

Ecological risk (riparian/wetland plants and fish habitat) related to projected changes in peak flow magnitude is generally low to moderate at higher elevations; under climate change scenarios this risk increases at most locations. At locations at lower elevations and on mainstems, peak flows are already reduced in general and reductions increase under climate change scenarios. Even though mid- and late-summer flows decline under climate change scenarios, flow-related risk to coldwater fish (trout) remains moderate. However, the metric used to assess risk for fish does not include the month of July because historically, July flows are sufficient. Under Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, July flows are predicted to drop, increasing risk for fish by reducing habitat and increasing stream temperatures. In at least one location (Cimmaron River), winter flows become low, also putting fish at risk.

In several locations, ISFs may be met less often, and at least one RICD (in Gunnison), may be met less often. In critical habitats for endangered species, lower mean annual flows and reduced flows in mid- and late-summer will make it more difficult to meet flow recommendations.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow issues related to E&R attributes arise from in-basin diversions and storage of peak flows in reservoirs. Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands contribute to reductions in mid- and late-summer flows. Several water management programs implemented in the context of the Upper Colorado Endangered Fish Program, including on the Gunnison River below the Apsinall Unit, have demonstrated that flow timing and magnitude can be planned in a way that better meets the needs of E&R attributes.

3.4 NORTH PLATTE BASIN

A total of three CDSS nodes were selected for the Flow Tool within the North Platte Basin (**Figure 3-4**):

- Michigan River near Cameron Pass, Colorado (06614800)
- Illinois Creek near Rand, Colorado (06617500)
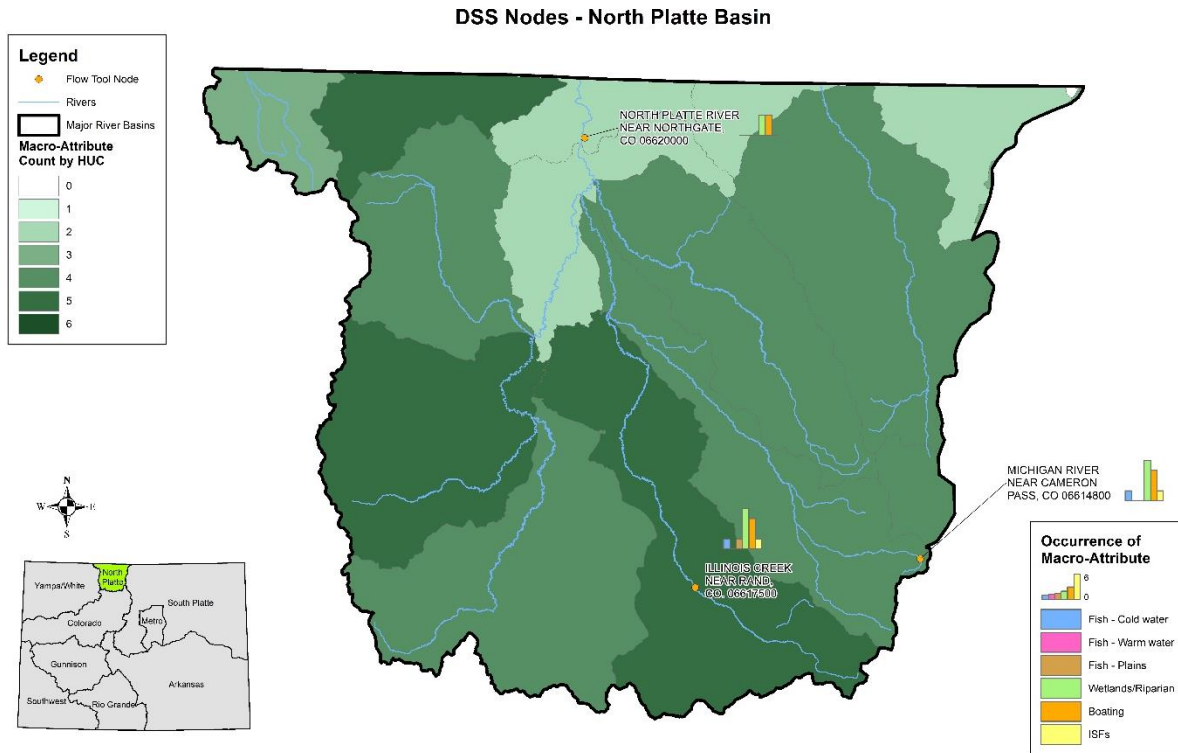- North Platte River near Northgate, Colorado (06620000)

Figure 3-4. North Platte Basin Nodes

Mean annual flows in North Platte Basin under Baseline conditions are 20-35% below Naturalized conditions. Unlike all other basins analyzed, mean annual flow changes little under all scenarios, including climate change scenarios.

Although there is little change in mean annual flow in future scenarios compared to Baseline (Existing), peak flows do change. Peak flow magnitude under Baseline conditions are approximately 15% below Naturalized conditions at higher elevations and decrease further below Naturalized conditions where the North Platte leaves Colorado near North Gate. Under Business as Usual and Weak Growth scenarios, peak flow changes little. Under climate change scenarios, peak flow magnitude may increase slightly. The timing of peak flows also changes; shifting earlier in the year (April and May flows increase, offsetting June flow decreases).

Under Baseline conditions, mid- and late-summer flows in North Park are 30-60% below Naturalized conditions, depending on locations. This condition may not be as ideal for trout as many other locations in Colorado at similar elevation. Under climate change scenarios, mid- and late-summer flows are likely to decline further.

Baseline peak flow magnitudes create some risk for maintaining riparian/wetland plants and fish habitat, but this risk may lessen under climate change scenarios as peak flow magnitude increases. However, earlier and larger peak flows lead to lower mid- and late-summer flows, and these lower flows increase risk for trout under Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. Also, the change in peak flow timing under climate change scenarios may lead to mis-matches between peak flows and species' needs.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow risks related to E&R attributes arise primarily from transbasin diversions and irrigation demands. Under climate change scenarios, both the shift in the timing of peak flow and increased irrigation demands contribute to reductions in mid- and late-summer flows.

3.5 RIO GRANDE BASIN

The Rio Grande Basin is somewhat unique in that a surface water allocation model is not currently available. Hydrologic data sets in the Flow Tool include only naturalized flows and naturalized flows as impacted by climate drivers. A total of four nodes, all in the mountains and foothills west of the San Luis Valley, were selected for the Environmental Flow Tool within the Rio Grande Basin (**Figure 3-5**):

- Rio Grande at Wagon Wheel Gap, Colorado (08217500)
- South Fork Rio Grande at South Fork, Colorado (08219500)
- Pinos Creek near Del Norte, Colorado (08220500)
- Conejos River below Platoro Reservoir, Colorado (08245000)

These sites were selected due to the location within the basin above major supply and demand drivers where impacts would likely be associated with only climate change factors. Management drivers impact river flows in areas downstream of mountainous areas in the Rio Grande and Conejos Basins. Because a water allocation model that incorporates management is not available, the Flow Tool results for the Rio Grande Basin include only Naturalized conditions and Naturalized conditions as impacted by climate drivers (In-between and Hot and Dry climate change scenarios) to illustrate a representative change in flow due to climate. These data do not represent changes in flow due to irrigation, transmountain imports, and/or storage.
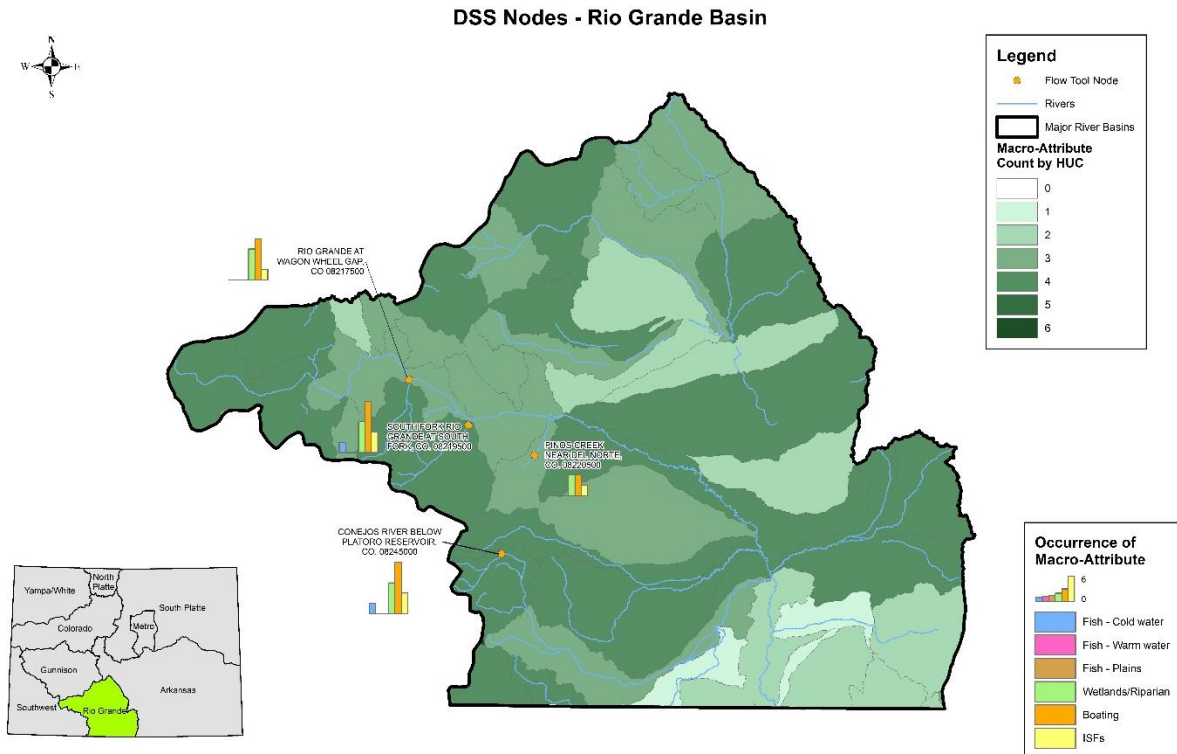

Figure 3-5. Rio Grande Basin Nodes

For the selected locations, overall peak flow magnitude does not change substantially under climate change scenarios. However, the timing of peak flow shifts to earlier in the year, with April and May flow magnitudes rising and June flows decreasing under the In-Between and Hot and Dry climate change scenarios. Mid- and late-summer flow is reduced in all locations under the In-Between and Hot and Dry climate change scenarios, with July streamflow decreasing by roughly half on the Rio Grande and tributaries and even more on the Conejos River.

Peak flow related risk for riparian/wetland and fish habitat remains low or moderate in most cases, although there are some indications that risk could increase in smaller streams. Risk to trout due to decreasing mid- and late-summer streamflow may remain moderate in most years, but could be higher in July and/or during dry years.

Because future flows under the five scenarios have not been modeled in the Rio Grande Basin, projected changes to flow and associated changes in risk to E&R attributes within the Flow Tool are attributable only to projected changes in climate. These climate-induced changes are similar to the general pattern seen in many parts of Colorado: earlier peak flow and reduced mid- and late-summer flows.

3.6   SOUTH PLATTE BASIN

A total of eight nodes were selected for the Flow Tool within the South Platte Basin (**Figure 3-6**):

- South Platte River at South Platte (06707500)
- South Platte River at Denver (06714000)
- St Vrain Creek at Lyons, Colorado (06724000)
- Middle Boulder Creek at Nederland, Colorado (06725500)
- Big Thompson River at Estes Park, Colorado (06733000)
- Big Thompson River at Mouth, near La Salle, Colorado (06744000)
- South Platte River near Kersey, Colorado (06754000)
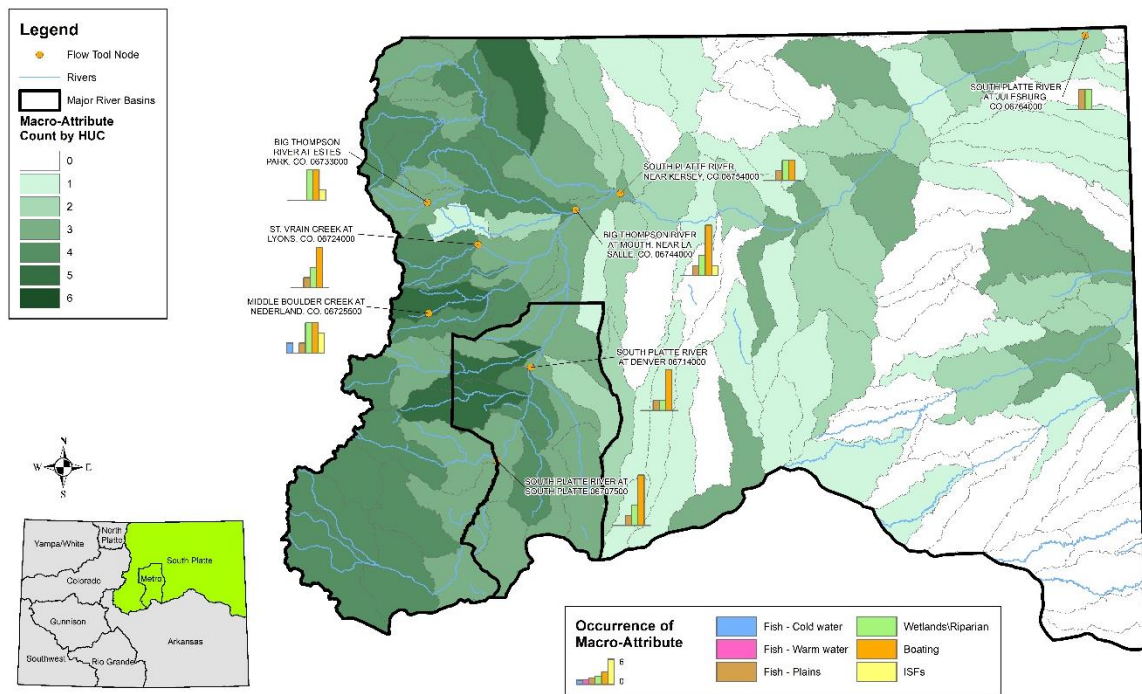- South Platte River at Julesburg, Colorado (06764000)

Figure 3-6. South Platte Basin Nodes

Patterns of peak flows are highly variable across locations in the basin. Baseline flow patterns diverge the most from Naturalized conditions in the Foothills and on the Plains. The magnitude of flows on the South Platte in Denver in May and June (historically the months of peak runoff) under Baseline (Existing) conditions are reduced from Naturalized conditions; the divergence from Naturalized conditions increases as the South Platte flows through Julesberg. In these locations, peak flow magnitude under the various future scenarios increases, stays the same, or decreases further, again depending on location. In the mountains (e.g., South Platte River at South Platte, Middle Boulder Creek at Nederland), Baseline peak flow magnitudes are only minimally below Naturalized peak flow magnitude. Changes to peak flow magnitude in these mountain locations also vary depending on location, with minimal changes to peak flow magnitude in some locations and larger declines elsewhere. Mountain locations demonstrate a pattern under the climate change scenarios where the timing of peak flows shifts earlier in the year, from June to May. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.

Mid- and late-summer flows are also highly variable across locations in the basin. On the Plains, Baseline low flows vary in range below Naturalized conditions. Under future scenarios, this range shifts to further departed from Naturalized conditions, with climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios) causing the greatest decline in flows. In the mountains, climate change scenarios cause a decline in low flows (e.g., Middle Boulder Creek at Nederland), while in other areas (e.g., South Platte River at South Platte) declines are less pronounced due to transbasin imports and releases of stored water.

In the Foothills and on the Plains, especially east of Interstate 25, decreased peak flow magnitudes under Baseline conditions and all future scenarios put many aspects of ecosystem function (e.g., over-bank flooding to support riparian plants, sediment transport to maintain fish habitat) at risk. Projected changes to mid- and late-summer flows also create risk for plains fishes. In the mountains, peak flow and low flows

generally create low to moderate risk for riparian plants and fish, although these risks increase under climate change scenarios.

There are numerous ISF reaches in the mountains and foothills, and several RICDs in the South Platte Basin. The location of modeled flow points does not allow specific insight into what future scenarios imply for these nodes, but the general pattern of diminished flows, especially diminished flows under climate change scenarios, suggests that the flow targets for ISFs and RICDs may be met less often.

Increasing risk to E&R attributes arise from several sources. Changes in flow timing through water management (e.g., storage of peak flows) can reduce ecosystem functions that are dependent on high flows (e.g., sediment transport) and can reduce boating opportunities. Changes in timing under climate change scenarios (early peak flow) can also increase risk for ecosystems and species. Under all scenarios in most locations, ecological and recreational risk is also increased by depletions from increasing human water consumption and decreasing supply under a changing climate. Water management (e.g., reservoir releases) has the potential to mitigate negative impacts.

3.7 SOUTHWEST BASIN

A total of nine nodes were selected for the Flow Tool within the Southwest Basin (**Figure 3-7**):

- Dolores River at Dolores, Colorado (09166500)
- San Miguel River near Placerville, Colorado (09172500)
- Navajo River at Edith, Colorado (09346000)
- San Juan River near Carracas, Colorado (09346400)
- Piedra River near Arboles, Colorado (09349800)
- Los Pinos River at La Boca, Colorado (09354500)
- Animas River at Howardsville, Colorado (09357500)
- Animas River near Cedar Hill, New Mexico (09363500)
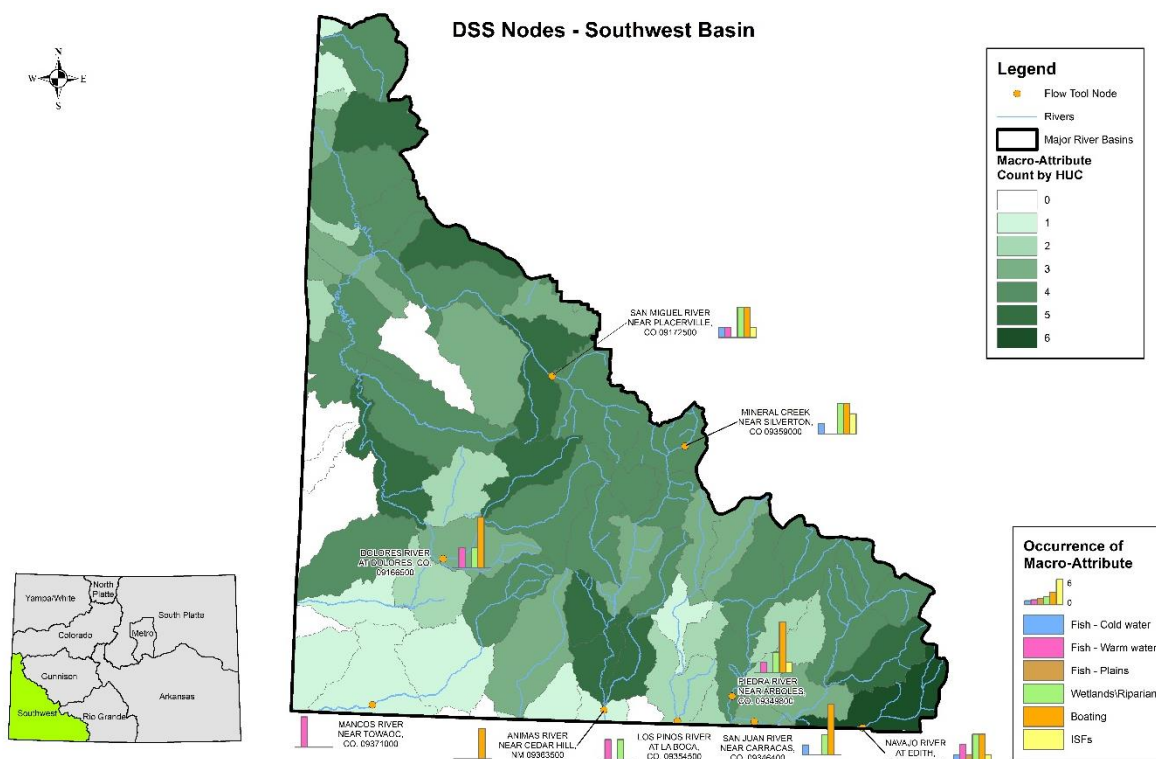- Mancos River near Towaoc, Colorado (09371000)

Figure 3-7. Southwest Basin Nodes

In locations where Baseline conditions are minimally depleted from Naturalized conditions (e.g., the San Miguel River), peak flow magnitude under Business as Usual and Weak Economy scenarios are projected to decline only slightly below Baseline. Under climate change scenarios, declines in peak flow magnitude are further below Baseline. At all locations, the timing of peak flow moves earlier in the year for all climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios). Under these climate change scenarios, June flows decrease the most (e.g., Dolores River at Dolores). Under these same scenarios, April flow increases, but the increase in April flow magnitude does not offset the decline in June flow magnitude. In all locations, mid- and late-summer flows are reduced under Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, increasing risks for coldwater and warmwater fish.

In locations where Naturalized and Baseline conditions are similar, peak flow-related risk to riparian/wetland plants and fish remain low to moderate under Business as Usual, Weak Economy, and Cooperative Growth scenarios. Under Adaptive Innovation and Hot Growth scenarios, this risk increases. In locations where peak flows under Baseline are already substantially less than Naturalized conditions, peak flow-related risk to riparian/wetland plants and fish is already high and increases under climate change scenarios. Under all climate change scenarios, runoff and peak flows occur earlier, and possible mis-matches between peak flow timing and species' needs may occur.

In locations where Naturalized and Baseline conditions are similar, risk to coldwater fish (mainly trout) increases under the various planning scenarios because of declines in mid- and late-summer flow. However, the risk remains moderate in most years. In locations that experience low summer flows, risk to fish increases. Note that the Flow Tool risk assessment using coldwater and warmwater fish metrics does not include July because historically July flows are sufficient. In some locations, July flows are significantly reduced under climate change scenarios, e.g., July flows under the Hot Growth scenario on the Piedra River near Arboles. The projected reduction will likely result in reduced habitat and increased stream temperatures.

ISFs throughout the Southwest and the RICD on the Animas River may not be met in many years under Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios. For example, flows on the San Miguel River near Placerville are projected to fall short of the 93 cubic feet per second (cfs) summer ISF regularly during mid- and late-summer. In August, this ISF is projected to be unmet during 1 out of 3 years under the Cooperative Growth scenario and during 2 out of 3 years under the Adaptive Innovation and Hot Growth scenarios. On the Animas River, the 25 cfs RICD near Howardsville is projected to not be met in numerous years during late summer (August) through October, and again in January and February (when the minimum flow is 13 cfs) under the three climate change scenarios.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow issues related to E&R attributes arise primarily because of depletions that increase moving downstream. In some locations, transbasin diversions reduce and change the timing of flow in the basin of origin while augmenting flows in the receiving basin. Under climate change scenarios, the shift in the timing of peak flow, reductions in total runoff, and increasing consumptive demands contribute to reductions in mid- and late-summer flows.

3.8   YAMPA/WHITE BASIN

A total of eight nodes were selected for the Flow Tool within the Yampa/White Basin (**Figure 3-8**):

- Yampa River at Steamboat Springs, Colorado (09239500)
- Elk River at Clark, Colorado (09241000)
- Elkhead Creek near Elkhead, Colorado (09245000)
- Yampa River near Maybell, Colorado (09251000)
- Little Snake River near Lily, Colorado (09260000)
- Yampa River at Deerlodge Park, Colorado (09260050)
- White River below Meeker, Colorado (09304800)
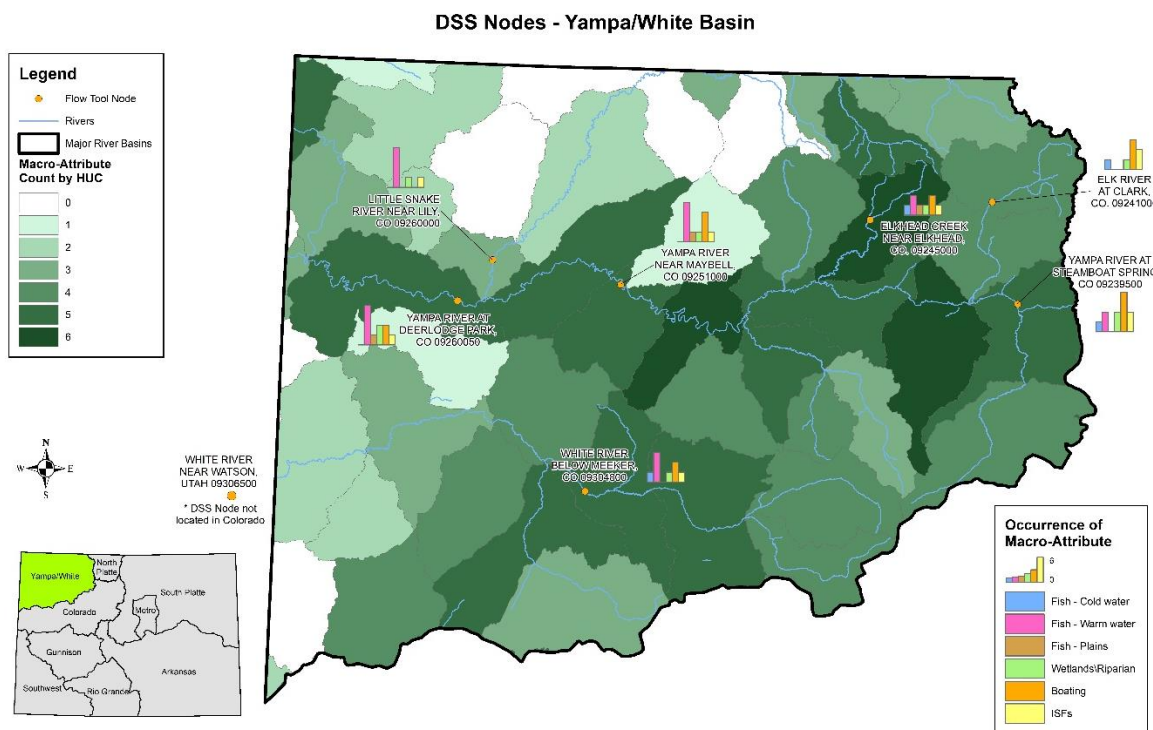- White River near Watson, Utah (09306500)

Figure 3-8. Yampa/White Basin Nodes

On the Yampa and White Rivers, peak flow magnitudes under Baseline (Existing) conditions are only slightly reduced (10%) from Naturalized conditions. A similar status holds for the Business as Usual and Weak Economy scenarios. Under the Hot and Dry scenario, total peak flows decline approximately 10%. At all locations, the timing of peak flow moves earlier in the year under all climate change scenarios (Cooperative Growth, Adaptive Innovation, and Hot and Dry scenarios). Under the climate change scenarios, June flow decreases approximately 30% at higher elevations (e.g., Elk River at Clark) and continues to decrease more at lower elevations (e.g., Yampa River at Deerlodge Park); under these same scenarios, April flows increase at a similar rate. May flows increase or decrease depending on location and scenario.

Under Baseline (Existing) conditions, mid- and late-summer flows are minimally depleted at higher elevations under Naturalized conditions, are reduced further through mid-elevations (e.g., Steamboat Springs), and continue to decline through low-elevations (e.g., White River below Meeker and Yampa River at Deerlodge Park). Under all climate change scenarios, in most locations, mid- and late-summer flows show a wide departure from Naturalized conditions.

Despite declines in peak flow magnitude, flow-related risk to riparian/wetland plants remains low to moderate across the basin. However, flow-related risk to warmwater fish increases, with the most risk occurring under the Hot and Dry scenario. The change in timing for peak flows may result in mismatches between peak flow timing and species' needs.

Projected reductions in mid- and late-summer flows result in increased risks for trout at high and mid-elevations, and for warmwater fish at low elevations. Increased risk is caused by reduction in habitat under reduced flows. For trout, increased stream temperatures under low-flow conditions also increases risks, as has been the case in some recent years in Steamboat Springs. Additionally, the projected reductions in flows in mid- and late-summer result in flows that are below the recommendations for endangered fish. For comparison, flows in August and September of 2018 were among the lowest flows on record and resulted in the first ever call on the Yampa River. September flows are projected to be similarly low in nearly one-quarter of all years under Cooperative Growth and nearly one-third of all years under Adaptive Innovation and Hot and Dry scenarios. These low flows lead to a loss of habitat for endangered fish and favor reproduction and survival of non-native fish that prey upon endangered fish.

ISFs and RICDs are at risk of being met less often in mid- to late-summer under all future scenarios that include climate change (Cooperative Growth, Adaptive Innovation, and Hot and Dry). An example of an ISF at risk is the 65 csf ISF on the Elk River. This ISF is met in July in every year under the Baseline scenario. However, under the Cooperative Growth Scenario, average July flow drops below 65 cfs in approximately one-third of years, and is unmet in approximately half of the modeled years under the Adaptive Innovation and Hot and Dry Scenarios. In August, the Elk River ISF is unmet in nearly every year under all climate change scenarios.

The total amount of boating flows during runoff may not change significantly if peak flow magnitude does not decline substantially, but the timing of boating opportunities will shift to earlier in the year under all climate change scenarios. An example of a RICD at risk is for the whitewater park in Steamboat Springs. The August RICD decreed flow of 95 cfs is often not met under Baseline conditions. Under Adaptive Innovation and Hot and Dry scenarios, the August RICD decree is almost never met.

Under Baseline (Existing), Business as Usual, and Weak Economy scenarios, current flow risk related to E&R attributes arises primarily because of depletions that increase moving downstream. Under climate change scenarios, both the shift in the timing of peak flow and reductions in total runoff contribute to reductions in mid- and late-summer flows.

Section 4: Future Tool Enhancements

The Flow Tool provides all of the information described in the previous sections, it currently lacks the ability to directly perform exploratory "what if" scenarios, with respect to flow modification or management scenarios. Any such scenarios currently require water allocation simulations, as a pre-processing step, using the CDSS models. However, potential future enhancements could include the programming of simple water allocation algorithms, on a coarse scale, into the Flow Tool. For example, generic storage, with simple routing and operating rules, could be added to the Flow Tool as an optional module. The user could use such functionality to investigate the impact of additional upstream storage on node flow regimes and environmental flow metrics. More specifically, such an enhancement would allow for simple investigations of flow storage and management alternatives to reduce risks to macroattribute categories. In addition to storage, coarse-scale flow and demand management options could be added to the Flow Tool, including (but limited to): conservation, reuse, agricultural water transfers, and trans-basin imports. Again, such enhancements would allow the Flow Tool to be used as a stand-alone predictive model for investigating, at a coarse scale, potential future flow modification scenarios. These potential enhancements are left for future consideration.

References

Poff, N. L., and J. K. H. Zimmerman. "Ecological Responses to Altered Flow Regimes: A Literature Review to Inform the Science and Management of Environmental Flows." *Freshwater Biology* 55, no. 1 (January 2009): 194–205. https://doi.org/10.1111/j.1365-2427.2009.02272.x.

Rossman, 1990 Rossman, L. "DFLOW USER'S MANUAL." U.S. Environmental Protection Agency, Washington, D.C., EPA/600/8-90/051 (NTIS PB90225616), 1990.

Appendix A: User Guide

Prepared for:

Colorado Water Conservation Board

Subject:

Appendix A: Colorado Environmental Flow Tool: User's Guide

Date: May 31, 2019

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Section A1: User's Guide

A1.1 OVERVIEW

The Colorado Environmental Flow Tool (Flow Tool) was developed to provide:

a) Concise summaries of Colorado Decision Support System (CDSS) flow projections across the State; and

b) Calculations of ecologically relevant flow metrics for any combination of selected key stream node locations and flow projection scenarios.

Modelled flow summaries are available for multiple pre-selected stream nodes in each of the nine (9) major river basins in Colorado and for up to five (5) future flow scenarios. Additionally, summaries of naturalized flow are also available, for baseline (historical) conditions and for two different future climate change scenarios. Calculation periods vary by river basin but are generally on the order of 35 years. Underlying CDSS flow data are included on a monthly timestep.

The Flow Tool was designed to serve as a resource to help Basin Roundtables refine, categorize, and prioritize their current portfolio of environmental and recreational (E&R) projects and methods through an improved understanding of flow needs and flow impairments, both existing and projected. The environmental flow metrics in the tool were developed in collaboration with The Nature Conservancy (TNC) and are based on the best available ecological science and literature. The flow metrics span a range of ecological and recreational considerations, including cold and warm water fish, wetlands plants, general ecosystem health, and boating.

The Flow Tool is easy to use and designed for a wide range of potential end users. Note, however, that adding new stream nodes, or new modelled flow scenarios, to the tool is not currently an option available to the user and would require additional programming by the tool developers.

A1.2 SOFTWARE PLATFORM AND INTERFACE

The Flow Tool has been developed in Microsoft Excel using Visual Basic for Applications (VBA) programming. The Excel platform provides a familiar, and portable, working space for the tool user, as well as offering standard spreadsheet pre- and post-processing capabilities. User inputs specific to the application of the tool are provided via a user-friendly input form (**Figure A1**). The actual hydrologic and environmental flow metrics are calculated with underlying Visual Basic code. The tool graphical and tabular outputs are also generated with VBA code.

Figure A1. Flow Tool User Input Form

A1.3 USER INPUTS AND FLOW DATABASE

For each set of calculations, the user selects a river basin and stream node combination from predefined dropdown menus (**Figure A1**). The user must also define the calculation period (start and end year), within the available simulation period. The available simulation period varies by basin. *Note that specifying start or end years outside of the available simulation period will result in a runtime error.*

Any number of the available flow data sets can be included in the tool calculations, selected by highlighting from two list boxes. The "Historical" list box includes a naturalized and a baseline data set. The naturalized data set represents "unimpaired" flows at the selected node, as modelled, without the impacts of water use, discharges, diversions, transfers, or storage. In other words, it is an estimate of "natural" river flows without anthropogenic impacts. The baseline data set was developed (modelled) by pairing estimates of current water use and impairment with historical variable hydrology. In other words,

it represents current activity in the basin superimposed on an extended variable hydrologic profile. Note that either the naturalized or the baseline data set can be used as the reference flow data for the environmental flow metric and hydrologic classification calculations. The naturalized flow data set is the default reference. However, the user can specify the baseline data set to be the reference by selecting the baseline data set from the list and de-selecting the naturalized data set.

The "Future" list box includes five different future growth and water use projections (Scenarios C – G) combined with varying levels of assumed climate change. These five scenarios have been described elsewhere, but short summaries of each are available within the tool, via the "Description of Future Scenarios" button. Also included as optional data sets are two sets of naturalized flow projections simulated under different climate change assumptions. The associated climate change projection scenarios have also been described elsewhere. These data sets are included in this tool to provide useful references that effectively isolate the impacts of climate change, and associated altered hydrologic conditions, on the node flow regimes.

Calculated environmental flow metrics can be provided in the output tables (described below) as color-coded categories only or as both numeric values and color categories. This is a user option provided on the input form (**Figure A1**). For users less familiar with TNC environmental flow equations (Section A1.4.3), the color-coding only option is recommended.

The modelled flow database is included in the tool with a series of basin-specific worksheet tabs. Each flow scenario data set is included as separate columns in the respective basin worksheets. Separate sets of worksheets are included for the impaired vs. naturalized data sets. The data in these worksheets can be modified by the user if, for example, the modeled scenarios are updated in the CDSS. In such a case, the new flow data must be copied and pasted into the corresponding worksheet in the same format as in the tool currently. Data date ranges cannot be changed by the user in these sheets. The worksheets should not be modified by the user in any other way as they provide the data, in a predefined format, that underpin all tool calculations. As noted above, the addition of new nodes or flow scenarios to the tool are not currently options for the user.

A1.4 TOOL CALCULATIONS AND OUTPUTS

The flow tool provides the following outputs, each on separate worksheet tabs:

- Monthly and annual timeseries plots;
- 3 and 10-year rolling average timeseries plots;
- Plot of monthly means;
- Monthly flow percentile plots;
- A tabular summary of annual hydrologic classifications;
- A tabular summary of statistical low flows; and
- A tabular summary of the calculated environmental flow metrics.

Monthly and annual timeseries plots are intended to provide concise summaries, and comparisons, of the underlying flow data sets and their associated temporal variability. The rolling average plots are provided to remove some of the year-to-year variability "noise" and help identify, and compare, larger timescale patterns and trends. Monthly mean plots highlight differences (and projected changes) in hydrologic seasonality, while the percentile plots highlight the modelled range of variability in the data sets and, particularly, the frequency of flow extremes. The hydrologic classification table (Section A1.4.1) provides information on the frequency of dry, average, and wet years in the simulated record under different simulated water impairment conditions. The table of calculated low flow metrics (Section A1.4.2)

provides low flow statistics that are particularly relevant to water quality considerations. And, lastly, the table of environmental flow metrics (Section A1.4.3) highlights the degree of ecologically-relevant flow changes associated with each modelled scenario. Color coding is provided to indicate levels of risk associated with the calculated metric values.

In addition to the summary output tables and graphs described above, the raw output underpinning the summaries are also provided in separate worksheet tabs ("X Output").

A1.4.1 HYDROLOGIC CLASSIFICATION

As part of the set of tool calculations, each water year included in the specified calculation period is assigned to one of five hydrologic classes: drought, dry, average, wet, or flood. Classifications are based on the total annual flow (AFY) in the given water year, compared to category threshold values. Classification thresholds are based on the selected reference flow data set (naturalized or baseline) for the given stream node, calculated according to the flow percentile values summarized in **Table A1**. For example, the annual flow threshold for classifying as a drought year is defined as the 5th percentile naturalized flow (exceeded 95% of the time in the naturalized record); while flood years are classified according to the 94th percentile naturalized flow (exceeded 6% of the time in the naturalized record).

Table A1. Hydrologic Classification Thresholds

Annual Flow Percentile (upper limit)	Hydrologic Category
5th	Drought
24th	Dry
75th	Average
94th	Wet
100th	Flood

A1.4.2 STATISTICAL LOW FLOWS

Statistical low flows, of a monthly duration, are calculated in the tool for reference to common water quality metrics. Monthly low flows are calculated for recurrence intervals of: 2, 5, 10, 25, 50, and 100 years. Calculations are performed generally following the USEPA's DFLOW (Rossman, 1990) methodology, assuming a Log Pearson Type 3 distribution to the underlying data. These values are calculated for reference only, particularly with respect to relative changes in low flow rates under the simulated scenarios. The calculated values themselves are not intended to be used for regulatory purposes.

A1.4.3 ENVIRONMENTAL FLOW CALCULATIONS

TNC environmental flow metrics, as included in the Flow Tool, are defined in **Appendix C**. Numeric output are generally presented as percent departure from reference flows. Reference flows can be specified as either the naturalized flow data set (default) or the baseline flow data set. The output table is also color coded based on risk category (from "low risk" to "very high risk") (**Table A2**). Risk categories are pre-defined by TNC experts according to percent departure threshold values (compared to reference condition). Risk category thresholds differ for each metric.

Table A2. Environmental Flow Risk Categories

Color Key:

	= low ecological risk
	= moderate ecological risk
	= less moderate ecological risk (cold water baseflow only)
	= high ecological risk
	= very high ecological risk

A1.4.4 IMPAIRMENT ANOMALIES CHART

Also included in the tool output is a chart of "impairment anomalies". Two metrics are calculated for this plot: annual average flow anomaly and the standard deviation of monthly flow anomalies. The former is calculated as the percent difference between annual average scenario flow and annual average reference flow (naturalized or baseline). It is intended to reflect the change in long-term physical flow availability. The latter is calculated as the standard deviation of the percent changes in monthly mean flow rates, compared to reference. This metric is intended to reflect changes in the *timing* (rather than magnitude) of flow rates. The relative positioning of each scenario plotted according to these calculated metrics provides useful information with respect to the drivers of impairment. Large negative percent changes in annual average flow indicate a depletion impairment (consumptive use and/or climate change); while high standard deviations of monthly anomalies indicate a timing impairment (storage, water transfers, or return flows). The plotting area is divided into four quadrants reflecting four possible combinations of impairment: "no impairment", "timing impairment only", "timing and depletion impairment", and "depletion impairment only". Quadrant boundary values have been predefined, based on a coarse review of the data sets, as 10% for annual average anomalies and 20% for the standard deviation of monthly anomalies.

References

Rossman, L A. DFLOW USER'S MANUAL. U.S. Environmental Protection Agency, Washington, DC, EPA/600/8-90/051 (NTIS 90-225616), 1990.

Appendix B: Flow Tool Nodes

Gage Number	Station Name	Status	Period Of Record Start	Period Of Record End	HUC10	HUC Name	Basin	Fish_Coldwater	Fish_Warmwater	Fish_Plain	Wetlands/Riparian	Boating	ISFs	Num of Categories	Latitude	Longitude	Elevation (ft)	Datum
07081200	ARKANSAS RIVER NEAR LEADVILLE, CO	Active	1967	2018	1102000102	Headwaters Arkansas River	Arkansas	1	0	0	2	6	2	4	39.24899982	-106.3481121	9665	NGVD 29
07111000	HUERFANO R AT MANZANARES XING, NR REDWING, CO.	Active	1923	2018	1102000601	Headwaters Huerfano River	Arkansas	1	0	0	1	3	2	4	37.72770544	-105.3538732	8206.415714	NAVD 88
07124200	PURGATOIRE RIVER AT MADRID, CO.	Active	1972	2018	1102001003	Trinidad Lake-Purgatoire River	Arkansas	0	0	0	0	4	0	1	37.12946461	-104.6399893	6261.61	NGVD 29
09041000	MUDDY CREEK NEAR KREMMLING, CO.	Historic	1937	1999	1401000107	Muddy Creek	Colorado	1	2	0	3	2	1	5	40.29359493	-106.4836477	7856	NGVD 29
09010500	COLORADO RIVER BELOW BAKER GULCH NR GRAND LAKE, CO	Active	1953	2018	1401000103	Headwaters Colorado River	Colorado	1	0	0	3	2	2	4	40.32581748	-105.8566794	8750	NGVD 29
09080400	FRYINGPAN RIVER NEAR RUEDI, CO.	Active	1964	2018	1401000405	Fryingpan River	Colorado	1	0	0	3	4	2	4	39.36554009	-106.8255959	7473.25	NGVD 29
09081600	CRYSTAL RIVER ABV AVALANCHE CRK, NEAR REDSTONE, CO	Active	1955	2018	1401000407	Cyrstal River	Colorado	1	0	0	4	4	2	4	39.23263837	-107.2275011	6905	NGVD 29
09063000	EAGLE RIVER AT RED CLIFF, CO.	Active	1910	2018	1401000302	Upper Eagle River	Colorado	1	0	0	3	4	2	4	39.50831845	-106.3666958	8653.8	NGVD 29
09057500	BLUE RIVER BELOW GREEN MOUNTAIN RESERVOIR, CO	Active	1937	2018	1401000206	Lower Blue River	Colorado	1	0	0	3	4	2	4	39.88026343	-106.3339189	7682.66	NGVD 29
09073400	ROARING FORK RIVER NEAR ASPEN, CO.	Active	1964	2018	1401000401	Upper Roaring Fork River	Colorado	1	0	0	3	4	2	4	39.17998786	-106.8019841	8014.01	NGVD 29
09095500	COLORADO RIVER NEAR CAMEO, CO.	Active	1933	2018	1401000514	Jerry Creek-Colorado River	Colorado	1	5	0	3	3	1	5	39.23914511	-108.2661958	4813.73	NGVD 29
09070500	COLORADO RIVER NEAR DOTSERO, CO	Active	1940	2018	1401000115	Big Alkali Creek-Colorado River	Colorado	1	3	0	3	4	1	5	39.64460942	-107.0780124	6130	NGVD 29
09163500	COLORADO RIVER NEAR COLORADO-UTAH STATE LINE	Active	1951	2018	1401000519	McDonald Creek-Colorado River	Colorado	0	5	0	3	3	0	3	39.13275927	-109.0270552	4325	NGVD 29
09085000	ROARING FORK RIVER AT GLENWOOD SPRINGS, CO.	Active	1906	2018	1401000410	Outlet Roaring Fork River	Colorado	1	2	0	3	4	0	4	39.54359252	-107.3294988	5720.73	NGVD 29
09152000	KANNAH CREEK NEAR WHITEWATER, CO.	Historic	1917	1982	1402000507	Kannah Creek-Gunnison River	Gunnison	1	4	0	2	4	1	5	38.96164843	-108.2303587	6084.498803	NAVD 88
09152500	GUNNISON RIVER NEAR GRAND JUNCTION, CO.	Active	1896	2018	1402000508	Outlet Gunnison River	Gunnison	0	5	0	2	1	1	4	38.98331587	-108.4506451	4631.37	NGVD 29
09146200	UNCOMPAHGRE RIVER NEAR RIDGWAY, CO.	Active	1958	2018	1402000602	Upper Uncompahgre River	Gunnison	1	0	0	2	5	2	4	38.18387868	-107.7458922	6877.58	NGVD 29
09115500	TOMICHI CREEK AT SARGENTS, CO	Active	1916	2018	1402000301	Headwaters Tomichi Creek	Gunnison	1	0	0	2	1	2	4	38.39502721	-106.4226255	8416	NGVD 29
09126000	CIMARRON RIVER NEAR CIMARRON, CO.	Active	1954	2018	1402000209	Cimarron River	Gunnison	1	1	0	2	3	2	5	38.25819317	-107.5461112	8641.48	NGVD 29
09114500	GUNNISON RIVER NEAR GUNNISON, CO.	Active	1910	2018	1402000202	South Beaver Creek-Gunnison River	Gunnison	1	0	0	1	5	1	4	38.54193584	-106.9497667	7655	NGVD 29
09149500	UNCOMPAHGRE RIVER AT DELTA, CO.	Active	1938	2018	1402000606	Lower Uncompahgre River	Gunnison	0	0	0	1	4	1	3	38.74194352	-108.0804178	4926.49	NGVD 29
09147500	UNCOMPAHGRE RIVER AT COLONA, CO.	Active	1912	2018	1402000603	Middle Uncompahgre River	Gunnison	0	0	0	2	3	0	2	38.33143299	-107.7792199	6320	NGVD 29
06617500	ILLINOIS CREEK NEAR RAND, CO.	Active	1931	2018	1018000104	Illinois River	North Platte	1	0	1	4	3	1	5	40.46282797	-106.1766898	8550.93	NGVD 29
06614800	MICHIGAN RIVER NEAR CAMERON PASS, CO	Active	1973	2018	1018000105	Michigan River	North Platte	1	0	0	4	3	1	4	40.49609395	-105.8650121	10390	NGVD 29
06620000	NORTH PLATTE RIVER NEAR NORTHGATE, CO	Active	1904	2018	1018000201	Douglas Creek-North Platte River	North Platte	0	0	0	2	2	0	2	40.93663819	-106.3391949	7810.39	NGVD 29
08245000	CONEJOS RIVER BELOW PLATORO RESERVOIR, CO.	Active	1952	2018	1301000501	Headwaters Conejos River	Rio Grande	1	0	0	3	5	2	4	37.35491208	-106.544228	9868.357416	NAVD 88
08219500	SOUTH FORK RIO GRANDE AT SOUTH FORK, CO.	Active	1910	2018	1301000111	South Fork Rio Grande	Rio Grande	1	0	0	3	5	2	4	37.65955327	-106.6491069	8224.966558	NAVD 88
08220500	PINOS CREEK NEAR DEL NORTE, CO.	Active	1919	2018	1301000201	Pinos Creek	Rio Grande	0	0	0	2	2	1	3	37.59096643	-106.4498324	8487.342445	NAVD 88
08217500	RIO GRANDE AT WAGON WHEEL GAP, CO	Active	1951	2018	1301000110	Shallow Creek-Rio Grande	Rio Grande	0	0	0	3	4	1	3	37.7664133	-106.8306458	8430	NGVD 29
06744000	BIG THOMPSON RIVER AT MOUTH, NEAR LA SALLE, CO.	Active	1914	2018	1019000606	Outlet Big Thompson River	South Platte	0	1		2	5	1	5	40.35064927	-104.7836473	4689.01882	NAVD 88
06725500	MIDDLE BOULDER CREEK AT NEDERLAND, CO.	Active	1907	2018	1019000504	Headwaters Boulder Creek	South Platte	1	0	1	3	3	2	5	39.96165477	-105.5044409	8182.677684	NAVD 88
06733000	BIG THOMPSON RIVER AT ESTES PARK, CO.	Active	1946	2018	1019000602	Headwaters Big Thompson River	South Platte	0	0	0	3	3	1	3	40.37831687	-105.513887	7492.5	NGVD 29
06724000	ST. VRAIN CREEK AT LYONS, CO.	Active	1895	2018	1019000507	Boulder Creek-Saint Vrain Creek	South Platte	0	0	1	2	4	0	3	40.22069988	-105.2634822	5309.949029	NAVD 88
06754500	SOUTH PLATTE RIVER NEAR KERSEY, CO	Active	1901	2018	1019000306	Little Dry Creek-South Platte River	South Platte	0	0	1	2	2	0	2	40.41250082	-104.5631794	4578.02	NGVD 29
06714000	SOUTH PLATTE RIVER AT DENVER, CO	Active	1895	2018	1019000303	Cherry Creek-South Platte River	South Platte	0	0	1	1	4	0	3	39.75944924	-105.0039926	5157.64	NGVD 29
06707500	SOUTH PLATTE RIVER AT SOUTH PLATTE	Active	1896	2018	1019000207	Chatfield Lake-South Platte River	South Platte	0	0	1	2	5	0	3	39.40886382	-105.1698698	6090.537038	NAVD 88
06764000	SOUTH PLATTE RIVER AT JULESBURG, CO	Historic	1902	2017	1019001801	Hartley Draw-South Platte River	South Platte	0	0	2	2	0	0	2	40.97499465	-102.2518551	3449.8	NGVD 29
09346000	NAVAJO RIVER AT EDITH, CO.	Historic	1912	1996	1408010106	Navajo River	Southwest	1	2	1	3	3	1	6	37.00278742	-106.9075374	7033	NGVD 29
09172500	SAN MIGUEL RIVER NEAR PLACERVILLE, CO	Active	1910	2018	1403000303	Beaver Creek-San Miguel River	Southwest	1	1	0	3	3	1	4	38.03070183	-108.1102916	7100	NGVD 29
09357500	ANIMAS RIVER AT HOWARDSVILLE, CO	Active	1935	2018	1408010401	Headwaters Animas River	Southwest	1	0	0	3	3	2	4	37.832915	-107.5995623	9628.987458	NAVD 88
09349800	PIEDRA RIVER NEAR ARBOLES, CO.	Active	1962	2018	1408010205	Lower Piedra River	Southwest	0	1	0	2	5	1	4	37.08833574	-107.3978239	6147.52	NGVD 29
09346400	SAN JUAN RIVER NEAR CARRACAS, CO.	Active	1961	2018	1408010108	San Juan River-Navajo Reservoir	Southwest	1	0	0	2	5	0	3	37.01362025	-107.3122644	6090	NGVD 29
09354500	LOS PINOS RIVER AT LA BOCA, CO.	Active	1951	2018	1408010115	Lower Los Pinos River	Southwest	0	2	0	2	0	0	2	37.00944831	-107.5995033	6143.58	NGVD 29
09166500	DOLORES RIVER AT DOLORES, CO.	Active	1895	2018	1403000203	McPhee Reservoir-Dolores River	Southwest	0	2	0	2	5	0	4	37.47248898	-108.4975905	6840	NGVD 29
09371000	MANCOS RIVER NEAR TOWAOC, CO.	Active	1921	2018	1408010703	Lower Mancos River	Southwest	0	3	0	0	0	0	1	37.02749206	-108.7414822	5055.98	NGVD 29
09363500	ANIMAS RIVER NEAR CEDAR HILL, NM	Active	1933	2018	1408010410	City of Farmington-Animas River	Southwest	0	0	0	3	0	1	2	37.0365686	-107.8753333	5960	NGVD 29
09239500	YAMPA RIVER AT STEAMBOAT SPRINGS, CO	Active	1904	2018	1405000104	Oak Creek-Yampa River	Yampa/White	1	2	0	2	4	2	5	40.4829852	-106.8324312	6695.47	NGVD 29
09241000	ELK RIVER AT CLARK, CO.	Historic	1910	2003	1405000102	Headwaters Elk River	Yampa/White	1	0	0	1	3	2	4	40.71747221	-106.9158841	7267.75	NGVD 29
09304800	WHITE RIVER BELOW MEEKER, CO	Active	1961	2018	1405000504	Strawberry Creek-White River	Yampa/White	1	3	0	2	1	1	5	40.02258198	-108.1199471	5900	NGVD 29
09260050	YAMPA RIVER AT DEERLODGE PARK, CO	Active	1982	2018	1405000206	Hells Canyon-Yampa River	Yampa/White	0	4	1	2	2	1	5	40.45163395	-108.5251015	5600	NGVD 29
09245000	ELKHEAD CREEK NEAR ELKHEAD, CO.	Historic	1953	1996	1405000106	Elkhead Creek	Yampa/White	1	2	1	2	1	1	6	40.66969321	-107.2850596	6845	NGVD 29
09251000	YAMPA RIVER NEAR MAYBELL, CO	Active	1916	2018	1405000204	Deception Creek-Yampa River	Yampa/White	0	4	1	1	3	1	5	40.50274637	-108.0334154	5900.23	NGVD 29
09260000	LITTLE SNAKE RIVER NEAR LILY, CO	Active	1921	2018	1405000311	Outlet Little Snake River	Yampa/White	0	4	0	1	0	1	3	40.54901612	-108.4243227	5685	NGVD 29
09306500	WHITE RIVER NEAR WATSON, UTAH	Historic	1923	2018	1405000707	Asphalt Wash-White River	Yampa/White	0	0	0	0	0	0	0	39.97885572	-109.1787275	4946.78	NGVD 29

Appendix C: Flow Ecology Matrix

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Native coldwater fishes	base flows	Trout (*Greenback Cutthroat Trout, Colorado River Cutthroat Trout, Rio Grande Cutthroat Trout*)	Colorado River Cutthroat	Later summer flows are a critical "pinch point" for trout.* "Headwaters" & "transitional" zones**	$$\frac{(\textit{Mean August Qscenario} + \textit{Mean September Qscenario}) \div}{\textit{Mean annual Qbaseline}}$$ $* 100$ Q=flow (cubic feet per second [cfs])	• <10 percent: Red node color. Low flows are inadequate to support trout (very high flow-ecology risk) • 10 to 15 percent: Orange node color. Low flows have potential to make trout viability sporadic (high flow-ecology risk) • 16 to 25 percent: Yellow node color. Low flows may severely limit trout stock every few years (moderate flow-ecology risk) • 26 to 55 percent: Blue node color. Low flows may occasionally limit trout numbers (minimal flow-ecology risk) • >55 percent: Green node color. Low flows may very seldom limit trout (low flow-ecology risk)
Notes	— "Mean Annual Q$_{natural}$" is the average monthly flow, i.e., sum of all monthly flows for the year divided by 12. For "current" should be each of the managed and future natural scenarios; Use "historical_natural" for "natural" *without flow modifications **will need to be adjusted for Front Range (or may not apply)					
References	Tennant, 1976; Binns and Eiserman, 1979; Coleman and Fausch, 2007; Wilding and Poff, 2008; Sanderson et al., 2012a; Sanderson et al., 2012b					

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Wetlands/ plant communities/ riparian	Peak/flood flows	Cottonwood recruitment (significant riparian wetland communities, rare aquatic-dependent plants, rare plant communities, national wetlands inventory, etc)	Cottonwood	Peak/flood flows are essential for cottonwood recruitment.	Calculate % alteration of peak flow: (Qscenario – Qnatural)/Qnatural	• Flow alteration of 30 to 100 percent was assigned a red node color representing very high flow-ecology risk • Flow alteration of 18 to 30 percent was assigned an orange node color representing high flow-ecology risk • Flow alteration of 7 to 18 percent was assigned a yellow node color representing moderate flow-ecology risk • Flow alteration of 0 to 7 percent was assigned a green node color representing low flow-ecology risk
Notes	Use only top 30% of years based on total Mean Annual Flow. Apply only below 9500 ft elevatoin. "Q" in above equation is average flow in Apr+May+June. (for peak flows) Thresholds for risk classes are based on probability of recruitment (see Sanderson et al. 2012, p.2-11. (Appendix I, Riparian Vegetation Methods) *Will vary based as:* • *If flow alteration is >0% (i.e. flow augmentation) then cottonwood abundance = 100%* • *If flow alteration is ≤0% then %abundance = 1.038 x %flow alteration + 1.005.*					
References	Merritt and Cooper, 2000; Merritt and Poff, 2010; Sanderson et al., 2012a					

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Warmwater fishes	Peak flows and base flows	Warmwater fishes (Bonytail chub, Colorado Pikeminnow, Humpback chub, razorback sucker, bluehead sucker, flannelmouth sucker, roundtail chub, etc.)	Razorback sucker	Minimum flows are essential for warmwater fish. Apply to nodes in West Slope transitional and West Slope warm water.	Calculate max sucker biomass under both natural and other scenarios as: • % max biomass = $0.125*Q_{sept}^{0.3021}$ Percent reduction in biomass is calculated as: • Reduction in biomass = (baseline - scenario)/baseline*100	• 50 to 100 percent reduction in potential biomass – nodes were assigned a red color (very high flow-ecology risk) • 25 to 50 percent reduction in potential biomass – nodes were assigned an orange color (high flow-ecology risk) • 10 to 25 percent reduction in potential biomass – nodes were assigned a yellow color (moderate flow-ecology risk) • <10 percent reduction in potential biomass – nodes were assigned a green color (low flow-ecology risk)
Notes	*Modified Sanderson et al. 2012; '30-day minimum flow' is a running mean calculated over the summer-autumn flow period (July 1 to November 30) for each year, then averaged over the study period. Biomass is estimated for natural conditions and current flow conditions. Apply only below 7000' elevation in West Slope and in Rio Grande.*					
References	Bestgen et al., 2017; Sanderson et al., 2012a, 2012b; Anderson and Stewart, 2007; Anderson, 2010; Wilding and Poff, 2008; Bezzerides and Bestgen, 2002					

Trout & Warmwater fish peak flows	Peak flows	River ecosystems (hydrology)		Peak flow is essential for mobilizing fine sediment to maintain spawning beds. Apply at all nodes.	Calculate % alteration of peak flow (Qaltered – Qbaseline)/Qbaseline. Use top 50% of years, based on total Mean annual flow (note that this differs from "cottonwood recruitement" metric. "Q" is average flow in Apr+May+Jun.	
Notes	*Greater degree of alteration = greater risk.* *Will be especially important in showing the shift in the transition zone between warm and cold water*					
References	Reiser et al., 1990 (comprehensive discussion of the need for flushing flows)					

| Mean annual flow (general hydrologic metric) | | River function/ structure (ecosystem health/ hydrology) | | Total flow constrains overall ability to meet flow needs. | Calculate % departure between all scenarios and natural. Total flow for the water year, Oct 1-Sept 30. | |
| Notes | *Basic hydrologic need to support stream ecology.* | | | | | |

Appendix C: Flow Ecology Metrics

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Winter flow (general hydrologic metric)		River function/ structure (ecosystem health/ hydrology)		Excessively low winter flow can limit over-wintering of species.	Calculate mean flows as avg (Dec, Jan, Feb). Calculate % departure between each scenario vs. historic natural.	
Notes	*Basic hydrologic need to support stream ecology.*					

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Late-summer flows (general hydrologic metric)		River function/ structure (ecosystem health/ hydrology)		Excessively low late summer flows can hinder both trout and native fish, and can enhance non-native fish	Calculate mean flows as avg (Aug, Sep). Calculate % departure between each scenarios vs. historic natural.	
Notes	*Basic hydrologic need to support stream ecology.*					

Fishing (river)	Base flows, lower flows	Stocked/sports fishing		Can be calculated on regulated systems	Calculate % departure between all scenarios and natural. Total flow for the water year, Oct 1-Sept 30.	
Notes	*Similar to cold water fishes, but emphasis in on regulated systems and the low flows for meeting fish needs for recreation.*					
References	Tennant, 1976; Binns and Eiserman, 1979; Coleman and Fausch, 2007; Wilding and Poff, 2008; Sanderson et al., 2012a; Sanderson et al., 2012b					

Boating (river)	Peak and high flows	Whitewater kayaking and rafting	RICDs		*use RICDS for this layer, similar to ISFs – and point users to the hydrologic metrics to further inform recreation scenario planning	
Notes	*Boatable days needs to be a daily time-step. SWSI is monthly. Best practice is to simply use this tool to determine if RICDs will be met*					
References	Fey and Stafford, 2012.; Sanderson et al., 2012a					

ISFs	Base flows/ minimum flow reqs.	Ecosystem and fish/aquatic needs	ISFs		Will simply be an overlay of ISF needs.	
Notes						

Macrocategory	Flow Need	Targets	Indicator species	How does the flow need relate to the target?	Calculation(s):	Risk Classes
Plains fishes	base flows, especially late summer	Plains fishes (darters, minnows, sunfish)		late-summer baseflow metric	Calculate mean flows as avg (Aug, Sep). Calculate % departure between each scenarios vs. natural.	- Mean July/August flow departure from baseline < 10% = low risk. - Mean July/August flow departure from baseline < 25% = moderate risk. - Mean July/August flow departure from baseline 25-50% = high risk. - Mean July/August flow departure from baseline > 50% = very high risk.
Notes	*Based on conversations with CSU and other academics. Applied only below 5500 ft east of the continental divide.*					
References	Bestgen et al., 2017.					

References

Anderson, C. 2010. Factors affecting populations of flannelmouth suckers on the Dolores River between McPhee Dam and the San Miguel River. *In* A. Oliver, C. Anderson, and R. Anderson, editors. Appendix B in "Baseline field investigations, science-based opportunities and potential tools for improvement of the downstream environment on the lower Dolores River". Colorado Water Conservation Board.

Anderson, R. M. and G. Stewart. 2007. Impacts of stream flow alterations on the native fish assemblage and their habitat availability as determined by 2D modeling and the use of fish population data to support instream flow recommendations for the sections of the Yampa, Colorado, Gunnison and Dolores rivers in Colorado. Colorado Division of Wildlife.

Bestgen, Kevin R., Cameron T. Wilcox, Angela A. Hill, and Kurt D. Fausch. "A Dynamic Flow Regime Supports an Intact Great Plains Stream Fish Assemblage." *Transactions of the American Fisheries Society* 146, no. 5 (September 3, 2017): 903–16. https://doi.org/10.1080/00028487.2017.1310137.

Bezzerides, Nick, and Kevin R. Bestgen. "Status Review of Roundtail Chub Gila Robusta, Flannelmouth Sucker Catostomus Latipinnis, and Bluehead Sucker Catostomus Discobolus in the Colorado River Basin." Larval Fish Laboratory Contribution 118. Fort Collins, CO: Colorado State University, 2002. https://tnc.box.com/s/hi5xn9it9kk7v06a48nqgc78wkmthv9d.

Binns, N. A. and F. M. Eiserman. 1979. "Quantification of Fluvial Trout Habitat in Wyoming." *Transactions of the American Fisheries Society*. 108(3):215-228.

Coleman, M. A. and K. D. Fausch. 2007. Cold summer temperature limits recruitment of age-0 cutthroat trout in high-elevation Colorado streams. Transactions of the American Fisheries Society **136**:1231-1244.

Fey, N. and E. Stafford. 2012. Assessing Streamflow Needs for Whitewater Recreation in the Yampa/White River basin. Appendix G in Sanderson, J. S., B. P. Bledsoe, N. L. Poff, T. Wilding, W. J. Miller, and Nathan Fey. "Yampa-White Basin Roundtable Watershed Flow Evaluation Tool (WFET) Study." Prepared for The Nature Conservancy, 2012. http://www.conservationgateway.org/Files/Documents/Sanderson%20et%20al.%202012%20Yampa-White%20WFET%20Report%20Appendix%20G%20Recreational%20Survey%20Report.pdf

Merritt, D. M. and D. J. Cooper. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River Basin, USA. Regulated Rivers: Research & Management 16:543-564.

Merritt, D. M. and N. L. R. Poff. 2010. Shifting dominance of riparian *Populus* and *Tamarix* along gradients of flow alteration in western North American rivers. Ecological Applications 20:135-152.

Reiser, D. W., M. P. Ramey, and T. A. Wesche (1990). Flushing flows. Pages 91–135, Chapter 4 in: Alternatives in Regulated River Management, J. A. Gore and G. E. Petts (Eds.), CRC Press, Inc., Boca Raton, FL, 360 p.

Sanderson, J. S., B. P. Bledsoe, N. L. Poff, T. Wilding, W. J. Miller, and Nathan Fey. "Colorado Basin Roundtable Watershed Flow Evaluation Tool (WFET) Study." Prepared by CDM Smith for the Northwest Colorado Council of Governments, 2012.
http://www.conservationgateway.org/Files/Pages/cobasinflowevaluation.aspx

Sanderson, J. S., B. P. Bledsoe, N. L. Poff, T. Wilding, W. J. Miller, and Nathan Fey. "Yampa-White Basin Roundtable Watershed Flow Evaluation Tool (WFET) Study." Prepared for The Nature Conservancy, 2012.
http://www.conservationgateway.org/Documents/Sanderson%20et%20al.%202012%20Yampa-White%20Basin%20Watershed%20Flow%20Evaluation%20Tool%20Final%20Report.pdf

Tennant, D. L. 1976. Instream flow regimens for fish, wildlife, recreation and related environmental resources. Fisheries **1**:6-10.

Wilding, T. K. and N. L. Poff. 2008. Flow-ecology relationships for the watershed flow evaluation tool. Colorado State University, Fort Collins.