Environmental Flow Assessment of the Upper Colorado and Fraser River Basins

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January 2026

Glossary of Terms

BESTSM : Boyle Engineering Stream Simulation Model

CWP: Colorado Water Plan

CWCB: Colorado Water Conservation Board

GC SMP: Grand County Stream Management Plan

EIS: Environmental Impact Statement

EFT: Environmental Flow Tool

GREP: Gross Reservoir Expansion Project (a.k.a., Moffat Firming Project)

ISF: Instream flow

PACSIM: Platte and Colorado Simulation Model

PHABSIM: Physical Habitat Simulation Model

TMD: Transmountain Diversion

WGFP: Windy Gap Firming Project

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1 Background and Purpose

The Upper Colorado Watershed Environment Team (UCWET) would like to better understand how the Windy Gap Firming Project (WGFP) and the Moffat Firming Project (a.k.a. Gross Reservoir Expansion Project) (GREP) will impact streamflows in Grand County under a range of potential future climate conditions. Furthermore, UCWET hopes to use the information generated by this project to help identify water available to meet instream flow (ISF) water rights and/or other flow targets identified for maintaining the integrity of aquatic ecosystems. Examples of the latter include flow targets outlined in the Grand County Stream Management Plan (GCSMP).

Lotic recently prepared several deliverables to support UCWET in its ongoing efforts to protect and improve conditions in streams and river in the Colorado River headwaters. Primary project deliverables include an Environmental Flows Data Dashboard (the Data Dashboard) and a Microsoft Power Point slide deck entitled "Streamflow Changes and Environmental Flow Gaps on the Colorado and Fraser Rivers" (the Slide Deck). These two deliverables can be accessed at the locations below:

- Data Dashboard: https://lotic-ucwet-eflows-dashboard.share.connect.posit.cloud
- Slide Deck: https://docs.google.com/presentation/d/1IKTF6zDOHnG6FGTHsewlG6-ahS07bNUzrTVF7Co6sP0/edit?usp=sharing

In addition, a PDF user manual for the Data Dashboard was delivered to UCWET to assist Board members in their use of the application. The Data Dashboard is intended to help UCWET understand the geographical and temporal distribution of environmental flow shortages in the Colorado River headwaters and explore the nexus of those shortages to transmountain diversions (TMDs) and local water uses. We expect that the functionality delivered by the Data Dashboard can assist UCWET in the development of outreach strategies to water users that can result in flow leasing or water conservation projects that help meet identified environmental flow gaps. The Data Dashboard may be accessed by the UCWET Board of Directors (BOD) at the link provided above. We developed the Data Dashboard as a tool for internal use by UCWET and not as an externally facing tool for use by the public. However, the existing form of the Data Dashboard does not preclude UCWET from embedded it in the organizations website as a component of a webpage, perhaps accompanied by additional context or user instructions relevant to public use. The Slide Deck was requested by the BOD as a tool for communicating to the broader public about existing and expected streamflow conditions relevant to aquatic ecosystem health. Speaker notes contained on each slide can support BOD members in their efforts to communicate around the graphics and ideas presented in the Slide Deck.

The sections of the technical report provided below include descriptions of the data sources and analysis approaches used to develop the primary project deliverables.

2 Project Area

UCWET's geographic area of interest (the Project Area) includes the mainstem Colorado above the confluence with the Blue River and its numerous tributaries (Figure 1).

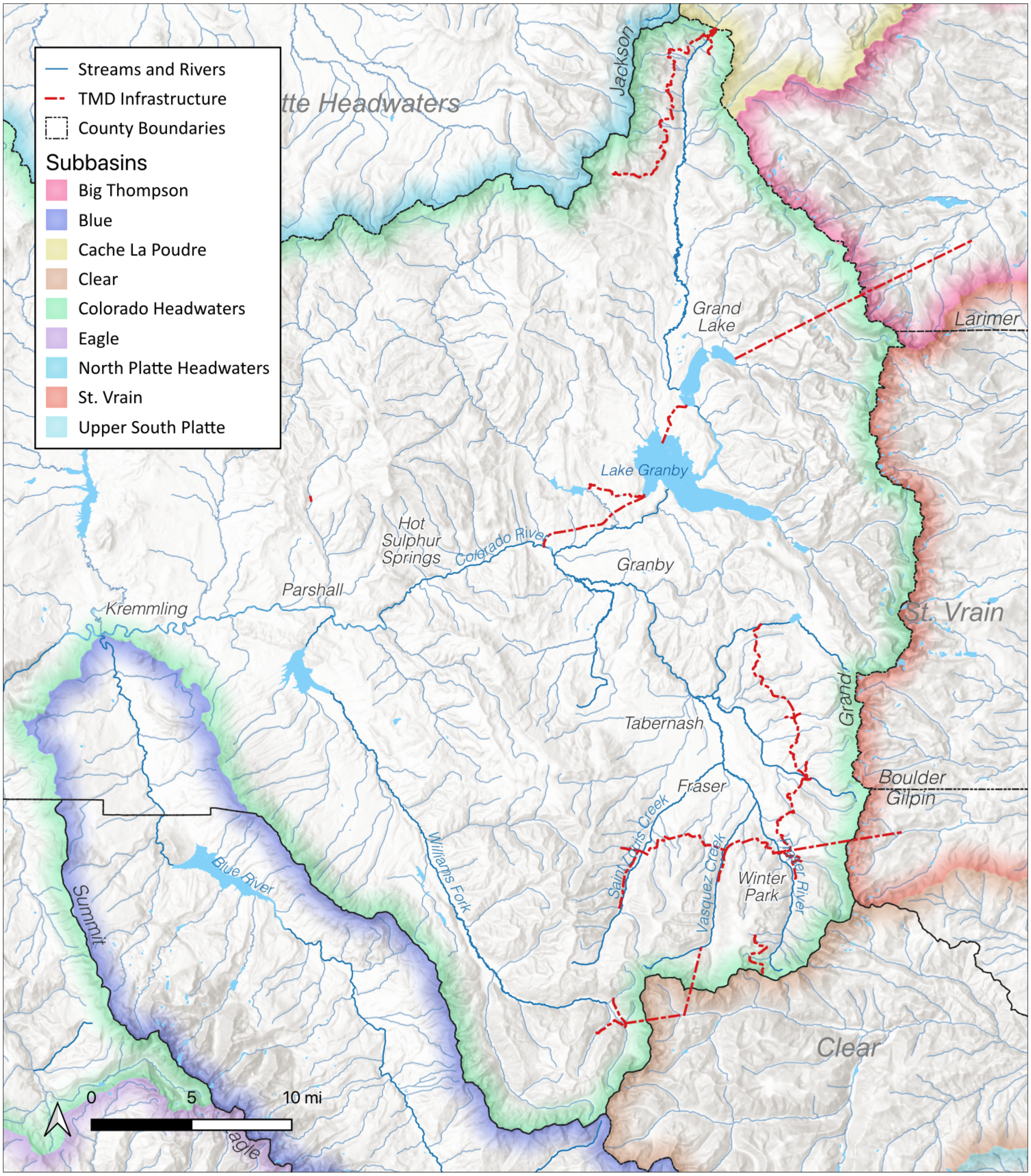

Figure 1. Map of streams, rivers, and TMD infrastructure in the Project Area.

3 Historical Impacts of Transmountain Diversions

Data sourced from real-time streamflow gauging stations and diversion records (Table 1, Figure 2) over a recent 30-year period (1995 – 2024) were used to calculate the proportion of streamflows at select locations in the Project Area. Each of these locations captured some element of impacts from TMD infrastructure associated with the Moffat Project and the Colorado-Big Thompson Project. The analysis performed here required comparison of streamflow gauge and/or diversion structure records that record TMD diversions to stream gauge records at locations on the Fraser and Colorado Rivers. A simple annual and monthly surface mass balance approach was used to describe the proportional impact of TMDs in the Project Area using the equation below:

$$P_t = \frac{Y_{TMD,t}}{(Y_{TMD,t} + Y_{WS,t})} * 100$$

Where:

- P_t = The percentage of basin yield captured by upstream TMDs at time step (t);
- $Y_{TMD,t}$ = TMD yield at time step (t), defined as the water flowing out of basin through the TMD infrastructure; and
- $Y_{WS,t}$ = West Slope streamflow yield at time step (t), calculated at a gauging station downstream of the TMD diversion point(s)

Table 1. USGS and CDWR streamflow and diversion record locations used for TMD impact analysis.

Site	Name	Basin of Origin	Operator
MOFTUNCO	MOFFAT WATER TUNNEL AT EAST PORTAL, CO	UPPER COLORADO	CDWR
09033300_ext	FRASER RIVER BELOW CROOKED CR (extended record)	UPPER COLORADO	USGS
5104625	BERTHOUD CANAL AND RESERVOIR TUNNEL	UPPER COLORADO	CDWR
09010500	COLORADO RIVER BELOW BAKER GULCH NEAR GRAND LAKE	UPPER COLORADO	USGS
09034250	COLORADO RIVER AT WINDY GAP	UPPER COLORADO	USGS
ADATUNCO	ALVA B. ADAMS TUNNEL AT EAST PORTAL NEAR ESTES PARK	UPPER COLORADO	CDWR
GRNDRDCO	GRAND RIVER DITCH AT LA POUDRE PASS	UPPER COLORADO	CDWR
5104603	WILLIAMS FORK TUNNEL (5104603)	UPPER COLORADO	CDWR
09036000	WILLIAMS FORK NEAR LEAL, CO	UPPER COLORADO	USGS

Water mass balance computations relied on daily mean discharge values or water diversion records. Data were secured from public data repositories maintained by the U.S. Geological Survey (USGS) and Colorado Division of Water Resources (CDWR). USGS data were accessed via the *dataRetrieval* software package in R (DeCicco et al., 2025). CDWR stream gauge and diversion structure records stored in the Colorado Decision Support System (CDSS) Hydrobase were similarly accessed using the *cdssr* package in R (Watters, 2023). The generalized order of preference for datasets used in this effort was: USGS gauge, CDWR gauge, administrative diversion record for a given structure. In cases where TMD operations were characterized by streamflow gauging records, mass balance computations using administrative water diversion records should be anticipated to produce somewhat different results. For example, using the administrative diversion records for the Colorado-Big Thompson Project's Adams Tunnel (WDID 5104634) will produce a slightly different mass balance result than those computed using the streamflow gauging station at the Adams Tunnel East Slope portal (CDWR ADATUNCO).

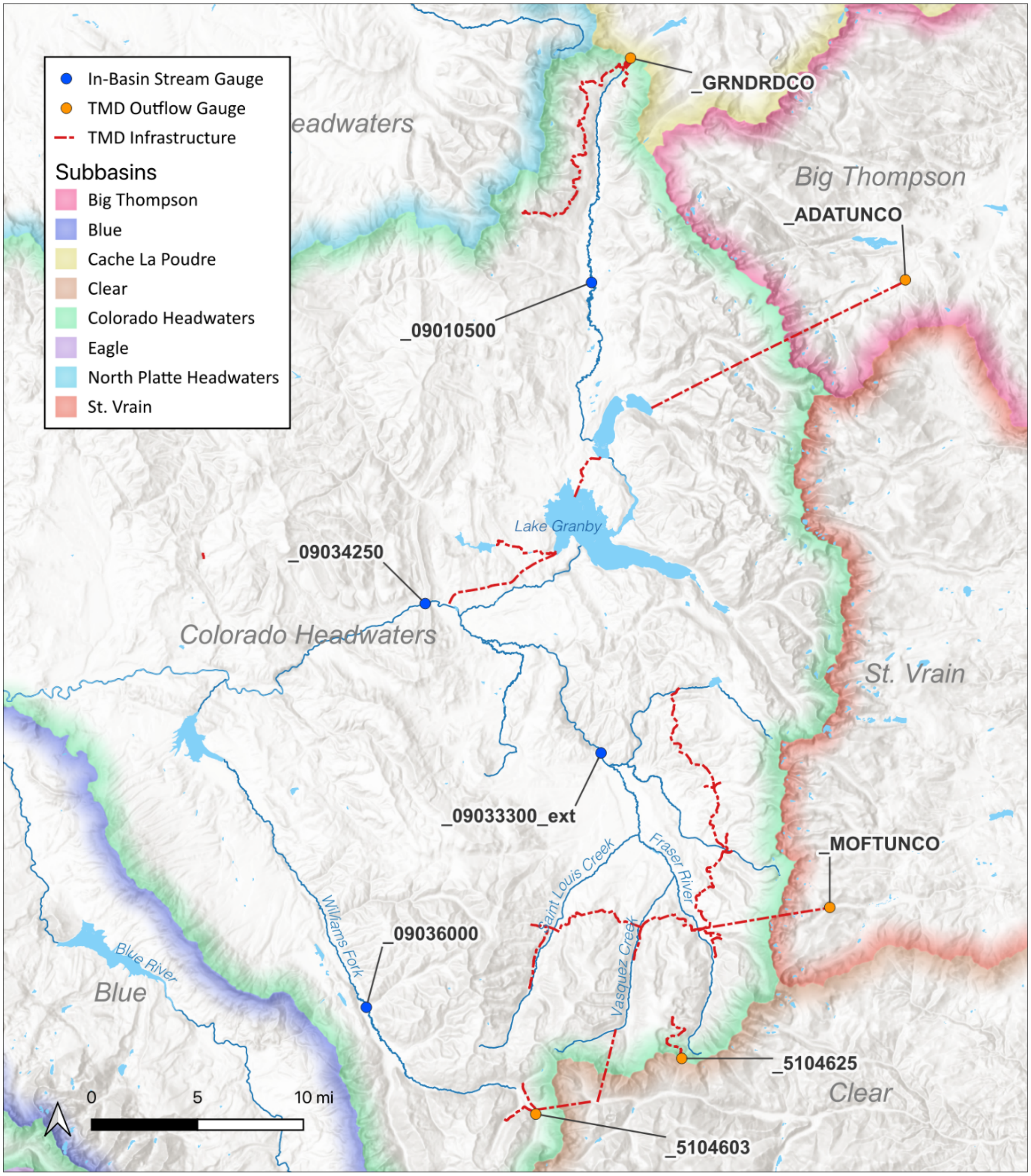

Figure 2. Locations of streamflow gauges and water diversion structures used to compute historical impacts of TMD operations on streamflows on the Fraser River, Colorado River, and Williams Fork.

At each location, results were classified into five hydrologic year types. The selected approach for binning hydrological year types was similar to the approach used to define year types in the WGFP and GREP EIS documents. Year types were classified as Drought, Dry, Average, Wet, and Flood using the 5th, 25th, 75th, 95th, and 100th non-exceedance percentiles of annual water yields, computed across a 30-year streamflow dataset from a regional reference gauge expected to reflect natural streamflow patterns. The reference gauge selected for use here was the USGS streamflow gauges at Big Thompson below Moraine Park near Estes Park (USGS-402114105350101). The year type classification of individual years in the record at the reference gauge were mapped directly onto the annual records for the data collected in the Project Area. We then provided monthly and annual statistics for mass balance results, stratified by year type.

Generally, incomplete streamflow gauging records were avoided for the analysis reported here. However, the Fraser River below Crooked Creek (USGS-09033300) is a seasonally operated gauge that produces data between Mar 1st or April 1st and November 1st of each year. We used the Maintenance of Variance Extension 2 (MOVE.2) method provided in the *smwrStats* library for R (USGS-R/smwrStats, 2024) to fill missing values in existing records at this locations. The MOVE.2 method predicts missing data values by constructing correlations in observed seasonal streamflow patterns with other nearby proximal analog streamflow gauge records (Helsel and Hirsch, 2002). The filled record period is typically characterized by low flows that contribute little to annual yield totals. The Colorado Climate Center reports that approximately 70-80% of annual runoff volume is produced between April and July (Bolinger et al., 2024). Related studies in Utah demonstrate that the April - July proportion of runoff in snowmelt-dominated headwaters accounts for ~75% of total annual runoff (Julander and Clayton, 2018). Accordingly, this work assumes that potential errors associated with record filling during are unlikely to significantly influence mass balance calculations at the annual time step. Estimates of monthly TMD impacts calculated during November-April period may be more affected.

Some additional important caveats regarding the analysis approach presented here should be noted. Complex administration of paper and physical water supplies that may occur in any given year or month complicates the effort to capture a wholly accurate picture of TMD impacts on streamflows via available streamflow gauging records. The analysis results presented here are a simple accounting of TMD impacts that reflect observed streamflows under varying reservoir storage, administrative, and operational conditions. Other approaches for quantifying TMD impacts exist. For example, the impact of TMD projects under different hydrological and administrative conditions may be modeled using the state's hydrologic planning model (StateMod). Such an approach might allow a more nuanced and spatially explicitly characterization of TMD impacts, unconstrained by streamflow gauge locations or record completeness. Alternatively, a full water rights engineering exercise could be performed to better track and understand the inter-annual and inter-seasonal role of reservoir storage, out-of-priority exchanges, and other physical or administrative TMD operations. Ultimately, these alternative approaches were not pursued by this effort.

TMD impacts computed and summarized as monthly percentages may be impacted by reservoir operations in a way that significantly offsets the timing of computed impacts. This may create distortions in results, particularly during the low flow winter and spring period. Monthly outputs should therefore be viewed as a potentially useful aid in understanding intra-seasonal patterns but should be contextualized with appropriate local knowledge about typical TMD operations before they are used in other reporting or analysis efforts. Direct consultation with the owners/operators of a given TMD project may be helpful in illuminating the drivers of apparent monthly patterns.

3.1 Fraser River Below Crooked and Ranch Creeks

Estimating proportional impacts of TMDs for the Fraser River remains difficult due to nuances in the locations of available gauges and collection system intakes, as well as the combined nature of water export records in the Moffat Collection System, which includes both native Fraser River diversions that not always recorded at the resolution of individual tributary diversion points, as well as imports from the Williams Fork basin.

The streamflow gauge on the Fraser River below Crooked Creek (USGS-09033300) is sufficiently downstream to capture most influences of the Moffat Collection System, while being subject to only moderate influence from local consumptive uses. However, this location likely under-represents flow impairments in the reaches of the Fraser near the communities of Winter Park and Fraser. Conversely, Fraser River at Tabernash (USGS-09027100) is upstream of the Ranch/Meadow Creek and Crooked/Pole Creek systems, each of which supply significant water to the Moffat Collection system. This means that the proportional impact of the Moffat Tunnel would be over-estimated at the Fraser River at Tabernash (USGS-09027100). Additionally, some diversions from St. Louis Creek provide return flow to the Crooked Creek drainage during the irrigation season, which would not be reflected above the Fraser River below Crooked Creek (USGS-09033300). The Fraser River basin receives Williams Fork import water from the Gumlick/Jones Pass/Vasquez tunnels. Imported water moves into the Moffat Collection System and then through the Moffat Tunnel. Estimating how much of the native Fraser River yield is diverted through the Moffat Tunnel thus requires backing out Williams Fork imports. A more detailed accounting designed to separate the various sources of water to the Moffat Collection System and assign individual impacts to the Fraser Rivers numerous headwaters tributaries is beyond the scope of this analysis and might require more-extensive investigation of individual water rights records or modelling datasets and outputs. The streamflow gauge and/or water diversion structure record locations used to compute water balances at this location are listed below:

- 09033300_ext - Fraser River below Crooked Creek (extended record)
- MOFTUNCO - Moffat Tunnel at East Portal
- 5104603 - Williams Fork Tunnel
- 5104625 - Berthoud Canal and Reservoir Tunnel

The mass balance computation proceeded as follows:

(MOFTUNCO + 5104625 - 5104603) / (09033300_ext + MOFTUNCO + 5104625 - 5104603)

3.2 Colorado River at Windy Gap

The Colorado River at Windy Gap USGS-09034250 provides the most reasonable Colorado River location to compute water balances, despite potential noise in the data associated with operations of Granby Reservoir. The Fraser River receives import water from the Williams Fork basin which flows through the Gumlick/Jones Pass/Vasquez tunnels into the Moffat Collection System and then into the Moffat Tunnel. Estimating how much of the native Fraser River yield contributes to flows on the Colorado River below Windy Gap thus requires backing out Williams Fork imports to avoid overestimating Moffat Collection System impacts on Fraser River flows. The streamflow gauge and/or water diversion structure record locations used to compute water balances at this location are listed below:

- 09034250 - Colorado River below Windy Gap
- ADATUNCO - Adams Tunnel at East Portal near Estes Park
- MOFTUNCO - Moffat Tunnel at East Portal
- GRNDRDCO - Grand River Ditch at La Poudre Pass

- 5104603 - Williams Fork Tunnel

The mass balance computation proceeded as follows:

(GRNDRDCO + ADATUNCO + MOFTUNCO - 5104603) /
(09034250 + GRNDRDCO + ADATUNCO + MOFTUNCO - 5104603)

3.3 Williams Fork Near Leal

Estimating impacts of TMD exports from the Williams Fork was straightforward but relied on the assumption that any in-basin uses of water (i.e., Henderson Mine) above the Williams Fork near Leal (USGS-09036000) have only minimal impact on mass balance computations. The streamflow gauge and/or water diversion structure record locations used to compute water balances at this location are listed below:

- 09036000 - Williams Fork near Leal
- 5104603 - Williams Fork Tunnel

The mass balance computation proceeded as follows:

5104603 / (5104603 + 09036000)

3.4 Results

TMDs deplete approximately 35% of the annual flow of the Fraser River below Crooked Creek in average year types. Those impacts increase to between ~40-50% in dry to drought year types. Impacts are proportionally highest during the summer and early fall (July - October) in most year types (Table 2). This seasonal pattern has implications for fisheries habitat availability, water temperature conditions, and system connectivity. Diversions impacts, as a proportion of native flows, are likely higher above the confluences with Crooked, Pole and Ranch creeks.

Isolating the impacts of TMDs to the Colorado River headwaters (i.e., above the Fraser River confluence) was challenged by the location and record continuity of existing streamflow gauges. Impacts of water releases from Granby Reservoir also mean that annual streamflow and TMD yield patterns across different year types are subject to various lags and alterations tied to reservoir operations. Monthly results should be viewed in this light. Viewed in the aggregate, approximately 62% of the annual flow of the Colorado River at Windy Gap is removed by upstream TMDs in average year types. Impacts to annual yield increase to between ~80% in dry to drought year types and decline to between ~40-50% in wet and flood year types. Monthly impacts are modestly higher during the low flow period (e.g., August-March) within individual year types. Seasonal differences in diversion impacts are greatest in wet and flood year types (Table 2).

The impact of TMDs on the Williams Fork drainage are significantly lower than on the Colorado and Fraser Rivers. Diversions out of the headwaters of the Williams Fork deplete approximately 6% of the annual flow of the Fraser River below Crooked Creek in average year types. Those impacts increase to between ~10-20% in dry to drought year types and fall to ~2% in wetter than average year types. Impacts are proportionally highest during the late summer period (July - September) in most year types (Table 2).

Table 2. Estimates of monthly TMD yield as a percentage of West Slope subbasin locations by month during different hydrologic year types. Monthly estimates are more likely affected by lags in localized reservoir and storage operations in each subbasin as compared to annual yield estimates and should be treated with caution.

Location	Year Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Colorado River below Windy Gap	Drought	85	83	81	75.5	81	80	75	84.5	83.5	80.5	72.5	69.5
	Dry	88	86.6	80.8	62.6	74	73.4	67.8	76	81	64.8	50.6	84.4
	Average	78.1	78.5	75.2	49.4	48.7	44.1	63.3	64.4	67.9	58.3	43.8	78.3
	Wet	83.5	82.3	70.7	39.3	37	20.7	40.3	66	70.7	52.8	38.7	74.2
	Flood	82	84	64.5	45.5	30	18.5	38.5	31	61.5	43	75	73.5
Fraser River below Crooked Creek and Ranch Creek	Drought	22	15	14	31.5	64.5	74.5	50.5	48	61.5	45	33	24
	Dry	18.2	15.6	13.4	18	46.6	41.8	59.4	54.8	46	36.6	25.6	20
	Average	21.9	17.9	16	15.3	33	27.5	47.4	46.7	45.7	52.1	35.8	27.1
	Wet	19.7	16.7	12.3	10.8	35.2	30.8	34.3	40	44.7	29.5	27.7	22.5
	Flood	18.5	14	10	7.5	31.5	11.5	29.5	31.5	36	45.5	41.5	25.5
Williams Fork near Leal	Drought	4.5	10.5	10	13.5	26.5	29	25.5	25	22	17.5	6	11
	Dry	11.6	11	9.2	7.2	13.4	8.2	12.6	21.2	17.4	10	12	13
	Average	6.1	5.1	4.2	3.9	6.4	1.9	10.3	12	9.9	9.1	8.1	7.1
	Wet	6	5	4.8	4.2	2.3	1.3	3.8	8.2	8.5	5	7.2	6
	Flood	5.5	4	4.5	2.5	4.5	0.5	5	4	8	5.5	6	4

4 Characterization of Future Streamflow Conditions

UCWET would like to understand how the completion of WGFP and GREP will further alter streamflows on the Colorado and Fraser rivers. The Moffat Firming EIS and Windy Gap EIS documents provide characterizations of historical hydrology and expected hydrological regime behaviors following development of both projects. The EIS documents provide tabular monthly streamflow simulation outputs at various points on the Colorado River below Granby Reservoir, at points on the Fraser River below the Moffat Tunnel, and at points on each of the Fraser River tributaries impacted by the Moffat Collection System (Figure 3). Expected streamflows are provided for the existing condition and a range of alternatives under wet, average, and dry year types. Hydrological year types correspond to a selection of representative years from the historical record. The EIS documents were the primary source of hydrological data for this effort.

Denver Water and its consultants developed the Platte and Colorado Simulation Model (PACSIM) to consider the hydrological impacts of alternative actions under the EIS and assess effects on aquatic life, wildlife, and stream morphology. Northern Water used an implementation of the Boyle Engineering Stream Simulation Model (BESTSM) for East Slope facilities as well as the Colorado Decision Support System (CDSS) StateMod model for Colorado Basin to provide a similar analysis of impacts under the WGFP. Due to the proprietary nature of the models referenced above, raw data outputs were not available for this effort and neither was the ability to run new models to answer specific questions relevant to UCWET's activities. Instead, Lotic used tabular monthly yield estimates provided for the existing condition and the preferred alternative in each EIS to assess impacts to environmental flows at locations throughout the watershed.

The analysis performed here utilized data associated with the Existing Condition and Alternative 1a from the Moffat Firming Project EIS, and Existing Condition and Alternative 2 from the Windy Gap Firming Project EIS Cumulative Effects tables. Modelled EIS locations (termed as *nodes* in this setting) were physically located in a spatial model of the project area either using known location coordinates for stream gauges or using narrative descriptions and names in the EIS documents to approximate locations. Each node was attributed with a variety of environmental flows, including Colorado Water Conservation Board (CWCB) instream flow (ISF) water rights and geomorphic and aquatic habitat flow thresholds documented in the GCSMP).

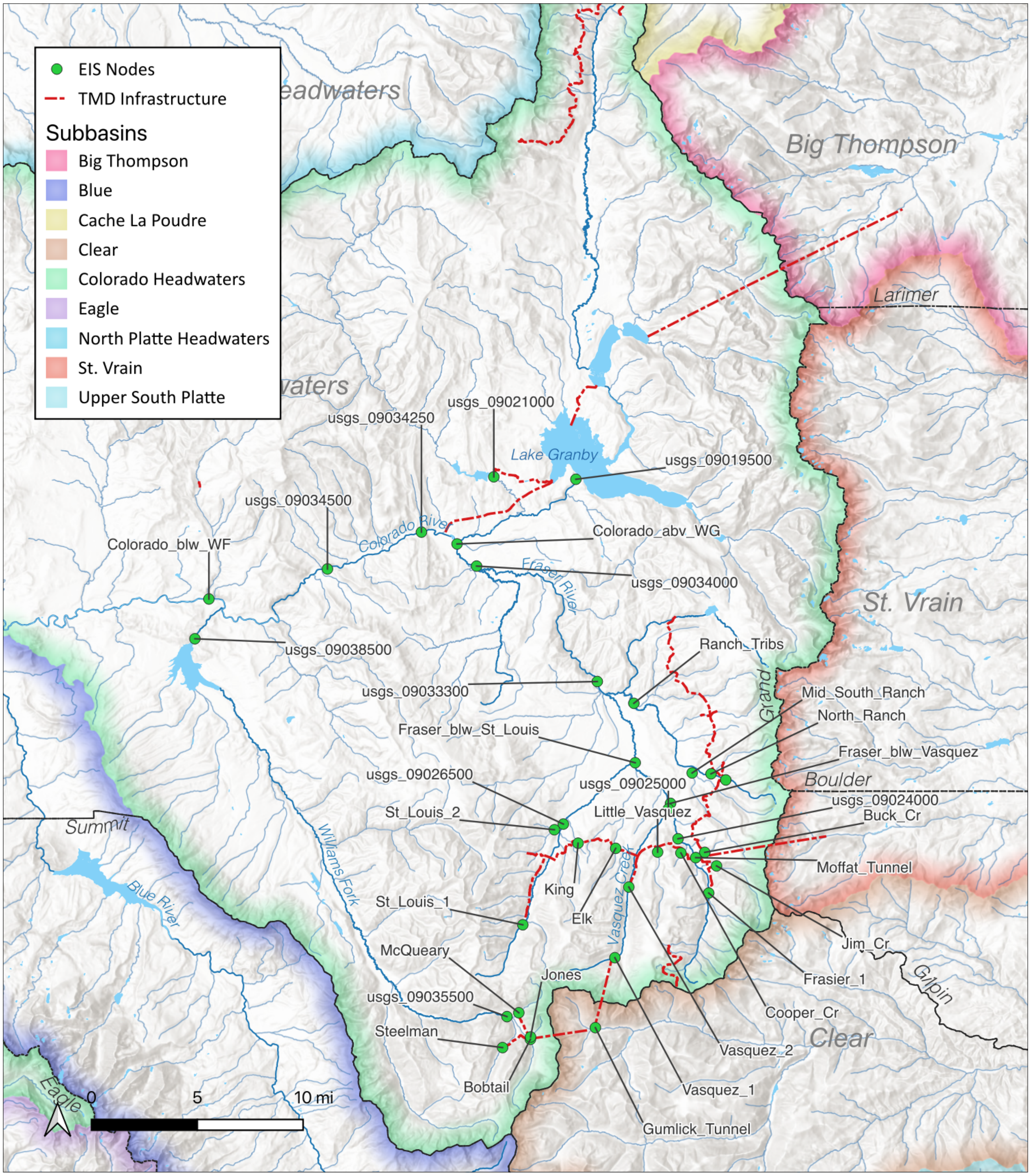

Figure 3. Locations where tabular streamflow information is provided in the WGFP and GREP EIS documents.

Table 3. Locations where tabular streamflow information is provided in the WGFP and GREP EIS documents.

EIS Node	Description	Latitude	Longitude
Bobtail	Below Denver Water's Diversion from Bobtail Creek	39.76339	-105.90756
Buck_Cr	Below Denver Water's Diversions from Cub and Buck Creeks	39.89074	-105.75294
Colorado_abv_WG	Colorado River above Windy Gap	40.1003	-105.9726
Colorado_blw_WF	Colorado River below Williams Fork	40.06293	-106.19259
Cooper_Cr	Below Denver Water's Diversion from Cooper Creek	39.89033	-105.77414
Elk	Below Denver Water's Diversions from Elk Creek and Tributaries	39.89347	-105.83194
Fraser_blw_St_Louis	Fraser River below St. Louis Creek	39.95169	-105.81465
Fraser_blw_Vasquez	Fraser River below Vasquez Creek	39.92409	-105.78332
Frasier_1	Below Denver Water's Diversion from Fraser River	39.86303	-105.74946
Gumlick_Tunnel	Gumlick Tunnel Diversions	39.77134	-105.84997
Jim_Cr	Below Denver Water's Diversion from Jim Creek	39.88152	-105.74255
Jones	Below Denver Water's Diversion from Jones Creek	39.76504	-105.90743
King	Below Denver Water's Diversion from King Creek	39.89696	-105.86529
Little_Vasquez	Below Denver Water's Diversion from Little Vasquez Creek	39.8909	-105.79478
Main_Ranch	Below Denver Water's Diversion from Main Ranch Creek	39.94001	-105.73435
McQueary	Below Denver Water's Diversion from McQueary Creek	39.7815	-105.91784
Mid_South_Ranch	Below Denver Water's Diversions from Middle and South Fork of Ranch Creek	39.94476	-105.76418
Moffat_Tunnel	Moffat Tunnel Diversions	39.88715	-105.76102
North_Ranch	Below Denver Water's Diversions from North Fork Ranch Creek and Dribble Creek	39.94416	-105.74744
Ranch_Tribs	Below Denver Water's Englewood Ranch Gravity System Diversions	39.9921	-105.81585
St_Louis_1	Below Denver Water's Diversion from St. Louis Creek	39.84143	-105.9143
St_Louis_2	Below Denver Water's Diversions from St. Louis Creek Tributaries	39.90613	-105.88632
Steelman	Below Denver Water's Diversion from Steelman Creek	39.75775	-105.93224
usgs_09019500	Colorado River below Lake Granby	40.144152	-105.86724
usgs_09021000	Willow Creek	40.145819	-105.94002
usgs_09024000	Fraser River near Winter Park	39.899986	-105.77667
usgs_09025000	Vasquez Creek	39.9202647	-105.78529
usgs_09026500	St. Louis Creek near Fraser	39.9099866	-105.87835
usgs_09033300	Fraser River below Crooked Creek	40.0068917	-105.84827
usgs_09034000	Fraser River at Granby	40.0852636	-105.95529
usgs_09034250	Colorado River below Windy Gap	40.108319	-106.00418
usgs_09034500	Colorado River at Hot Sulphur Springs	40.0833	-106.0875
usgs_09035500	Williams Fork River below Steelman Creek	39.7788755	-105.92835
usgs_09038500	Williams Fork Reservoir Outflow	40.0359278	-106.20501
usgs_09041400	Wolford Mountain Reservoir Outflow	40.1085963	-106.41392
usgs_09058000	Colorado River near Kremmling	40.036652	-106.44003
Vasquez_1	Vasquez Creek below the Gumlick Tunnel	39.81902	-105.83267
Vasquez_2	Below Denver Water's Diversion from Vasquez Creek	39.86713	-105.82031

4.1 Monthly to Daily Disaggregation

To disaggregate monthly yield data, each location was associated with a proximal streamflow gauging station in the project area to serve as a pattern gauge. Historical streamflow data at each pattern gauge were binned into dry, typical, and wet years based on ordered rankings of annual streamflow yields. This approach adopted same percentile breaks to perform the final year type classifications as those utilized in the EIS documents. The median daily flow rates and volumes were assessed at each pattern gauge for each of the classified year types. These percentage of daily flow contributing to monthly totals for each month and each year type was then computed. The resulting daily streamflow fractions were used to disaggregate the monthly streamflow yield values from the EIS documents into representative daily streamflow time series for each node. Finally, the disaggregated values were converted from daily volumetric totals (acre feet) to mean daily streamflow (cfs).

Disaggregated daily flow estimates indicated significant future decreases to streamflows under WGFP and GREP on the Fraser River and reaches of the Colorado River during spring and early summer runoff, especially in years classified as 'average' and 'wet'. WGFP modelling results predicted that streamflows would be lower in most or all months of the year, with the most acute impacts occurring during the summer months. WGFP diversions are not in priority during dry years therefore have little effect on those year types. These future flow changes are expected to impact aquatic ecosystems in the Project Area.

4.2 Environmental Flow Gap Analyses

The environmental flow gap analyses performed here considered geomorphological flows indicated in the GCSMP, CWCB ISF water rights, and fish habitat availability modeling thresholds identified in the GCSMP. Other characterizations of environmental flow needs (e.g. streamflows required to moderate high summer water temperatures) were not directly assessed here.

4.2.1 Geomorphological Flows

Fluvial geomorphological flow targets outlined in the GCSMP reflect flows necessary to maintain in-channel and meso-scale habitat (channel width, geometry, forms, and riparian/floodplain patchworks). Geomorphic flow targets include both an interannual duration (typically 3 days) and inter-annual return frequency (typically 1 in 2 years). Because this exercise made use of estimated flows for statistically computed year types rather than simulation results for an extended flow record over many years, the interannual frequency component of geomorphic flows could not be assessed directly. Nonetheless, the number of days per month under each scenario and year type that met geomorphic flow targets were tallied to provide a coarse view of impacts to those flow conditions. Tabular results from this analysis are provided in Appendix A. Some caution is advised when interpreting these analysis results.

4.2.2 CWCB Instream Flows

Minimum ISF water rights can be useful tools to support aquatic ecosystems where they are able to protect flows during critical periods for aquatic organisms, preventing total loss of habitat refugia, limiting habitat fragmentation, and protecting food-producing channel habitats (e.g. riffles). Establishment of ISF thresholds in Colorado begins with a biologically-based method (i.e. R2Cross) but is then subject to additional physical and socio-legal constraints during the adoption and adjudication process. This means that the final appropriated ISF threshold may diverge from biological recommendations produced through application of the R2Cross methodology.

For reaches in the geography of interest with established ISF rights, disaggregated daily streamflow traces for each node were compared to the ISF threshold. Periods when streamflows fell below the ISF threshold were identified as environmental flow gaps/shortages. These gaps/shortages were characterized by tallying the total number of days during which flows remained below ISF targets in each year type under existing and expected future conditions. The mean daily flow gap (cfs) was also computed for each month, along with the total water volume (acre-feet) required to fill the computed gap. Generally, the operation of WGFP and GREP will extend the low flow period of the hydrograph. The period time when flows hover just above the ISF will begin earlier in the summer in many locations. Longer low flow periods during the hot summer months are expected to decrease habitat quality and availability for aquatic organisms and increase the frequency and duration of stressful water temperature conditions for fish. Tabular results from this analysis are provided in Appendix B. Results are also presented in graphical form in the Data Dashboard.

4.2.3 GC SMP Targets

The GCSMP included PHABSIM modelling results for selected locations in the project area. The PHABSIM methodology makes linkages between available habitat for different life stages of a target fish species across different streamflows. The GCSMP used the resulting habitat curves to identify two critical flow threshold conditions: a lower threshold representing an inflection point at which habitat area for all life stages is rapidly lost and an upper threshold representing a flow providing optimal adult habitat. Notably, some stream reaches were only assigned a minimum value rather than a pair of values.

For reaches in the geography of interest where PHABSIM results were available, disaggregated daily streamflow traces for each node were compared to the lower threshold to compute several environmental flow gap metrics. The total number of days in each month were tallied for periods when streamflows fell below the minimum PHABSIM threshold. The mean daily flow gap (cfs) for these periods was computed for each month, along with the total water volume (acre-feet) required to fill the computed gap. Generally, the operation of WGFP and GREP will extend the low flow period of the hydrograph. Hydrological changes produced by these projects will increase in the magnitude and duration of shortages relative to habitat targets from the GC SMP. Tabular results from this analysis are provided in Appendix C. Results are also presented in graphical form in the Data Dashboard.

4.3 Considering Impacts of Climate Change

Notably, EIS simulations do not include any formal consideration of climate change or shifts in either East or West Slope water demands that may arise due to growing populations or warming air temperatures. These types of analyses are available in select outputs of the state's StateMod models for the Upper Colorado Basin. This is a limitation that parties interested in assessing future impacts to Grand County streams in a more-holistic context than that provided by the EIS are currently faced with, until such time as additional resources and/or modelling work can be completed.

No explicit modeling of climate change impacts was conducted here. Instead, those impacts were inferred by considering the changing frequency in various year types (e.g., wet years vs. dry years) under different potential climate futures documented by CWCB in the Technical Update to the Colorado Water Plan (CWP). The water planning scenarios included in the Technical Update are intended to help local communities understand how interaction between climate change, population growth, and changing social values may conspire to impact streamflows in different parts of the state. Each scenario reflects a unique combination of effects from climate change, social values, and water demands. Readers interested in the details of each modeled scenario are directed to the Technical Update[1]. The basic components of each scenario are listed below:

Natural Flow

- Estimated streamflow conditions in the absence of human use or management

Current Conditions

- Current irrigated acreages and irrigation practices
- Historical IWR
- Historical hydrology

Business as Usual

- Includes reduction of irrigated acreage near urbanized areas
- Increased stress to streamflow and water supplies

[1] https://cwcb.colorado.gov/colorado-water-plan/technical-update-to-the-plan

- Climate is similar to conditions in the 20th century

Weak Economy
- Reduction of irrigated acreage near urbanized areas
- Economy struggles with reduced population growth
- Climate is similar to conditions in the 20th century
- Little change in social values, levels of water conservation, urban land use patterns, and environmental regulations

Cooperative Growth
- Reduction of irrigated acreage
- 20% in Irrigation Water Requirement (IWR) climate factor (i.e. warmer)
- Population growth consistent with current forecasts
- Increased water and energy conservation
- Emergence of water saving technology
- Water development more restrictive requiring high efficiency as well as environmental/recreational benefits
- Moderate warming of the climate increasing water demands in all sectors

Adaptive Innovation
- Much warmer climate with technological innovation to address the problem
- Population growth higher than current projections
- Reduction of acreage, but lesser than other scenarios due to demand for locally produced food
- 31% IWR climate factor (i.e. warmer)
- 10% IWR reduction (i.e. lower water use by crops)
- 10% system efficiency increase to offsets water use in warmer climate

Hot Growth
- Much warmer climate with increased population
- Rapid transition of agricultural lands to urban
- Reduction of irrigated acreage
- Decline in streamflow and water supply
- 31% IWR climate factor

The Environmental Flow Tool (EFT) from CWP Technical Update provides annual streamflow yield volumes for three nodes in the Project Area for each of the scenarios above. Critically, none of the above scenarios include the effects of additional transmountain diversion of water brought about by WGFP or GREP. This is an important data gap that affects the assessment of risk for hydrological change provided by the EFT. As a result, we focus on EFT results provided at a single node on the Colorado River that will not be impacted by either WGPF or GREP: the Colorado River below Baker Gulch (USGS-09010500). We recalculated the percentile values for annual yield under the Natural Flow scenario to match the flow percentiles in the 1950-1996 record used in the GREP. Although the use of differing year periods inevitably produces differing results for quantile breaks, results should still be informative for understanding relative changes in year type recurrence in the future, and by extension, the potential and likelihood of changing frequencies in environmental flows gaps or shortages. Years when the annual streamflow yield was less than the 10^{th} percentile of Natural Flows were classified as ‘dry’ years. Years when annual streamflow yield was greater than or equal to 90^{th} percentile of Natural Flows were classified as ‘wet’ years. All other years were classified as ‘typical’ years. The results produced for the Colorado River below Baker Gulch were presumed to approximate climate change induced impacts to water supply at other locations in the Project Area (Figure 4, Table 4).

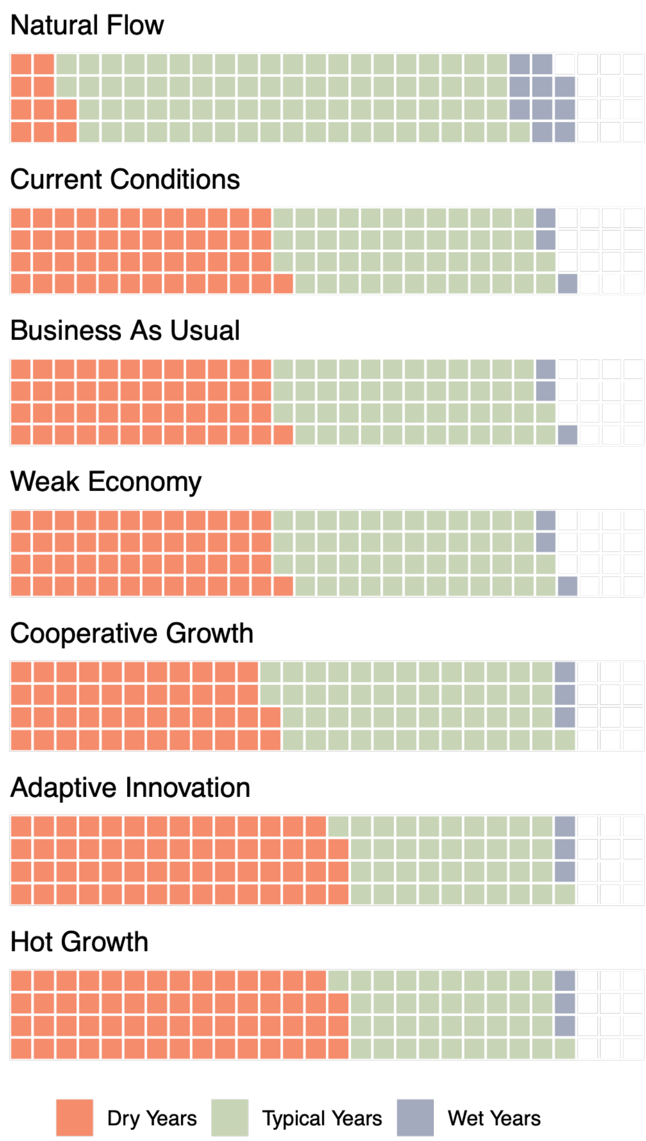

Figure 4. Year type frequencies associated with different hydrological futures presented in the Colorado Water Plan. Each colored box represents the occurrence of a given year type. The total number of boxes indicate the full set of simulation years. An increase or decrease in the count of one year type, relative to the count indicated in the Current Conditions scenario indicates an increasing or decreasing frequency of occurrence for that year type.

Table 4. Percentage of years predicted to fall into each year type category under each of the modeled scenarios presented by the Colorado Water Plan.

Year Type	Natural Flow	Current Conditions	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Dry	10	49	49	49	46	59	59
Typical	79	49	49	49	51	38	38
Wet	10	3	3	3	3	3	3

The representation of changes to hydrological year type frequency presented in the EFT when moving between the Natural Flow and Current Conditions scenario are dominated by the impact of Grand Ditch. Low streamflow conditions that were typically experienced in a small number of years under natural conditions are experienced much more frequently under Current conditions. What was once atypical is now typical. The changes observed when moving between Current Conditions and the suite of future scenarios are dominated by climate effects, rather than impacts due shifting water use patterns, social values, or population growth. The scenario representing a hot and dry climate future (i.e. Hot Growth) indicates a substantial shift from Current Conditions toward an increasing frequency of dry year types at the expense of typical year types. A dry year experienced and described currently as a 1-in-5 year drought may become an event that occurs with a frequency of 1-in-4 years or 1-in-3 years in the future.

Shifts in climate toward a hotter and drier future are expected to increase the frequency, duration and intensity of environmental flow shortages at many locations across the Colorado headwaters region. An increase in the frequency of dry years will place additional pressure on aquatic ecosystems by raising stream temperatures and reducing the quality and availability of aquatic habitat. A decrease in the frequency of wet years will alter patterns of sediment movement and storage along streambeds in a manner that will likely impact the way that channels maintain instream habitat quality and interact with and help maintain riparian habitats.

4.4 Water Rights Inventory

Lotic catalogued water rights in the geographic area of interest to help UCWET understand the local opportunities for addressing environmental flow gaps. Our work in other West Slope geographies suggests that agricultural rights tend to represent greater opportunities for formal flow leasing or other temporary water conservation agreements than municipal and industrial water uses. Assuming that most municipal or storage rights in Grand County are efficiently utilized with little margin across the year, the focus was primarily on agricultural water rights, which may offer flexibility in use and administration that is not otherwise available for other water use types.

Water diversion structure information, including location, use types, and decreed diversion rates are available via the Colorado Decision Support System (CDSS). Each structure is typically associated with one or more water rights of varying size and priority. Relevant water rights information was procured from the CDSS. Decreed absolute rates were summed at each structure. Average monthly water diversion rates were computed from the most recent ten years of records. Diversion record summaries are available in Appendix D. Structures were then mapped to stream reaches in the geography of interest and presented graphically in the Data Dashboard.

Historical consumptive use associated with each water use can be quickly estimated by applying efficiency factors to different water use types. An efficiency between 0.4-0.6 may be applied to agricultural uses. An efficiency ~0.9 may be applied to all municipal water uses. An efficiency of 1.0 should be applied to all transmountain diversions and industrial water uses. This coarse approach to characterizing consumptive uses can help UCWET and its partners estimate the water volumes and flow rates that may be available for water leasing. More opportunity tends to exist for helping to meet environmental flow gaps where consumptive uses are high. Specifically, formal water leasing through the CWCB's Instream Flow Program is only applicable to the consumptive portion of water use.

5 Potential Environmental Flow Goal Prioritization Strategy

We anticipate that UCWET can use the information presented here and the Data Dashboard to evaluate opportunities to meet environmental flow gaps at selected locations within the Project Area. Many strategies may be applied to accomplish this objective but one potential workflow is provided below:

1. Review environmental flow shortages throughout the Project Area, incorporate additional context about environmental and/or social needs and constraints to select and prioritize locations of interest.

2. Use the Data Dashboard to identify water use structures located upstream of a location of interest.

3. Summarize the potential for supporting environmental flows at the location by summing the total number of individual rights, the total monthly diversion rates and volumes for all upstream structures, and by ordering water rights by adjudication/appropriation data and absolute decreed diversion rates.

4. Generate an opportunity ranking by applying a set of agreed-upon scoring weights and criteria. Some examples of qualitative prioritization weights and associated criteria are provided below. This is not an exclusive list.

    - High Priority – a large number of upstream water rights exist, any number of which may be used to help meet environmental flow shortages.
    - Medium Priority - one large upstream water right appears capable of addressing identified flow gaps, but without participation of this water right, the environmental flow gaps cannot be met.
    - Medium Priority - a small number of water rights are capable of addressing identified flow gaps, but without participation of at least on of these water rights, the environmental flow gaps cannot be met.
    - Low Priority – participation of many small water rights in close coordination is required to meet environmental flow gaps.
    - Low Priority – an insufficient number of upstream structures exists to effectively address identified flow gaps.

Alternatively, the information provided here and in the Data Dashboard may provide UCWET with a starting point for engagement with Grand County Learning By Doing about utilization of storage or bypass water allocated for maintenance or improvement of the aquatic environment under WGFP and GREP.