Upper Rio Grande Functional Flows Assessment

Rio Grande Resilient Basin Report Card project

By Noelle Patterson and Dr. Samuel Sandoval Solis
Water Management Lab
University of California, Davis
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Reviewed by: Enrique Prunes

Overview

WWF under its Healthy Rivers for All initiative and in partnership with Audubon New Mexico, the University of Maryland Center for Environmental Science (UMCES), the University of Massachusetts-Amherst (UMass-Amherst), and with sponsor from the Arthur Vining Davis Foundation are implementing a two-year project to develop a Resilient Basin Report Card in the Upper Rio Grande sub- basin that spurs action towards collaborative, climate-smart water management while serving as a framework for future interventions across the entire Rio Grande Basin.

This project that started in July 2019 has engaged diverse stakeholders towards establishing a common understanding and sound baseline of the current health of the Upper Rio Grande Basin; model possible future scenarios—including testing different interventions to improve overall basin health; and publish a data-driven, transparent, and replicable report card. This process will involve three phases: (1) defining the system; (2) assessing status and functioning of the system; and (3) identifying management options for a better future.

The strategy to achieve the goal follows the template developed by WWF, UMCES and UMass-Amherst by combining two existing methodologies the Basin Health Report Cards and Freshwater Resilience by Design, with Steps 1-5 to occur as specific activities and outputs of this project, while Steps 6 and 7 are included as project outcomes (Figure 1).

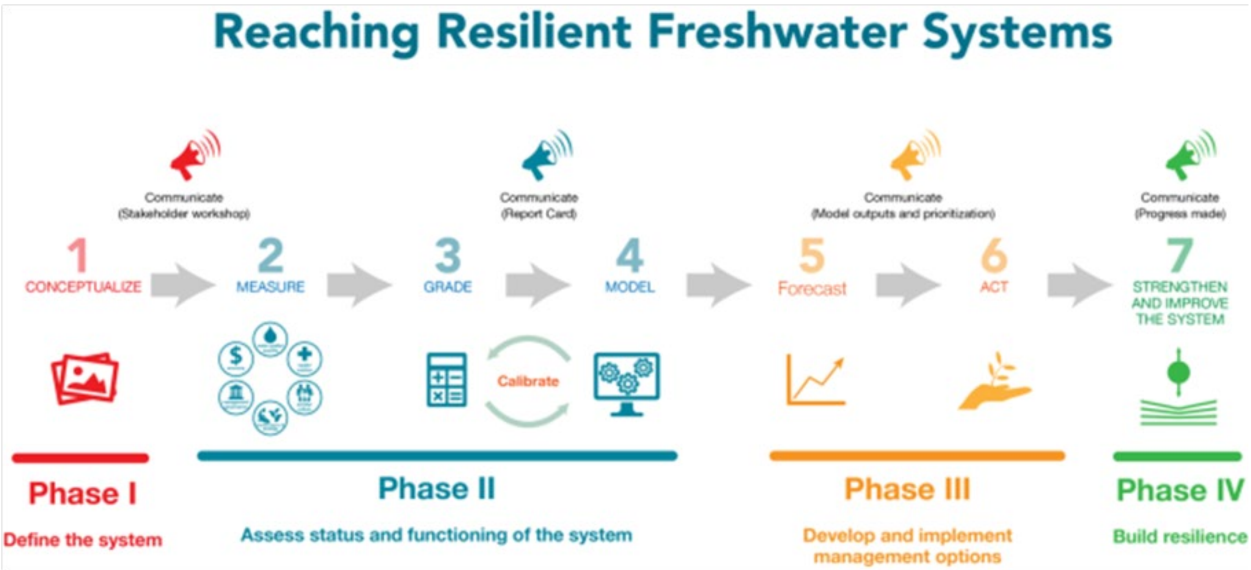


Figure 1. Phased approach towards reaching a resilient upper Rio Grande

The project stakeholder mapping is complete, with representatives from different sectors and regions of the Upper Rio Grande sub-basin guiding stakeholder engagement, activities, and communications. Stakeholders identified 64 values and 72 threats for basin health and proposed 80 indicators, along with 31 potential management options, to achieve basin health objectives. The first stages to build a hydro-ecologic-economic resilience planning model are complete, incorporating three existing hydrologic models for the Rio Grande. The project team, with support from stakeholder working sessions, narrowed the list to 22 indicators and 48 potential metrics, and the team is gathering data to enable preliminary indicators and data sources—and identify targets and grades for each indicator to initiate the draft report card and finalize the future scenario modeling in the next six months.

Environmental flows have been identified as a priority indicator for the Report Card and to strengthen the future scenario modeling and framework for environmental flows in the region. The environmental flows indicator assesses the timing, amount and quality of water flows necessary to sustain life in a river basin. Thus, the experts from the University of California-Davis will contribute to strengthen the research underpinning this metric and for the project to respond to community demand for data to inform their decision-making in the Rio Grande basin by estimating Instream Flow requirements in the Rio Grande mainstem above El Paso, Texas

Instream flow requirements and functional flows approach

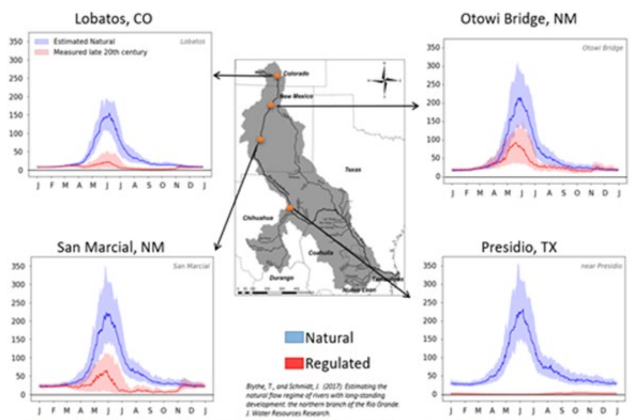


Figure 2.- Comparison of natural and altered flow regimes in the northern branch of the Rio Grande

In the Rio Grande, current patterns of water use (e.g., river diversions and groundwater overdraft), infrastructure development (e.g., proliferation of water intakes, dams, and levees), and pollution have together greatly altered the natural water regime, with adverse impacts on local riparian and aquatic ecosystems (Fig. 2). Recognition of the mounting threats to riparian and aquatic species in the Rio Grande basin has led to increased consideration of environmental flow needs within water resources management efforts. Instream flow requirements, which only consider ecological water needs, are key for determining environmental flows because they define a set of initial flow targets from which flow regimes that balance human and ecosystem water needs are derived. Fundamentally, determining instream flows requires selecting appropriate estimation methods based on spatial scale, temporal resolution, data availability, technical requirements, costs, and ecological management goals.

In basins where there is already human alteration, there is a method to determine instream flows requirements called the Functional Flows Approach that estimates ecologically relevant flows to sustain the different types of flows (quantity, quality, physical habitat, and connectivity) needed to adequately sustain a healthy river ecosystem. Functional flows are those aspects of the flow regime that directly relate to ecological, geomorphic, or biogeochemical processes in a river. In other words, functional flows support foundational processes related to the ecology of the river (freshwater and riparian ecosystems), the physical habitat (geomorphology), water quality, connectivity, and in general the well-being of the biological communities. Unlike other environmental flow approaches that focus on single species management, the functional flows approach to freshwater ecosystem management focuses on those components of the flow regime that support key ecosystem functions. Five key functional flow components have been identified for California’s rivers and streams and they can serve as a starting point for snowmelt flow regimes in the Rio Grande. Each functional flow component supports several critical physical, biogeochemical, and biological functions that maintain stream ecosystem health and satisfy life history requirements of native species.

Scope of work

The **overall goal** of this research project is to determine instream requirements by characterizing the natural flow regime of the Rio Grande using Functional Flow Metrics and to estimate the degree of alteration when comparing these naturalized flow regime metrics with the current hydrology or that of an alternative water management strategy (scenario).

Objective 1.- Estimate the Functional Flow Metrics of the Naturalized Flow Regime for a selected number of control points. *Product(s)*: (1) A set of statistics (mean, standard deviations and quantiles) for the functional flow metrics of the set of selected control points, (2) a set of reference hydrographs to visualize the annual flow regime, one for each control point.

Objective 2.- Estimate the Functional Flow Metrics of the Observed Flow Regime for a selected number of control points. *Product(s)*: (1) A set of statistics (mean, standard deviations and quantiles) for the functional flow metrics of the set of selected control points for the observed data and different scenarios, and (2) a set of reference hydrographs to visualize the annual flow regime, one for each control point. If observed flows do not exhibit seasonality of the natural flow regime, functional flow metric products may need to be limited to magnitude only.

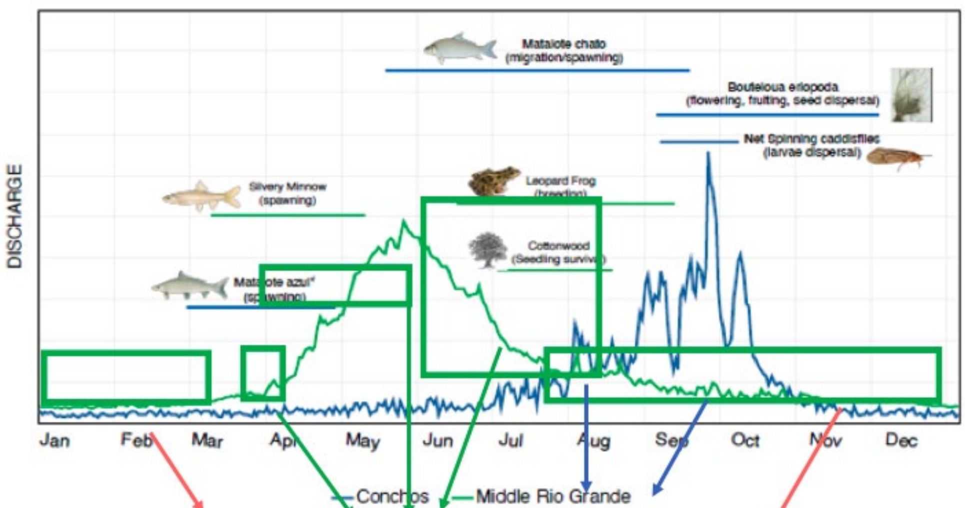
Objective 3.- Determine the degree of hydrologic alteration and the gap in environmental flows by comparing the functional flow metrics of the naturalized flow regime against the observed and alternative scenario results. *Product(s)*: (1) A comparison for each functional flow metric, e.g. change in the mean and standard deviations; and (2) a frequency-based reliability analysis that quantifies how many times in a given scenario a functional flow metric fell within the range of the natural functional flow metrics, presented as an “exceedance score” for each functional flow component for the selected control points. If observed flows do not exhibit seasonality of the natural flow regime, functional flow metric comparisons may need to be limited to magnitude only.

Objective 4.- In collaboration with WWF and Resilient Basin Report Card partners, and based on the results of objectives 1, 2 and 3, develop a draft environmental flow indicator to be potentially included in the Rio Grande Report Card and recommendations to incorporate environmental flows as a reference for future scenario modeling under the Freshwater Resilience by Design methodology. Product: Draft report that describes the estimation of an environmental flow indicator for the Report Card and set of recommendations for future scenario modeling.

Methodology

Overview

The analytical process used in this study relies on the functional flow approach for streamflow analysis. Functional Flows are seasonal aspects of the annual flow regime needed to sustain a healthy river ecosystem, and are described by the magnitude, timing, duration, frequency, and rate of change of flow. Three functional flow components specific to the upper Rio Grande natural flow regime were identified and developed for this project, based on seasonally occurring flows that are important for sustaining native species as pictured in Figure 3. An annual flow component describing general metrics of average annual flow and coefficient of variation constitute a fourth component. The full set of functional flow components includes: 1) Spring Flood Pulse, 2) Monsoon, 3) Dry Season, and 4) Annual flows. Each functional flow component is described by several functional flow metrics. Functional flow metrics are calculated for sites along the upper Rio Grande using the Functional Flows Calculator, a software tool that automatically identifies and quantifies functional flow components from daily streamflow data. A version of the Functional Flows Calculator was adapted specifically for this project, and is available online as a public code repository on the code sharing platform Github. January 1 was used as the water year start date for calculations.



Flow characteristics	Spring flood pulse	Monsoon	Dry Season
Magnitude	X	X	X
Timing	X	X	X
Duration	X	X	X
Rate of Change	X		

Figure 3. Functional flows and biotic responses for the snowmelt flow regime of the Middle Rio Grande and for the hurricane-driven flow regime of the Conchos River. Functional flow metrics describe flow components of the Middle Rio Grande flow regime.

Fifteen sites along the upper Rio Grande river are used for analysis, primarily within New Mexico. Both observed streamflow data from 1990-2020 and naturalized data from 1908-2015 were analyzed. Although observed data was available beginning in 1975, analysis of flow metrics over time indicated that flow conditions starting in 1990 are most representative of current conditions (see Fig. 16 in Results). Naturalized data was used to develop baseline conditions for functional flows representing healthy ecosystem functioning, and this baseline was compared to real flow conditions from observed streamflow. Both naturalized and observed flow data was processed using the functional flow calculator to create a suite of 15 functional flow metrics, calculated for each year on record. Annual metrics were summarized as percentiles over the period of record.

Additionally, reference hydrographs summarizing the full period of record were calculated at each site for both observed and naturalized data, both separately and overlaid. These reference hydrographs consist of the median, 25th, and 75th percentile of daily flow across the period of record, to visually represent average, dry, and wet conditions at a site.

Hydrologic alteration was quantified at each site using the differences in naturalized and observed functional flow metrics. For each metric, observed conditions were compared against both the interdecile range (10th to 90th percentiles) and the interquartile range (25th to 75th percentiles) of naturalized conditions. The number of years that observed metrics fell into either the interdecile or interquartile range was tallied out of the 31 years total of observed conditions, and calculated as a percentage (alteration scores). The alteration score for the interdecile range and interquartile range are both considered in the determination of a final alteration status and report card score (see Step 1. below). The alteration scores at each site were averaged together by functional flow component (four components total) using an arithmetic mean. These site-specific values were then averaged across each region of the upper RGB to create region-specific alteration scores representing each functional flow component. Finally, the scores for the regions and functional flow components are averaged together to create one final value for the environmental flow report card score.

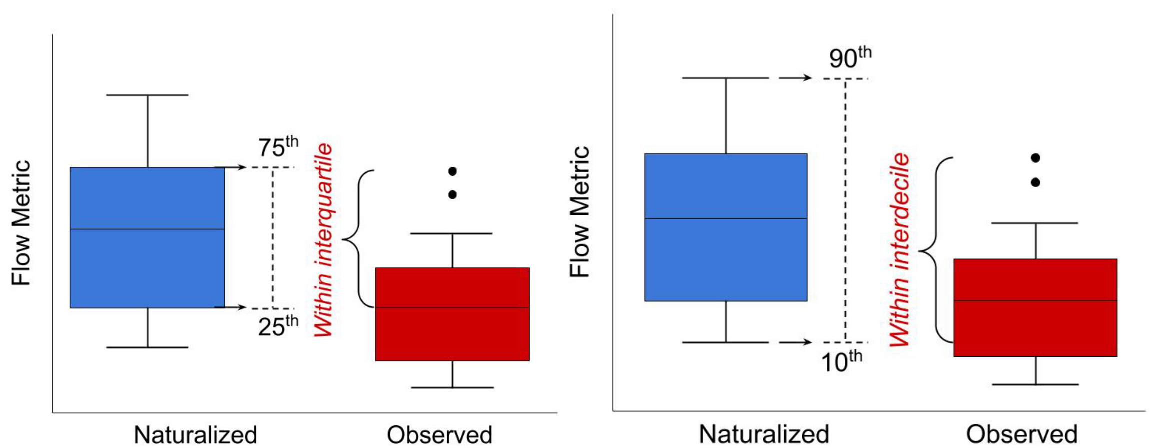
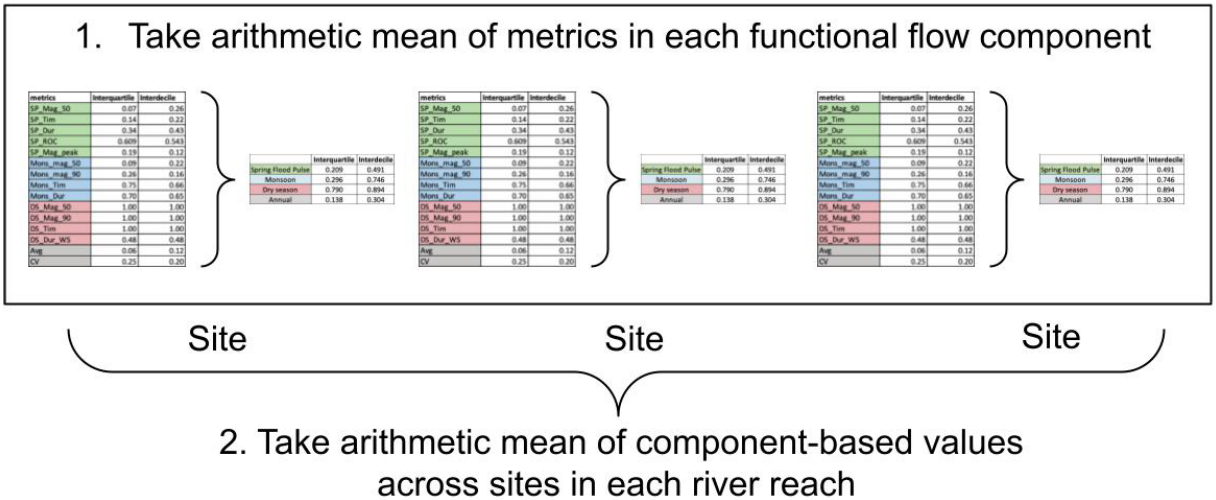


Figure 4. **Step 1**: Calculate the percentage of observed values within the interdecile and interquartile range of naturalized values for metrics at each site. This percentage value is scaled with a multiplier (1/0.5 for interquartile, 1/0.8 for interdecile) to account for the range of naturalized values used in each calculation).



	Interquartile	Interdecile
Spring Flood Pulse	0.209	0.491
Monsoon	0.296	0.746
Dry season	0.445	0.894
Annual	0.138	0.304

Figure 5. **Step 2**: Aggregate the results: find the arithmetic average of all metrics in each functional flow component, then find the arithmetic average of the component-based results across all sites in each river reach.

	Interquartile	Interdecile
Spring Flood Pulse	0.209	0.491
Monsoon	0.296	0.746
Dry season	0.445	0.894
Annual	0.138	0.304

	Alteration score
Spring Flood Pulse	35
Monsoon	52
Dry season	84
Annual	22

Figure 6. **Step 3.** Calculate one value for each component using the arithmetic average of the *interquartile* and *interdecile* components values.

Reach #2: Upper NM	
	Alteration score
Spring Flood Pulse	35
Monsoon	52
Dry season	84
Annual	22

Figure 7. **Step 4.**- Calculate the *arithmetic average for each component across all gauges in a given reach*. For instance, averaging the Dry Season component for the 3 gauges in the northern reach of New Mexico would produce a single value for each functional flow component in a reach.

Reach #2: Upper NM	
	Alteration score
Spring Flood Pulse	35
Monsoon	52
Dry season	84
Annual	22

Figure 8. **Step 5.**- Calculate the *arithmetic average across all functional flow components for a given reach to obtain a single value*. For instance, averaging all functional flow components for the Reach #2 - Upper New Mexico, results in a final score of 43 out of 100.

Table 4.4. A grade and description are assigned based on the score that the indicator or sub-region achieves.

Score (%)	Grade	Description
≥0 to <20	F	Very poor
≥20 to <25	D−	Poor
≥25 to <35	D	Poor
≥35 to <40	D+	Poor
≥40 to <45	C−	Moderately Poor
≥45 to <55	C	Moderate
≥55 to <60	C+	Moderate
≥60 to <65	B−	Moderately Good
≥65 to <75	B	Moderately Good
≥75 to <80	B+	Moderately Good
≥80 to <85	A−	Good
≥85 to <95	A	Good
≥95 to <100	A+	Good
=100	A+	Very Good

Figure 9. **Step 6**.- Use the rubric to determine the letter grade for that given reach. For instance, the associated grade for 43 is “C-”, Moderately Poor.

Results

Functional Flows Metrics

Functional flow metrics and reference hydrographs are presented here for a selection of the fifteen RGB stations used in this study. There are 15 functional flow metrics total, separated by functional flow components and presented in tabular format. The metrics calculated across the period of record for each dataset, observed and naturalized, are summarized as percentiles (10th, 25th, 50th, 75th, and 90th). Reference hydrographs for both observed and naturalized data are also created for each station. Finally, hydrologic alteration is measured across each functional flow metric and tabulated for each site. All outputs are included in the report appendices, and results from a subset of stations are presented below.

Reference Hydrographs

Reference hydrographs are presented for three sites across the upper RGRB study area, in which both observed and naturalized flow data are overlaid. While naturalized flow retains similar flow patterns across the sites, actual observed flow is greatly reduced in all scenarios, and especially near the furthest downstream end of the study site at Fort Quitman, Texas. Reference hydrographs for all sites are available in the appendix.

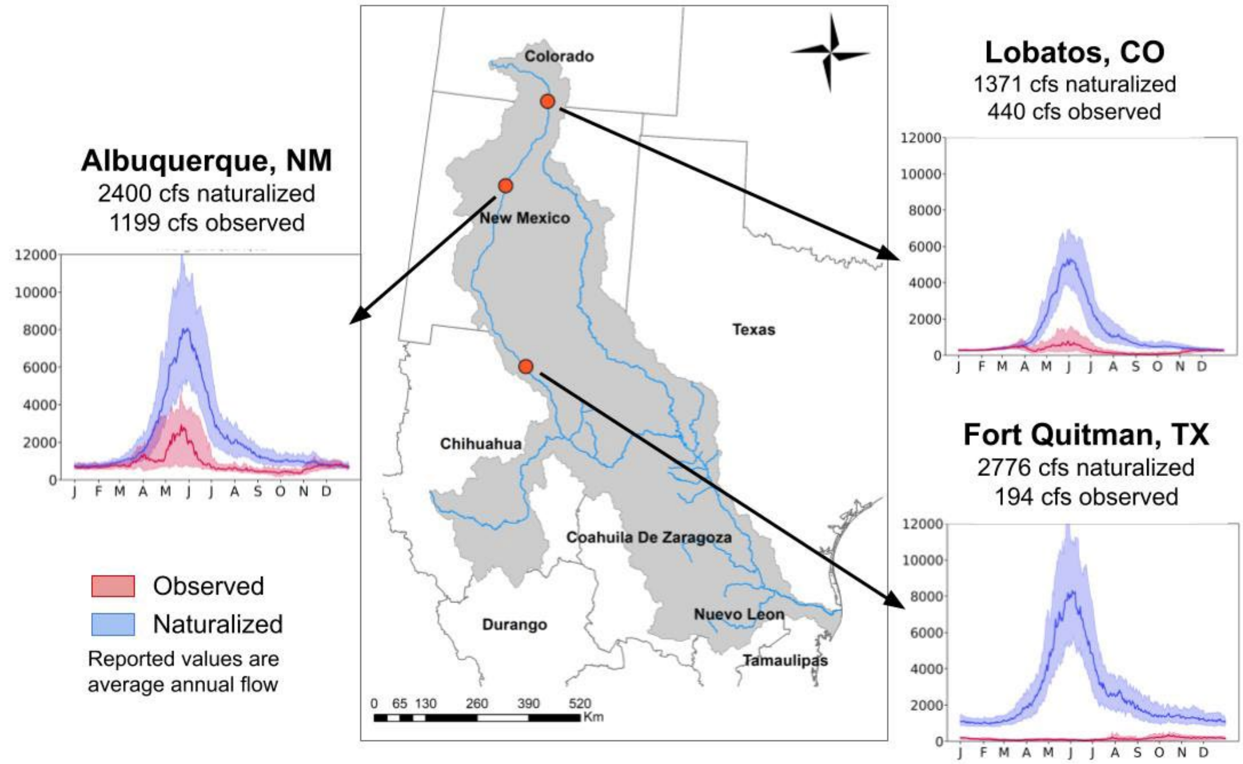


Figure 10. Selected study sites in the upper RGB illustrate the range of natural and observed conditions occurring across the subbasin.

Naturalized and Observed Functional Flow Metrics

Functional flow metrics are presented for Rio Grande streamflow near Albuquerque, New Mexico, for both naturalized and observed streamflow. Functional flow metrics are calculated individually for each water year on record: 1990-2020 for observed data, and 1905-2015 for naturalized data. In the presented table, annual records have been summarized into percentiles.

Table 1. Functional flow metrics for naturalized and observed flow near Albuquerque, NM.

Naturalized / **Observed**	**units**	**tenth**	**tenth**	**twenty-fifth**	**twenty-fifth**	**fiftieth**	**fiftieth**	**seventy-fifth**	**seventy-fifth**	**ninetieth**	**ninetieth**
Spring flood median magnitude	cfs	2355.5	743.0	3084.8	1062.5	4729.3	1615.0	6822.4	3215.0	8571.2	3779.0
Spring flood peak magnitude	cfs	4933.8	920.7	6126.1	1520.0	9161.9	3440.0	13518.0	4795.0	17330.5	5731.0
Spring flood timing	date	68.9	33.0	77.3	52.0	91.0	67.0	100.8	79.0	105.2	97.4

Spring flood duration	days	82.0	83.0	92.0	100.5	103.5	118.0	116.8	128.5	128.2	155.8
Spring recession rate of change	percent	0.0397	0.0269	0.0455	0.0520	0.0540	0.0699	0.0679	0.0838	0.0775	0.1382
Monsoon median magnitude	cfs	729.8	356.2	912.1	468.3	1212.8	548.5	1620.6	714.4	2131.2	1043.7
Monsoon magnitude 90th	cfs	1301.6	558.5	1789.6	676.0	2375.1	883.6	3308.8	1214.8	4099.3	1755.8
Monsoon timing	date	179.0	169.1	186.0	181.0	194.0	192.0	203.0	200.0	210.1	214.4
Monsoon duration	days	92.0	102.3	106.0	106.8	119.5	115.0	144.0	156.3	169.4	164.5
Dry season median magnitude	cfs	561.1	514.6	657.6	635.0	768.0	735.0	956.4	859.0	1088.7	1030.0
Dry season magnitude 90th	cfs	742.2	636.0	917.2	768.0	1145.1	923.5	1472.1	1070.0	1988.9	1287.2
Dry season timing	date	296.0	296.0	296.0	296.0	310.0	308.5	342.0	346.0	358.2	363.6
Dry season duration	days	94.0	52.2	113.8	66.0	138.0	111.0	162.0	133.0	171.6	148.2
Average annual flow	cfs	1367.5	490.3	1655.6	676.7	2272.1	920.5	3012.8	1484.7	3701.5	1673.8
Coefficient of variation	percent	0.8	0.4	0.9	0.5	1.0	0.7	1.1	0.9	1.2	0.9

Seasonality discussion

Extra consideration was given to the seasonality of observed-condition hydrographs, because seasonality in the hydrograph is necessary for the functional flows calculator to identify functional flow components. If the timing of each component cannot be accurately identified then the subsequently calculated metrics, such as duration and magnitude, cannot be accurately quantified. However, assessment of the observed-condition reference hydrographs in comparison to the naturalized hydrographs indicates that seasonality is mostly preserved in observed conditions, although the magnitude of all flows are greatly reduced. Because flows in observed conditions are still highest from about April to August, as they are in natural conditions, the functional flow components calculated from observed flow data are relevant and acceptably accurate, although inconsistencies appear in the most altered flow years at each site. Generally, timing and duration metrics stay similar between observed and naturalized conditions at each station, while magnitude-based metrics dramatically decrease in observed conditions. With confirmation that all functional flow metrics calculated properly across both naturalized and observed datasets, the rest of the analysis proceeded using all functional flow metrics to calculate environmental flow gaps and the subsequent report card indicators.

Functional Flows Hydrologic Alteration

A hydrologic alteration analysis was performed to determine the extent that observed flows fell within the range of naturalized functional flow metrics. This quantification is presented as an “alteration score” for each functional flow component, averaged across each region of the upper RGB. The alteration score results and boxplots shown here for an example site, the RGB near Cerro, are available for each upper RGB site in the report attachments.

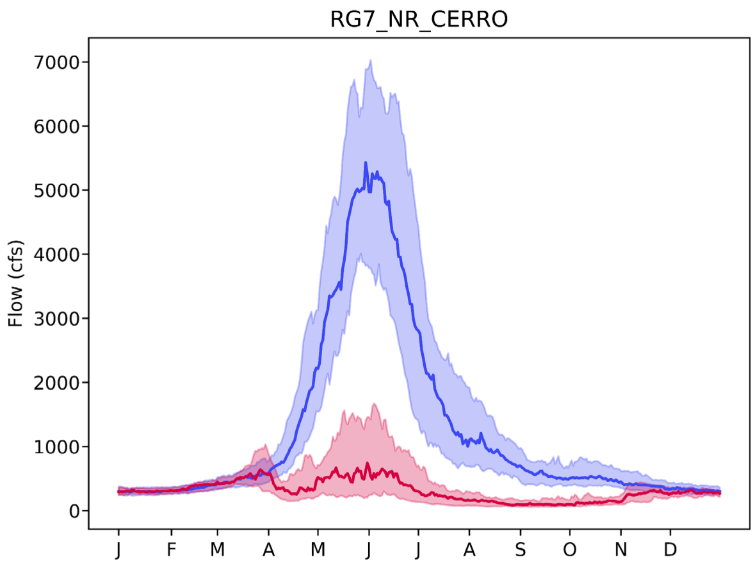


Figure 11. Naturalized (blue) and observed (red) annual streamflow patterns for the Rio Grande Near Cerro.

Table 2. Functional flow metrics and hydrologic alteration scores for the Rio Grande Near Cerro, for the Spring Flood Pulse functional flow component.

Spring Flood Pulse Metrics	Interquartile occurrence	Interdecile occurrence	Final score	description	grade
Spring flood median magnitude	0.000	0.000	0	Very poor	F
Spring flood peak magnitude	0.000	0.000	0	Very poor	F
Spring flood timing	0.286	0.179	23	Poor	D-
Spring flood duration	0.000	0.357	18	Very poor	F
Spring recession rate of change	0.300	0.438	37	Poor	D+

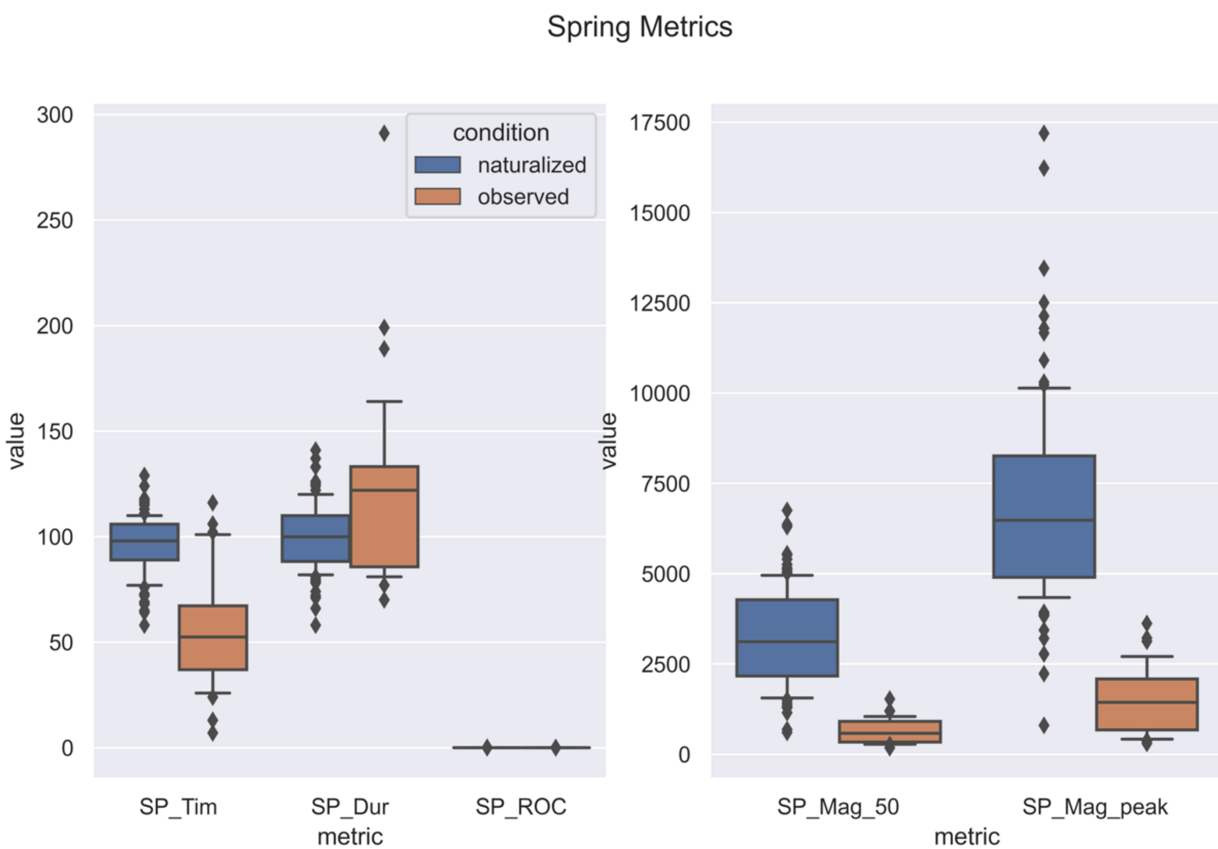


Figure 11. Boxplots demonstrating the frequency of observed values within the interquartile and interdecile ranges of naturalized values, for Spring Flood Pulse flow metrics on the Rio Grande Near Cerro.

Table 3. Functional flow metrics and hydrologic alteration scores for the Rio Grande Near Cerro, for the Monsoon functional flow component.

Monsoon Metrics	**Interquartile occurrence**	**Interdecile occurrence**	**Final score**	**description**	**grade**
Monsoon median magnitude	0.100	0.125	11	Very poor	F
Monsoon magnitude 90th	0.300	0.188	24	Poor	D-
Monsoon timing	0.581	0.444	51	Moderate	C
Monsoon duration	0.700	0.563	63	Moderately good	B-

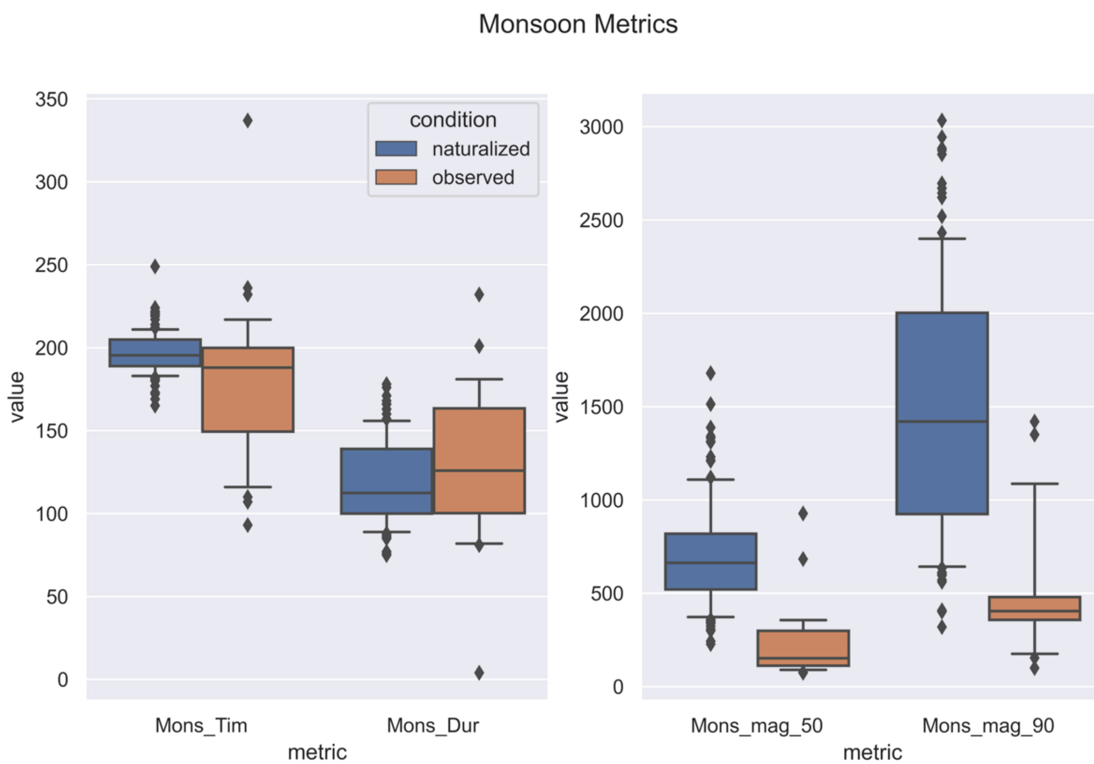


Figure 12. Boxplots demonstrating the frequency of observed values within the interquartile and interdecile ranges of naturalized values, for Monsoon functional flow metrics on the Rio Grande Near Cerro.

Table 4. Functional flow metrics and hydrologic alteration scores for the Rio Grande Near Cerro, for the Dry Season functional flow component.

Dry Season Metrics	Interquartile occurrence	Interdecile occurrence	Final score	description	grade
Dry season median magnitude	0.100	0.125	11	Very poor	F
Dry season magnitude 90th	0.300	0.188	24	Poor	D-
Dry season timing	0.581	0.444	51	Moderate	C
Dry season duration	0.700	0.563	63	Moderately good	B-

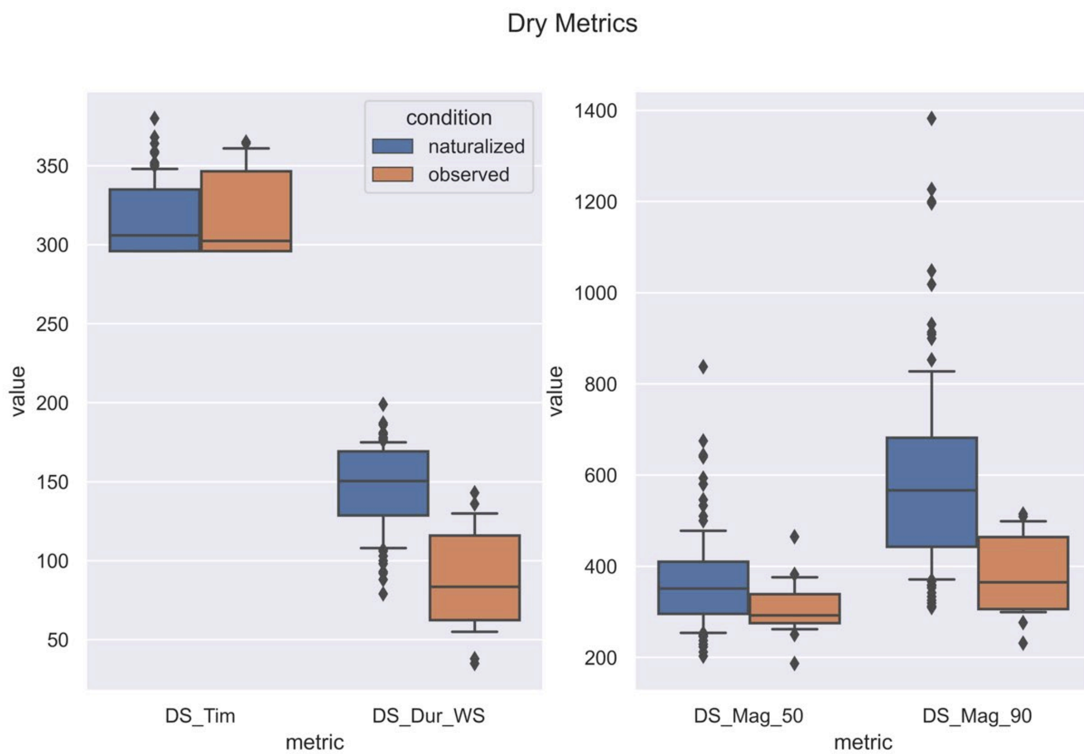


Figure 13. Boxplots demonstrating the frequency of observed values within the interquartile and interdecile ranges of naturalized values, for Dry Season functional flow metrics on the Rio Grande Near Cerro.

Table 6. Functional flow metrics and hydrologic alteration scores for the Rio Grande Near Cerro, for the Annual flow metrics.

Annual Metrics	Interquartile occurrence	Interdecile occurrence	Score	Description	Grade
Average annual flow	0.000	0.040	2	Very poor	F
Coefficient of variation	0.194	0.242	22	Poor	D-

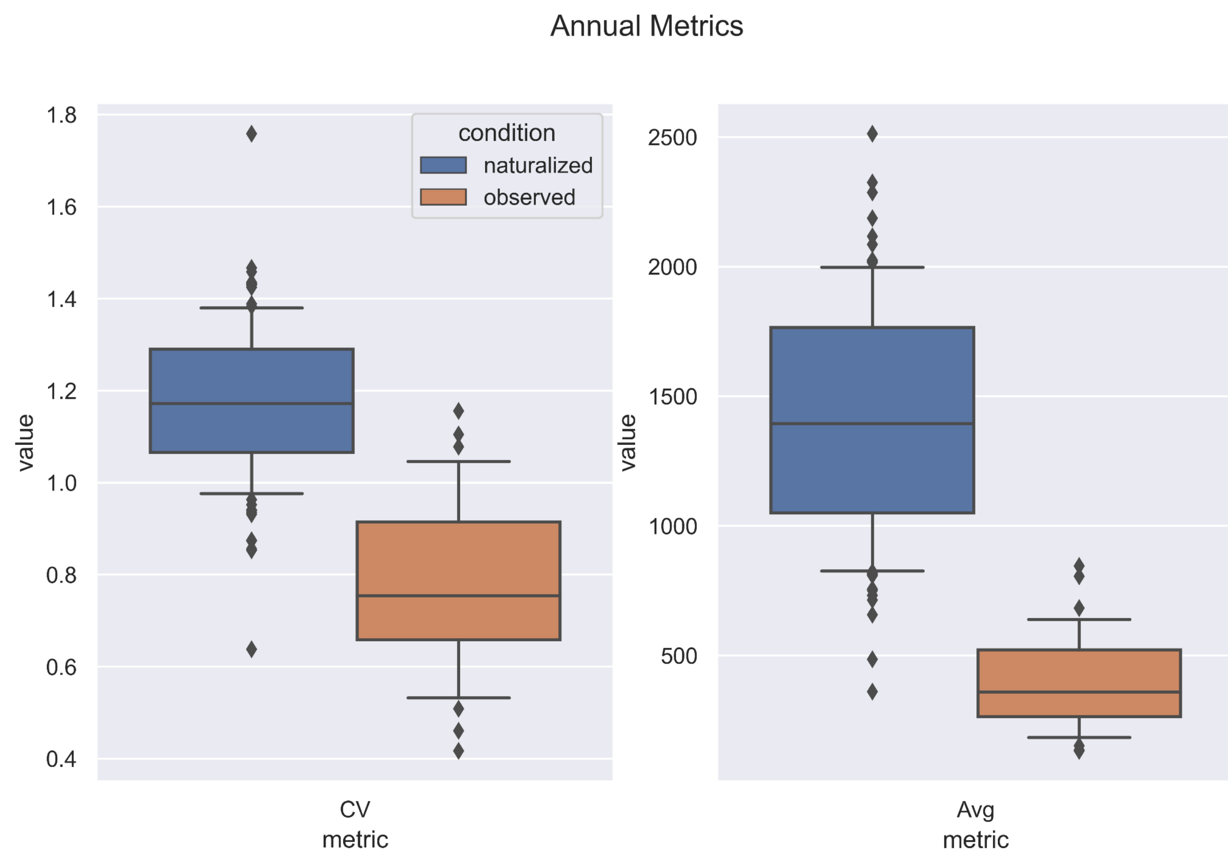


Figure 15. Boxplots demonstrating the frequency of observed values within the interquartile and interdecile ranges of naturalized values, for Annual functional flow metrics on the Rio Grande Near Cerro.

Hydrologic Alteration through time

Change in alteration of functional flows was assessed over the time period 1975-2020, using intervals of 25 years. Quality of functional flows has been degrading steadily over the observation period, with an abrupt drop evident between the periods 1985-2010 and 1990-2015. The functional flow components that respond most strongly to changes in flow volumes are always the lowest scored components, and the gap distinguishing them from the Dry Season increases over time. These results reflect steady decreases in river flow through time that affect the Spring Flood Pulse, Monsoon, and Annual flow components.

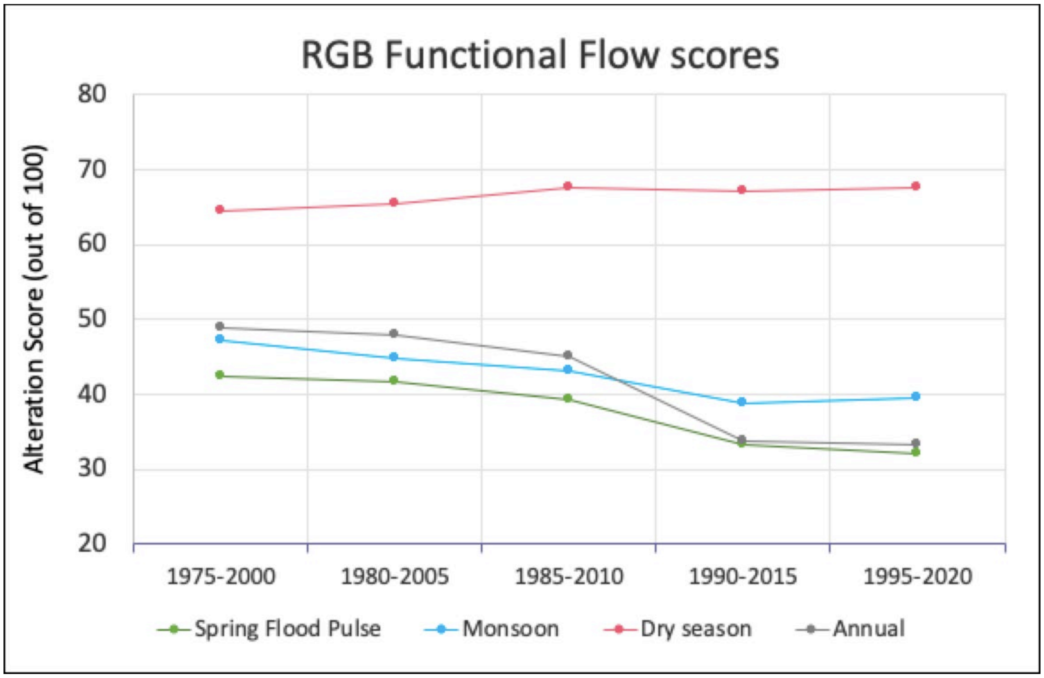


Figure 16. Change through time of functional flow component alteration scores on the Upper Rio Grande, averaged over time across 25-year time intervals between 1975 and 2020. An abrupt drop in scores in most components, indicating degradation of flow conditions, is observed between the time periods 1985-2010 and 1990-2015.

Hydrologic Alteration across the Upper RGRB

Hydrologic alteration scores were summarized across functional flow components at each site, and then site values were averaged across the four reaches of the Upper Rio Grande (using an arithmetic mean), as shown below. While all four reaches show significant signs of alteration, results get increasingly worse towards the lower reaches of the river, with the lowest reach scoring “F” or “D” in all four categories of hydrologic alteration.

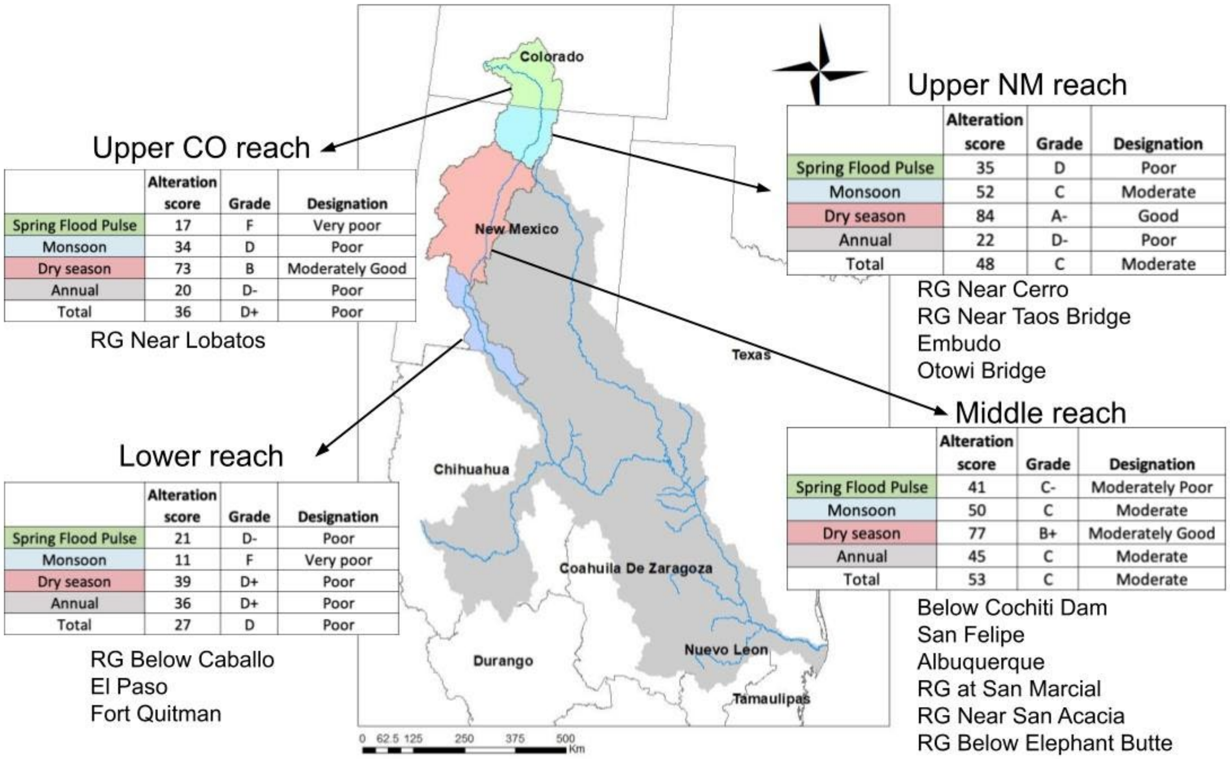


Figure 17. Functional flow alteration scores summarized across each subreach of the Upper Rio Grande Basin. The Middle Reach performs the best, with no scores below a C-, and the Lower Reach performs the worst, with all components scoring a D+ or below.

Basin-wide Report Card Score

The table below presents the final report card score, averaged across all sites in the Upper RGB study area. The average score across all components is a C- (Moderately Poor). The functional flow components scoring the lowest, the Spring Flood Pulse, Monsoon, and Annual flows, are the most impacted by flow reductions. The Dry Season generally did not experience as great of flow reductions and therefore tended to score higher than other functional flow components. This is likely because dry season flows are already low in naturalized conditions, and further reductions are proportionally less than in other flow seasons. There is considerable variation in hydrologic alteration across sites and functional flow components, and it is valuable to consider how this variation contributes to the final report card score for the entire basin.

Table 7. Hydrologic alteration scores for the entire Upper Rio Grande Basin, for each functional flow component and for all flow components combined.

	Alteration score	Grade	Designation
Spring Flood Pulse	32	D	Poor
Monsoon	39	D+	Poor
Dry season	68	B	Moderately Good
Annual	34	D	Poor
Total	**43**	**C-**	**Moderately Poor**