The Colorado East River Community Observatory Data Collection

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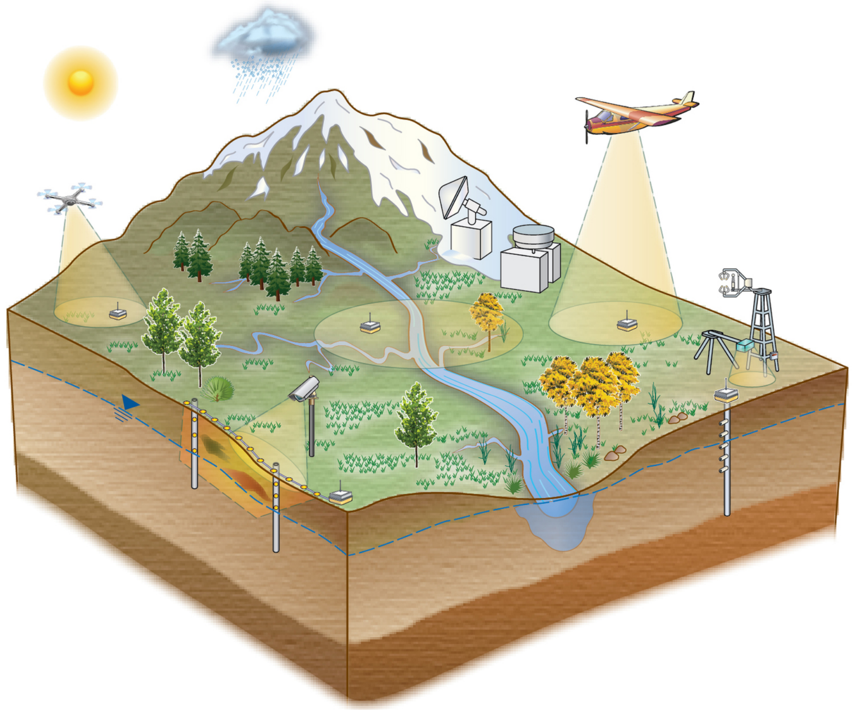
Graphical Abstract



Abstract

The U.S. Department of Energy's (DOE) Colorado East River Community Observatory (ER) in the Upper Colorado River Basin was established in 2015 as a representative mountainous, snow-dominated watershed to study hydrobiogeochemical responses to hydrological perturbations in headwater systems. The ER is characterized by steep elevation, geologic, hydrologic and vegetation gradients along floodplain, montane, subalpine, and alpine life zones, which makes it an ideal location for researchers to understand how different mountain subsystems contribute to overall watershed behavior. The ER has both long-term and spatially-extensive observations and experimental campaigns carried out by the Watershed Function Scientific Focus Area (SFA), led by Lawrence Berkeley National Laboratory, and researchers from over 30 organizations who conduct cross-disciplinary process-based investigations and modeling of watershed behavior. The heterogeneous data generated at the ER include hydrological, genomic, biogeochemical, climate, vegetation, geological, and remote sensing data, which combined with model inputs and outputs comprise a collection of datasets and value-added products within a mountainous watershed that span multiple spatiotemporal scales, compartments, and life zones. Within five years of collection, these datasets have revealed insights into numerous aspects of watershed function such as factors influencing snow accumulation and melt timing, water balance partitioning, and impacts of floodplain biogeochemistry and hillslope ecohydrology on riverine geochemical exports. Data generated by the SFA are managed and curated through its Data Management Framework. The SFA has an open data policy, and over seventy ER datasets are publicly available through relevant data repositories. A public interactive map of data collection sites run by the SFA is available to inform the broader community about SFA field activities. Here, we describe the ER and the SFA measurement network, present the public data collection generated by the SFA and partner institutions, and highlight the value of collecting multidisciplinary multiscale measurements in representative catchment observatories.

Data Set Name

The Colorado East River Community Observatory Data Collection

Site Description

The East River community observatory (ER) in the Upper Colorado Basin, United States (39.033° N 107.12° W, 38.83° N 106.88° W) is a 300 square kilometer headwater catchment representative of watersheds in the Rocky Mountains of the western United States (Hubbard et al., 2018) degrees. The ER lithology consists of igneous formations intruding into carbon-rich marine shale in the Mancos Formation, as well as sedimentary strata grading older (Permian) to younger (Tertiary) as one moves east to west across the ER domain with pockets of significant mineralization (Carroll et al., 2018; Gaskill, 1991). The watershed comprises montane, subalpine, and alpine life zones that collectively include aspen, meadow, mixed conifer, sagebrush, grasses, and sedges. Further details about the ER are provided in Hubbard et al. (2018) and Carroll et al. (2017).

Since 2015, the ER has been the primary field site for the Watershed Function Scientific Focus Area (SFA; http://watershed.lbl.gov) led by Berkeley Lab, and is one of several U.S. Department of Energy testbeds conducting interdisciplinary research to gain a predictive understanding of watershed functioning and their response to perturbations using measurements and modeling from the bedrock through soil and vegetation to the atmospheric interface. The ER serves as a community testbed for over 30 collaborating institutions that collectively aim to understand the impacts of perturbations, such as drought and early snowmelt, on the hydrobiogeochemical dynamics of mountainous, headwater catchments at seasonal to decadal timescales.

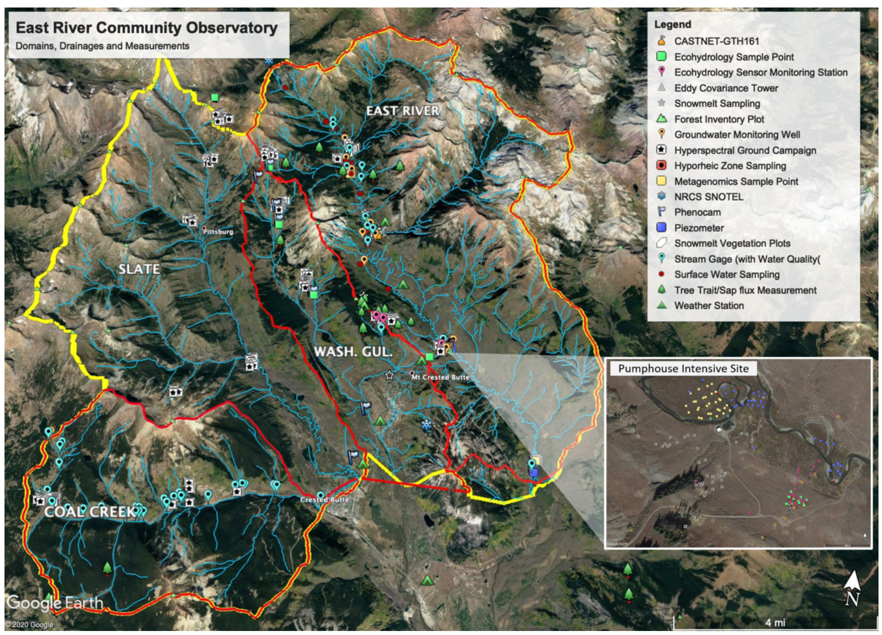


Figure 1: Map of ER site and measurements of the SFA and some collaborators. The yellow line indicates the East River Community Observatory domain. The red lines indicate the major drainage boundaries of the East River, Washington Gulch (Wash. Gul.), Slate River, and Coal Creek. The blue lines show stream flow lines determined from the National Hydrography Dataset (U.S. Geological Survey, 2001). Measurements by community partners in the Slate River and Redwell basin are not shown. The white box shows the intensively sampled Pumphouse subregion, which include measurements along a hillslope transect and and the meandering floodplain of the East River.

East River Measurements, field and data management infrastructure

The SFA and collaborators have collected sample- and sensor-based measurements at several locations across the East River and adjacent drainages (Figure 1). Regions of particular emphasis include "SFA-intensive" sites located within representative meanders and a hillslope in a lower montane subregion (labeled 'Pumphouse') of the pristine East River drainage basin, where several cross-disciplinary, co-located measurements are being conducted. Additional "satellite" sites, targeting specific research questions are located near the

Brush Creek confluence floodplain, an elevation gradient of research meadows along Washington Gulch and on the flanks of Cinnamon Mountain and Mount Baldy, Snodgrass Mountain, and mining-impacted sites in both Coal Creek and the Redwell Basin.

The ER instrumentation network maintained by the SFA and collaborators includes 15 stream-gaging and water quality stations used to obtain paired concentration-discharge measurements, 6 weather stations with soil moisture and temperature probes, 18 instrumented groundwater wells (e.g Figure 2a-2c), and about ~40 piezometers, ~15 ecohydrological sensor stations, and ~40 digital phenocam locations (Varadharajan et al. 2020). An eddy flux tower is maintained in the East River floodplain by the National Center for Atmospheric Research (NCAR). Extensive measurements of depth-resolved snow density, snow water equivalent, whole snowpit and rain chemistry, and stable isotopes of snow, rain and snowmelt water have been conducted over multiple years to inform stream water sources (Fang et al., 2019). Snowmelt manipulation experiments in vegetation plots in different mountain life zones were used to study the impacts of snowmelt timing on vegetation phenology. Metagenomic analyses of microbial communities have been conducted for soils and sediments representing various locations across the floodplain meanders and lower montane hillslopes that contribute water and solutes to the river (Lavy et al., 2020; Matheus Carnevali et al., 2020; Sorensen et al., 2020), resulting in over 5,000 metagenome-assembled genomes. In addition, several multi-institutional remote sensing campaigns have been conducted at the ER which include a 2015 Light Detection and Ranging (LiDAR) survey led by the SFA (Wainwright & Williams, 2017), Airborne Snow Observatory (ASO) flights by the National Aeronautics and Space Administration's Joint Propulsion Laboratory (NASA JPL) in 2016, 2018 and 2019 (Painter et al., 2016), a 2017 USGS Airborne Electromagnetic survey, and a 2018 National Ecological Observation Network (NEON) hyperspectral survey paired with an extensive ground-based campaign conducted in coordination with Stanford University (Chadwick et al., 2020). In 2021, a two-year deployment of the DOE's Atmospheric Radiation Measurement (ARM) Program mobile Surface Atmosphere Integrated Field Laboratory (SAIL) will use more than three dozen instruments to collect a suite of meteorology, clouds, aerosol and other atmospheric measurements in the ER (*http://sail.lbl.gov*). The SFA's ER measurement locations are viewable through a public, user-friendly field information portal (*https://wfsfa-data.lbl.gov/watershed/*).

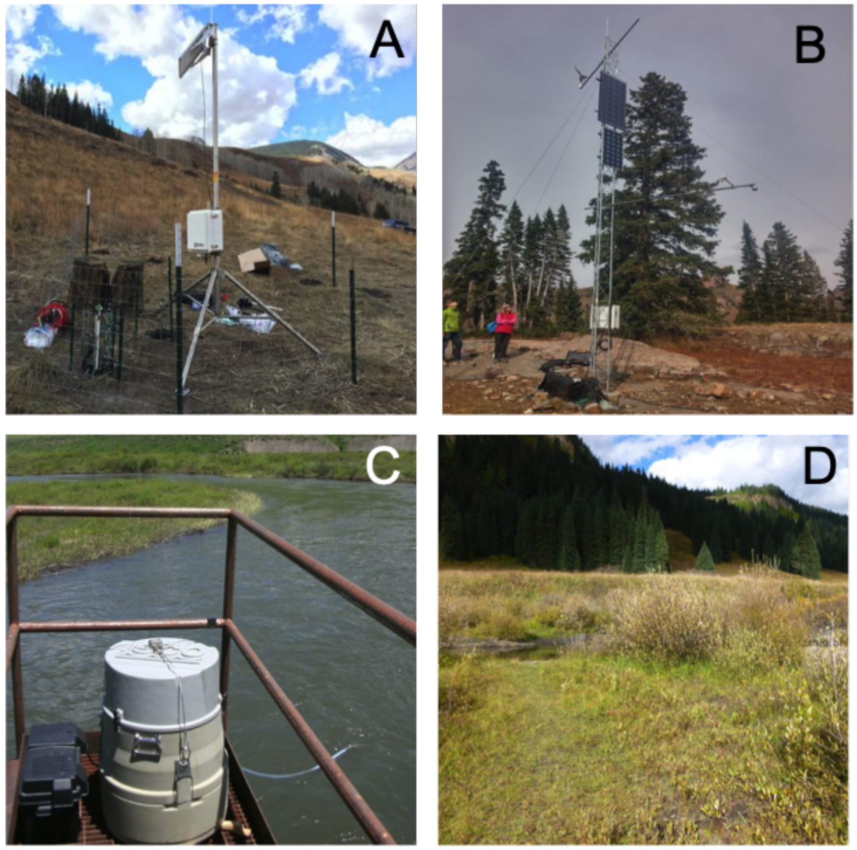


Figure 2 . Photographs of some field locations and infrastructure installations in the ER: (A) Hillslope borehole, subsurface water and carbon inventory well (B) Weather station, atmospheric weather sensor in the alpine zone, (C) Pumphouse ISCO, sampler for subsurface discharge and solute flux in the subalpine zone, (D) A plot to study impacts of early snowmelt on vegetation at a subalpine location along an elevation gradient

The ER watershed also has infrastructure maintained by several federal, state, and local agencies that have different data systems (some of these are indicated in Figure 1a). Notably, the Rocky Mountain Biological Laboratory (RMBL, https://www.rmbl.org/) is situated in the townsite of Gothic, and has over 90 years of data collection activities in the watershed. Snow measurements and associated meteorological data are available from the National Resources Conservation Service (NRCS) snow Telemetry (SNOTEL) sites 'Butte' and 'Schofield Pass', Crested Butte Cooperative Observer Network (COOP), and a number of Weather Underground stations. The USGS maintains gaging stations (located downstream of the SFA gages), and collects water quality measurements across the East-Taylor watersheds, and makes the data available through NWIS (HUC: 14020001). Additional water quality data are available from the National Water Quality Portal, which includes measurements by the U.S. Environmental Protection Agency (EPA), Colorado Department of Public Health and Environment (CDPHE), and local groups including the Coal Creek Watershed Coalition and the Rivers of Colorado Water Watch. The EPA also maintains a National Atmospheric Deposition Program (NADP) and Clean Air Status and Trends Network (CASTNET) station at Gothic.

Thus collectively, the SFA and its collaborators generate diverse, multiscale datasets at the ER including hydrological, (bio)geochemical, climate, vegetation, geophysical, microbiological, and remote sensing data. Additionally, several model datasets, including inputs, outputs and preprocessing codes are generated from numerical simulations of different watershed subsystems and their aggregated behavior. Detailed descriptions of the data types, data variables collected, and methods used are listed in Table 1. The most common publicly available data types from the ER during 2015-2020 are biogeochemistry and hydrology data.

The SFA has a Data Management Framework component that provides services and infrastructure to support the project's data lifecycle. The framework comprises systems, workflows and scripts to acquire and store data in a queryable database, conduct QA/QC, integrate project data with external data for real-time queries, discover and download data, and to publish data with digital object identifiers (DOIs) in the DOE's Environmental Systems Science Data Infrastructure for a Virtual Ecosystem (ESS-DIVE) repository (Varadharajan et al., 2019). Additionally, the SFA has developed an integrated field-data workflow to acquire critical metadata from these diverse data streams, and to manage data at each stage of the scientific process. The field-data workflow outlines guidelines for managing metadata and identifiers for field locations, samples, sensors, and data package creation and publication. While developed by the SFA, the workflow is available to other collaborating organizations, and is built based on community feedback and established data management best practices.

4. **Scientific Impact of ER Datasets**

The multidisciplinary data from the ER have advanced the understanding of hydrological processes in mountainous catchments, and the simultaneous collection of diverse data types across the watershed allows researchers across institutions to share knowledge and draw conclusions. Examples of datasets collected through periodic sampling or from sensor instrumentation that are frequently used in analysis and modeling include daily river stage observations and discharge estimates (dataset 43; observed measurement errors ranging from ~2-15%), weekly-daily surface and groundwater geochemistry (e.g. datasets 3, 5, 9, 15, 21, 41; measurement uncertainties in Tables S2-S3), and instantaneous groundwater elevations and temperature in the hillslope and floodplain (e.g. datasets 30, 46). Examples of research topics that ER datasets are used for include water partitioning as a function of hydrological perturbations such as drought and early snowmelt (e.g. datasets 18, 26, 39-44), surface-groundwater interactions (e.g. datasets 63-68), nitrogen cycling and export to the river (e.g. datasets 15, 20, 21, 27, 31-32, 52, 56), the impact of weathering and other processes on river water composition (e.g. datasets 10, 28, 32), and more broadly an aggregated understanding of watershed hydrobiogeochemical processes given their variation over space and different watershed functional zones and compartments (e.g. datasets 49-54).

The ER datasets have been used in numerous publications of which a select few are highlighted here. For example by combining measurements of river, rain, groundwater and snow chemistry, stream discharge, remote sensing (LIDAR, ASO), Carroll et al. (2018, 2019) found that groundwater recharge, an important contributor to streamflow, is dependent on elevation and vegetation (datasets 42-44, 51, 70-72). Specifically, groundwater recharge increases in higher elevations, such as the upper subalpine zone where there is greater snow accumulation and lower canopy cover. Through analyses of data on groundwater chemistry, water table depth, and rock mineralogy, Wan et al. (2019) found that the seasonal water table depth determines the weathering zone and weathering front in sedimentary bedrock, and that the Mancos shale can be a significant contributor to river nitrogen exports (datasets 30-32). Combining snow measurements with metagenome analysis, Sorensen et al. (2020) found that snowmelt triggers a pulse of nitrogen in hillslope soils concomitant with a collapse in microbial biomass, and changes in microbial community composition (datasets 17, 20). Using model simulations of floodplain meanders and regions of hyporheic exchange, Dwivedi et al. (2017, 2018) found these subsystems exert critical controls on nitrogen cycling and other solute exports to the river (datasets 29, 46-47).

The interdisciplinary data from the ER can also be used in future investigations that address science questions identified by the broader community such as the impacts of climate change and extreme events on the critical zone, and the scale dependence of hydrology (Blöschl et al. 2019). These data along with future measurements from the SAIL campaign will provide integrated observational datasets for benchmarking atmospheric and hydrological models in mountainous watersheds, thus addressing an identified data gap in modeling mountain rain and snow (Lundquist et al. 2019). More broadly the data from the ER will help understand the impacts of hydrological perturbations on water availability and quality in the Western United States.

The findings from the ER community, and the potential for gaining future scientific insights using the data, highlight the value of designing multidisciplinary watershed observatories using open science by design principles, and publishing data generated in open, public repositories (Stegen et al., 2019).

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Data Availability Statement

Datasets generated by the SFA and collaborators at the ER are publicly available in online repositories, including ESS-DIVE, NCBI, United States Geological Survey (USGS), NASA DAAC: National Snow and Ice Data Center, Figshare, and HydroShare (as listed in Table S1 of the Supplementary Information). The SFA alone has 43 public datasets with associated metadata available on ESS-DIVE that include many of the long-term monitoring and spatially-extensive remote sensing and associated ground campaign datasets. A majority of the ER data collection can be accessed on ESS-DIVE through the East River watershed portal (https://data.ess-dive.lbl.gov/portals/east-river-watershed). Users must be logged into ESS-DIVE with their ORCiD credentials to download the public data packages. Large datasets such as the remote sensing or model products are stored and distributed through public data transfer nodes on the DOE's National Energy Scientific Computing Center (NERSC).

The SFA has an open data policy where project-generated data are made publicly available following the U.S. Department of Energy's guidelines (https://watershed.lbl.gov/data/data-policy/). The data are typically licensed under Creative Commons by Attribution (CC-By4.0) or Creative Commons Public Domain (CC0) usage policies. The usage license, measurement uncertainties, quality checking process, and dataset metadata are specific to each dataset and should be obtained directly from the published data in the listed repositories.

Table 1 . ER Data types, variables, and methods of data generation. Methods and instruments used, and uncertainties (if available) are described in the published datasets on the repositories. Several time series measurements are ongoing; see Varadharajan et al. (2020) for location and instrumentation metadata associated with these measurements. Table S1 has the full list of 72 East River datasets spread across different repositories; some datasets are listed under multiple data types.

Data Type	**Data Variables**	**Methods/Instrumentation**	**Datasets**

Hydrology [24]*	Evapotranspiration, Water Table Depths, Groundwater Temperature, Stream Water Temperature, Stream Discharge, Soil Moisture, Soil Temperature, Snow Chemistry, Snow Depth, Stable Isotopes of Water, Ecosystem Respiration, Stream Gas Exchange Rates, Hydraulic Conductivity	Groundwater Wells, Snowpits, Pressure Transducers, Acoustic Doppler Current Profiler, Dissolved Gas Sample Collection, Mass Spectrometry, Snowmelt lysimeter, Models (e.g. ParFlow-CLM, GSFLOW)	(S. Hubbard et al., 2019), (Berkelhammer et al., 2020), (Rosemary Carroll et al., 2019), (Arora et al., 2020), (Dwivedi, 2019), (Tokunaga et al., 2019), (Wan, Tokunaga, Williams, Brown, et al., 2019), Williams et al. 2020, (Rosemary Carroll et al., 2018), (Rosemary & Williams, 2019), (R. Carroll, Deems, et al., 2019), (Bryant et al., 2019), Dafflon et al. 2020, (Dafflon & Dwivedi, 2020), (Malenda H, n.d.), (Johnson et al., 2019), (Briggs, Wang, et al., 2019), (Briggs et al., 2017), (Özgen-Xian et al. 2020), (Faybishenko 2020), (Tran et al. 2019), (Carroll et al. 2020), (Wan, Tokunaga, et al., 2021), (Rogers et al., 2020)

Biogeochemistry [39]*	Surface Water Geochemistry, Groundwater Geochemistry, Isotopes, Anions, Cations, Total Dissolved Nitrogen, Dissolved Organic Carbon, Dissolved Inorganic Carbon, Ammonia, Dissolved Gas Concentrations, Mineralogy, Metagenomics, Microbial Biomass, Spectroscopy, Transcriptomics	Soil Lysimeter, Nucleic Acids Sequencing, Piezometers, Soil Sensors, Radiation Sensors, Infrared Sensors, Flux devices, MicroMET, MC-ICPMS, TIMS, Chromatography, Laser Absorbance Spectroscopy, ISCO samplers	Williams et al. 2020, (Sutfin & Rowland, 2019a), Dong et al. 2020, (Rowland & Stauffer, 2020a), (Sutfin & Rowland, 2019b), (Saup et al., 2019), (Dong, Beutler, Brown, et al., 2020), (Zhi et al., 2019), (Nelson et al., 2019), (Fox et al., 2019), (Newcomer, Raberg, et al., 2020), (Dong, Fox, et al., 2020), (Bouskill et al., 2020), (Rowland & Stauffer, 2020b), (P. Sorensen et al., 2019a), (Berkelhammer, 2020), (Winnick et al., 2020), (P. Sorensen et al., 2019b), (Dong, Beutler, Bouskill, et al., 2020), (Sitchler et al., 2019), (Christensen et al., 2019), (S. Hubbard et al., 2019), (Berkelhammer et al., 2020), (Rosemary Carroll et al., 2019), (P. Matheus Carnevali et al., 2020), (Arora et al., 2020), (Dwivedi, 2019), (Tokunaga et al., 2019), (Wan, Tokunaga, Williams, Brown, et al., 2019), (Newcomer, Bouskill, et al., 2020), (Rogers et al., 2020), (Wan, Tokunaga, et al., 2021), (Carbone, 2019), (Zaremba-Niedzwiedzka et al., 2017), (P. B. Matheus Carnevali et al., 2019), (Briggs, 2018), (Dawson et al., 2018), (Johnson et al., 2019), (Briggs, Wang, et al., 2019)
Climate [3]*	Atmospheric deposition, Meteorology, Precipitation, Energy Fluxes, Heat Flux	Weather Stations, Microclimate Loggers	(S. Hubbard et al., 2019), (Chen et al., 2020), (Newcomer and Rogers 2020)

Vegetation [5]*	Plant growth, Biophysical Characteristics of Plant Canopy, Plant Nutrients, Snowmelt Date, Growing Season Microclimate, Leaf Litter Quality, Mass Loss, Sap Flux, Canopy Temperature	Direct physical observations of phenophases and plant canopy characteristics, Sap Flux Sensors, Thermal Cameras,	(Chen et al., 2020), (Chadwick, Brodrick, et al., 2020), (Chadwick, Grant, Bill, et al., 2020), (Chadwick, Grant, Henderson, Scott, et al., 2020), (Chadwick, Grant, Henderson, Breckheimer, et al., 2020)
Geology and Geophysics [3]*	Soil Electrical Conductivity, Electrical Resistivity Tomography, Seismic, Bedrock Properties, Porosity, Permeability, Hydraulic Flow, Soil Thickness, Soil Organic Carbon	Sensor Network, Groundwater Well 2-D Spatial Geotiff, Sampling Stations, self-developed model (SCALE)	(Uhlemann et al., 2020), (Falco et al., 2020), (Wan, Tokunaga, Williams, Brown, et al., 2019)
Remote Sensing [14]*	Hyperspectral, Land Surface Elevation, Normalized Difference Vegetation Index	Ground-penetrating radar, LiDAR, Electromagnetic and Spectroscopic Imaging, Drones	(Newcomer, Bouskill, et al., 2020), (Chen et al., 2020), (Brodrick et al., 2020), (Wainwright & Williams, 2017), (Chadwick, Brodrick, et al., 2020), (Goulden, Hulslander, et al., 2020), (Goulden, Hass, et al., 2020), (Goulden & Musinsky, 2020), (Malenda H, n.d.), (Briggs, Dawson, et al., 2019), (T. H. Painter & Bormann, 2020), (T. H. Painter, 2018), (T. Painter, 2018a), (T. Painter, 2018b)
Site Description [2]*	Field location metadata (e.g. coordinates, description), watershed and subbasin boundaries	Metadata templates, GIS	Varadharajan et al. 2020, (R. Carroll, Bill, et al., 2019),

* Counts of datasets of each data type

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Supporting Information for "The Colorado East River Community Observatory Data Collection"

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Table S1. As of March 2021, there are 72 public datasets generated by the Watershed Function SFA and collaborating institutions available in many data repositories. The datasets can be accessed using a digital object identifier (DOI) by appending a prefix http://dx.doi.org/DOI. Further details for these data, including descriptions, methods, and author contact information are available on the dataset landing pages. To access the latest published datasets on ESS-DIVE, view the East River Watershed portal (*https://data.ess-dive.lbl.gov/portals/east-river-watershed*).

No.	**M**
ESS-DIVE (Environmental Systems Science Data Infrastructure for a Virtual Ecosystem): 589 datasets	**E**
1	Si
2	Si
3	B
4	B
5	B
6	B
7	B
8	B
9	B
10	B
11	B
12	B
13	B
14	B
15	B
16	B
17	B
18	B
19	B
20	B
21	B

22	B
23	B
24	B
25	B
26	B
27	B
28	B
29	B
30	B
31	B
32	B
33	B
34	B
35	C
36	C
37	H
38	H
39	H
40	H
41	H
42	H
43	H
44	H
45	H
46	H
47	H
48	G
49	G
50	R
51	R
52	R
53	R
54	R
55	R
56	V
57	V
58	V
Figshare: 1 dataset	**F**
59	B
HydroShare: 1 dataset	**H**
60	H
NCBI (National Center for Biotechnology Information): 2 datasets	**N**
61	B
62	B
USGS Sciencebase: 6 datasets	**U**
63	B
64	B
65	B
66	B
67	H
68	R

National Snow and Ice Data Center (NSIDC): 4 datasets	**N**
69	R
70	R
71	R
72	R

+ Datasets generated by the Watershed Function Science Focus Area.

Table S2 Determination of Minimum Detection Limits (MDLs) for 37 cations using ICP-MS (Elan DRC II, PerkinElmer, SCIEX) from the Dong et al. (2020) dataset "Cation Data for the East River Watershed, Colorado. Watershed Function SFA." doi:10.15485/1668055. The relative standard deviation (RSD) of each measurement varies with concentrations and detection limits, and is generally < 3% based on 3 - 5 replicate measurements for concentrations higher than detection limits. Further details on the measurement uncertainties are included in the published dataset.

Element	Cailbration Range, ppb	*Spiked conc., ppb	** Analyzed mean conc., ppb	Spiked MDL, ppb	Blank MDL, ppb	¥ Selected instrument MDL, ppb	§ DF = 10 corrected MDL, ppb
Li	0.0063-6.0256	0.0063	0.0535	0.0230	0.0134	0.0230	0.2299
Be	0.0503-48.2045	0.0503	0.0520	0.0087	0.0200	0.0200	0.2005
B	0.0126-12.046	0.0126	0.5410	0.0206	0.3281	0.3281	3.2813
Na	2.5136-2410.23	2.5136	2.5804	0.2229	0.1812	0.2229	2.2286
Mg	2.5136-2410.23	2.5136	2.8855	0.3957	0.5719	0.5719	5.7188
Al	2.5141-2710.71	2.5141	2.3712	0.3124	1.5447	1.5447	15.4471
Si	1.2830-2710.71	1.2830	4.8348	1.7082	1.9642	1.9642	19.6416
K	2.5136-2710.23	2.5136	2.5370	0.2896	0.4299	0.4299	4.2993
V	0.0503-48.2045	0.0503	0.0492	0.0018	0.0016	0.0018	0.0179
Cr	0.0503-48.2045	0.0503	0.0523	0.0062	0.0019	0.0062	0.0615
Mn	0.0503-48.2045	0.0503	0.0483	0.0030	0.0008	0.0030	0.0295
Ca	2.5136-2410.23	2.5136	3.7709	0.6698	2.1914	2.1914	21.9142
Fe	2.5125-2409.26	2.5125	2.5523	0.0610	0.0724	0.0724	0.7240
Se(O)	0.0251-14.469	0.0251	0.0359	0.0377	0.0800	0.0800	0.7997
Ti	0.0257-24.659	0.0257	0.0918	0.0463	0.1836	0.1836	1.8364
Ni	0.0503-48.204	0.0503	0.0586	0.0094	0.0102	0.0102	0.1015
Co	0.0503-48.204	0.0503	0.0499	0.0033	0.0006	0.0033	0.0328
Cu	0.0503-48.204	0.0503	0.0620	0.0112	0.0055	0.0112	0.1117
Zn	0.0503-48.204	0.0503	0.0781	0.0543	0.0310	0.0543	0.5433
Ge	0.0026-2.462	0.0026	0.0029	0.0014	0.0015	0.0015	0.0154
As	0.0503-48.204	0.0503	0.0487	0.0059	0.0048	0.0059	0.0593
Rb	0.0126-12.046	0.0126	0.0129	0.0056	0.0013	0.0056	0.0556
Sr	1.2568-1205.1	1.2568	1.2394	0.0339	0.0392	0.0392	0.3924
Zr	0.0026-2.4615	0.0026	0.0085	0.0012	0.0076	0.0076	0.0757
Mo	0.0257-24.659	0.0257	0.0260	0.0030	0.0128	0.0128	0.1278
Ag	0.0251-24.0974	0.0251	0.2993	0.0048	0.2731	0.2731	2.7307
Cd	0.0251-24.0974	0.0251	0.0245	0.0075	0.0044	0.0075	0.0752
Sn	0.0257-24.659	0.0257	0.0259	0.0133	0.0200	0.0200	0.2000
Sb	0.0257-24.659	0.0257	0.0259	0.0019	0.0151	0.0151	0.1510
Cs	0.0251-2.4112	0.0025	0.0021	0.0009	0.0006	0.0009	0.0089
Ba	0.0503-48.204	0.0503	0.0528	0.0085	0.0018	0.0085	0.0851
Eu	0.0251-2.4107	0.0025	0.0017	0.0006	0.0004	0.0006	0.0057
Pb	0.0503-48.204	0.0503	0.0515	0.0032	0.0018	0.0032	0.0320
Th	0.00251-2.4102	0.0025	0.0011	0.0031	0.0094	0.0094	0.0936
U	0.0013-12.0559	0.0013	0.0086	0.0054	0.0199	0.0199	0.1992
As(O)	0.0503-9.650	0.0503	0.0731	0.0055	0.0199	0.0199	0.1989
P(O)	0.2514-241.023	0.2514	0.2628	0.3931	1.4995	1.4995	14.9954

* Spiked samples have the same concentrations as the lowest calibration standard.

** Actually analyzed concentrations of spiked samples with the lowest calibration standard.

¥ Select the greater of MDLs or MDLb as the MDL for the instrument.

§ The corrected MDL = Selected MDL * dilution factor (DF = 10). These are the actual MDLs because most of samples were diluted and analyzed with a DF =10.

Table S3 Determination of MDLs of DIC, NPOC and TDN using Shimadzu TOC-VCSH and TNM-1 system from the Dong et al. (2020) datasets "Dissolved Inorganic Carbon and Dissolved Organic Carbon Data for the East River Watershed, Colorado" doi: 10.15485/1660459 and "Total Dissolved Nitrogen and Ammonia Data for the East River Watershed, Colorado." doi: 10.15485/1660456. The relative standard deviation (RSD) of each measurement varies with concentrations and detection limits, and is generally $< 3\%$ based on 3 - 5 replicate measurements for concentrations higher than detection limits. Further details on the measurement uncertainties are included in the published datasets.

Analyte	**Calibration range**	**Spiked conc.**	**Analyzed mean conc.**	**Spiked MDL_s**	**Blank MDL_b**	***S**
DIC, mg/L	0 - 50	5.00	4.999	0.880	0.754	**0.**
NPOC, mg/L	0 - 5	1.00	1.001	0.0991	0.2351	**0.**
TΔN, μγ/Λ	0 -1000	100.0	103.4	22.34	21.98	**22**