Arkansas Basin Water Quality

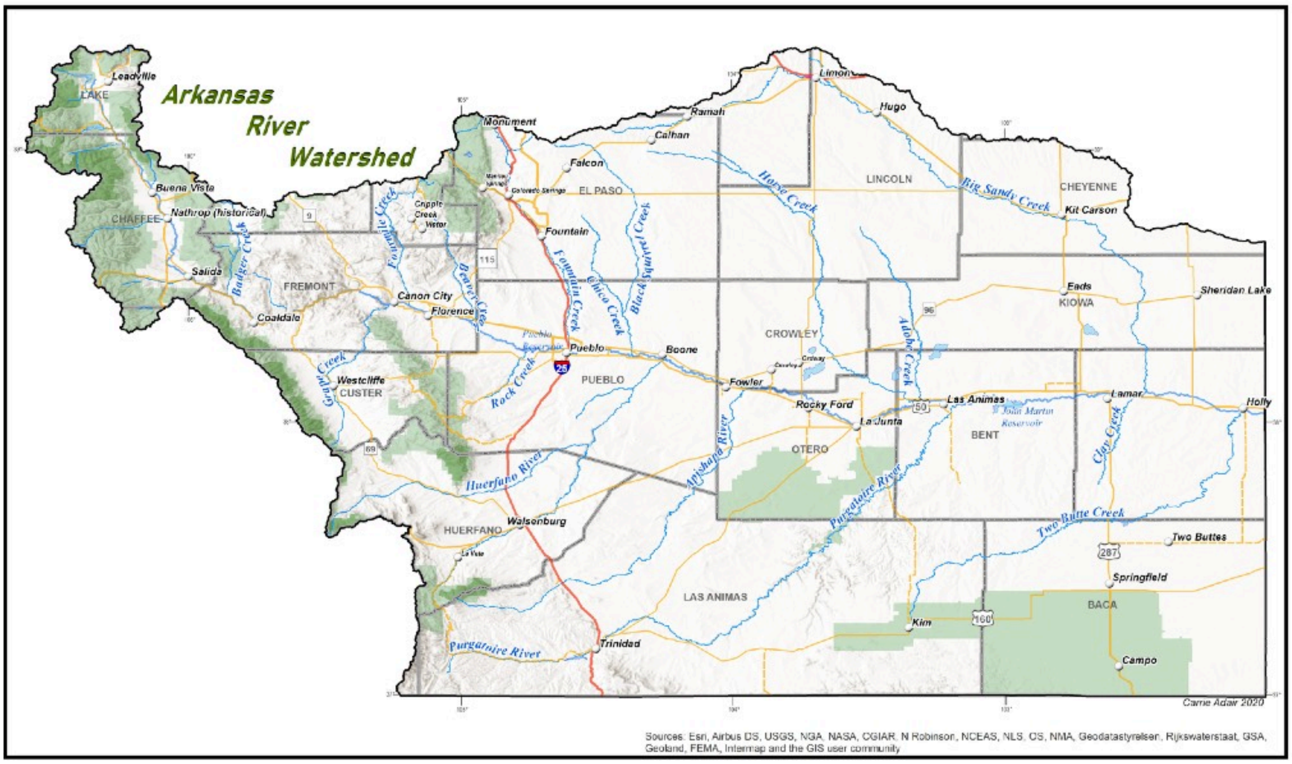
Science Plan

March, 2021

Special thanks to the Colorado Water Conservation Board for providing funding for this project. Thanks also to Mike Weber of Lower Arkansas Valley Water Conservancy District and Annie Berlemann of Colorado Springs Utilities for their work in creating the framework pieces we used for analysis. Finally, thanks to the Water Quality Working Group for supporting efforts in the basin to improve water quality.

Background

The Arkansas basin drains approximately 27% of the state of Colorado's landmass, or an area of almost 25,000 square miles, ranging from the Continental Divide near Leadville, to the Kansas state line, and from the Monument Divide in northern El Paso County to the New Mexico state line. The Arkansas river also carries significant water delivered via trans-mountain diversions from the Western Slope of Colorado.



Water quality in the Arkansas River drainage in Colorado is generally poor. The river, and many of its tributaries, are "impaired" (or not meeting water quality standards) for a variety of constituents, including heavy metals, nutrients, coliform bacteria, temperature. Selenium (SE) and uranium (U) are of particular interest to stakeholders in the lower basin who are participating in a Water Quality Working Group (WQWG), but nutrients and other contaminants are also of concern to the group.[1] The WQWG includes federal and state agency personnel, local government personnel, agricultural producers, and nonprofit organizations, who came together to explore voluntary approaches to improving water quality.

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[1] https://cdphe.colorado.gov/regulation-93-dashboard

Segment ID	Segments not meeting attainment for Selenium	Cycle First Listed
COARFO04e	4e_C. Sand Creek (near Colorado Springs), including all tributaries and wetlands.	2018
COARLA01b	1b_A. Mainstem of the Arkansas River from the Colorado Canal headgate to the inlet to John Martin Reservoir.	2008
COARLA01c	1c_A. Mainstem of the Arkansas River from the outlet of John Martin Reservoir to the Colorado/ Kansas border.	2008
COARLA04a	4a_A. Mainstem of Timpas Creek from the source to the Arkansas River.	2012
COARLA04a	4a_B. Mainstem of the Apishapa River from I-25 to the confluence with the Arkansas River.	2012
COARLA09a	9a_A. Mainstem (MS) of Buffalo, Cheyenne, Clay, Gageby, Two Butte, Wildhorse and Wolf Cks from sources to the Ark. R. MS of Chacuacho, San Francisco, Trinchera and Van Bremer Cks from sources to the Purgatoire R. MS of Willow Ck from HWY 287 to the confl. with the Ark. R. MS of Big Sandy Creek from source to the El Paso/Elbert cty line. MS of South Rush Ck from source to the confl. with Rush Ck. MS of Middle Rush Ck from source to the confl. with North Rush Ck. North Rush Ck from source to the confl. with South Rush Ck. MS of Rush Ck to the Lincoln cty Line. MS of Antelope Ck from source to the confluence with Rush Ck; the West May Valley drain from Fort Lyon Canal to the confl. with the Ark. R.	2008
COARLA09a	9a_B. Mainstem of Horse Creek	2008
COARLA09b	9b_A. Mainstem (MS) of Apache Ck. MS of Breckenridge Ck. MS of Little Horse Ck. MS of Bob Ck. MS of Rule Ck from Bent/Las Animas County line. MS of Muddy Ck from south boundary of Setchfield SWA. MS of Caddoa Ck from CC Rd. MS of Cat Ck. MS of Mustang Ck from the source to the confl. with Apishapa R. MS of Chicosa Ck from source to the Ark. R. MS of Smith Canyon from Otero/Las Animas county line to the confl. with Purgatoire R. MS of Mud Ck from V Rd to the confl. with the Arkansas R. MS of Frijole Ck and Luning Arroyo from sources to confl. with Purgatoire R. MS of Blackwell Arroyo from source to the confl. with Luning Arroyo. MS of San Isidro Ck from source to the confl. with San Francisco Ck.	2008
COARLA09b	9b_B. Big Sandy Creek within Prowers County	2008
COARLA10	10_B. Adobe Creek Reservoir	2012
COARLA10	10_C. Nee Gronda Reservoir	2012
COARLA11	11_A. John Martin Reservoir.	2006
COARLA12	12_A. Lake Meredith	2016
COARLA12	12_B. Lake Henry	2008
COARMA02	2_A. Mainstem of the Arkansas River from Blue Ribbon Creek to a point immediately above the confluence with Wildhorse/Dry Creek Arroyo.	2018
COARMA02	2_B. Mainstem of the Arkansas River from Pueblo Reservoir to Blue Ribbon Creek	2018
COARMA03	3_A. Mainstem of the Arkansas River from a point immediately above the confluence with Wildhorse/Dry Creek Arroyo to a point immediately above the confluence with Fountain Creek.	2016
COARMA09	9_A. Mainstem of Greenhorn Creek, from a point immediately below the Greenhorn Highline (Hayden Supply Ditch) diversion dam, to the confluence with the Saint Charles River.	2018
COARMA10	10_A. Mainstem of Sixmile Creek from the source to the confluence with the Arkansas River.	2010
COARMA12	12_A. Mainstem of Huerfano River from Highway 69 at Badito to the confluence with the Arkansas River.	2004

Over the last several decades, a great deal of monitoring and research has taken place with respect to water quality in the lower basin. The United States Geologic Survey (USGS) has the most robust monitoring data-set for water quality, but other studies have also occurred throughout the basin. (See literature review in Appendix 1).

The WQWG chose to work on a project to: 1.) review existing data in order to develop a better understanding of what we do know, where data gaps may exist, and to provide insight for future monitoring and research questions, and 2.) create an implementation guide that will help farmers, ranchers, and community leaders understand the problem and to consider approaches for addressing it by developing an implementation guide. The group, through the Arkansas River Watershed Collaborative (ARWC), sought and received funding for the project through a grant from the Colorado Water Conservation Board.

Stakeholders from the WQWG helped gather data and reports, collect data, and develop tools for evaluating data. Special thanks for their efforts go to Mike Weber of the Lower Arkansas Water Conservancy District and Annie Berlemann of Colorado Springs Utilities for working extensively with data and developing tools and analysis that we can utilize in the future for understanding the current state of affairs, trends, and needs for continuing research and monitoring.

Lower Arkansas Valley Water Conservancy District Analysis and Implementation Guide

The Lower Arkansas Valley Water Conservancy District (LAVWCD) formed in 2002 to serve Bent, Crowley, Otero, Prowers, and Pueblo Counties, with the primary function of acquiring, retaining, or conserving water resources for these counties. In 2017, LAVWCD joined the WQWG, and became a regional lead in helping to address water quality issues. These issues have negative economic impacts on the lower basin counties that LAVWCD serves, and could lead to more stringent regulations being applied to agriculture in the valley. Water quality could also impact the lower valley if Kansas, which has raised the issue with Colorado, chose to sue under the Clean Water Act.

As a local leader who works directly with the agricultural community in the lower valley, LAVWCD began a partnership with the Colorado Department of Public Health & Environment (CDPHE) Nonpoint Source Program to implement of a number of demonstration projects designed to reduce water quality impacts from agriculture in the lower valley. Projects include installation of sprinklers or drip irrigation as a replacement for traditional ditch irrigation, lining laterals, improving riparian buffer zones, increasing the use of cover crops, and stabilizing head ponds.[2] LAVWCD has also begun a partnership with the USDA Natural Resources Conservation Service and the Colorado Department of Agriculture to address soil health. Improving soil health can significantly improve overall water quality in the river, by reducing surface runoff, and capturing/utilizing nutrients better in the soil matrix.

For this project LAVWCD was specifically interested in pulling together all publicized data they could acquire to help them understand the impacts in their service area, reviewing literature for studies that may have had interpretation of data, and creating the "implementation guide" (Appendix 2) and story map (https://storymaps.arcgis.com/stories/da010ebdcd7147869a2591877c220466) as communication tools.

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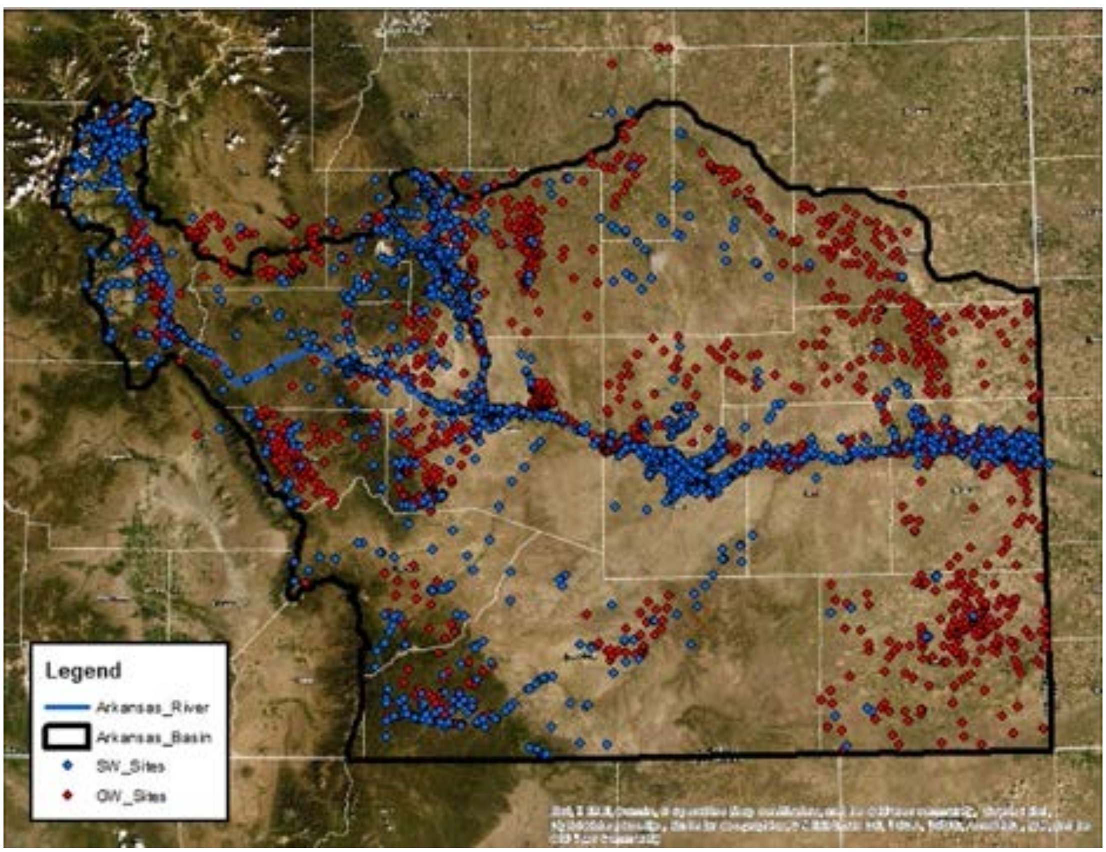
[2] https://storymaps.arcgis.com/stories/01f334b05df349fd8f72747247222347

LA ANALYSIS DISCUSSION

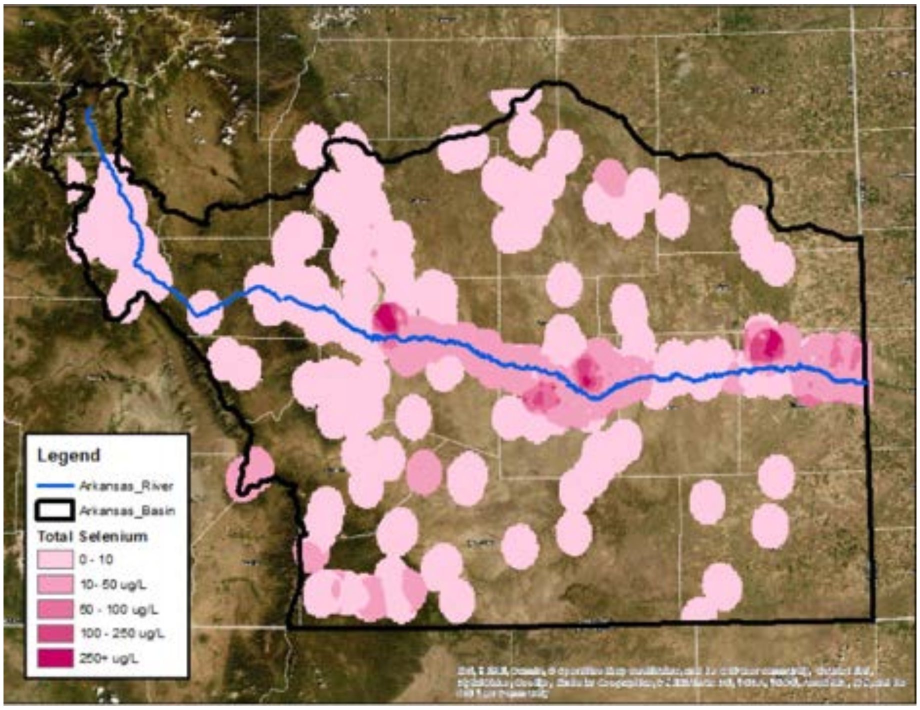
The first information that LAVWCD documented was all points that have been monitored at any time (red is ground water; blue is surface water sites). As seen here, monitoring has been extensive in the history of the basin, with samples as early as the 1930s. As LAVWCD points out in their data gap analysis, “There are five data gaps in particular that are of interest in helping to tell the story of what is going on in the basin. The first of these is the lack of surface water sited on the east side of the map. Of course, the mainstem of the river was heavily sampled, but the tributaries seem to be lacking a lot of flow data. One explanation of this is that once you get outside of the mainstem agricultural lands going either north or south the irrigation type become dry-land farming. In dry-land farming there is no way of identifying exactly when a storm is going to come and have substantial field runoff to capture and sample. If there were more studies to be looked at this could be a possibility of capturing data during a heavy rain event on the dryland farming area.”

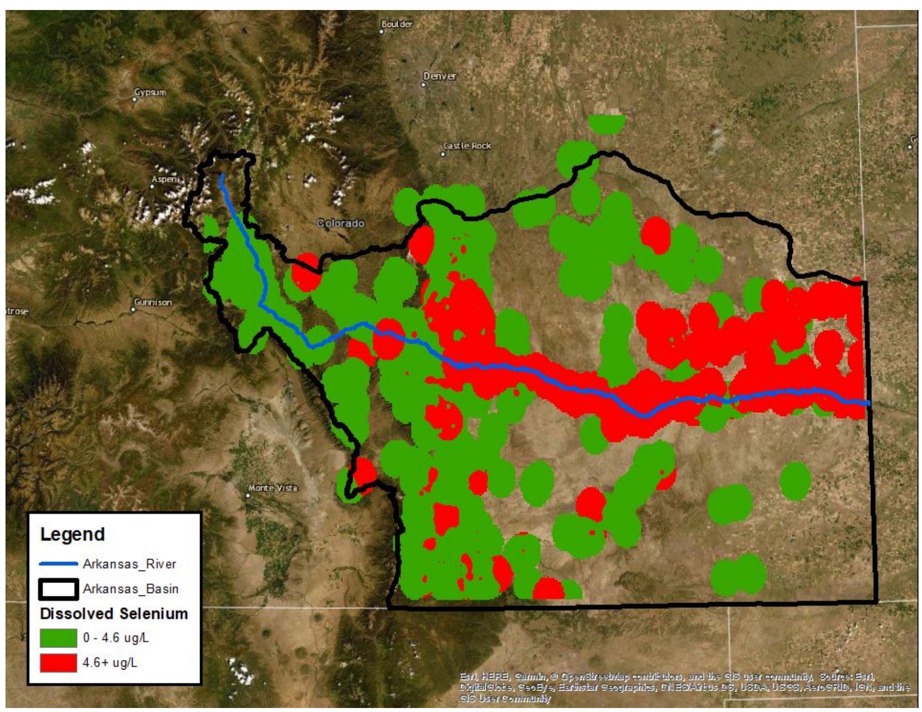


WATER QUALITY MONITORING SITES

Water Quality Trends

LAVWCD used a heat-map graphic approach to review water quality impacts for all constituents that are listed by CDPHE as having an impairment in the Arkansas River or its tributaries.





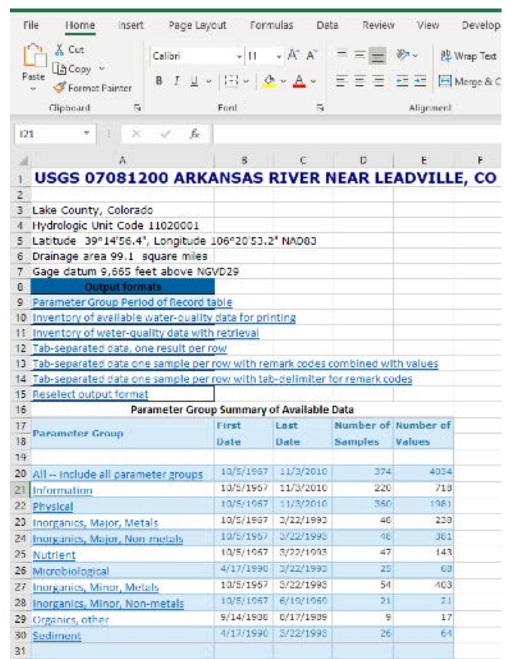
As seen in the trend analysis (above) for SE, this constituent is well represented throughout the basin. There is selenium throughout the basin, but what does this mean in terms of water quality compliance.

LAVWCD next step was to look at it from a compliance issue: There are exceedances for dissolved arsenic, iron, selenium (at right), and uranium; there are also exceedances for manganese, nitrate, nitrite, phosphorous, total selenium, and sulfate. They ran mapping for each constituent that has exceedances. They are using this for education of farmers and ranchers in the lower basin.

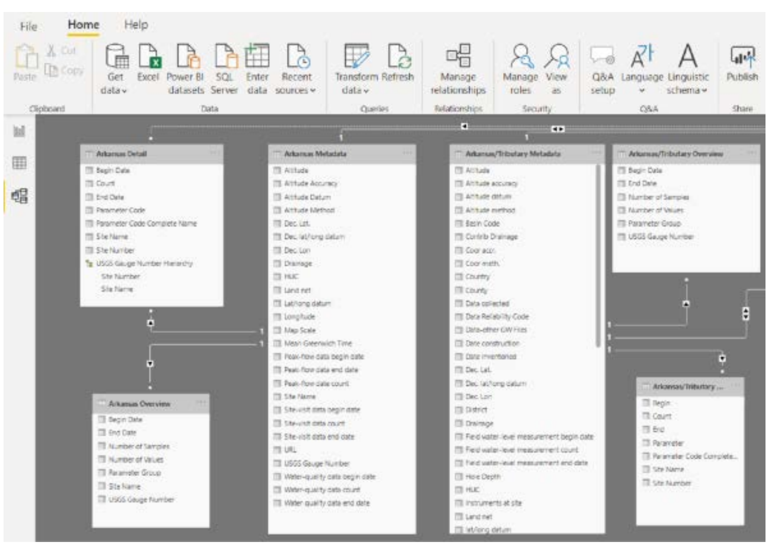
Colorado Springs Utilities Analysis Tool

Colorado Springs Utilities (CSU) depends on water sources throughout much of the Arkansas Basin to meet its water-supply demands. Water quality impacts its operations directly through increased treatment costs, but also impacts its ability to manage water resources from different sources, and has a political cost for the Utilities in working with neighboring and downstream counties. As an in-kind support component for the Science Plan, staff from the watershed program at CSU agreed to undertake development of a tool for assessing data, using PowerBi, a Microsoft product that can use data from different sources (spreadsheets or databases), and form connections and produce visualizations that help users to gain insight into the data sets.

All data in this Science Plan Element were queried from National Water Information System (NWIS) (https://nwis.waterdata.usgs.gov/usa/nwis/qwdata) and EPA's Water Quality Data Portal (https://www.waterqualitydata.us). The data set was then saved in Microsoft Excel and loaded into PowerBI for creating relationships, shaping, editing and creating visualizations. Initially Arkansas Basin sites where selected, and data imported, with no period of record defined using USGS Parameter Groups. Parameter Groups are defined from a collaborative effort between the USGS and USEPA. For a complete list of Parameters that are included in each Parameter Group reference: https://help.waterdata.usgs.gov/codes-and-parameters/parameters. Power Bi can use relationships from various sources to build information into a system that allows robust analysis and visualizations.



EXAMPLE OF EXCEL OUTPUT FROM NWIS



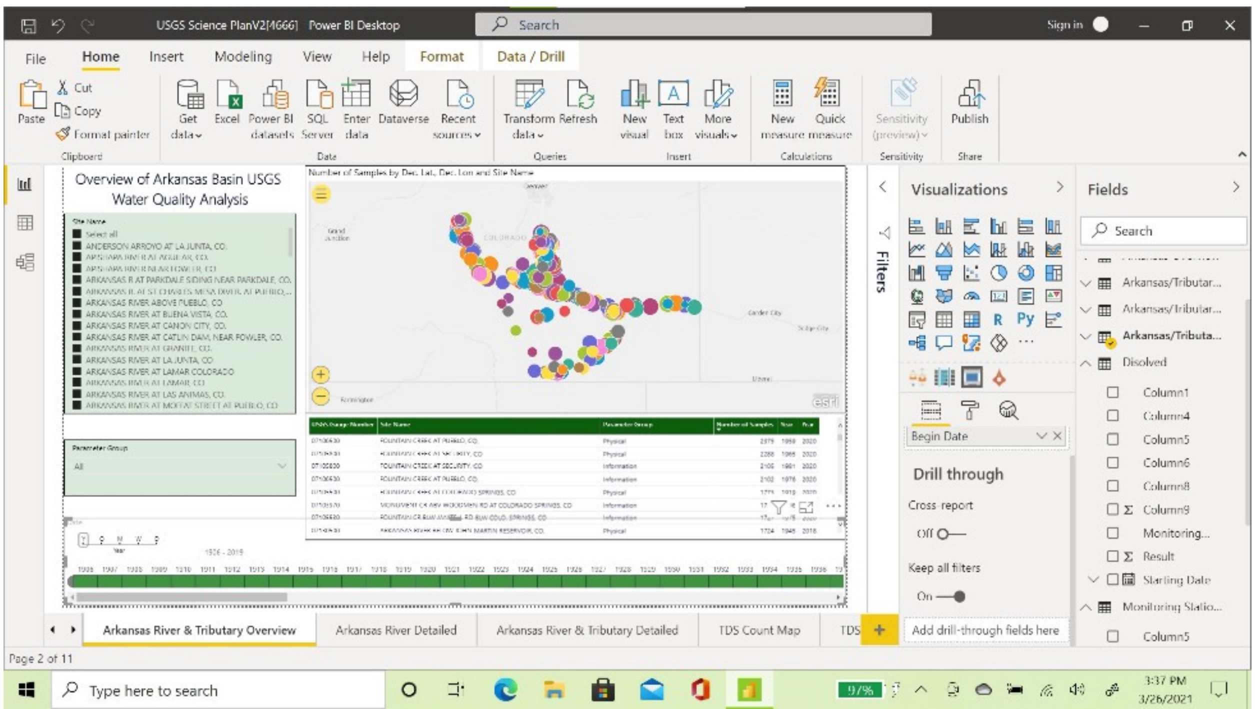
EXAMPLE OF RELATIONSHIPS CONNECTING DATA AND

In the PowerBI Dashboard, this dataset is referred to as "Overview." Each Parameter Group contains the amount of data for that grouping. This is intended to be high level perspective and inform further how much data exits for each kind of data.

Introduction to the Science Plan PowerBI Dashboard

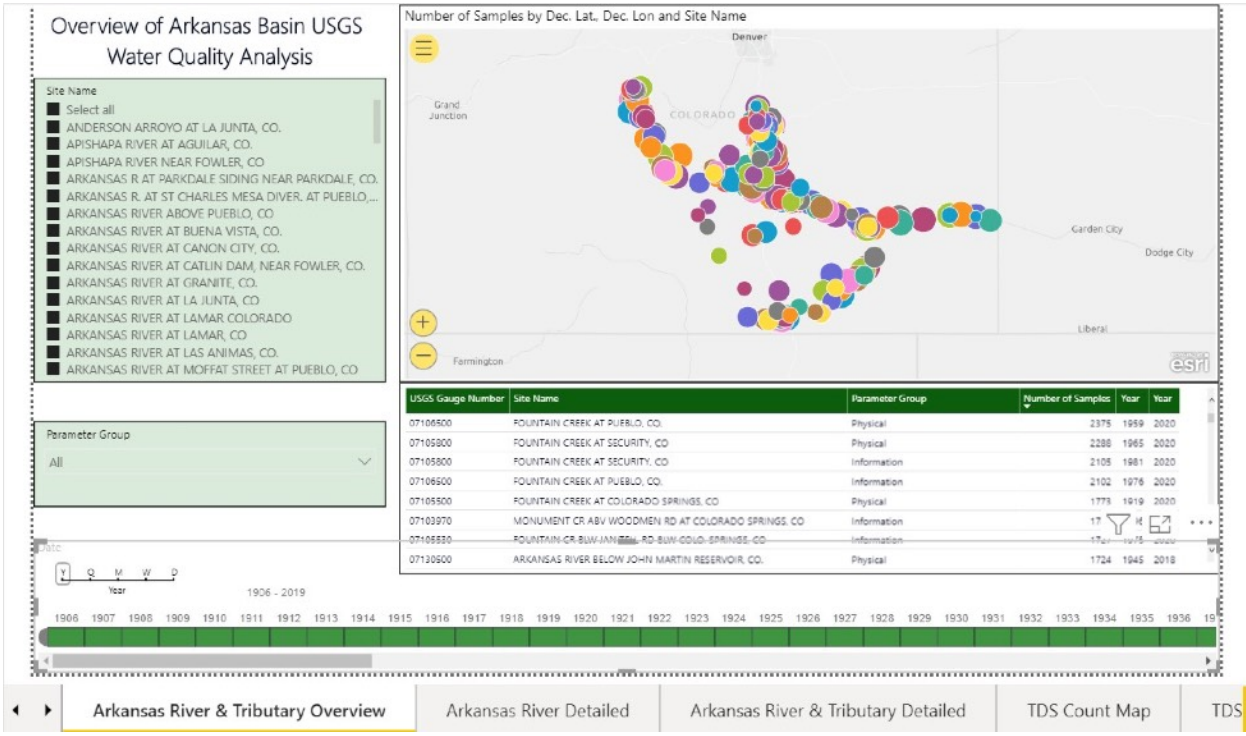
The Dashboard is a layered approach to viewing data in the Arkansas Basin. The Dashboard combines the data type as parameter groups (e.g. biological, inorganic, nutrients, etc.) and parameters (or individual contaminants), the amount of data as sample and value counts, the time period that the data reflects and the geographical locations.

The beginning layer is an Overview of how much data exists in the Arkansas Basin for Parameter Groups, with no defined period of record. This is a coarse view to give users a general understanding of what kind of data is available, how much is available over what timeframes and geographical locations. The Dashboard divides the mainstem Arkansas River sites or all sites in the basin including tributaries. This allows users to view the whole basin or just a portion easily.



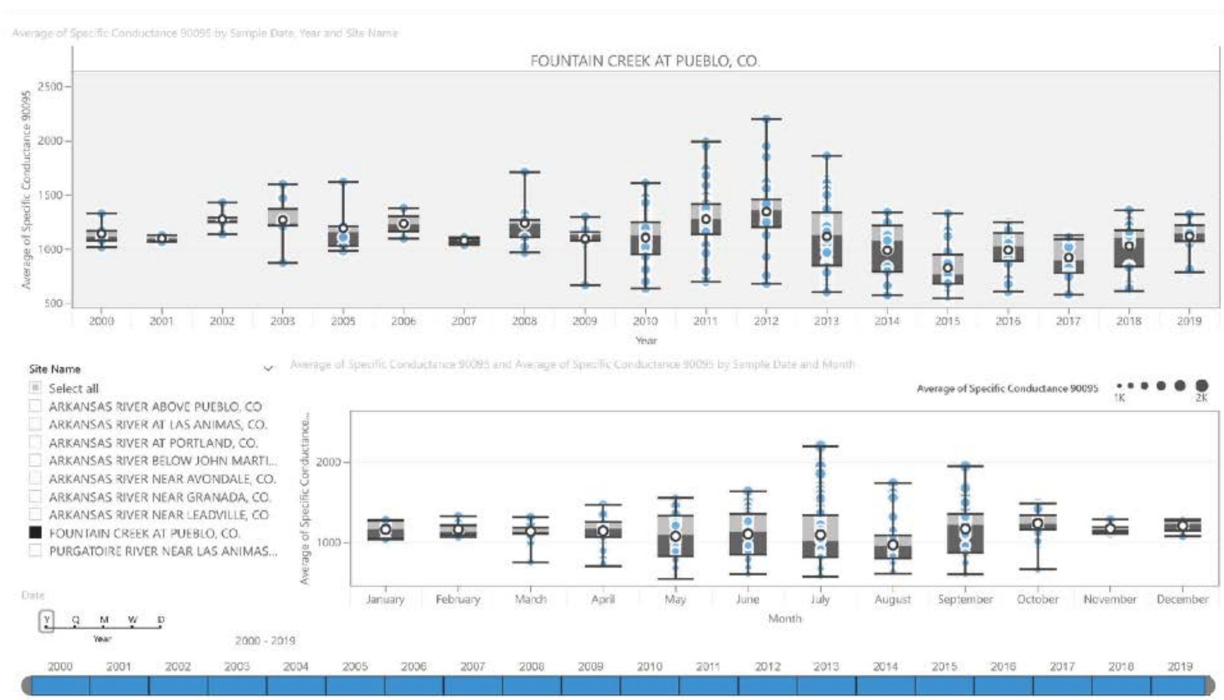
EXAMPLE OF THE POWER BI DASHBOARD WINDOW, INCLUDING MENU BAR AND TOOL BARS AT RIGHT.

From this report, the user can select sites individually or as groups, then select the parameter group in part or all, and the period of record using the slicer at the bottom of the screen by year, quarter, month, week or day. The two visualizations on the right of the pane show geographical location of sites and the size of the marker indicate the amount of data present. The table below the map shows the same information just in tabular form. Hovering or clicking (see illustration, next page) on sites highlights that information as well. The tool allows you to select specific parameters, locations, and time frames.

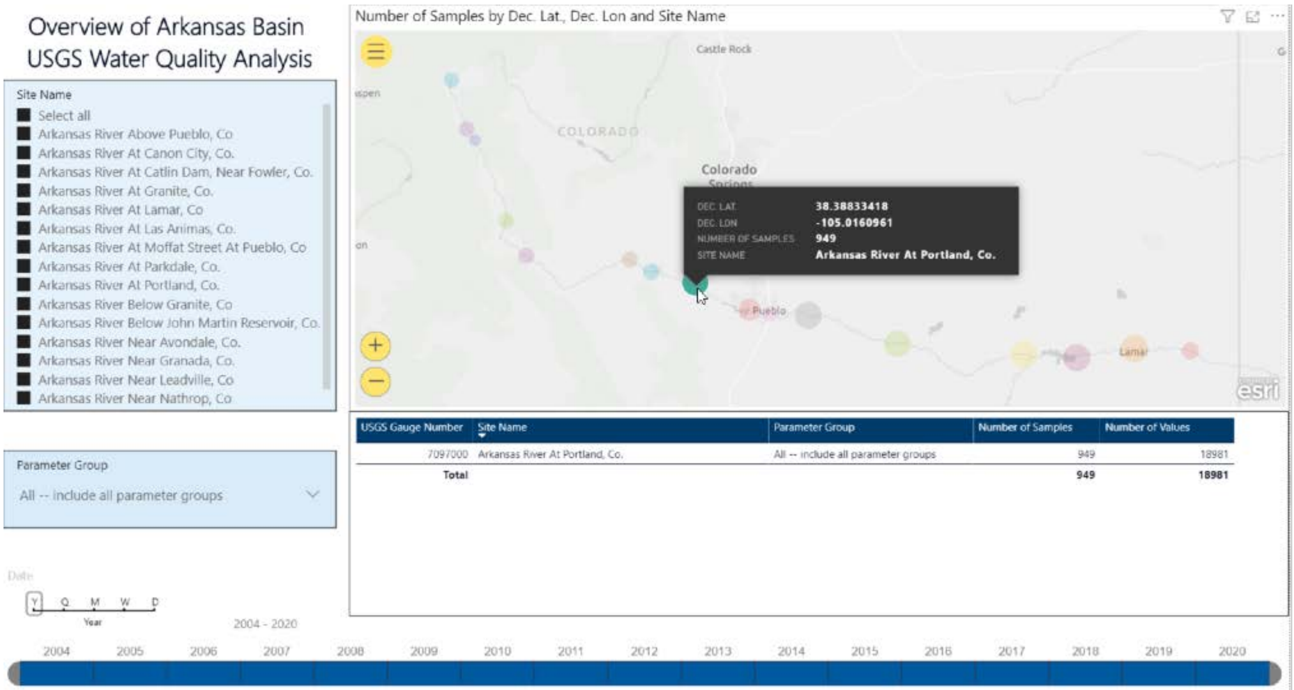


CLOSE UP OF THE OVERVIEW RESULTS PAGE

The user may query the result values of that data as well, by clicking on the URL link, and it will take the user directly to that site in the data set. From there the user can define the period of record and parameter code to find actual monitoring results for the specific site. Users can use the tool to do additional analysis of specific information, in a specific time and place, such as seen in the image below.

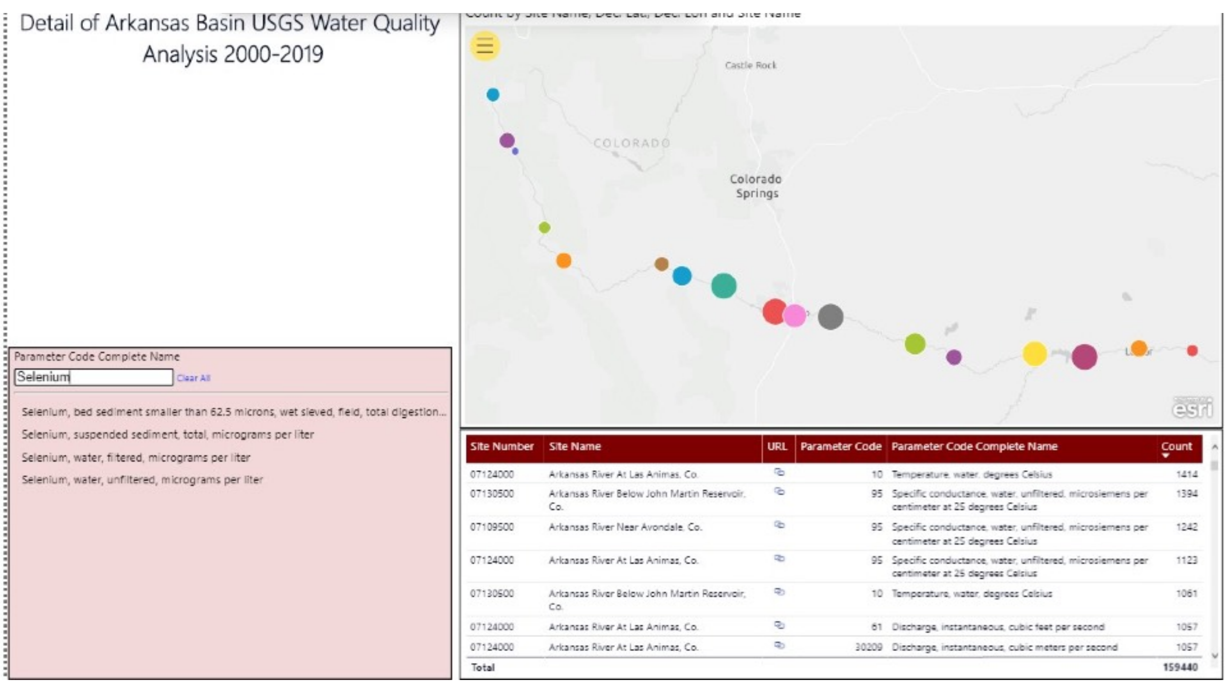


Users can hover on particular points, and that brings up more detail on that specific point:

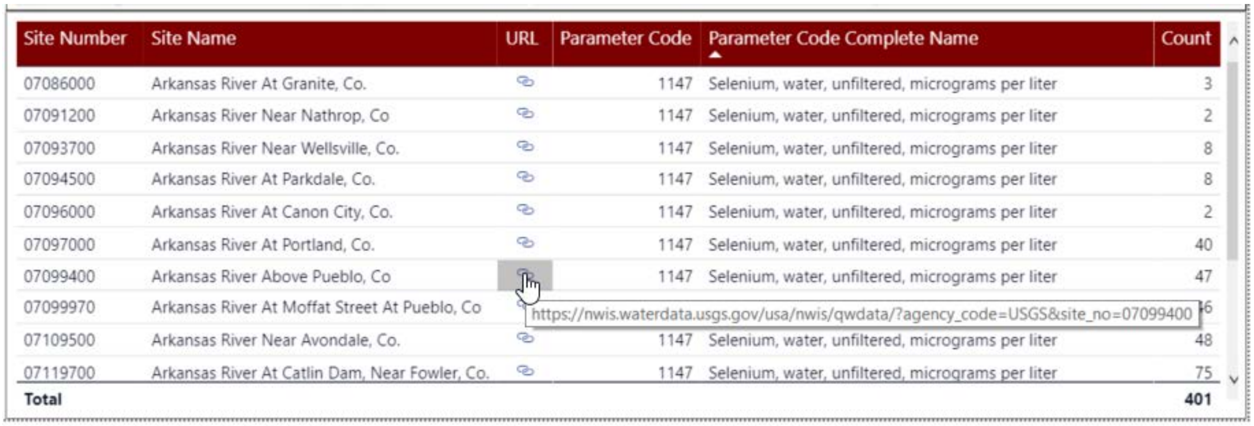


EXAMPLE OF HOVERING AND CLICKING

Tables within the dashboard are used to provide additional information, and can contain links to external data sources used to generate the visualizations.



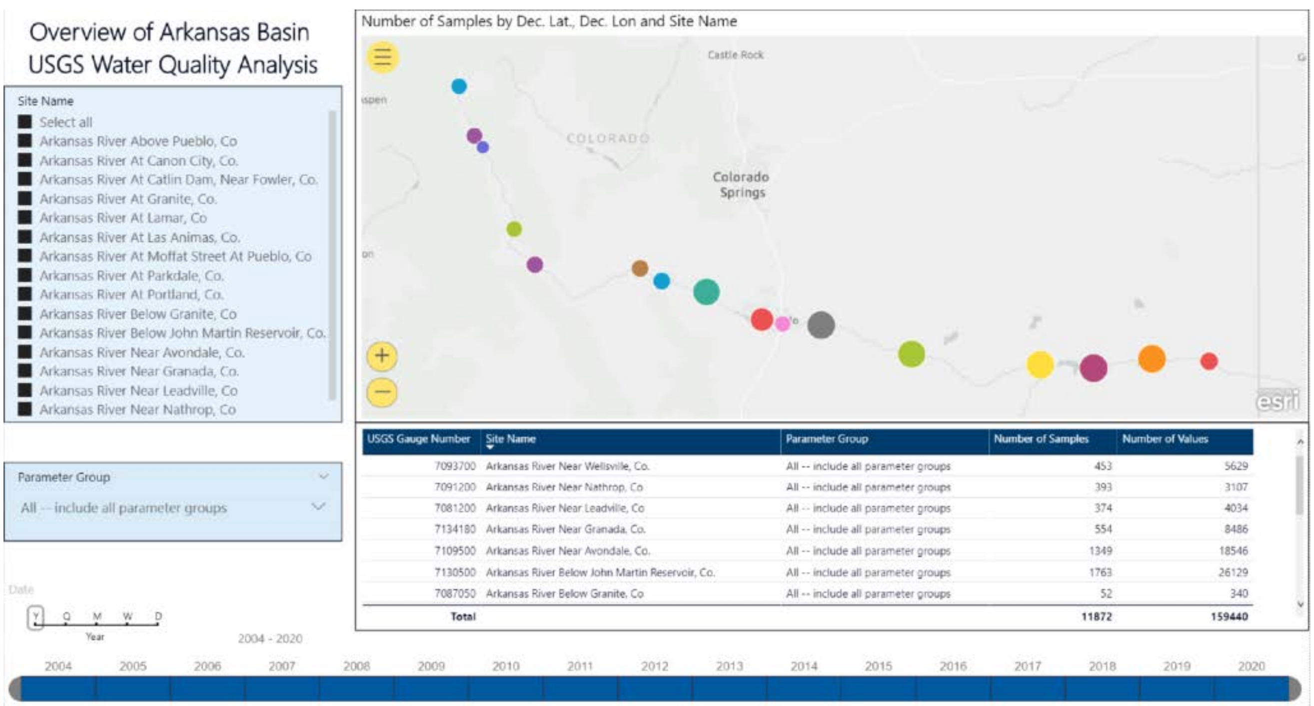
EXAMPLE OF PARAMETER SEARCH. LINKS IN THE LOWER TABLE WILL TAKE THE USER TO THE SITE OF DETAILED INFORMATION.



Site Number	Site Name	URL	Parameter Code	Parameter Code Complete Name	Count
07086000	Arkansas River At Granite, Co.		1147	Selenium, water, unfiltered, micrograms per liter	3
07091200	Arkansas River Near Nathrop, Co		1147	Selenium, water, unfiltered, micrograms per liter	2
07093700	Arkansas River Near Wellsville, Co.		1147	Selenium, water, unfiltered, micrograms per liter	8
07094500	Arkansas River At Parkdale, Co.		1147	Selenium, water, unfiltered, micrograms per liter	8
07096000	Arkansas River At Canon City, Co.		1147	Selenium, water, unfiltered, micrograms per liter	2
07097000	Arkansas River At Portland, Co.		1147	Selenium, water, unfiltered, micrograms per liter	40
07099400	Arkansas River Above Pueblo, Co		1147	Selenium, water, unfiltered, micrograms per liter	47
07099970	Arkansas River At Moffat Street At Pueblo, Co	https://nwis.waterdata.usgs.gov/usa/nwis/qwdata/?agency_code=USGS&site_no=07099400			[illegible]
07109500	Arkansas River Near Avondale, Co.		1147	Selenium, water, unfiltered, micrograms per liter	48
07119700	Arkansas River At Catlin Dam, Near Fowler, Co.		1147	Selenium, water, unfiltered, micrograms per liter	75
Total					401

EXAMPLE OF A LINK IN A TABLE—THIS ONE TAKES THE USERS TO THE DATA SOURCE.

The time function at the bottom of the slide allows users to select specific time periods for data review.



USGS Gauge Number	Site Name	Parameter Group	Number of Samples	Number of Values
7093700	Arkansas River Near Wellsville, Co.	All -- include all parameter groups	453	5629
7091200	Arkansas River Near Nathrop, Co	All -- include all parameter groups	393	3107
7081200	Arkansas River Near Leadville, Co	All -- include all parameter groups	374	4034
7134180	Arkansas River Near Granada, Co.	All -- include all parameter groups	554	8486
7109500	Arkansas River Near Avondale, Co.	All -- include all parameter groups	1349	18546
7130500	Arkansas River Below John Martin Reservoir, Co.	All -- include all parameter groups	1763	26129
7087050	Arkansas River Below Granite, Co	All -- include all parameter groups	52	340
Total			11872	159440

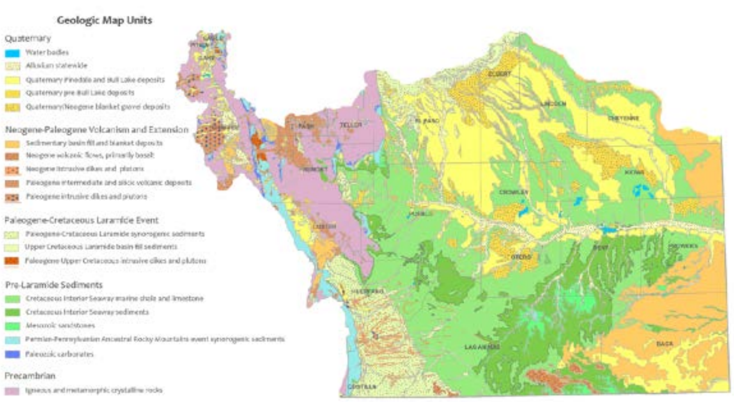
EXAMPLE OF ARKANSAS RIVER OVERVIEW WITH THE TIME BAR ACTIVATED.

Selenium & Uranium

Although there are a number of water quality concerns for the lower basin, Selenium and Uranium were the two constituents of greatest interest to the WQWG. Best management practices that are designed to address these two concerns will ultimately have a positive impact on other parameters of concern, such as nutrients or coliform bacteria.

SE is an essential trace element, and a critical dietary micronutrient for humans and other animals, but at higher levels it becomes toxic. It is derived from selenium-bearing rocks, but weathering of rock releases selenium. In much of the arid West, shale and sandstone deposits from Cretaceous-era marine environments are rich in selenium. Rainfall, wind, and freeze-thaw cycles cause weathering of these surfaces when exposed, releasing selenium, and groundwater or surface water interactions with these formations can dissolve additional selenium from the formations.[3]

U, which is found in most rocks in small concentrations, is a silver-grey heavy metal with weak radioactive characteristics. It is found in higher concentrations in certain granites, and pegmatite (a combination of quarts, feldspar, and mica), which are common minerals in much of the basin. It is also found in in lower concentrations, but is more easily mobilized, in shales, which are common in the lower basin.



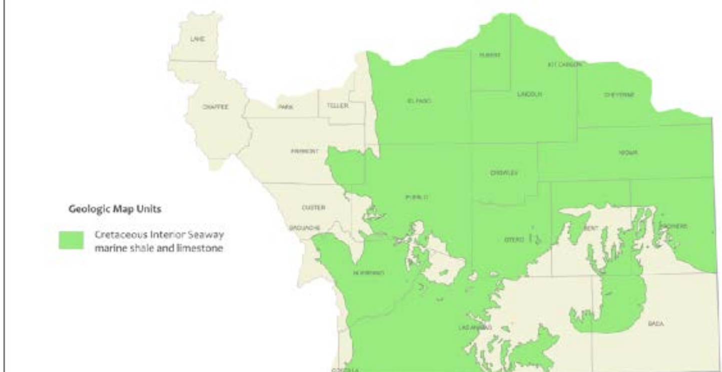
Map 1. Generalized geologic map of the Arkansas River Basin in Colorado, by event. Geology modified from Tweto (1979) and Green (1992). Colorado Geological Survey ON-010 Colorado Groundwater Atlas. Map by Andy Lerch, ARWC 2021.

Geologic setting

The Arkansas Basin within Colorado spans a broad geologic timeframe. The western mountains are dominated by igneous and metamorphic rock (in pink) that date back to precambrian times (~550 million years ago) and that later uplifted during the Laramide orogeny, a mountain building period in the late Cretaceous period, 70-80 million years ago (MA). Uplift and deformation continued into the

[3] https://pubs.usgs.gov/pp/1802/q/pp1802q.pdf

Tertiary (65-1.8 MA) and Quaternary (1.8MA to current) with development of the Rio Grande Rift which produced the Upper Arkansas Valley. Once you leave the high-elevation areas formed by volcanic activity and uplift, and move into the Lower Arkansas Basin the landscape is dominated by Upper Cretaceous marine shales and limestone, deposited in the ancient Western Interior Seaway that flooded the region from an estimated 100 to 76 MA.



Map 3. Cretaceous Interior Seaway marine shale & limestone deposits of the Arkansas River Basin, Colorado. Geology modified from Tweto (1979) and Green (1992). Colorado Geological Survey ON-010 Colorado Groundwater Atlas. Map by Andy Lerch, ARWC 2021.

Shale is a fine-grained sedimentary rock that is formed primarily by the compression of muds, often rich in organic material, that accumulated in the seaway away from the shoreline in generally anoxic conditions. The limestone deposits are made up of calcium carbonate that is often micro-organisms or fragments of larger shelled organisms. After the seaway retreated regional uplift and erosion exposed these marine sediments at the surface. For the most part, these marine shale and limestone formations are covered with a thin layer of surficial deposits of alluvium, slopewash and colluvium, and eolian sand and silt (loess) soils, but in some areas, shale and limestone bedrock is exposed or within a few feet of the surface, thus exposed to shallow groundwater.[4]

Map 2. Alluvial deposits of the Arkansas River Basin, Colorado. Geology modified from Tweto (1979) and Green (1992). Colorado Geological Survey ON-010 Colorado Groundwater Atlas. Map by Andy Lerch, ARWC 2021.

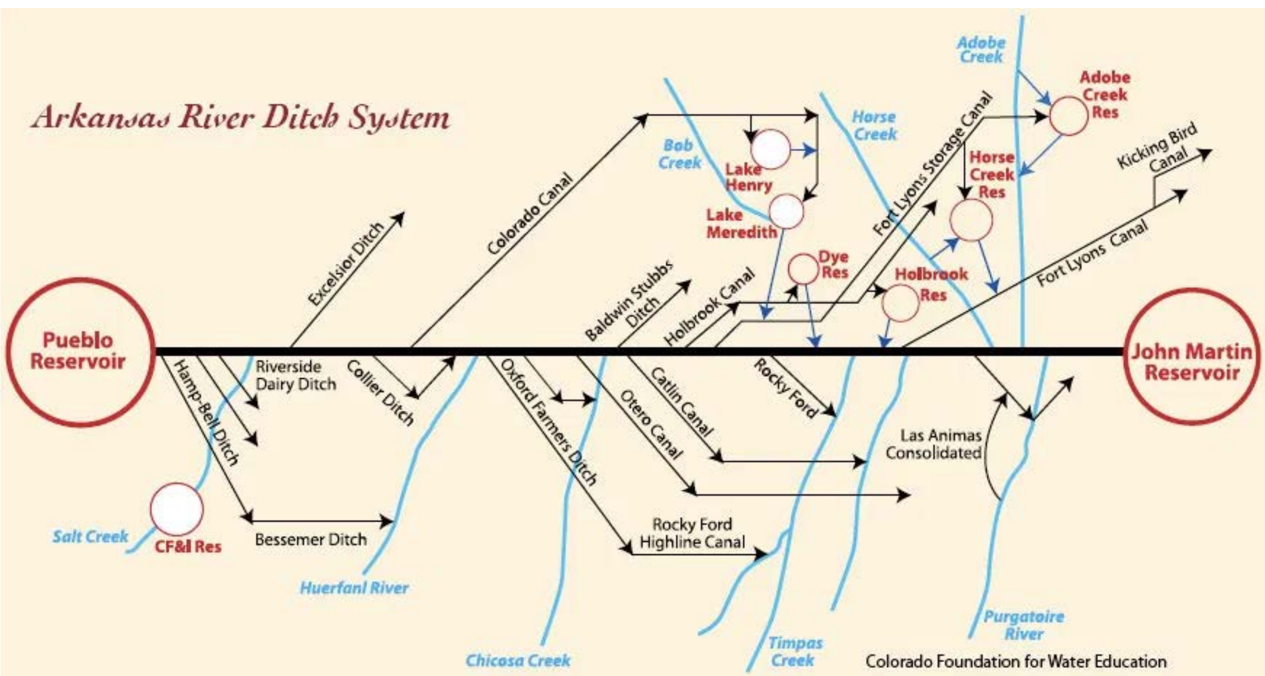
River and tributary valleys are characterized by Quaternary alluvial deposits of sediments that accumulated in the last 1.8 million years during cycles of glaciation in the upper reaches of the watershed. Gradual incision by the river systems during this time accompanied by cycles of glacial advance and retreat led to a series of terrace deposits along the riverways that are older and higher in the uplands of the landscape, and younger closer to the modern river level.. These deposits tend toward loose, and unconsolidated sand, gravel,

[4] Draft: “Natural Sources of Mobile Uranium in the Downstream Reach of Colorado’s Arkansas River Valley and Evaluation of Best Management Practices for Mitigation” Colorado Geological Survey, 2020.

clay, and some larger rock. On the plains, depths of alluvium can reach up to 50 feet, but most are thinner. These deposits tend to downcut during flooding events, and in many areas, that downcutting leaves floodplains disconnected from their associated channels, and cause channel instability that results in increased bank erosion. This downcutting results in terraced lands in the tributaries, which are frequently fragmented due to incision in the tributaries.

Land and Water Use

Land and water use on the plains of southeastern Colorado, overlying the shale bedrock, is dominated by agriculture. Uplands are characterized by pasturage for livestock and dryland farming, while areas nearer the mainstem of the Arkansas River are utilized for irrigated agriculture for fruit and vegetable crops, and alfalfa and grasses for livestock forage. Historically, the overwhelming majority of irrigated ag lands in the Arkansas basin were served exclusively by surface water, delivered through canals and ditches. The majority of the ditches and canals that serve the basin are old, dating back to the late 19th century.



Although the majority of irrigation water has come from surface water sources, groundwater (from shallow alluvium or deep-wells into the Ogallala aquifer) is also utilized, and in recent years, more irrigators are installing sprinklers, which may serve as a Best Management Practice to reduce water quality impacts.

Approximately 87% of the the water consumed in the basin supports agriculture, municipalities, including the Cities of Pueblo and Colorado Springs, and smaller towns, such as Rocky Ford and

Lamar, are critical for the economic vitality of the basin, which has a population of a little over one million people.[5]

Natural water supplies in the basin are limited, so supplies are supplemented by trans-mountain diversions from the West Slope, particularly the Fry-Ark Project, which delivers about 69,000 acre-feet of water per year on average, but has delivered as much as 98,000 acre feet in high water years.[6] A constraining factor on water supplies in the basin is the Compact with Kansas. Originally signed in 1948, the Compact is designed to apportion water between Colorado and Kansas, and requires Colorado to deliver 40% of the river's flow to Kansas.[7]

Source, transport, and fate

All indications from existing research, studies, and monitoring, support the assumption that the Se and U in waters of the Arkansas and its tributaries originate from geologic sources. Weathering processes of exposed shale, and oxidation and mobilization of soluble salts that have accumulated in shallow aquifers, provide the source and supply.

Irrigation, and groundwater/surface water interaction, drive the delivery of Se and U to the river and its tributaries. As these constituents mobilize, they continue to transport down gradient. Once mobilized into the river, these constituents can be recycled back onto the land, in a cyclical fishing, through irrigation, and bioaccumulate in fish, crops, and wildlife.

John Martin Reservoir currently acts as a sink, with a significant reduction in concentrations immediately below the reservoir.

Se and U are bioaccumulating in fish and in crops in southeastern Colorado and southwestern Kansas.[8]

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5 https://www.arkansasbasin.com/ark-basin-details.html

6 https://www.usbr.gov/projects/index.php?id=460

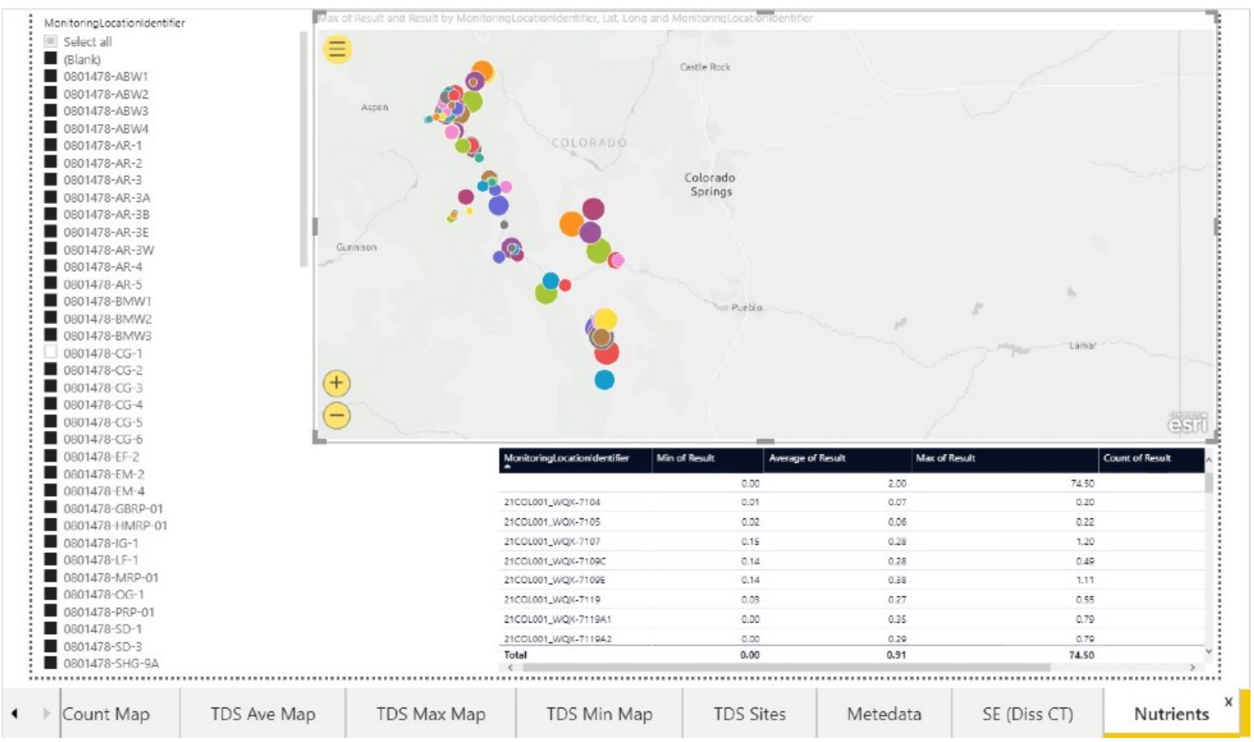
7 https://www.co-ks-arkansasrivercompactadmin.org

8 https://link.springer.com/article/10.1007/BF02393871
https://www.usgs.gov/news/mercury-and-selenium-are-accumulating-colorado-river-food-web-grand-canyon
http://www.kgs.ku.edu/Hydro/Publications/2017/OFR17_2/index.html

Nutrients

Selenium and uranium were primary drivers of the WQWG coming together, but there are other contaminants of concern in the lower Arkansas. Nutrients are expected to have a larger impact on management decisions, particularly for agricultural producers, as the State's "Regulation 85" comes into play. Currently, Reg 85 seeks voluntary action from the ag sector, but may add regulatory requirements to the sector if goals for nutrient reduction are not met.

As much as nutrients are an issue in their own right, nitrogen has a direct relationship to Se. According to a study by Tim Gates of Colorado State Univeristy, "The data also exhibited, among other relationships, a moderate to strong correlation between dissolved Se and total dissolved solids in groundwater and surface water, a strong correlation with uranium in groundwater, and power relationships with nitrate in groundwater. The relationship to nitrate, derived primarily from N fertilizers, reveals the degree to which dissolved Se depends on oxidation and inhibited reduction due to denitrification and suggests that there are prospects for reducing dissolved Se through nitrate control.[9]



[9] https://pubmed.ncbi.nlm.nih.gov/19875790/

Analysis: Monitoring and Research Needs

Concentrations and loading of Se and U in the waters of the Arkansas are controlled by four geophysical processes: release of Se from geologic materials, transpiration, evaporation, and immobilization. Proposed needs outlined below will help us better understand how and where these processes are at play, and will help to better identify and prioritize implementable projects to improve water quality.

Geology & Soils

We have almost no understanding of the hydrogeologic conditions of the limestone aquifers! The Fort Hayes and Greenhorn limestone aquifers underlie much of the region and we really don't know what the groundwater flow conditions are. Is groundwater discharging from the limestone aquifers into the alluvial aquifer- and mixing waters with different chemistry? What happens in the reactive mixing zones between shale and limestone?

Geologic mapping of the basin has primarily been done at large scale (1:250,000), but this scale is extremely rough for understanding how soils and water interact, and where different BMPs might best be applied to achieve water quality goals.

In the Gunnison Basin, the Natural Resources Conservation Service completed a selenium leaching mapping project that identified soils that were most likely to leach selenium. As with increased understanding of underlying geology, this type of product would assist in prioritizing areas for BMPs in the basin.

Deeper Permian formations are known to have beds of salt and gypsum. In Kansas it is recognized that these evaporitic deposits have been dissolved over geologic time causing localized collapse. The extent of such dissolution is not well understood or defined inthe lower Arkansas River basin in Colorado. It may have ramifications for geologic conditions and potential contribution of natural salinity to shallow groundwater.

RECOMMENDATIONS:

1. Study hydrogeology of limestone aquifers.
2. Continue quadrangle mapping to 1:24k scale in lower basin.
3. Study and map soil leaching characteristics of ag lands in the lower basin
4. Delineate areas of salt dissolution from deeper Permian formations.

Water Quality Monitoring Data Gaps

There is significant monitoring along the mainstem, but monitoring becomes scant to nonexistent in many of the tributaries (Fountain Creek being an exception to this). Monitoring has not always been done in a fashion that provides strong spacial and temporal data to be able to prioritized BMP implementation. Sampling that has occurred in tributaries has not always included flow data, and so loading can't be calculated.

John Martin Reservoir (JMR) appears to be a sink, and the reach of the river from Avondale to JMR appears to behave in a fashion as a sink due to irrigation management. This leads to some questions to be explored. For example, with regards to the JMR itself, does it act as a sink during seasonal inversions, or is there a flush of contamination carried to the surface and discharged from the reservoir during inversion processes? As for the reach between Avondale and JMR, the sink affect is due to the way river water is pulled and irrigated in this reach, but in wet years, when water is extremely abundant, this reach does return greater amounts of Se and U than in dryer periods. This is counterintuitive, but upon greater reflection it makes sense that high water periods allow fields that are not regularly irrigated to be irrigated, or fields that generally received limited water to receive abundant water, and thus flushes accumulated salts from more acres.

Arsenic and manganese are under-represented in sampling, and yet when samples have been analyzed for it they show levels that are high.

Healthy soils and riparian zones are known to reduce water quality impacts. Documenting the current state of soil and riparian health through GIS mapping will provide a baseline as BMP projects to improve these are implemented.

RECOMMENDATIONS:

1. Collect flow data concurrently with sampling to provide loading analysis.
2. Perform additional intensive monitoring in a strategic approach, reach-by-reach, and with several seasons of sufficient sampling to provide both detailed spatial and temporal analysis in order to better analyze trends.
3. Perform additional monitoring of tributaries, particularly those north of the river and east of Fountain Creek. Based on an initial scanning approach, intensify sampling on a reach-by-reach basis as needed.
4. When performing intensive reach sampling, concurrently sample accessible groundwater sources in its watershed of influence to correlate groundwater affect on the surface samples.
5. Increase nutrient monitoring, and include nutrients in the spatial/temporal reach-based analysis to better identify sources of nutrients.
6. Analyze for arsenic and manganese during sampling sessions.
7. Perform an analysis and map in GIS the current state of soil carbon (a soil health indicator, and riparian vegetation.

Appendix 1

Science Plan Water Quality Studies Literature Review

Note: There are additional, older reports that were left out of this report as they were superseded by reports listed below.

AGENCY RESOURCES

1. Bureau of Reclamation, Great Plains Region

   Fryingpan-Arkansas Project

   Annual Operating Plan 2018

   This report details the operations of the Fryingpan-Arkansas Project during the 2018 Water Year. The report summarizes hydrologic and weather conditions, water collection, diversions, exchanges and releases, storage levels, and water sales and deliveries. The Fryingpan-Arkansas project brings snowmelt from Colorado's western slope to the semi-arid Arkansas River Basin on the eastern slope, providing water for irrigation, municipal and industrial use, hydroelectric power generation, recreation and wildlife habitat, and flood control.

2. CDPHE Total Daily Maximum Load (TDML) Assessments - Arkansas Basin

   https://www.colorado.gov/pacific/cdphe/tmdl-arkansas-river-basin

   Section 303(d) of the federal Clean Water Act requires states to identify water bodies that are water quality impaired. Water quality impaired segments are those water bodies or stream segments that are not fully attaining one or more assigned use classifications or standards. Once listed, unless standards are attained through other mechanisms such as implementation activities, the original listing is shown to be in error or the standards have been changed, the state is required to quantify the amount of a specific pollutant that a listed water body can assimilate without exceeding applicable water quality standards. This maximum allowable pollutant quantity is referred to as the Total Maximum Daily Load ("TMDL").

3. Colorado State Geological Survey (CGS)

   IS-74 Lower Arkansas River Alluvial Aquifer: Geographic, Digital Bibliography

   https://coloradogeologicalsurvey.org/publications/lower-arkansas-river-alluvial-aquifer-bibliography/

   This series provides a digital, geo-referenced bibliography of studies and data related to the alluvial aquifer system of the Lower Arkansas River below the Pueblo Reservoir. It includes existing literature that assesses the configuration, hydrologic properties, water levels and water quality of the aquifer. It features a map with the associated study limits along the Lower Arkansas River that includes portions of its tributaries.

4. CGS

Surface Water Quality, Colorado's Upper Basins

https://coloradogeologicalsurvey.org/water/surface-water-quality/

This introduction to surface water quality in Colorado explains the process by which impaired water quality can occur due to seepage of dissolved rock components or other materials into the ground, including natural erosion processes, abandoned mine and waste rock piles, acid rock drainage, naturally occurring uranium in the groundwater zone, and salinity and selenium from natural deposits. The article cautions that geology and local water quality should be assessed prior to development.

5. CGS

ON-010 Colorado Groundwater Atlas

https://coloradogeologicalsurvey.org/water/colorado-groundwater-atlas/

To supplement statewide efforts to identify aquifers that are vulnerable to pollution and enable protection of these resources, this atlas offers a comprehensive online portal of existing geoscience that informs this protection effort.

6. CGS

OF-19-11 Sources of Mobile Uranium in the Downstream Reach of Colorado's Arkansas River Valley and Evaluation of Best Management Practices for Mitigation

The goal of this effort was to understand the underlying geology of the area and the distribution of naturally occurring U in the strata of the irrigated area in order to develop, simulate, and evaluate BMP alternatives using computational models of flow and reactive solute transport.

7. Colorado State University (CSU)

Irrigation Practices, Water Consumption and Return Flows in Colorado's Lower Arkansas Valley: Field and Model Investigations, T.K. Gates, et al., 2012

https://www.engr.colostate.edu/~tkg/Irrigation%20Practices%20Water%20Consum%20and%20Return%20Flows%20in%20Colorado's%20LARV%20FINAL%20June%202012.pdf

This document summarizes the methods, findings, and implications of an extensive irrigation monitoring study undertaken by Colorado State University during the 2004-2008 irrigation seasons in regions both up and downstream of the John Martin Reservoir. The purpose of the synthesis is to provide baseline data to inform decision-making for system improvements to address local water quality challenges and ensure compact compliance in the Lower Arkansas Basin.

8. CSU

Lower Arkansas River Watershed Plan: John Martin to State Line (Nine Element Plan)

Osborn, Blake. Colorado Water Institute, Colorado State University Extension

https://www.lowerarkplanjm.com/final-plan.html

This plan addresses impaired water quality in Colorado's Lower Arkansas River watershed and highlights the need to improve conditions to protect drinking water supplies, agricultural water quality, and ecosystems. The plan summarizes existing water quality data - including new research findings - and identifies future projects that hold the most potential for improving water quality in the watershed.

9. Colorado Water Conservation Board

Colorado Decision Support Systems

https://www.colorado.gov/cdss

This comprehensive online collection of tools and data is designed to assist in decision-making for diverse water-related issues across the state, with a unique system for each basin. The website provides access to online tools that connect to the state's water data repository and software tools for surface or groundwater modeling, processing data or estimating consumptive use. The site includes access to modeling data to support water supply and planning studies as well as GIS layers showing locations of streams, rivers, water diversion and irrigation infrastructure, climate stations and irrigated acreages. The site hosts link to projects reports and information, technical memoranda, meeting materials, basin information and publications.

10. Environmental Protection Agency (EPA)

Water Quality Assessment Report

https://iaspub.epa.gov/tmdl_waters10/attains_watershed.control?p_huc=11020001&p_cycle=&p_report_type=T

This online collection of tools and data contains searchable water quality information for waterbodies within the Arkansas River Basin. The database contains listed impaired waterbodies for 2016, associated contaminants and the Total Daily Maximum Load (TDML) documents that detail causes and factors for each waterbody as well as recommendations for remediation.

11. EPA

Water Quality Portal

https://www.waterqualitydata.us

The Water Quality Portal is an online database of water quality data collectively managed by the United States Geological Survey (USGS), Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC). It includes data submitted by over 400 federal, state, tribal and local agencies. The tool allows users to search more easily in one location for needed data stored elsewhere in various large water quality databases.

12. US Geological Survey (USGS)

    Scientific Investigations Report 2010-5069

    https://pubs.usgs.gov/sir/2010/5069/pdf/SIR10-5069.pdf

    This report summarizes and characterizes available dissolved selenium and uranium concentrations in groundwater and surface water for 1970–2009 and describes these loads in surface water along the mainstem Arkansas River and selected tributary and diversion sites from the headwaters near Leadville, Colorado, to the Arkansas River near Coolidge, Kansas stream gage, a drainage area of 25,410 square miles.

13. USGS

    Scientific Investigations Report 2012-5252

    https://pubs.usgs.gov/sir/2012/5252/SIR12-5252.pdf

    This report describes estimates of gains and losses from unmeasured sources and sinks for streamflow and dissolved-solids load in the Arkansas River along two main study reaches to help identify sub-reaches where gains or losses from unmeasured sources and sinks could have a pronounced effect on river water quality.

14. USGS

    Scientific Investigations Report 2012-5234

    https://pubs.usgs.gov/sir/2012/5234/SIR12-5234.pdf

    This report describes the characteristics of streamflow, water quality, and dissolved solids, selenium, and uranium loads in select reaches of the Arkansas River Basin in southeastern Colorado. The study identifies critical reaches where stream-aquifer interactions may have a significant effect on water quality (or where point-source discharges are a significant load to the stream), and pinpoints potential load source areas for selected sections within the study reaches.

15. USGS

    Scientific Investigations Report 2016-5134

    https://pubs.usgs.gov/sir/2016/5134/sir20165134.pdf

    This report presents the methods of investigation and study results to characterize groundwater and surface-water interaction, water quality, and processes affecting loads of dissolved solids, selenium, and uranium to Fountain Creek near Pueblo, Colorado for the period from August 2012 to January 2014.

16. USGS

Scientific Investigations Report 2005-5179

https://www.uawcd.com/uploads/2/5/5/3/25530864/quality_of_ground_water_in_the_upper_arkansas_river_basin.pdf

This study describes the results of a groundwater quality study completed in the Upper Arkansas River Basin between Buena Vista and Salida during September and October 2001. Data was used from 39 water-supply wells to characterize the general physical properties and chemical characteristics of ground water in the study area. The data is available at http://waterdata.usgs.gov/nwis/qw/ or http://co.water.usgs.gov/.

17. USGS

Scientific Investigations Report 2014-5095

https://www.uawcd.com/uploads/2/5/5/3/25530864/groundwater_and_surface-water_interaction_and_potential_for_underground_water_storage_2011.pdf

This report describes results from a study of groundwater and surface-water interaction and potential for underground water storage including identification of gaining and losing segments of selected tributaries, water budgets for selected areas for 2011, results from hydraulic testing of the alluvial-outwash and basin-fill aquifers, identification of areas with hydrologic characteristics suitable for development of underground water-storage projects, and estimates of stream accretion response time factors for the alluvial-outwash aquifer.

18. USGS

https://www.usgs.gov/centers/co-water/terms-used-within-identifying-changes-background-water-quality-conditions-arkansas?qt-science_support_page_related_con=0#qt-science_support_page_related_con

This online database allows users to understand changes in background water quality conditions using dissolved solids concentrations and loads as indicators at selected sites in the Arkansas River and Fountain Creek near Pueblo, Colorado. Daily dissolved-solids concentrations were estimated from daily specific-conductance values. This informational page also explains terminology and background concepts used in the Colorado Water Science Center online tool.

19. USGS

https://co.water.usgs.gov/infodata/ark_summaries/index.html

This online comparison tool summarizes water quality data collected during water years 1990-2017 for a collection of sites in the Arkansas River Basin of Colorado. Data from 2016-2017 for each site are compared to previously collected data and state instream standards.

20. USGS

https://www.usgs.gov/centers/co-water/science/paleoflood-investigations-improve-flood-frequency-estimates-eastern?qt-science_center_objects=0#qt-science_center_objects

This study utilized historical stream gage records to develop peak-flow equation models to improve reliability of flood prediction for Eastern Colorado, to help bridge the gap in information caused by large areas with no gages in this region. This information is critical for the proper design of stream-related infrastructure, such as bridges and dams, and floodplain inundation maps

21. USGS

https://www.usgs.gov/centers/co-water/science/fountain-creek-watershed-flood-and-sediment-transport-study?qt-science_center_objects=0#qt-science_center_objects

To address concerns of periodic large streamflows, sediment transport and associated flooding in Fountain Creek, this study utilized hydrologic modeling to assess 14 remediation scenarios proposed to reduce sediment loading and attenuate peak streamflows in the creek.

22. USGS

https://www.usgs.gov/centers/co-water/science/identifying-changes-background-water-quality-conditions-arkansas-river-and?qt-science_center_objects=0#qt-science_center_objects

This report describes methods that have been developed to identify changes in existing water quality conditions using dissolved solids concentrations and dissolved solids loads as indicators at selected sites in the Arkansas River and Fountain Creek near Pueblo, Colorado. The purpose of the new methodology is to help determine whether future water quality conditions have changed significantly from preexisting water quality conditions because of changes in water operations.

23. USGS
https://www.usgs.gov/centers/co-water/science/development-a-fecal-contamination-monitoring-and-control-strategy-upper?qt-science_center_objects=0#qt-science_center_objects

This study identifies major sources of *Escherichia coli* in the upper reaches of Fountain Creek during exceedances of the state recreational water standard. A new approach was developed and tested that uses genetic marker analyses for microbial source tracking to evaluate potential contributions of fecal contamination from various sources.

24. USGS

https://www.usgs.gov/centers/co-water/science/upper-arkansas-toxic-substances-hydrology?qt-science_center_objects=0#qt-science_center_objects

This long-term monitoring project tracks metal transport in streams affected by mining in the Upper Arkansas River Basin. The study characterizes the instream chemical processes that affect transport and transformation of metals downstream from mine drainage and evaluates the effectiveness of remediation efforts.

25. USGS

https://www.usgs.gov/centers/co-water/science/comprehensive-water-quality-study-arkansas-river-basin-colorado?qt-science_center_objects=0#qt-science_center_objects

This study builds a framework for a basin-wide decision support system model in the Arkansas River Basin by summarizing existing water quality data and identifying priority water quality issues, gaps in existing data, and data and analytical tools needed to address urgent water quality issues.

26. USGS

https://pubs.er.usgs.gov/publication/70188789

Cretaceous sedimentary rocks in the western US pose challenges to water quality, often through mobilization of salts and trace metals by irrigation. However, in the Arkansas River Basin of Colorado, patchy exposure of multiple Cretaceous formations has made it difficult to identify which formations are most problematic. This paper examines water quality in surface-water inflows along a 26-km reach of the Arkansas River relative to the presence or absence of the Cretaceous Niobrara Formation within the watershed.

OTHER RESOURCES

27. Achieving a Sustainable Irrigated Agroecosystem in the Arkansas River Basin: A Historical Perspective and Overview of Salinity, Salinity Control Principles, Practices and Strategies, Proceedings, Central Plains Irrigation Association.

Sutherland, P.L. 2008. 2008-102-138.

This review explores the complex problem of salinity, or dissolved mineral salts, in the water and soils of parts of the Arkansas River Basin. The author discusses the nature of the problem of salinity, the relationship of the problem to historical and contemporary agricultural practices, and offers alternative practices for controlling salinity.

28. Applicability of models to alluvial valleys: Arkansas River Valley, Colorado, USA

Case history no. 1

Leonard F. Konikow and John D. Bredehoeft

To determine how flow and salinity changes occur in an irrigated river system, an 18 kilometer reach of the Arkansas River valley was selected for development of a hydrologic simulation. The study simulates a 1-year period of record (March 1971 through February 1972) which includes one complete irrigation season. During this time, a network of 4 surface water stations and 63 observation wells was maintained to determine all inflows, outflows, and changes in aquifer storage of both water and dissolved solids within the study area. These observed data were used as a basis for calibrating the simulation model, which is used to improve irrigation practices to reduce salinity.

29. Assessment of Fort Lyon Water Rights and Water Quality

Tipton and Kalmbach, Inc., Consulting Engineers, Denver, Colorado, February 1987

This report assesses Fort Lyon Canal Company (FORT-CO) water rights, including historic and consumptive uses, and assesses the quality of water available under these water rights. The investigation covers water years 1951-1985 and was prepared for FORT-CO, an organization of majority stockholders with the Fort Lyon Canal Company at the time. The assessment was intended to provide information needed to assist FORT-CO in its decision to potentially convert water to municipal uses.

30. Salt Flushing, Salt Storage, and Controls on Selenium and Uranium: A 31-Year Mass-Balance Analysis of an Irrigated, Semiarid Valley

Carleton R. Bern , Michael J. Holmberg , and Zachary D. Kisfalusi, Journal of American Water Resources Association, August, 2020

This study used 31 years of continuous discharge and specific conductances monitoring data to assess inter annual patterns of water quality using mass balance on a 120-km reach of the river.

31. Transit losses and travel times of reservoir releases along the Arkansas River from Pueblo Reservoir to John Martin Reservoir, January 2011

Livingston Professional Services, LLC/Hydrologic Sciences

This report describes a 12-year hydrologic investigation of the transit losses and travel times associated with reservoir releases to the Arkansas River that are made from the Pueblo Reservoir for delivery to water users in Colorado and Kansas.

Appendix 2
Lower Arkansas Valley Water Conservancy District, Arkansas Basin Implementation Guide