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Spatial Analysis of Fluoride and Arsenic Patterns in Colorado Waters

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1.0 Introduction

1.1 Problem Definition

Fluoride and arsenic are naturally occurring anions that can commonly be found together in natural water bodies that serve as source waters for community drinking water treatment plants across the US. They are also both considered to be inorganic contaminants. Because of their potential impacts on human health, the EPA has set maximum contaminant levels (MCLs) for fluoride and arsenic as 4 mg/L and 10 μg/L, respectively. While the toxic effects of arsenic are widely recognized, communities have been adding fluoride to their drinking water since the 1940's for dental health benefits.[1,2,3] At low levels, between 0.5 – 1.5 mg/L, fluoride can slow down the acidic weathering of tooth enamel to help prevent the development of dental caries and cavities. The EPA established the fluoride MCL of 4 mg/L as a precaution for potential health impacts. Over time, more information about the effects of long-term fluoride exposure led the EPA to set a secondary MCL of 2 mg/L to protect against any potential negative health or aesthetic impacts.[3] In 2003 the EPA reviewed the fluoride standard and found that many studies had provided new health and exposure data for fluoride. Based on their review of this data, the National Research Council (NRC) and the National Academies of Science (NAS) recommended EPA update its risk assessment for fluoride as well as its public health goal to protect against teeth pitting and bone fractures in addition to stage III skeletal fluorosis.[3]

Due to the influx of new knowledge surrounding fluoride exposure, the EPA is considering lowering the MCL for fluoride from 4 mg/L to a concentration anywhere between 0.5 – 2 mg/L; the World Health Organization (WHO) already recommends a limit of 1.5 mg/L.[4] Meeting a lower standard could be very challenging for drinking water facilities that already struggle to meet the current MCL, and it may be a novel problem for many other facilities. Arsenic is commonly discussed alongside fluoride with regards to water treatment because both species are found in geologic deposits throughout the earth's crust; arsenic and fluoride can frequently occur together so there is a potential link in contamination. Additionally, little is understood about the mechanistic interactions between the two during removal processes or in the body when ingested.[5] In order to prepare for future regulatory changes and protect the public against contamination, it is necessary to identify regions and water systems at high risk.

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[1] Ripa, L. (1993). A Half-century of Community Water Fluoridation in the United States: Review and Commentary. *Journal of Public Health Dentistry, 53*(1), 17-44.,

[2] The Story of Fluoridation. (2014, February 26). Retrieved December 4, 2015, from http://www.nidcr.nih.gov/oralhealth/Topics/Fluoride/TheStoryofFluoridation.htm

[3] Questions and Answers on Fluoride. (n.d.). Retrieved December 1, 2015, from http://www2.epa.gov/sites/production/files/2015-10/documents/2011_fluoride_questionsanswers.pdf

[4] Fawell, J., Bailey, K., Chilton, J., Dahi, E., Fewtrell, L., & Magara, Y. (2006). Fluoride in Drinking-water. Retrieved December 3, 2015, from http://www.who.int/water_sanitation_health/publications/fluoride_drinking_water_full.pdf?ua=1

[5] Chouhan, S., & Flora, S. (2010). Arsenic and Fluoride: Two Major Ground Water Pollutants. *Indian Journal of Experimental Biology, 48*, 666-678. http://www.ncbi.nlm.nih.gov/pubmed/20929051

1.2 Problem Area of Interest

This study focuses on public water systems in Colorado. Colorado has a long history with fluoride contamination; dental fluorosis was first discovered in 1901 in Colorado Springs by a recent dental school graduate Dr. Frederick McKay. Dr. McKay noticed the prevalence of black, mottled teeth among the town's residents, and coined the term 'Colorado Brown Stain,' which is what we know of as dental fluorosis. McKay's research helped form the distinction between beneficial and detrimental levels of fluoride, and ultimately led to Grand Rapids, MI becoming the first city to fluoridate their waters in 1945.[6,7] Given the history, it is likely there are still elevated levels of fluoride throughout the state, which could indicate the presence of arsenic as well. Colorado was chosen as the study area because of its high potential for fluoride and arsenic contamination.

Within Colorado, there are 870 community water systems, 952 transient non-community water systems, and 161 non-transient non-community water systems. This study focuses on community water systems. The 870 systems serve 63 counties and define six different water sources; groundwater, surface water, purchased groundwater, purchased surface water, groundwater under influence of surface water, and purchased groundwater under influence of surface water. Figure 1 depicts the distribution of these sources among Colorado water systems.

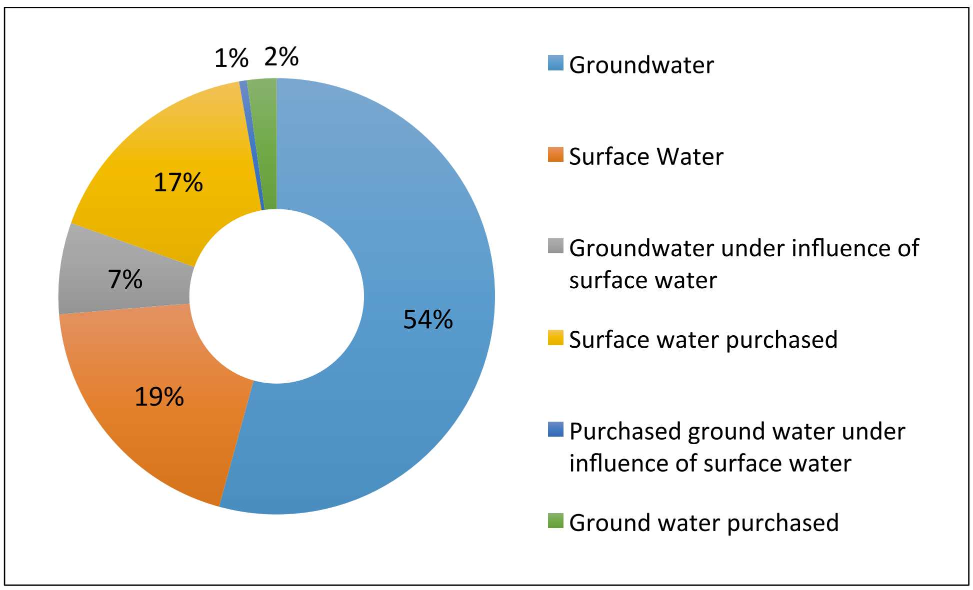

Figure 1: Distribution of Water Sources in Community Water Systems

Fluoride and arsenic are commonly found in groundwater, but there are cases of elevated fluoride in surface waters. Surface waters are also more likely to contain particles and complex constituents such as natural organic matter (NOM), a disinfection by-product precursor, which requires methods such as enhanced alum coagulation to remove. Inorganic contaminants like fluoride and arsenic can potentially inhibit the coagulation process and their interactions with

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[6] The Story of Fluoridation. (2014, February 26). Retrieved December 4, 2015, from http://www.nidcr.nih.gov/oralhealth/Topics/Fluoride/TheStoryofFluoridation.htm

[7] Ripa, L. (1993). A Half-century of Community Water Fluoridation in the United States: Review and Commentary. *Journal of Public Health Dentistry, 53*(1), 17-44.

NOM are not well characterized. Lower removal of NOM could lead to higher concentrations of DBP's at the tap and pose a public health risk. Additionally, a total of 8% of water systems use groundwater under the influence of surface water, meaning that there is a hydrologic connection between the aquifer and surface water. This places the groundwater at risk for contamination usually specific to surface water and adds complexity to the treatment process.[8] Because of these unique treatment concerns associated with fluoride and arsenic, and because they serve over a third of Colorado's public water systems, surface waters should also be considered.

Regions of fluoride and arsenic contamination need to be identified so water systems can be aware of their risk and pursue new treatment strategies if necessary, and so private well users can be aware of their personal risks and take precautions as well.

1.3 Problem Goal

The goal of this study is threefold; to identify areas at high risk for fluoride and arsenic contamination, to investigate the trends surrounding individual and joint contamination, and to isolate potentially impacted water systems. Fluoride and arsenic are naturally occurring inorganic contaminants that can be found in water sources throughout the globe. In the United States, fluoride and arsenic can be found in many communities within Colorado. This study aims to elucidate the perceived relationship between arsenic and fluoride and to incorporate demographics to determine which communities are most likely to be impacted. This study will be useful to local communities and large systems alike that are invested in water quality monitoring, and it will serve to prepare municipalities that already struggle with fluoride should the EPA lower its MCL in the future.

[8] Groundwater Under the Direct Influence of Surface Water. (n.d.). Retrieved December 4, 2015, from https://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/SourceWater/Pages/gwudi.aspx

2.0 Methods

2.1 Data Acquisition

This project required geographic, hydrologic, and demographic datasets. The specific datasets used are outlined in the following sections.

2.1.1 Elevation

A shapefile of states in the US was obtained from GIS online. The Split tool was used to isolate a shapefile for Colorado specifically. Geographic elevation data was obtained from the NED30 layer found within the GIS server http://elevation.arcgis.com/arcgis. The digital elevation model (DEM) for Colorado was obtained using the Extract (By Mask) tool with NED30 as the input raster and the Colorado shapefile as the mask.

2.1.2 Hydrology

Bedrock and Alluvial aquifer data was obtained online from Colorado's Decision Support Systems (CDSS). CDSS is a water management system developed for Colorado's major water basins by both the Colorado Water Conservation Board (CWCB) and the Colorado Division of Water Resources (CDWR). Zipped shapefiles were obtained for bedrock and alluvial aquifers throughout the state. These were added to the map and displayed as separate layers. Additional flowlines were obtained from the NHDplusv2 within the Gis server http://landscape1.arcgis.com/arcgis. These were added to the map and utilized for the study of smaller geographic areas of interest.

2.1.3 STORET

Water quality data for both fluoride and arsenic were obtained through the EPA STORET database. STORET, short for storage and retrieval, is an online data warehouse for water quality, biological, and physical data. It is used by the EPA, state and federal environmental agencies, universities, and private citizens. To retrieve information, users must select from various parameters and submit a request through the STORET interface.

Figure 2: STORET Warehouse Interface

Separate reports were requested for fluoride and arsenic, but the same request parameters were used. The applicable parameters are summarized in table 1. Government data was selected for consistency and reliability. Multiple different types of sample station types were selected to provide a broad range of results for interpretation.

Table 1: STORET Data Warehouse Parameters

Criteria	Selection
State	Colorado
Organization	Federal/US Government
	State/US Government
	Local/US Government
Station Type	River/Stream
	Lake
	Well
	Ocean
	Estuary
	Spring
	Reservoir
	Other - Groundwater
	Other - Surface Water
	River/Stream Ephemeral
	River/Stream Intermittent
	River/Stream Perennial
Date Range	Jan 2000 - Nov 2015
Activity Medium	Water
Species	Fluoride/Arsenic

Each data request through the STORET database returns two datasets, one including station location information and one containing sample location and measurement result information. The two datasets were added as tables and joined in ArcMAP to connect station geographic locations with their respective contaminant measurements. Latitude and longitude data were provided in the datasets, and the joined results were added as xy-data to arcMAP choosing the NAD1983 (2011) datum as the geographic coordinate system because it was the reference datum listed in the datasets. Results were mapped with graduated color schemes to illustrate measurement differences. The Station Types of the returned results were limited to river/stream, reservoir, or lake, or well.

2.1.4 Population

Population data for the state of Colorado was obtained from the CDPHE Colorado Socio-Demographics WebMap available on arcGIS online. The map was produced by the Colorado Department of Public Health and Environment (CDPHE) using socio-demographic estimates from the 2009-2013 American Community Survey and the 2010 US Census. Included in the map are county boundaries, population density, poverty, income, education, health insurance coverage, unemployment, percent Hispanic, percent African American, and percent minority. Results were displayed in a graduated color scheme in all categories. Any further population information desired for select counties was obtained from the US census bureau.

2.1.5 Public Water Systems

Information on public water systems was obtained from the CDPHE Source Water Assessment and Protection (SWAP) assessment phase website. Water reports for public water systems within each county are readily available. For each system, the number of water sources and various contamination profiles are reported.

3.0 Results

3.1 Elevation

A digital elevation model for Colorado was obtained using the Extract (by Mask) tool with the NED30 input raster and a Colorado state shapefile. The resolution was increased by selecting to display statistics from current extent in the symbology tab under layer properties. The elevation ranged from approximately 1000 to 4400 meters; identified mountain ranges can be found in figure 3 for reference. Fluoride and arsenic data were obtained from the STORET database, and location data were matched with corresponding measurement data. Figures 4 and 6 show the location and concentration range of fluoride and arsenic stations, respectively. Upper limits for concentration ranges were chosen based off of the current MCLs and the highest recorded measurement. Every measurement was left in the dataset even if they seemed abnormally high. This is because, for both arsenic and fluoride, there were other measurements in the same range and because these measurements could still be useful in identifying trends and potential problem areas

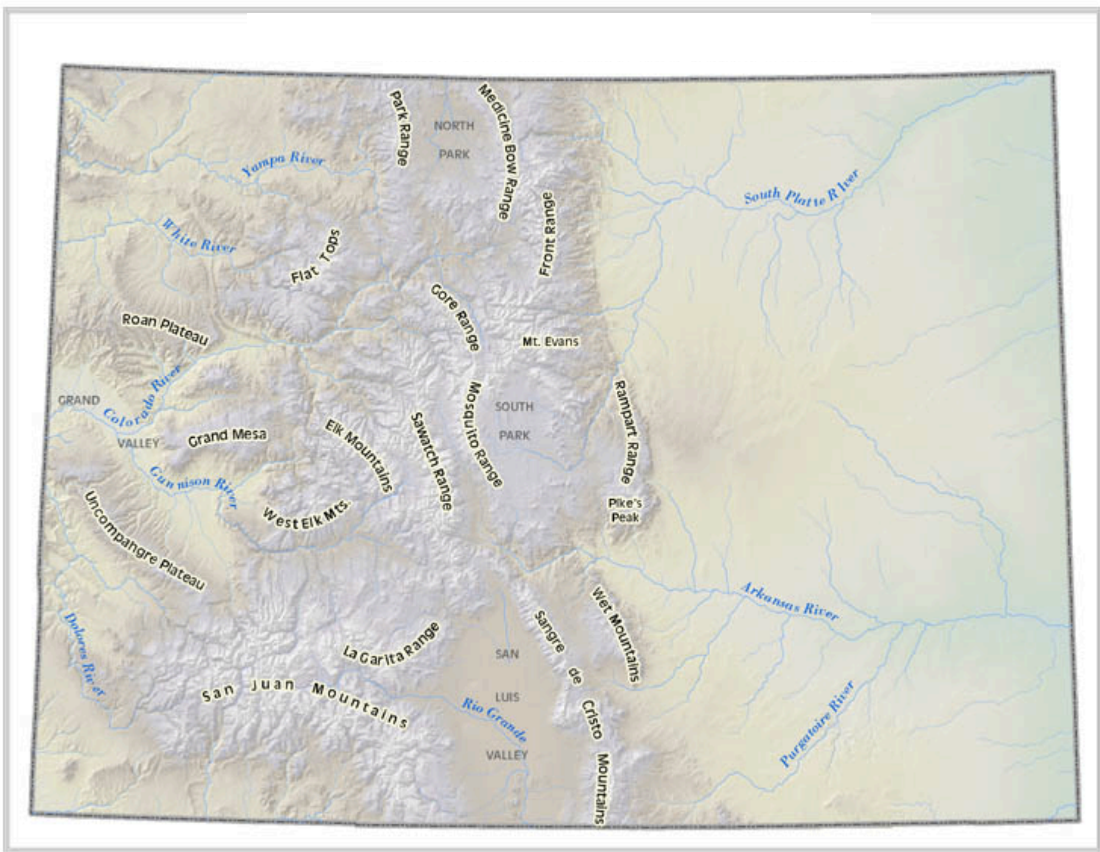

Figure 3: Colorado Mountain Ranges *obtained from http://shelledy.mesa.k12.co.us/staff/computerlab/ColoradoLifeZones_Maps.htm*

3.1.1 Fluoride and Elevation

Fluoride data was displayed as xy-data from the joined tables reflecting station location and measurement. Overall, the recorded fluoride measurements were predominantly under 1 mg/L. However, there were a few instances of elevated fluoride. The highest recorded fluoride concentrations (>4mg/L) all occurred in the center of the state, with moderately high measurements (1 - 2 mg/L) southwest and northeast. These values, while below the current MCL, are still important to consider as they may exceed a lower MCL of between 1 – 2 mg/L. No measurements were recorded between 2 and 3 mg/L. Figure 4 shows the geographic distribution of fluoride data.

The highest instances of fluoride in the center of the state also fall in regions of high elevation. Comparing with Colorado geography, this is because the stations are located within the Rocky Mountains along the north of the Sawatch Range. Some slightly elevated, between 1 – 2 mg/L, measurements occur in the more southern San Juan Mountains, but they also occur further east at lower elevations in the Great Plains. Figure 5 shows fluoride concentrations with elevation.

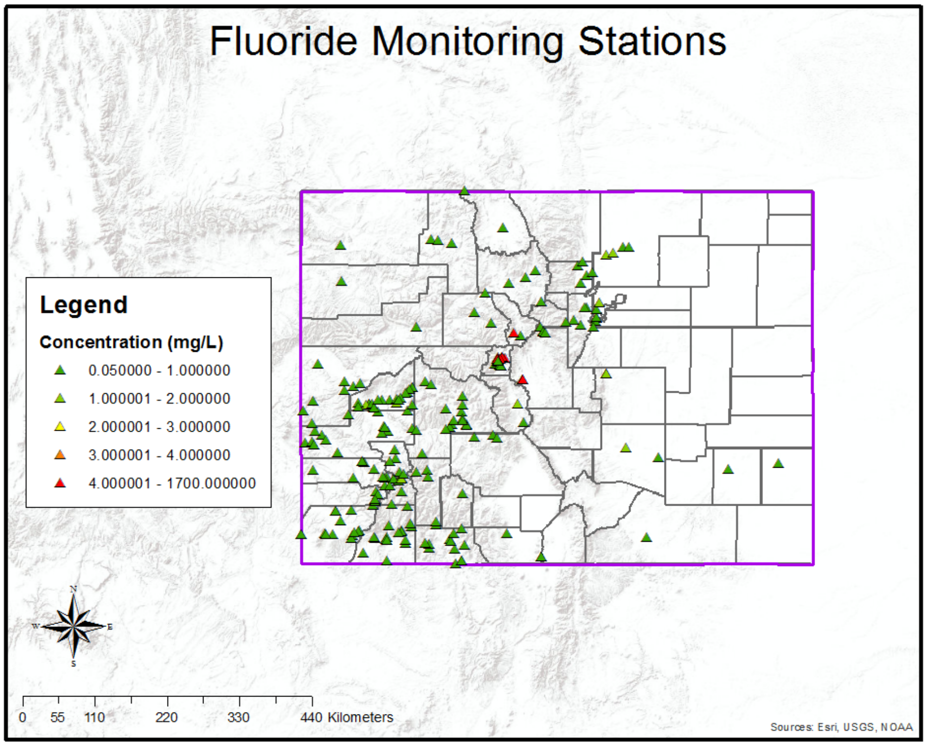

Figure 4: Fluoride Monitoring Stations in Colorado by County

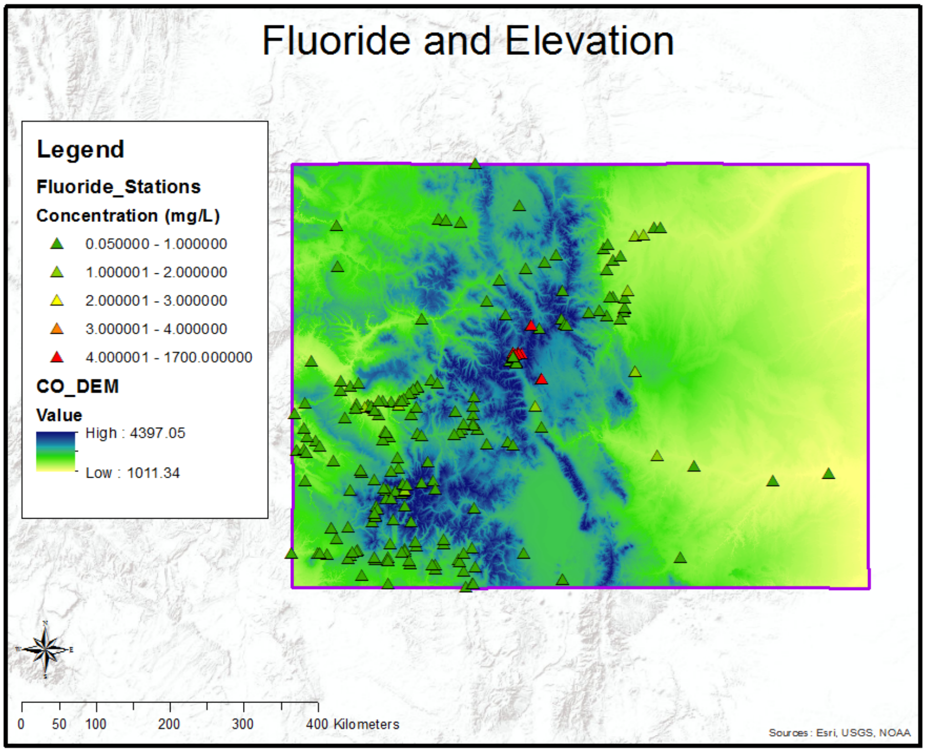

Figure 5: Fluoride Concentration and Elevation in Colorado

3.1.2 Arsenic and Elevation

Arsenic sampling was much more extensive than fluoride. Locations of elevated arsenic concentrations were also much more scattered across Colorado. Like fluoride, the measurements were predominantly lower than the MCL. However, as it is more toxic at lower levels, even slightly elevated arsenic concentrations could be dangerous. Arsenic measurements in the highest classification (>50 μg/L) were found in the San Juan Mountains, Sangre de Cristo Mountains, Sawatch Range, Mosquito Range, Park's Range, Flat Tops, Front Range, and near Pike's Peak. They were also found further east in the Great Plains at lower elevations. Intermediate measurements, 5 – 20 μg/L, were distributed throughout the state.

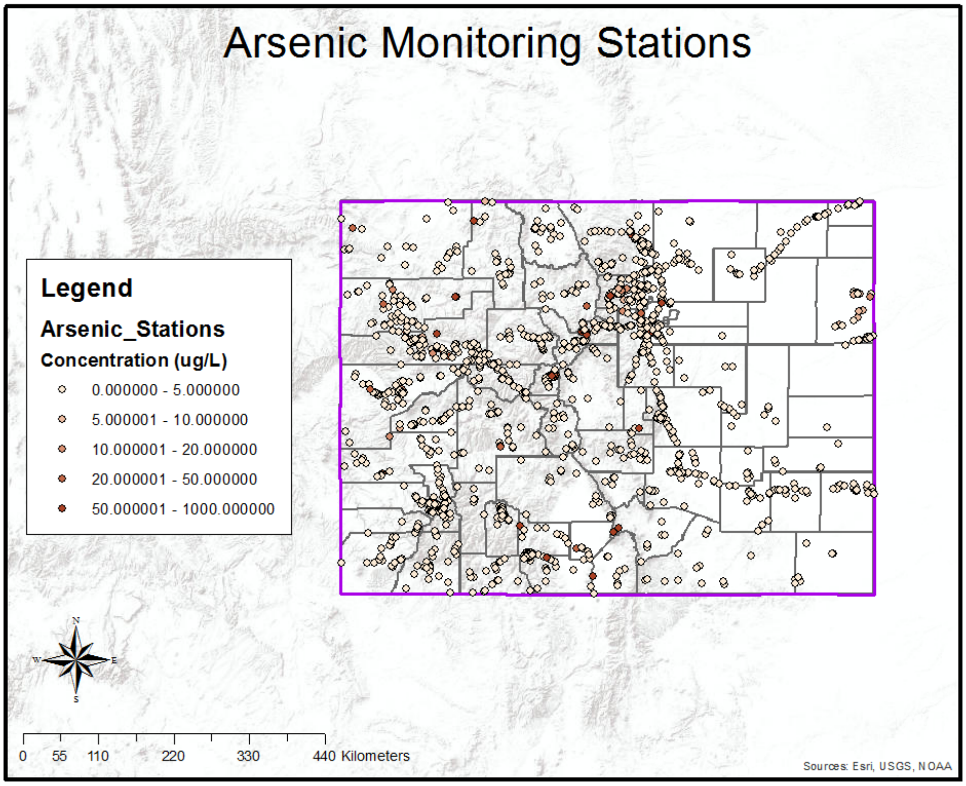

Figure 6: Arsenic Monitoring Stations in Colorado

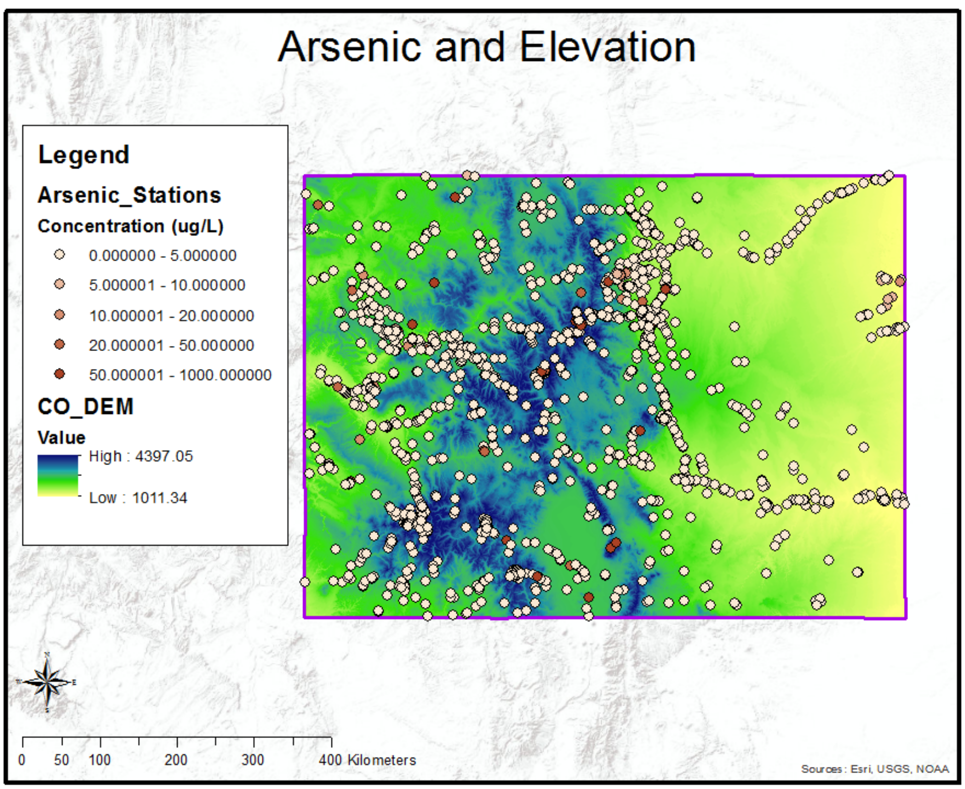

Figure 7: Arsenic Concentration and Elevation in Colorado

3.2 Hydrology

Bedrock and alluvial aquifer data was retrieved from public online GIS data provided by the CDSS. There are 13 unique water basins were identified and can be found in figure 8. Alluvial aquifers were identified down to the creek level and were too numerous to display with color differentiation. Reaches of interest are identified in figures 11 and 13.

Colorado has 13 Groundwater Management Districts (GWMDs), which are designated by the Colorado Groundwater Management Commission.[9] The 13 GWMDs in Colorado are to the east in the High Plains, which have a history of stress and high groundwater demand. These districts lie on top of the Denver and the High Plains basins, as illustrated by figure 9. Residents within a GWMD are required to register their wells and comply with any rules and regulations pertaining to groundwater administration set forth by the district. Aquifers under stress with high levels of drawdown can be at risk for contamination, and they can impact rivers and streams that rely on them for recharge.[10]

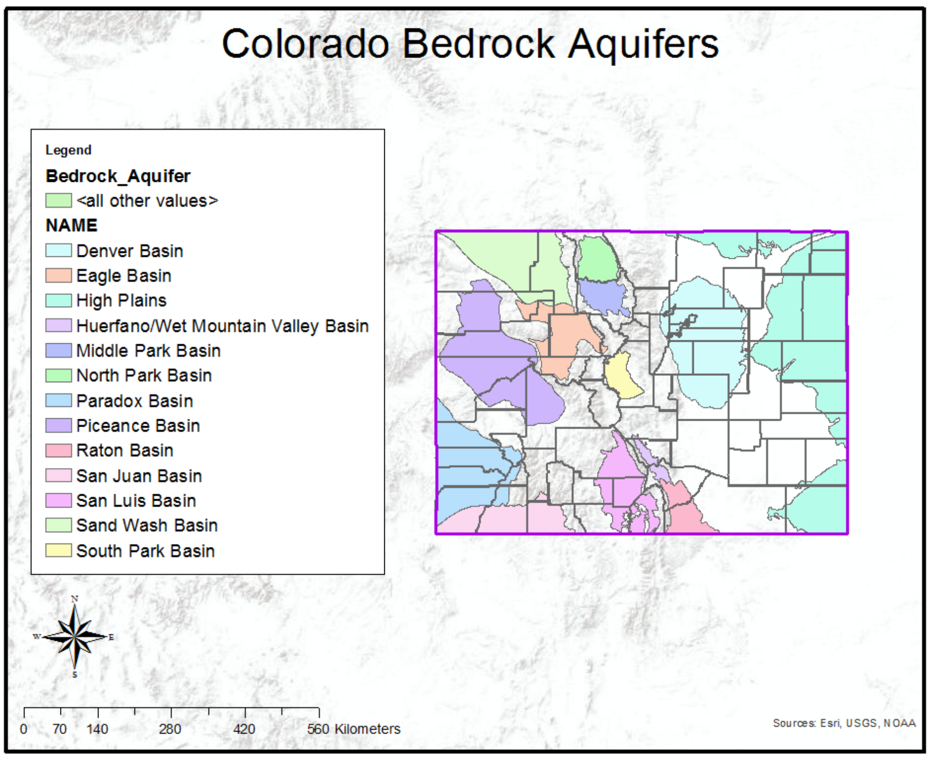

Figure 8: Fluoride Concentration and Underlying Bedrock Aquifers in Colorado

[9] GWMD Information can be found at http://water.state.co.us/groundwater/cgwc/pages/managementdistricts.aspx
[10] Groundwater depletion. (2015, August 12). Retrieved November 28, 2015, from http://water.usgs.gov/edu/gwdepletion.html

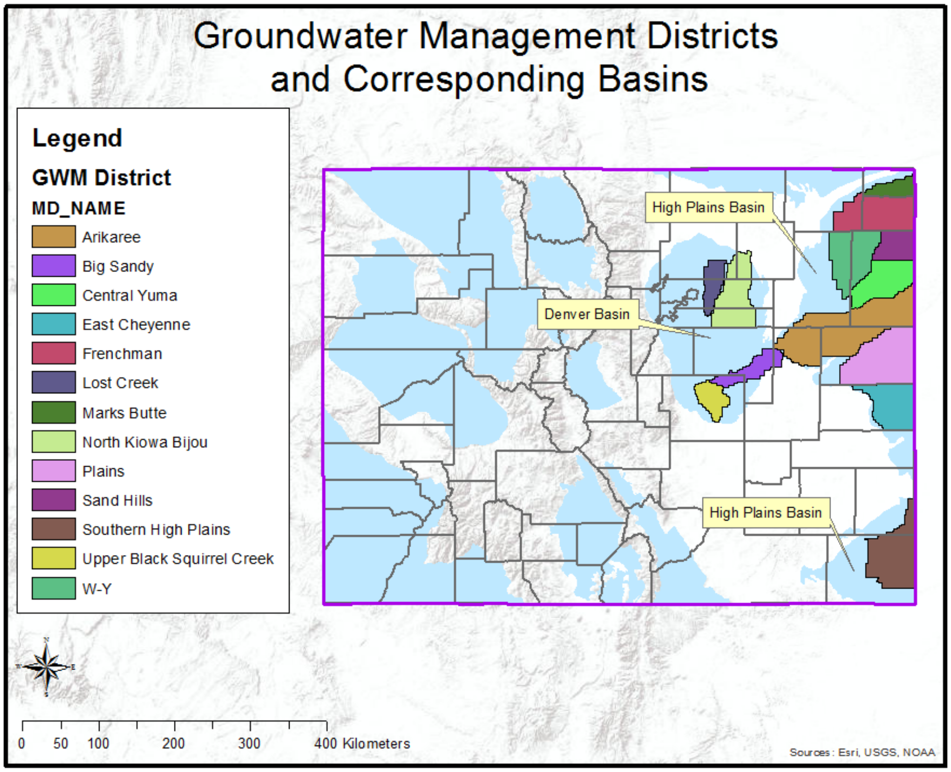

Figure 9: Colorado Groundwater Management Districts and Underlying Basins

3.2.1 Fluoride and Hydrology

The highest fluoride measurements were all surface water stations and classified as river/stream types within the STORET dataset. The stations with measurements between 1 – 2 mg/L were also all from surface waters and classified as river/stream types. Figure 11 shows the elevated fluoride concentrations found in stations along the Arkansas, Gunnison, and South Platte Rivers. All groundwater measurements, classified as well types, recorded below 0.5 mg/L.

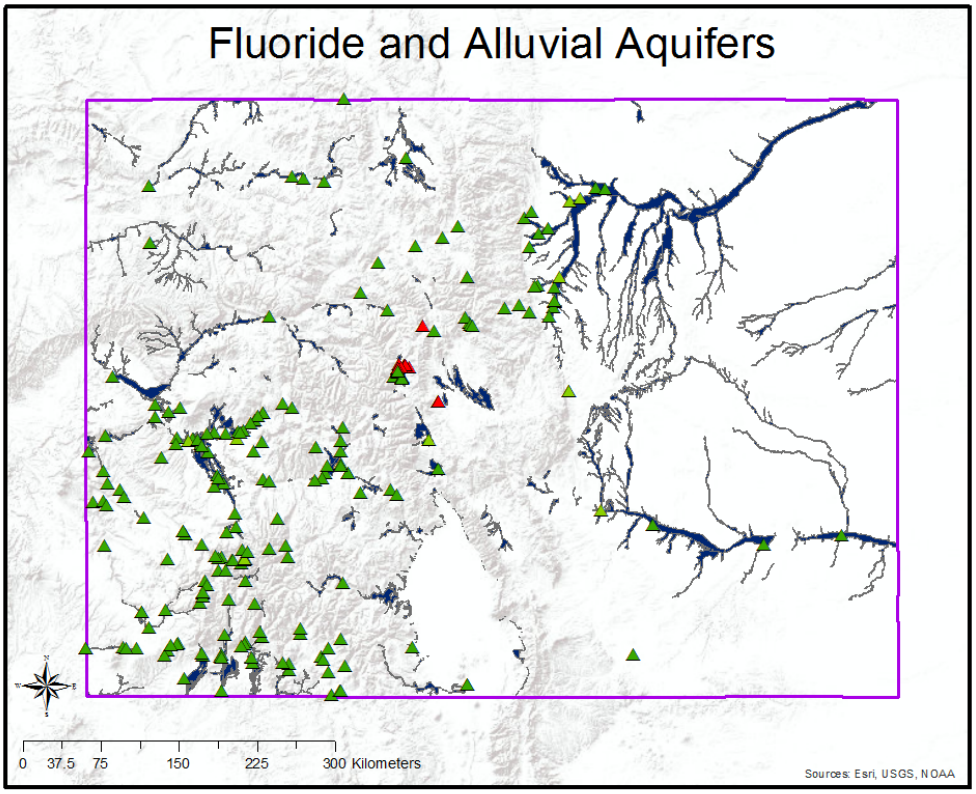

Figure 10: Fluoride Concentration and Alluvial Aquifers in Colorado

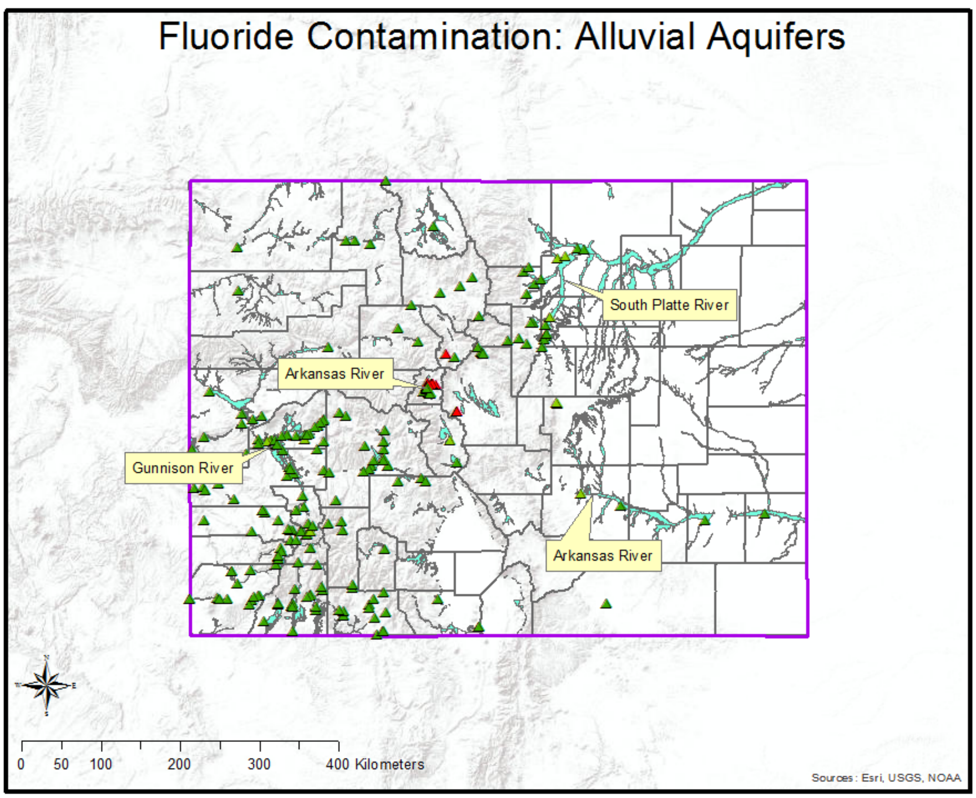

Figure 11: Alluvial Aquifers with Potential Fluoride Contamination in Colorado

3.2.2 Arsenic and Hydrology

The majority of arsenic stations were surface water sources, either river/stream or reservoir stations, and there were only a few groundwater well stations. Every station in the top concentration tier (>50 μg/L) was a surface water river/stream station, with the exception of one reservoir. There were a few high measurements congregated in the center of the state as well as around offshoots of the South Platte River. Alluvial aquifers displaying elevated arsenic measurements are identified in figure 13.

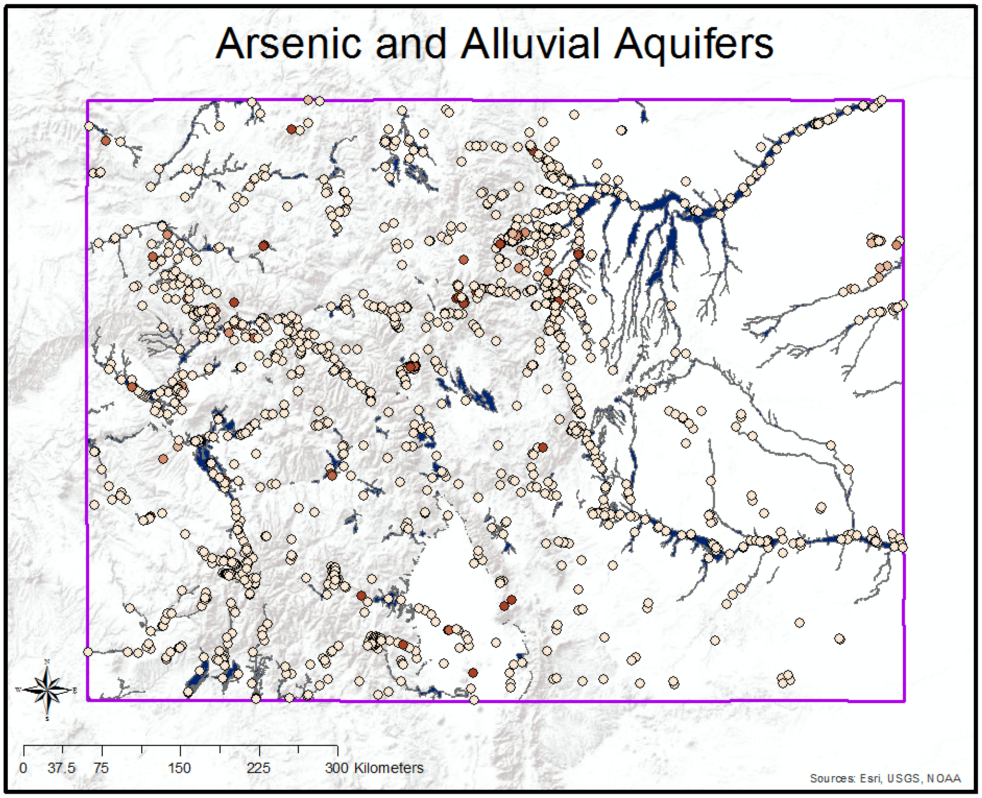

Figure 12: Arsenic Concentration and Alluvial Aquifers in Colorado

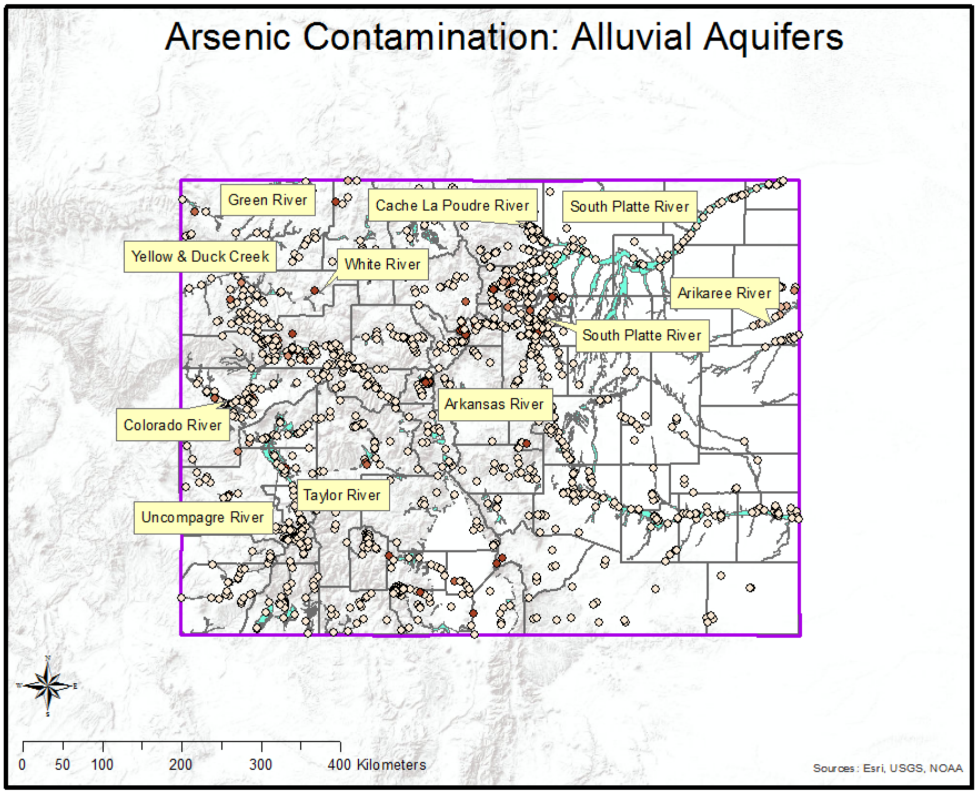

Figure 13: Alluvial Aquifers with Potential Arsenic Contamination in Colorado

3.3 Dual Contamination

3.3.1 Identification of High-Risk Regions

Two regions were identified with high occurrence of both fluoride and arsenic; Lake County in Central Colorado, and the area surrounding the lower reaches of the South Platte River. These regions were identified by comparison of county averages, data processing, and visual interpretation of the produced maps. Average arsenic and Fluoride measurements for each county are displayed in Table 2; where fields are blank, there was no data for that county. Regions with both elevated fluoride and arsenic are identified in figure 14. It is important to note that contamination by either species is not limited to these two regions; fluoride and arsenic were found in multiple locations throughout the state. However, for the purposes of this study, areas with both species present were identified to further explore possible contaminant relationships and affected populations in addition to water system identification. Information presented in previous sections of this report would still be very useful for government officials and water-conscious residents throughout the state.

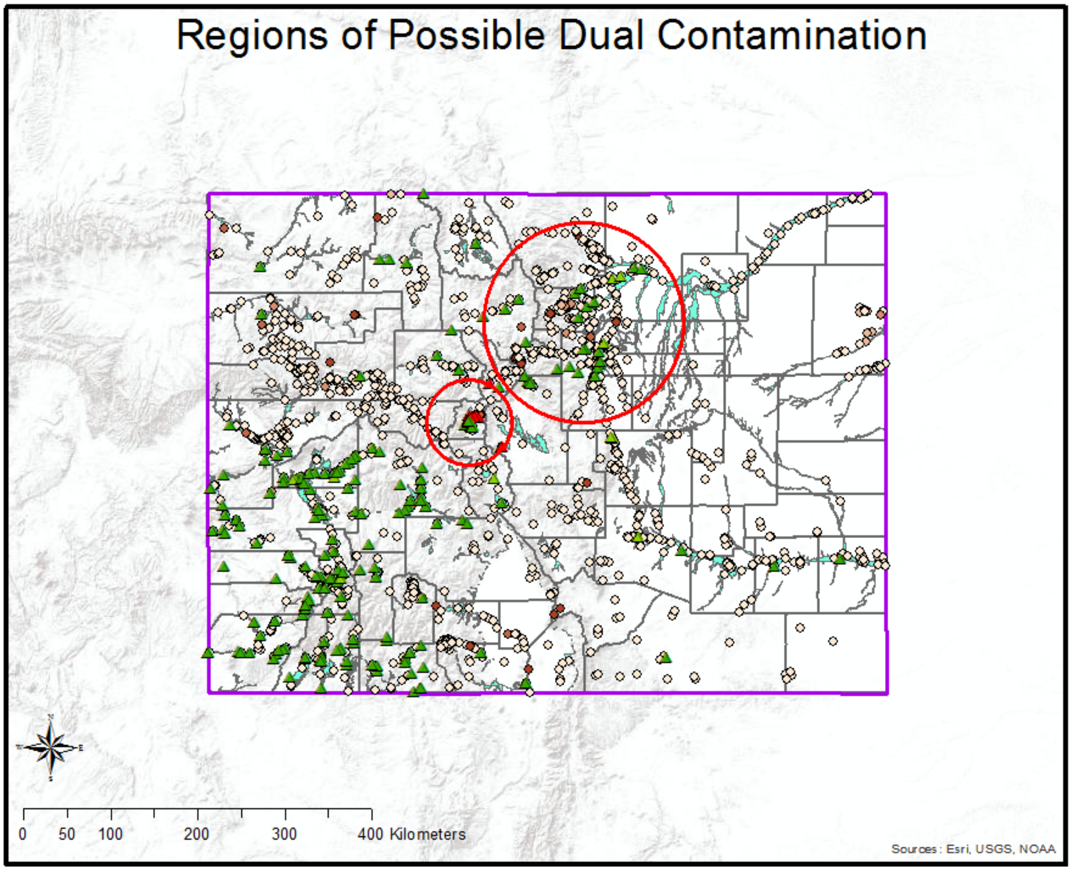

Figure 14: Identified Regions of Possible Dual Arsenic and Fluoride Contamination

Table 2: Summary of County Averages and Maxima for Fluoride and Arsenic Measurements

County	Average [F] (mg/L)	Average [As] (µg/L)	County	Average [F] (mg/L)	Average [As] (µg/L)
Adams	1.3	1.34	Kit Carson	-	1.44
Alamosa	-	3.53	La Plata	0.21	2.68
Arapahoe	0.73	1.8	Lake	232.65	34.76
Archuleta	0.21	2.09	Larimer	0.06	1.87
Baca	-	1	Las Animas	0.3	4.3
Bent	0.32	1.1	Lincoln	-	0
Boulder	0.66	3.55	Logan	-	1.09
Broomfield	-	-	Mesa	0.36	3.53
Chaffee	1.26	2.15	Mineral	0.14	1.39
Cheyenne	-	0	Moffat	0.24	1.18
Clear Creek	-	3.97	Montezuma	0.23	3.85
Conejos	0.37	10.91	Montrose	0.42	1.69
Costilla	0.24	0.92	Morgan	-	1.17
Crowley	-	1.69	Otero	-	1.56
Custer	-	1.43	Ouray	0.61	3.76
Delta	0.54	1.93	Park	0.39	4.97
Denver	0.73	6.39	Phillips	-	-
Dolores	0.22	0.01	Pitkin	-	1.51
Douglas	0.94	1.98	Prowers	0.14	0.46
Eagle	0.18	1.69	Pueblo	1.35	0.74
El Paso	1.7	3.62	Rio Blanco	0.26	1.75
Elbert	-	0	Routt	0.33	4.33
Fremont	-	0.47	Saguache	0.66	0.26
Garfield	0.22	2.3	San Juan	0.44	2.73
Gilpin	-	0.35	San Miguel	0.25	3.08
Grand	0.27	1.75	Sedgwick	-	2.13
Gunnison	0.24	3.8	Summit	2.83	1.69
Hinsdale	0.27	0.06	Teller	-	13.47
Huerfano	-	5.89	Washington	-	0.8
Jackson	0.17	1	Weld	1.16	1.22
Jefferson	0.42	1.99	Yuma	-	4.17
Kiowa	-	1.7			

3.2.2 Lake County

Lake County is located in central Colorado and has a population of over 7000. It is home to the highest summit in the state as well as in all of the Rocky Mountains: the peak of Mt. Elbert (4401m). The only municipality within the county, Leadville, is the start of over 150 miles of water within the Arkansas Headwaters Recreation Area (AHRA). The AHRA is one of the most popular outdoor recreation sites in the country, with a large emphasis on whitewater rafting and kayaking. Fluoride and Arsenic distribution is displayed in figure 15, with the city of Leadville marked for reference. NHDplus flowlines were incorporated into the maps of these counties for enhanced accuracy and visibility of waterways.

3.3.2.1 Fluoride and Arsenic Contamination in Lake County

Lake County exhibited the highest combined arsenic and fluoride contamination. From Table 2, the average fluoride and arsenic concentrations calculated were 232.65 mg/L and 34.76 μg/L respectively. This represents the highest county fluoride average and the second highest county arsenic average.

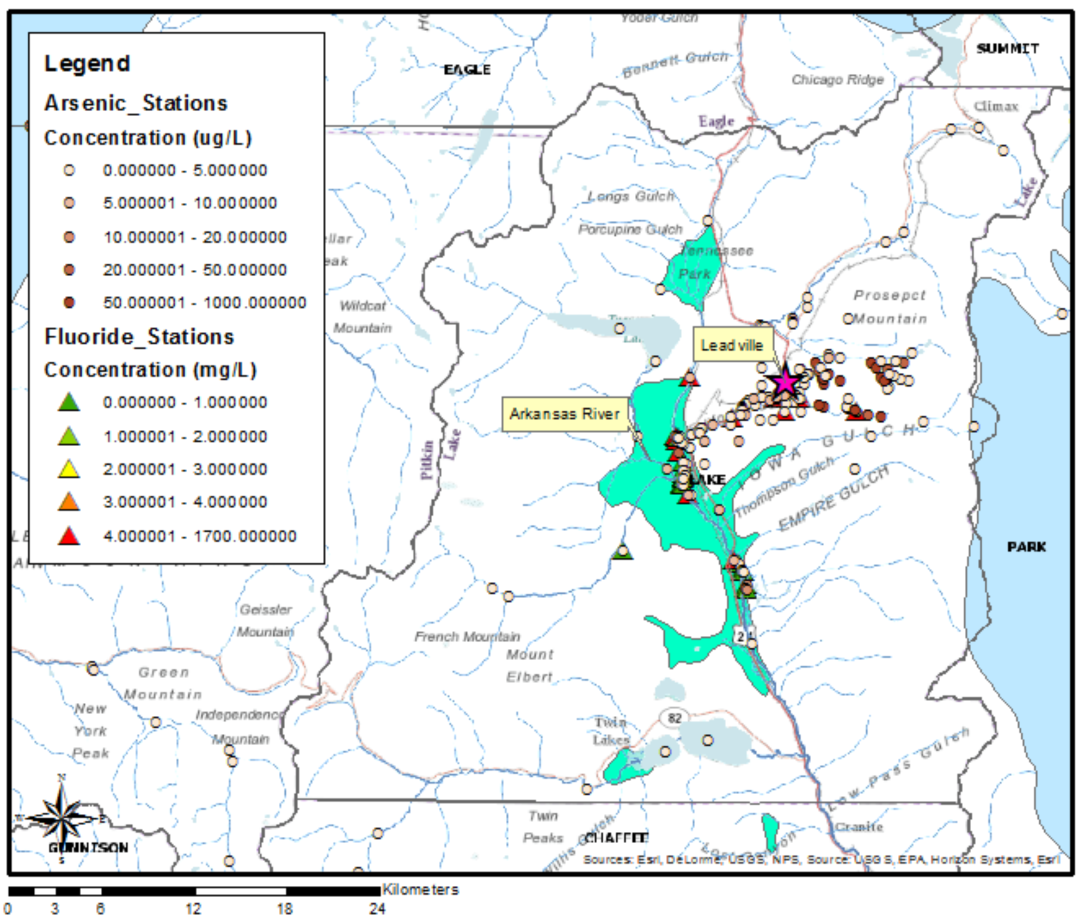

Figure 15: Fluoride and Arsenic in Lake County, Colorado

A maximum arsenic concentration of 2560 μg/L was observed, with multiple concentrations above 1000 μg/L also present. These elevated measurements were all from surface water stations. 282 measurements were equal to or exceeded the MCL of 10 μg/L, including 11 from groundwater well stations. There were 2420 measurements below the MCL, including 347 from groundwater well stations.

A maximum fluoride concentration of 1620mg/L was observed in Lake County; this was also the highest fluoride concentration observed in the entire state. While exceptionally high, there were multiple other measurements of this magnitude from separate stations throughout the county, so these results were still included. There were 20 measurements exceeding the MCL of fluoride (4 mg/L), all from surface water sources. The majority of measurements below the MCL, 18 out of 25, were from groundwater stations. There was also an interesting division between fluoride measurements in Lake County; measurements ranged between 0.06 - 0.41 mg/L and then jumped to 56 – 1620 mg/L. There were no intermediate fluoride measurements, only very low or exceptionally high. This, combined with the accompanying division of groundwater and surface waters respectively, points to possible anthropogenic sources of fluoride in the surface waters. Further investigation revealed a strong history of mining operations in the area.

3.3.2.2 Lake County Mining Operations

The city of Leadville, located in the center of Lake County, is right outside the historic Leadville Mining District. This district has been mined for gold, silver, lead, and zinc for over 100 years. Mining activities such as these contaminate runoff, which leads to pollution of nearby water bodies. Sulfides that are released can be oxidized and release chemicals like lead, cadmium, silver, zinc, and arsenic into runoff that then pollutes nearby water bodies. In Leadville, runoff drains into the Arkansas River.[11] The Leadville Mining District is located in the Colorado Mineral Belt, and was a prolific producer of gold and silver. Currently, the California Gulch EPA superfund site occupies 18 square miles within Lake County and contains Leadville, parts of the Leadville Mining District, and a portion of the Arkansas River. According to the EPA, the contaminated groundwater status and human exposure status are not under control. [12]

3.3.2.3 Lake County Public Water Systems

Lake County houses 6 community water systems. They are summarized in Table 3. Information on all water systems was obtained online through the CDPHE SWAP assessment phase website. Profiles for all water systems in Colorado are available.[13] The town of Leadville has a water system serving 8450 people year round, with multiple water sources susceptible to contamination from previous mining operations.

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[11] USGS Spec Lab: Environmental Mapping at Leadville Colorado. (1996). Retrieved November 28, 2015, from http://speclab.cr.usgs.gov/PAPERS.Leadville95/leadville1.html

[12] EPA Superfund Program: California Gulch, Leadville, CO. (2015). Retrieved December 3, 2015, from http://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0801478

[13] available online at https://www.colorado.gov/pacific/cdphe/swap-assessment-phase

Table 3: Summary of Lake County Public Water Systems

System Name	Population Served	City Served	System ID	Source Waters	Total Susceptibility	Sources of Contamination
MT ELBERT WA	170	N/A	CO0133500	Groundwater	Moderate	
MOUNTAIN VIEW VILLAGE EAST	226	N/A	CO0133600	Groundwater	Moderate	
VILLAGE AT EAST FORK	244	N/A	CO0133300	Groundwater	Moderate	
LAKE FORK MHP	400	Mobile Home Park	CO0133100	Groundwater	Moderately High	EPA Superfind Site
MOUNTAIN VIEW VILLAGE WEST	440	N/A	CO0133150	Groundwater	Moderately High	
PARKVILLE WD	8450	Leadville	CO0133700	Ground and Surface Water	Moderate	Existing/Abandoned Mine Sites

3.3.2.4 Lake County Population Demographics

As of 2014, Lake County has a population of 7357 people distributed over 937km^2. Figure 16 illustrates the population distribution, with majority of residents concentrated in the center of the county near the town of Leadville. Also evident from Figure 16 is that the contaminated water quality monitoring stations are concentrated near the highest population density area, amplifying the human reach of the pollution. Given the high reported concentrations, arsenic and fluoride are likely to be present throughout the rest of the county as well.

Figures 17 and 18 further illustrate the population demographics of Lake County. The census tract with the lower population density also has a lower percent of individuals with health insurance, a higher poverty rate, and a high minority percentage. Few monitoring stations were outside of central Lake County, so the individuals in those areas are at risk for unmonitored contamination. This may pose a higher health risk for the affected individuals, as fewer of them have health insurance or fall above the poverty line. Residents of outer Lake County are less likely to have the resources they need to combat the adverse health impacts of drinking contaminated water. Additional water quality monitoring should be performed throughout outer Lake County in order to ensure the safety of these individuals.

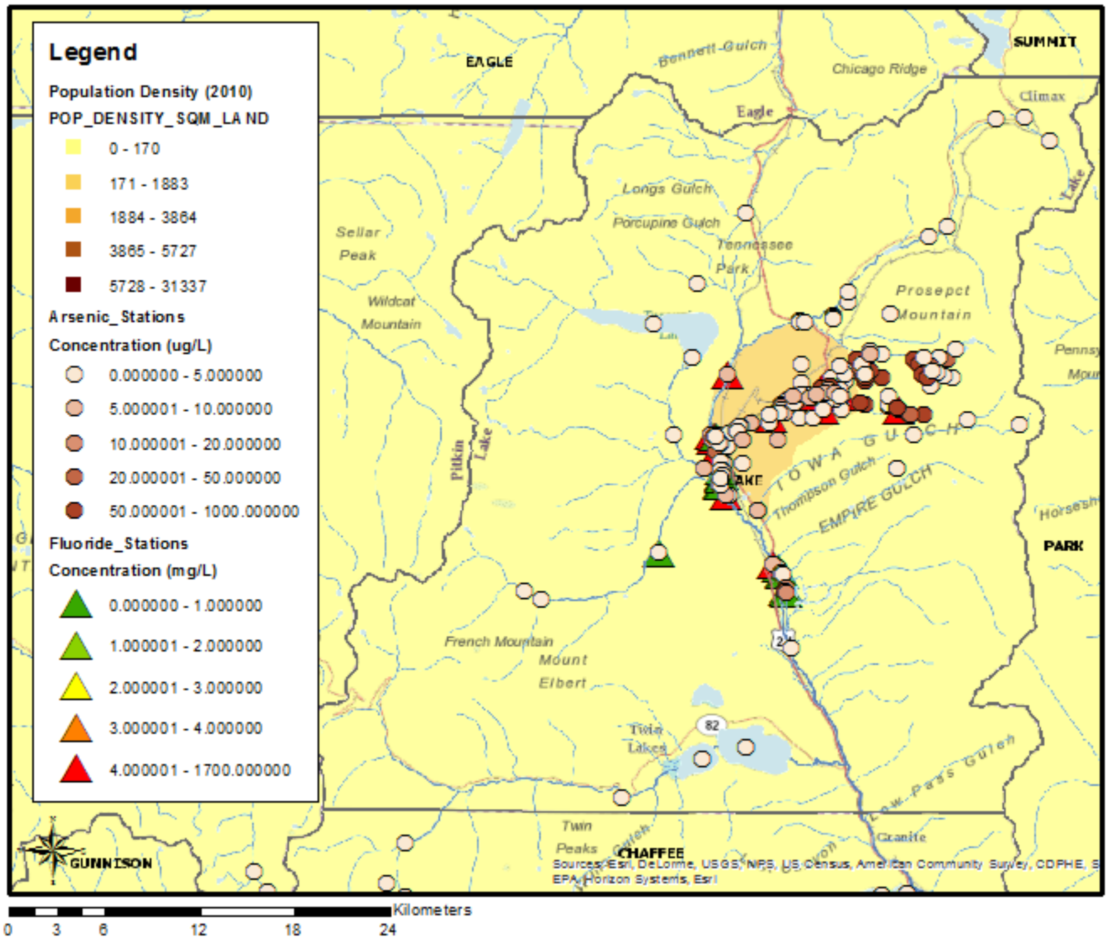

Figure 16: Lake County Population Density

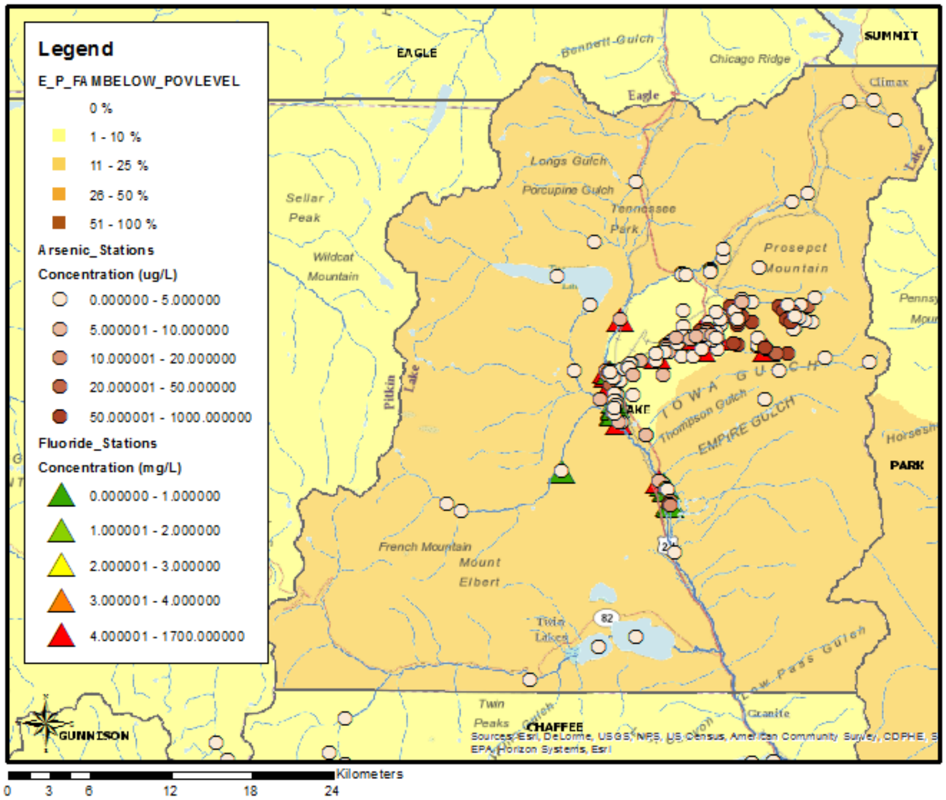

Figure 17: Lake County Poverty Distribution

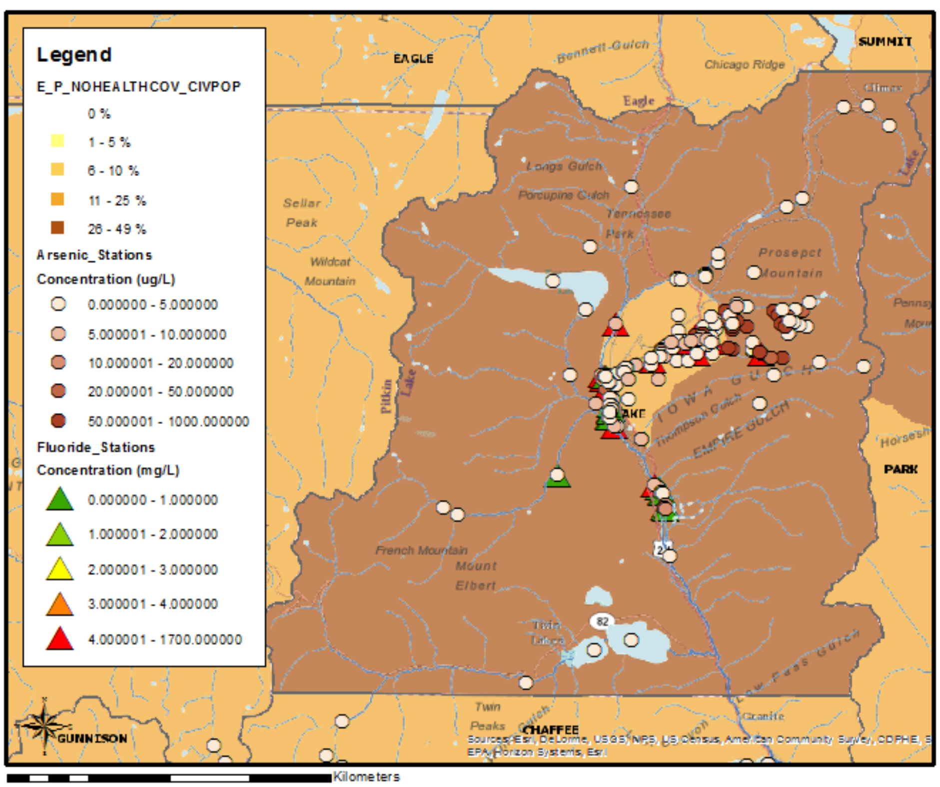

Figure 18: Lake County Health Coverage Insurance

3.3.3 South Platte River Region and Summit County

Counties included in the South Platte River Region are Adams, Boulder, Clear Creek, Denver, Larimer, Summit, and Weld. Figure 19 displays the fluoride and arsenic distribution among these counties. The averages and maxima for fluoride and arsenic measurements are summarized for these counties specifically in Table 4. From these counties, Summit and the surrounding area were chosen for further study. While it does not have the highest reported arsenic concentrations, it is at risk for exceeding both current arsenic and reduced fluoride MCLs. Additionally, Summit is surrounded by other areas of high contamination in Clear Creek and Eagle counties, with Lake County located to the South. Figure 19 presents a visual of the contaminant distribution throughout the South Platte River area, and Figure 20 highlights Summit County.

Table 4: Average Concentrations in the South Platte River Region

County	Average [F] (mg/L)	Max [F] (mg/L)	Average [As] (µg/L)	Max [As] (µg/L)
Adams	1.30	1.30	1.34	138
Boulder	0.66	1	3.55	980
Clear Creek	-	-	3.97	230
Denver	0.73	0.92	6.39	275
Larimer	0.06	0.49	1.87	218
Summit	2.83	4.2	1.69	127
Weld	1.16	1.30	1.22	78

3.3.3.1 Fluoride and Arsenic Contamination in Summit

Summit County is named Summit for the multitude of mountain summits within its 1600km^2. As presented in Table __, the highest fluoride and arsenic concentrations reported in Summit were 4.2 mg/L and 127 µg/L. Elevated measurements were recorded along Snake River and Tenmile Creek. In the surrounding counties, elevated measurements were recorded along Eagle River in Eagle County and Clear Creek in Clear Creek County. Every arsenic and fluoride station was a river/stream type. Summit County is also near many popular skiing locations, like Copper Mountain, Keystone, Breckenridge, and Vail in neighboring Eagle County.

Fluoride is naturally occurring in Summit County waters. Fluoride is also a frequent topic of discussion; it is mentioned on the county drinking water website and in the local newspaper.[14,15,16] There were no distinct jumps observed in fluoride or arsenic concentrations. This could potentially indicate a dominance of natural sources, though further sample stations would be needed; there were only eight fluoride measurements available.

[14] Drinking Water. (n.d.). Retrieved December 4, 2015, from http://www.co.summit.co.us/drinkingwater

[15] Corazzelli, K. (n.d.). Questioning the benefits of water fluoridation in Summit County | SummitDaily.com. Retrieved December 5, 2015, from http://www.summitdaily.com/article/20120424/NEWS/120429917

[16] Hendershott, D. (n.d.). Why Summit County has fluoride in the water (column) | SummitDaily.com. Retrieved December 4, 2015, from http://www.summitdaily.com/opinion/14956519-113/why-summit-county-has-fluoride-in-the-water-column

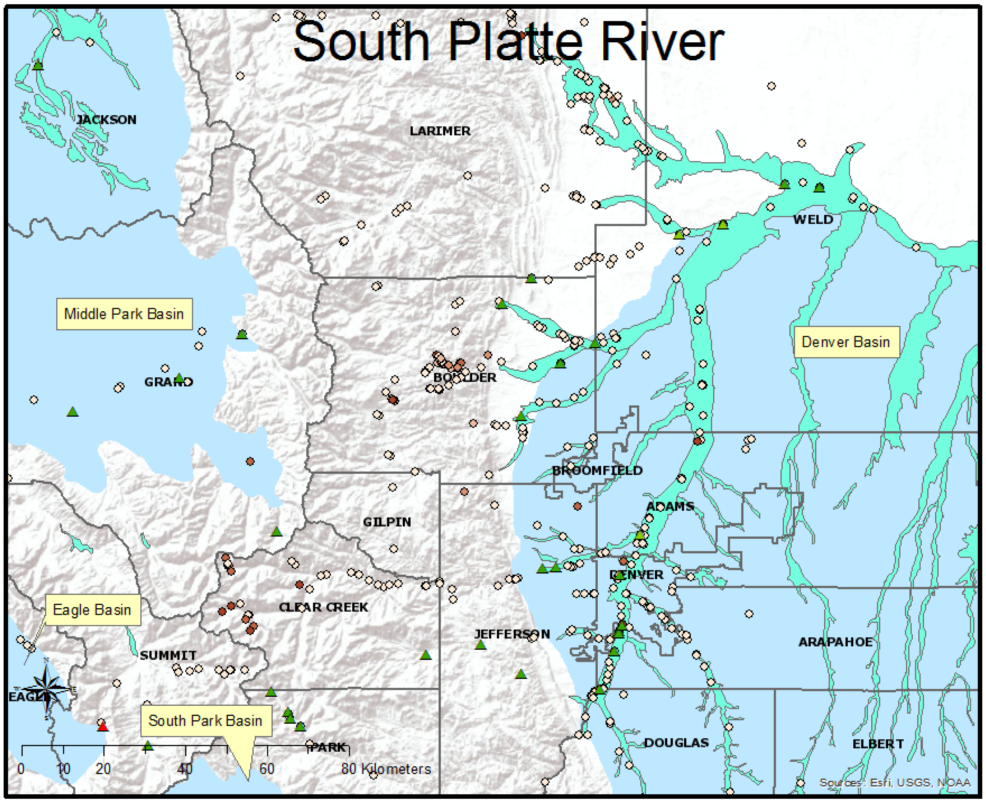

Figure 19: Fluoride and Arsenic Monitoring Stations in the South Platte River Region

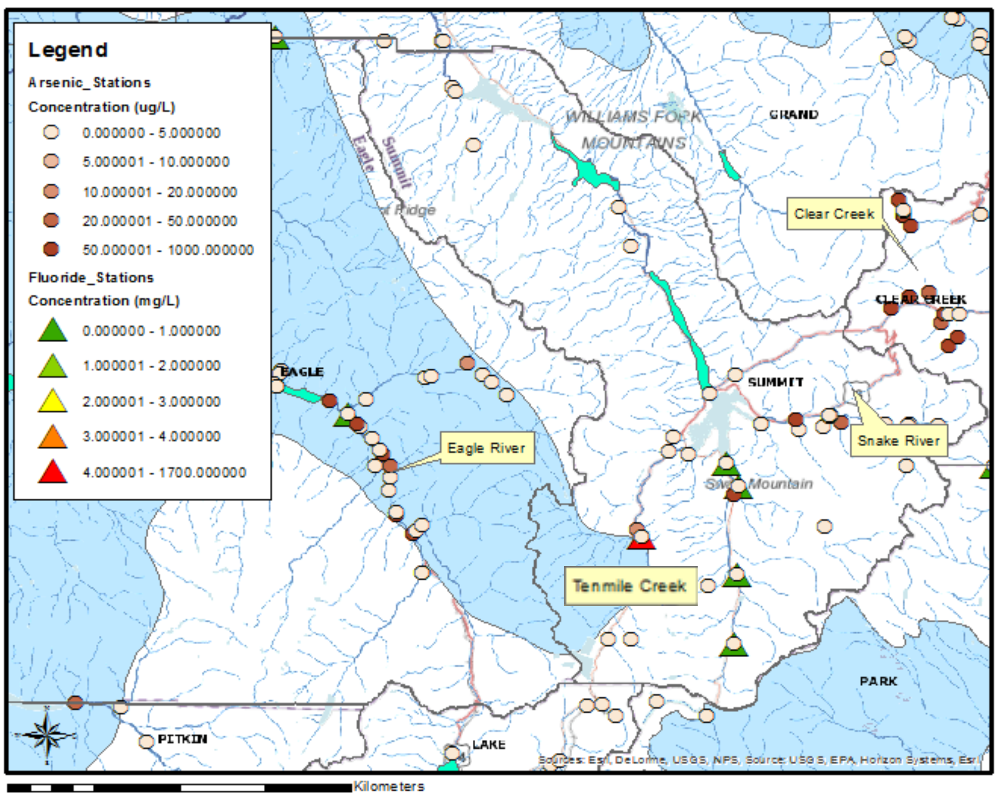

Figure 20: Fluoride and Arsenic Monitoring Stations in the South Platte River Region

3.3.3.2 Summit County Community Water Systems

Summit County has 20 community water systems. Table 5 summarizes these systems. The primary source is groundwater, with a few surface water sources. Information on all water systems was obtained online through the CDPHE SWAP assessment phase website. Profiles for all water systems in Colorado are available. Contamination seemed to be from leaking storage tanks, existing or abandoned mining sites, EPA hazardous waste generators, permitted wastewater discharge, and other activities.

Table 5: Summary of Summit County Community Water Systems

System Name	Population Served	System ID	Source Waters	Total Susceptibility	Sources of Contamination
TANGLEWOOD WS	60	CO0159120	Groundwater	Moderately High	Leaking Storage Tanks, EPA Haz Waste Sites
KINGDOM PARK COURT	70	CO0159070	Groundwater	Moderately High	Other
FARMERS KORNER MHP	105	CO0159050	Groundwater	Moderately Low	-
BLUE RIVER VALLEY RANCH LAKES	150	CO0159005	Groundwater	Moderately Low	-
HEENEY WATER INC	150	CO0159060	Groundwater	Moderately Low	-
SAGE CREEK CANYON CORP	150	CO0159090	-	-	-
TIMBER CREEK WC	150	CO0259003	Groundwater	Moderate	Existing/Abandoned Mine Sites
MESA CORTINA WSD	466	CO0159080	Ground and Surface Water	Moderately High	E/A Mines, Leaking Storage Tanks, Other
KEYSTONE RANCH	670	CO0159065	Groundwater	Moderate	Leaking Storage Tanks
BUFFALO MOUNTAIN MD	2465	CO0159025	Groudnwater	Moderately High	Leaking Storage Tanks, EPA Haz Waste Sites
EAST DILLON WD	2501	CO0159045			
SILVERTHORNE TOWN OF	3520	CO0159095	Groundwater	High	Leaking Storage Tanks, Other
COPPER MOUNTAIN CONSOLIDATED MD	5000	CO0159030	Groundwater	High	Leaking Storage Tanks, EPA Haz Waste, Other
SNAKE RIVER WD	9900	CO0159105	Groundwater	Hoderately High	E/A Mines, Leaking Storage Tanks, Wastewater Discharge
SWANS NEST MD	200	CO0159725	-	-	-
HAMILTON CREEK MD	200	CO0159063	-	-	-
DILLON TOWN OF	2992	CO0159035	Surface Water	Moderately Low	-
DILLON VALLEY DISTRICT	3063	CO0159040	-	-	-
FRISCO TOWN OF	4426	CO0159055	Groundwater	Moderately High	E/A Mines, Leaking Storage Tanks, EPA Haz Waste, Other
BRECKENRIDGE TOWN OF	36258	CO0159020	Groundwater	Moderate	Existing/Abandoned Mine Sites

3.3.3.3 Summit County Population Demographics

Summit County has a population of 27,994. The population is spread fairly evenly throughout the county, as seen in Figure 21. Summit also has a low percent of the population living below the poverty line, with one region of higher poverty surrounding Snake River. Even so, Summit and the surrounding areas have very high proportions of the population without health insurance coverage. As previously stated, this leaves those individuals fairly unequipped to deal with any health ramifications due to consuming potentially contaminated water. Figures 22 and 23 display poverty and health insurance coverage, respectively.

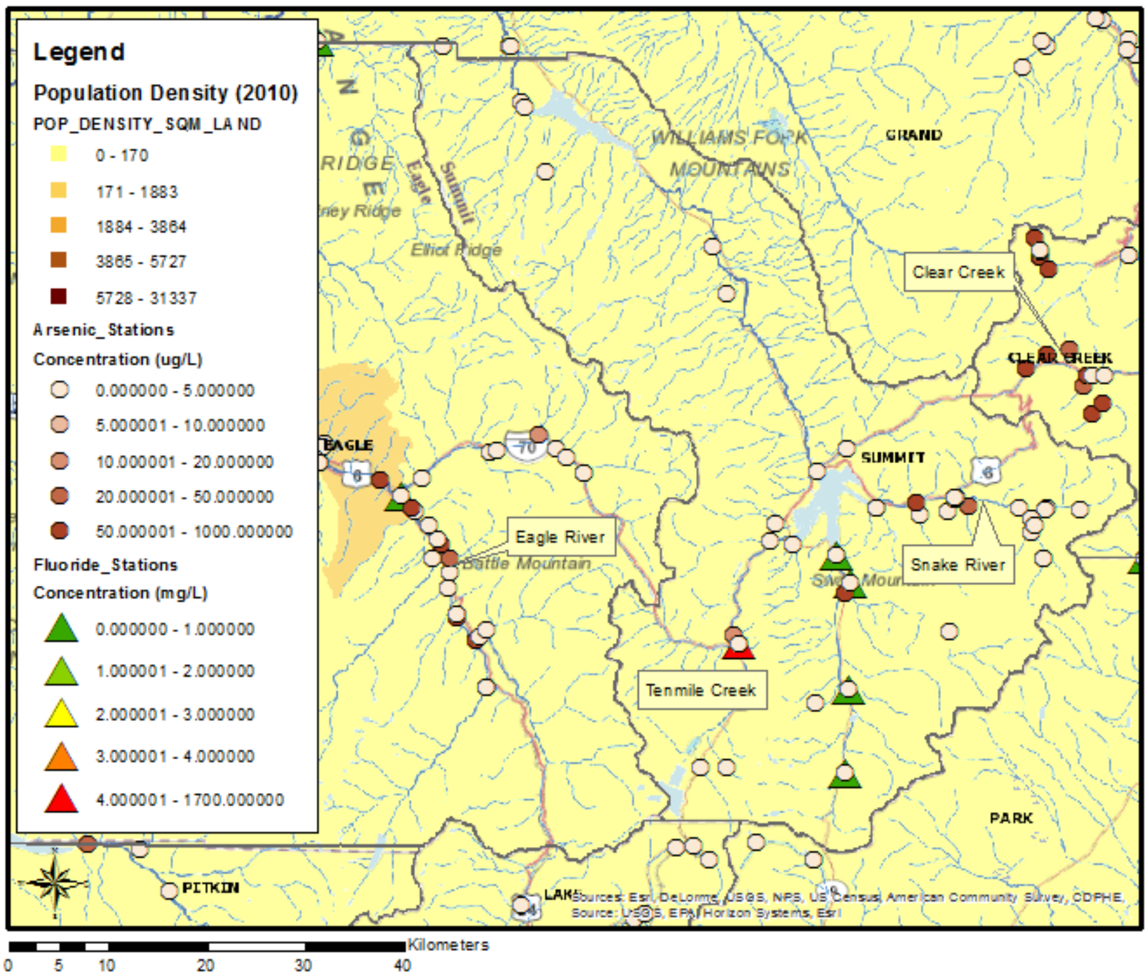

Figure 21: Summit County Population Density

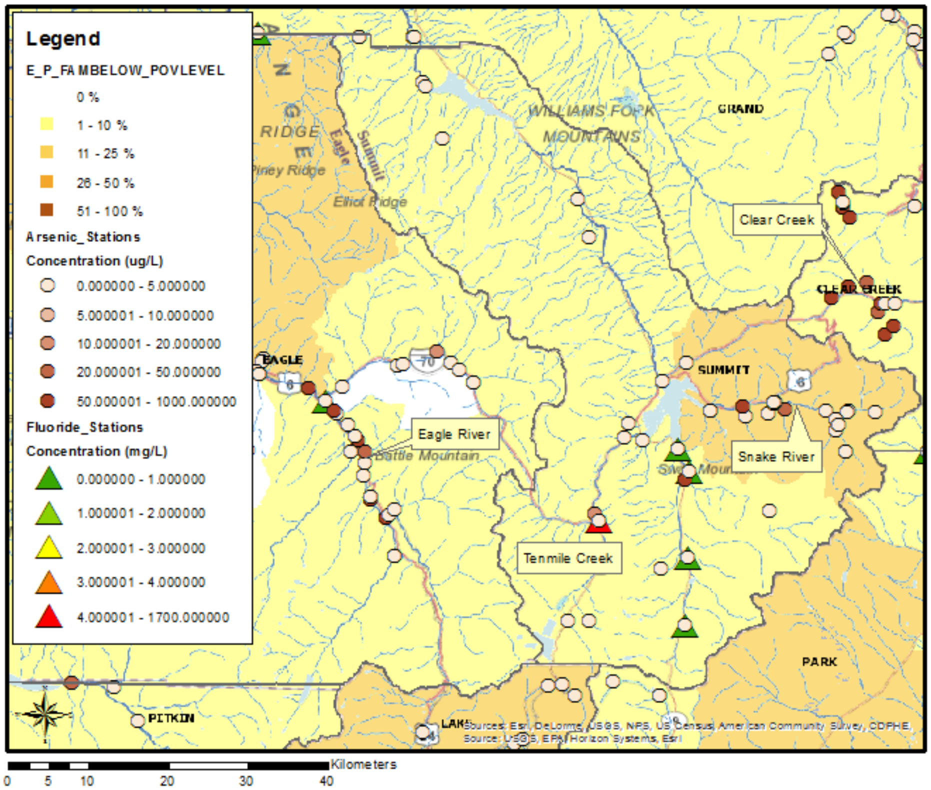

Figure 22: Summit County Poverty Distribution

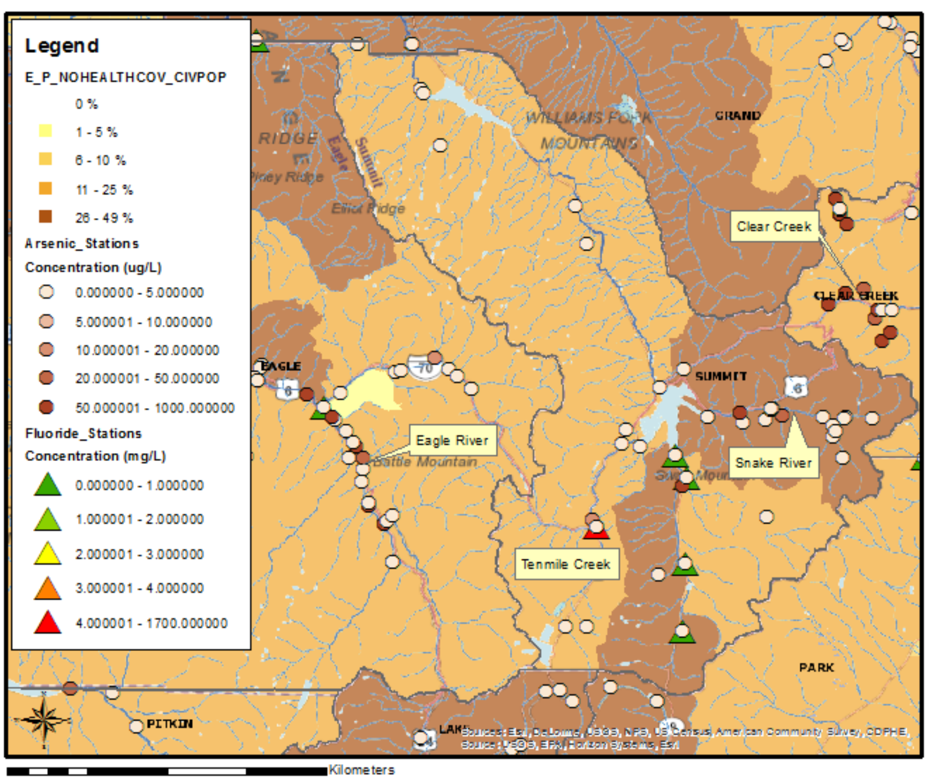

Figure 23: Summit County Health Insurance Coverage

4.0 Future Work

This report provides a solid groundwork for future study. These data lend themselves to various statistical analysis efforts that could help determine whether a recorded concentration is statistically significant. Further investigation of connections between groundwater aquifers and surrounding surface waters would also be illustrative and aid in understanding the full potential reach and spread of contamination. Geologic data were considered for this project, but time did not permit for the search and addition of such information. The Colorado Mineral Belt and locations of historic and present mining operations would be especially interesting. Individuals and organizations looking at this report should pursue this information, as it is certain to elucidate many of the observed trends. Finally, higher quality hydrologic data should be obtained. The bedrock aquifer data were high-level and very general. The true subsurface composition of the aquifers is stratified and much more complex.

5.0 Conclusions

This project aimed to investigate the distribution of arsenic and fluoride throughout the state of Colorado, as well as elucidate the trends and relationships between the two contaminants and their surrounding environment. Water quality monitoring data was retrieved from the EPA STORET data warehouse and combined with geographic, hydrologic, and population information to produce illustrative maps. These maps were then used to identify areas of high contamination and isolate potentially impacted public water systems and populations. Colorado's unique geography and predominance of mountain towns makes it an interesting study area for two contaminants so closely tied to mineral geology.

Fluoride and arsenic were present at elevated concentrations in waters throughout the state of Colorado. The majority of fluoride and arsenic contamination was found in surface waters, which was surprising given the species' natural geologic sources. However, the data presented was limited to what was returned by the STORET data warehouse. There were many more surface water sample stations provided than groundwater, so it was difficult to draw conclusions on groundwater or compare trends between the two.

Fluoride and arsenic were present in elevated concentrations at high elevations throughout the state. Many of these sites were found in ranges of the Rocky Mountains. However, elevated concentrations were also found at lower elevations in the eastern Great Plains. While there were more instances of elevated arsenic and fluoride at higher elevations, there did not seem to be a concrete correlation between contamination and elevation. The highest fluoride concentrations were found in ranges of the Rocky Mountains, but there were also some elevated concentrations observed further east away from the mountains. The locations of fluoride monitoring stations were unevenly distributed, however, with an apparent disparity between stations near the mountains and those elsewhere. Any predominance of contamination at high elevations could potentially be due to the high number of stations in the mountains in comparison to those at lower elevations; more sampling should be done further east outside of mountainous regions to provide a more complete basis for comparison. Arsenic had a stronger apparent connection to arsenic, as there were multiple mountain ranges with high reported concentrations. Arsenic monitoring stations were also more evenly distributed throughout the state. However, due to the prevalence of mining operations, it is unclear whether the connection is due in part or at all to elevation. Further research of the underlying geologic structure should be performed to compare with these results.

The vast majority of monitoring stations obtained through the STORET database were surface water stations, with a very small number of groundwater well stations in comparison. This could introduce bias into any comparison of groundwater versus surface water trends. While there were exceptionally few groundwater wells with elevated arsenic or fluoride measurements, save for one highly arsenic-contaminated station in Denver County, the lack of data prevented a sufficiently robust comparison. It was very apparent, however, that there were many impaired surface waters throughout the state.

Lake County and Summit County presented notably high averages of both arsenic and fluoride. Further investigation showed a predominance of contamination from historic mining activities in Lake County, and various forms in Summit. While there were many instances of surface water contamination, most of the community water systems identified draw from groundwater. However, the hydrologic connections between subsurface aquifers and surface waters should be investigated to ensure the safety of these groundwater sources.

Colorado surface waters face potential anthropogenic contamination from mining activities, as well as naturally occurring levels of fluoride and arsenic throughout the state. This report highlights some of the potential individual and combined trends with respect to arsenic and fluoride, and it also draws attention to at-risk communities and populations. Water systems outlined in this report should take the necessary precautions to investigate fluoride and arsenic removal, and would benefit from further research regarding the interrelationships between arsenic and fluoride during removal processes.

6.0 Sources

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