

# Regulatory overview of PFAS and identification of potentially impacted sites in Denver, CO using GIS analysis

by  
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## **ABSTRACT**

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Per- and polyfluoroalkyl substances (PFAS) are considered an emerging contaminant due to their persistence in the environment and their ability to cause adverse health effects in humans. Once released into environmental media, they can easily infiltrate to and impact vadose zones and groundwater where they remain for very long periods of time and can be transported great distances with groundwater flow. Most releases of PFAS into the environment can be attributed to industrial discharges, spills, leachate from landfills, and the use of aqueous film-forming foam (AFFF) on class B fires. PFAS have already been identified in numerous drinking water systems and in groundwater across the United States. Given the relatively recent discovery of the adverse health and environmental effects of these chemicals and the widespread impacts already seen across the country, federal, state, and local governments have begun regulating many PFAS, such as PFOA and PFOS. This applies to the State of Colorado which has passed numerous bills and policies that set numeric standards for state waters, limit the use of AFFF, and track facilities that use the chemicals. The U.S. Environmental Protection Agency (USEPA) has set health advisory levels for PFAS in water and is planning on proposing to designate certain PFAS like PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or Superfund. This will have serious implications for sites impacted by PFAS. If EPA identifies or suspects sites of having PFAS impacts, they would be able to order the potentially responsible parties (PRPs) to conduct investigation, remediation, and monitoring efforts until the sites are deemed clean and protective of human health and the environment. Denver, Colorado is one of many places that may be subjected to

such enforcement in the future. It is highly likely that PFAS impact exist within the City and County of Denver (CCD) due to the presence of heavy industrial areas, historic urban fill (HUF) areas, and large number of fire stations and fire training facilities. The exact locations of potential impacts are currently unknown so it would be beneficial for CCD to preemptively identify potentially impacted city-owned sites and conduct site investigations, assessments, and before the federal government subjects the city to costly and time-consuming enforcement actions and potential Superfund designations.

To help identify potentially impacted sites across the city, a geographic information system (GIS) was used to create a PFAS “heatmap” by running a site suitability analysis utilizing fuzzy analysis. Fuzzy analysis assigns values to cells within a map based on their proximity to certain input factors. The higher the value, the closer to that input the cell is. In this case, the input factors included proximity to fire stations, HUF areas, industrial sites that are suspected dischargers of PFAS, industrial sites that have registered quantities of PFAS, and groundwater accumulation areas. The results of this analysis showed that multiple potential hotspots existed along the South Platte River corridor along the western central portion of the city. This corridor houses many of the city’s industrial zones and HUF areas and is also where much of the local groundwater flows. These factors combined make these locations top candidates for potentially impacted sites and are therefore where preliminary site investigations should begin. CCD has property interest/ownership in some of these areas; specifically in an existing Superfund site and in various areas of right-of-way (ROW). CCD should therefore prioritize investigating these sites in in order to identify actual impacts so they can be remediated, and its future environmental and financial liabilities can be limited.

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## **BIOGRAPHY**

I am originally from Trumbull, Connecticut and moved to Wilmington, North Carolina to obtain a Bachelor of Science (B.S.) in Environmental Science with a concentration in Conservation from 2010 to 2014. I was a Senior Consultant for Booz Allen Hamilton and from 2014 to 2018 I served clients including the Environmental Protection Agency (EPA), the United States Food & Drug Administration (FDA), United States Postal Service (USPS), National Park Service (NPS), Federal Aviation Administration (FAA). My expertise is Environmental Site Assessments (ESAs), Preliminary Assessments/Site Investigations (PA/SIs), and providing technical support to the transition, environmental due diligence, and decommissioning of federal facilities and commercial properties.

In 2018, I moved from North Carolina to Denver, Colorado where I accepted a position with the City & County of Denver (CCD) as a Senior Environmental Public Health Analyst / Environmental Projects Manager. In this role, I manage both Phase I and II ESAs and remediation projects for city-owned properties and properties being conveyed to CCD, and conduct research & analysis of emerging contaminants and their presence at city-owned properties. I am an active member of the Emergency Response and Department Operations Center (DOC) teams which included an 18-month deployment to focus on the City's response to the COVID-19 pandemic.

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## **CHAPTER 1: Introduction to PFAS**

### **1.1 Background and Problem**

Per- and polyfluoroalkyl substances (PFAS) belong to a class of emerging contaminants that are increasingly prevalent in the natural environment. An emerging contaminant is one that was not commonly or historically monitored in the environment, but has become a chemical of concern due to new evidence that it can cause adverse environmental and/or human health impacts (Rosenfeld & Feng, 2011). PFAS, which were first discovered in the 1930s, are very stable, resistant to degradation, and are great surfactants (ITRC, 2020c). These characteristics make them a very useful class of chemical in various industries and processes. They can be found in a wide range of products including Gore-Tex®, non-stick coatings, food packaging, ski wax, firefighting foam, etc. (ITRC, 2020d). To date, there are over 4,700 known PFAS compounds with some of the most common or most recognized ones being perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), and GenX (NIH, 2021). Unfortunately, the same characteristics that make these compounds so useful in numerous applications, also make them very persistent in the environment and in the human body. Exposure to PFAS can lead to a variety of health concerns including low infant birth weight, cancer, thyroid issues, and immune system issues (NTP, 2016).

PFAS are anthropogenic and their presence in the environment can be traced to industrial discharges, waste treatment, and the use of firefighting foam (Aqueous Film Forming Foam (AFFF)) (Barzen-Hanson, 2017). Until recently, PFAS AFFF was used commonly across the country by fire departments, airports, military installations, and in industrial fire suppression systems to suppress fires involving simple hydrocarbon fuels such as gasoline, diesel, jet fuel, heating oil, etc. as well as in fire training activities. Because of its use in firefighting, PFAS

AFFF is found in surrounding soils or runoff into nearby waterbodies of fire-fighting areas (Sunderland et al, 2018). Other common releases of PFAS are related to industrial discharges. For instance, in North Carolina GenX had been historically released into waterbodies like the Cape Fear River by Chemours whose emissions contained PFAS compounds (Hegstad, 2018).

As the federal government works on creating national regulations, it is likely that at least PFOA and PFOS will be regulated nationwide under CERCLA or the Comprehensive Environmental Response, Compensation, and Liability Act, also known as Superfund, within the next one to two years (USEPA, 2021b). The EPA created the PFAS Action Plan in 2019 which outlines the specific steps the federal government is taking to address PFAS in the environment with a goal of protecting human health (USEPA, 2019). As part of this, EPA developed groundwater cleanup recommendations for PFOA and PFOS at contaminated sites and is in the process of considering designating both PFOA and PFOS as hazardous substances regulated under CERCLA. Many states have also begun to regulate some of these compounds, such as PFOA, PFOA, PFNA, and PFHxS, and develop policies regarding safe levels in water (drinking water and groundwater) and soil (Moody, 2020). For instance, the State of Colorado recently promulgated standards for five (5) PFAS compounds at their points of discharge and has conducted statewide testing of water bodies (both surface and ground) and of wastewater treatment plants (Beaven, 2020). When state regulations are implemented and PFOA and PFOS are regulated under CERCLA, there is the possibility that many locations within Denver County may become regulated hazardous waste sites. The impacts of this could be extensive as Denver has large industrial areas and PFAS firefighting foams have been used in various applications across the city for decades.

The locations of potential sources and sites of PFAS contamination in Denver is largely unknown due to the fact that PFAS have not become a contaminant of concern until very recently. Given their widespread use historically, there is the potential that many locations in Denver may be at least somewhat contaminated with PFAS. Identifying potential PFAS locations, prior to federal regulation, would assist the City and County of Denver (CCD) in managing environmental and financial liabilities in the future and protecting public health.

As EPA designates PFAS compounds as hazardous substances under CERCLA, there is the very real possibility that many places in Denver will become regulated sites and depending on the ability to identify ownership of those sites, significant environmental and financial liabilities and burdens may be placed on the City. CERCLA involves making potentially responsible parties (PRPs) responsible for cleanup actions. For PFAS sites where the city is considered a PRP or where a PRP is unknown, clean-up and remediation will be the City's responsibility leading to potentially numerous simultaneous investigation and remediation projects. This project identifies, pre-emptively, those locations within the CCD where PFAS contamination may exist by using spatial analytics. Based on spatial analyses, potential PFAS sites are discussed and prioritized based on city ownership and interest, and on the number of influencing factors that are near each particular site (i.e., HUF, fire station, suspected discharger, etc.). With the inevitability of CERCLA designation of PFAS chemicals as hazardous substances, sites that are deemed most suitable or most likely to have high potential for vast PFAS impacts will also be prioritized.

## **1.2 Introduction to PFAS**

Generally, PFAS include a chain of two or more carbon atoms attached to a charged functional group. That chain of carbons, which can be either fully or partially fluorinated where

the carbons are bonded to fluorine atoms, is also referred to as the tail of a PFAS molecule. The tail of these molecules is both hydrophobic and lipophobic, meaning it is not soluble in water or fats and will not mix with either (ATSDR, 2021). Alternatively, the charged function group is referred to as the head (ITRC, 2020e). The head of a PFAS compound is charged and is typically hydrophilic, meaning it is attracted to water and will readily mix or dissolve in water. The carbon-fluorine (C-F) bond is a very short bond and is considered the strongest covalent bond in organic chemistry, making PFAS very persistent in the environment and giving the tail end of the PFAS lipid and water repelling properties (Murry-Rust et al, 1983).

There are two main classes of PFAS. These include polymer and nonpolymer PFAS. For the purposes of this study, the focus will be on nonpolymer PFAS which are the ones more commonly detected in the environment as well as in both humans, plants, and animals (biota), and are therefore also more commonly studied and better understood (ITRC, 2020c). The two subclasses of nonpolymer PFAS are perfluoroalkyl substances and polyfluoroalkyl substances and these two subclasses are made up of numerous additional subgroups of chemicals.

Perfluoroalkyl substances get their name from being fully fluorinated PFAS (*Per-* means fully) (ITRC 2020c). Like PFAS in general, they are made up of a chain or tail of carbon atoms attached to a functional group or head. In this case, the carbon tail consists of at least two carbon atoms and is fully fluorinated, so each carbon is bonded to a fluorine atom wherever possible with the exception of the bond between the tail and the head of the molecule which is typically a sulfonate (sulfur and oxygen) or carboxylate (carbon and oxygen). These perfluoroalkyl substances can be further broken down into the following chemical types: perfluoroalkyl acids (PFAAs), Perfluoroalkane sulfonamides (FASAs), Perfluoroalkane sulfonyl fluorides (PASFs), Perfluoroalkanoyl fluorides (PAFs), Perfluoroalkyl iodides (PFAIs), and

Perfluoroalkyl aldehydes (PFALs) (Buck et al, 2011). Most of these are typically used as raw materials for the production of surfactants and surfacing materials using the electrochemical fluorination (ECF) or fluorotelomer processes (ITRC, 2020c). Out of these different types, PFAAs are the most significant as they are the most environmentally persistent when released into the environment and can also be formed from the environmental breakdown of precursor substances, which includes some of the other nonpolymer PFAS such as FASA, listed above (ITRC, 2020c).

PFAAs are also referred to as “terminal PFAS” as they are in their final, non-degradable states under normal environmental conditions. Other PFAS, referred to as “precursor chemicals” or just “precursors”, can degrade into other products, with PFAAs being the final product that can be formed from that environmental breakdown. As such, once in this state, the chemical will not break down into another substance (Buck et al, 2011). PFAAs can be further divided into additional subgroups including perfluoroalkyl carboxylic, sulfonic, sulfinic, phosphonic, and phosphinic acids, with the first two, perfluoroalkyl carboxylic and perfluoroalkyl sulfonic acids being the major two. Common examples of each kind are perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), respectively, which are the two most common PFAS substances historically found in the environment and the two that have been studied most to date. The naming conventions for PFAAs follows a somewhat simple pattern. According to ITRC and as described in *Table 2-1. Basic naming structure and shorthand for PFAAs* of their PFAS guidance document, PFAAs are symbolized using the following method:

**PFX**Y where:

**PF** = perfluoro

**X** = the carbon chain length (based on the number of carbons (**B** for butane or 4 carbons, **Pe** for pentane or 5 carbons))

**Y** = the functional group (, **A** = carboxylate or carboxylic acid and **S** = sulfonate or sulfonic acid) (ITRC, 2020c)

When referring to PFAAs, the terms “long-chain” and “short-chain” are commonly used. This, like described earlier, is in reference to each substance’s carbon backbone chain length. In general, “long-chain PFAS” are PFCAs with seven (7) or more carbons, PFSAs with six (6) or more carbons, or PFCA/PFSA precursor compounds, while “short-chain PFAS” are considered PFCAs or PFSAs with less than 7 and 6 carbons, respectively (OECD, 2013).

Polyfluoroalkyl substances get their name from being only partially fluorinated PFAS (*‘Poly-‘* means partially) Like their fully fluorinated counterparts, polyfluoroalkyl substances have carbon chain backbones, but some carbons are not bonded to a fluorine atom. The atoms that are typically present instead of some of the fluorines include oxygen and hydrogen, predominantly. For these to be considered polyfluoroalkyl substances, though, at least two of the carbon in the backbone need to be fully fluorinated (ITRC 2020c). Unlike perfluoroalkyl substances, these still contain carbon-hydrogen bonds or other bonds that are not fully fluorinated. These bonds, which are weaker than carbon-fluorine bonds, are more likely to degrade, or break, in the environment. Because of this, some polyfluoroalkyl substances can also be considered precursor compounds. As those non-fluorinated bonds degrade, fully fluorinated terminal compounds (PFAAs) can break off and be released as a result.

### 1.2.1 Characteristics of PFAS

The characteristics of PFAS compounds can be attributed to their various physical and chemical properties; characteristics which have historically (and still currently) made them very useful substances in various industrial, commercial, and consumer applications. According to the ATSDR Profile for Perfluoroalkyls (2021), PFAAs are very stable due to the presence of C-F bonds which, as discussed earlier, are very short and are the strongest bond in organic chemistry. In addition to this, the head is hydrophilic while the tail is hydrophobic and lipophobic (Kissa, 2001), causing the head to be attracted to/mix well with water, while the tail repels water and oils. This is also the basic chemistry of what defines a surfactant or “any substance that when dissolved in water or an aqueous solution reduces its surface tension or the interfacial tension between it and another liquid.” (Dictionary.com, 2021). This particular property of PFAS is caused by how the two different ends of the molecule act in the air-water interface, or where air and water meet. The hydrophilic head will orient itself towards the water, while the tail orients itself the air, which causes the molecules to form micelles, or a group of surfactant molecules suspended colloiddally in the liquid. These surfactants properties make PFAS extremely useful as surface coatings and protectants (Kissa, 2001).

The significant chemical properties of PFAAs can largely be attributed to the presence of fluorine (F). As discussed, the C-F bond is the strongest covalent bond in organic chemistry, and this leads to some of the desired traits of PFAAs. The high electronegativity of F leads to the C-F bond, which results in high thermal stability and high chemical stability (chemical stability is also attributed to the small atomical size of F), while the low polarizability leads to low surface energy and helps create the surfactant properties described above (ITRC, 2020d).

### **1.2.2 Release Mechanisms, Fate and Transport**

PFAS can be released into the environment in various manners. Typically, they end up being released as waste products. Given the sheer number of products PFAS are found in, it is of no surprise that some may end up being thrown out after being used, where they make their way to landfills and/or in some cases directly to the surrounding environment (waterways, streets, yards, etc.). Other PFAS, in addition to their precursor substances which eventually transform into PFAAs, can be released into the environment through various industrial emissions including wastewater, air, etc. where they can then make their way to wastewater treatment facilities and/or deposit in soils and surface waters/sediments near the emission site. With the exception of spills/leaks of material directly to the surrounding environment, one of the more commonly understood and more immediate released of PFAS to the environment, historically, has been attributed to AFFF. When AFFF was used to fight fires, the foam concentrate would be mixed with water, aerated, and sprayed as a foam product. Depending on the size of the fire, in some cases thousands of gallons could be used at one time. Once the fire was extinguished, the foam material would either be washed away (sometimes directly into storm inlets) or would be left in place where it would eventually return to a liquid solution (Anderson et al, 2016). Once reverted to a liquid, the solution could then make its way to water bodies and/or storm sewers via runoff, leach into soils, and infiltrate groundwater. Once released into the surrounding environmental media, the PFAS substances could then easily impact an area larger than the original release. Releases like this were very common at/near airports, Air Force bases, industrial sites, and along highways/interstates where large vehicular fires would often require the use of AFFF.

Once released into the environment, understanding the fate & transport of these substances is crucial. Fate & transport describes how certain chemicals/substances will behave in

the environment once released and details, based on that behavior, where they are likely to end up. The physical and chemical characteristics and properties of a chemical or substance will largely affect how it moves through the environment. For the purposes of this discussion, the fate & transport processes of PFAAs like PFOA and PFOS will be reviewed.

PFAAs can be transported through migration processes including advection, diffusion, dispersion, and leaching (ITRC, 2020f). Advection can be defined as the transport of a material via a fluid. Fluids in this case can be things like water or air. Examples here include the flow of PFAS molecules through media such as surface waters, groundwater, and air emissions. This type of transport will move molecules through media but will not necessarily reduce the concentration of said molecules on their own. Sorption and partitioning to other media will affect the concentrations during transport, but that will be discussed more in depth in the next section. Dispersion of contaminants like PFAS will occur when the velocity of the fluid in which they are being transported is altered. An example of this would be when water flows into sediment. Some of the contaminant will remain in the fluid, but the decrease in the velocity of the fluid/water will cause a portion of those contaminants to mix with the other media (Higgins & Luthy, 2006). Diffusion, or the process of transport determined by changes to a concentration gradient can also affect PFAS contaminant transport. This typically occurs when PFAS will move to a location with a lower concentration, similar to how a gas will diffuse from a high concentration area to a lower one given the chance. The most common form of this is the diffusion of PFAS into lower permeability materials like soil, bedrock, and even concrete (ITRC, 2020f). Once diffused into these materials, the PFAS can eventually diffuse back out when conditions are favorable, leading to a phenomenon known as back-diffusion. This can lead to plumes persisting long after the source material is removed, and previous plumes remediated (Baduel et al. 2015). Finally

leaching is another process by which PFAS contaminants can be transported through environmental media. Leaching is the process by which a chemical or soluble substance drains out another substance by percolating liquid, such as runoff or rainwater. This typically occurs vertically where PFAS will leach from the surface soil or shallow subsurface material down into groundwater, but can also lead to a more horizontal leaching towards surface bodies of water. Leaching is a common manner by which contaminants like PFAS can leave landfills or historic urban fill areas.

In addition to the processes mentioned above, partitioning or the function of a solute distributing between two phases, such as soil and water, is a significant factor in the fate & transport of PFAS. Partitioning will affect things like sorption and will alter the overall transport of PFAS more so than the simple transport functions like advection, diffusion, and leaching. Partitioning is largely affected by the hydrophobic/lipophobic tails and the polar and hydrophilic heads. These conflicting characteristics can lead to varying distributions throughout the environment as various partitioning mechanisms can be at play depending on the specific scenario (Guelfo et al., 2013). Typically, these competing properties can lead to partitioning of PFAS to different environmental interfaces. When discussing partitioning to solid phases in general, the hydrophobicity of the tail ends of PFAAs molecules tend to also allow them to adsorb to organic carbon in saturated soils even though the molecules overall are fairly mobile in groundwater (Xiao et al., 2015). This sorption will also increase, typically, as the tail length of the molecule increases, meaning that more short chain PFAS are likely to reach groundwater through soil than their long chain counterparts. Additionally, given the surfactant properties of PFAAs, they will tend to form films at the air-water interface, or where air and water meet (Costanza et al.; 2019). The hydrophobic tail will orient away from the water, while the

hydrophilic head will orient towards it, dissolving into the water. This can be significant when discussing releases of PFAS into the air. If those released molecules are deposited on surface waters, they will tend to form a thin layer or film on the surface of that water and accumulate there. This is also significant when discussing the unsaturated vadose zone, or the subsurface zone from the ground surface to groundwater. In these zones, there is pore space that is not saturated with water. Instead, those pores contain air and allow for sufficient space with which PFAAs can partition. This, like the relationship with PFAAs in the saturated zone, can cause some PFAAs in unsaturated zones to either slow or become retarded /“stuck” in these zones and not transport further towards groundwater (Brusseau, 2018).

### **1.2.3 Human Health and Toxicology**

The Agency for Toxic Substances and Disease Registry (ATSDR) developed a toxicological profile for Perfluoroalkyls in 2021 (ATSDR, 2021). According to this profile, PFAS such as PFOS and PFOA, have been detected in all environmental media (water, soil, air, biota). Human exposure, while originating from all of these media, is greatest via ingestion of contaminated drinking water (ATSDR, 2021). PFAS compounds are very resistant to water, grease, oils, and heat which contributes to their persistence in the environment. PFAS compounds are absorbed rapidly by animals (including humans) and are distributed throughout the body via plasma proteins (serum albumin) with the highest extravascular concentrations found in the liver and kidneys. The mechanism of transfer of PFAS from the blood to soft tissue has not yet been fully identified (ATSDR, 2021).

Additionally, there is a potential association between PFAS exposure and adverse human health effects including pregnancy-induced hypertension, liver damage, increase in serum lipids (total cholesterol and LDL cholesterol), increased risk of thyroid disease, decreased antibody

response to vaccines, increased risk of asthma, decreased fertility, small decrease in birth weight, and possible carcinogenic effects (increases in testicular and kidney cancer have been observed in highly exposed humans) (ITRC, 2020g).

While adverse health effects have been observed in humans, most of the epidemiological studies revolving around humans did not include monitoring exposure data, only focused specifically on exposure to long-chain PFAS (PFOS, PFOA), and therefore cannot establish causality with certainty. There is also a high possibility for multiple routes of exposure in humans, all of which lead to the potential for many other unknowns regarding long-term effects (ATSDR, 2021).

#### **1.2.4 Existing Federal Regulations and Policies**

The federal laws that currently incorporate or regulate PFAS are the Safe Drinking Water Act (SDWA), the Toxic Substance Control Act (TSCA), the Toxics Release Inventory (TRI) Program, the Food and Drug Administration (FDA), and the National Defense Authorization Act (NDAA). The SDWA, as its name implies, exists to ensure drinking water is safe for human consumption. While there are currently no maximum contaminant limits (MCLs) for any PFAS chemicals, there are several PFAS compounds currently being monitored in drinking water under the Third Unregulated Contaminants Monitoring Rule (UCMR3). Under SWDA, every five (5) years the EPA must develop a list of currently unregulated chemicals (not to exceed 30) to monitor in public water supply systems. The data collected under UCMR3 will be used to develop MCLs for those PFAS chemicals which include PFOS, PFOA, PFNA, PFHxS, PFHpS, PFHpA, and PFBS (USEPA, 2020c). TSCA which allows the EPA to require reporting and restrictions on certain chemicals passed a significant new use rule (SNUR) in 2020 that restricts the manufacture, use, and import of various long-chain PFAS in the United States (USEPA,

2021c). The TRI program was created by the Emergency Planning and Community Right-to-Know Act (EPCRA) to manage and track the management (recycling, treatment, waste, etc.) and releases of chemicals to the environment that are known or suspected to pose a threat to human health and/or the environment. In 2020, 172 PFAS chemicals were added to the list of chemicals whose releases must be reported per TRI and EPCRA (USEPA, 2020b). The FDA has banned the use of three (3) PFAS chemicals in food packaging, although many others are still permissible (FDA, 2021). The NDAA for 2020 centered largely around the Department of Defense (DOD). The FY 2020 NDAA requires DOD to share monitoring data with municipalities and drinking water exposure data with personnel and their families. It also requires DOD to offer testing for PFAS in blood of all DOD firefighting employees during annual physical exams and restricts the use of water impacted with PFAS above the current EPA advisory levels for irrigation and other agricultural uses. In addition, this also prohibits DOD from using AFFF during training exercises with a complete phase out by 2024 (NDAA, 2020). The NDAA also directed the EPA to publish interim guidance on the destruction/disposal methods of PFAS that are not from consumer products (Interim PFAS Destruction and Disposal Guidance, 2020). The purpose of this is to guide interested parties in their destruction and disposal decision-making processes. This interim guidance was released on December 18, 2020, with public comment due by February 22, 2021.

In addition to these policies, the EPA has created a PFAS Action Plan, the EPA Council on PFAS, has created recommended screening levels and health advisories for certain chemicals in the PFAS family, and has most recently released the PFAS Strategic Roadmap in October of 2021. *EPA's Per- and Polyfluoroalkyl Substances (PFAS) Action Plan* was published in February of 2019 with the main goals of “demonstrating the agency’s critical national leadership

by providing both short-term solutions and long-term strategies to address [PFAS]”, “provid[ing] a multi-media, multi-program, national research and risk communication plan to address this emerging [contaminant]”, and to “respond to the extensive public input the agency has received over the past year during the PFAS National Leadership Summit, multiple community engagements, and through the public docket” (USEPA, 2019). The EPA, specifically the Office of Water, has also issued health advisories for PFOS and PFOA in drinking water at 0.070 µg/L, or 70 ppt which are the concentrations at which no adverse health effects are expected over a lifetime (USEPA, 2021a). Additional EPA “standards” are in place for groundwater and include interim recommendations issued by the Office of Land and Emergency Management (OLEM) of 0.040 µg/L for both PFOA and PFOS in groundwater, and EPA regional RSLs for PFOA and PFOS in groundwater at 0.400 µg/L, and 6.01 µg/L for PFBS, which were issued in 2021 (ITRC, 2020a). The PFAS Strategic Roadmap entitled *PFAS Strategic Roadmap: EPA’s Commitments to Action 2021-2024*, aims to show how the USEPA will further research, restrict, and remediate PFAS over the coming years. The roadmap’s key actions include, but are not limited to, publishing a national PFAS testing strategy, enhancing TRI reporting, establishing national drinking water regulations for PFOA and PFOS by 2023, publishing HAs for GenX, creating an industrial effluent limitations program, including PFAS in National Pollutant Discharge Elimination (NPDES) permitting, developing and validating PFAS testing methods, establishing a PFAS Voluntary Stewardship Program, and designating PFOA and PFOS as CERCLA hazardous substances (USEPA, 2021b).

### **1.2.5 The Future/Forecast of Federal Regulations and Policies**

The EPA is currently in the regulatory development process of categorizing PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response,

Compensation, and Liability Act (CERCLA), also known as Superfund. This rule is estimated to be proposed in the spring of 2022 with a final rule expected in the summer of 2023, and would give the EPA more authority over PFOA- and PFOS-contaminated sites nationwide (USEPA, 2021b). Specifically, this would give them the ability to order responsible parties (RPs) or PRPs to conduct remediation actions and/or pay for them. As such, cleanup standards will be required for these chemicals once they are classified as hazardous substances. Currently, the interim cleanup recommendations for addressing groundwater is 0.040 µ/L (40 ppt), but this could change by the time the designation is made. These interim guidelines currently provide a benchmark for what the remediation goals of a contaminated sites may be. This also has implications for RCRA, and specifically corrective action sites. Once designated, the USEPA, state agencies, etc. will be able to enforce cleanup to the applicable standards.

### **1.2.6 Current Colorado Regulations and Policies**

As part of the State's PFAS Action Plan, there are numerous policies currently in place in the State of Colorado with the goal of addressing PFAS exposure and PFAS in the environment. These include House Bill (HB) 19-1279, HB 20-1119, Senate Bill (SB) 218, and Policy 20-1. These bills and policies deal with numerous PFAS factors including its permitting and storage and firefighting foam usage. More details on each can be found below.

HB 19-1279 – This House Bill was introduced, passed, and signed into law during the Colorado General Assembly 2019 Regular Session. The goals of this law are to manage the use, storage, and distribution of AFFFs in the State of Colorado. It primarily bans the use of AFFF for training and/or testing purposes by any person or fire department. In addition to this, the Bill created the "Firefighting Foams Control Act". This act prohibits the sale of PFAS AFFF with the exception of instances where it is still required by Federal law (e.g.: for use at airports per FAA

regulations, use at chemical plants, for use at certain fuel storage and distribution facilities), requires manufacturers to notify sellers/distributors of PFAS AFFF of the new act, requires manufacturers of PFAS-containing PPE to disclose that information, allows the Colorado Department of Public Health & Environment (CDPHE) to request certificates of compliance from manufacturers of PFAS AFFF or PPE, creates a civil penalty for any violations of the act, and requires CDPHE to conduct triennial state-wide surveys of fire department inventories and usage of PFAS AFFF (HB 19-1279, 2019). The results of the first CDPHE survey were published on January 1, 2020, and the sale of PFAS-containing AFFF was officially banned (with certain exceptions) on August 2, 2021 (PFAS-AFFF-Notification-Fact Sheet, 2019).

HB 20-1119 – This bill was introduced in January 2020 and signed into law in June of 2020, during the Colorado General Assembly 2020 Regular Session. It was designed to amend the laws designated in HB 19-1279, detailed above, and created the “Certification of Registration Program”. Whereas HB 19-1279 restricted the use of PFAS AFFF for testing, HB 20-1119 permits the use of these foams for testing until January 1, 2023, given proper containment, capture, and disposal methods are utilized. This bill also allows any facility to use and store PFAS AFFF if they have an approved certificate of registration with the State (HB 20-1119, 2020).

SB 218 – This bill was introduced and passed during the 2020 Regular Session of the Colorado General Assembly. It created the PFAS Cash Fund, the PFAS Grant Program, and the PFAS Takeback Program. The PFAS Cash Fund is designed to raise funds for the PFAS Grant Program. This is done by collecting additional fees from fuel transport of products produced in the State and on products manufactured outside the State but intended for sale/use within the State (\$25.00 per truckload). Those fees are collected until a total of \$8,000,000 is collected

within any given fiscal year. These funds are designated to support the Grant Program which will fund the sampling, assessment, and investigation of PFAS in groundwater, surface water, wastewater, and will also be used for emergency assistance for communities that are affected by PFAS either currently or in the future. The bill also created the PFAS Takeback Program which is used to purchase PFAS products from their current owners so they can be properly disposed of (HB 20-218, 2020). According to the first annual PFAS Takeback and Grant Program Report, as of December 15, 2020, the fund had raised \$819,458 and no grant applications had yet been received (2021 PFAS Takeback and Grant Program Annual Report, 2020).

Policy 20-1 – Policy 20-1, or the “Policy for Interpreting the Narrative Water Quality Standards for Per- and Polyfluoroalkyl Substances (PFAS)” also known simply as the PFAS Narrative Policy, was approved on July 14, 2020, by the Colorado Water Quality Control Commission (WQCC) to determine how they would regulate PFAS chemicals in waters until numerical standards are set in place. Since it can take a very long time to develop numerical standards, it was essential that the WQCC take action to determine potential regulatory actions, cleanup levels, etc. prior to official standards being implemented by either the Federal government or the State. This Policy created “translation levels” for certain PFAS chemicals and precursor compounds based on their interpretation of the narrative water quality standards detailed in Colorado Regulation 31: The Basic Standards and Methodologies for Surface Water (Reg. 31) and in Regulation 41: The Basic Standards for Ground Water (Reg. 41). Reg. 31.11(1)(a)(iv) says, “state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharge in amounts, concentrations or combinations which are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life” (Regulation No. 31 - The Basic Standards And Methodologies For Surface Water, 2020), and

Reg. 41.5(A)(1) says, “Groundwater shall be free from pollutants not listed in the tables referred to in section 41.5(B), which alone or in combination with other substances, are in concentrations shown to be (a) Carcinogenic, mutagenic, teratogenic, or toxic to human beings, and/or, (b) A danger to the public health, safety, or welfare” (Regulation No. 41 - The Basic Standards For Groundwater, 2020). Since these regulations do not currently have numeric standards for any PFAS chemicals, the WQCC utilized the narrative standards described above to create the translation levels. These translation levels, in ng/L (ppt), are as follows:

- PFOA: 70
- PFOS: 70
- PFNA: 70
- PFHxS: 700
- PFBS: 400,000

The translation value of 70ng/L for PFOA, PFOS, and PFNA was determined/based on the existing EPA health advisories as well as on existing toxicity data developed by ATSDR and EPA. This translation value refers to each compound individually, or the combined concentration of each. While EPA has not yet issued or included PFNA in the current health advisory, the WQCC decided to pair it with PFOA and PFOS based on its similar drafted toxicity level/minimal risk level (same order of magnitude ( $\times 10^{-6}$ )) as determined by ATSDR (ATSDR, 2021). The same translation values exist for the precursors of both PFOA and PFOS. The ATSDR drafted toxicity level for PFNA is an order of magnitude greater than those of PFOA, PFOS, and PFHxS so it was given a translation value one order of magnitude greater (700 ng/L). A slightly different approach was taken for PFBS. Its translation value of 400,000ng/L was

determined based on existing EPA toxicity values and EPA Regional Screening Levels in tap water (WQCC, 2020).

Policy 20-1 also states that the Water Quality Control Division (WQCD) should consider PFAS monitoring it in its issuance of discharge permits under the Colorado Discharge Permit System. The Policy would allow them to monitor effluent from current discharge permit holders. The permit application also indicates the WQCD may require monitoring of the effluent at any time, so this would also apply to prospective permit holders. As such, the division can also request monitoring data, and specific chemical/analytical data, under its duty to provide information clause. This can be requested from a permit holder at any time. This allows them to monitor the PFAS constituents listed in this policy for any current permit holder where their presence is suspected or expected to be present. The results of this monitoring will determine whether or not the State believes there is reason to further investigate the site and/or the potential source location, and will allow the WQCD to create site-specific effluent limits. The Policy states that monitoring, investigations, and effluent limitations should be conducted with the intention to protect surface and groundwater that are either used for drinking water or can potentially affect drinking water sources(WQCC, 2020).

## CHAPTER 2: Methods

### 2.1 Study Site

The study site for this research was the City and County of Denver, Colorado. Denver sits in a region known as the Front Range Urban Corridor with the plains to the east and the foothills and Rocky Mountains to the west. Denver itself is a mostly flat area with gradual hills to the west and northwest. There are some small/minor elevation changes throughout the area, but a lot of them can be tied to development projects and grading in the more urban areas. There are two main waterbodies in the Denver area. These include the South Platte River which runs north through the City and Cherry Creek which runs northwest through the city. The confluence of these two streams is just northwest of the downtown area. The South Platte River continues northeast from here and leads out of CCD. The groundwater in the area is generally suspected to flow towards these two waterbodies.

### 2.2 Data Sources

Most of the data used in this project were provided by the CCD Open Data Catalogue which can be found at <https://www.denvergov.org/opendata/> (CCD, 2021). This data was comprised mainly of vector data which included point, polyline, and polygon files for features such as fire stations, streams, lakes, surface elevation contours, groundwater elevation contours, zoning designations, etc. Additional data sources included the Digital Elevation Models (DEMs) and the PFAS industry and storage data. The DEMs that were used in this research were sourced from the USGS National Map Data Delivery System which can be found at <https://www.usgs.gov/core-science-systems/ngp/tnm-delivery> (USGS, 2021). Two 3D Elevation Program (3DEP) 1/3 arc second resolution DEM tiles were used as the areas encompassing Denver was split between two available tiles. The PFAS-specific data which included sites with

known and/or suspected use of PFAS within Denver was created by the CDPHE and made available through their ArcGIS Services Directory (CDPHE, 2021).

The coordinate system used for this project was “NAD 1983 HARN StatePlane Colorado Central FIPS 0502 (US Feet)”. Since the majority of the data came from the same source, no data conversions were necessary to complete the subsequent analyses. ArcGIS Pro was used for all of the data manipulation and analyses discussed in the following sections.

### **2.3 Analytical Methods**

In order to complete the objective of this project and identify potential PFAS impacted sites in Denver, some basic initial analyses would need to be conducted on the data. As previously discussed, a site’s proximity to fire stations, industrial areas where PFAS are stored and/or used, sites that are suspected dischargers of PFAS, HUF/landfill areas, and groundwater flows/paleochannels are a few significant factors in relation to identifying the potential presence and buildup of PFAS.

To start, the DEMs would need to be modified. Manipulation of the DEM data included the mosaicking or combining of the two DEMs for the Denver area. The combined DEM was used to generate a surface elevation contour polyline dataset which then, along with groundwater elevation contour polyline data, was converted into rasters. These analyses were conducted prior to any additional analyses. These new rasters along with the newly combined DEM would then be used to run various hydrologic analyses to determine flow accumulation on the surface (to be compared to known streams), and underground (groundwater flows). From the groundwater polyline raster, the flow direction was determined by creating a new raster of the flow direction from each cell within the map area to its neighboring steepest downslope cells. This is done using tools that look at the value of each elevation cell and determine which direction water

would flow from that cell based on the slope and elevation of the neighboring cells. This can be done using single flow direction (SFD) or multiple flow direction (MFD). One example of the SFD method is called D8. This takes one cell and looks at the neighboring 8 cells to determine which direction flow would be based on the differences in elevation values. This method takes the largest difference in values and assigns the flow direction towards that cell. Flow direction can go in one of 8 directions based on 45-degree angles beginning at 0 (directly above the cell) and moving clockwise to each cell surrounding the input cell. In SFD, each cell or pixel only has one flow direction associated with it. MFD uses a similar approach but allows the flow direction to move in more than one direction from the input cell based on the slope and the elevation of the neighboring cells. This results in more accurate flow direction because it takes into account every potential flow in a downslope direction from the input cell. For this analysis, MFD was utilized to create a new raster of flow direction. Then using this new raster, the flow accumulation tool was used to determine into which cells most flow would accumulate. Flow accumulation was determined by calculating the total number of cells that eventually flow into the output cell or endpoint. This helps give an idea of the total upslope area that contributes water to that cell or location. The result was an approximate paleochannel or where groundwater from a certain area tends to accumulate before continuing further downgradient. This new layer was then used to identify the areas where groundwater would likely flow from any given point, and would help determine where PFAS that have infiltrated into groundwater may end up over time. The idea here was that these flow accumulation locations could be used to help determine where large portions of dissolved PFAS released into the surface or into groundwater may eventually end up after its release. Once completed, the additional point and polygon datasets

(i.e., fire stations, HUF locations, industrial locations suspected of using PFAS, and locations with registered quantities of PFAS) were added to the map.

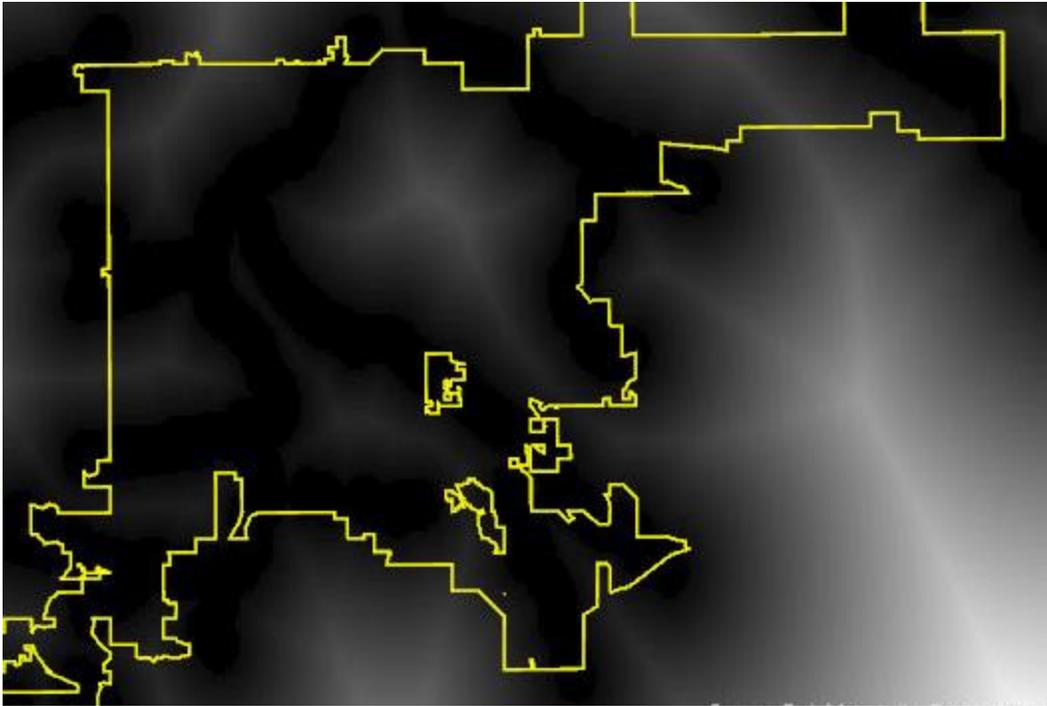
Once all pertinent data was added to the map, the site suitability analysis could be conducted. This was done using fuzzy logic. Fuzzy logic is a type of logic that deals with approximate reasoning. Other types of logic, like binary logic deal, with precise reasoning where values of 1 or 0 (true or false) are assigned based on certain factors. With fuzzy logic, on the other hand, values other than 1 or 0 can be assigned based on a degree or possibility of truth rather than on a certainty of truth. This type of logic would be useful in this particular site suitability analysis due to the fact that there are numerous factors being used to assess the potential presence of PFAS (proximity to industrial zones, fire stations, etc.), but none of them can certainly tell whether or not PFAS will in fact be present and it is unknown which factor may be more influential than another. Rather, they can tell whether or not it is possible PFAS may be present. Another more common type of site suitability analysis is a weighted site selection/suitability analysis. In contrast to the fuzzy logic analysis, a weighted site suitability analysis applies different weights or significance to each input criteria. A common scale is applied to each criterion and then a weight (0-100) is applied to each, with the total of the weights equaling 100. Criteria that are more significant will be given a higher weight value compared to those that are less significant. This is a great tool to use when the significance of each input criterion is known in relation to the hopeful outcome. For instance, when attempting to find a suitable sites for a specific species of nesting bird, one may know that the type of vegetation is more important than the distance to a water body so the vegetation type criterion would have a higher weight in the suitability analysis. In this case, fuzzy logic makes more sense to utilize because the individual significance of each criterion impacting the likely presence of

PFAS is unknown/uncertain. One may argue that the proximity to a suspected industrial discharger of PFAS would carry more weight than the proximity to a HUF area, but in this case those suspected dischargers are only assumed due to their industrial processes and may not even use PFAS chemicals. Since some of the input criteria are not exact, and since it is unknown which would be more influential on the potential presence of PFAS in the environment, fuzzy logic was determined to be the best method. It would be used to approximate the locations of potential PFAS impacted locations based on the combination of various factors that may play into the likelihood of PFAS compounds being present.

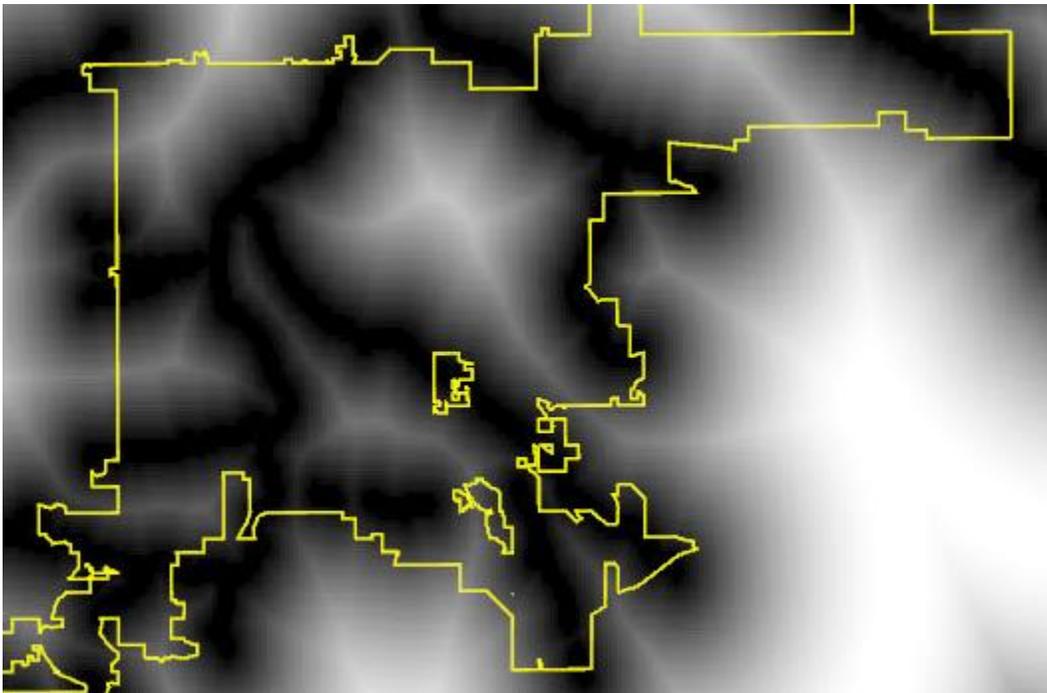
In order to successfully complete the fuzzy logic, the various factors that would later be used to determine site suitability would first need to be identified. In this case, they were proximity to fire stations, proximity to industrial facilities suspected of storing and/or using PFAS, proximity to sites who self-reported to the State of Colorado their storage of PFAS, proximity to HUF area, and proximity to streams and groundwater flows. The way fuzzy logic works using these types of factors involves assigning membership values to different cells within and surrounding each of these input factors. Typically, to create a layer representing a distance from or proximity to certain features would be done using the buffer tool, but since values need to be assigned to specific cells based on their proximity to a feature, rasters needed to be created for each input factor representing the distance of each cell in the raster to that feature. This was done by calculating Euclidean distances, which determines the distance from each cell within a raster to the closest input feature such as fire stations. The result of the Euclidean Distance analysis uses gradient color symbology to visually show which cells are closer to an input and which are further. The standard default shows close cells as black and further cells as white. This was done for each of the input features mentioned above, and once completed, Fuzzy

Membership was applied to each new raster assigning high membership values to those cells closest to the input features and low membership values to those cells further away, resulting in new Fuzzy Membership rasters. In this case, high membership areas would represent those area where PFAS are more likely to be encountered in the environment based on that specific input feature.

The resulting Fuzzy Membership rasters were then combined using the Fuzzy Overlay tool. This was used to calculate the areas where PFAS would be most likely to be found in the environment based on a combination of all of the input factors' membership value rasters. Essentially, locations that had high membership values for each input would be considered the most suitable sites for PFAS impacts, while those locations where the overall membership values were low would not be suitable. Once the Fuzzy Overlay analysis was completed, the resulting raster's symbology was changed to a green-red color gradient to make the results easier to understand visually. Figures 1 and 2 below show examples of Euclidean distance and fuzzy membership when applied to the groundwater flows data derived from the groundwater elevation contour data. In both of the instances the darker areas represent locations closer to groundwater flows, while the light-colored areas are further away.



*Figure 2-1: Euclidean distance applied to groundwater flows*



*Figure 2-2: Fuzzy membership applied to groundwater flows*

### **CHAPTER 3: Results**

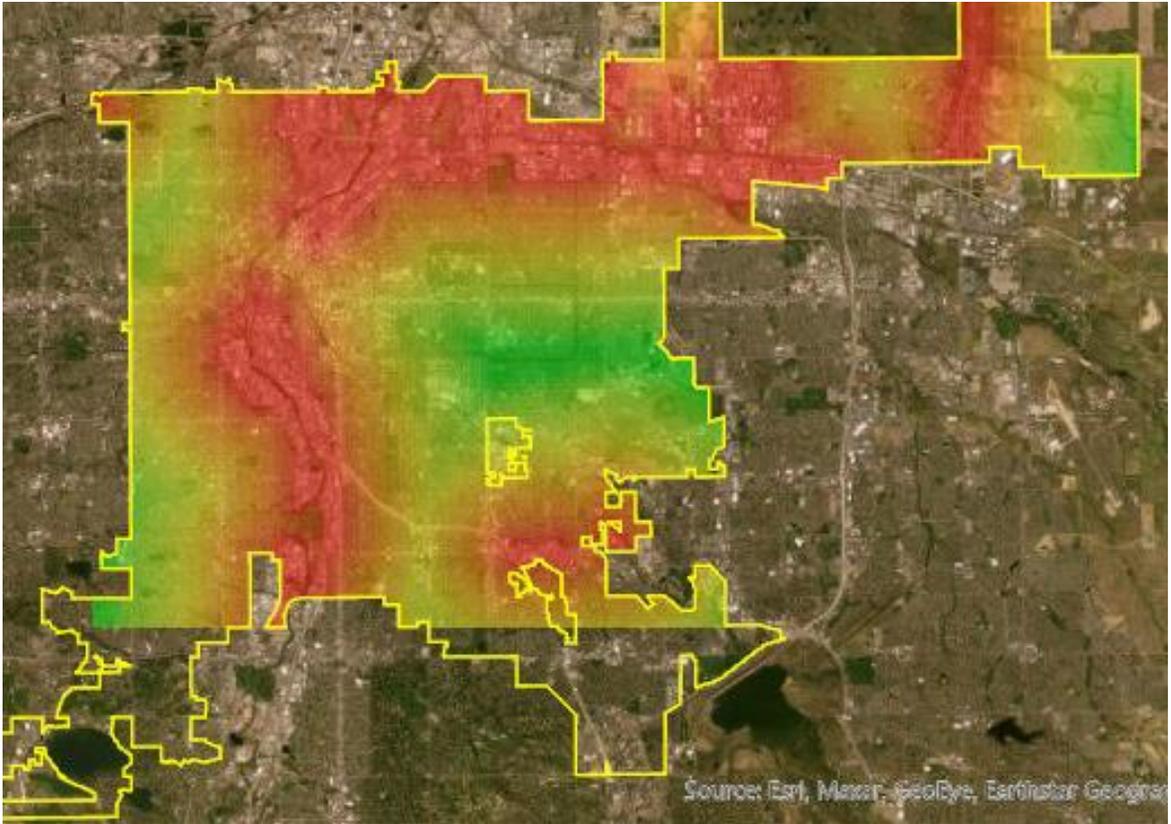
The goal of this analysis was to identify locations within Denver, CO that could potentially be impacted by PFAS based on their proximity to fire stations, industrial sites suspected of using and/or storing PFAS, sites with registered quantities of PFAS, HUF areas, and groundwater accumulation areas. The fuzzy logic analysis was designed to assign values to each cell in the map ranging from 0 to 1 with 1 being closest to and 0 being further from each input factor. This cell valuation was done with each of the input factors in the fuzzy membership step of the process creating new rasters for each. Once completed, each fuzzy membership raster was combined to determine which cells that had the highest combined values, and which had the lowest. The cells with high combined values would be considered suitable while those with low combined values would be considered unsuitable. Suitable cells were colored red and unsuitable ones were colored green while the remaining cells were colored along a gradient from green to red depending on their values between 0 and 1.

The result showed that the overall most likely locations where PFAS may be encountered in the environment were mostly in heavier industrial areas along the South Platte River corridor from south Denver north up towards the downtown area. These general areas also happen to be where most of the City's HUF areas are located (most HUFs in Denver can be found adjacent to the South Platte), where there is a larger portion of the City's fire departments due to the proximity to more urban and industrial areas, and where clusters of suspected and registered PFAS facilities can be found. Figure 3, below, shows the resulting heatmap of this Site Suitability analysis.



South Platte River and I-25 with the major hotspots being found within the Globeville, Five Points, Auraria, Lower Highlands, and Central Platte Valley neighborhoods. These specific neighborhoods have a long environmental history that includes the presence of current and historic Superfund sites as well as numerous other voluntary cleanup sites, corrective action sites, environmental covenant sites, and heavy industrial sites such as oil refineries, ore processing factories, and bulk fuel farms. Additional suitable areas or hotspots are found scattered throughout other portions of the city particularly near the Denver Health Hospital campus located just south of downtown Denver, near the University Hills area, and in a heavy industrial area located north of I-70. Another significant hotspot can be found in Glendale which is located in the middle of Denver but is its own municipality. While not in Denver, this location could potentially also impact environmental media within Denver city limits.

It is apparent that the suitable locations make up a rather large area, but this result represents a good starting point for potential investigations. Compared to a previous rendition of this analysis which included all properties zoned as industrial rather than just sites suspected of using and/or storing PFAS or sites with registered quantities of PFAS, the results are much more refined and specific. This can lead to more efficient and effective site investigation and characterization across the city. The results of the previous heatmap can be seen in Figure 4. The results of the updated site suitability analysis are not especially surprising, especially the resulting areas where there are clusters of facilities near the South Platte and known HUF areas, but compared to the previous analysis, are much more precise and give a more accurate view of likely impacts.



*Figure 3-2: Results of previous PFAS heatmap*

## **CHAPTER 4: Discussion**

### **4.1 Discussion**

The results of this research indicate that there are numerous areas in Denver that may be potential sources of PFAS contamination or may be contaminated with PFAS from offsite sources. This is due to the fact that Denver has large areas that include the multiple factors that influence the potential existence of PFAS in the environment, including the presence of large industrial areas that house facilities that use and/or store PFAS, numerous HUF areas, groundwater flow/accumulations areas consisting of two significant paleochannels that generally follow the South Platte and Cherry Creek, and numerous fire stations. Interestingly, in Denver many of these factors are found in the same general areas, so it made the analysis somewhat simple. The industrial areas and most locations where suspected users/storers of PFAS are located can be found mainly along the South Platte and along I-25. Along the South Platte also happens to be where most of the City's HUF areas are located, where a major groundwater accumulation flow was calculated to be, and where a majority of the fire stations exist due to a higher density of the population and industry living within the general proximity of the South Platte River.

These results are significant because they can be used to inform the local public health and environmental agency, the Denver Department of Public Health & Environment (DDPHE) of locations where PFAS may be present in the environment at unacceptable quantities, which is especially significant given the inevitable regulation of some of these chemicals by both state and federal agencies. This is especially significant for properties owned by CCD or ones where CCD has some form of ownership interest like an easement, as CERLCA can apply to any party associated with the title of a property. Having this knowledge may help DDPHE conduct

voluntary site investigations, characterizations, and even remediation of city-owned properties ahead of the release of new regulations. By being proactive it is possible that the city may avoid enforcement actions and oversight by CDPHE and federal government agencies like the USEPA which would reduce the financial liability and time-consuming burden that would likely come with them.

One especially interesting result of the heat map can be found in North Denver, specifically within the boundaries of a current Superfund National Priorities List (NPL) site. The Vasquez Boulevard/I-70 (VB/I-70) Superfund site is associated with the historic operation of two smelters, the Omaha & Grant Smelter and the Argo Smelter, which caused the deposition of heavy metals onto the surrounding land. The main contaminants of concern here were and are arsenic and lead (USEPA, n.d.). PFAS hotspots were identified in this analysis that are located within the boundaries of Operable Unit (OU) 1 and OU2. OU1, which included soils of approximately 4,500 residential yards in the general vicinity of the smelters, was delisted from the NPL in 2019 after soil testing and the subsequent remediation and disposal of impacted soils (USEPA, n.d.). While delisted, OU1 only included residential properties so no testing or remediation was conducted in industrial areas. PFAS hotspots can also be seen in OU2, which is the former location of the Omaha & Grant Smelter and is owned by the CCD. OU2, whose contaminants of concern are arsenic and lead in both soil and groundwater, is still active on the NPL with remedial investigations currently ongoing. Some remediation has taken place within OU2 as part of the installation of the Globeville Landing Outfall in 2018, but a workplan is currently being finalized so that more investigations can begin in 2022 to address data gaps across the site (USEPA, n.d.). This is significant because given the potential for PFAS impacts to be present at these sites and the fact that the EPA is planning on regulating certain PFAS

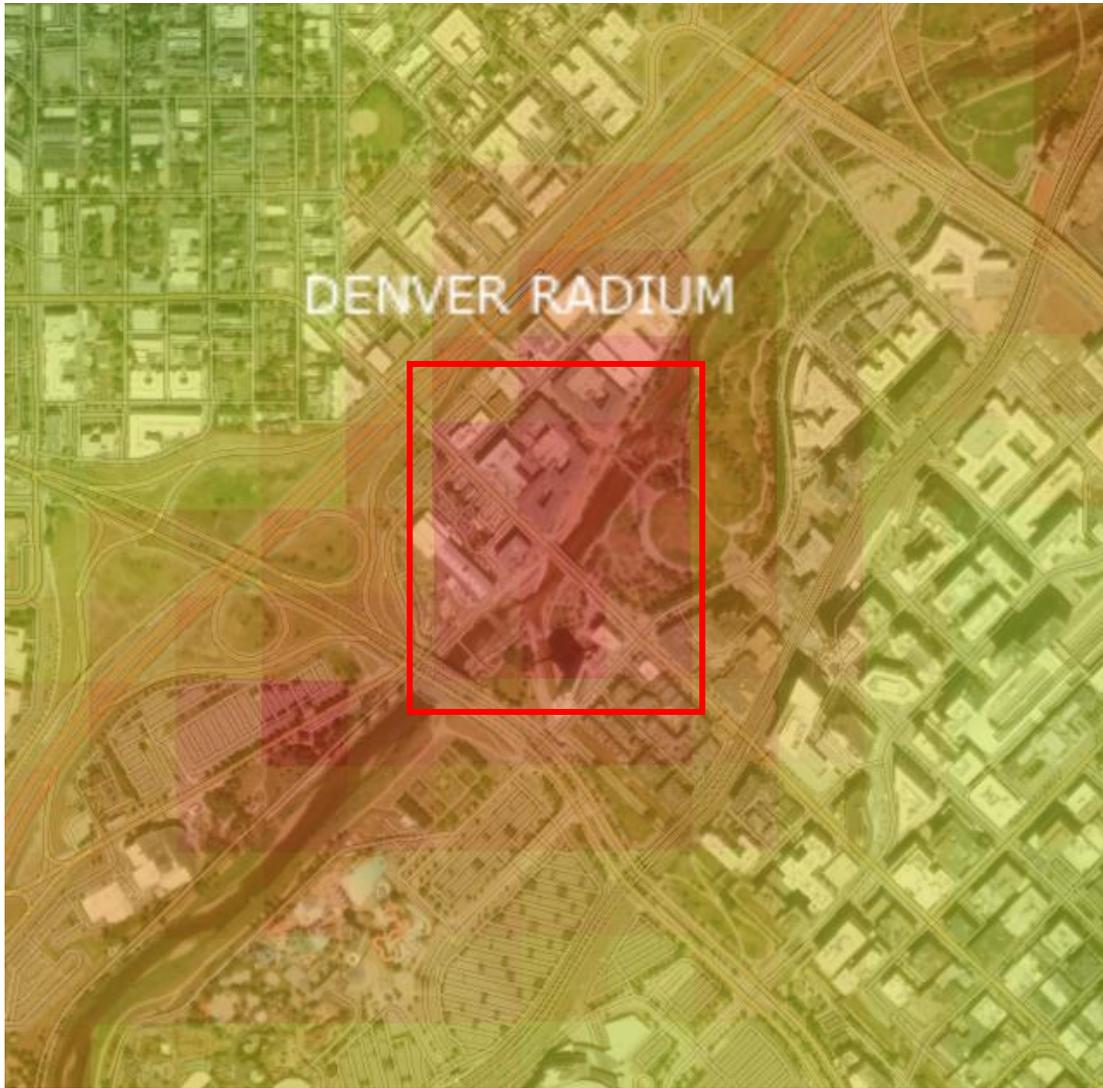
compounds under CERCLA within the next year to two years (USEPA, 2021b), CCD could be faced with additional site assessment and remediation orders at a Superfund site that has already been in its purview for decades, or could be faced with a new Superfund site that intersects the boundaries of an existing one. The addition of a new Superfund site where CCD is a PRP would mean years of investigation, remediation, monitoring, and reporting, which all come with a significant financial burden and need for a substantial amount of labor-hours. On the other hand, since some remediation has already taken place, it is possible that PFAS impacts may have unknowingly been remediated and either no contamination or acceptable concentrations of PFAS may be found, resulting in no further action being necessary. Figure 5, below, shows the hotspots within the VB/I-70 boundary.



Figure 4-1: PFAS Hotspots with the VB/I-70 boundary (VB/I-70 outlined in blue)

Additional locations where hotspots are located intersect or include locations that have already undergone some form of remediation. For instance, another hotspot exists in the area of Shoemaker Plaza which is adjacent to the South Platte just west of downtown Denver and a former Superfund site (Denver Radium Site OU6A). CCD and DDPHE were extensively involved with these sites due to partial ownership across both. Denver Radium Site OU6A was remediated in the early 1990s to remove radiological material and polycyclic aromatic hydrocarbons (PAHs) in soil (DDPHE, 2014) and during the redevelopment of Shoemaker Plaza, soils impacted with coal tar and other hydrocarbons was excavated and disposed of offsite. Given the extensive excavations that took place during these remediation processes, it is possible

that any PFAS contaminated soils were also removed, although it could be possible that PFAS-impacted groundwater could remain. This hotspot location can be seen in red in Figure 6 below.



*Figure 4-2: Shoemaker Plaza and Denver Radium Site OU6A (outlined in red)*

With the exception of land located within the VB/I-70 Superfund site, the former Denver Radium site, and a few park locations, CCD is not a clear owner of any of the properties/locations where the hot spots are found. The main CCD ownership interest in the remaining hotspots includes right-of-way (ROW), which could limit potential city liability in the event of CERLCA designation of PFAS as ROW is highly unlikely to have been a source of any

contamination. That being said, since CCD has ownership of these lands, it could be liable for remediation efforts and if a clear potentially responsible party (PRP) cannot be identified, CCD would likely take on any investigation, remediation, and financial responsibilities associated with them.

#### **4.1.1 Sampling / LSI Needs and Priorities**

With the knowledge of where potential PFAS hotspots are located within Denver, the next step would be to begin preliminary site assessments or limited subsurface investigations (LSIs). Since CCD is not an outright owner of most of the hotspots identified in this study, it should prioritize the sites where it currently has ownership interests. This would primarily be within the boundaries of OU2 of the VB/I-70 Superfund site, where CCD/DDPHE is already working with CDPHE on groundwater investigations, locations within the Central Platte Valley such as the Central Platte Campus (CPC) which is home to CCD's Department of Transportation and Infrastructure (DOTI), and the fire stations and training facilities located within hotspot areas.

Additional priority locations include the former Stapleton International Airport (SIA) property, the Denver International Airport (DEN) property, the former Lowry Air Force Base, and the Roslyn Fire Training Center. These were not included in this suitability analysis because it can be supposed with a high level of certainty that PFAS impacted soils and groundwater already exist at these sites. Due to the requirements set forth by FAA and the Department of Defense (DoD), these airports and air base would have been required to train with and perform tests using PFAS AFFF. In addition to that, there was a major airplane crash at SIA and a bulk fuel farm fire that required the use 56 million gallons of water and 28,000 gallons of PFAS AFFF concentrate to extinguish (NTSB, 1990). The Roslyn Fire Training Center is the main fire

departments across the greater Denver area and AFFF has historically been used there, although the total quantities are unknown. These four sites could also very well become regulated under CERCLA and would benefit from preemptive and proactive site assessments and subsequent remediation as necessary.

For locations where CCD does not have any ownership issue, they could work in conjunction with CDPHE to identify sites where preliminary assessments and LSIs may be needed to ensure there is no significant threat to human health or the environment. CDPHE has the authority to order such investigations and the subsequent remediation as necessary, and can lean on CDPHE for oversight, report review, and general assistance. This will be especially true once PFOA and PFOS are regulated under CERCLA.

#### **4.1.2 Land Use Impacts**

If PFAS contamination is identified in any of these hotspots there would be various land use impacts that could coincide with them. Known contamination could result in CDPHE placing environmental covenants on properties which could limit site uses and could limit/restrict the use or access to soils and groundwater for any reason until it can be proven that the site has been sufficiently cleaned and is protective of human health and the environment. Specifically for CCD, this would limit its ability to acquire real property or ROW. According to Denver Executive Order 100: (XO-100), CCD should avoid acquiring any contaminated property whenever possible or should budget sufficient remediation funds if acquisition is unavoidable (CCD, 2016). These acquisitions include ROW acquisitions associated with new developments. Typically, CCD will acquire fee title ROW during new developments so it can implement infrastructure like utility corridors, streets, emergency access, etc. Fee title acquisition is preferred as it gives the city ownership of that property and the rights to make improvements in

the future. Developers also prefer this as it limits their responsibilities associated with that property once development is complete. Prior to any conveyance of property to CCD, DDPHE must conduct an environmental review, per XO-100, to identify any potential recognized environmental concerns (RECs) and based on those reviews, can either approve the conveyance, deny it, or request additional information like a Phase II ESA to show whether or not undocumented contamination exists at that property. Once PFAS are regulated under CERCLA, these Phase II ESAs could potentially become more expensive and complicated if PFAS needs to be screened for in environmental media in addition to other typical contaminants of concern like RCRA-8 metals, volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), etc. Based on the results of the heatmap, many locations within Denver would now be considered to potentially have PFAS impacts, so it would need to be proved that they do not exist before any fee title acquisitions can be made. Many of the hotspots are located in areas where extensive redevelopment is being planned and if PFAS contaminated property is identified or suspected, CCD would not be able to take fee title ownership of ROW in those cases, per XO100, which could complicate, delay, and even cancel potential developments. This could in turn result in negative financial impacts on the city in the form of revenue lost.

## **4.2 Conclusions**

This analysis identified numerous potential PFAS hotspots across a large portion of Denver. It was determined that a large portion of them exist along the South Platte River corridor which overlaps with many of the city's heavy industrial areas as well as a large portion of its known HUF locations. These factors combined with the proximity to additional influencing factors like fire stations make them good candidates for having environmental media impacted with PFAS. While these results are a good jumping off point for future site assessments, they

cannot prove for certain or exactly where PFAS impacts may actually exist. The only way to do this for certain is with field work consisting of intrusive site investigations, but the results at least provide a guide detailing where these investigations should initially take place. Future federal and state regulation may soon require such assessments to be conducted, so it would be beneficial for CCD to get a head start and show that they are being proactive in their attempts to protect human health and the environment from PFAS contamination. This has the potential to result in remediation and removal actions prior to more stringent regulations which could result in the potential addition of Superfund site designations within Denver along with timely and costly remediation and monitoring efforts.

This heatmap, and its associated analyses, is intended to be a living “tool” that can have additional input factors and data added to it as they become available, and can even be used to assist with the identification of PRPs. Continuing to incorporate data and characteristics of groundwater and soil, such as soil type, groundwater/soil conductivity, etc. would help further improve upon this research. This data would allow one to determine, more specifically, the likely paths, rate of transport, etc. in soil and groundwater, and would help further determine the approximate fate of PFAS contaminants from suspected hotspots. That being said, the current heatmap is a good starting point that can be used to guide CCD’s decision-making process when it comes to addressing PFAS in Denver.

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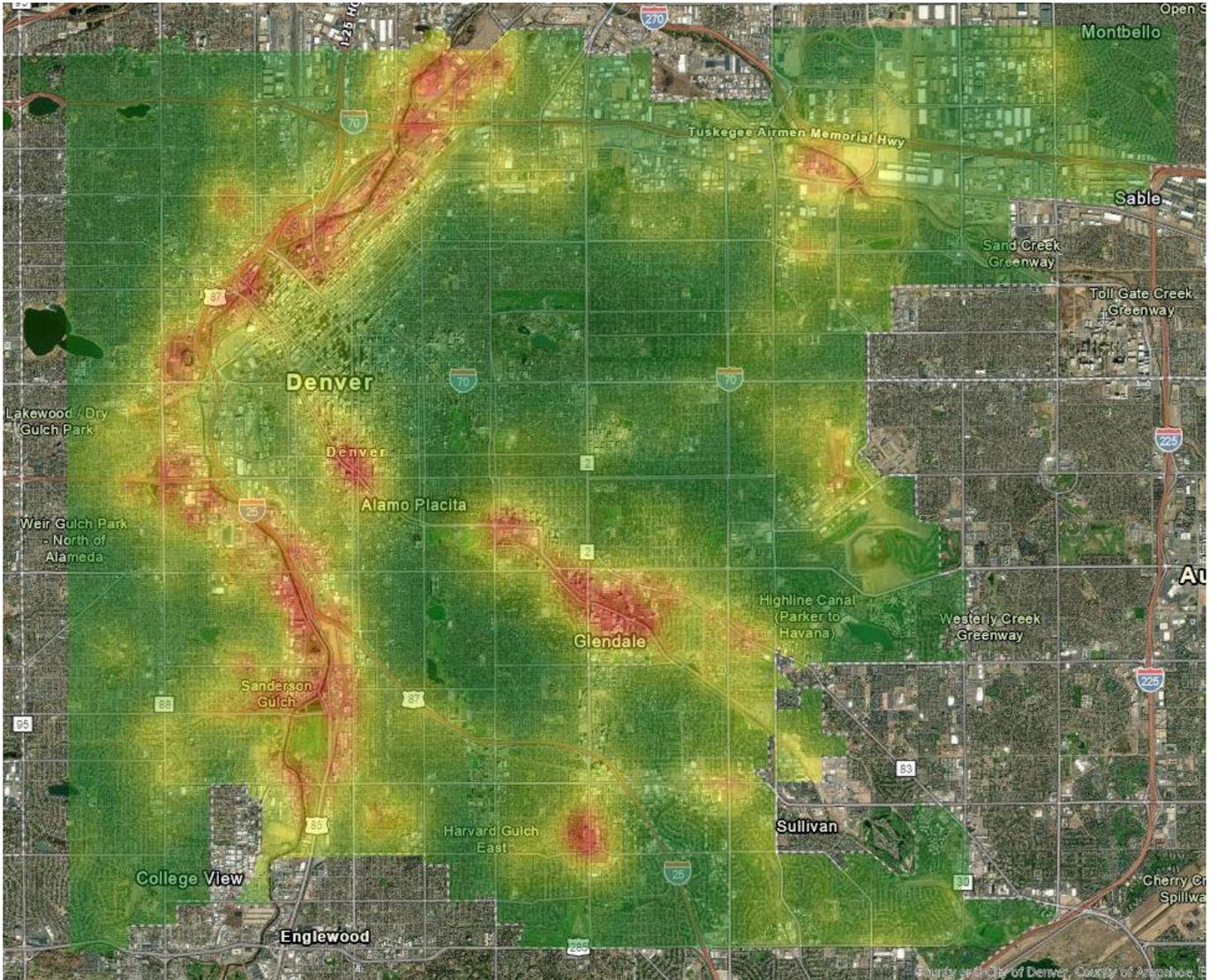
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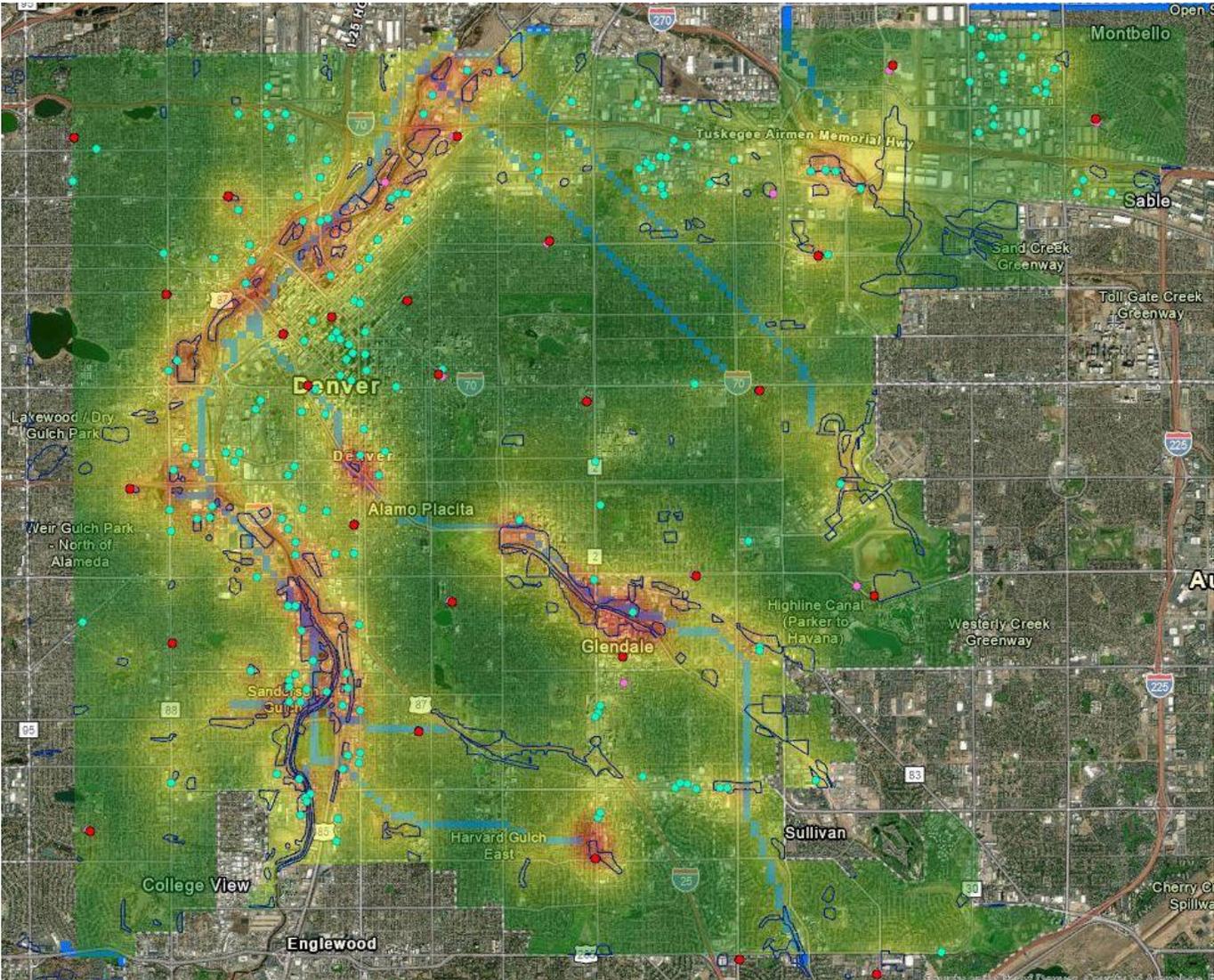
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## **APPENDIX**

## Appendix A: Final Heatmap Results



Final Heatmap Result



Final Heatmap Result with Input Factors Visible