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Staying Fresh: Unconventional Approaches Towards Advancing Energy Sustainability, Water Resources, and Community Resiliency in the Southwestern United States

Judith Hoyt
University of Texas at El Paso

STAYING FRESH: UNCONVENTIONAL APPROACHES TOWARDS ADVANCING ENERGY SUSTAINABILITY, WATER RESOURCES, AND COMMUNITY RESILIENCY IN THE SOUTHWESTERN UNITED STATES

JUDITH R. HOYT

Doctoral Program in Geological Sciences

APPROVED:

Benjamin Brunner, Ph.D., Chair

Mark Engle, Ph.D.

Gail Arnold, Ph.D.

Richard Langford, Ph.D.

Aaron Velasco, Ph.D.

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

DEDICATION

To my mentors – Benjamin Brunner, Mark Engle, and Nicholas Pingitore – who taught me more than they will ever know.

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JUDITH R. HOYT, M.Ed., B.A.

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ABSTRACT

This dissertation addresses critical challenges in urban heat management, sustainable energy resource utilization, and water quality communication through three studies. Study 1 investigates the impact of roof color on urban heat islands in Tucson, Arizona where approximately 70% of roofs display high albedo (i.e., light) colors. Energy consumption simulations conducted indicate that converting dark- to light-colored roofs could save Tucson approximately $1,400,000 annually in energy costs, highlighting the potential of cool roofs for energy savings and improved thermal comfort. Study 2 assesses the sources of lithium in subsurface waters in West Texas and South Central New Mexico. Water chemistry data from the Hueco, Mesilla, Tularosa, and Jornada del Muerto Basins were analyzed to predict lithium (Li) endmember composition using positive matrix factorization (PMF). Lithium is pivotal in energy storage and PMF source apportionment helps the assessment of the economic potential for Li extraction. The PMF model identified two out of four factors (i.e., sources) with high Li contributions, averaging 0.082 mg/L for Factor 1, a shallow, low-salinity water source, and 0.089 mg/L for Factor 2, an older groundwater source influenced by mineral dissolution from old evaporite deposits. Study 3 examines effective written communication of water quality data to the public, which is essential for informing residents about their water's safety. The complexity and variability of reports hinder public understanding, especially in communities with diverse linguistic and cultural backgrounds. Based on an evaluation of established practices in regulated water quality reporting in diverse communities, a water quality reporting template for the immediate implementation by researchers was developed. Together, these studies contribute to the fields of urban planning, sustainable energy, and public health communication, guiding policymakers, researchers, and practitioners in addressing these pressing challenges and promoting sustainable development.

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1. INTRODUCTION

1.1 Background

Most Earth scientists look at the challenges society faces through a multifaceted, interconnected lens. This perspective comes from the recognition that earth processes do not act independently. Rather, they are interwoven – connected to, affected by, and informed by each other; they are part of a system. When parts of this system change, making the planet less habitable, scientists and engineers respond by delving into the intricate tapestry of interactions that govern our world, seeing these challenges not as problems, but rather as opportunities for solutions. These solutions often arise from a deep understanding of the natural world's complexity and from innovative approaches that draw upon the interconnectedness of earth systems to foster resilience and sustainability.

Consequently, solutions proposed by earth scientists are not isolated fixes but are integrated strategies that recognize, utilize and sometimes foster symbiotic relationships within natural systems. For instance, addressing the urban heat island (UHI) effect in cities in the Southwestern United States, through the implementation of light-colored roofs is not just about cooling individual buildings. It is about understanding how these changes can influence the broader urban ecosystem, leading to reduced energy consumption and improved public health (Santamouris, 2014). This approach exemplifies how a single intervention can have cascading benefits, reinforcing the need for holistic solutions that consider the broader environmental and societal context. Such solutions hold the potential to impart monumental change, transforming entire communities and ecosystems. However, difficulties in effectively communicating complex ideas and associated uncertainties to the public and sometimes even to other scientists can hinder their implementation. The gap between scientific discovery and public understanding represents a profound barrier. Bridging this gap requires not only clear communication but also the ability to connect timely information on a level that resonates with diverse audiences, fostering a shared vision and engagement for a sustainable future.

A sustainable future is not possible without successfully bridging the gap between the rapid development of scientific ideas, methods and ever-increasing complexity and community engagement at all levels. The nature of groundwater flow provides a fitting metaphor for this challenge. Just as groundwater moves silently beneath our feet, carrying minerals like lithium that reveal hidden stories of the Earth's interior and surface processes, so too must our efforts to disseminate scientific information permeate society. The lessons learned from the subterranean journeys of water teach us that to reach every corner and to nourish the roots of understanding, communication must be persistent and pervasive. Just as groundwater sustains life by slowly and steadily making its way through unseen pathways, our dissemination of knowledge must find its own channels, making its way into the hearts and minds of the public.

1.1.1 Statement of the Problem

This dissertation focuses on three interconnected themes, each reflecting the concept of intense interaction between human endeavors and natural processes. The investigation into UHIs and mitigation efforts, the search for alternate sources of lithium from groundwater, and the development of effective communication strategies for water quality results are distinct topics. However, they are informed by each other through the overarching need to understand and harmonize human impacts on the environment. These themes illustrate how local solutions can have broader implications for sustainability and environmental stewardship. Each of these challenges plays a significant role in shaping public health, energy consumption, and environmental sustainability, yet they are often approached in isolation rather than through an integrated lens that acknowledges their interconnected nature.

The UHI effect, particularly in cities such as Tucson, Arizona, results from the increased absorption of solar energy due to dense urban development and reduced vegetation (Knight et al., 2021). This phenomenon leads to higher ambient temperatures, elevated energy consumption, and adverse public health outcomes, necessitating sustainable mitigation strategies (Singh et al., 2020). Global warming and elevated energy consumption ties into the goal to reduce greenhouse gas emissions and to transition to an electricity-driven society, which drives increased demand for resources such as lithium. This brings us to the realm of sustainable energy, where the underutilized geothermal resources in regions such as West Texas and South Central New Mexico represent an interesting solution. Economic and logistical barriers have hindered the exploitation of these renewable energy sources. Additionally, the potential for co-extraction of mineral resources such as lithium, from geothermal waters remains largely untapped (Richter, 2021; Sengun Cetin et al., 2024), posing an opportunity for enhancing the economic viability of geothermal projects and supporting the growing demand for lithium in renewable energy technologies. UHI, geothermal energy, and lithium extraction then tie into the topic of water availability and quality. Research on these topics directly links to the effective communication of water quality information which is another pressing issue. Water quality reports are essential for informing residents about the safety of their drinking water. However, the complexity and variability of these reports can impede public understanding, particularly in communities with diverse linguistic and cultural backgrounds. Clear and accessible communication is crucial for ensuring that residents can make informed decisions about their water use and trust in the safety of their water supply.

1.1.2 Scope and Delimitations

The scope of this dissertation encompasses specific geographic areas and methodological approaches tailored to each study's objectives. Study 1 focuses on the residential, commercial, and industrial roofs in Tucson, Arizona, examining their impact on UHIs and energy consumption. Study 2 involves groundwater sample data from the Hueco and Mesilla Bolsons in West Texas, as well as the Tularosa and Jornada del Muerto Basins in Southern New Mexico, to assess lithium distribution and concentration. Study 3 investigates local practices in El Paso, Texas, and examines broader regulatory mandates to enhance the communication of water quality results.

The delimitations of this dissertation exclude economic analyses and other mitigation strategies not directly related to the primary research objectives of each study. This ensures a concentrated and focused examination of the specific challenges and solutions addressed in the dissertation.

1.1.3 Chapter Summaries, Purpose, and Significance

This dissertation addresses interconnected environmental and public health communication challenges through innovative and unconventional approaches. The first study investigates a relatively novel approach of using roof color as a proxy for albedo to mitigate UHIs, a pressing issue in Southwestern cities like Tucson, Arizona. UHIs result from increased absorption of solar energy in densely built environments, leading to higher temperatures, elevated energy consumption, and adverse public health outcomes. The phenomenon is particularly pronounced in rapidly urbanizing areas, where conventional building materials and reduced vegetation exacerbate heat retention. This study investigates the use of light-colored roofs as a mitigation strategy for curtailing the effects of UHIs, by quantifying the distribution of roof colors, examining the impact of roof color on land surface temperatures, simulating energy savings for individual residences by altering roof colors, and estimating the potential energy savings for the entire Tucson metropolitan area. By highlighting the impact of light-colored roofs on reducing land surface temperatures and energy consumption, this research offers a cost-effective approach for urban areas experiencing extreme heat. This study illustrates how small, intentional changes can ripple through urban ecosystems, creating a cooler, more sustainable living environment.

The second study addresses the quest for alternate sources of lithium, an essential element in the age of renewable energy. Geothermal resources, which offer a promising renewable energy source, remain underutilized in regions such as West Texas and South Central New Mexico due to economic and logistical challenges (Bureau of Economic Geology, 2021). By analyzing groundwater constituent data and employing positive matrix factorization for source apportionment, the research aims to uncover specific sources of lithium in subsurface waters. Specifically, this study focuses on the distribution and concentration of lithium in subsurface waters in this region, to inform future work by other scientists focusing on innovative approaches that enhance the economic viability of geothermal energy projects through mineral commodity co-extraction. This research contributes to the understanding of locally sourced, minimally invasive lithium supply chains, and offers innovative solutions for the economic and logistical challenges of geothermal resource exploitation.

The third study turns attention to the crucial task of improving water quality communication to the general public. Water quality reports are a vital public health resources and are essential for informing residents about the safety of their drinking water. However, the complexity and varying content of these reports can hinder public understanding, especially in communities with diverse linguistic and cultural backgrounds. This study examines established practices in regulated water quality reporting, evaluates their effectiveness, and offers best practices for clear, accessible, and culturally sensitive communication. Through the development of a comprehensive water quality reporting template, the hope is to bridge the gap between scientists and residents, fostering better understanding and trust in scientific findings. Effective communication is key to promoting collaborative efforts between scientists and the communities they seek to assist.

These studies while distinct in their focus, are united by a common thread: the credence that scientific inquiry and practical solutions are most impactful when they embrace the complexity and interconnectedness of the world. By navigating the delicate balance between rigorous analysis and empathetic communication with the public, this research strives to honor Gaia's wisdom and contribute to a more harmonious coexistence between nature and society.

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2. HOT SUN, COOL ROOF: AN ENERGY- AND COST-EFFECTIVE SOLUTION FOR MITIGATING URBAN HEAT ISLANDS IN TUCSON, ARIZONA

2.1 Abstract

Tucson, Arizona is located within the hot semi-arid climate zone within the Sonoran Desert. In 2020, Tucson experienced a record-breaking 108 days of temperatures exceeding 100°F (37.8°C), prompting the urgent need for mitigation and adaptation efforts to safeguard vulnerable populations from warming associated with climate change. Cool roofs provide Urban Heat Island (UHI) mitigation as they have high albedo values, while significantly reducing indoor temperature and energy consumption in buildings. In this study, roof albedos in Tucson were evaluated using color as a convenient proxy, understanding that such factors as materials, construction, insulation, etc., also play significant roles in building heat capture. The colors of ~2,500 roofs were recorded by random sampling of the points on an orthogonal grid (i.e., point-counting) overlain on a satellite image of the city. Roughly 70% of the sampled roofs displayed high albedo colors of white or light gray. GIS software was used to establish a ground truth correlation between roof colors and land surface temperatures. This was achieved using daytime imagery from the Landsat 8 satellite, including data from the OLI and TIRS sensors with 15 m spatial resolution in the panchromatic band and 30 m resolution in the reflective and thermal bands. From this comparison, it was found that these developments are correlated to lower overall Land Surface Temperatures (LST). Similarly, LSTs were compared in adjacent housing developments with light and dark roofs. Higher pixel values confirmed that dark roofs contributed to warmer land surfaces in these developments. Using eQUEST, a building energy simulation tool, the energy consumption of

buildings based on their roof colors was estimated. Results showed that converting dark-colored roofs to light-colored ones could save approximately $1,400,000 annually in energy costs for the city. This study validates that roof color is a convenient proxy for albedo, and light-colored roofs offer a cost-effective solution towards mitigating urban heat islands while achieving significant energy savings.

2.2 Introduction

Increasing urban populations and the resulting urban heat from infrastructure development have profound implications on sustainable energy infrastructures. The global population is projected to experience significant growth in the coming decades, potentially to over 1.6 billon by 2050 (United Nations, 2022). While population growth itself may not directly cause the increasingly complex environmental challenges, its influence can intensify existing issues or expedite their onset. In addition to the warming induced by climate change, urban areas worldwide are experiencing warming exacerbated by the urban heat island (UHI) effect, where urban area temperatures are significantly warmer than the surrounding rural areas (Santamouris, 2001). Urban heat buildup primarily arises from increased absorption of solar energy from expanding developed areas, the prevalent use of light absorbent building materials, higher anthropogenic heat, and reduced urban vegetation (Garshasbi et al., 2023). Replacement of natural landscapes with sidewalks, streets, and buildings impacts how effectively an area can reflect solar radiation. Continued population growth will only intensify the UHI effect, as it is largely influenced by human activities associated with the rural-to-urban landscape transition and intensification of urban development (Yang et al., 2016). A well-documented effect of UHIs is an increase in energy consumption in air-conditioned buildings. The UHI reduces the thermal comfort indoors, leading to increases in energy consumption as residents use air conditioning to lower indoor temperatures (Zhang et al., 2019; Bonamente et al., 2013), further contributing to UHIs by adding heat to the exterior of the building.

The escalating urbanization trend, coupled with intensifying UHI effects elucidate the critical need for sustainable interventions that address the challenges associated with energy usage and public health. Vulnerable populations bear the brunt of UHI-related health risks, facing heightened susceptibility to heat-related illnesses such as dehydration and heatstroke. The American College of Cardiology has highlighted the increased risk of heart attacks among these vulnerable groups due to extreme temperature fluctuations (American College of Cardiology, 2018). The needs of vulnerable populations must also be considered when researching and developing sustainable mitigation strategies.

Cool roofs – roofs that stay cool and are characterized by high solar reflectance and thermal emissivity – represent a multifaceted mitigation strategy that addresses both energy efficiency and cooling efficacy across residential, commercial, and industrial buildings (Zhang et al., 2019; Spaulding, 2008; Roman et al., 2016; Taylor & Hartwig, 2018; Baniassadi et al., 2018; Vellingiri, et al., 2020; Sheffer et al., 2021; EPA, 2021). Cool roofs mitigate UHI effects as they reduce indoor temperature and concomitant energy consumption. Solar reflectance, or albedo, is considered to be the most important factor when constructing cool roofs, with potential energy savings between 50 to 65% (Gartland, 2001). Moreover, the considerable temperature differentials between highly reflective and absorptive roofs accentuate the impact of cool roofs on mitigating heat. Highly reflective roofs show a difference between ambient and surface air temperatures of ~20°F (11°C), compared to highly absorptive roofs that show a difference of as much as 90°F (50°C) (Konopacki et al., 1998). Widespread adoption of cool roofs over highly absorptive roofs could potentially lower maximum heat wave temperatures by at least 2°C (Pearce, 2018). Cool roofs can even offset a significant amount of future warming over large scales in urban areas (Georgescu et al., 2014).

It is important to note that cool roofs are not the only factor contributing to reducing the heat load on residential buildings. One study showed that thermal insulation and the incorporation of various insulating materials within structures also prove to be environmentally and economically feasible (El-Awardly et al., 2021). A similar study showed that thick insulation also lowers heat loss from a building during colder months, whereas albedo plays a dominant role in reducing heat absorption on a building (Ramamurthy et al., 2015). While predicting the efficacy of any single intervention over another is a challenge, cool roofs remain one of the most effective UHI mitigation strategies (Synnefa et al., 2007; Garshasbi et al., 2023). For this reason, the focus of this study is on the impact of albedo (e.g., roof color) on mitigating UHIs. Here, a variety of techniques were used to assess the impact of roof color modification by quantifying the energy savings through building energy simulation modeling.

The main objectives of this study are:

(1) to quantify the distribution of roofs and their respective colors across Tucson, Arizona using a spatial stratified sampling technique known as point-counting.

(2) to develop land surface temperature maps and digitize roofs within an ArcGIS environment.

(3) to simulate energy savings for a prototypical home in Tucson by only altering the roof color using the QUick Energy Simulation Tool (eQUEST), a building energy simulation tool.

(4) to apply energy saving simulation results based on sampling of selected areas to estimate energy savings for the whole of the Tucson metropolitan statistical area.

2.3 Methodology

The assessment of the overall energy savings potential for Tucson through the conversion of dark-colored roofs to light-colored roofs involved a multi-faceted approach. First, a spatial stratified sampling technique known as point-counting was applied using satellite imagery to quantify the distribution of roofs and their respective colors across the city (Lempitsky & Zisserman, 2010). Next, ArcGIS was used for satellite image processing, manual digitization of roofs, and the development of land surface temperature maps to understand the thermal characteristics of different roof colors. Finally, eQUEST, a building energy simulation tool, was used to estimate the energy consumption of buildings based on their roof colors.

2.3.1 Study Area

Tucson, Arizona, situated within the hot semi-arid climate zone (BSh, B = arid, S = Steppe, h = Hot arid) within the Sonoran Desert, is characterized by hot summers and mild winters, and annual rainfall of about 11 inches (270 mm) from winter Pacific storms and the summer North American Monsoon. Summer temperature highs typically are in the triple digits, averaging over the past 3 decades at 101.3°F (38.5°C) in June, 100.2°F (37.9°C) in July, and 98.6°F (37.0°C) in August. Monthly average relative humidity ranges from 21 to 50% (NOAA, 2023).

Tucson's strategic significance for the study of UHI lies in its representation of rapidly warming cities in the desert southwest, where the sustainability of energy resources is of paramount importance. Beyond this, the selection of Tucson as the study area is driven by several factors: (1) climate conditions that provide a pertinent backdrop for investigating the efficacy of roof color modifications; (2) geographical similarities with other desert southwest cities (i.e., El Paso, Texas, Phoenix, Arizona), such as surrounding mountain ranges and high elevations (e.g., above 2,000 ft); (3) other similarities to desert southwest cities such as climate, demographics, cultural influences, and economic factors.

Tucson is in the southeastern part of Arizona, some 60 miles (97 km) from the U.S.—Mexico international border. The current population is over 543,000 in the city proper, and over 1,060,000 in the metropolitan statistical area (MSA). The city covers 227 square miles (587 km^2) with a nominal elevation (at Tucson International Airport) of 2,643 feet (806 m) (PimaLib, 2014). The city is surrounded by several minor mountain ranges, including the Santa Catalina Mountains and the Tortolita Mountains to the north, the Santa Rita Mountains to the south, the Rincon Mountains to the east, and the Tucson Mountains to the west.

In 2020, Tucson experienced a record-breaking 108 days of temperatures exceeding 100°F (37.8°C) (McMahan et al., 2020). Tucson is especially vulnerable to extreme temperature risks due to climate change and UHI effects (McMahan et al., 2020). According to an ongoing assessment conducted by CLIMAS (Climate Assessment for the Southwest), August 2020 temperatures broke records for the warmest temperatures for all of Arizona, as well as the record driest conditions, showing wide expansion of extreme drought across the states of Arizona and New Mexico (Garfin et al., 2020).

The City of Tucson Climate Change Planning Consultant Services Division proposed a plan to mandate cool roof systems in Tucson on future residential and commercial construction (Westmoreland Associates, 2010). In one case study, on the 23,400 square-foot (2,175 m^2) Thomas O. Price Service Center building, cool roofing could save up to 50% of cooling costs to the property. In an economic analysis, considering the premium cost of cool roofing products and projected electricity costs, energy savings to a homeowner would equal $4,316 over the 20-year lifetime of the roof. In addition, cool roofs provide multiple other benefits such as added life to air-conditioning capital investments, possible extension of the life of the roof, and stability in Tucson's electric grid (Westmoreland Associates, 2010).

2.3.2 DATA COLLECTION

2.3.2.1 Point-counting

To quantify roofs and their colors in Tucson, we repurposed a spatial stratified sampling methodology developed over decades in the earth sciences for quantifying the proportion of mineral types in rock samples. This method, known as point-counting, is a common sampling technique in geological and biological microscopy for quantitative determination of features such as different minerals in a thin section of a rock or identification of pollen grains in a slide mount. Similar approaches in using point-counting in combination with satellite images have been applied successfully in various studies (Meulenyzer et al., 2013; Guyassa et al., 2018; Robinson et al., 2021).

To apply this method for the present work, a 100-meter grid was overlaid onto satellite images of the city from Google Earth imagery. Intersecting lines of the grid provided a uniform spacing of point sites to be sampled, identified, and tallied. The features that are counted and recorded are only those that lie directly below the intersecting lines. The tally provides an estimation of the area of each category relative to the total area of, say, the rock specimen surface or, in this case, the map region under study. Thus, we can determine statistically the fraction or percent of the area of Tucson studied that is, for example, commercial roof, sidewalk, or white residential roof. We also can compare the popularity of different roof colors based on their sampled areas.

Note that the point-counting procedure underestimates the total area of roofs in the maps. When a tree covers part or the entire roof and the grid-intersection point being sampled lies over the tree, we record that point as a tree, not as the underlying roof. However, because of the arid climate the extent of trees covering roofs is considerably less that what one would encounter in a temperate climate municipality, minimizing this issue.

2.3.2.2 Map Preparation

In total, 37 maps of sampled areas were created from satellite images clipped from Google Earth taken in 2020, with a consistent elevation set to maintain uniform resolution (Figure 2.1). Each covered an area of approximately 3.2 km x 1.3 km, and each contained 416 uniformly spaced points (grid intersections), apart from a single map with 320 points. The studied sample area of Tucson was approximately 154 km^2 of a total area of about 595 km^2, yielding a total of 15,296 grid data points. Sampled areas included in this study (Figure 2.2) focused primarily on urban core areas of the city, where the heat island effect would be most intense. More recent peripheral developments were also included for a better representation of the current roof situation, as these developments are generally newer and constructed following different building codes than those in the urban core.

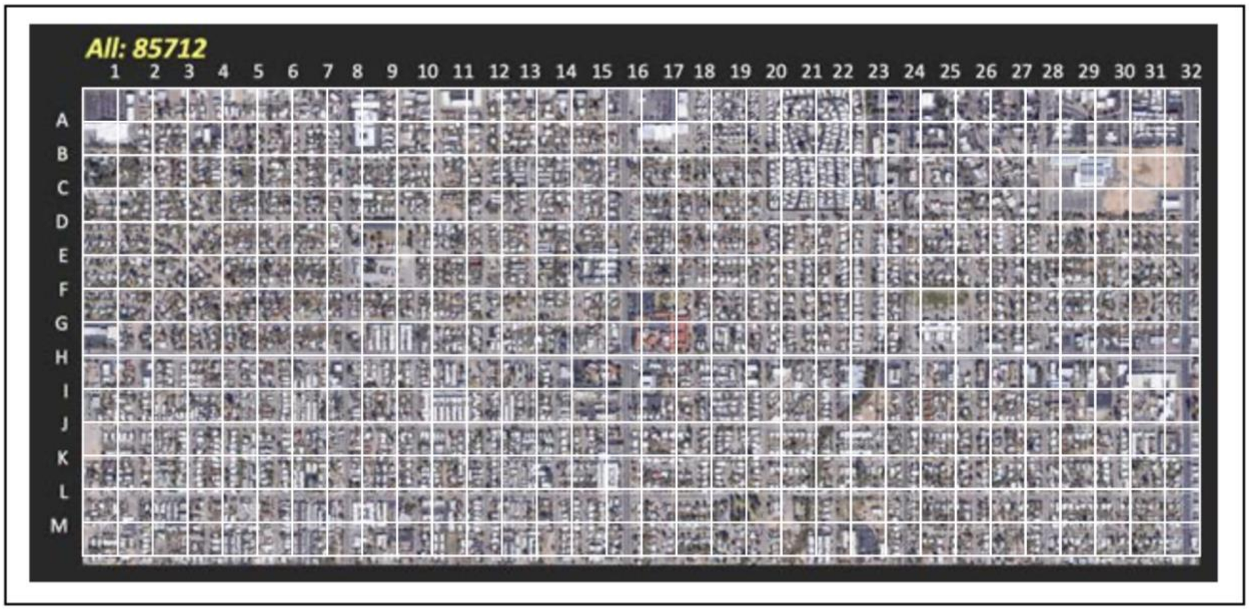

Figure 2.1: Representative map of sampled area.
White lines illustrate 100-meter grid for point counting.

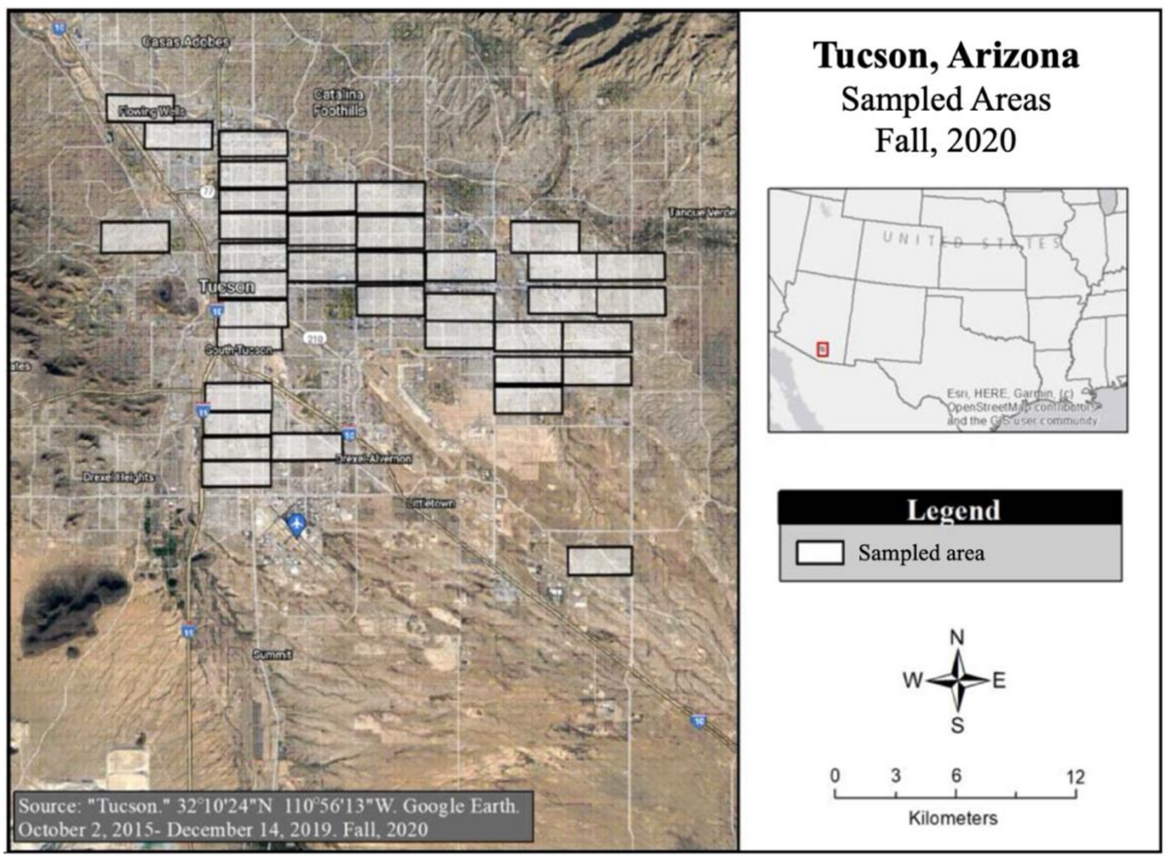

Figure 2.2: Map of Tucson with locations of sampled areas for point counting.

2.3.2.3 Point-Counting Data Collection Process

To record the data from these prepared maps, consistent computer display settings were used to reduce errors associated with data collection and color identification. Data points were visually inspected and tallied using a classification spreadsheet, which included various object classes (i.e., highway, street/parking lot, vehicle, tree, grass, shrub, gravel/rocks, dirt/soil, water/pool, sports field/court, wall/fence, junkyard/dump, other, unknown, industrial roof, commercial roof, and residential roof). These categories were selected and refined (i.e., grouped with similar objects such as streets and parking lots) based on preliminary trials conducted using this method prior to the commencement of this study. From those preliminary trials, 99.5% of data points fell in the aforementioned object classes. Some object classes (i.e., highway, junkyard/landfill, water/pool) could have been excluded from this study area because of the small number of occurrences. However, this method was established with the intent of being used for comparison to other study areas in related companion studies whose preliminary trials indicated a need for such categories. The ‘other’ category records objects that were identified but did not correspond to one of the listed categories. The ‘unknown’ category comprised objects that could not be identified. Combined, these two categories comprised less than 0.5% of the data.

Roof type (i.e., residential, commercial, and industrial) was distinguished using several visual cues and analytical methods commonly employed in remote sensing applications such as (1) size and shape of roof, (2) surrounding context and location, (3) roof features (e.g., chimneys on residential roofs, or rooftop HVAC units on commercial and industrial roofs), (4) color and material, i.e., residential roofs tend to have a variety of colors and materials while commercial and industrial roofs often have more uniform colors and materials, such as flat roofing materials like built-up roofing, and (5) texture (e.g., shingles patterns on residential roofs, smoother surfaces on commercial and industrial buildings).

The guidelines used for roof color classification were based on the Munsell Color System. When a data point was characterized as a roof, its color was inferred based on analyst review and recorded. Color categories included white, light gray, dark gray, light brown, dark brown, light blue, dark blue, light green, dark green, red, terracotta, black, or other. Identified roof colors were grouped according to their solar reflectance or albedo, α; which was estimated through visual inspection using satellite imagery analysis. Light-colored (white, light gray) represented a high α value of 0.75 – 0.90, medium-colored (light brown, light blue, light green, and terracotta) represented an intermediate α value of 0.4 – 0.75, or dark-colored (dark brown, dark gray, dark green, dark blue, and black) represented a low α value of 0.4 and below. The data verification process included re-tallying and re-classifying data points from the unknown and other object classes. Double entries (i.e., single points counted twice) and missing entries were also identified and corrected during the data verification process.

2.3.2.4 Considerations

Initially, a machine learning approach using pixel-based classification of satellite imagery was evaluated for data collection. While this method offers automation, it presented significant limitations in accurately categorizing complex urban surfaces as roofs. Specifically, pixel-based classification was found to be inadequate due to its reliance on uniform pixel values to identify objects, which often led to misclassifications where similar pixel values did not correspond to the intended object categories, such as different types of roofs. This method predominantly identified objects based on pixel color and intensity, which does not necessarily correspond to distinct object types like roofs. Consequently, the approach would have required extensive manual verification and object detection adjustments to ensure accurate representation of the number of buildings within each color category. These challenges were compounded by the cost and availability of high-resolution (i.e., 3- or 5-meter resolution) satellite imagery necessary for detailed and accurate classification. The minimum costs for satellite imagery with high-spatial resolution sufficient for characterizing various urban surfaces are roughly $15/km^2 (Vailshery, 2022), translating to about $8,805 for the city of Tucson. Using open-source high resolution imagery to measure a sample large enough to statistically represent roof coverage in Tucson was determined sufficient for the purposes of this study.

2.3.3 Data Processing

2.3.3.1 Land Surface Temperatures

To determine the applicability of roof color as proxy for albedo and estimate the impact of light-colored surfaces on lowering Land Surface Temperatures (LST) in highly urbanized areas, we first obtained LANDSAT 8 satellite imagery from EarthExplorer - Landsat collection 1 level-1 – acquired by Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS; Table 2.1). Bands 4, 5, and 10 were processed in ESRI ArcGIS [10.8.2] to prepare the LST layer. Band 4 is within the visible red spectrum (0.64 – 0.67 μm). Band 5 is within the Near Infrared (NIR) spectrum (0.85 – 0.88 μm) and was combined with band 4 to produce a Normalized Difference Vegetation Index (NDVI) layer. The NDVI layer is used in the determination of land surface emissivity, making it a significant factor for LST estimation (Guha & Govil, 2020). Band 10 is within the Thermal Infrared (TIR) spectrum (10.60 – 11.19 μm), was used to determine ground surface temperature. These TIR bands are particularly useful for studying urban heat islands (Loyd 2013).

Table 2.1: Satellite imagery meta data used in study. Imagery source earthexplorer.usgs.gov.

Sensors	**Dates**	**Path/row**	**Bands**	**Resolution (m)**
Landsat 8 OLI	08/04/2021	36/38	4, 5	30
Landsat 8 TIRS	08/04/2021	36/38	10	100 x 30

To produce the LST map, a model for mapping LANDSAT 8 Satellite Data developed by Avdan and Jovanovska (2016) and Ihlen (2019) was used. The six-step process is described below.

1) Top of Atmosphere Spectral Radiance (TOA). The first step requires a conversion of digital numbers (DN) to values of spectral radiance in the upper atmosphere (Joel et al., 2022) using

$$L_\lambda = M_L * Q_{cal} + A_L - O_i$$

Where L_λ = TOA spectral radiance, M_L = band-specific multiplicative rescaling factor, Q_{cal} = Level 1 pixel value in DN, A_L = Band-specific additive rescaling factor, O_i = correction value for band 10.

2) Conversion of Radiance to At-Sensor Temperature. The second step is to convert TOA to brightness temperature (BT) using

$$BT = \frac{K_2}{\ln[(K_1/L_\lambda)+1]} - 273.15$$

Where BT = brightness temperature (°C), K_1 = Band-specific thermal conversion constant, K_2 = Band-specific thermal conversion constant, L_λ = TOA spectral radiance.

3) Calculate Normalized Difference Vegetation Index (NDVI). Before calculating NDVI, bands 4 and 5 were corrected for atmospheric effects due to absorption and dispersion

processes, the existence of water vapor, gases, and molecules in the atmosphere that affect the amount of radiation received by the sensor (Sobrino et al., 2004; Joel et al., 2022). NDVI values demonstrate 3 surface classes: 1) bare soil (NDVI<0.2), 2) mixed surface (0.2 ≥ NDVI ≤ 0.5), and 3) entire vegetation surface (NDVI ≥ 0.87; Sobrino et al., 2004). NDVI was calculated using

$$\text{NDVI} = \frac{\text{NIR (band 5)} - R\text{ (band 4)}}{\text{NIR (band 5)} + R\text{ (band 4)}}$$

Where NIR = near-infrared band (band 5), R = red band (band 4).

4) Calculate the Proportion of Vegetation. To calculate land surface emissivity values, the emissivity of each pixel must be determined. To do this, the proportion of vegetation must be calculated using the NDVI values.

$$P_v = \left(\frac{\text{NDVI} - \text{NDVI}_s}{\text{NDVI}_v - \text{NDVI}_s} \right)^2$$

Where NDVI = NDVI raster image produced in step 3, NDVI_s = NDVI minimum value (from NDVI raster image), NDVI_v = NDVI maximum value (from NDVI raster image).

5) Calculate Land Surface Emissivity.

$$\varepsilon_\lambda = \varepsilon_{v\lambda} P_v + \varepsilon_{s\lambda} \left(1 - P_v\right) + C_\lambda$$

Where $\varepsilon_{v\lambda}$ = vegetation emissivity, $\varepsilon_{s\lambda}$ = soil emissivity, C_λ = surface roughness, taken as a constant value of 0.005 (C_λ = 0 for homogenous and flat surfaces). Emissivity for this study was calculated using

$$E = 0.004 * P_v + 0.986$$

Where 0.986 corresponds to a correction value of the equation.

6) Calculate the Land Surface Temperature. LST is the radiative temperature, and can be calculated since all objects emit radiation if their temperature is > 0 K.

$$T_S = \frac{BT}{\{1+[(\lambda * B_T/\rho) * \ln(\varepsilon_\lambda)]\}}$$

Where T_S = LST in °C, BT = at-sensor brightness temperature in °C, λ = the wavelength of emitted radiance (average wavelength of band 10), ε_λ = land surface emissivity from step 5, σ = Boltzmann constant ($1.38*10^{-23}$ J/K), h = Planck's constant ($6.626*10^{-34}$ Js), c = the velocity of light ($2.998*10^{8}$ m/s), and $\rho = \sigma h/c = 1.438*10^{-2}$ mK.

2.3.3.2 Classification of Roofs via Manual Digitization

In this study, roofs were digitized and categorized into three distinct groups—light, medium, and dark-colored—based on their color attributes and albedo potentials previously described using ArcGIS Pro. This categorization was achieved through a meticulous visual inspection of raster pixels, with points strategically placed on the centers of rooftops that matched established color criteria. The selection process for digitizing roofs involved subsampling a representative set of rooftops from each category, rather than digitizing all roofs. This approach allowed for a manageable, yet comprehensive analysis of surface temperature values extracted from the LST raster for each digitized point, as illustrated in Figure 2.3. To validate the accuracy and consistency of our manual digitization process, quality control measures were implemented, including random checks of digitized rooftops. Additionally, a subset of the manually classified roofs was compared with ground-truth data obtained through the point-counting method previously described. While manual digitization provided a robust dataset for this specific study area, it also established a 'ground truth' dataset that could be used to train machine learning models, potentially enabling the application of this methodology across broader regions, though such an expansion was beyond the scope of this study.

Figure 2.3: Manual digitization of roof colors vs. land surface temperatures.
On the left is an example of manual digitization of light, medium and dark-colored roofs in a small portion of the sampled area, with land surface temperature raster added to the same sampled area on the right. Here, neighborhoods with predominantly light roofs were adjacent to dark roofs. These neighborhoods were chosen where other object types, such as trees, or streets had similar values, and only roof colors were different to demonstrate how roof colors correspond to land surface temperatures.

This process was performed for all residential buildings and limited to about 40% of the overall study area (Figure 2.4). Manual digitization served two purposes for this study: (1) ensure accuracy of the point-counting method and (2) determine the surface temperatures of individual rooftops to identify areas of interest for future studies. From this process, 45,676 light, 5,126 medium, and 6,694 dark-colored roofs were digitized. These values were consistent with point-counting values for the respective sampled areas, validating the viability of that method for the purposes of this study.

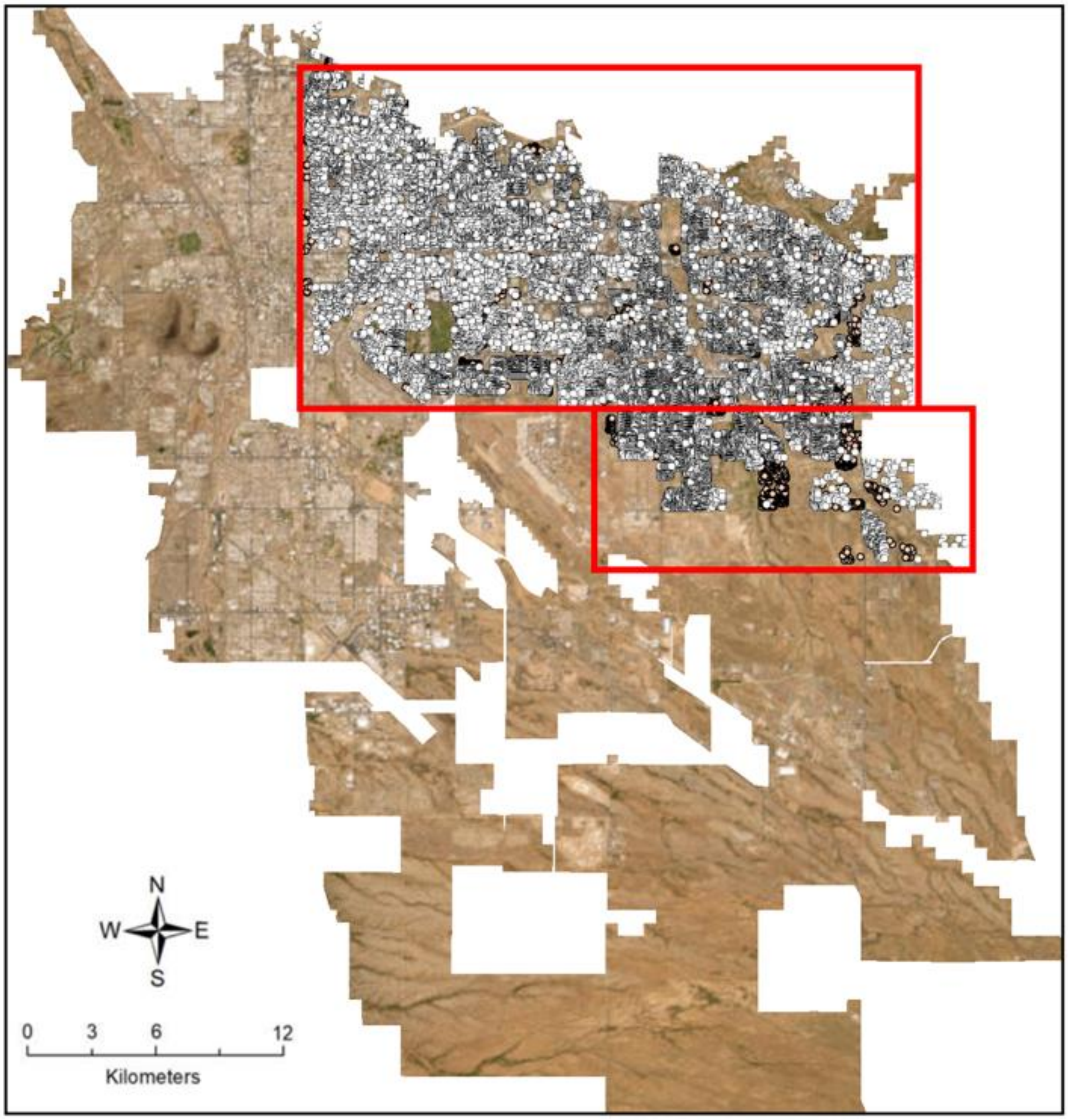

Figure 2.4: Sampled areas in Tucson, Arizona.
Tucson, Arizona city limits with manual digitization sampled areas boxed in red. Note that dots within the red boxed areas are the digitized centers of residential roofs. This figure incompletely represents all digitized points due to the abundance of data points and the extent of zooming out.

2.4 Energy Savings Model Development- eQUEST

eQUEST is a software tool that calculates building energy consumption on an hourly basis for an entire year using location-specific weather data. Variables include the building's characteristics, occupancy schedules, lighting, equipment, HVAC systems, amongst others. The software accurately simulates various building features such as shading, fenestration, and heating/cooling systems, allowing for the assessment of many different energy-saving variables. By comparing baseline and alternative scenarios, eQUEST facilitates the determination of the most effective efficiency measures to optimize energy use in buildings (James J. Hirsch & Associates, 2010).

This study utilized eQUEST to simulate the potential energy savings resulting from altering the roof color of a prototypical home for Tucson. A baseline model of the building was developed based on standard building codes and actual building practices for the region. The baseline scenario represented a typical single-storied, 1,600 ft^2 home in Tucson with a conventional dark-colored roof, shown in Figure 2.5.

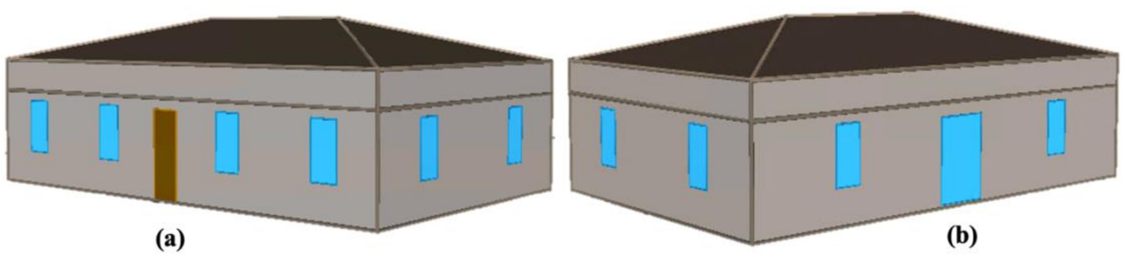

Figure 2.5: Baseline model of prototypical home for study area.
(a) North-west view. **(b)** South-east view.

Two alternative building models were created and run to simulate energy savings from medium and light-colored roofs. Only roof color was adjusted to isolate the specific impact of roof color on energy savings for these models. All other variables (i.e., building geometry, construction materials, etc.) were kept constant for these alternative scenarios and are listed in Table 2.2. Other input data such as HVAC system information, and current electric / gas rates are listed in Table 2.3. The weather data specific to Tucson, Arizona was imported via the eQUEST data repository.

Table 2.2: Input values for building geometry and construction.

Variables	**Description**
Roof properties	
Pitch	14 degrees (low-slope)
Construction	Wood standard frame
Exterior finish	Roofing, shingle
Walls	
Construction	Wood frame, 2x4, 24 in. o.c.
Exterior finish	Stucco / Gunite
Ceilings	
Interior finish	Drywall finish
Framing	Wood, standard framing
Doors	
Opaque (main entry)	Quantity: 1 Orientation: North
Dimensions / construction	8 ft x 3 ft Wood, hollow core flush, 1-3/4 in.
Sliding / atrium glass	Quantity: 1 Orientation: South
Dimensions / construction	8 ft x 6 ft Single clear 1/4in, aluminum frame 3 in.
Windows	
Double clear / tint	Percent window (floor to ceiling, by orientation): North: 15 South: 10 East: 10 West: 10
Dimensions / construction	5.22 ft x 3 ft Glass: double clear 1/8in, 1/4in Air Frame: aluminum, fixed, 1.3in

Table 2.3: Utility rate and HVAC end use input values.

Variables	**Description**
Utilities and rates	Electric Service fee: $15 /month Charges: $0.15 /kW, $0.130400 /kWh Gas Service fee: $10.70 /month Charges: $0.0616 /Therm/hr, $1.804840 /Therm
HVAC	System: Packaged single zone DX, furnace (residential) Cooling Typical unit size: <65 kBtuh or 5.4 tons Condenser type: air-cooled Heating Typical unit size: <225 kBtuh

2.5 Results and Discussion

2.5.1 Quantification of roofs: Point-counting

Of the total of 15,296 data points on satellite imagery of Tucson, Arizona, 2,714 were identified as residential roofs, 640 as commercial roofs, and 153 as industrial roofs (Figure 2.6). Four general categories of objects account for virtually all the land surface of Tucson, as viewed from above. These are, in order of occupied area: (1) Street/Parking lot + Sidewalk/Driveway + Highway with 29%; (2) Residential + Commercial + Industrial Roof with 23%; (3) Tree + Grass + Shrub with 21%; and (4) Dirt/Soil + Gravel/Rocks with 18%. These four categories are also reasonably close in scale. It is of interest that ~23% of the surface area of the parts of Tucson studied are roofs. This emphasizes the potential importance of roof albedo in mitigating the solar thermal radiation load and resultant heat island effect but also shows that the albedo of other areas (i.e., the color of pavement) can be targets to combat UHIs.

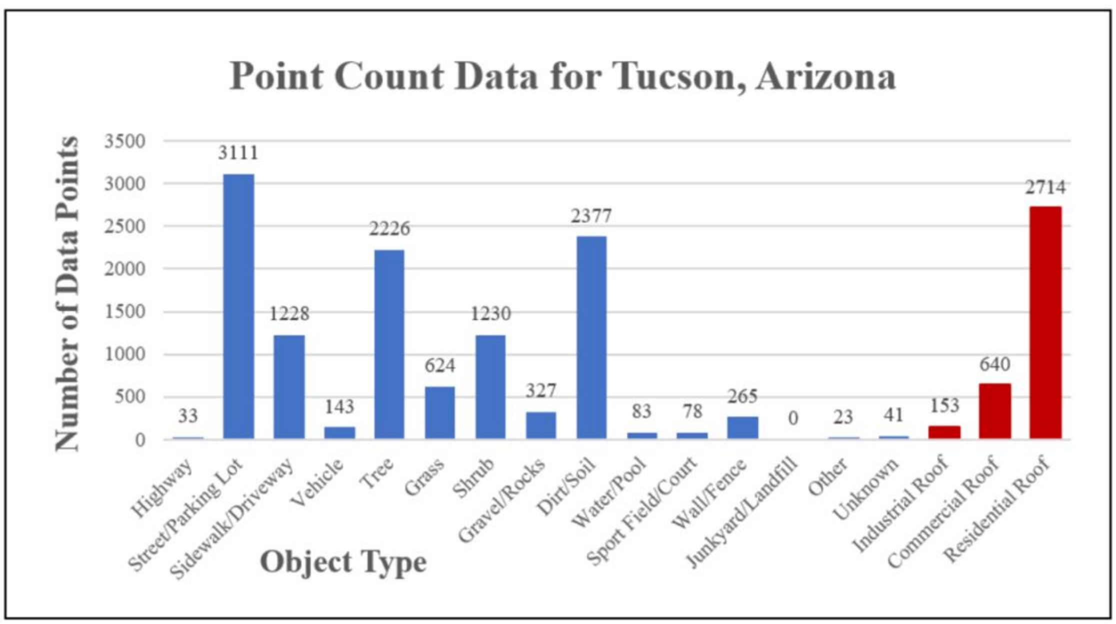

Figure 2.6: Point count data results for sampled areas in Tucson, Arizona.

2.5.1.1 Residential Roof Colors and Quantities

Point-count data revealed that white roofs dominated the sampled areas in Tucson, accompanied by light hues of gray and brown. Of the 2,714 residential roofs identified, 1,897 (70%) were classified as light-colored, 380 (14%) as medium-colored, and 437 (16%) as dark-colored (Figure 2.7). This suggests a trend towards high albedo (light-colored) roofs, especially when compared to residential roof colors in other cities in the Southwest (Alvarez et al., 2020; Martinez et al., 2020).

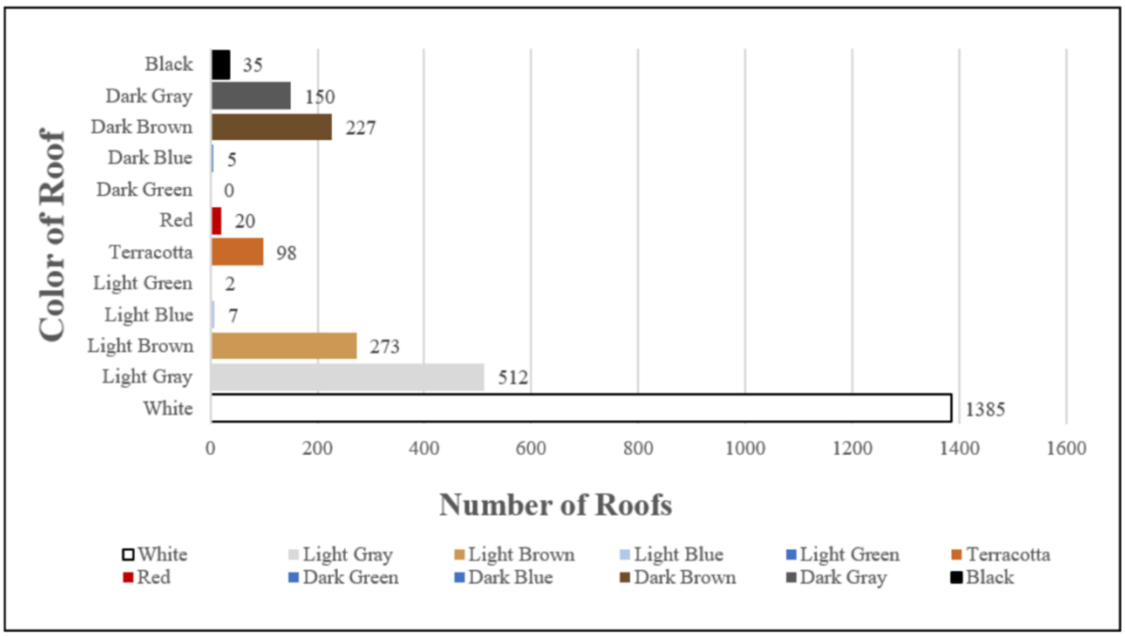

Figure 2.7: Residential roof color totals by color within selected areas of Tucson, Arizona.

2.5.1.2 Commercial and Industrial Roof Quantities

A total of 640 commercial roofs were identified; 486 (76%) were light-colored, 55 (9%) were medium-colored, and 99 (16%) were dark-colored. The contrasting albedo potential for commercial roofs shows a trend towards high albedo (light-colored) roofs. Additionally, a total of 153 industrial roofs were identified; 129 (84%) were light-colored, 13 (9%) were medium-colored, and 11 (7%) were dark-colored. Industrial roofs showed a similar trend towards light-colored roofs.

2.6 Energy Savings Estimates- eQUEST

Building performance simulation results from the three eQUEST models representing buildings with light, medium, and dark-colored roofs were analyzed to assess their respective energy performance. This process, in combination with the point-counting method and classification of roofs via manual digitization, enabled an estimation of the potential overall energy savings for the broader Tucson area. Comparisons of the total energy demand for all models are summarized in Figure 2.8. The total energy demand by roof color and total annual energy costs are summarized in Table 2.4.

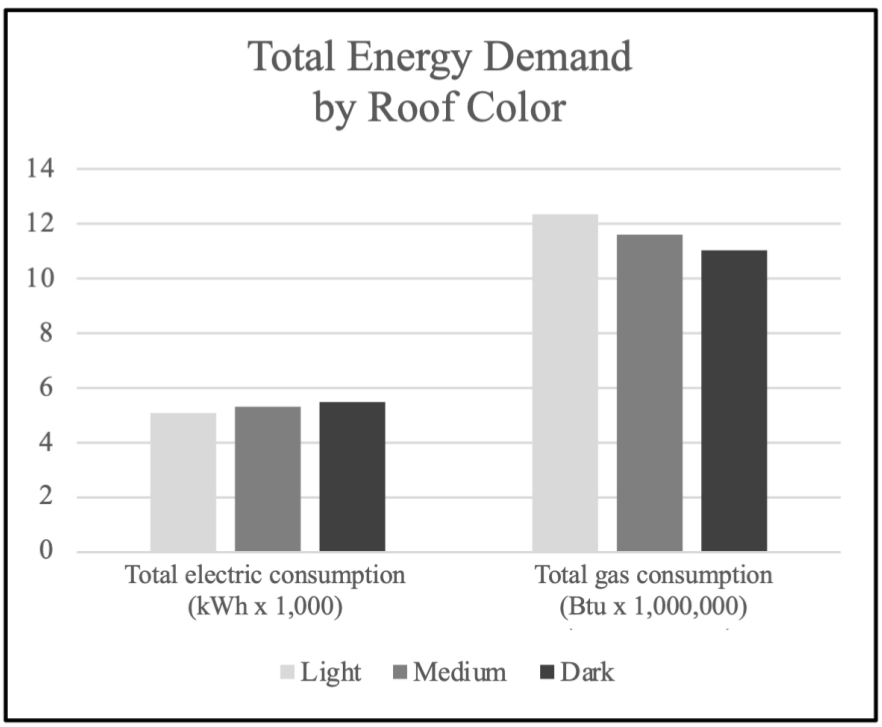

Figure 2.8: Summary of eQUEST simulation results for different roof colors.
The total energy demand by roof color for individual houses is visualized in kWh x1,000 for electric consumption, and Btu x1,000,000 for total gas consumption.

Table 2.4: Summary of eQUEST simulation results with total annual energy costs.

	Light	**Medium**	**Dark**
Total Annual Cooling Energy Demand (Electricity in kWh)	507,000	529,000	547,000
Cost ($)	919	951	977
Total Annual Heating Energy Demand (Gas in kWh)	3,622	3,405	3,238
Cost ($)	352	338	328
Total Annual Energy (kWh)	510,622	532,405	550,228
Total Annual Energy Cost ($)	**$1,271**	**$1,289**	**$1,305**

The monthly electric and gas consumption and their associated costs by roof color are reported in Figure 2.9, and in Table 2.5. These data illustrate typical seasonal trends of inversely related electric and gas consumption. In the case for all three models, electric consumption for cooling was higher during summer months and gas consumption was higher during winter months. One could expect that if light-colored roofs would produce favorable indoor thermal conditions for cooling during the summer months due to their albedo, then dark-colored roofs would produce favorable indoor thermal conditions for heating during winter months. This is known as a heating penalty, where an increase in energy consumption or cost associated with light-colored roofs when compared with dark-colored roofs (Akbari et al., 1999; Yang et al., 2015; Ascione et al., 2018). A heating penalty exists for the light roof during the winter months, meaning that the cost to heat the home is more than what could be expected for the same home with a dark roof (i.e., $352 annually to heat a home with a light roof, $328 annually to heat a home with a dark roof). However, the reduced cost of electricity due to cooling during the summer months for a light roof far outweigh the heating penalty (i.e., $919 annually to cool a home with a light roof, $977 annually to cool a home with a dark roof). The light roof model demonstrated the lowest total annual energy cost among the three roof color scenarios. Specifically, the light-colored roof model exhibited a total annual energy cost of $1,271, representing a 2.5% reduction when compared to the dark-colored roof model (i.e., $1,305).

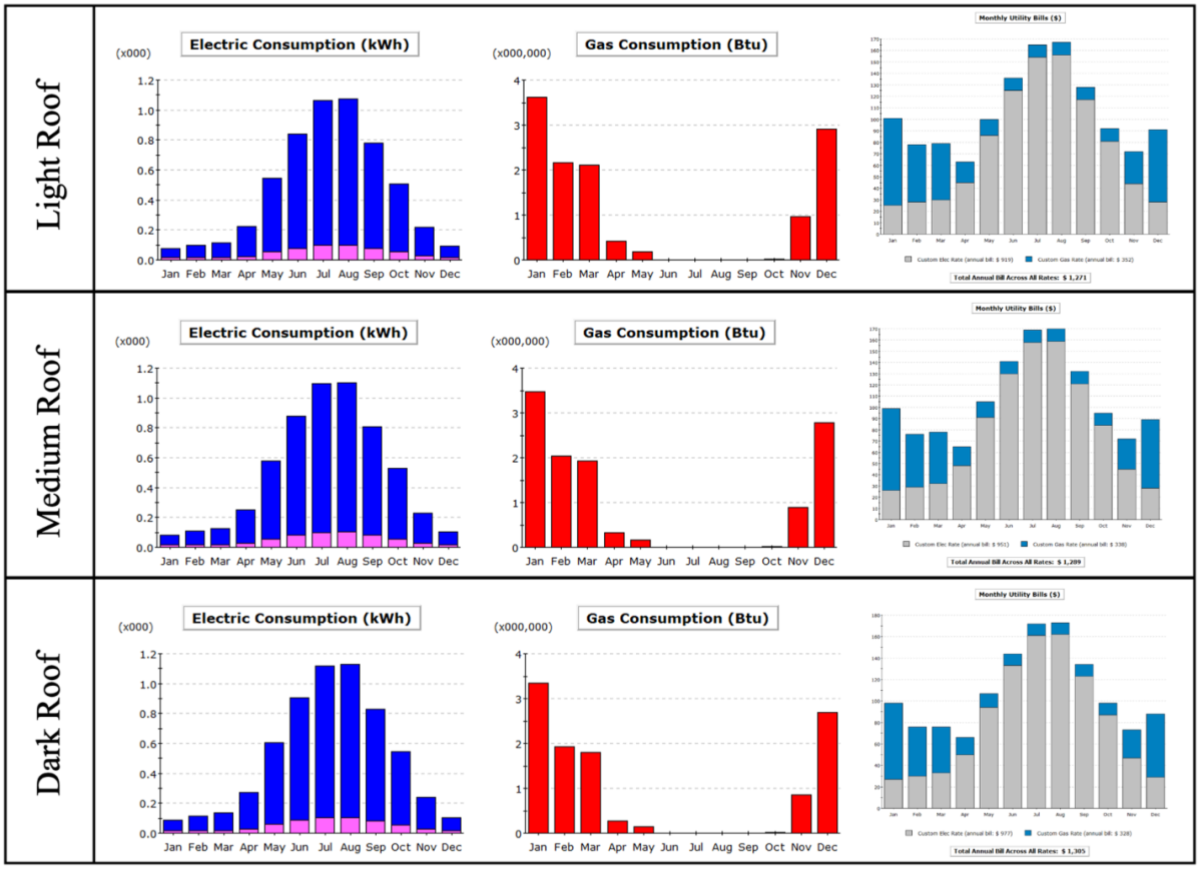

Figure 2.9: eQUEST simulation results for monthly energy consumption.

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Table 2.5: Summary of eQUEST simulation results. Monthly electric and gas consumption values are shown by roof color.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Electric - Light (kWh x000)	0.06	0.08	0.10	0.20	0.49	0.76	0.97	0.98	0.71	0.45	0.19	0.08	5.07
Gas (Btu x000,000)	3.61	2.16	2.10	0.42	0.17	-	-	-	-	0.02	0.96	2.91	12.36
Electric – Med. (kWh x000)	0.06	0.09	0.11	0.22	0.52	0.79	0.99	1.00	0.73	0.47	0.20	0.08	5.29
Gas (Btu x000,000)	3.46	2.03	1.93	0.33	0.16	-	-	-	-	0.02	0.90	2.79	11.62
Electric - Dark (kWh x000)	0.07	0.10	0.12	0.24	0.55	0.82	1.02	1.02	0.75	0.49	0.21	0.09	5.47
Gas (Btu x000,000)	3.35	1.93	1.80	0.28	0.14	-	-	-	-	0.02	0.85	2.70	11.05

2.6.1 Overall Energy Savings for Tucson

Drawing from the individual building estimates derived from eQUEST, an evaluation of energy savings for the city of Tucson was conducted. These estimations were based on the representative sampling from point-counting method described previously and the assumption that comparable trends in energy savings would hold uniformly across the city.

Tucson housing data were obtained from the most recent 2022 American Community Survey census data. According to these data, there are about 242,000 total housing units in the greater Tucson area. Of these, about 66,000 are in apartment complexes and not considered as part of the economic impact of roof color modification on a city-wide scale for this study (Tucson Association of Realtors, 2024). Approximately 30% of all residential roofs were identified as medium and dark-colored (14% or 24,640 and 16% or 28,160, respectively) equating to a potential annual net energy savings for Tucson of ~$1,400,000. This estimate, while conservative, highlights the potential energy savings Tucson can expect should the entirety of residential buildings with dark-colored roofs be replaced with light-colored roofs.

2.7 Conclusions

The findings of this study offer a compelling dataset to advocate for light-colored roofs as effective measures for urban heat mitigation. At 70% light-colored roofs, Tucson exhibits a much higher overall percentage of light-colored roofs when compared to other cities that share similar current and projected climates in the southwestern United States such as San Diego, California (19%), Albuquerque, New Mexico (40%), and El Paso, Texas (48%) (Martinez et al., 2020; Vazquez et al., 2020; Alvarez et al., 2020). Despite Tucson's comparatively higher percentage of light-colored roofs, this study demonstrates the tangible impact of roof color on energy savings (~$1,400,000 per year), highlighting the potential for even greater savings in larger cities. Findings from this study can be extrapolated to inform policies and strategies for reducing urban heat and energy consumption.

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3. ASSESSMENT OF LITHIUM SOURCES IN GROUNDWATER BODIES USING POSITIVE MATRIX FACTORIZATION

3.1 Abstract

The global imperative to shift away from fossil fuels towards sustainable energy sources underscores the critical need for the development of reliable and ecologically sound energy infrastructures. Despite their potential, geothermal resources remain largely untapped in the United States, particularly in the region stretching from west Texas into southern New Mexico, where high surface and subsurface temperatures, thermal gradients, and heat flow present promising opportunities. However, the economic viability of geothermal exploration and development poses a significant challenge, as the most favorable resources in the region exist in remote areas. This study proposes a novel approach to leverage geothermal resources for sustainable energy production and domestic mineral diversification through lithium extraction from thermal fluids. Water chemistry data from the Hueco and Mesilla Bolsons in West Texas, and the Tularosa and Jornada del Muerto Basins in Southern New Mexico were processed to predict lithium endmember composition using positive matrix factorization (PMF), a receptor-based model commonly used in air quality studies. Concentration source apportionment derived from PMF can denote the relationship between chemical concentrations and the location of samples contributing to sources. The aim of this study is to elucidate the relationship between chemical concentrations from groundwater sample data and their sources, contributing to the understanding of the distribution of lithium in the region. The research identified two out of four factors (i.e., major solute sources) contributing to lithium concentrations, with Factor 1 and Factor 2 showing the highest lithium contributions, averaging 0.082 mg/L and 0.089 mg/L respectively. Factor 1 is interpreted as a

shallow, low-salinity water source, and Factor 2 as older groundwater influenced by mineral dissolution from old evaporite deposits. This research addresses the dual imperatives of economic viability and environmental sustainability of mineral extraction from groundwater sources. Innovative approaches to lithium extraction demonstrated here contribute significantly to the diversification of mineral resources, ensuring sustainable and economically viable resource management.

3.2 Introduction

Constrained fossil fuels reserves, the global transition towards renewable energy sources, and effort to reach net-zero greenhouse gas emissions emphasize the need for the development of sustainable energy infrastructures to ensure a reliable energy future. In this context, geothermal energy emerges as a pivotal player due to its reliability and minimal ecological footprint. Moreover, by providing energy constantly, geothermal energy can provide baseload for electrical power generation. This property bypasses many of the challenges related to energy storage that is associated with many other renewable energy sources (e.g., wind, solar, tidal, etc.). The United States holds a substantial, largely untapped geothermal energy potential, estimated to contribute approximately 60 gigawatts by 2050, accounting for 8.5% of domestic electricity production (Roberts, 2018; DOE, 2019). The regions extending from West Texas into Southern New Mexico are recognized for their high geothermal energy prospects, characterized by anomalously high subsurface temperatures, thermal gradients, and significant heat flow.

Despite their vast potential, geothermal resources remain largely underutilized and focused on obvious targets like The Geysers field in California. Recent technological advancements, including enhanced geothermal systems (EGS) and improved drilling techniques, have renewed interest in exploring previously inaccessible geothermal sources. These advancements particularly benefit settings where traditional geothermal development has been hindered by factors such as deep reservoirs located in complex geological settings, the high cost of drilling, and limited land access due to environmental and ownership issues.

In the region spanning from West Texas into Southern New Mexico, the most favorable geothermal resources exist in remote locations (Figure 3.1), posing significant challenges for economic exploitation using traditional methods of geothermal energy production (Tester et al., 2006). However, the co-extraction of lithium from geothermal waters presents an interesting opportunity for the immediate utilization of these resources to extract lithium, effectively diversifying domestic critical mineral production and perhaps defraying some of operating costs for geothermal energy production. Lithium is critical for various technologies including batteries for renewable energy storage and electric vehicles and is increasingly recognized as a crucial component in the energy transition due to its role in Lithium-ion battery technology (Krishnan & Gopan, 2024). Demand for lithium is expected to rapidly increase, primarily fueled by the expansion of the electric vehicle market (Martin et al., 2017).

While the potential for increased geothermal energy utilization in West Texas into Southern New Mexico is considerable, co-extraction of lithium is critical to make the development of this energy source economically viable. Thus, rather than developing the geothermal energy itself, this study explores the presence of lithium in subsurface waters, leveraging preexisting groundwater chemistry data to analyze the composition of potential end-member sources and quantify likely concentrations of lithium in those end-members. The estimated lithium concentrations in end-members can be used to assess their economic viability of lithium extraction from geothermal brines. This approach not only aligns with national priorities to secure domestic sources of critical minerals (DOE, 2021), but also leverages the geothermal context to enhance the efficiency of lithium extraction processes from these unique hydrogeological environments.

Specifically, this study aims to enhance the understanding of lithium distribution in the subsurface waters of the aquifers within the region (i.e., Hueco and Mesilla Bolsons in West Texas, and Tularosa and Jornada del Muerto Basins in South Central New Mexico; Figure 3.1) to inform future exploration and sustainable exploitation of these resources. By identifying and characterizing the sources of lithium in thermal brines, this research contributes to the optimization of extraction processes, minimizing environmental impacts while developing sustainable management practices for geothermal resources.

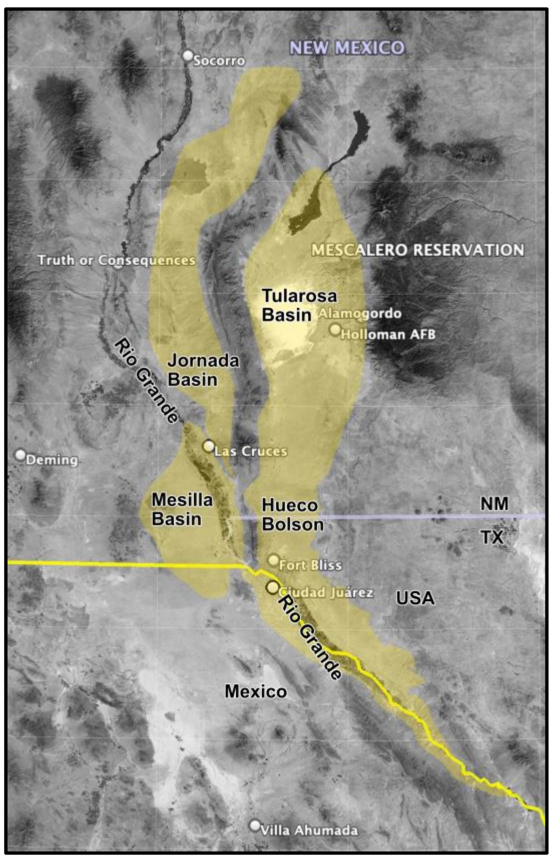

Figure 3.1: Map of aquifers (yellow) studied.
The Hueco and Mesilla Bolsons are located in West Texas, and the Tularosa and Jornada del Muerto Basins in South Central New Mexico. Redrawn on Google Earth© image from Hawley & Kennedy, 2004.

3.2.1 Geothermal Resource Potential in West Texas and South Central New Mexico

West Texas and South Central New Mexico are collectively estimated to contain significant thermal energy, with West Texas alone having a thermal energy density of about $3.15*10^{+8}$ J/m^3 (Zafar & Cutright, 2013). Previous studies in the Trans-Pecos area of West Texas and the adjacent areas in South Central New Mexico have highlighted the presence of anomalously high surface and subsurface water temperatures, thermal gradients, and elevated heat flow, indicating favorable conditions for geothermal energy development. Research by Kopp (1977) identified the Presidio and Hueco Bolsons as areas with high geothermal potential, findings that were later supported by detailed structural mapping in these regions (Henry, 1979). Subsequent studies by Henry (1979) and Hoffer (1979) also identified the Presidio and Hueco Bolsons as areas with high geothermal potential, validated by geochemical and geophysical analyses (Taylor, 1981; Roy et al., 1983). Continued exploration supported by the Department of Energy through the early 1980s has reinforced the feasibility of geothermal development in these regions. Additional support for this potential was provided by geochemical and geophysical analyses conducted by Taylor (1981) and Roy et al. (1983), which delineated areas rich in geothermal resources (Figure 3.2).

In South Central New Mexico, studies have similarly demonstrated significant geothermal potential. A study by Reiter et al. (1978) identified several geothermal anomalies in the region, particularly in areas with deep sedimentary basins that are conducive to geothermal activity. The New Mexico Bureau of Geology and Mineral Resources has conducted surveys that reinforce the high geothermal potential of these basins, driven by the heat from the Earth's mantle and facilitated by the unique geological structures present in the area (Kelley, 2005). More recently, researchers studying the Tularosa Basin found that there exists the potential for geothermal resources that could support several federal facilities in the area (Madunuru et al., 2023).

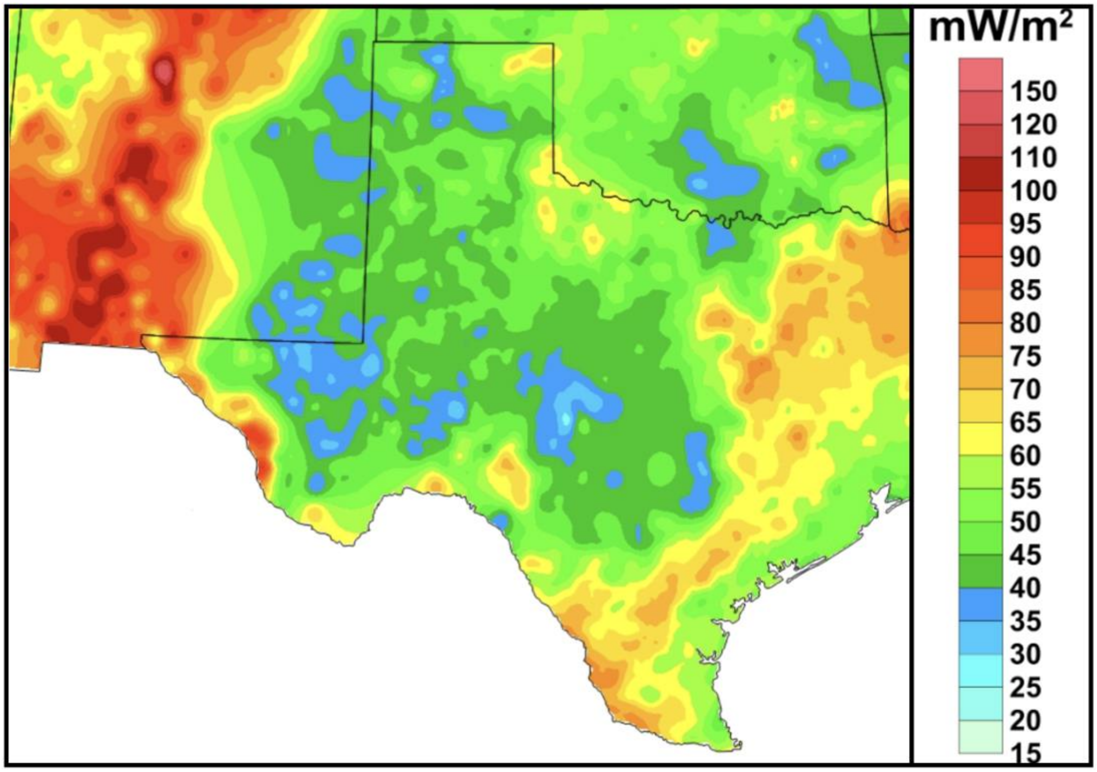

Figure 3.2: Map depicting the heat flow in Texas and Southern New Mexico regions of the U.S. Heat Flow.
Modified from Blackwell et al., 2011.

3.2.2 Study Area: Description and Background

The study area includes the Hueco and Mesilla Bolsons in West Texas, and the Tularosa and Jornada del Muerto Basins in Southern New Mexico. The Mesilla Bolson is approximately 2,000 feet (~600 m) at its deepest point, while the Hueco Bolson to the east has a maximum depth of up to 9,000 feet (~2,700 m). These basin-fill aquifers are characterized by their accumulation of unconsolidated to slightly consolidated clastic sediments (Hawley & Lozinsky, 1992; Sheng et al., 2001). Despite their proximity, limited hydrological exchange occurs between them, due to geological barriers imposed by the Franklin Mountains, although there is a small amount of flow from the Mesilla Bolson into the Hueco Bolson at the southern end of the Franklin Mountains (Figure 3.1).

The Tularosa Basin, hydrologically connected to the Hueco Bolson, is a closed desert basin distinguished by its white gypsum sands and significant military and testing range activities, which may influence local subsurface waters (EPA, 1995). The Jornada del Muerto Basin, located to the east of the Rio Grande and north of the Mesilla Bolson, is similarly characterized by its arid conditions and historical mining activities which have impacted its hydrogeology (Merkel et al., 2005; Newton et al., 2015). Geologically, the Hueco and Mesilla Bolsons offer a unique window into the interaction between geological formations and subsurface water chemistry, primarily composed of alluvial and aeolian deposits with underlying limestone and dolomite formations. These formations contribute to the mineralization of the waters through dissolution processes (Ging et al., 2020; Eastoe et al., 2022). Additionally, volcanic rocks in the surrounding areas suggest potential geogenic influences on water chemistry, particularly trace minerals and rare earth elements, often mobilized under geothermal conditions (Witcher et al., 2004; Garcia et al., 2021).

Hydrothermal activity associated with crustal thinning along the Rio Grande Rift and past volcanic events may have enriched subsurface fluids with a variety of minerals, making these basins ideal locales for studying geothermal energy prospects and associated mineral extraction. The thermal and chemical gradients present in these basins indicate geothermal processes that may influence the composition of subsurface waters, potentially increasing mineral concentrations such as lithium in geothermal waters. In addition to natural geogenic contributions, anthropogenic activities have also impacted water qualities in these regions. Agriculture, urban development, and industrial activities, particularly in the El Paso area, have introduced various contaminants into the water systems. A recent study by Talchabhadel et al. (2021) identified nitrates, pesticides, and heavy metals such as arsenic and lead as common pollutants derived from agricultural runoff and urban waste. The extensive use of groundwater for irrigation in these basins not only stresses the water resources but also increases the risk of contaminant spread through leaching and runoff. Mining activities in South Central New Mexico and its vicinity has also left a mark on the hydrology of the region. Abandoned mines and ongoing mining operations contribute to a range of water quality issues, including acid mine drainage and elevated levels of sulfates and heavy metals, which can alter the chemical makeup of both surface and subsurface waters (Plumlee & Logsdon, 1999). The interaction between these anthropogenic factors and the natural geological and hydrothermal dynamics of the area plays a significant role in the interpretation of the potential sources of water in the region.

3.3 Methodology

3.3.1 DESCRIPTION OF INPUT DATA AND PREPARATION

This study utilized historical datasets from established databases to examine lithium concentrations in subsurface waters for the study area. Data were sourced from the following databases:

- National Water Information System (NWIS) provided by the US Geological Survey (USGS): This dataset included a total of 1228 measurements samples with lithium concentrations.
- Texas Water Development Board (TWDB): An additional 138 samples with lithium measurements were retrieved.
- Texas Water Development Board Brackish Resources Aquifer Characterization System (BRACS): An additional 101 samples with lithium measurements were retrieved.

These sample data were combined and formatted to meet EPA PMF program specifications. To ensure data integrity and relevance to the study objectives, samples with any missing entries were excluded from the analysis. The final dataset comprised a total of 631 samples, each vetted to include complete records of all specified analytes. This selection process is critical for maintaining the quality and reliability of the subsequent positive matrix factorization (PMF) analysis. Input data is further described in the EPA PMF data preparation and processing section and in Table 3.1.

3.3.2 Positive Matrix Factorization Description

In this study, EPA's PMF 5.0 model (Norris et al., 2014) was used to analyze groundwater quality data to differentiate and quantify lithium source contributions that result in the observed lithium concentrations in the studied area. The PMF analysis provides insight about the sources of analytes, to what extent they are present in each source, and allows to assess the prevailing geochemical conditions at each source. The results provide a comprehensive view of the sources influencing the groundwater chemistry in the region.

Groundwater studies often use receptor models to understand the sources and contributions of contaminants. First described for use in environmental studies by Paatero and Tapper in 1994, PMF is a multivariate analysis technique designed to resolve the identities and contributions of various sources within a mixture (Zonotti et al., 2019). The PMF model accomplishes this by factoring a multivariate dataset consisting of the concentration matrix of water samples into two primary matrices: the G matrix (factor contributions) and F matrix (factor profiles), alongside a residual matrix. This method of data reduction or decomposition allows for a detailed examination of the underlying sources affecting the water chemistry assuming that the number of solute sources is already known.

Distinct from Factor Analysis (FA) or Principal Component Analysis (PCA), PMF does not impose constraints on the orthogonality of factors. Instead, it adheres to constraints that are more reflective of natural physical systems: (a) the composition of any predicted source must be non-negative, as a source cannot logically contribute a negative mass of any element; and (b) all predicted source contributions to each sample must also be non-negative, ensuring that a source cannot contribute negatively to the mass of a sample. These constraints enhance the environmental relevance of the results, making them more interpretable (Norris et al., 2014). Comparative studies have shown that PMF provides better outputs used for understanding of water chemistry phenomena than FA, which tends to merge various overlapping environmental processes into fewer factors (Norris et al., 2014).

The solution to the PMF model is obtained through a weighted least squares approach to minimize the value of the objective function *Q* for a given number of factors *p* (which is assumed or provided). *Q* is defined as:

$$Q = \sum_{i=1}^{n} \sum_{i=1}^{m} \left(\frac{x_{ij} - \sum_{k=1}^{p} g_{ik} f_{ik}}{\sigma_{ij}} \right)^2 ,$$

where Q is the sum of the squares of the difference between the observed (X) and the modeled (G×F) concentration data for the input dataset, weighted by the measurement uncertainties (σ_{ij}). σ_{ij} is the uncertainty of constituents j concentration data in the i^{th} sample, x_{ij} is the observed concentration with j^{th} chemical constituents of i^{th} sample, g_{ik} is the k^{th} factor contribution of i^{th} sample, and f_{ik} is the j^{th} factor profile of factor k^{th} (Norris et al., 2014).

Two versions of *Q* are calculated by EPA's PMF software: Q(true), which utilizes all points, and Q(robust) excluding a subset of points not fit by the model. The difference between Q(true) and Q(robust) helps to assess the impact of data points with high scaled residuals, which could be linked to source impacts not present throughout the sampling period. High uncertainties might cause Q(true) and Q(robust) to appear similar due to the scaling of residuals by these uncertainties. The Multilinear Engine (ME) is the underlying program used to solve PMF. PMF uses multiple iterations of the ME to determine optimal factor contributions and profiles, initiating with a random factor profile. This profile is methodically adjusted using a gradient approach within a multidimensional space to find the path to the best-fit solution (Figure 3.3). The lowest Q(robust) value typically indicates the best solution, representing the deepest point in the multidimensional space. However, the randomness of the models starting point (i.e., seed) introduces the risk of settling at a local minimum rather than the global minimum. To mitigate this, the model was run multiple times to increase the likelihood of finding the global minimum. Q(robust) serves as a critical measure for selecting the optimal model run. Variations in Q(robust) suggest differences in the stability of the paths to the minimum due to the initial conditions set by the random seed. Once an optimal run has been identified the seed number generated by the model was recorded so that results could be duplicated, if necessary.

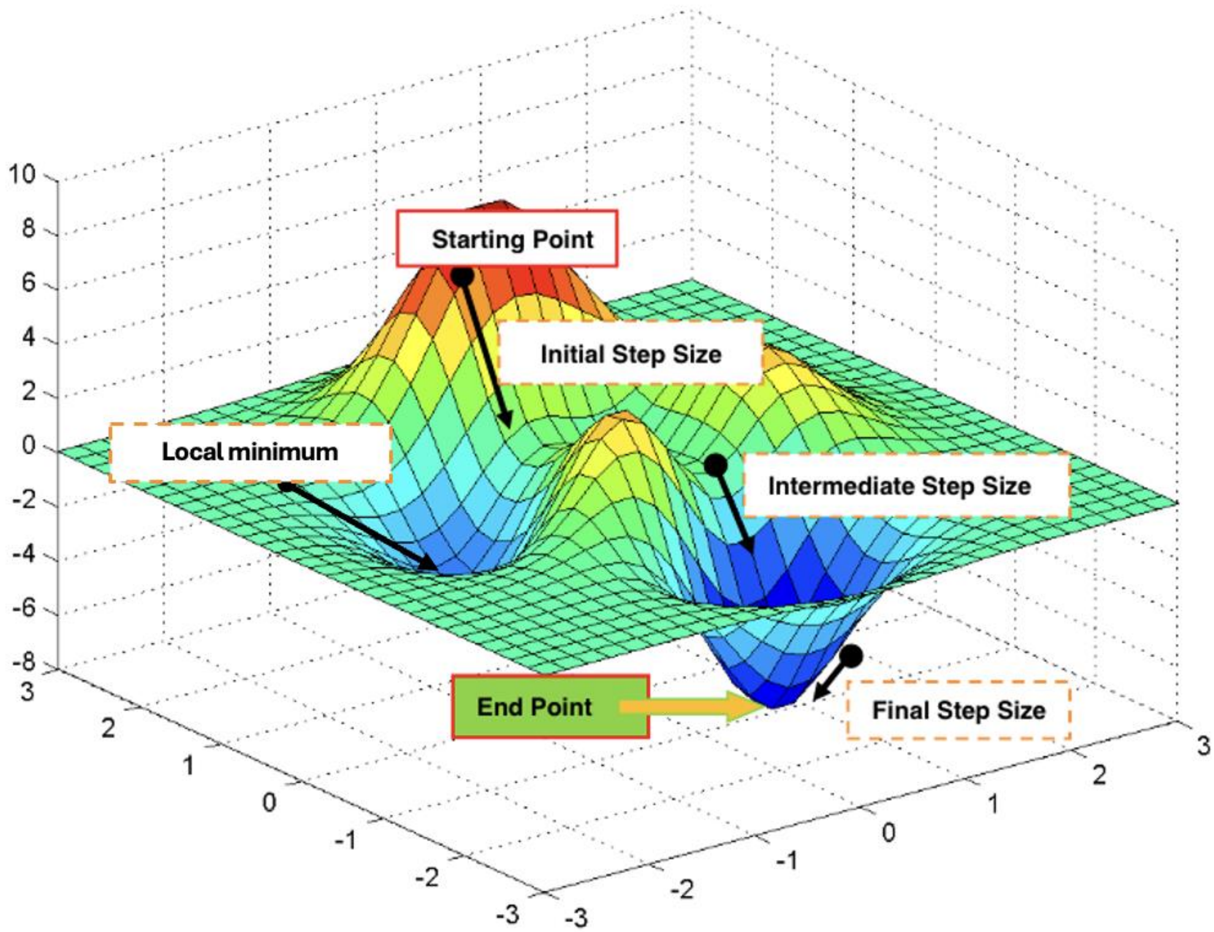

Figure 3.3: Visualization of the conjugate gradient method used by EPA's PMF program.
The method allows to local and global minima (modified from Norris et al., 2014).

The stability of model results can be evaluated through error estimates and intra-run diagnostics (Paatero et al., 2014). These evaluations help determine the reliability of the factor profiles across different runs, which may vary significantly due to chemical transformations or process changes. Variability in PMF solutions can be assessed using three error estimation methods: (1) Bootstrap (BS), which evaluates how a few observations might disproportionately influence the solution. It accounts for random errors and addresses rotational ambiguity, where numerous similar solutions exist due to possible matrix rotations with the only constraint being non-negativity. (2) Displacement (DISP), which analyzes the solution's sensitivity to minor changes, considering effects from rotational ambiguity in the factors but not random errors. Data variability can lead to larger DISP error intervals, especially for downweighed constituents. (3) BS-DISP, which is a method that combines BS and DISP, enhancing stability by incorporating both random errors and rotational ambiguity, and preventing excessive displacements seen in DISP alone. These methods together help determine the solution's stability and reliability under various uncertainties and ambiguities characteristic of PMF modeling (Norris et al., 2014). All three error estimation methods are essential to understand the uncertainty related to the solution.

The modeling procedures can be categorized into three main steps: (1) preparation of data for modeling, (2) application of PMF to generate a stable solution, and (3) analysis and interpretation of the results (Reff et al., 2007). During these stages, key decisions need to be made concerning input data, determining the optimal number of factors, and error modeling.

3.3.3 DATA PREPARATION

3.3.3.1 Input data

Two input files are required to run PMF: (1) sample constituent concentration values and (2) sample constituent uncertainty values. Only samples containing data for all eight analytes were included were included for this study. 631 samples, out of 14,757 from the original combined database, were used to generate the constituent concentration file. To create the subset of data appropriate for this study and to input into PMF, the following steps were applied: (1) filter out samples not containing lithium (1,467 samples with lithium); (2) isolate the relevant constituents (Ca^{2+}, Cl^{-}, HCO_3^{-}, K^{+}, Li^{+}, Mg^{2+}, Na^{+}, SO_4^{2-}); (3) remove any samples with blank or missing values for the selected constituents (reduced to 631 samples); (4) convert units for all constituents to mg/L, (5) format all values to have the same number of digits; (6) format cell widths and heading rows; (7) calculate uncertainty values for each constituent. A summary of the concentration and uncertainty data used for PMF input is provided in Table 3.1.

Column and row headers and dimensions must match the uncertainty values file and concentration values file, otherwise the program will not allow the data to be evaluated. Like with the concentration values, uncertainty inputs with negative and zero values are not permitted by the program, as with concentration values. Since uncertainty value are not always reported by agencies or easily obtained from databases, the uncertainty values for this study were calculated for each constituent from each sample using an equation-based method recommended by the EPA PMF 5.0 User Guide.

Table 3.1: Summary of concentration data and uncertainties used for PMF input.

	Concentration Data					Uncertainties				
	min	max	average	median	std dev	min	max	average	median	std dev
Ca (mg/L)	2.41	996.00	129.59	58.80	181.84	0.24	99.60	12.96	5.88	18.18
Cl (mg/L)	4.85	15300.00	606.89	175.00	2029.44	0.49	1530.00	60.69	17.50	202.94
HCO_3 (mg/L)	13.00	1970.00	239.67	168.41	231.91	1.30	197.00	23.97	16.84	23.19
K (mg/L)	0.57	154.00	9.41	8.61	8.90	<0.06	15.40	0.94	0.86	0.89
Li (mg/L)	<0.001	2.28	0.17	0.10	0.30	<0.0001	0.02	<0.002	<0.001	<0.004
Mg (mg/L)	<0.02	932.00	40.32	14.70	117.07	<0.002	93.20	4.03	1.47	11.71
Na (mg/L)	14.80	8910.00	460.42	162.00	1285.51	1.48	891	46.04	16.20	128.55
SO_4 (mg/L)	17.40	5100.00	444.73	185.00	877.29	1.74	510.00	44.47	18.50	87.73

3.3.3.2 Number of factors

Selection of the number of factors (i.e., sources) in the PMF model typically does not follow standardized methods (Zanotti et. Al., 2019). Instead, it involves using a gradient method to search for solutions with varying factor counts and evaluating criteria such as the Q/Qexp ratio, residual distributions, and the environmental interpretability of the factors (Norris et al., 2014; Karanasiou et al., 2011). The choice of the appropriate factor number is a balancing act: while increasing factors reduces residuals, too many factors may split meaningful groups into improbable ones, leading to solutions that lack environmental relevance (Yan et al., 2016). The determination of the appropriate number of factors in the PMF model was guided by the EPA PMF 5.0 User Guide criteria, outlined by Reff et al. (2007). Several models ranging from three to five factors with random starting points were analyzed to select the optimal number based on these recommendations (Table 3.2).

Table 3.2: Summary of recommendations for the determination of the appropriate number of factors and overall assessment of the PMF model fit for a four-factor model.

	Description
Residual Analysis	Uncertainty-scaled residuals for the chosen run are presented as histograms for each analyte, allowing to assess how well the model fits each analyte. Many large-scale residuals or deviations from a normal distribution curve indicate a poor fit.
Observed/Predicted Scatter Plot (goodness of model fit)	Comparisons between input values and modeled values are useful for assessing how accurately the model represents each analyte, including the identification of outliers. Additionally, tables displaying base run statistics for each analyte help to determine if residuals follow a normal distribution, as verified by the Kolmogorov-Smirnov test.
Profiles/Contributions	Factors are illustrated in a graph that shows the concentration of each analyte allocated to the factor. This can be used to determine if the sources identified by PMF make sense given the geochemical characteristics and known environmental factors of the region. This evaluation helps ensure that the sources derived from the model are consistent with the geological and hydrological context of the study area

To determine the most parsimonious model, an iterative approach was used, starting with a single factor and progressively increasing the number of factors while closely examining the residual analysis. For each run, the residuals were analyzed to assess their distribution, focusing on the uncertainty-scaled residuals and their normality. The goal was to identify the point at which the residuals were approaching normal distribution, and the large z-values diminished, indicating a good fit without overfitting the data. As the number of factors increased, models were analyzed to ensure that the addition of a new factor provided meaningful, geochemically and environmentally plausible sources rather than merely redistributing existing elements in an arbitrary manner. This iterative process continued until adding more factors no longer improved the model's fit and began to yield improbable or environmentally irrelevant solutions.

3.3.4 Data Processing

The order of operations suggested by the EPA PMF 5.0 User Guide was followed and is summarized in Figure 3.4. This data processing workflow involved a sequence of operations to ensure accurate source apportionment analysis.

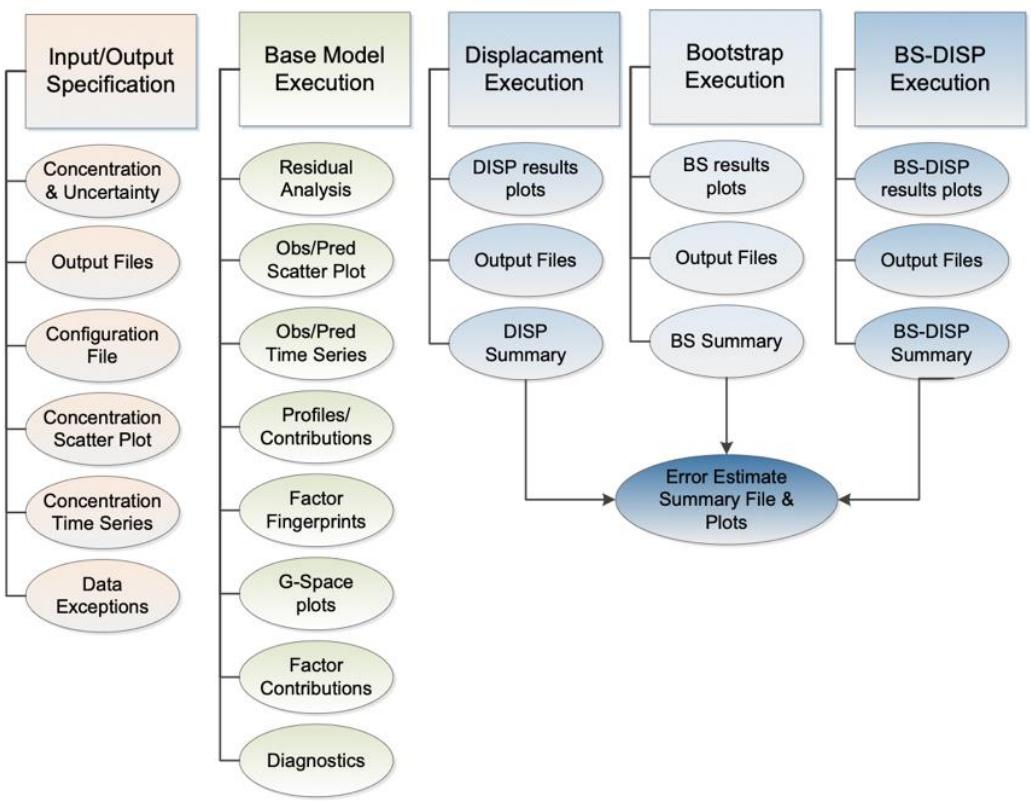

Figure 3.4: Flow chart of suggested order of operations within EPA PMF.
Figure from Norris et al. (2014).

After the specification of input data, the process continued with the execution of the base PMF model, which included a detailed residual analysis to assess the model fit through observed/predicted scatter plots and time series, as well as generating profiles of factor contributions and fingerprints. This step helped to understand the distribution and impact of each identified source and included comprehensive diagnostics to ensure model stability and accuracy. Following the base model execution, the displacement method (DISP) was implemented to analyze the sensitivity of the solution to minor data perturbations, which helped in identifying stable and significant sources. Subsequently, bootstrap analysis (BS) was conducted to assess the robustness of the model outputs by resampling the data multiple times to analyze variability in the results. This was supplemented by the BS-DISP method, which combined both bootstrap and displacement error estimate methods to further refine the stability and reliability of the factor analysis.

These analyses led to the creation of an error estimate summary file and associated plots, providing a comprehensive view of the uncertainties and the reliability of the model outcomes. Each step in this approach was designed to build upon the previous, ensuring that the final PMF model outputs were both robust and environmentally relevant, enabling a thorough understanding of the underlying sources contributing to the water chemistry. This enhanced the reliability of environmental assessments and decisions based on the PMF analysis.

3.4 Results and Discussion

The optimal number of factors was determined to be four, as it best represented the system under investigation with the fewest number of sources and is therefore the most parsimonious model. Executing 100 PMF runs with different starting points (i.e., seed number) ensured convergence for each run and provided a final solution for the base model. The run with the lowest Q(robust) value were automatically selected by the program, with all runs having converged (i.e., a stable solution or minima was found for every run). Run 26 represented the optimal run and was used to run error estimations through the base model displacement and bootstrap methods.

Lithium was apportioned to two out of four factors (i.e., Factors 1 and 2), suggesting that only two solute sources for regional groundwater contributed significant contribution of lithium

(Figure 3.5; Figure 3.6). Factor profiles reveal the mass of each analyte apportioned to the factor (Figure 3.7). Despite initial expectations to identify a geothermal fluid end-member characterized by elevated lithium and other monovalent ions, no such end-member was found. The analysis did not reveal a distinct geothermal source, perhaps due to insufficient data or the absence of geothermal characteristics in the study area. Specifically, the dataset lacked adequate silica measurements, which would have been a key indicator of geothermal activity, as silica enrichment is typically associated with high-temperature geothermal fluids. In the following section, the composition and origin of each source identified in the PMF model are discussed based on model results and known sources of groundwater salinity in the region.

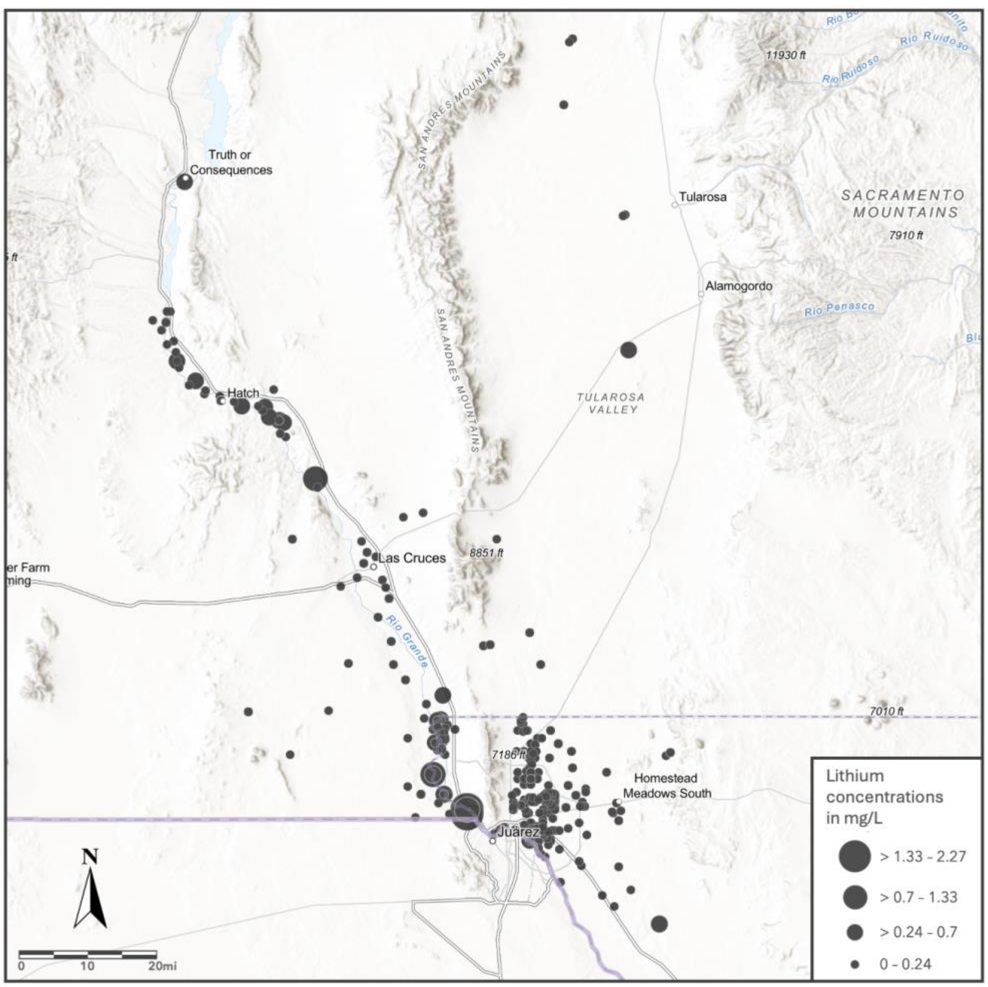

Figure 3.5: Spatial distribution of lithium concentrations in groundwater for the studied area.

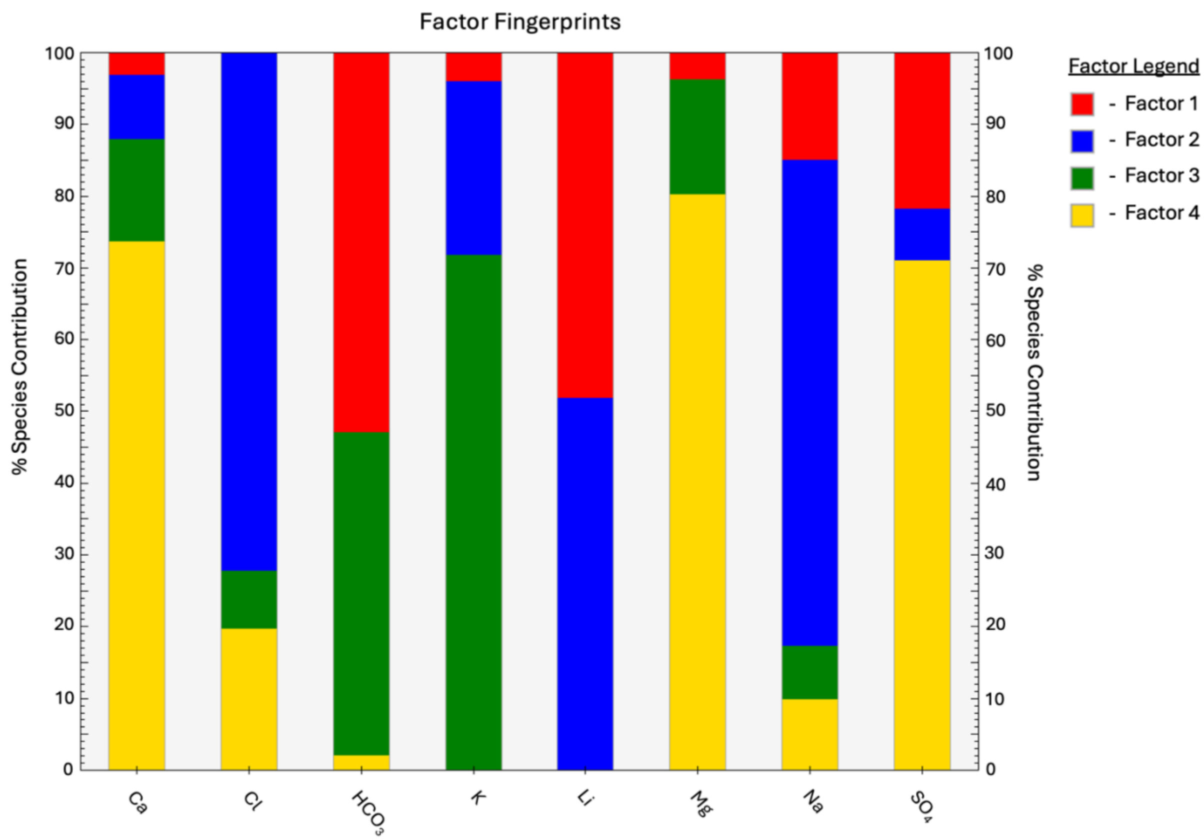

Figure 3.6: Factor fingerprints for each factor by analyte.
Factor fingerprints display the concentration (in percent) of each analyte (i.e., species) contributing to each factor. Each bar represents an analyte, and the different colors in each bar represent the distribution of factors for indididual analyte.

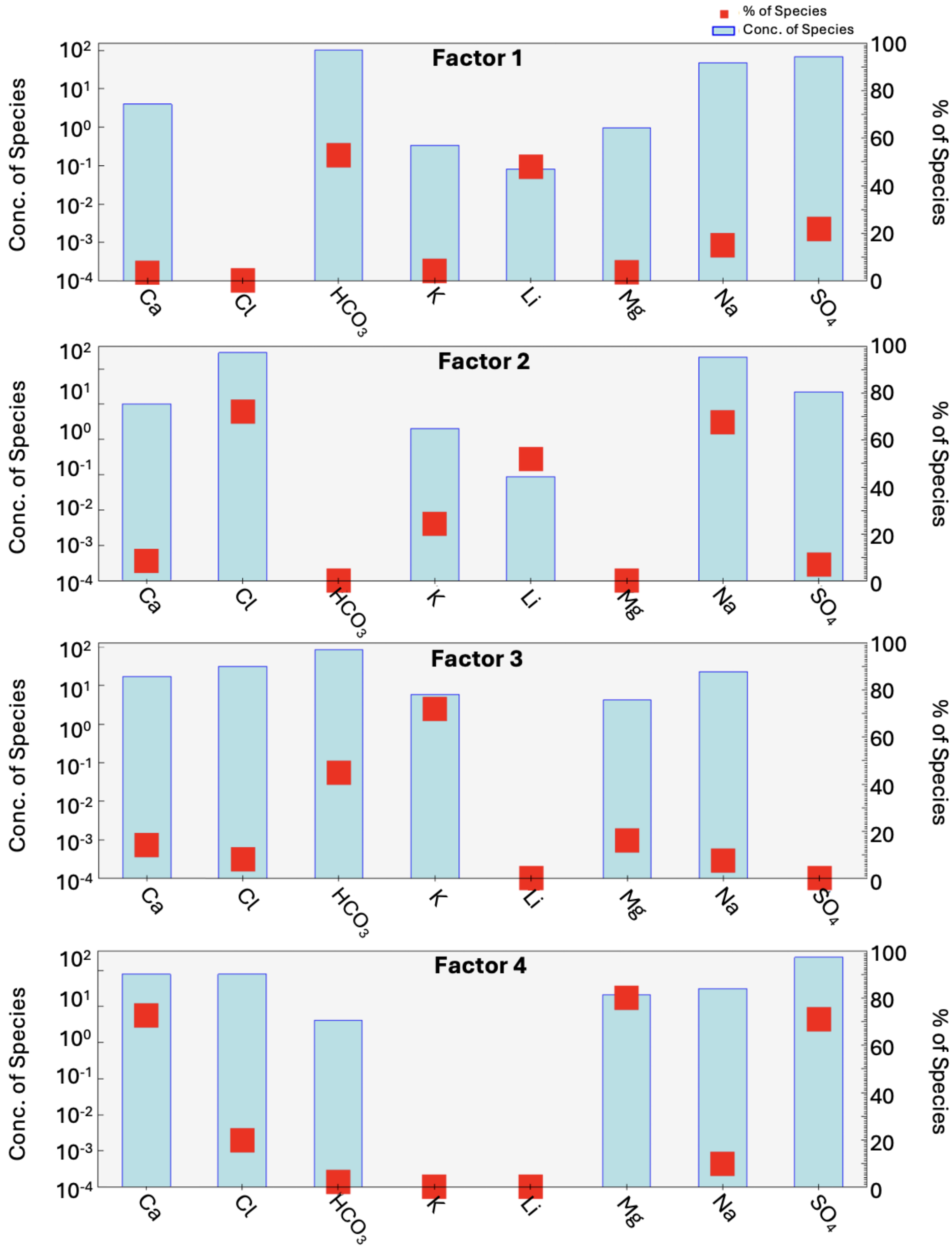

Figure 3.7: Factor profiles showing the mass or concentration of each analyte.
Blue bars, left Y axis, indicate absolute values on logarithmic scale and red boxes, right Y axis, the percent of each analyte apportioned to each factor.

3.4.1 Factor 1

Factor 1 is interpreted to be predominantly shallow, low-salinity water source heavily influenced by surface activities and minor geological interactions. Samples with large contributions of this end-member (i.e., factor) are predominantly characterized by Na-HCO_3-SO_4 water types. The hydrogeochemical profile of this factor indicates a very shallow source of water, influenced by local, surface-level hydrological processes rather than deeper groundwater interactions. This factor is likely associated with fresh water, possibly from agricultural drainage, as indicated by its low total dissolved solids (TDS). Typical TDS measurements for the highest individual sample contributions to Factor 1 range between 200 to 500 mg/L, aligning closely with TDS levels commonly found in Rio Grande water. Low TDS concentrations are indicative of limited water-rock interaction and a shallow groundwater system with low migratory history (Talabi & Tijani, 2013). This suggests that the water from Factor 1 is a mixture of shallow, local recharge water combined with Rio Grande water (Figure 3.8).

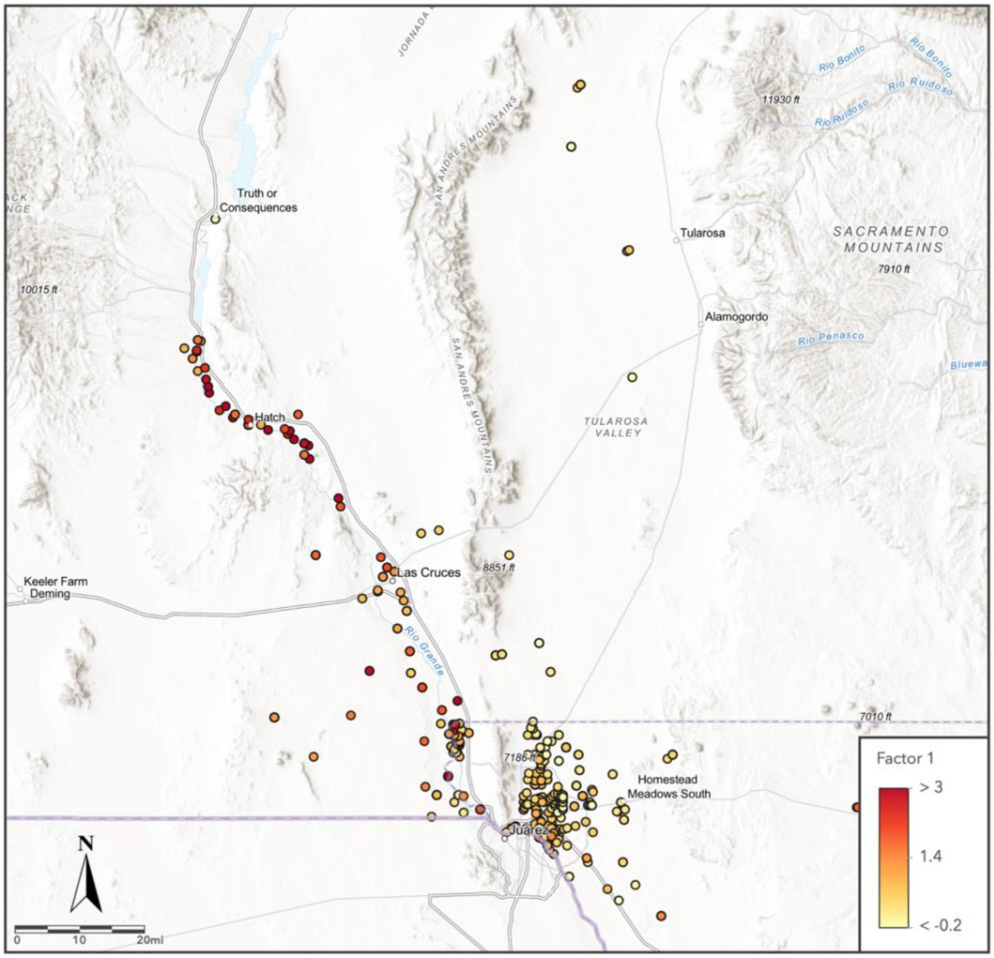

Figure 3.8: Spatial distribution and contributions of samples apportioned to Factor 1.

The bicarbonate (HCO_3^-) levels in this factor are likely derived from atmospheric carbon dioxide (CO_2), through a process whereby CO_2 dissolves in water to form carbonic acid (H_2CO_3), which then dissociates to release bicarbonate ions (HCO_3^-) and hydrogen cations (H^+, i.e., acidity) (Frankignoulle et al., 1994). This process results in waters with elevated bicarbonate concentrations without a proportional increase in other ions. The presence of sulfate (SO_4^{2-}) in this factor supports the hypothesis of an agricultural influence (Giao et al., 2021), possibly from drainage systems used in agricultural sites which are prevalent in the study area.

Regional differences for Factor 1 and are more pronounced in the Mesilla Bolson (Figure 3.9). This area might act as a converging point for the most evaporated water due to its geographical and hydrological conditions that facilitate the accumulation and upward movement of brines. This scenario could explain the observed increase in lithium concentrations within the Mesilla Basin, suggesting a non-geologic, perhaps anthropogenically influenced hydrochemical profile. Conversely, the Hueco Bolson does not show significant variance to the contribution of Factor 1. The lack of geological differentiation between the Mesilla and Hueco Bolsons further suggests that the sources contributing to Factor 1's chemical signature are not geogenic. If contributions to Factor 1 were influenced by calcite dissolution, we would expect to see higher concentrations of calcium and magnesium (Gledhill & Morse, 2006). These analytes do not appear as significant contributors, although their concentrations are slightly elevated. This suggest that while calcite might contribute to the geochemical profile, it does not dominate the composition of Factor 1.

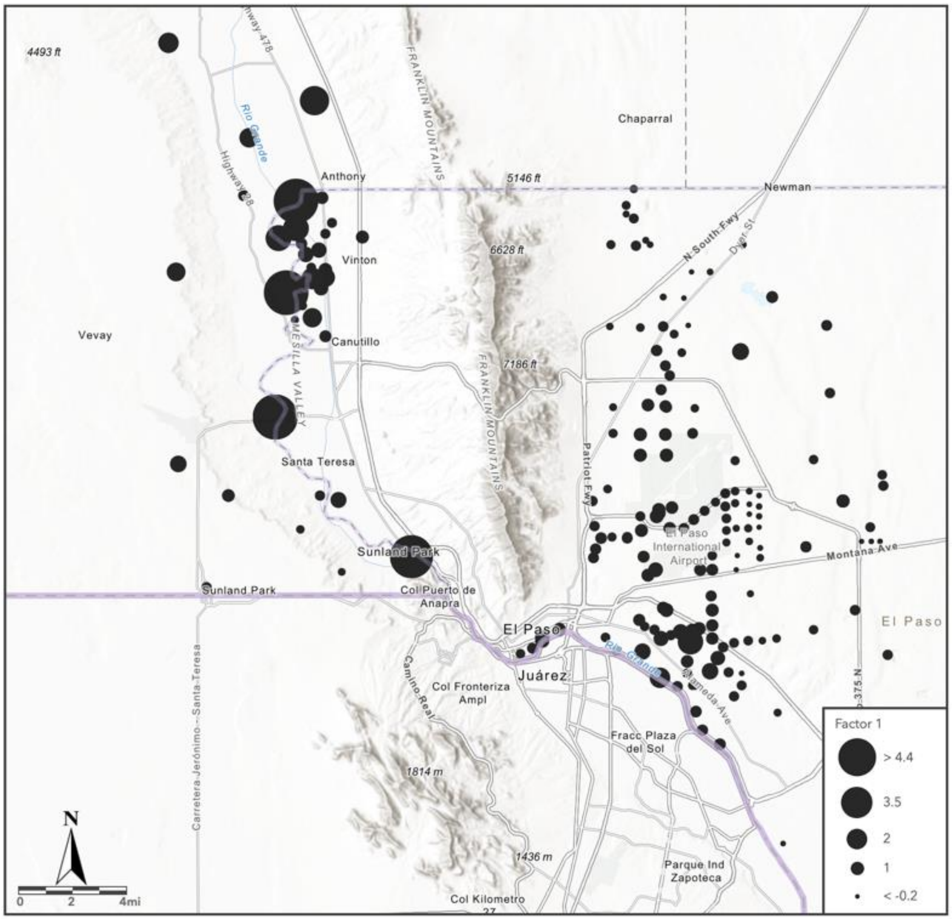

Figure 3.9: Spatial distribution and contributions of samples to Factor 1.
Circle by size illustrates differences between the Mesilla and Hueco Bolsons - apportioned to Factor 1.

3.4.2 Factor 2

Factor 2 corresponds to Na-Cl-SO_4-type water, indicative of a saline groundwater environment. The high salinity in this factor is likely due to the dissolution of halite and gypsum, minerals commonly associated with evaporite deposits. The dissolution of halite and gypsum significantly affects groundwater chemistry, leading to high chloride concentrations (Mallick et al., 2018). This factor's chemical profile suggests an influence from evaporite deposits, supporting the hypothesis that the observed salinity originates from ancient, possibly deep evaporite layers rather than from surface-level processes.

The low mass of calcium (10.73 mg/L) and absence of magnesium apportioned to Factor 2 points towards a lack of calcite dissolution, which typically contributes to water hardness (i.e., high amounts of dissolved calcium and magnesium). This absence, along with the high TDS, suggests that the primary mineral dissolution processes contributing to this source involves halite and gypsum, although their contribution appears to be relatively moderate. The chemical makeup here does not indicate significant evaporation; instead, it aligns more with mineral dissolution from old evaporite deposits.

The relative contributions to Factor 2 are more pronounced in regions far from the Franklin Mountains to the east (Figure 3.10), suggesting a hydrological connection to sources other than immediate mountain runoff. It is reasonable assumption that these waters represent older groundwater that is less influenced by and not well connected to the Rio Grande. This hypothesis is reinforced by the distinct chemical signatures that differentiate these waters from those recharged more directly by the river (Druhan et al., 2007; Hibbs & Merino, 2022), potentially categorizing them as pre-dam versus post-dam waters (Figure 3.11). The factor's composition likely reflects groundwater from the upper Santa Fe group, which historically has had less connectivity to the Rio Grande (Hibbs & Merino, 2006; Eastoe et al., 2010). This groundwater appears to be primarily locally derived, with its recharge and flow mechanisms largely independent of the river's influence (Figure 3.12).

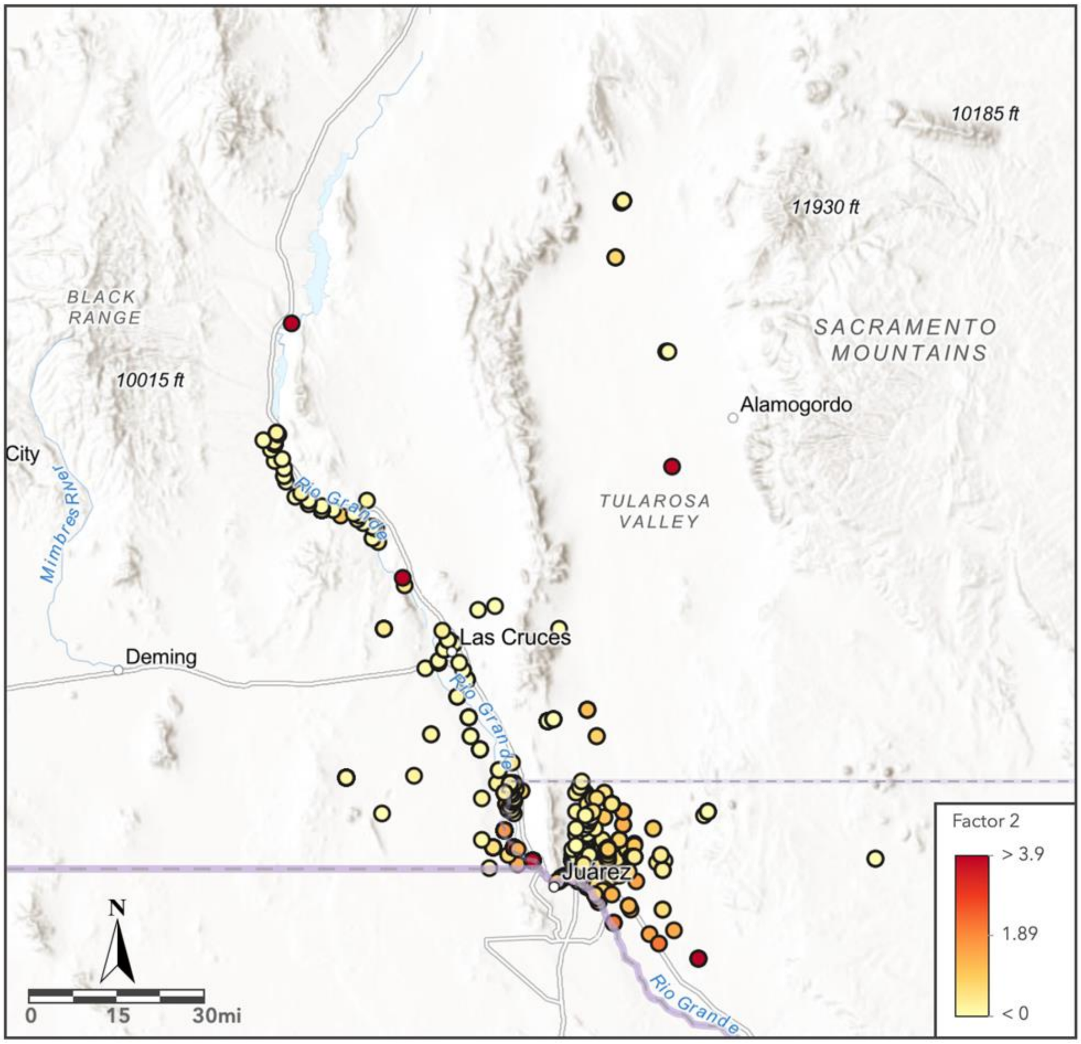

Figure 3.10: Spatial distribution and contributions of samples apportioned to Factor 2.

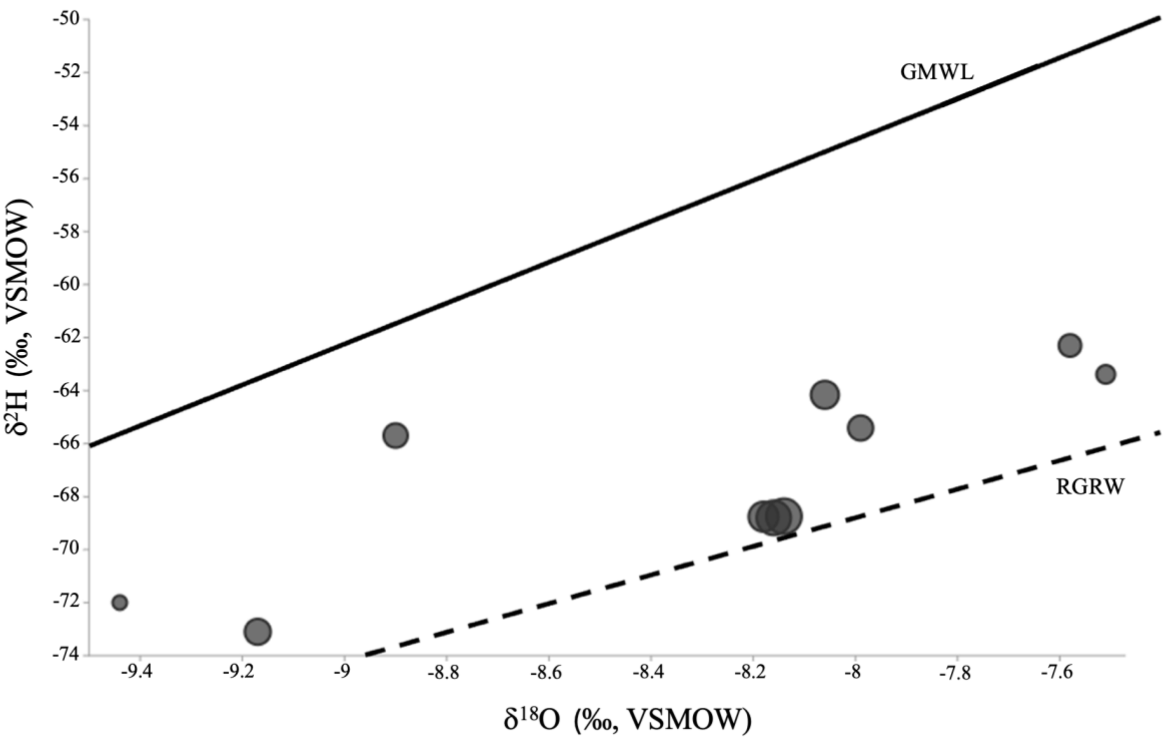

Figure 3.11: Stable isotope composition of water samples.
Stable oxygen and hydrogen isotopes in the top 10 samples shown proportional to their relative contributions to Factor 2. $\delta^{18}O$ versus $\delta^{2}H$ values are in per mil relative to the VSMOW standard. GMWL is the global meteoric water line and RGRW represents the stable oxygen and hydrogen isotopes in the Rio Grande River water (Philips et al., 2003).

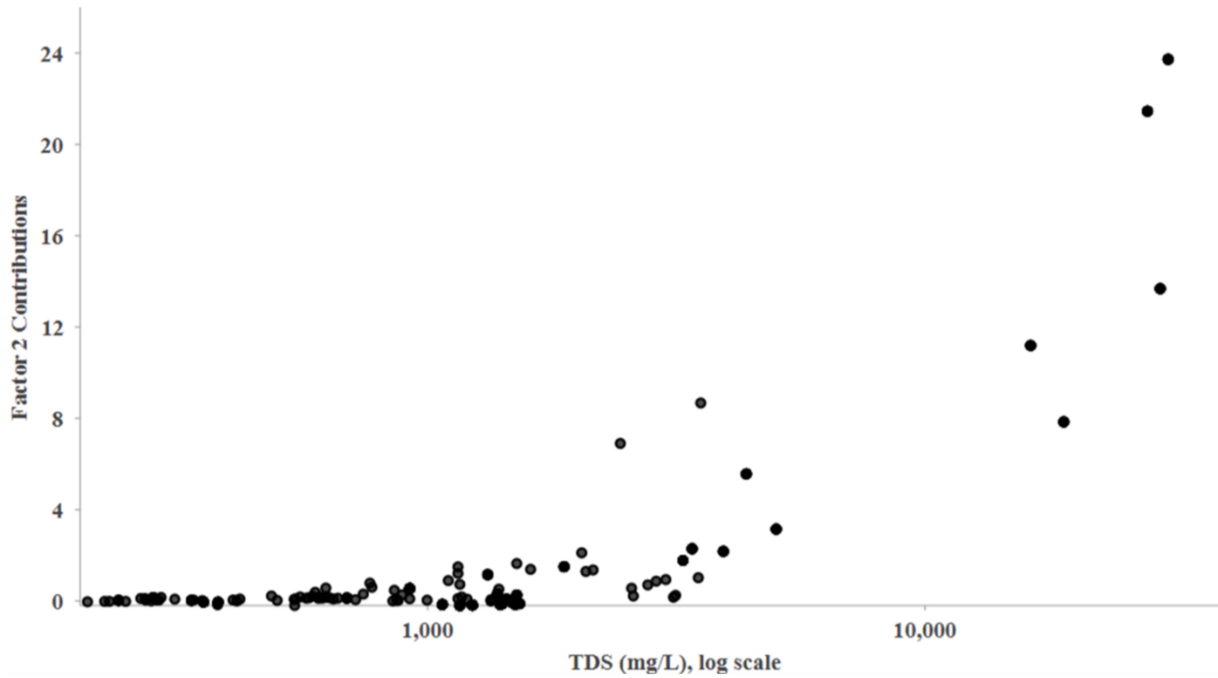

Figure 3.12: Plot of TDS versus relative contribution to Factor 2.

3.4.3 FACTOR 3

Factor 3 highlights the dynamic and mixed hydrology of the area, heavily influenced by historical flow paths of the Rio Grande River. The interaction of river-derived groundwater with limestone and clay within the aquifer system illustrates the natural processes of mineral dissolution and ion exchange that shape the chemical composition of this factor. Factor 3 is defined by Na-Ca-HCO_3-SO_4 water types, representing a more typical mixed source of groundwater influenced by the Rio Grande River and the associated geological features (Figure 3.13). This factor suggests a complex hydrogeochemical interaction involving old Rio Grande water that has interacted substantially with limestone formations, leading to a presence of calcium and bicarbonate in the water.

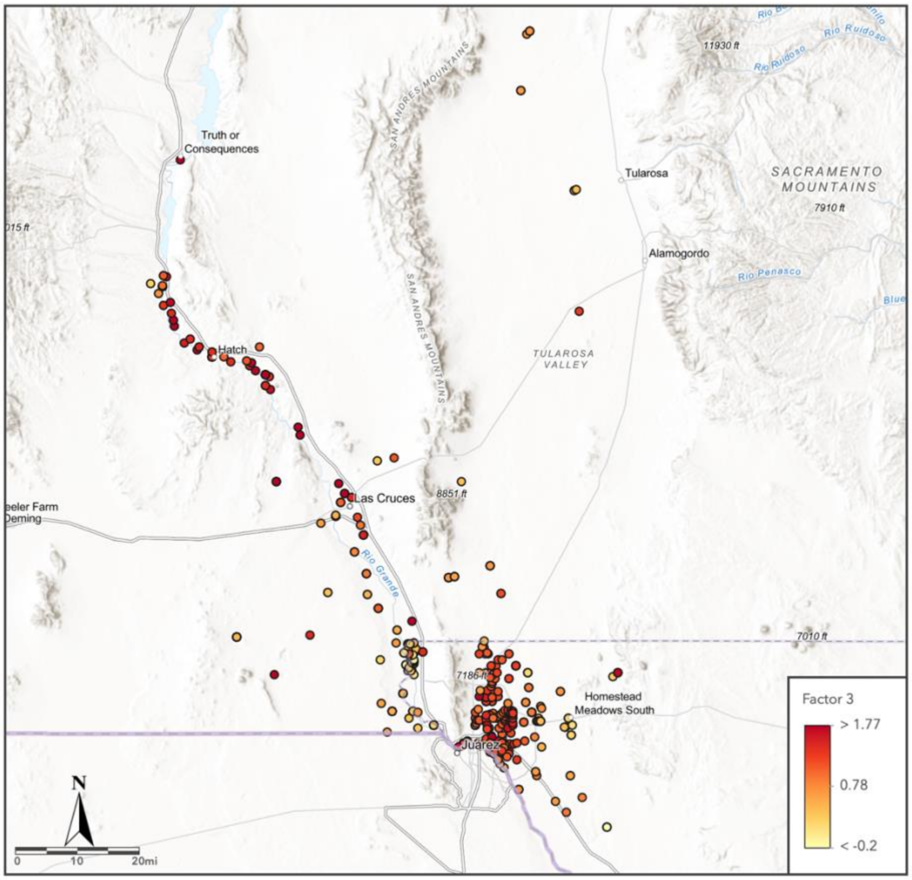

Figure 3.13: Spatial distribution and contributions of samples apportioned to Factor 3.

The dominance of sodium over calcium in the groundwater may also result from cation exchange processes where calcium ions are replaced by sodium ions on clay minerals (Kura et al., 2013). This softening process, where groundwater originally rich in calcium becomes enriched in sodium, is a common reaction in initially calcium-rich groundwater systems that contain clays and are initially rich in calcium. As the water progresses through the aquifer, the interaction with clay leads to an increase in sodium content, which is evident in the hydrogeochemical profile of this factor. This softening process results in the Na-Ca-HCO_3-SO_4 type water that characterizes Factor 3, reflecting a typical signature of groundwater modified by both limestone dissolution and subsequent clay interactions.

3.4.4 FACTOR 4

Factor 4 represents a unique source within the study area. Initially, evaporative processes were considered, but low TDS values of this factor do not support this. The typical signs of evaporation, such as increased concentrations of lithium and potassium, are notably absent. This absence indicates that the processes influencing this factor are not related to evaporation, suggesting alternative geochemical or hydrological influences. The hydrogeochemical makeup of Factor 4 suggests the possibility of mixing between deep saline water in the Tularosa basin and locally derived upper Santa Fe group groundwater (potentially influenced by Factor 2 waters). Many sample contributions to Factor 4 are predominantly observed along the Rio Grande River, possibly influenced by agricultural return flows. The highest individual sample contributions come from 6 samples within the Tularosa Basin east of the San Andreas Mountains and White Sands National Park (Figure 3.14). Those samples add a layer of complexity to the interpretation of this factor's geochemical signature.

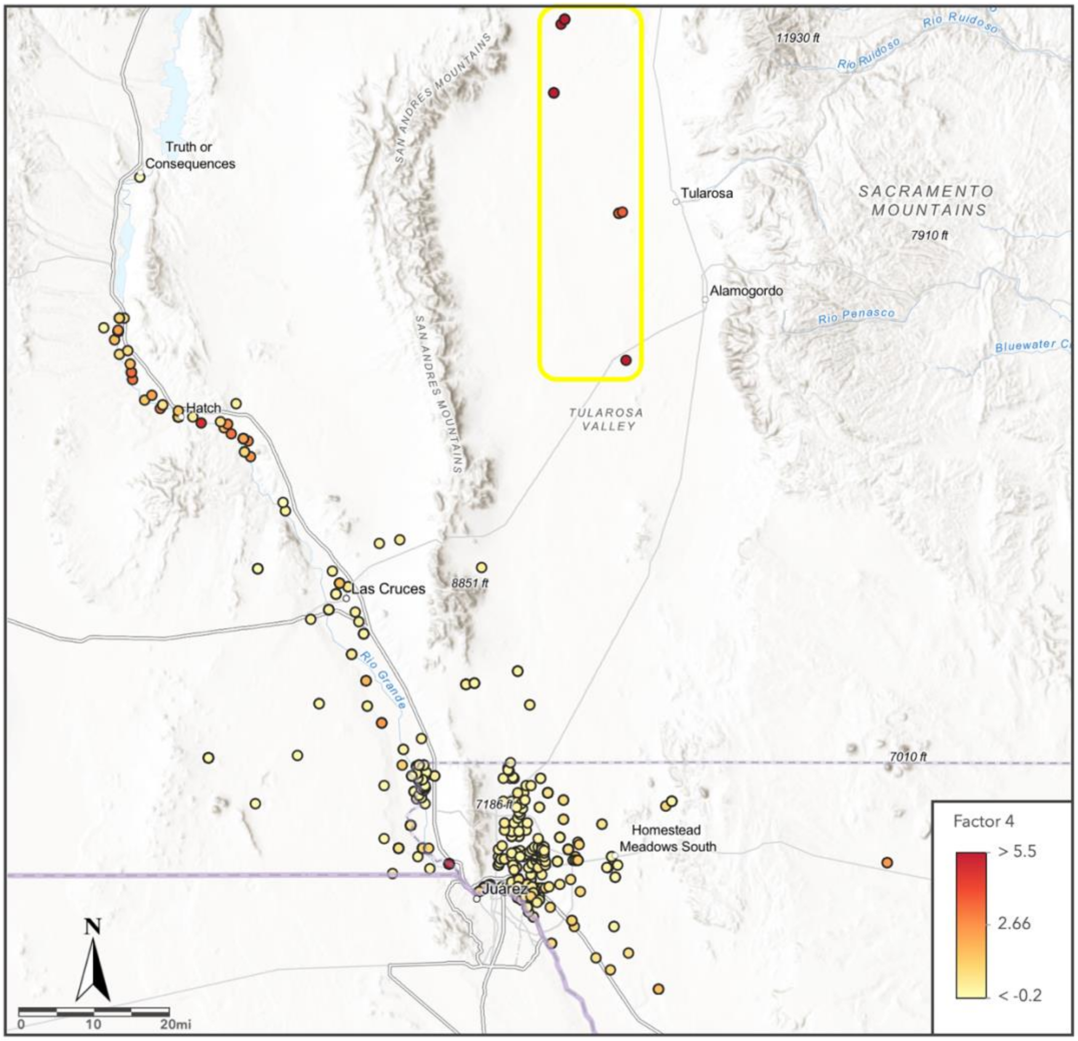

Figure 3.14: Spatial distribution and contributions of samples apportioned to Factor 4. Samples within the yellow box indicate the highest contributors to Factor 4.

Further analysis suggests that Factor 4 could be influenced by the dissolution of evaporite minerals, particularly gypsum, rather than halite or anhydrite, given the geological context. This is supported by the moderate TDS levels, which are not as high as would be expected in a heavily evaporative environment. It appears that Factor 4's contributions are discontinuous, possibly shaped by waters interacting with evaporite deposits. At the interface between the base of the Camp Rice Unit and top of the Fort Hancock unit in the upper Santa Fe group (Figure 3.15) there are stratigraphic layers with old evaporite sources. Towards the latter stages of the deposition of these evaporite layers, there are sporadic and likely thin deposits from ancient lakes. These evaporites are present in in parts in the Hueco Bolson as a result of a playa that was present in this area during the mid- to late-Pliocene. Moreover, older gypsum-rich deposits are found in late Permian Units, such units in the Yeso Group, which outcrop in the Franklin and Organ Mountains and are found at depth along some of the basin margins, where the Cenozoic sediment is thin (Kottlowski, 1965). The interactions between groundwater and these deposits can lead to the dissolution of minerals like gypsum, contributing to the observed sulfate levels without the high salinity typically associated with more soluble evaporites like halite. The relatively high concentrations of SO_4^{2-} found in Factor 4 are likely due to input from Permian gypsum found in the Tularosa basin (Druhan et al., 2008). SO_4^{2-} concentrations for Factor 4 are roughly ~1/3 that of Cl^-. This is lower than the Tularosa input with 0.4 ratio of Cl^- to SO_4^{2-} suggested by Druhan et al. (2008), further validating the assumption of a mixture of deep saline water in the Tularosa basin with locally derived groundwater from the upper Santa Fe group (i.e., Factor 2).

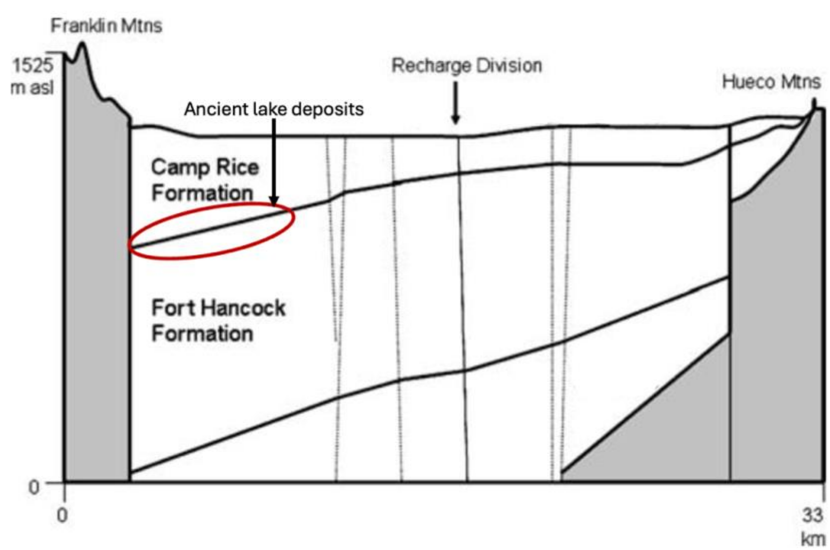

Figure 3.15: E-W cross section of the Hueco Bolson.
The circled area denotes the location of discontinuous evaporite deposits from ancient lakes that likely contribute to the moderate TDS levels from Factor 4. (Modified from Druhan et al., (2008) originally modified from Eastoe et al., 2008).

3.5 Conclusion

3.5.1 Economic Relevance of Lithium Endmembers

Although the amount of lithium is seemingly low for the samples used in this study (i.e., 0.001 mg/L – 2.28 mg/L), the overall natural occurrence of lithium in El Paso, TX, and the surrounding region, is high compared to other cities in Texas and the United States (Schmidt et al., 2005). In a national-scale evaluation of lithium in groundwater used for drinking-water supply (Lindsey et al., 2020), lithium concentrations were found to be high in unconsolidated clastic deposits and sandstones, such as in the Rio Grande aquifer system (Figure 3.16). This highlights the significant potential for lithium extraction in these areas.

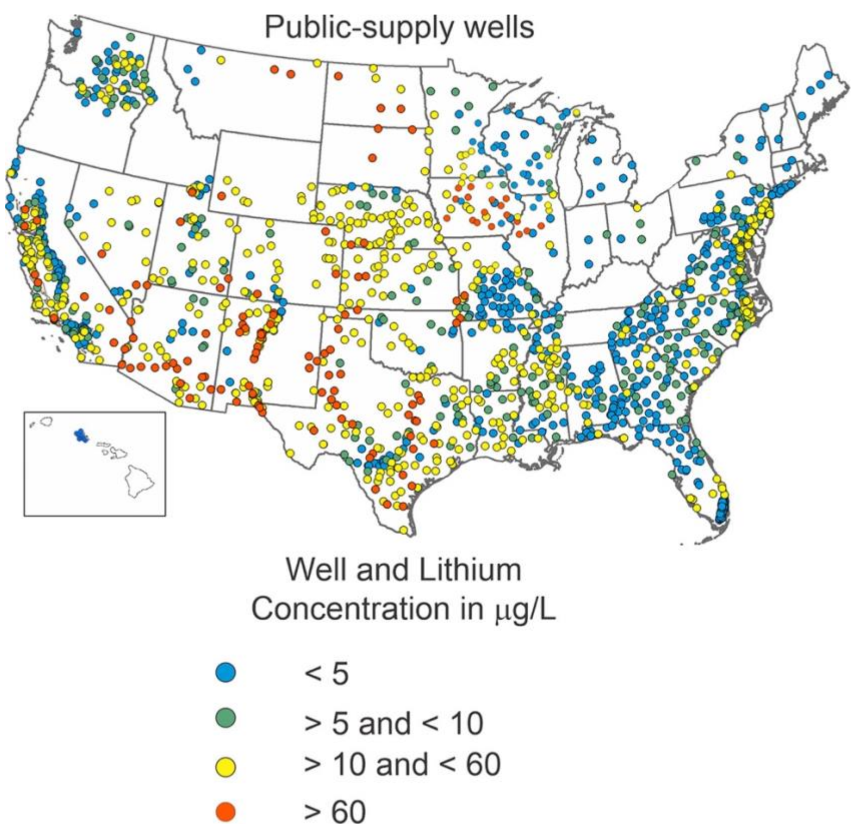

Figure 3.16: National-scale evaluation of lithium in groundwater (Lindsey et al., 2020).

The analysis from this study indicates that lithium endmembers (i.e., Factors 1 and 2), despite their low concentrations, may still hold economic relevance. Specifically, Factor 1 exhibits relatively high lithium contributions and low concentrations of other monovalent elements like sodium and potassium, making it an attractive target for lithium extraction. The presence of fewer competing ions can simplify the extraction process, potentially lowering operational costs and increasing the efficiency of lithium recovery.

3.5.2 PMF Approach: Benefits and Caveats

The PMF approach has proven to be effective in differentiating and quantifying the sources contributing to the observed lithium concentrations. One substantial benefit of PMF over other methods, such as Principal Component Analysis (PCA), is that it does not impose orthogonality constraints, making it more reflective of natural physical systems. This results in more environmentally relevant and interpretable outcomes (Paatero & Tapper, 1994). Handling non-negative constraints for source contributions and compositions enhances PMF's applicability in environmental studies (Wu et al., 2011). The non-negative constraints in PMF provide two important advantages over traditional factor analysis (FA) or PCA: the rotational ambiguity of the solution space is reduced, and all the results are more likely to be physically meaningful (Wu et al., 2011). Furthermore, PMF produces a better fit to the data than FA, since the result of FA often cannot be rotated to eliminate all negative entries (Paatero & Tapper, 1994). These features make PMF particularly well-suited for complex environmental data (Wu et al., 2011). PMF also provides improved resolution of sources and better quantification of the impacts of those sources compared to PCA (Huang et al., 1999).

However, there are caveats to using PMF. The solution may depend on the initial conditions set by the random seed, which can lead to local rather than global minima. Additionally, PMF requires careful preparation and selection of input data, including the calculation of uncertainties, which can be labor-intensive (Paatero & Tapper, 1994). Resolving PMF algorithms can be slower than PCA. PCA is also relatively simpler to use as there are less parameters to control (Comero et al., 2009). While PMF is more complex and harder to use it offers significant advantages in terms of source resolution and quantification, making it a valuable tool for groundwater studies.

3.5.3 Insights

Significant insights from this study supplement the understanding of the groundwater systems in the region, emphasizing the complexity and diversity of sources influencing salinity levels of distinctive waters. Specifically, the analysis of the four factors derived from PMF accentuate the geochemical processes associated with and contributing to the sources of salinity in these waters, offering a more nuanced view of the region's hydrogeochemistry.

Factor 1 revealed that lithium contributions from shallow, low-salinity water sources are influenced predominantly by surface activities, such as inflows of surface brines via agricultural drains and waste effluent, with minimal geological interactions. The relatively high lithium concentrations and low levels of competing ions like sodium and potassium in these sources indicate a promising potential for efficient lithium extraction. This finding suggests that researchers and industries interested in lithium extraction in the region can potentially leverage shallow, non-geogenic sources of lithium identified through Factor 1 analysis. Factor 2 pointed to the importance of saline groundwater environments, where the dissolution of deep evaporite layers significantly contribute to lithium levels. This accentuates the role of ancient evaporite deposits in shaping the region's groundwater chemistry and highlights the diverse origins of salinity. Factor 3 demonstrated the complex hydrology of the area, where historical interactions between river-derived groundwater and geological formations like limestone and clay impact groundwater salinity. This emphasizes the significant influence of river-aquifer interactions on groundwater geochemistry, contributing to the understanding of the geochemical evolution of the groundwater system. Factor 4 challenged initial assumptions about evaporative influences, revealing instead how geochemical interactions at the interfaces between different geological units influence groundwater salinity. These interactions highlight the complexity of the groundwater system and the role of ancient lake deposits in influencing groundwater salinity.

These insights collectively enhance the understanding of the hydrogeochemical processes in the region through source water identification and characterization. Understanding groundwater origin and its subsequent geochemical evolution aids in assessing potential mineral commodities, such as lithium, present in groundwater. The findings from this study provide a foundation for future exploration and sustainable exploitation of lithium and other mineral resources that can be applied in other regions. This study has also demonstrated the value of advanced analytical techniques like PMF in uncovering intricate groundwater dynamics and guiding future resource management and mineral extraction.

3.6 References

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4. REVIEW AND TEMPLATE DEVELOPMENT OF PLAIN LANGUAGE COMMUNICATION OF WATER QUALITY RESULTS

4.1 Abstract

Access to safe drinking water remains a significant global challenge and information on water quality reports available to the public is not uniform and often overly technical for the general population. Corresponding water quality reports serve as a key resource for public health and safety information distribution to inform the public about their water quality. These reports are essential for informing residents about the quality of water they use daily. However, the complexity of these reports and varying content can hinder public understanding and response. This issue is further exacerbated by the technical nature of the information presented, which can be difficult for non-experts to interpret. Balancing the need for clear communication without causing unnecessary concern over safe contaminant levels is central to this challenge, especially in communities with diverse linguistic and cultural backgrounds. While clear communication in water quality reports is crucial, research on how these reports are prepared, disseminated, and received by diverse communities is limited. In this review this gap is addressed by synthesizing established practices in regulated water quality reporting, drawing conclusions for the unregulated (i.e., as part of research studies) dissemination of water quality reports to residents by researchers, a field in which literature on is currently much more limited. The water quality regulatory framework is described, reporting practice types are categorized and accessed, and best practices for general water quality reporting are summarized. It also investigates the broader implications of reporting strategies on trust and awareness, specifically focusing on adaptations for diverse communities. Analyzing local regulated reporting practices in El Paso, Texas, alongside broader

regulatory mandates, this study synthesizes findings to propose practical recommendations for unregulated water quality reporting. A proposed template for researchers to comprehensively and understandably report water quality results to residents is provided as a final outcome of this review. It is intended to guide researchers conducting water quality testing in homes and improve the communication of these results to residents, ensuring clarity, accessibility, and trust in water quality communications.

4.2 Introduction

Access to safe drinking water is one of the leading global challenges, with water quality reports playing a crucial role in providing information about public health and safety (Xiang et al., 2019). These reports provide residents with critical information about the water they use daily. Yet, the complexity and variance in the content presented can considerably affect how residents understand and react to the information (Roy et al., 2015). The primary challenge lies in balancing the need to inform effectively without causing undue alarm over constituents that are within safe limits (Phetxumphou et al., 2016). This challenge is further compounded when considering the needs of communities comprised of populations with diverse linguistic and cultural backgrounds, emphasizing the need for clarity and accessibility in communication.

Despite the importance of effective communication in water quality reports, there has been limited research addressing how these reports are prepared, disseminated, received, and understood by communities with diverse linguistic and cultural backgrounds. Sparsity of existing literature on this topic highlights a critical gap in the understanding and practice of effective water quality reporting. This study aims to close this gap by compiling and enhancing the available information while offering practical insights regarding the dissemination of water quality information. This contribution will aid in the development of strategies that enhance resident comprehension and trust in public health communications.

To address these challenges, this research investigates established practices for communicating water quality reports to residents. It evaluates how well these practices meet regulatory standards and enhance resident comprehension. Additionally, it analyzes the broader implications of these reporting strategies in fostering trust and awareness about water quality. Special attention is given to how water quality reports are adapted to meet the needs of diverse linguistic and cultural communities, assessing the effectiveness of these adaptations under existing regulatory frameworks. El Paso, Texas, serves as a case study, illustrating how local practices intersect with broader regulatory mandates to address public health communication and community-specific needs. By drawing on successful approaches in regulated water quality reporting, this research formulates practical recommendations for researchers to improve the communication of water quality information to residents.

4.3 Methodology

To ensure a comprehensive review of the available literature on water quality reporting, searches were conducted across several academic databases and search engines. Specifically, Academic Search Complete (EBSCO), MinerQuest (i.e., a search tool used to search The University of Texas at El Paso's libraries and catalogs at once), ScienceDirect (Elsevier), Web of Science, and Google Scholar were used to gather relevant studies and articles. Challenges were encountered in finding literature that directly addresses both the comprehensibility of and public engagement with water quality reports. The issue was that many studies identified using the search phrases 'water quality reporting', and 'water quality communication', focused on one of the following areas: (1) resident perceptions of water quality; (2) best practices for technical communication; (3) water utility (i.e., regulated) reporting practices and (4) communication modalities during emergencies. While such reports are valuable, their scope is too narrow to encompass the range of topics related to water quality reporting. Therefore, search terms and phrases were broadened to capture a wide range of related topics useful for the present work. The following search terms and phrases were used: Residential water quality reporting; Homeowner water quality information; Water quality testing communication; Reporting practices for residential water quality; Residential water quality communication; Household water quality reporting; Water quality disclosure; Home water quality monitoring; Reporting standards for residential water quality; Community water quality communication; Maximum contaminant levels; Water quality guidelines; Household water testing; Consumer water reports; Homeowner reactions to water quality reports; Public perception of water quality; public communication of scientific study results.

The use of these search terms and phrases, and variations of these facilitated the identification of key studies and articles relevant to residential water quality reporting. The pertinence of the studies was determined through a systematic approach. The titles and preview texts of the search results were reviewed to assess their relevance. Studies deemed relevant were further evaluated by reading their abstracts. This process ensured the inclusion of key studies and articles pertinent to residential water quality reporting. The most pertinent research studies are summarized, highlighting their findings and contributions (Table 4.1).

Table 4.1: Summaries of relevant research studies.

Reference	Publisher / Journal	Impact Factor (2022)[1]	Number of Citations
Roy et al., 2015	IWA Publishing / Journal of Water and Health	2.3	27
SUMMARY: Highlights gap between the current effectiveness of water quality reports and their comprehensibility to US residents and provides recommendations for restructuring the language and scientific details in Consumer Confidence Reports (CCRs) to ensure they are easily understood by the general public.			
Phetxumphou et al., 2016	IWA Publishing / Journal of Water and Health	2.3	22
SUMMARY: According to this study, CCR content and formats are regulated, while there is no guidance that ensures consumers understand report contents. This study evaluated 30 CCRs across the United States for clarity of message using the Centers for Disease Control (CDC) Clear Communication Index Indices. The indices include (1) (1) Main Message/Call to Action; (2) Language; (3) Information Design; (4) State of the Science; (5) Behavioral Recommendations; (6) Numbers; and (7) Risk. No CCR achieved acceptable index scores (i.e. 90%), indicating that Community Water Systems (CWSs) are failing to communicate effectively with their consumers. The CDC index used in this study can be utilized both as a measure of CCR effectiveness and as a guide to enhance communications about water quality.			
Pierce et al., 2019	Taylor & Francis Online / Journal of Environmental planning and Management	3.9	9
SUMMARY: This study presents a compelling argument for planning interventions to tackle the widespread issue of water system sprawl. Using data from every publicly regulated drinking water system in Los Angeles County as a case study, this research highlights the extent of this sprawl and its implications. To explore viable solutions to this problem, the study examines development approval regulations, general plans, and includes interviews with state and regional officials in California. The findings indicate that while planning authorities offer basic protections against sprawl, they are seldom utilized to shape the boundaries of drinking water systems. However, the mechanisms of Local Agency Formation Commissions (LAFCOs) and innovative governance models appear more effective for potential reforms.			
Tito et al., 2022	MDPI / Toxins	4.2	7
SUMMARY: This research identifies environmental factors triggering toxic cyanobacteria growth in Cuban water reservoirs. It emphasizes the social impacts of cyanotoxin occurrences, particularly the critical issues of public comprehension and risk perception, highlighting the need for effective communication strategies in water quality reports.			
Boudville et al., 2023	IEEE Xplore / IEEE International Conference on Control System, Computing and Engineering (ICCSCE)	-	1
SUMMARY: This study introduces an Internet of Things (IoT)-based system for monitoring and detecting water piping leaks in domestic settings. It showcases the role of technological advancements in enhancing water management and the need for integrating such technologies into water quality reporting to provide real-time, actionable data to residents.			

[1] Impact factors and number of citations found in tables 4.1 and 4.3 were retrieved from the official websites of the respective journals and databases such as Journal Citation Reports and Scopus.

4.4 Regulatory Framework

Water quality reporting to residents is primarily governed by national and international regulations designed to ensure safe drinking water. In the United States, the cornerstone of these regulations is the Safe Drinking Water Act (SDWA), which mandates that water suppliers must provide consumers with an annual Consumer Confidence Report (CCR). The CCR includes information on detected contaminants, possible health effects, and the water's source (Ow & Ogwdw, 2015).

- Safe Drinking Water Act (SDWA): Enacted in 1974 and amended in 1986 and 1996, the SDWA requires that all contaminants detected at levels above health-based standards must be reported. The United States Environmental Protection Agency (EPA) sets these standards, defining Maximum Contaminant Levels (MCLs) for various pollutants (Ow & Ogwdw, 2015).
- National Primary Drinking Water Regulations (NPDWR): These regulations, set by the EPA under the SDWA, are legally enforceable standards, expressed as MCLs. They are designed to protect public health by setting limits to the levels of contaminants allowable in drinking water. MCLs define the highest levels of a contaminant that should be found in drinking water, typically expressed as micrograms or milligrams per liter. Each contaminant deemed unsafe by the EPA has its own MCL or treatment technique. Treatment techniques are enforceable procedures for certain contaminants (e.g., copper, viruses, and total coliforms) when there is no economical or technically practicable method to measure the compound.
- Consumer Confidence Reports: There are over 148,000 public water systems in the United States, providing drinking water to about 90 percent of Americans (United States

Environmental Protection Agency (EPA), 2023). The EPA classifies these water systems based on the number of people they serve, how often they serve the same customers (i.e., year-round, or occasionally), and their sources. A Community Water System (CWS) is a public water system that supplies water to the same population throughout the year. CWSs with at least 25 people served or 15 connections must prepare and distribute yearly water quality reports to their consumers, known as consumer confidence reports (CCRs). These reports must contain material informing consumers about the water quality at the point at where it leaves the utility's system (e.g., levels of detected contaminants, and how water is treated), water source type (e.g., groundwater, surface water, etc.) and definitions of standard acronyms used in these reports (e.g., 'MCLG', maximum contaminant level goal, and 'ND' not detected). Additional details for basic CCR requirements are listed in Figure 4.1. EPA supports CCR implementation with tools like CCRiWriter software, aiding in report standardization with contaminant tables and compliance scripts.

- Local Variations: In addition to federal standards, state and local governments may have their own additional regulations that require more frequent reporting or include additional contaminants not covered by national regulations. For example, in Texas, the Texas Commission on Environmental Quality (TCEQ) enforces state-specific water quality standards that complement the SDWA. These standards are often more stringent, especially in areas with specific water quality issues related to local industrial activities or natural resource extraction (Ow & Ogwdw, 2016).

These regulations ensure that a basic level of information is consistently provided to all residents. However, the extent of information beyond these baseline requirements can vary widely, influenced by local policies, the capabilities of individual water suppliers, and regional water quality concerns.

Basic CCR Requirements	
Item 1: Required Information about the Water System • Name/phone number of contact person • Information on public participation opportunities • Information for non-English speaking populations, if applicable	**Item 5: Information on Monitoring for *Cryptosporidium*, Radon, and Other Contaminants** • Warning for vulnerable populations about *Cryptosporidium*, if detected • Explanation of radon and its presence in the finished water, if detected • Explanation of unregulated contaminants and their presence in drinking water, if detected
Item 2: Source(s) of Water • Type, name, and general location of water sources • Availability of source water assessment • Information on significant sources of contamination, if available	**Item 6: Compliance with Other Drinking Water Regulations** • Explanation of violations, potential health effects, and steps taken to correct the violations • Special notices for GWR
Item 3: Definitions (specific language) • MCL • MCLG • Others as needed	**Item 7: Variances and Exemptions** • Explanation of variance/exemption, if applicable
Item 4: Reported Levels of Detected Contaminants • Table summarizing data on detected regulated & unregulated contaminants • Known or likely source of each detected contaminant • Health effects language and explanation for any violations or exceedances	**Item 8: Required Educational Information (specific language)** • Explanation regarding contaminants that may reasonably be expected to be found in drinking water, including bottled water • Information to customers that some people may be more vulnerable to contaminants in drinking water • Explanation of contaminants and their presence in drinking water, if detected • Informational statements on arsenic and nitrate, if necessary, and lead, always required

Figure 4.1: Outline of the basic CCR requirements, according to EPA guidelines.
The items cover various aspects such as required information about the water system, sources of water, definitions, reported levels of detected contaminants, information on monitoring for specific contaminants, compliance with other drinking water regulations, variances, and exemptions, and required educational information (EPA, 2009). Note that finished water in Item 5, second bullet refers to water that has been treated and is ready to be delivered to consumers (EPA, 2024). GWR in Item 6 refers to ground water rule.

4.5 Reporting Practice Types

Reporting practices for water quality to residents vary significantly based on regulatory compliance, technological capabilities, and consumer demand for information. These practices can generally be categorized into several distinct types; (1) comprehensive reporting, (2) threshold-based reporting, (3) selective reporting, and (4) request-based reporting.

4.5.1 Comprehensive Reporting

Some water providers offer detailed reports that include every tested constituent, regardless of whether the levels are above or below the established MCLs. This style of reports often provides extensive details about each constituent, including its source, potential health impacts, and preventive measures if necessary (Maguigan, 2021). For example, larger cities, such as Los Angeles, California, with advanced water treatment facilities, employ this method to ensure thorough transparency and maintain public trust (Figure 4.2). In Table II of the 2022 Annual Water Quality Report from Los Angeles, secondary drinking water standards are used to report contaminants. Secondary drinking water regulations are not federally enforceable and not required by the EPA (EPA, 2024). Reports that are not comprehensive will typically include a table of contaminants detected based on primary drinking water standards (i.e., mandatory to report and enforceable).

TABLE II **Calendar Year 2022 Water Quality Monitoring Results**
Aesthetic-based Secondary Drinking Water Standards (SMCLs)
Substances Detected in Treated Water

Substances	Major Sources in Drinking Water	Units	Meets Secondary Standard (YES/NO)	State SMCL or Federal (SMCL)	Los Angeles Aqueduct Filtration Plant		Northern Combined Wells		Southern Combined Wells		MWD Weymouth Plant		MWD Diemer Plant		MWD Jensen Plant	
					Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Aluminum	Erosion of natural deposits; residue from some surface water treatment processes	µg/L	YES	(200)	<50	<50	<50	<50	<50	<50	156 *(a)*	58- 240	140 *(a)*	85 - 210	62 *(a)*	<50 -81
Chloride	Runoff / leaching from natural deposits; seawater influence	mg/L	YES	(500)	64	60 - 69	56	44 - 67	56	49 - 82	102	98 - 105	101	98 - 104	70	67 - 73
Color, Apparent (unfiltered)	Naturally-occurring organic materials	ACU	YES	(15)	3	3	<3	<3 - 3	<3	<3 - 3	<3	<3	<3	<3	<3	<3
Copper	Internal corrosion of household water plumbing systems	µg/L	YES	(1000)	<50	<50 - 50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Manganese	Leaching from natural deposit	µg/L	**NO**	(50)	<20	<20	<20	<20	<20	**<20-338 *(h)***	<20	<20	<20	<20	<20	<20
Odor	Naturally-occurring organic materials	TON	YES	(3)	<1	<1	<1	<1	<1	<1	3	3	3	3	3	3
pH	Naturally-occurring dissolved gases and minerals	Unit	YES	(6.5 - 8.5)	7.7	6.8 - 8.5	7.8	7.0 - 8.6	7.8	7.1 - 8.6	8.1	8.1	8.1	8.1	8.3	8.2 - 8.3
Specific Conductance	Substances that form ions when in water; seawater influence	µS/cm at 25°C	**NO**	(1600)	490	337 - 659	728	**180 - 1773**	728	**180-1773**	992	964 -1020	988	965 - 1010	564	557 - 572
Sulfate (as SO4)	Runoff / leaching from natural deposits	mg/L	YES	(500)	64	55 - 70	173	65 - 173	173	93 - 218	222	212 - 232	221	213 - 229	76	71 - 80
Total Dissolved Solids (TDS)	Runoff / leaching from natural deposits	mg/L	YES	(1000)	300	280 - 319	462	300 - 523	462	393 - 597	638	632 - 643	628	608 - 648	334	332 - 335
Turbidity *(g)*	Soil runoff	NTU	YES	(5)	<0.1	<0.1	0.1	<0.1 - 0.2	0.1	<0.1 - 0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Figure 4.2: Example for comprehensive reporting practice.
This portion (i.e., Table 2 of 4 tables) of the 2022 Annual Water Quality Report from Los Angeles, California, illustrates comprehensive reporting practices (City of Los Angeles, 2023).

4.5.2 Threshold-Based Reporting

This approach involves reporting only those constituents that exceed MCLs or are deemed most critical for testing. It focuses on compliance and immediate health concerns, without necessarily providing information on how to obtain details about other tested contaminants. Many smaller communities or rural areas, such as in Prairie City, Iowa, use this method due to limited resources (Figure 4.3). Their reports focus on contaminants that exceed regulatory limits, ensuring critical concerns are communicated to manage public health risks effectively.

CONTAMINANT	MCL - (MCLG)	Compliance		Date	Violation	Source
		Type	Value & (Range)		Yes/No	
Total Trihalomethanes (ppb) [TTHM]	80 (N/A)	LRAA	17.00 (17 - 17)	09/30/2023	No	By-products of drinking water chlorination
Copper (ppm)	AL=1.3 (1.3)	90th	0.202 (0.0349 - 0.407)	2023	No	Corrosion of household plumbing systems; Erosion of natural deposits; Leaching from wood preservatives
Lead (ppb)	AL=15 (0)	90th	0.00 (ND - 1)	2023	No	Corrosion of household plumbing systems; erosion of natural deposits
950 - DISTRIBUTION SYSTEM						
Chlorine (ppm)	MRDL=4.0 (MRDLG=4.0)	RAA	0.9 (ND - 1.5)	09/30/2023	No	Water additive used to control microbes
Total Coliform Bacteria	TT (TT)	RTCR	1 sample(s) positive	08/31/2023	No	Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other waterborne pathogens may be present, or that a potential pathway exists through which contamination may enter the drinking water.
Nitrate [as N] (ppm)	10 (10)	SGL	1.100	2023	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
01 - WELLS 1_2R AFTER TR						
Fluoride (ppm)	4 (4)	RAA	0.65 (0.400 - 0.700)	06/30/2023	No	Water additive which promotes strong teeth; Erosion of natural deposits; Discharge from fertilizer and aluminum factories
Sodium (ppm)	N/A (N/A)	SGL	98.3	06/01/2023	No	Erosion of natural deposits; Added to water during treatment process
Nitrate [as N] (ppm)	10 (10)	SGL	4.700 (1.000 - 4.700)	2023	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits

Figure 4.3: Example for threshold-based reporting practice.
Portion of the 2023 Annual Water Quality Report from Prairie City, Iowa, illustrating threshold-based reporting practices (Prairie City, 2023). This water quality report included only detected contaminants.

4.5.3 SELECTIVE REPORTING

Select constituents deemed critical or of particular concern to the community are reported or emphasized, even if other constituents are also monitored and reported. This might be based on local environmental issues, such as agricultural runoff or industrial pollutants. For example, in Flint, Michigan, the water quality reports have featured lead levels due to the well-documented lead contamination crisis (Figure 4.4). Although other water quality constituents may be monitored, the reports typically focus heavily on containments of particular concern due to their significant health impacts on the community. This targeted reporting helps address the specific local environmental concern of lead contamination.

January 1, 2016 – June 30, 2016 Lead and Copper Monitoring at Customer Tap in the City of Flint								
Regulated Contaminant	Test Date	Unit	Health Goal MCLG	Action Level AL	90th Percentile Value*	Number of Samples over AL	Violation yes/no	Major Sources in Drinking Water
Lead	2016	ppb	0	15	20	88**	No	Corrosion of household plumbing system; service lines that may contain lead; Erosion of natural deposits.
Copper	2016	ppm	1.3	1.3	0.17	7**	No	Corrosion of household plumbing system; Erosion of natural deposits

*The 90th percentile value means 90 percent of the homes tested have lead and copper levels below the given 90th percentile value. If the 90th percentile value is above the AL additional requirements must be met.
**Out of 633 confirmed compliance samples collected at verified Tier 1 sites.

An action level exceedance is not a violation but triggers other requirements to minimize exposure to lead and copper in drinking water, that include water quality parameter monitoring, corrosion control treatment, source water monitoring/treatment, public education, and lead service line replacement.

July 1, 2016 – December 31, 2016 Lead and Copper Monitoring at Customer Tap in the City of Flint								
Regulated Contaminant	Test Date	Unit	Health Goal MCLG	Action Level AL	90th Percentile Value*	Number of Samples over AL	Violation yes/no	Major Sources in Drinking Water
Lead	2016	ppb	0	15	12	24***	No	Corrosion of household plumbing system; service lines that may contain lead; Erosion of natural deposits.
Copper	2016	ppm	1.3	1.3	0.12	6***	No	Corrosion of household plumbing system; Erosion of natural deposits

*The 90th percentile value means 90 percent of the homes tested have lead and copper levels below the given 90th percentile value. If the 90th percentile value is above the AL additional requirements must be met.
***Out of 368 confirmed compliance samples collected at verified Tier 1 sites.

Figure 4.4: Example for selective reporting practice.
Portion of the 2017 Annual Water Quality Report from Flint, MI, illustrating selective reporting practices (City of Flint, 2018).

4.5.4 Request-Based Reporting

Minimal information is provided in the standard reports, with additional data available upon request. This method may help reduce information overload for the average consumer while still making detailed data accessible to those who seek it. For example, some providers in suburban regions, such as the Woodland Water Department in Woodland, California, might include a summary report with an option to request detailed test results online or through a customer service center (Figure 4.5). This allows residents to access comprehensive data without overwhelming the general public with extensive details.

Test Results

Our water is monitored for many different kinds of substances on a very strict sampling schedule, and the water we deliver must meet specific health standards. Here, we only show those substances that were detected in our water (a complete list of all our analytical results is available upon request). Remember that detecting a substance does not mean the water is unsafe to drink; our goal is to keep all detects below their respective maximum allowed levels.

The state recommends monitoring for certain substances less than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

REGULATED SUBSTANCES

				WDCWA RWTF		Aquifer Storage and Recovery Wells			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	PHG (MCLG) [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
1,2-Dichlorobenzene (ppb)	2022	600	600	52.5	45–61	56.6	49–71	No	Discharge from industrial chemical factories
Aluminum (ppm)	2022	1	0.6	0.08	ND–0.11	0.04	ND–0.12	No	Erosion of natural deposits; residue from some surface water treatment processes
Arsenic (ppb)	2022	10	0.004	ND	NA	1.19	ND–2.5	No	Erosion of natural deposits; runoff from orchards; glass and electronics production wastes
Bromate (ppb)	2022	10	0.1	1.15	ND–2.5	NA	NA	No	By-product of drinking water disinfection
Chlorine (ppm)	2022	[4.0 (as Cl2)]	[4 (as Cl2)]	0.9	0.8–0.9	0.7[1]	0.1–1.4[1]	No	Drinking water disinfectant added for treatment

Figure 4.5: Example for request-based reporting practice.
Portion of the 2022 Annual Water Quality Report from Woodland, California, illustrating request-based reporting practices (City of Woodland, 2023).

These reporting practice types reflect differing priorities and capacities among water providers. Comprehensive and threshold-based reporting are the most common, with the choice often reflecting a balance between full transparency, the practicalities of resource allocation, and CCR reporting requirements. According to Utah's Department of Environmental Quality (2023), common reporting mistakes on CCRs include; (1) listing non-detected contaminants in the same table as detected contaminants; (2) making general statements about the safety of the water such as "your water is safe"; (3) MCL, MCLG (i.e., maximum contaminant level goal) and reported detected levels are not listed in the same units; and (4) violations are noted on the detected contaminants table without further explanation of these violations in the report (Utah's Department of Environmental Quality, 2023). These issues not only represent noncompliance with CCR regulations, but also hinder effective communication and transparency, potentially eroding public trust in water quality reports.

4.6 Communication and Resident Understanding

Effective communication of water quality information is crucial for ensuring that residents understand the implications of the reports they receive. The format and clarity of the information can significantly influence resident comprehension and subsequent action. Supplemental visual aids, plain language summaries, and digital platforms and portals enhance the accessibility and comprehensibility of water quality reports.

4.6.1 Supplemental Visual Aids

Many reports incorporate visual aids to supplement water quality test results. These visuals aids are often more accessible for the general public, helping to simplify complex data. For example, Santa Fe, New Mexico provides visual aids and detailed explanations of contaminants in drinking water (Figure 4.6). Additionally, some reports use visual aids to illustrate the drinking water sources for the system, such as in Portland Oregon (Figure 4.7).

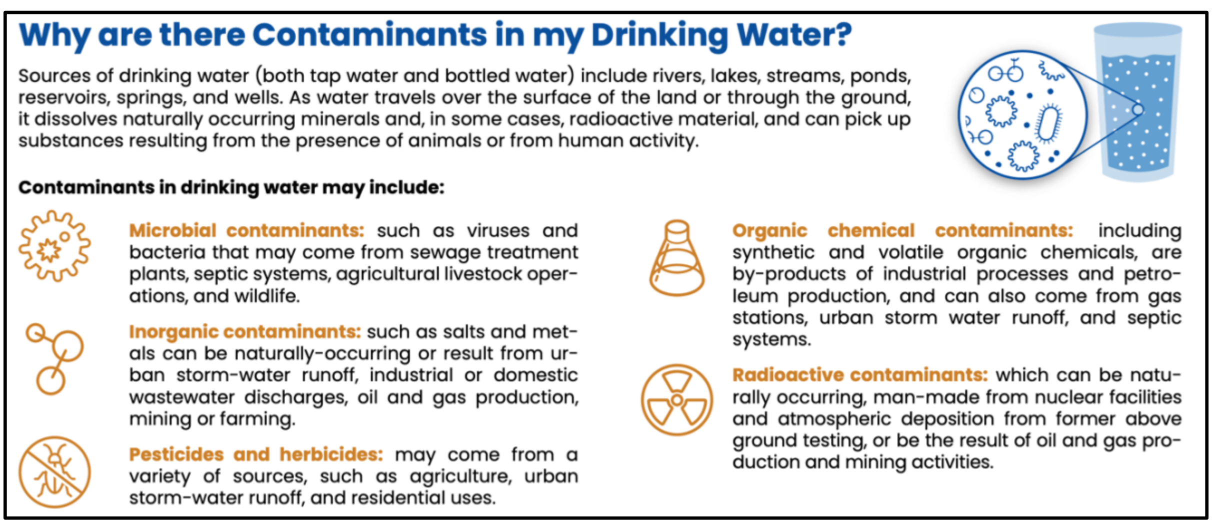


Figure 4.6: Example for use of visual aids to simplify complex information.
Portion of the 2022 Annual Water Quality Report from Santa Fe, New Mexico, demonstrating supplemental visual aids used to simply complex information about contaminants in drinking water (City of Santa Fe Water, 2023).

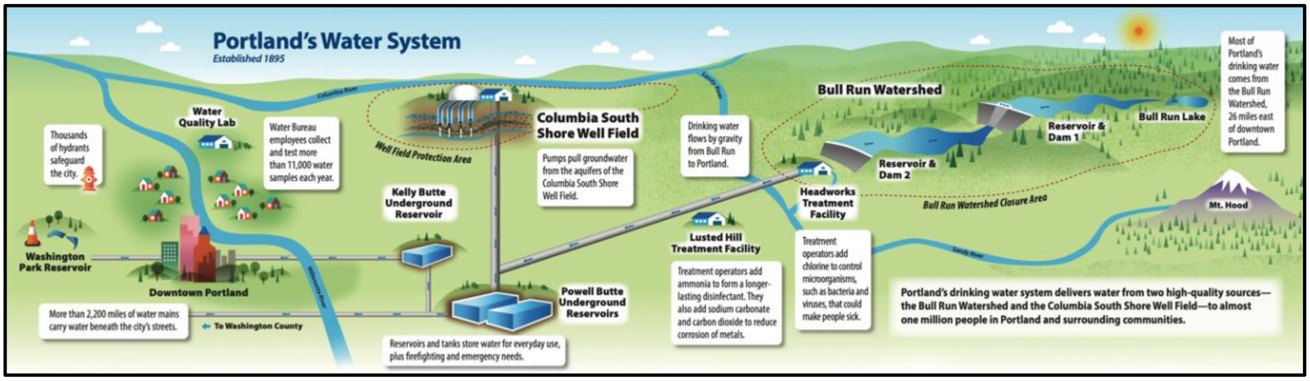


Figure 4.7: Example for use of supplemental visual aids to simplify complex information. Portion of the 2023 Annual Water Quality Report from Portland, Oregon, demonstrating supplemental visual aids used to simply complex information about drinking water sources (Portland Water Bureau, 2024).

4.6.2 Plain Language Summaries

Some water providers include a summary in plain language either within a report or on the webpage leading to the report, that explains the key findings of the report and their significance, making the information more digestible for non-experts, such as in Seattle, Washington (Figure 4.8).

Water Quality Annual Reports

Invisible Systems, Visible Benefits

The Drinking Water Quality report, which the Environmental Protection Agency requires us to create and share with every customer, gives you information about how we're doing regarding the water you drink every day. We're pleased to report that our water is among the best in the nation, both in purity and taste.

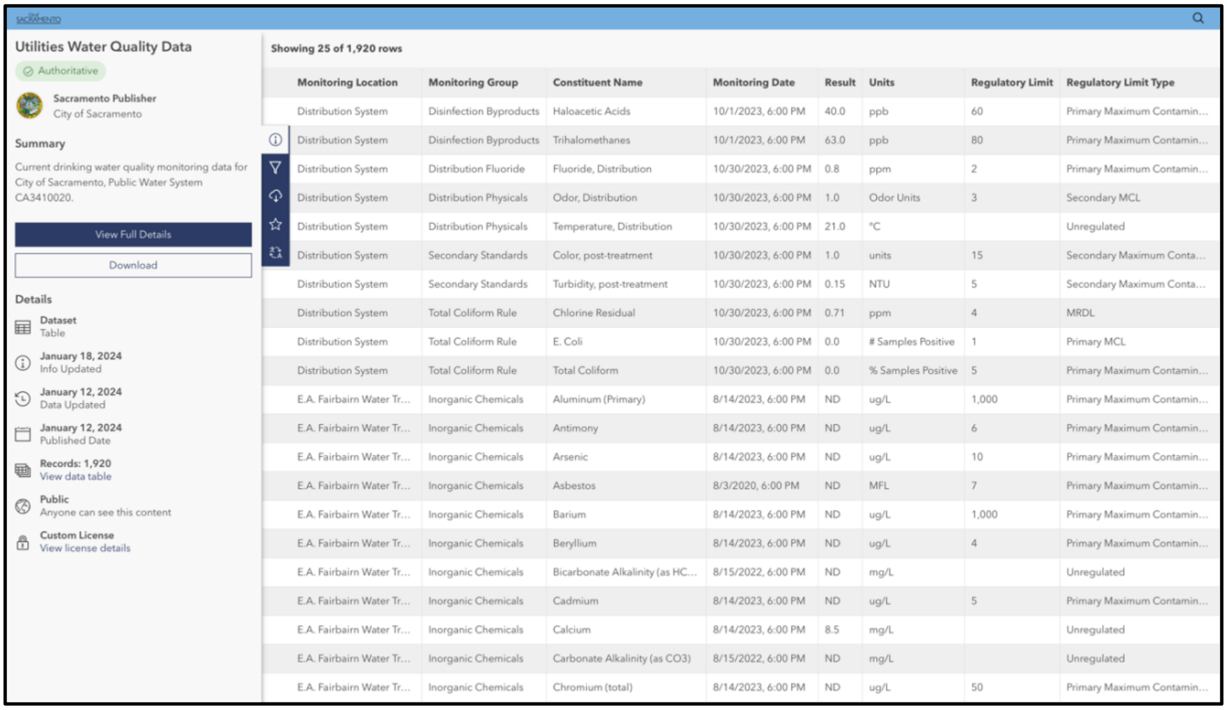
We provide fresh, clean water daily to 1.6 million people thanks to pipes, pumps, plants, and people:

- 2 pristine, protected mountain sources: the Cedar River and South Fork Tolt River watersheds
- 2 state-of-the-art water treatment plants
- 1,900 miles of pipes
- 13 reservoirs
- 14 storage tanks
- numerous pumping stations
- more than 600 people testing, treating, fixing, monitoring, building and protecting
- a mission control center that ensures all elements work together

Figure 4.8: Example for use of plain lanuage in summarizing general information.
Plain language summary providing general information about Seattle, Washington's water quality, available on their water quality reports webpage (Seattle Public Utilities, 2022).

4.6.3 Digital Platforms and Portals

Interactive online platforms are used to allow users to explore their water quality data more deeply. These can include FAQs, glossaries, and detailed breakdowns of contaminants. For example, the City of Sacramento, California's water quality data portal (https://www.cityofsacramento.gov/utilities/water-quality/data-portal) offers an interactive platform where residents can access comprehensive water quality reports (Figure 4.9). The portal includes features such as an extensive searchable database of contaminants and detailed explanations of water quality standards and results that can be filtered, downloaded, or translated, enhancing transparency and user engagement.



SACRAMENTO

Utilities Water Quality Data

Authoritative

Sacramento Publisher
City of Sacramento

Summary

Current drinking water quality monitoring data for City of Sacramento, Public Water System CA3410020.

View Full Details

Download

Details

Dataset
Table

January 18, 2024
Info Updated

January 12, 2024
Data Updated

January 12, 2024
Published Date

Records: 1,920
View data table

Public
Anyone can see this content

Custom License
View license details

Showing 25 of 1,920 rows

Monitoring Location	Monitoring Group	Constituent Name	Monitoring Date	Result	Units	Regulatory Limit	Regulatory Limit Type
Distribution System	Disinfection Byproducts	Haloacetic Acids	10/1/2023, 6:00 PM	40.0	ppb	60	Primary Maximum Contamin...
Distribution System	Disinfection Byproducts	Trihalomethanes	10/1/2023, 6:00 PM	63.0	ppb	80	Primary Maximum Contamin...
Distribution System	Distribution Fluoride	Fluoride, Distribution	10/30/2023, 6:00 PM	0.8	ppm	2	Primary Maximum Contamin...
Distribution System	Distribution Physicals	Odor, Distribution	10/30/2023, 6:00 PM	1.0	Odor Units	3	Secondary MCL
Distribution System	Distribution Physicals	Temperature, Distribution	10/30/2023, 6:00 PM	21.0	°C		Unregulated
Distribution System	Secondary Standards	Color, post-treatment	10/30/2023, 6:00 PM	1.0	units	15	Secondary Maximum Conta...
Distribution System	Secondary Standards	Turbidity, post-treatment	10/30/2023, 6:00 PM	0.15	NTU	5	Secondary Maximum Conta...
Distribution System	Total Coliform Rule	Chlorine Residual	10/30/2023, 6:00 PM	0.71	ppm	4	MRDL
Distribution System	Total Coliform Rule	E. Coli	10/30/2023, 6:00 PM	0.0	# Samples Positive	1	Primary MCL
Distribution System	Total Coliform Rule	Total Coliform	10/30/2023, 6:00 PM	0.0	% Samples Positive	5	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Aluminum (Primary)	8/14/2023, 6:00 PM	ND	ug/L	1,000	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Antimony	8/14/2023, 6:00 PM	ND	ug/L	6	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Arsenic	8/14/2023, 6:00 PM	ND	ug/L	10	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Asbestos	8/3/2020, 6:00 PM	ND	MFL	7	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Barium	8/14/2023, 6:00 PM	ND	ug/L	1,000	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Beryllium	8/14/2023, 6:00 PM	ND	ug/L	4	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Bicarbonate Alkalinity (as HC...	8/15/2022, 6:00 PM	ND	mg/L		Unregulated
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Cadmium	8/14/2023, 6:00 PM	ND	ug/L	5	Primary Maximum Contamin...
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Calcium	8/14/2023, 6:00 PM	8.5	mg/L		Unregulated
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Carbonate Alkalinity (as CO3)	8/15/2022, 6:00 PM	ND	mg/L		Unregulated
E.A. Fairbairn Water Tr...	Inorganic Chemicals	Chromium (total)	8/14/2023, 6:00 PM	ND	ug/L	50	Primary Maximum Contamin...

Figure 4.9: Example for use of digital portal to make full data sets accessible.
Portion of the water quality data digital portal for Sacramento, California (City of Sacramento, 2024).

4.7 Challenges and Best Practices for Effective Water Quality Reporting

Water quality reporting encompasses various challenges that can impact the effectiveness and reception of the information provided to residents. Identifying challenges and the corresponding best practices is crucial for enhancing the transparency and usefulness of these reports.

4.7.1 Challenges

Balancing detail and clarity is a major challenge in water quality reporting. Providing enough detail to be informative while ensuring the information is understandable to non-specialists can be difficult. Overly technical reports can confuse residents, while overly simplified reports might omit important details. Reports containing technical jargon without explanations can confuse those who might not have professional background in water quality. Resource limitations pose another challenge. Smaller water providers often struggle with the resources necessary to conduct extensive testing or develop sophisticated reporting formats. Rural or smaller communities might not have the budget to test for a wide range of contaminants regularly or to invest in interactive online reporting tools. Ensuring that reports build and maintain public trust in the water quality system is essential, especially in areas where water safety concerns have historically been an issue. Areas affected by high-profile water contamination incidents may require more detailed and frequent reporting to restore and maintain community trust.

4.7.2 Best Practices

Using clear and accessible language is a key best practice in water quality reporting (EPA, 2012). Explaining water quality issues and the significance of various contaminants in plain language helps ensure that the information is understandable to all residents. Including a glossary or FAQ section can further clarify technical terms. Regular updates and proactive, ongoing communication are also essential (AWWA, 2023). Frequent updates about water quality and any changes in contaminant levels keep the community informed and (Smith et al., 2017). Proactive communication, especially during crises, can prevent misinformation and ease public concerns. Engagement and education programs can provide additional means for raising awareness about water quality issues. Developing community engagement initiatives, such as hosting community meetings, school programs, or online webinars, can educate the public about how water is treated and the importance of maintaining safe drinking water. Leveraging technology can make water quality reports more interactive and user-friendly. Utilizing digital platforms that allow residents to check specific data relevant to their area can personalize the experience and increase engagement.

4.8 Case-Study: Water Quality Reporting in El Paso County, Texas

El Paso County, Texas, situated in the Chihuahuan Desert, faces water scarcity exacerbated by its arid climate and limited water resources. The region's diverse population, with a significant proportion of Spanish-speaking residents, presents challenges for effective communication and outreach regarding water quality. Historical issues such as contamination from industrial activities and aging infrastructure have contributed to residents' concerns about water quality (Hibbs, 1999; Hibbs and Boghici, 1999; McDonald, 2012). This section of the review examines current practices and challenges in water quality reporting in El Paso, Texas, and proposes context-specific communication strategies to enhance resident understanding and engagement. By examining the unique characteristics and innovative approaches in El Paso, this case study highlights the importance of multilingual reporting, community-specific outreach, and the use of digital tools to address residents' diverse needs and build public trust in water quality management.

4.8.1 Reporting Practices in El Paso, Texas

The approach to water quality reporting in El Paso County, Texas, is shaped by its status as a border city with a significant bilingual population, necessitating diverse communication strategies to ensure all community members are informed about water quality issues. For a comprehensive review of reporting practices in El Paso County, a search was conducted through the Public Utility Commission of Texas website using the search input: utility type – ‘water utility’;

county – ‘El Paso’; activity status – ‘active’. The search results are shown (Figure 4.10), and the reporting practices for select El Paso Counties are summarized (Table 4.2). The water quality reporting practices in Sunland Park, New Mexico and Santa Teresa, New Mexico (i.e., served by one water utility, CRRUA) were also included in Table 4.2 for comparison to the El Paso counties water utilities, as these cities are adjacent to the area and have experienced recent water quality issues related to arsenic contamination. The following is a detailed summary of the methods used for El Paso Water, the largest service provider for the county.

4.8.1.1 Bilingual Reporting

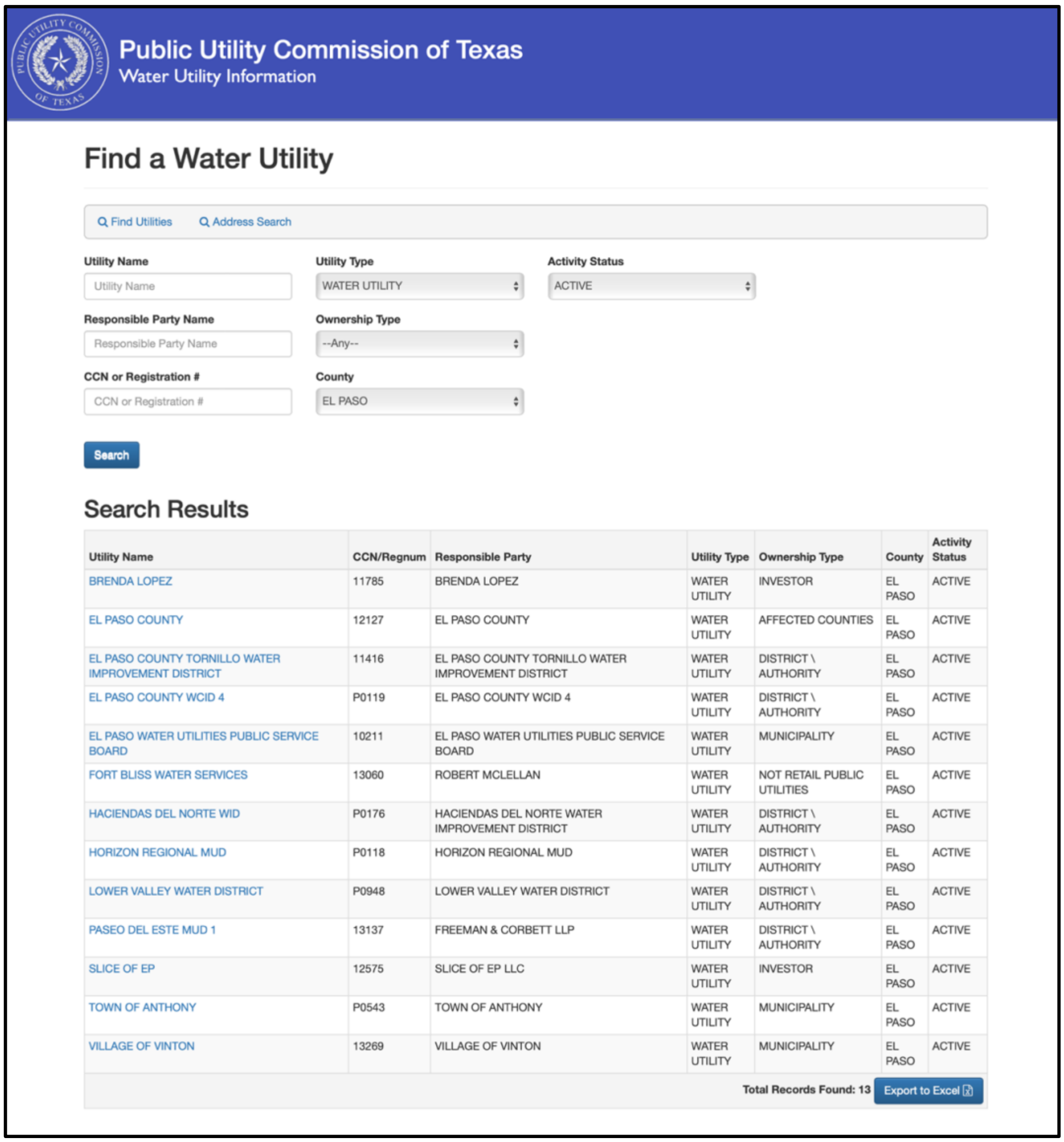
El Paso Water provides CCRs in English, with some informational videos available in Spanish, such as "Trust Your Tap (Spanish)”. However, not all documents are consistently available in both languages. This limited availability of bilingual resources means that information may not be readily accessible to all residents of El Paso County, particularly those who are primarily Spanish-speaking.

4.8.1.2 Community-Specific Outreach

El Paso Water engages with the community through meetings and educational programs conducted in both English and Spanish. These sessions discuss water quality reports and address resident concerns directly. Such initiatives foster an informed and engaged community, especially in border regions where public health advocacy must bridge cultural and linguistic divides.

4.8.1.3 Digital Accessibility

El Paso Water enhanced its digital platforms with Google Translate to provide interactive access to water quality data. Features on these platforms support both English and Spanish languages, making the information more accessible to a diverse demographic. The use of advanced technology helps reach a broader audience, including younger residents, and facilitates better engagement with the community on important water safety issues.



Public Utility Commission of Texas
Water Utility Information

Find a Water Utility

Find Utilities | Address Search

Utility Name: Utility Name
Utility Type: WATER UTILITY
Activity Status: ACTIVE
Responsible Party Name: Responsible Party Name
Ownership Type: --Any--
CCN or Registration #: CCN or Registration #
County: EL PASO

Search

Search Results

Utility Name	CCN/Regnum	Responsible Party	Utility Type	Ownership Type	County	Activity Status
BRENDA LOPEZ	11785	BRENDA LOPEZ	WATER UTILITY	INVESTOR	EL PASO	ACTIVE
EL PASO COUNTY	12127	EL PASO COUNTY	WATER UTILITY	AFFECTED COUNTIES	EL PASO	ACTIVE
EL PASO COUNTY TORNILLO WATER IMPROVEMENT DISTRICT	11416	EL PASO COUNTY TORNILLO WATER IMPROVEMENT DISTRICT	WATER UTILITY	DISTRICT \ AUTHORITY	EL PASO	ACTIVE
EL PASO COUNTY WCID 4	P0119	EL PASO COUNTY WCID 4	WATER UTILITY	DISTRICT \ AUTHORITY	EL PASO	ACTIVE
EL PASO WATER UTILITIES PUBLIC SERVICE BOARD	10211	EL PASO WATER UTILITIES PUBLIC SERVICE BOARD	WATER UTILITY	MUNICIPALITY	EL PASO	ACTIVE
FORT BLISS WATER SERVICES	13060	ROBERT MCLELLAN	WATER UTILITY	NOT RETAIL PUBLIC UTILITIES	EL PASO	ACTIVE
HACIENDAS DEL NORTE WID	P0176	HACIENDAS DEL NORTE WATER IMPROVEMENT DISTRICT	WATER UTILITY	DISTRICT \ AUTHORITY	EL PASO	ACTIVE
HORIZON REGIONAL MUD	P0118	HORIZON REGIONAL MUD	WATER UTILITY	DISTRICT \ AUTHORITY	EL PASO	ACTIVE
LOWER VALLEY WATER DISTRICT	P0948	LOWER VALLEY WATER DISTRICT	WATER UTILITY	DISTRICT \ AUTHORITY	EL PASO	ACTIVE
PASEO DEL ESTE MUD 1	13137	FREEMAN & CORBETT LLP	WATER UTILITY	DISTRICT \ AUTHORITY	EL PASO	ACTIVE
SLICE OF EP	12575	SLICE OF EP LLC	WATER UTILITY	INVESTOR	EL PASO	ACTIVE
TOWN OF ANTHONY	P0543	TOWN OF ANTHONY	WATER UTILITY	MUNICIPALITY	EL PASO	ACTIVE
VILLAGE OF VINTON	13269	VILLAGE OF VINTON	WATER UTILITY	MUNICIPALITY	EL PASO	ACTIVE

Total Records Found: 13 | Export to Excel

Figure 4.10: Active water utilities in El Paso County.
Search results were obtained from the Public Utility Commission of Texas.

Table 4.2: Current water information availability for select El Paso County and adjacent water utilities.

		English Available	Spanish Available
El Paso Water, https://www.epwater.org Spanish website translation available			
	CCRs	Yes	Yes
	Informational Videos	Yes	Yes
	Educational Content	Yes	Yes
Horizon Regional MUD, https://horizonregional.com No Spanish website translation available			
	CCRs	Yes	No
	Informational Videos	No	No
	Educational Content	Yes	Yes
Lower Valley Water District, https://www.lvwd.org Spanish website translation available			
	CCRs	Yes	No
	Informational Videos	No	No
	Educational Content	Yes	Yes
El Paso County Tornillo WID, https://epctwid.com Spanish website translation available			
	CCRs	Yes	No
	Informational Videos	No	No
	Educational Content	Yes	Yes
Camino Real Regional Utility Authority, CRRUA, https://www.crrua.org **Santa Teresa and Sunland Park, New Mexico** Spanish website translation available			
	CCRs	Yes	Yes
	Informational Videos	No	No
	Educational Content	No	No

4.8.2 Communication Challenges and Strategies in El Paso County, Texas

4.8.2.1 Challenges

Technical Translation Accuracy. Translating technical water quality reports and data into Spanish poses significant challenges. It is essential to preserve the accuracy of the technical content while ensuring it remains understandable. Misinterpretations can lead to misinformation about water safety and public health risks (Biraghi, Gambetti, & Beccanulli, 2020).

Cultural Relevance. The cultural context in El Paso requires communications to be linguistically accurate and culturally resonant. Information should be presented in a way that feels relevant and respectful to the community's cultural nuances, which enhances trust and receptivity among community members.

Readability and Engagement. Technical documents can be dense and difficult to navigate. Ensuring that translated materials remain engaging and easy to comprehend without oversimplifying scientific facts is a delicate balance that needs careful management (Shahady & Boniface, 2018).

4.8.2.2 Strategies

Local Translators and Cultural Consultants. Employing local translators and cultural consultants who are not only proficient in Spanish but are also familiar with the local dialects and cultural expressions of El Paso's Hispanic community can significantly enhance the effectiveness of the communication. These professionals can ensure that the language used is appropriate and accessible (Kai, 2022).

Cultural Tailoring of Messages. Collaborating with cultural consultants can help tailor messages that resonate well with the local community's values and concerns. This approach goes beyond mere translation to adapt the style, tone, and examples used in communications to reflect the cultural contexts of El Paso's residents (Maunah, 2020).

Community Engagement and Feedback. Implementing ongoing community engagement initiatives, such as workshops, town hall meetings, and feedback sessions, helps assess the effectiveness of current communication strategies. These interactions provide invaluable insights into how information is received and understood by the community, allowing for continuous improvements (Morreale et al., 2023).

Use of Multiple Communication Platforms. To reach a broader audience, CWSs can diversify their communication platforms. This might include digital media, local radio stations, community centers, and schools, each providing content tailored to the specific medium and audience. For instance, shorter, more visually engaging content can be developed for social media to highlight key points from the CCRs, while more detailed discussions can be hosted in community meeting spaces.

Educational Programs for Schools. Expanding educational programs like El Paso Water's Tech2O Water Resources Learning Center to more schools and community centers can enhance understanding of water quality issues early on. These programs, offered in both English and Spanish, play a crucial role in community education and engagement (Sinche et al., 2023).

Addressing these challenges with thoughtful and inclusive strategies - such as those above - enable water providers and researchers providing communications to residents in El Paso County and similar regions can enhance their communication efforts, ensuring that all members of the community are well-informed about their water quality and the measures being taken to protect their health and safety.

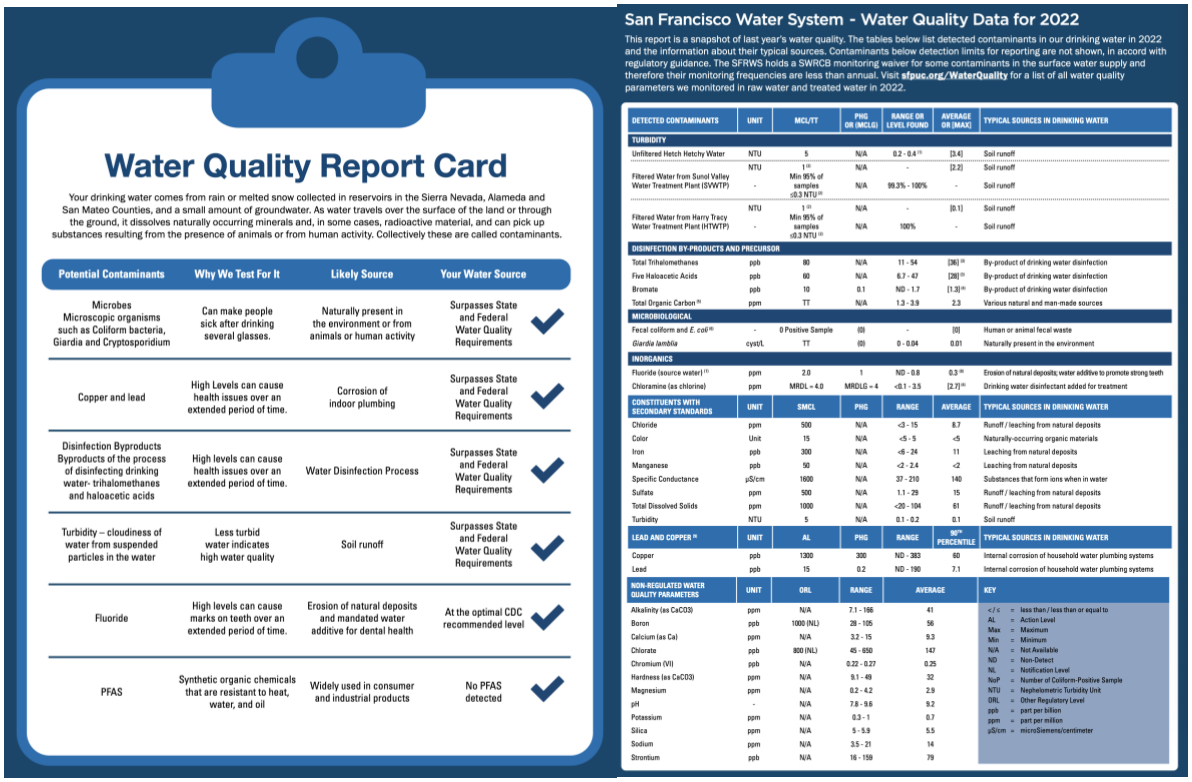
4.9 Enhancing Unregulated Water Quality Communication

Effective communication of water quality research findings is essential for public understanding and policymaking, no matter if regulated water quality reporting by water utilities or unregulated dissemination of water quality reports to residents by researchers. Indeed, researchers have employed various strategies to report water quality data effectively, ensuring comprehensibility and applicability to various stakeholders, including the general public, policymakers, and fellow researchers. A selection of approaches is listed in Table 4.3. These references highlight the importance of effective communication in water quality research and the strategies researchers have adopted to make their findings accessible and actionable. However, as with smaller community water districts (CWDs), researchers may lack the financial and time resources to engage in comprehensive, all-encompassing communication with the public. In such situations, most effective/impactful communication becomes critical, and lessons can be learned from the comparison of communication strategies employed in regulated water quality reporting.

Table 4.3: Summaries of applicable research studies.

<table>
<tr><th>Reference</th><th>Publisher / Journal</th><th>Impact Factor (2022)</th><th>Number of Citations</th></tr>
<tr><td>Sharma et al., 2011</td><td>IndianaJournals.com / International Journal of Environmental Sciences</td><td>-</td><td>9</td></tr>
<tr><td colspan="4">TITLE: Acid Mine Discharge - Challenges Met in a Hydro Power Project
SUMMARY: Reports on the challenges of communicating the impact of acid mine discharge on water quality. The paper details the scientific community's efforts to convey the detrimental effects of such discharges on hydro power equipment and water quality, emphasizing the need for clear communication to prevent equipment degradation and health risks.</td></tr>
<tr><td>Carmichael et al., 2013</td><td>IWA Publishing / Journal of Water and Health</td><td>2.3</td><td>8</td></tr>
<tr><td colspan="4">TITLE: Water Shortages and Extreme Events: A Call for Research
SUMMARY: Addresses the need for robust communication strategies in times of crisis. The paper advocates for the development of coordinated plans that are easily understandable and scientifically accurate to better manage water shortages during extreme events.</td></tr>
<tr><td>Stoate et al., 2019</td><td>British Society of Soil Science / Soil use and Management</td><td>3.8</td><td>26</td></tr>
<tr><td colspan="4">TITLE: Participatory Research Approaches to Integrating Scientific and Farmer Knowledge of Soil to Meet Multiple Objectives in the English East Midlands
SUMMARY: Discusses the role of participatory research in combining scientific and local knowledge. The study emphasizes the importance of community involvement in scientific communication, enhancing the relevance and acceptance of water quality data among local farmers.</td></tr>
<tr><td>Florea & Kuban, 2021</td><td>IUScholar Works Journals / Indiana Journal of Earth Sciences</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">TITLE: Trans-Disciplinary Pedagogy for Science and Journalism Majors Linking Water Resource Information to Communities
SUMMARY: Illustrates an educational approach where science and journalism students collaborate to communicate water quality issues to the community. This program has successfully increased civic engagement and improved students' understanding and communication skills regarding scientific data.</td></tr>
<tr><td>Chidiac et al., 2023</td><td>Springer Link / Reviews in Environmental Science and Bio/Technology</td><td>14.4</td><td>54</td></tr>
<tr><td colspan="4">TITLE: A Comprehensive Review of Water Quality Indices (WQIs): History, Models, Attempts, and Perspectives
SUMMARY: Provides an overview of various water quality indices used globally. This review serves as a resource for researchers and practitioners to choose appropriate indices for reporting water quality, which in turn aids in better communication of water quality statuses to non-expert audiences.</td></tr>
</table>

A great learning example is the 2022 Annual Water Quality Report by the San Francisco Utilities Commission. It scaffolds (i.e., builds upon pre-existing knowledge) typically difficult information to promote learning and understanding by the general public. It does so by providing an executive summary entitled Water Quality Report Card (Figure 4.11a). The use of the expression ‘report card’ in place of ‘executive summary’ or another science-based construct demonstrates the aim to tailor messages to the audience’s prior knowledge. Additionally, the aesthetic appeal, simple explanations of water sources, contaminants, and why they are tested enhance the comprehensibility of the drinking water quality for the region. While laudable, the Water Quality Report Card is not without pitfalls. Four potential contaminant groups out of six state that the water source “surpasses state and federal water quality requirements”. Despite the discrepancy in these statements, the column to the right of them uses check marks for all contaminants in the attempt to convey that ‘everything is ok,’ resonating the general “your water is safe” statement which is considered a common reporting mistake according to Utah’s Department of Environmental Quality (2023). Another potential issue is that while more typical water quality data is also provided in the report (Figure 4.11b), link must be used to retrieve a list of all monitored water quality parameters. This means that additional steps are required to find information. The key takeaway from these deliberations for researchers is three-fold; scaffolding information in a visually appealing way to enhance comprehensibility of water quality reports is a powerful tool, however, care must be taken that information is not misrepresented in any way and easy access to full information needs to be ensured.



Water Quality Report Card

Your drinking water comes from rain or melted snow collected in reservoirs in the Sierra Nevada, Alameda and San Mateo Counties, and a small amount of groundwater. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals and, in some cases, radioactive material, and can pick up substances resulting from the presence of animals or from human activity. Collectively these are called contaminants.

Potential Contaminants	Why We Test For It	Likely Source	Your Water Source
Microbes Microscopic organisms such as Coliform bacteria, Giardia and Cryptosporidium	Can make people sick after drinking several glasses.	Naturally present in the environment or from animals or human activity	Surpasses State and Federal Water Quality Requirements ✓
Copper and lead	High Levels can cause health issues over an extended period of time.	Corrosion of indoor plumbing	Surpasses State and Federal Water Quality Requirements ✓
Disinfection Byproducts Byproducts of the process of disinfecting drinking water- trihalomethanes and haloacetic acids	High levels can cause health issues over an extended period of time.	Water Disinfection Process	Surpasses State and Federal Water Quality Requirements ✓
Turbidity – cloudiness of water from suspended particles in the water	Less turbid water indicates high water quality	Soil runoff	Surpasses State and Federal Water Quality Requirements ✓
Fluoride	High levels can cause marks on teeth over an extended period of time.	Erosion of natural deposits and mandated water additive for dental health	At the optimal CDC recommended level ✓
PFAS	Synthetic organic chemicals that are resistant to heat, water, and oil	Widely used in consumer and industrial products	No PFAS detected ✓

San Francisco Water System - Water Quality Data for 2022

This report is a snapshot of last year's water quality. The tables below list detected contaminants in our drinking water in 2022 and the information about their typical sources. Contaminants below detection limits for reporting are not shown, in accord with regulatory guidance. The SFRWS holds a SWRCB monitoring waiver for some contaminants in the surface water supply and therefore their monitoring frequencies are less than annual. Visit **sfpuc.org/WaterQuality** for a list of all water quality parameters we monitored in raw water and treated water in 2022.

DETECTED CONTAMINANTS	UNIT	MCL/TT	PHG OR (MCLG)	RANGE OR LEVEL FOUND	AVERAGE OR [MAX]	TYPICAL SOURCES IN DRINKING WATER
TURBIDITY						
Unfiltered Hetch Hetchy Water	NTU	5	N/A	0.2 - 0.4 [1]	[3.4]	Soil runoff
Filtered Water from Sunol Valley Water Treatment Plant (SVWTP)	NTU	1 [2]	N/A	-	[2.2]	Soil runoff
	-	Min 95% of samples ≤0.3 NTU [2]	N/A	99.3% - 100%	-	Soil runoff
Filtered Water from Harry Tracy Water Treatment Plant (HTWTP)	NTU	1 [2]	N/A	-	[0.1]	Soil runoff
	-	Min 95% of samples ≤0.3 NTU [2]	N/A	100%	-	Soil runoff
DISINFECTION BY-PRODUCTS AND PRECURSOR						
Total Trihalomethanes	ppb	80	N/A	11 - 54	[36] [3]	By-product of drinking water disinfection
Five Haloacetic Acids	ppb	60	N/A	6.7 - 47	[28] [3]	By-product of drinking water disinfection
Bromate	ppb	10	0.1	ND - 1.7	[1.3] [4]	By-product of drinking water disinfection
Total Organic Carbon [5]	ppm	TT	N/A	1.3 - 3.9	2.3	Various natural and man-made sources
MICROBIOLOGICAL						
Fecal coliform and *E. coli* [6]	-	0 Positive Sample	(0)	-	[0]	Human or animal fecal waste
Giardia lamblia	cyst/L	TT	(0)	0 - 0.04	0.01	Naturally present in the environment
INORGANICS						
Fluoride (source water) [7]	ppm	2.0	1	ND - 0.8	0.3 [8]	Erosion of natural deposits; water additive to promote strong teeth
Chloramine (as chlorine)	ppm	MRDL = 4.0	MRDLG = 4	<0.1 - 3.5	[2.7] [4]	Drinking water disinfectant added for treatment

CONSTITUENTS WITH SECONDARY STANDARDS	UNIT	SMCL	PHG	RANGE	AVERAGE	TYPICAL SOURCES IN DRINKING WATER
Chloride	ppm	500	N/A	<3 - 15	8.7	Runoff / leaching from natural deposits
Color	Unit	15	N/A	<5 - 5	<5	Naturally-occurring organic materials
Iron	ppb	300	N/A	<6 - 24	11	Leaching from natural deposits
Manganese	ppb	50	N/A	<2 - 2.4	<2	Leaching from natural deposits
Specific Conductance	µS/cm	1600	N/A	37 - 210	140	Substances that form ions when in water
Sulfate	ppm	500	N/A	1.1 - 29	15	Runoff / leaching from natural deposits
Total Dissolved Solids	ppm	1000	N/A	<20 - 104	61	Runoff / leaching from natural deposits
Turbidity	NTU	5	N/A	0.1 - 0.2	0.1	Soil runoff

LEAD AND COPPER [9]	UNIT	AL	PHG	RANGE	90TH PERCENTILE	TYPICAL SOURCES IN DRINKING WATER
Copper	ppb	1300	300	ND - 383	60	Internal corrosion of household water plumbing systems
Lead	ppb	15	0.2	ND - 190	7.1	Internal corrosion of household water plumbing systems

NON-REGULATED WATER QUALITY PARAMETERS	UNIT	ORL	RANGE	AVERAGE
Alkalinity (as CaCO3)	ppm	N/A	7.1 - 166	41
Boron	ppb	1000 (NL)	28 - 105	56
Calcium (as Ca)	ppm	N/A	3.2 - 15	9.3
Chlorate	ppb	800 (NL)	45 - 650	147
Chromium (VI)	ppb	N/A	0.22 - 0.27	0.25
Hardness (as CaCO3)	ppm	N/A	9.1 - 49	32
Magnesium	ppm	N/A	0.2 - 4.2	2.9
pH	-	N/A	7.8 - 9.6	9.2
Potassium	ppm	N/A	0.3 - 1	0.7
Silica	ppm	N/A	5 - 5.9	5.5
Sodium	ppm	N/A	3.5 - 21	14
Strontium	ppb	N/A	16 - 159	79

KEY

< / ≤ = less than / less than or equal to
AL = Action Level
Max = Maximum
Min = Minimum
N/A = Not Available
ND = Non-Detect
NL = Notification Level
NoP = Number of Coliform-Positive Sample
NTU = Nephelometric Turbidity Unit
ORL = Other Regulatory Level
ppb = part per billion
ppm = part per million
µS/cm = microSiemens/centimeter

Figure 4.11: Example for water quality report card.
(a) Left, water quality report card used as an executive summary in the San Francisco 2022 Annual Water Quality Report. **(b)** Right, standard water quality report found in addition to the water quality summary (San Francisco Water Power Sewer, 2023).

4.9.1 Recommendations for Researchers Disseminating Water Quality Reports to Residents

Building on these insights and others from this review, the development of a standardized template for researchers conducting water quality testing in homes is practical approach to addressing the challenges of clear communication, enhancing data accessibility, and ensuring that diverse community needs are met. Such a template should incorporate best practices for clear communication and effective data presentation, tailored to meet the diverse needs of residents. By providing a structured and user-friendly format, this template facilitates the accurate and accessible dissemination of water quality information for researchers. The template provided in the appendix is designed to help researchers create comprehensive reports that are easily understood by the public, ensuring that residents receive reliable and comprehensible information about their water quality. This approach not only improves public awareness and trust but also empowers communities to make informed decisions regarding their water use and safety.

4.10 Conclusion

This chapter synthesizes the diverse practices surrounding the reporting of water quality constituents to residents, examining the regulatory frameworks, reporting practices, communication methods, and the challenges and best practices associated with these reports. From the regulatory perspective, laws like the Safe Drinking Water Act in the U.S. set the baseline for what and how contaminants must be reported, ensuring a minimum standard across different regions. However, the actual implementation of these regulations can vary significantly, influenced by local needs, resource availability, and public interest. Reporting practices range from comprehensive to request-based, each with its own set of advantages and challenges. Comprehensive reporting ensures transparency and builds trust but may overwhelm residents with too much information. On the other hand, threshold-based and selective reporting simplify the data but might omit important details that could affect resident decisions and perceptions.

A consistent pattern emerges from the literature on communication in water quality reporting. Effective communication is key to ensure that water quality reports are both informative and reassuring. Employing clear language, visual aids, and interactive digital tools make complex information more accessible and understandable. Regular updates and proactive communication, particularly in response to specific incidents or detected contaminants, are critical for maintaining public trust. Given the limited literature on unregulated dissemination of water quality reports by researchers, this review draws insights from regulated practices and applies them to how unregulated reports can be prepared, disseminated, and received by diverse communities. To facilitate this communication a structured and user-friendly template is provided. This template can be powerful tool, as long as water providers and researchers reporting water quality data consider the following recommendations and guiding questions:

- Understand your audience: What are the demographics of the community you plan to engage with? What do people care about most concerning water quality? What are some key issues affecting water and water quality in the community you plan to study? Who do community members in your study area trust for information? Where and how do community members in your study area get their information?
- Enhance Clarity and Accessibility: Utilize clear, non-technical language and visual aids to make reports more understandable.
- Increase Transparency and Engagement: Offer more comprehensive information through digital platforms that allow residents to explore their water quality data in depth.
- Foster Community Involvement: Implement educational programs to raise awareness about water quality issues and treatment processes.
- Adapt to Local Needs: Tailor reporting and communication strategies to the specific needs and concerns of the local population.

While reporting water quality in a way that is both comprehensive and comprehensible remains a challenge, adopting best practices in communication and community engagement can help ensure that residents are well-informed and reassured about the safety of their drinking water.

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5 CONCLUSION & OUTLOOK

5.1 Summary of Key Findings

This dissertation investigated three disparate, yet interconnected needs of modern society facing environmental change: urban heat management, finding new resources (i.e., lithium sources in groundwater), and improved public health communication in the context of groundwater resources. While distinct in their focus, these studies are unified through the common goals of promoting environmental sustainability, effective resource management, and societal well-being.

The study on heat islands examined how the implementation of light-colored roofs with high albedo values could mitigate UHIs in Tucson, Arizona, reducing energy consumption and costs for individual residencies and the whole city. The study quantified the distribution of roofs and their respective colors in Tucson using a spatial stratified sampling technique known as point-counting. Approximately 70% of roofs were identified as having high albedo colors (i.e., white or light gray). ArcGIS was used for satellite image processing, manual digitization of roofs (to validate the viability of the point-counting method), and the development of land surface temperature maps to understand the thermal characteristics of different roof colors. Finally, eQUEST, a building energy simulation tool, was used to estimate the energy consumption of buildings based solely on their roof colors. Energy simulations using eQUEST indicated that converting dark roofs to light-colored ones could save Tucson around $1,400,000 annually in energy costs. This reduction in energy demand directly ties into broader efforts to enhance energy efficiency and sustainability in urban planning. This creates a synergistic relationship to the study on lithium resources. The reduction in energy consumption from cool roofs can help lessen the strain on the overall energy grid, complementing efforts to localize and diversify lithium production in the United States.

The study on lithium resources investigated the sources of lithium in groundwater in West Texas and South Central New Mexico, to provide a foundation in the quest for alternative sources of and sustainable lithium extraction. Water chemistry data from the Hueco and Mesilla Bolsons, and Tularosa and Jornada del Muerto Basins, were analyzed using positive matrix factorization (PMF) to identify and quantify lithium sources. The study used historical water sample data with lithium concentrations ranging from 0.001 to 2.28 mg/L. Results from the PMF model revealed four factors (i.e., sources) reflecting natural and anthropogenic processes influencing the geochemical composition of groundwater in the region and were interpreted as: 1) shallow, low-salinity waters heavily influenced by surface activities and minor geological interactions; (2) high-salinity groundwater influenced by ancient evaporite layers; (3) mixed-sourced groundwater influenced by both limestone dissolution and subsequent clay interactions; and (4) mixture of deep saline water in the Tularosa basin with locally derived groundwater from the upper Santa Fe group. The highest contributions of lithium came from two significant factors averaging 0.082 mg/L and 0.089 mg/L. By understanding the distribution and concentration of lithium in these groundwater sources in the region, this study supports the localization and diversification of lithium production in the United States, an effort aimed at reducing dependence on imports and enhancing energy security (The White House, 2022). Moreover, co-extraction of lithium from geothermal waters can enhance the economic feasibility of geothermal energy projects, supporting renewable energy storage and contributing to sustainable energy solutions.

The final study focused on the challenge of effectively communicating water quality information to the public. This study reviewed established practices in regulated water quality reporting and provided practical recommendations for unregulated reporting by researchers. A comprehensive water quality reporting template was developed as a final product to guide researchers in unregulated reporting of water quality results to residents. The use of effective communication strategies from researchers to the public supports greater public trust, enabling initiatives such as those presented in the study on urban heat and the study on lithium resources to transition from theoretical to practical solutions.

5.2 Limitations

While this dissertation provides valuable insights into urban heat management, lithium sources in groundwater, and public health communication, several limitations must be acknowledged to contextualize the findings and suggest areas for future improvement.

5.2.1 Scope of the Study

One of the limitations of this research is geographic focus. The urban heat and lithium resources studies are confined to specific regions—Tucson, Arizona for urban heat islands, and West Texas into South Central New Mexico for lithium sources. While these regions were selected for their relevance and specific characteristics, the findings may not be directly applicable to other areas with different climatic, geological, or subsurface geochemical conditions. Future research should aim to replicate these studies in other settings to enhance the generalizability of the results.

5.2.2 Analytical Methods

The analytical methods used in this dissertation, while rigorous, have their constraints. In the urban heat study, the point-counting method involved overlaying a grid on satellite imagery and manually counting and categorizing roof colors at each grid point. Manual digitization of roofs was then performed to validate the results of the point-counting method. While these techniques provided accurate and reliable data, they were profligate in their use of time and labor, requiring significant man-hours to complete. This may impede the application of this approach elsewhere. Additionally, the point-counting method for roof color identification, though validated, can introduce sampling errors or biases. To enhance efficiency and scalability, the point-counting method and manual digitization could be replaced by machine learning techniques. Machine learning algorithms, particularly those in the realm of image recognition and classification, have the potential to automate the process of identifying and categorizing roof colors from satellite imagery (Wang et al., 2020). Developing a robust machine learning model for roof color classification can provide insights into the thermal characteristics of urban environments on a larger scale. If developed, this model could be integrated into urban planning tools and used by city planners and policymakers to implement effective UHI mitigation strategies. Additionally, the use of eQUEST for simulating energy consumption based on roof color is inherently limited by the assumptions and parameters set within the simulation model. Real-world variations in building construction, insulation, and occupant behavior may lead to differences between simulated and actual energy savings.

In the lithium study, PMF was used to identify and quantify lithium sources in groundwater. While PMF is a robust statistical tool for source apportionment, it relies on the accuracy and representativeness of the input data. Any inaccuracies in the water chemistry data could affect the reliability of the source apportionment results. It also has limitations in its ability to handle multiple constituents simultaneously. The PMF model is primarily designed to decompose complex datasets into a limited number of source contributions based on the observed concentrations of specific constituents. However, the complexity of groundwater systems often involves multiple interacting constituents that collectively define distinct water types. Here, eight constituents were selected to run PMF, potentially resulting in incomplete or less detailed source profiles. This can affect the accuracy and reliability of the source apportionment results, potentially leading to misinterpretations of the origins and dynamics of the groundwater constituents. Moreover, the successful application of PMF depends on user experience and fundamental understanding of groundwater chemistry. The relative ease with which PMF can be used may lead unexperienced users to incorrect interpretations – or overinterpretation – of datasets. Future work thus relies as much as on comprehensive and reliable primary datasets as on training of users in the application and interpretation of this powerful tool.

The study on water quality reporting to residents addressed the challenge of effectively communicating water quality information to the public. A limitation of this chapter is that it is predominantly based on literature review, without exhaustive additional search, and heavily relied on insights from regulated water testing efforts. Challenges in identifying all relevant sources and stakeholders in the field of water quality communication thus represents a limitation. It is possible that pertinent studies and best practices were unintentionally omitted in the review, missing out on additional insights and guidance for the development of the reporting template. Additionally, the template has so far not been tested in real-world settings with resident feedback. This limitation means that the effectiveness of the template in improving public understanding and trust has not been empirically validated. An obvious next step in this effort is to do real-world tests, including testing of version of the template that is translated to Spanish.

Despite these limitations, this dissertation presents valuable and actionable insights that can guide future research and practice. While generalizability may be limited, the findings offer a foundation for further research in different settings. By addressing these constraints in future subsequent studies, the impact and applicability of the research can be further enhanced, ultimately contributing to more comprehensive and effective solutions for urban heat management, sustainable resource utilization, and public health communication.

5.3 Community Impact

5.3.1 COMMUNITY-DRIVEN INCLUSIVE EXCELLENCE AND LEADERSHIP OPPORTUNITIES IN THE GEOSCIENCES (CIELO-G)

Earth scientists strive to improve the world by addressing complex environmental, health, and technological challenges. However, their efforts are meaningful only when the public is engaged, informed, and included. Bridging the gap between scientific research and public understanding is essential for fostering a shared vision for a sustainable future. By working together, scientists and the public can go much further in achieving greater resilience and sustainability in environmental management, making scientific endeavors that much more worthwhile and impactful.

This dissertation is part of a broader effort funded by the National Science Foundation (NSF) through the Community-Driven Inclusive Excellence and Leadership Opportunities in the Geosciences (CIELO-G) program at The University of Texas in El Paso. The mission of CIELO-G is to transform the geoscience community culture in a profound and lasting way by consciously and organically changing the way we interact with our broader local community (Hardy et al., 2023; CIELO-G Program, 2023). This project serves as a model to transform the culture of the geosciences nationally toward a more diverse, equitable, inclusive, and accessible community. Central to this effort is the concept of collective impact, which embodies the commitment to integrate diverse viewpoints from different sectors to formulate a common agenda (i.e., a foundation for a shared understanding of science goals; Hardy et al., 2023) to solve specific problems. By leveraging the principles of collective impact, this dissertation's findings can be implemented in a way that promotes community engagement and support. The CIELO-G program ensures that the research is not only scientifically rigorous but also socially relevant and inclusive, aligning with the broader goals of transforming the geoscience community and fostering a sustainable future. By addressing urban heat management through cool roofs, supporting sustainable lithium extraction from groundwater resources, and enhancing public trust in water quality reporting, this dissertation offers integrated strategies for promoting resilience and sustainability. Bridging the gap between science and society remains a cornerstone of effective and meaningful scientific progress, further reinforced by the collaborative and inclusive framework provided by CIELO-G.

5.4 Outlook: Earth Science Tackling Future Challenges

For most people, the speed of time and life appears to accelerate. While the perception of time passing is individual, and likely every generation from Ancient Egypt to modern times has felt the same, one could argue that for earth scientists especially, the passing of time has indeed accelerated. Temperature data, albeit with large uncertainties, indicate that global surface temperatures have warmed at a rate of 0.19 ºC per decade between 1970 and 2008 (Hausfather, 2020). However, this warming has accelerated to a rate of approximately 0.3 ºC per decade over the past 15 years (Hausfather, 2020). Another acceleration deeply impacting how earth scientists work is the increase in data availability, the computing speed with which we process these data, and the use of machine learning to interpret them.

These two acceleration trends converge on how humanity will tackle environmental challenges that appear inevitable: heat, water scarcity, and changing demands on resources in the wake of the energy transition. As Earth scientists, we are witnessing a time where the urgency to find solutions to these challenges coincides with the opportunities offered by new technologies. The interwoven dependencies on resources create unprecedented complexity. It is our choice how we deal with this situation—whether with excitement, fear, or indifference.

In this view, it is not surprising that this dissertation brought together three pressing issues: finding new resources (lithium), managing urban heat (cool roofs), and addressing water quality communication issues. The last of these topics highlights a crucial point: as earth scientists, we cannot afford to be indifferent or nervous about communicating our findings and their implications to the public. Effective communication is essential, not only to create factually driven solutions and hope, but also to minimize apprehension to avoid unnecessary fears and panic. Communicating across age, gender, cultural, and language barriers will be key in building a promising and sustainable future for all humanity.

The perceived or real acceleration in time by Earth scientists has definitively pulled us from our ivory towers of intellectual protection. Despite any hesitation we may have to connect with our own humanity, we are a part of society, and must provide solutions that not only make scientific sense, but also resonate with our fellow citizens. By doing so, we can ensure that our research leads to practical, impactful outcomes that benefit the planet and its inhabitants.

5.5 References

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APPENDIX

Water Quality Reporting Template

Template Instructions

This template is designed to be comprehensive and flexible, allowing users to adapt it to specific needs and contexts. It is designed for clarity, transparency, and accessibility, enabling effective communication of water quality results between researchers and residents.

Explanations and guidance for each section are found in the italicized text in brackets found on the template. Replace this text with the relevant information from your study. If any sections are left unused, delete them prior to dissemination to the public.

General Instructions

1. **Adaptation:** Tailor the template to fit the specific context and requirements of the community or region being studied. Ensure all sections are relevant and appropriately filled out.
2. **Plain Language:** Use plain language to make the report accessible to a broad audience. Recommendations for plain language words and example sentences can be found using CDC's Everyday Words for Public Health Communication.
3. **Consistency:** Maintain consistent formatting throughout the report for a professional and easy-to-read document. This includes font style, size, headings, and subheadings.

Communication Tips

1. Know your audience. Focus your main message around how your audience will resonate with its delivery.
2. Avoid acronyms, abbreviations, and jargon. Define any technical terms used in the "Reading Your Water Quality Test Results" section.
3. Keep your message simple, not simplistic, and straightforward. Leave out unnecessary details that may distract from your main message.
4. Use graphics and other visual methods to help communicate your message, without distracting from your main message.

Additional Resources

- Translations for Public Notification: This resource provides more than two dozen translations for informational statements to use on CCRs.
- American Association for the Advancement of Science – Communication Toolkit: This resource provides guidance for scientific communication with the public.
- A quick guide for Developing High Quality Public Engagement: This resource provides information about understanding your audience, defining your message, and more.

[Institution, organization, agency name and/or logo]

Water quality results report for ______________________________________
[community, region, or household]

Testing date _____________
[Month, Year]

Purpose of the water quality analysis:
[Provide a brief explanation of why the water quality testing was conducted and the significance of the results for residents.]

What was tested?
[List the specific contaminants and parameters that were tested in the water samples.]

Why were these items tested?
[Explain the relevance and/or potential health impacts of each contaminant. Describe the importance of testing these specific items in the context of the study and/or public health and safety. Be sure to indicate what the common sources of aqueous constituents are (i.e., whether they are naturally occurring) using plain language to avoid unnecessary fear or panic about contaminants such as trace elements.]

How were samples analyzed?
[Provide detailed information about the methods and technologies used to analyze the water samples. Include the name of the laboratory, the analytical techniques employed, and any relevant standards or protocols followed.]

Summary of key findings
[Include a general summary of the water quality results, indicating whether overall water quality surpasses, falls within, or below state and federal water quality standards. A template for the summary of key findings is found on page 6 of this document.]

Overall water quality:
[Summarize the overall quality of the water. Do not use broad statements such as "safe for drinking" as they may lead to legal liabilities if individuals experience adverse health *effects linked to water consumption. An effective statement here might be, "Recent tests show that the levels of [specific contaminants] in your water are below the limits set by the EPA for safe drinking water. The [specific contaminant] level is X mg/L, which is well within the EPA's maximum contaminant level of Y mg/L. If you have specific health concerns, such as a weakened immune system or are pregnant, please consult with your healthcare provider."]*

Key contaminants detected:
[List major contaminants detected, and their levels compared to safety standards.]

Trends over time:
[If applicable, note any trends observed in water quality over the study period.]

Reading your water quality test results
[Include an explanation of terms and/or glossary for any technical jargon specific to your report.]
Detailed water quality test results
[Include a table of detected contaminants. If additional tables for non-detected contaminants are needed, the following table can be copied to report these separately.]

Detected Contaminants

Contaminant	Unit	Detected level	MCL*	Source of contaminant	Health implications	Meets requirements

* MCL: Maximum Contaminant Levels set by the United States Environmental Protection Agency (EPA)

Graphs/Charts
[Include visual representations of the data for easier understanding.]

Discussion

Interpretation of results:
[Detailed analysis of what the results mean for residents.]

Comparative analysis:
[Comparison with previous years' data and regional benchmarks.]

Identified trends:
[Trends in contaminant levels over time.]

Recommendations & next steps
[Provide practical recommendations for residents to address water quality concerns, such as using water filters or boiling water.]

Immediate actions:

[Steps that should be taken in response to the findings.]

Long-term strategies:
[Suggestions for improving water quality over time.]

Contact information
For more information or if you have any questions, please contact:
[Provide contact details name(s) and contact details of the researcher(s) involved and/or responsible for the report.]

Additional resources:
[List websites or resources where residents can find more information.]

For more information about safe levels of potential contaminants in drinking water, visit the EPA website to view primary and secondary drinking water standards.

Water Quality Summary Example

Water quality *[Overview/Summary/Report Card]*

[Include a brief overview of the report's key findings in plain language.]

Contaminants tested	Why it is tested	Likely source	Your water source	Meets federal standards
Microorganisms *[List microorganisms tested, such as total coliforms]*	*[Briefly explain why it is being tested. For example, can make people sick in large amounts]*	*[Use EPA's sources of contaminants information using plain language]*	*[Better than/ Within/Worse than federal water quality standards]*	*[Indicate whether levels detected within or below state and federal water quality standards using one of the following]*
Disinfectants *[List disinfectants tested, such as chlorine]*	*[Briefly explain why it is being tested]*			
Inorganic Chemicals *[List inorganic chemicals tested, such as arsenic]*	*[Briefly explain why it is being tested]*			
Organic Chemicals *[List organic chemicals tested, such as benzene]*	*[Briefly explain why it is being tested]*			
Radionuclides *[List radionuclides tested, such as uranium]*	*[Briefly explain why it is being tested]*			

VITA

Judith Robin Hoyt (Chapman) is a force to be reckoned with. Slow to trust in her own meandering path, she discovered the passage to her way by guiding those willing to allow her to lead while she learned to trust being led. A former public school science teacher of 8 years, she has found great peace in flowing with the tides innate to life and community.

Before earning a B.A. in Interdisciplinary studies to become a teacher, Judith studied cosmetology, recognizing a truth innate to humans – how many of us desire to enliven the beauty we have inside to share with the world. As a teacher, her students gave Judith great purpose; purpose that informs her motivation to build communities more resonant with the beauty of humanity. While teaching, Judith earned an M.Ed. in Curriculum and Instruction, with a focus on earth science education. This gave her the opportunity to formally learn while teaching – to place herself in the shoes her students walked daily, while once again walking in her own shoes, furthering her practice.

From a young age, Judith also studied music, hoping to one day share her own music with others. It was not until she met her late Ph.D. mentor, Nicholas Pingitore, who taught her that academic writing can flow like music, that she became reconnected with her own song – a song she had not realized she had been singing all along. This song guided her to pursue a Ph.D. in Geological Sciences, studying subjects of great importance for future generations.

Judith hopes to encourage all those around her to find what they love doing, and then to do those things for the betterment of society. She recognizes that some of us thrive in pushing others towards the stars, and others in reaching towards the stars. Most of us, however, thrive in doing both. She reminds us that wherever life finds us, bring love there. She can be reached at judith.hoyt@outlook.com.