

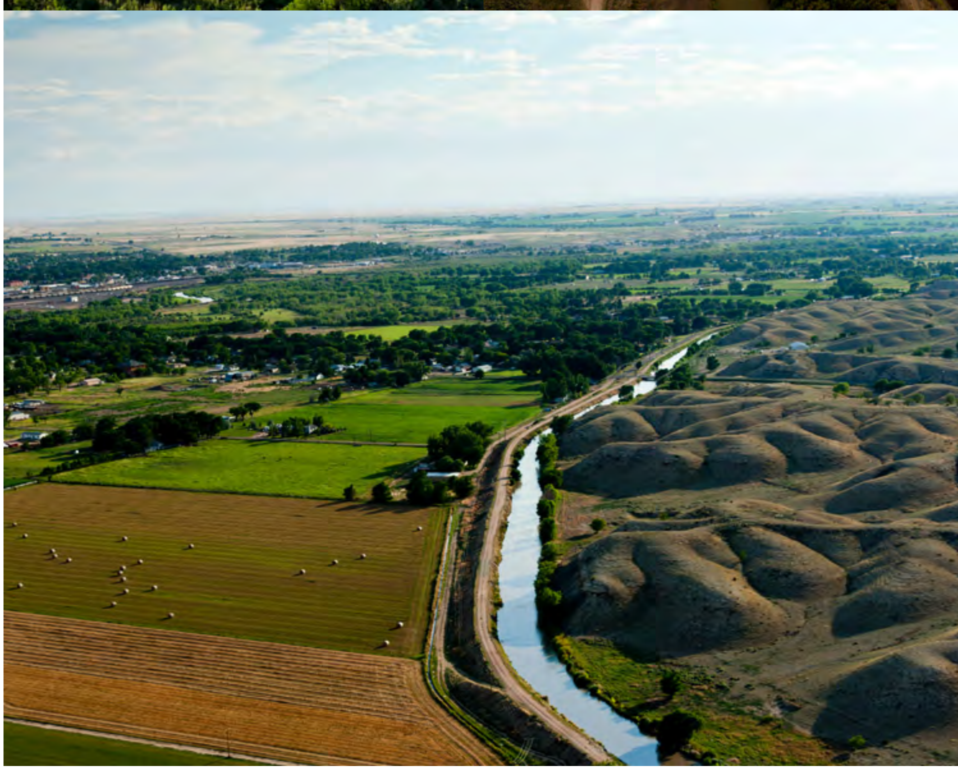


Lower Arkansas River Watershed Plan

John Martin Reservoir to Stateline

Prepared For:

This report is prepared for and intended to be used by water managers and water users of the lower Arkansas River Valley, from John Martin Reservoir to the state border with Kansas. This work was commissioned by the Colorado Department of Public Health and Environment (CDPHE) and uses guidelines established by CDPHE and the Environmental Protection Agency (EPA).

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Chapter 1
Introduction

1. INTRODUCTION

For decades, and perhaps centuries, waters in the Lower Arkansas River Watershed have been impaired by water quality pollutants such as selenium, uranium, sulfates, and salts. Water quality issues in the lowest reaches of Colorado's Arkansas River have presented problems for natural ecosystems, agriculture, municipal drinking water, and even industrial applications. In recent history, high levels of selenium and uranium have been observed, thus accelerating the need to improve water quality to protect drinking water supplies, agricultural water quality, and ecosystems. **The purpose of this watershed plan is to improve water quality within a sub-watershed of the Arkansas River Basin through community involvement and implementation projects that benefit local stakeholders.** This can be achieved in many ways, but the most feasible paths to success for this specific watershed are:

1. Work with local stakeholders, including agricultural producers and state and federal agencies, to identify and disseminate water quality data and identify specific water quality problems.

2. Develop partnerships with local private landowners and private water users to better understand the constraints for improving water quality and identify opportunities to improve water quality.

3. Create a watershed plan that is usable, accountable, and fundable with strong buy-in from local stakeholders ready to implement new management practices for the benefit of their operations and the benefit of water quality.

1.1 Purpose of this Plan

A comprehensive watershed plan accomplishes three main purposes: 1) synthesize previous experiences and introduce new techniques to improve a resource of concern, 2) use the best available science to identify management strategies/techniques that have the potential to improve this resource concern, and 3) identify projects that incorporate these strategies/techniques and make the most efficient use of resources. These three foundational components create a road-

Figure 1: Large irrigation canals, such as this, supply water to farms and are used to grow a variety of different crops. Photo courtesy of Bill Cotton, Colorado State University.

map for improving water quality on a large landscape scale. These three components are broad by definition, and more information will need to be distilled from these three topics to make this plan actionable, accountable, and fundable.

Watershed planning, or any form of planning, is an exercise in evaluating a complex system and then identifying the relationships among the system's parts that can most efficiently and effectively make the biggest positive impact on the system. **This watershed plan attempts to summarize existing information, including new research findings, and identify future projects that hold the greatest potential for improving water quality in the Lower Arkansas River Watershed of Colorado.** The Lower Arkansas River Watershed (LARW) is a geographically, culturally, and ecologically diverse landscape with several different land uses and resource concerns.

One of the primary landscape-scale resource concerns for this area is water quality and the resulting impacts on environmental, agricultural, industrial, and municipal water uses. The largest water user in this watershed (measured in stream diversions) is agriculture, and entire economies and communities of the area are built on the agricultural industry. **It is critically important that we work with agricultural interests to achieve mutually beneficial outcomes from taking action to improve water quality.** Agricultural practices can both benefit or degrade water quality. However, it is important to work proactively with agricultural interests to implement **voluntary** practices for many beneficiaries. Finding and funding water quality projects that demonstrate multiple benefits is the clearest and easiest path to success. This watershed plan attempts to find "win-win" projects that enhance agriculture while also improving water quality.

This watershed plan will also capitalize on cutting edge scientific investigations in the Lower Arkansas River Watershed, as well as examples from watersheds with similar water quality problems. These scientific studies have provided substantial insights and thus a much better understanding of the potential sources of water quality impairments and what management practices might best remediate or mitigate poor water quality.

1.2 History and Geographic Scope

This watershed plan is a more geographically specific and more current version of a larger watershed plan developed in 2008. The plan developed in 2008 addressed water quality problems from Pueblo to the Kansas border. While the 2008 plan was comprehensive, the large geographic scale was not sufficient in meeting the needs of specific regions in the Lower Arkansas River Valley. This current plan, on the other hand, attempts to build a more involved stakeholder network within a smaller region of the Lower Arkansas River Valley by focusing on the specific needs of water users and managers in the most downstream parts of the Arkansas River Valley.

The watershed area for this 2018 plan extends east from Las Animas, CO, and includes the main stem of the Arkansas River and all of the tributaries feeding it below Las Animas, as well as John Martin Reservoir and several other smaller off-channel reservoirs (Figure 1). Three main tributaries to the Arkansas River are included within this watershed: Rush and Big Sandy Creeks to the North and Two Buttes Creek to the south (Figure 2). These three tributaries are included because each flows into the Arkansas River below John Martin Reservoir. Because this watershed plan is interested in improving water quality below John Martin Reservoir, it was critically important that all pollution sources that enter the river from these three tributaries are accounted for.

In total, 4,395 miles of streams exist within the Lower Arkansas River Watershed, most of which are perennially dry and only flow during major storm events. More than 76 miles of the Arkansas River flows through the watershed, with the next largest stream network—Big Sandy Creek—at 62.3 miles and Two Butte Creek at 54.8 miles. Several large storage reservoirs are located within the watershed, including John Martin Reservoir, Adobe Creek Reservoir (also called Blue Lake), and the "Plains Reservoir System" of Nee Gronda, Nee Noshe, and Nee Sopah Reservoirs. Many water bodies, including streams and reservoirs, contain water with poor water quality. In this context, "poor water quality" is defined as waters that contain pollutants in excess of state water quality standards. Examples of water quality pollutants within the Lower Arkansas River Watershed include selenium, uranium, iron, and E. coli. Table 1 shows the spatial extent of each pollutant within the watershed. A more detailed explanation of the water quality concerns can be found in Chapters 2 and 3 and Appendix 1-A.

This plan does not include the lands or waters of the Purgatoire River Watershed. This river merges with the Arkansas River immediately above John Martin Reservoir. The Purgatoire River is one of the largest tributaries to the Arkansas River, and the scale of the watershed is beyond the scope of this plan. Additionally, the Purgatoire Watershed Partnership developed a watershed plan for the Purgatoire River Watershed,

Figure 2: The Lower Arkansas River Watershed – John Martin to State Line encompasses all of the lands that contribute water to the Arkansas River from John Martin Reservoir to the state line with Kansas. This does not include the Purgatoire River, which enters the Arkansas River directly above John Martin Reservoir.

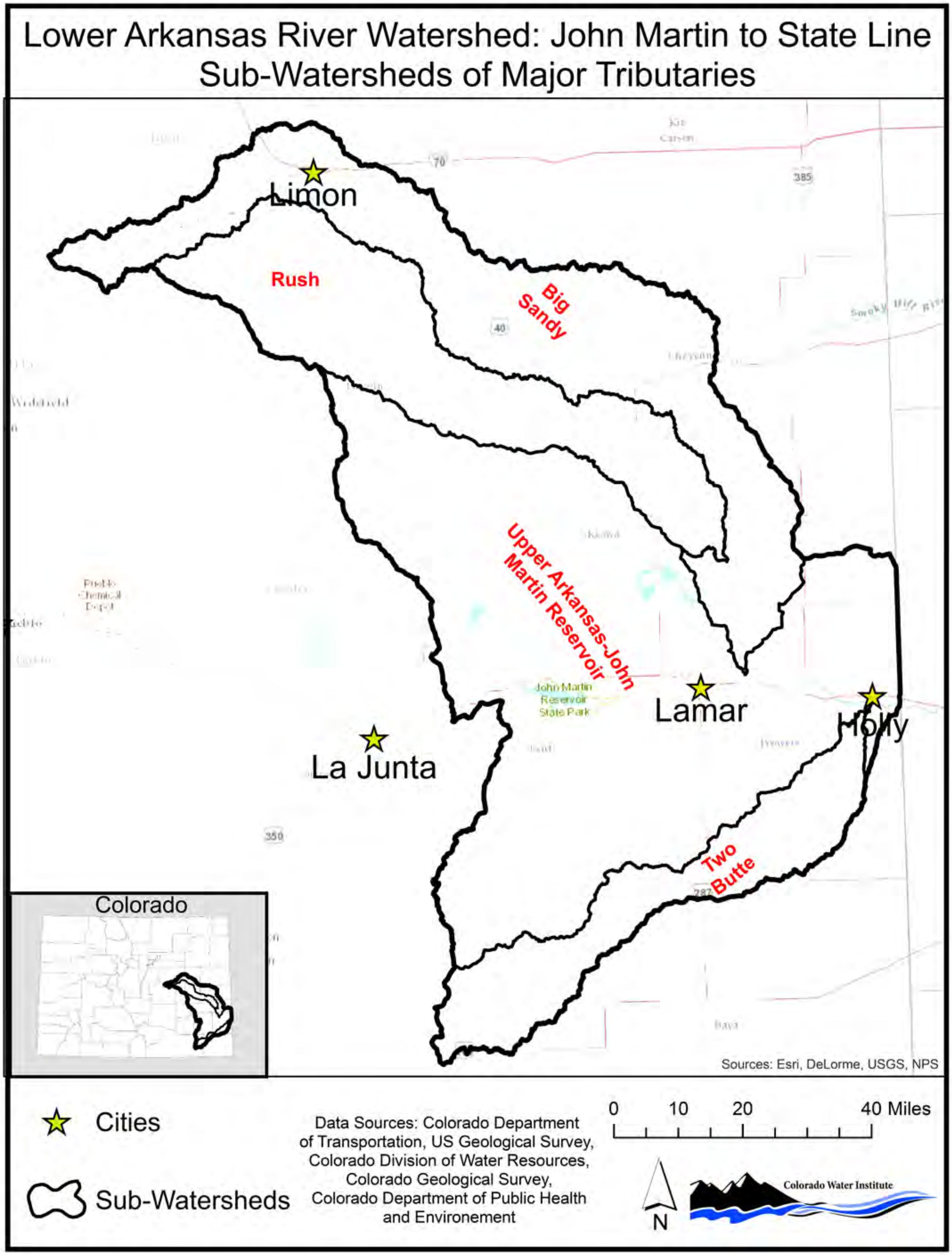

Figure 3: Four smaller watersheds make up the Lower Arkansas River Watershed – John Martin to State Line: 1) the Upper Arkansas John Martin Reservoir subwatershed, 2) the Big Sandy subwatershed, 3) the Rush subwatershed, and 4) the Two Buttes subwatershed.

Impairment Status	Parameter	Total Stream Miles
Impaired (Category 5)	Selenium	768.5
	Uranium	64.1
	Arsenic	630.3
	Manganese	4155.6
	Iron	145.9
	E. coli	66.2
	Temperature	14.8
	Sulfate	3525.4
Monitored and Evaluated (Category 3b)	Selenium	66.2
	Uranium	7.7
	Arsenic	66.2
	Manganese	138.3
	Iron	66.2
	Temperature	202.4
	Sulfate	145.9

Table 1: Total stream miles for each parameter listed as Impaired or Monitored and Evaluated

which was published in 2014. More detailed information on the Purgatoire River Watershed Plan can be found at **purgatoirepartners.org**.

1.3 Sources of Water Pollution

Point Source Pollution

Point source discharges of water at a single location are one pathway that allows pollutants (i.e., ammonia, selenium, uranium, pesticides, etc.) to enter waters from a single point, such as the end of a pipe discharging directly to the Arkansas River. Common point sources include wastewater treatment plants, industrial operations that use water to manufacture goods, or power plants that use water for cooling purposes. Each of these activities has a beneficial water use that results in some water being left over, which in turn needs to be discharged back into a stream or river. In each case, the water is taken to the river or stream using pipes or other means, and the water that is discharged from the pipe occurs at that discrete location, making it a "point source." All point source discharges are regulated and, therefore, it is easier to measure the pollutant loading from these sources. The primary mechanism to control point source pollution is regulation, and more specifically, Total Maximum Daily Load (TMDL) allocations. Specific TMDL allocations are established for individual river segments and allocate safe pollution "allowances" to different water-consumptive activities and dischargers.

Non-Point Source Pollution

As the name implies, non-point source pollution is pollution derived from diffuse sources. Non-point source pollutants can be the same as point source pollutants (i.e., ammonia, selenium, uranium, pesticides, etc.), but if measured, it would be very difficult to determine the exact source of these pollutants. One example of non-point source pollution is the dissolved salts from irrigated farm soil, which percolate down into the shallow alluvial groundwater and then eventually return to the river as subsurface return flows (this "pollutant" is simply used as a relevant example in the Lower Arkansas River Watershed, salt ions are not a regulated pollutant). In this example, it would be nearly impossible to trace salt in the river (or even in the groundwater) back to an original point in a field.

Clearly, these practices that contribute to non-point source pollution are very difficult to regulate because it is difficult to directly measure. However, other methods exist to estimate the amount of non-point source pollution, primarily models or mass balance equations that rely on existing stream data. Because it is not regulated, one of the most proven methods for reducing non-point source pollution is the development of watershed plans that encourage the voluntary adoption of best management practices (BMPs).

1.4 Planning Process

The planning process consisted of multiple stakeholder meetings, data summaries/analyses, and network building. Guidelines exist for TMDL development, however, TMDL development is not being pursued due to the 1) unique local circumstances, 2) initial review of selenium and causes of impairment can be addressed through a watershed planning effort to achieve water quality standards, and 3) stakeholder interest in alternative restoration approach. The State of Colorado is encouraging a grassroots approach to improve water quality through watershed planning, pilot/implementation projects, and stakeholder buy-in.

In addition to this three prong approach, an alternative restoration approach is a near-term plan, or description of actions that includes a schedule and milestones that are immediately beneficial or practicable to achieving water quality standards versus developing a TMDL for the waterbody being addressed. These three processes can contribute to an *Alternative Restoration Approach*, and the watershed plan is just one piece in this process. In addition to watershed planning, on-the-ground demonstration studies are an important component of an *Alternative Restoration Approach*. Alternative approach plans are written as a way to make immediate progress toward meeting water quality standards with the understanding that if the water quality standard goals are not achieved within a specified time, TMDLs must be developed.

Demonstration studies, also called pilot projects, are most commonly studies between research organizations and willing stakeholders. Colorado State University (CSU) is one institution with a long history of working with local stakeholders to implement pilot projects within this watershed. Currently, many efforts to demonstrate BMP effectiveness are being conducted by various CSU research groups. These efforts include watershed-scale modeling of water quality impacts from BMP implementation, field-based trials of nutrient management planning and the impact on selenium mobilization, and economic analyses of different BMPs. The Lower Arkansas River Water Conservancy District is also undertaking water quality studies funded by the Colorado Department of Public Health and Environment. Watershed planning, together with pilot project implementation, represents a starting point for improving water quality while also trying to boost rural economies.

Figure 4: Half of the participants in the first stakeholder meeting held in Lamar on July 13th 2017. Photo courtesy of Prowers Journal.

In addition to watershed planning, on-the-ground demonstration studies are an important contribute to an *Alternative Restoration Approach*. To be effective, both approaches need to build trust and a strong stakeholder network capable of implementing projects on a large scale, and they should occur in tandem with a long-term plan in order to increase the effectiveness of these projects.

Trust is built through adequate and robust data collection, interpretation, and dissemination, as well as the efficient use of technical and financial resources that provide the greatest benefit at the smallest cost. **This watershed plan is the first step in creating an efficient path forward, with the ultimate goal of improving water quality.**

Water quality improvements can be achieved only through a collaborative effort from many stakeholder participants. State and federal agencies provide critical technical and financial resources, local conservation districts are a great conduit of information and expertise regarding agricultural practices, and local business owners (i.e., farmers) are willing to adopt management strategies and implement practices to improve water quality.

Admittedly, there are several “links” in the water quality improvement chain (such as those listed above), and the complexity of perspectives, relationships, and administrative actions can make it difficult to get resources to those who need them the most. For this reason, **this plan advocates for collective action through workgroup participation to implement the strategies and actions identified.** This plan has relied heavily on voluntary participation from water users and water managers, and will continue to do so. This plan document serves only as a "knowledge bank," and the changes recommended are only possible if participants take action. The plan is organized into five main sections:

1. **Introduction and Background**
   The chapter is meant to make readers more familiar with the watershed and describe the issues and what is being proposed to help improve these issues.

2. **Watershed Planning**
   Watershed planning is a broad term used to describe many different activities, but most uses of this term include an analysis of land health issues common to a large area and what can be done to help address the problems. This plan is being developed to address water quality, and this chapter gives more background on the planning process.

3. **Characterization of the Lower Arkansas River Watershed**
   All watershed plans must carefully analyze the attributes of the watershed to better understand opportunities and challenges. This chapter provides more background information on the watershed and gives a summary of water quality.

4. **Water Use**
   It was clear early in the planning process that this watershed plan would not be useful if it did not include a description of water use, the history of water use, and how water uses and water quantity affect water quality. This chapter summarizes the history of water use, some of the different water uses, and factors that affect the hydrology within the watershed.

5. **Best Management Practices to Improve Water Quality**
   This chapter is the culmination of the watershed planning process. It includes feedback from stakeholder meetings and uses the best available science to make recommendations to help improve water quality.

The VISION for the Lower Arkansas River Watershed is:

1. A healthy river system that supports and enhances agricultural communities by improving agricultural productivity while supporting the integrity of natural ecosystems.

2. The adoption of land management activities and Best Management Practices that improve or maintain water quality to meet state standards.

3. Sufficient in-basin water storage to support the conversion of antiquated irrigation methods to more advanced irrigation techniques that require augmentation supplies.

Chapter 2
Watershed Planning

2. PURPOSE OF WATERSHED PLANNING

Watershed planning is an important starting point for improving degraded natural resources that occur widely throughout specific geographic locations. But it is just that, a ***starting point***. A watershed plan without a dedicated group of stakeholders to carry it forward is nothing more than a paperweight. Conversely, a group of dedicated stakeholders without a plan is not enough to make efficient and effective progress toward improving a resource. Watershed plans attempt to fulfill both of these roles by building a dedicated stakeholder network and then developing a technical plan with solutions to address the problems.

Watershed *(noun)*
A watershed is the area of land where all of the water that falls within the boundary high-points flows to a common outlet.

- US Geological Survey

Plan *(noun)*
A detailed proposal for doing/achieving something; or an intention or decision about what is going to be done.

- Oxford English Dictionary

This plan attempts to bring together all parties who have a stake in clean and reliable water sources in the Lower Arkansas River Watershed. These parties include local, state, and federal agencies with a mandate to protect water bodies from contamination, as well as local water users and water managers who depend on this natural resource for their health and livelihoods. Acknowledging these diverse interests, this plan recognizes:

- Prior Appropriation doctrine is respected in all matters concerning water allocation in the lower Arkansas River Basin.
- The importance of water quality in production agriculture.
- Water quality and water quantity are connected in complex ways.
- Many scientific studies in the lower Arkansas River Basin have successfully increased the understanding of subsurface water movement and its impacts on water quality.
- Functionally healthy ecosystems are critical for improving water quality, providing wildlife habitat, and generating outdoor recreation opportunities.
- The need to maintain a critical relationship bridge between private landowners, private water users, and state/federal agencies.
- There are opportunities for and constraints to improving water quality at the watershed scale inherent to locally and privately owned lands.
- Opportunities exist for new management practices and projects on private lands that can benefit the landowner and improve water quality.
- The recommendation items put forth by this plan are voluntary and non-regulatory.

2.1 Watersheds

A watershed is an area of land where all water that falls within a particular boundary flows to a common outlet. For example, the entire Mississippi watershed includes water from many different rivers (the Missouri, Ohio, Arkansas, etc.), but all of the water that flows to the Mississippi will eventually leave the watershed and enter the Gulf of Mexico near New Orleans, LA. Following the Mississippi River upstream, we will eventually branch off into smaller watersheds, including the Arkansas River watershed or the Missouri watershed. The Arkansas River watershed is the area of land that collects water and ultimately delivers that water to the Mississippi River. But watersheds are much more than just stream systems: they include all of the land located within the boundaries of the watershed. The majority of the land within a watershed consists of natural ecosystems such as prairies and forests, irrigated and dryland agriculture, and cities.

The Lower Arkansas River Watershed – John Martin to Stateline represents only a fraction of the larger Arkan-

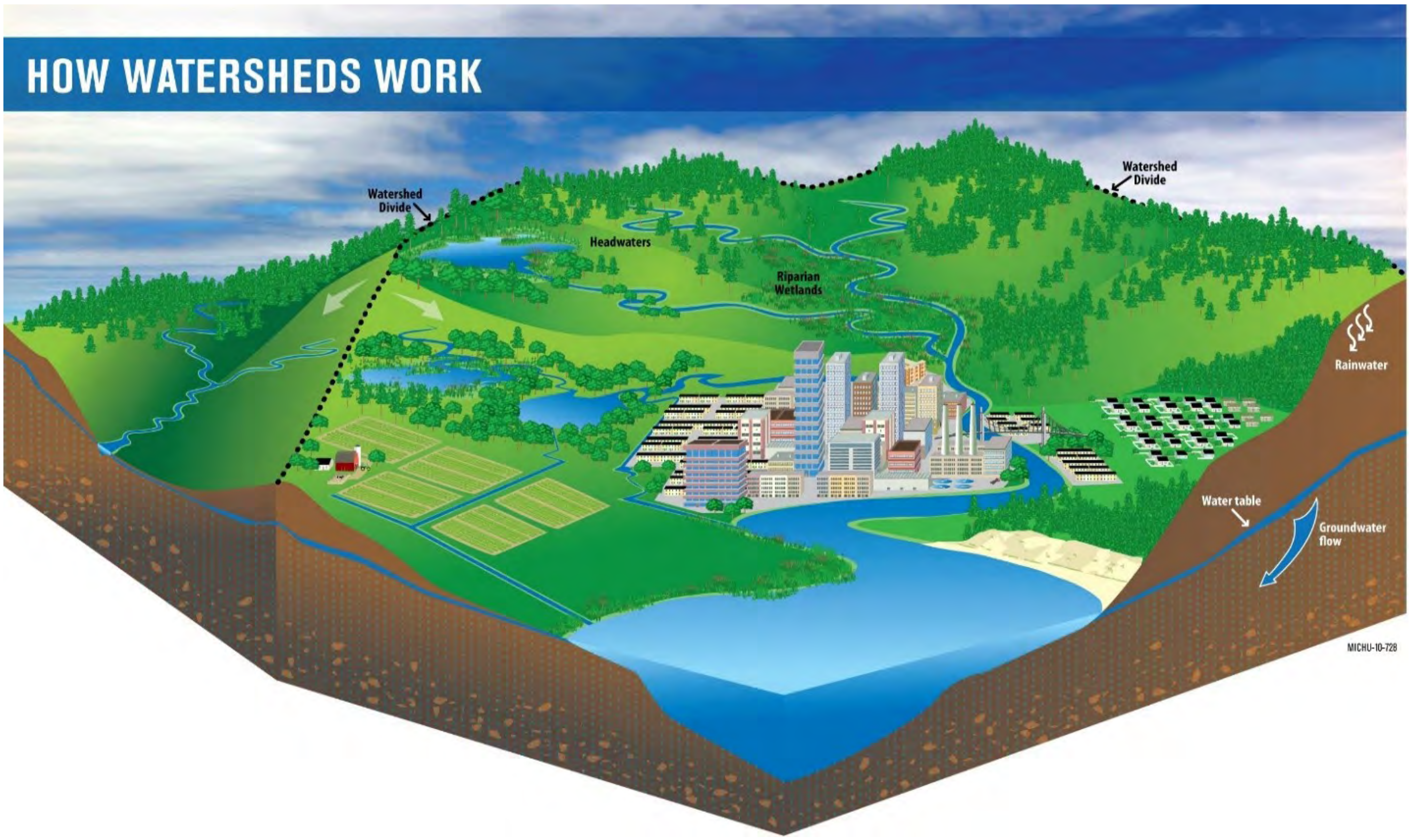

Figure 5: Basic schematic of a small watershed with potential non-point source and point source pollution contributions. Courtesy of mwmo.org.

sas River watershed. This Lower Arkansas River Watershed is the terminal, or bottom, of the Arkansas River watershed in Colorado. The entire Lower Arkansas River Watershed is quite large—nearly 8,000 square miles—which is typical for plains watersheds with large catchment areas. The Lower Arkansas River Watershed includes the main stem of the Arkansas River from a point near Las Animas, CO, until it reaches the state line with Kansas. The watershed has three major tributaries: Big Sandy Creek, Rush Creek, and Two Buttes Creek, as well as many smaller tributaries such as Limestone Creek, Caddoa Creek, and many others. The Lower Arkansas River Watershed also consists of four smaller sub-watersheds: Upper Arkansas – John Martin, Big Sandy, Rush, and Two Buttes. Each of these smaller sub-watersheds either contain or contribute water to the mainstem of the Arkansas River from Las Animas, CO, to the Kansas-Colorado state line. More detailed information on this watershed is presented in Chapter 3.

2.2 Planning

Without a plan to improve them, problems can be costly, create inefficiencies, and become permanent. Planning is a necessary component to any effort trying to make improvements. Planning is used to efficiently and cost effectively design cities, buildings, water infrastructure, farm budgets, weed eradication strategies, vacations, transportation infrastructure (just a few examples), and anything else that requires forethought. The reason for planning *anything* is to reduce the amount of time and money needed to perform a task most efficiently.

Watershed planning is a process of bringing together a diverse group of stakeholders to help improve a resource of concern (i.e., water quality, soil erosion, weed infestations, etc.) and build a network of willing participants who can implement projects to improve the resource. Watershed planning exists for two purposes:

1. Build a stakeholder network capable of thoughtfully discussing issues and forming partnerships to implement on-the-ground projects.

2. Develop a roadmap, or plan document, with solutions to improve a resource of concern.

Resource of Concern *(noun)*
A resource of concern is...an expected degradation of the soil, water, air, plant, or animal resource base to an extent the sustainability of intended use of the resource is impaired.

- Natural Resources Conservation Service

These two processes of watershed planning are critical to efficiently, cost effectively, and permanently improve resources concerns. Watershed planning is also considered an iterative process and uses an adaptive management framework to self-evaluate and restructure future activities based on the outcomes of previous activities. For example, we developed a process model that helps describe this watershed planning effort and the steps needed to develop the plan, as well as future considerations to strengthen the plan when it is ultimately implemented (Figure 6).

First, we convened a stakeholder network to create momentum for improving water quality and to provide qualitative data; we also performed broad data analyses to refine our understanding of the major water quality problems within the watershed. Further discussions by the stakeholder groups led to further data analyses, which narrowed the focus of our planning efforts to specific issues that can be effectively addressed by the stakeholder group. This included a list of water quality impairments, the potential sources of these impairments, and how widely these impairments are distributed throughout the watershed. Eventually, our understanding of water quality problems progressed to a point where we were comfortable making recommended management changes to improve the problem. This included identifying appropriate Best

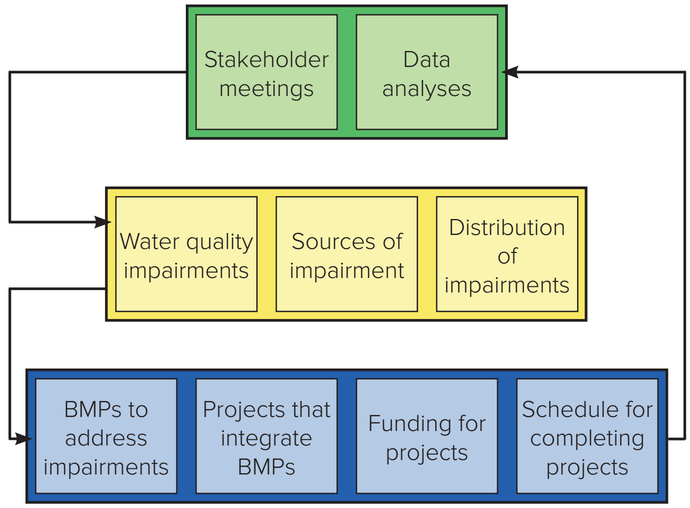

Figure 6: General process model for watershed planning.

Management Practices (BMPs) to address the impairments and, in turn, projects that could be implemented that incorporate the BMPs; identifying potential funding sources for these projects; and finally, determining the appropriate timeline for implementing these BMPs.

This process does not stop when the plan is implemented. It will be important for the local stakeholder groups to revisit these steps as project are implemented and data is collected. Based on additional data collected from implementation projects, it is likely that refinement of the recommendations will need to happen to achieve the ultimate goal of meeting water quality standards. These refinements will be based on funding availability, new scientific understandings, progress towards meeting water quality standards, and/or the willingness of stakeholders to implement the projects.

2.3 Previous Watershed Groups and Activities

There have been previous efforts by many different groups to improve a resource of concern at the watershed scale in the Lower Arkansas River Watershed. All of these groups and projects had one thing in common: building a broad stakeholder network with a common goal of making improvements to either soil or water resources.

Two of the more successful watershed plans previously developed are:

1. **Lower Arkansas River Watershed Plan (2008)**
   Core Team: Southeast Colorado Resource Development and Conservation, Tetra Tech

2. **Arkansas River Watershed Invasive Plants Plan (2008)**
   Core Team: Southeast Colorado Water Conservancy District, Bent County, Tamarisk Coalition

2.3.1 Lower Arkansas River Watershed Plan (2008)

The Lower Arkansas River Watershed Plan (developed in 2008 and hereafter referred to as the "2008 plan") was developed for the Lower Arkansas River Watershed from Pueblo, CO, to Kansas to improve water quality using an EPA 9-Elements watershed planning framework. In many ways, this first plan is the foundation on which the current plan is being built. There are a few key differences that make the two plans unique, but the approach and the resource of concern is the same.

The greatest difference between the two plans is the geographic extent. The 2008 plan defined the watershed area as the mainstem of the Arkansas River from Pueblo Reservoir to the state line and all tributaries feeding water to the mainstem (except Big Sandy Creek). This included the main tributary rivers such as the Purgatoire, Huerfano, and Apishapa; the 2008 plan also included Fountain Creek. This more current version of the Lower Arkansas River Watershed Plan – John Martin to State Line (also referred to as the "2018 plan") only extends from John Martin Reservoir to the state line, including all of the tributaries entering along this reach of river.

There are two critical reasons for the differences between these two plans. The first is the realization that the 2008 plan was considered by many to be too broad in scope. Essentially, the proposed actions from the 2008 plan were more general and all-encompassing instead of specific and targeted. And, although the entire Lower Arkansas River Watershed from Pueblo to the state line experiences similar

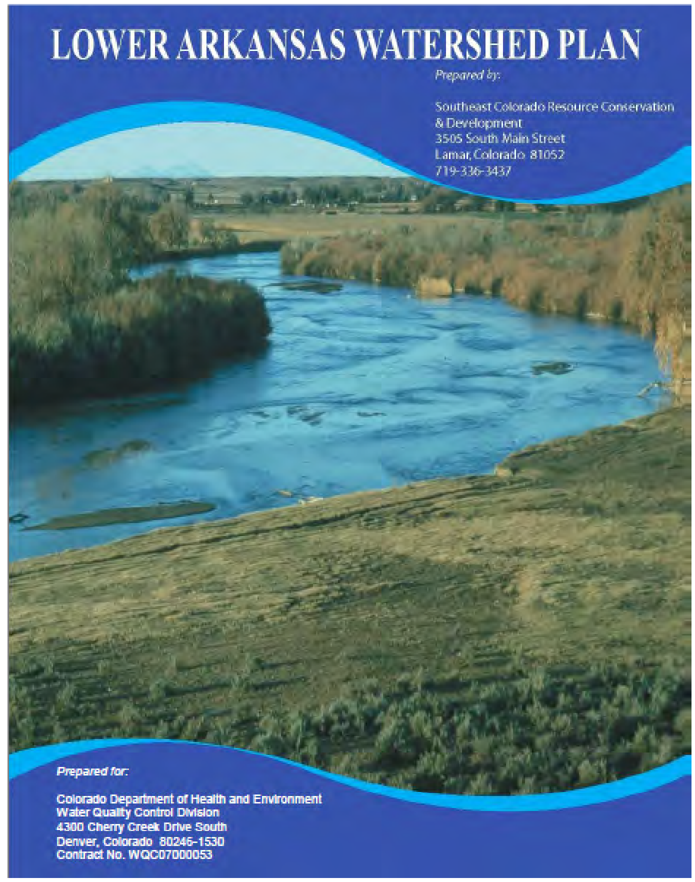

Figure 7: Lower Arkansas River Watershed Plan from 2008.

water quality problems, the solutions for remediating such problems can be highly specific depending on the location. The 2018 plan endeavors to be more specific in the sources of contamination and specifically identifies projects with willing stakeholders. This is achieved by shrinking the size of the watershed and giving the projects a better chance for success through more direct contact with stakeholders.

The second major difference between the two plans is the organizational structure for implementing the plan. The 2008 plan was developed by the Southeast Colorado Resource Conservation and Development group (SECRCD). Implementation goals for this group included creating a new watershed coordinator position within the SECRCD to oversee implementation of the projects. The 2018 plan is being developed by Colorado State University and will depend on local partners to implement specific parts of the plan. For example, the new plan will function much the same way the Arkansas River Basin Roundtable Basin Implementation Plan functions. Each entity is responsible for championing their own cause. This plan highly encourages local water management and conservation groups to use the information presented in this watershed plan in your organizational strategic planning. **This plan sets goals, estimates water quality benefits, and provides the first point of reference for technical and financial assistance requirements.**

Also included in the 2018 plan are more detailed water quality and load analysis, revised maps of 303(d) listed streams, and new stakeholder partnerships with specific projects to improve water quality. The 2008 plan and the 2018 plan are united by a 9-elements framework for improving water quality. Many watersheds throughout the state do not have successive plans from which to build, and the Lower Arkansas River Watershed is fortunate to have a new "version" of a 9-elements watershed plan. The 2018 plan also builds on research by a number of scientists and students from Colorado State University. These scientific investigations, which have been ongoing for nearly 20 years, have greatly increased our understanding of potential water quality pollution sources and how these pollutants are released into ground and surface water sources. Central to many of these research activities is the question, *How can water users and water managers adapt their management strategies to improve water quality?* The watershed has benefitted greatly from their work, and a more detailed description of the scientific investigations can be found in Chapter 5.

2.3.2 Arkansas River Watershed Invasive Plants Plan (ArkWIPP, 2008)

The Arkansas River Watershed Invasive Plants Plan (ArkWIPP) is a comprehensive management strategy for combatting invasive plants (primarily Tamarisk and Russian Olive trees). The plan extends to the headwaters of the Apishapa, Purgatoire, and Huerfano Rivers, and even Fountain Creek, but the majority of the plan focuses on reducing invasive plant populations in the Lower Arkansas River Watershed. This plan, though narrow in scope by only focusing on invasive plants, is a terrific example of watershed planning. The core planning team received stakeholder involvement from over 30 different organizations, including federal and state agencies, private landowners, industry, and non-governmental organizations. This broad stakeholder involvement is reflected in the plan, with projects created with unique partnerships. This plan is a great example of a well-executed watershed plan. For more information, visit **riversedgewest.org/events/arkansas-river-watershed-invasive-plants-partnership**.

2.3.3 Current Watershed Organizations

Watershed organizations, or groups with a mission to address resource concerns at the watershed scale, are critical for implementing watershed plans. These groups consist of stakeholders from different parts of the watershed who can act as champions for the plan and bring critical information and resources to their constituents. Watershed organizations usually have two organizational structures: 1) a formal group of stakeholders with diverse backgrounds interested in improving a resource of concern or 2) a central group with a singular focus of carrying out watershed-scale projects and usually working with many different resource concerns. Although southeast Colorado is not densely populated, at least three watershed groups work within the Lower Arkansas River Watershed (see Table 2).

Two of the groups, the Lower Arkansas Watershed Association and the Arkansas River Watershed Invasive Plants Plan, function like traditional watershed groups in Colorado. They rely on multiple organizations or Conservation Districts to facilitate and implement the priorities of the group. This approach has advantages—increased collaboration and multi-source funding opportunities, for example—and disadvantages, such as shared accountability and, often, reliance on volunteers. Conversely, the Arkansas River Watershed Collaborative (ARWC) is a single non-governmental organization with a specific mission to improve watershed health across the entire Arkansas River Watershed. The advantages of this approach include acting as a clearinghouse for watershed health education throughout the basin and creating wide-reaching partnerships. The disadvantages to this approach are the difficulty of engaging with local stakeholders and

Table 2: Specific groups working within the Lower Arkansas River Watershed with responsbilities in water health				
Watershed Organization	Date of Formation	Membership	Oversight	Focus Watershed
Lower Arkansas Watershed Association		USDA-NRCS Conservation Districts of: Powers, Baca, Spanish, Peaks-Purgatoir, East Otero, West Otero, Onley-Boone, NE Prowers, Kiowa	Colorado Association of Conservation Districts	Lower Arkansas River Watershed below Pueblo, CO
Arkansas River Watershed Invasive Plants Plan	2008	RiversEdge West, Purgatoire River Watershed Partnership, SE Colorado Water Conservancy District, Bent County	RiversEdge West, Puragtoire Watershed Partnership	Lower Arkansas River Watershed below Pueblo, CO, specifically the Purgatoire River
Arkansas River Watershed Collaborative	2015	Singular non-governmental organization	Board of Directors	Entire Arkansas River Watershed of Colorado

creating content and projects that may not apply to all parts of the watershed.

Regardless of approach, each organization has strengths to help implement watershed planning projects. For the successful implementation of the 2018 plan, local watershed groups will be key allies and on-the-ground advocates for the watershed health projects. ARWC can be a great asset for helping to bring the message of this watershed plan into a larger context and possibly used as a model in other parts of the Arkansas River Watershed.

Other regional water organizations, such as the Lower Arkansas Valley Water Conservancy District or Lower Arkansas Water Management Association, will be critical partners in helping to implement some of the goals of this watershed plan. However, these organizations have a broader scope of work than just watershed health; some of the projects they oversee may contain watershed health principles or aspects, but these organizations are not driven to exclusively address watershed health, unlike the watershed groups in Table 2.

2.4 Connection to the Colorado Water Plan

The Colorado Water Plan (CWP), the overarching plan for the state's water future, is a roadmap for identifying how to address Colorado's water challenges for the next several decades. The CWP focuses significant resources on addressing water quantity goals and water quality is discussed in lesser detail. This is partly due to the existing duties of the Water Quality Control Division in regulating the state's water quality. However, the CWP calls for more integrated cooperation between water quality and quantity agencies to better understand and address the interconnected relationship between water quality and quantity.

The CWP suggests several actions to improve the water quality/quantity nexus. Some of these include:

1. Address nonpoint sources through management activities and planning.

2. Pursue state funding of regional watershed-based water quality planning to better integrate future water-quantity efforts.

3. Assist Basin Roundtables in developing water quality goals, objectives and measurable outcomes.

4. Explore how entities can most efficiently and cost-effectively integrate the Clean Water Act requirements and Safe Drinking Water Act Requirements. Develop specific implementation recommendations.

5. Continue to fund nonpoint-source pollution management efforts.

6. Use a "watershed approach' for outreach and community engagement.

7. Refine future water quality goals and measurable outcomes by monitoring public attitudes and options about water quality.

In addition to the recommended actions CWCB suggests, several other goals and actions recommended by the CWP can be used to better understand and improve water quantity and water quality. They include goals for Alternative Transfer Method water sharing agreements, supporting innovative and collaborative science, establishing new opportunities to increase water storage (both surface and subsurface), and planning for shifts in the water-use landscape of Colorado. They suggest multiple funding source for accomplishing these goals, however, many of the funds are subject to appropriations and can vary from year to year. They include the Alternative Transfer Methods (ATM) Grant Program, Colorado Healthy Rivers Fund, Colorado Watershed Restoration Grants, and Water Supply Reserve Fund Grants. These grants can be used to implement water quality improvement projects like updating aging and leaky infrastructure, enhancing the filtration capacity of riparian environments, facilitating ATM projects, etc.

2.5 Regulatory Framework

For centuries, flowing water bodies have been perceived as an effective "solution to pollution." At its most basic, flowing waters such as rivers and streams can be used as a transport mechanism to carry away non-desirable constituents (such as chemical pollution or even sediment). However, when too many non-desirable elements or materials are added the water, often from many different sources, the ability of the river to function and provide clean water to downstream users becomes compromised. For this reason, the regulation of water quality often occurs at many levels of government.

As early as 1948, the federal government instituted the Federal Water Pollution Control Act (US EPA). In 1972, amendments to the Federal Water Pollution Control Act:

- established the basic structure for regulating pollutant discharges into the waters of the United States;
- gave the EPA the authority to implement pollution control programs, such as setting wastewater standards for industry;
- maintained existing requirements to set water quality standards for all contaminants in surface waters;
- made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions;
- funded the construction of sewage treatment plants under the construction grants program; and
- recognized the need for planning to address the critical problems posed by nonpoint source pollution.

These amendments are more commonly known as the Clean Water Act (CWA). The CWA gave the federal government broad license to define water quality standards for the US, but some of the implementation and regulation authority was allocated to individual states. This approach is appropriate given the broad needs and varying environmental conditions of individual states.

Section 303(d) of the CWA requires individual states to make a list of water bodies (lakes/reservoirs and streams) that do not meet water quality standards. The phrase "not meeting water quality standards" has proven to be highly subjective and, therefore, criteria has been established for listing water bodies on the 303(d) list. In Colorado, the 303(d) list is provided in **Regulation 93**, and this regulation is typically updated every two years. The methodology criteria used for determining the listing status of all waterbodies is also revised and updated in-preparation for the biennial Regulation 93 review (Water Quality Control Division, 2015). Regulation 93 also establishes Colorado's list of water quality limited segments requiring TMDLs.

Regulation 93 can be considered, in part, a compilation of water bodies not meeting state water quality standards. In Colorado, the general water quality standards for state water is presented in **Regulation 31**. Regulation 31, first developed in 1979, sets the basic water quality standards and methodologies for water quality assessment for the entire state of Colorado. In addition to this statewide approach to basic water quality standards, the state also implements basin-specific regulations that address the diverse needs of Colorado's different river systems.

In the Arkansas River Watershed, **Regulation 32** is the basin-specific water quality addendum to Regulation 31. This regulation lists the exact water quality standards for specific waterbodies within the entire Arkansas River Watershed and helps determine permitting allowances and load allocations given the specific beneficial uses of water in the basin. Regulation 32 pays specific attention to individual river/stream segments, including high-order reaches of the main stem of the Arkansas River and its tributaries. For example, the main stem of the Arkansas River has specific standards from John Martin Reservoir to the state line (segment COARLA01C) and different standards for the main stem from the Colorado Canal headgate to John Martin Reservoir. This shows the flexibility, but also the level of detail, in Regulation 32.

2.5.1 Regulation 85

In addition to the basic water quality standards of Regulation 31 and the standards of Regulation 32 specific to the Arkansas River, other regulations exist, most of which pertain to point source dischargers or water distributors. **Regulation 85**, on the other hand, has the potential to significantly affect non-point sources of pollution, including stormwater, agriculture, and land-use practices. Because this Lower Arkansas River Watershed Plan is concerned with limiting non-point source pollution, this regulation must be discussed in greater detail.

Regulation 85 is called the "Nutrients Management Control Regulation." This regulation, adopted in 2012, identifies nutrients (specifically nitrogen and phosphorus) as pollutants that often do not meet state water quality standards. For this reason, the state of Colorado is encouraging water users and land managers *"…to adopt and implement/install Best Management Practices (BMPs) to the maximum extent practicable to reduce nutrient loads from such sources"* (Water Quality Control Division – Regulation 85 (2012)).

However, the language of this regulation also states, *"…after May 31, 2022 the commission may consider adopting, in consultation with the commissioner of agriculture, control regulations specific to agricultural and silvicultural practices if the commission determines that sufficient progress has not been demonstrated in agricultural nonpoint source nutrient management."*

This language in Regulation 85 is encouraging for non-point source contributors, including irrigated agriculture, because it grants ten years from the year of adoption (three years as of the writing of this plan) for sufficient progress to be made through the voluntary adoption of BMPs. Part of this Lower Arkansas River Watershed Plan describes nutrient management options and how they can be used as a BMP to improve water quality. Regulation 85 is an open regulation and all water users—and specifically those who possibly contribute to non-point source pollution—should remain informed of the latest Regulation 85 information.

Chapter 3

Watershed Characterization

3. SUMMARY

Watersheds are best described using the analogy of a bathtub; all of the water that falls inside the bathtub eventually leaves through one common point, the drain. Similarly, the Lower Arkansas River Watershed – John Martin to State Line is a watershed roughly the size of Connecticut and Delaware combined and is about 7% of the land area of Colorado. All of the water that falls within the watershed (including some water from the western slope brought to the Arkansas River via trans-mountain diversion, but not important for the purposes of this description) will (theoretically) leave this watershed in the Arkansas River at the border with Kansas. Some of the water, however, will never make it this far and is used by plants and animals or evaporated into the atmosphere. But if each water molecule continued, unobstructed, it would eventually reach the Arkansas River and leave the state at the border with Kansas.

It is through this hydrologic connection that all of the rivers and streams in the watershed can be considered linked. Many of the land use practices and native ecosystems are common throughout the watershed, but a great amount of diversity also exists, and all land uses within the boundaries of the watershed could have an impact on the extensive stream network.

The Lower Arkansas River Watershed from John Martin to the state line is a diverse watershed with several different land and water uses and a variety of demographics, historical and cultural resources, wildlife, and biodiversity. However, the diversity in the watershed is not immediately apparent simply because of the size of the watershed—nearly 8,000 square miles—and the homogeneity of the visual landscape.

A diverse mix of water uses occur, including irrigated agriculture, ecosystem function and wildlife habitat, municipal drinking water, industrial manufacturing, power generation, and livestock watering. A diverse set of land cover classes exist within the watershed, including native range/shrubland, irrigated and dryland agriculture, developed urban areas, and mixed riparian forests, among others. The same is true for land ownership: the majority of land is privately owned, but other landowners include the State of Colorado, the Department of Defense, the US Forest Service, and the National Park Service. The following sections better highlight this multifaceted diversity throughout the watershed.

Figure 8: Aerial view of the Arkansas River with healthy riparian vegetation, stable channel morphology, and adjacent productive agricultural fields. Photo courtesy of Bill Cotton, Colorado State University.

3.1 Watershed Location

The Lower Arkansas River Watershed – John Martin to State Line is the furthest downstream river segment in Colorado's Arkansas River Basin. Some of the larger towns in the watershed include Las Animas, Lamar, Eads, Holly, and Limon. The watershed

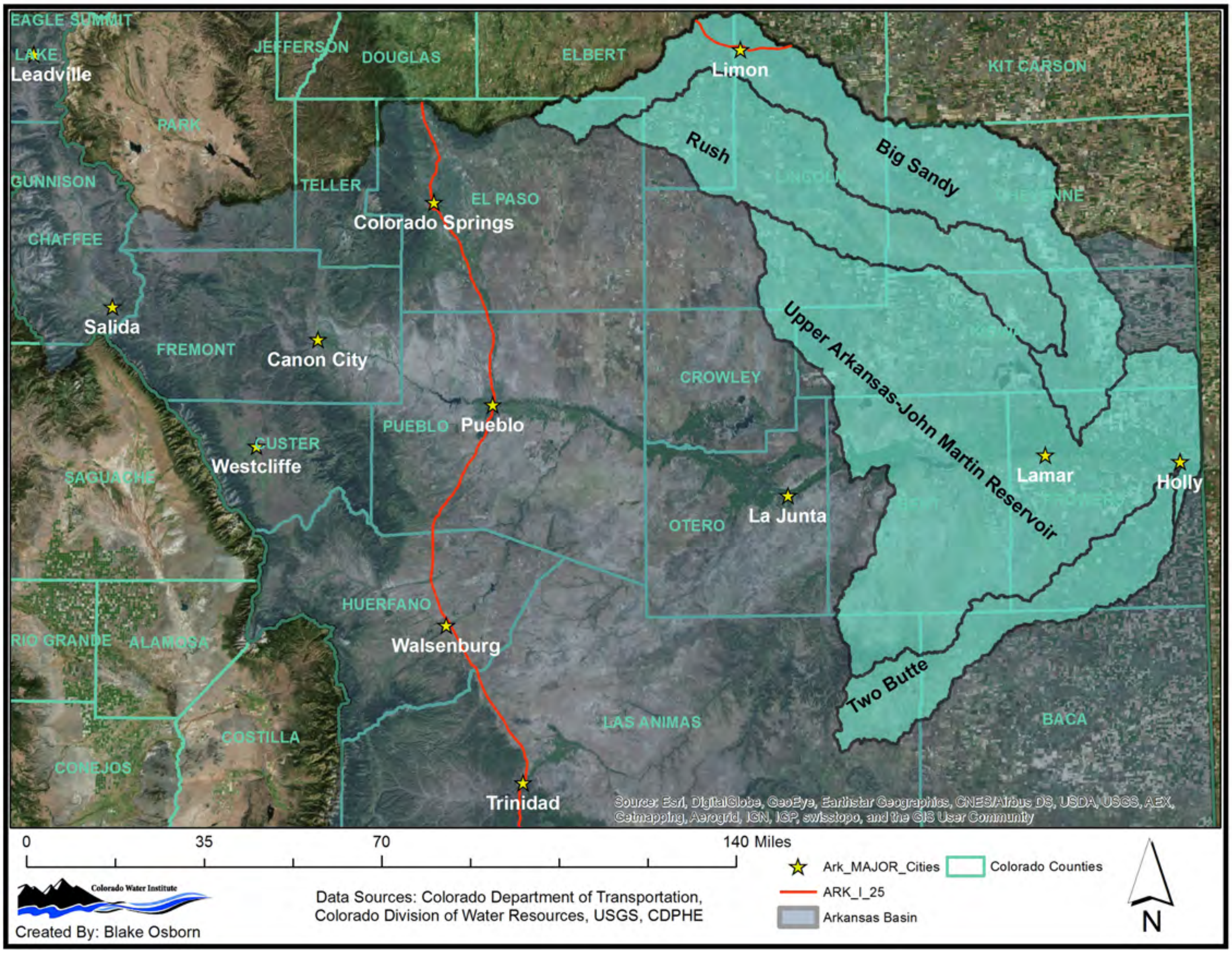

Figure 9: Location of the lower Arkansas River Watershed – John Martin to State Line in relation to the larger Arkansas River Watershed of Colorado.

extends north to the town of Limon and south to Las Animas County and starts just east of the town of Las Animas and extends west to the state border with Kansas (Figure 9). The watershed includes many surface water bodies, including the John Martin Reservoir, Adobe Creek Reservoir, Nee Gronda Reservoir, the Arkansas River, and Big Sandy Creek, among many other smaller tributaries.

The watershed includes four main "sub-watersheds": 1) Upper Arkansas – John Martin Reservoir, 2) Big Sandy, 3) Rush, and 4) Two Buttes (Figure 7). These four smaller sub-watersheds were chosen for this plan because they encompass the main stem of the Arkansas River from John Martin Reservoir to the State Line as well as all of the major tributaries that contribute water to the river from John Martin to the state line. This gives us the ability to analyze water quality below John Martin Reservoir from all potential sources, including upland tributary sources.

This watershed, like many high plains watersheds in Colorado, presents challenges to understanding the hydrologic connectivity between many of the tributaries and the river. Undoubtedly, a hydrologic connection exists to some degree when one accounts for alluvial groundwater, but many of the streams are ephemeral and do not flow continuously. With this understanding, the watershed team determined priority zones for this watershed plan with a primary focus on the water quality of the Arkansas River. As such, much of the plan is dedicated to understanding the contribution of pollutants to the river from adjacent agricultural practices, which line much of the north and south river floodplain. This, and the amount and quality of data, helped to steer the focus of the watershed plan. Most of the data analyses and potential water quality improvement projects are located within this region of the watershed.

3.2 Watershed Features

3.2.1 Climate of Arkansas River Basin

Globally, climate trends are mostly driven by latitude, altitude, and proximity to large water bodies. The Lower Arkansas River Watershed is located in a high plains ecosystem with a large mountain range to the west, with rain shadow affects, and no large water bodies in close proximity. The watershed is relatively homogeneous in elevation, but it is located east of the Rocky Mountains and a considerable rain shadow effect is observed based on topographic features to the west. Most of the precipitation that falls in the watershed originates in the Pacific Ocean (and falls consistent with El Niño/Southern Oscillation "monsoon" patterns) or the Gulf of Mexico.

The Arkansas River Basin, Colorado's largest single river basin, is divided into two primary regions: 1) the upper Arkansas River valley, which encompasses the land and waters above Pueblo Reservoir, and 2) the lower Arkansas River valley, encompassing the land and waters below Pueblo Reservoir (including the major tributaries of the Huerfano, Purgatoire, and Apishapa). The majority of the precipitation for the entire watershed falls as snow in the upper Arkansas River valley.

The evaporative demand in the Lower Arkansas River Watershed exceeds average yearly rainfall events in most years. For this reason, this watershed can be considered "water negative" when computing

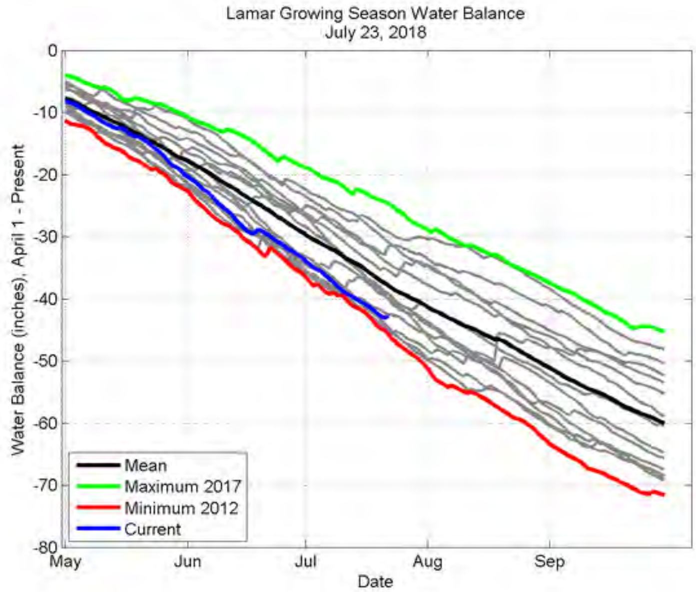

Figure 10: The climate of the Lower Arkansas River Watershed – John Martin to Stateline is considered a net "water deficit" region with fewer water inputs than evaporative demands. The growing season water balance (April-October) averages -60 inches of water for well watered alfalfa fields.

a simple hydrological water balance (Figure 10). To offset this "water negative" condition, many water uses (such as growing crops and providing municipal drinking water) are only achievable through supplemental water sources from the Arkansas River and are therefore dependent on precipitation that falls outside of the Lower Arkansas River Watershed, but still within the larger Arkansas River Basin (or trans-mountain diversion watersheds on the western slope of Colorado).

The climate of the Lower Arkansas River Watershed can generally be classified as semi-arid with relatively little precipitation and low humidity. The temperature can fluctuate by as much as 140 degrees Fahrenheit in a given year, with summer temperatures occasionally reaching triple digits and winter lows well below zero. The entire watershed, independent of cardinal direction, receives similar amounts of yearly precipitation, which averages 13.5-15.5 inches annually.

The sun drives the energy balance with hot summer days that give way to cool summer nights. Some

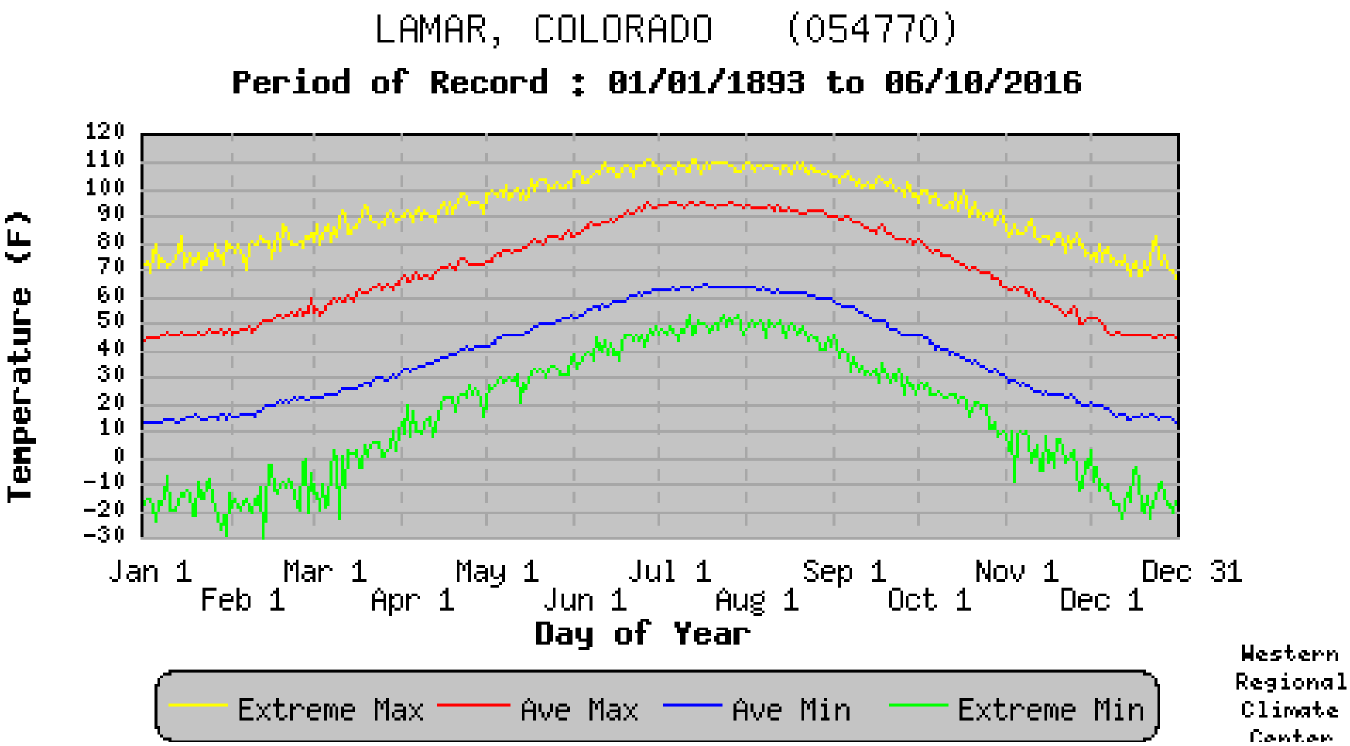

Figure 11: Annual temperature averages for Lamar, CO.

agricultural commodities, like melons and peppers, respond positively to this diurnal fluctuation in temperature. Farmers and scientists agree this temperature fluctuation promotes a response in fruiting plants (corn, melons, peppers, etc.) to increase sugar production and therefore creates a sweeter and more desirable fruit. Most agricultural commodity crops, however, would not exist in this watershed without supplemental irrigation from the Arkansas River and its tributaries. The combined factors of low humidity, high temperatures, and relatively strong winds contribute to high evaporative demand and therefore high crop water uses.

Lamar, CO (elevation: 3,630 feet), is the most centrally located and largest city in the watershed and experiences temperatures as high as 111 °F and as low as -30 °F (Figure 11). Based on available data from 1893 -2012, there are 79 days each year, on average, when the temperature in Lamar is above 90 °F and roughly 16 days every year when daily maximum temperature never gets above 32 °F. On average, Lamar has 209 frost-free days each year. Most of Lamar's precipitation falls from May through August and averages 15.2 inches per year (Figure 12). 2012 is the driest year on record for Lamar; only 7.53 inches of precipitation fell. This annual precipitation total rivals that of the Dust Bowl period (7.73 inches in 1931, 7.67 inches in 1937, and 9.68 inches in 1939). The wettest year on record is 2006, with an annual total precipitation amount of 26.2 inches, more than 10 inches above the yearly average. The relatively wet years of 2015 (24.0 inches) and 2017 (21.8 inches) helped to ease the effects of the 2012 drought by increasing soil moisture levels, recharging shallow aquifers, and making water available for storage in reservoirs.

In Limon, CO, the northernmost city in the watershed, the climate is milder. The highest temperature recorded in Limon is 103 °F in June of 2012, and the lowest observed temperature is -26 °F in February of 1961 (data from 1948-2012). Limon, on average, has only 174 frost-free days. Average annual precipitation amounts are slightly less than Lamar, at 13.7 inches of moisture; the timing of moisture is similar, with most falling in the late spring and summer months. Limon has received

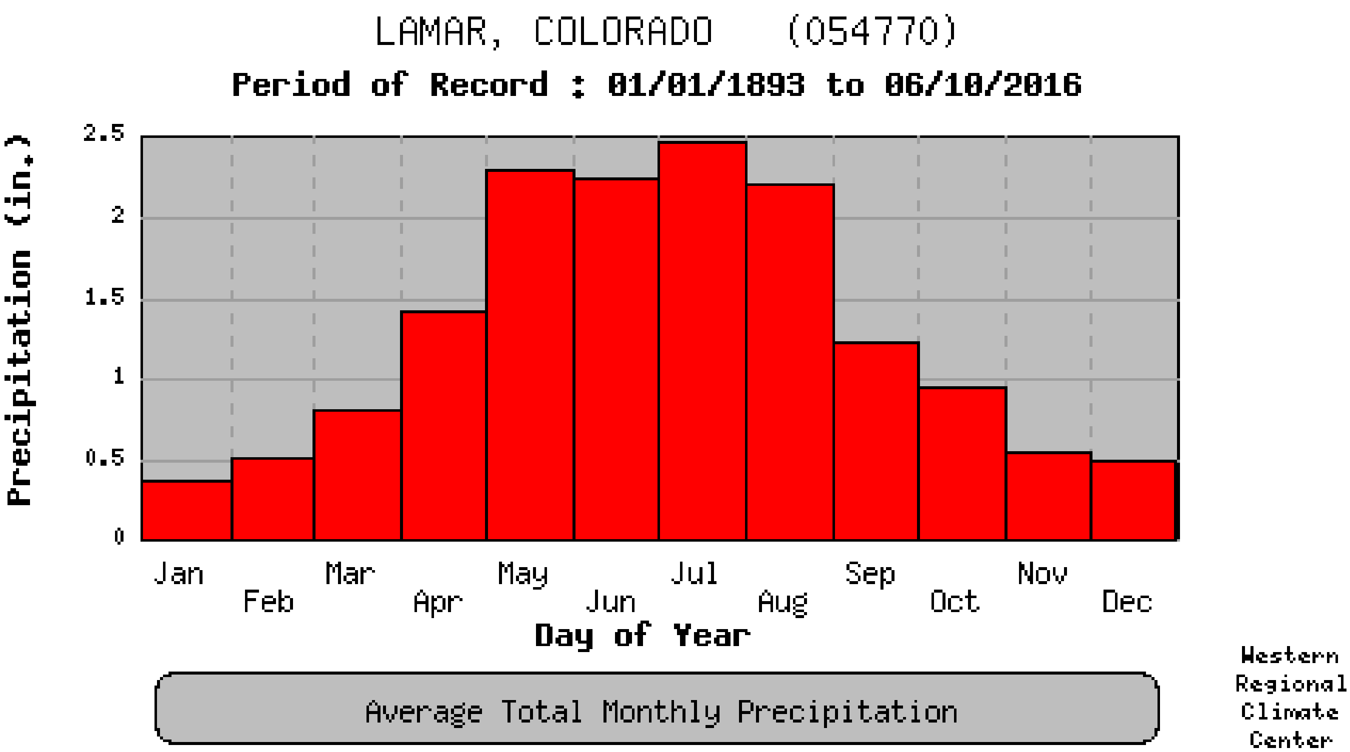

Figure 12: Monthly precipitation averages for Lamar, CO.

as much as 23.8 inches of annual moisture (1967) and as little as 7.8 (1954).

The southern extent of the watershed, mostly the sub-watershed of Two Buttes Creek, has a very low population density and very few towns. Weather data from 1900-1972 was observed and recorded at the current site of the Two Buttes Reservoir. During this period, the highest observed temperature was 111 °F (1902 and 1903), and the lowest observed temperature was -25 °F in 1949. On average, there were more than 215 frost-free days at this location and 15 days during which the temperature did not get higher than 32 °F. The average annual precipitation for this location was 13.9 inches, with the driest year being 1953 (8.0 inches) and the wettest being 1941 (31.5 inches).

3.2.2 Water administration

The surface waters of the state of Colorado are considered a public good—a resource owned by the people of Colorado. However, this resource is subject to use by public and private entities using a system of prior appropriation. This administrative system issues water rights (sometimes called a usufructuary right and often compared most closely with a private property right) to use this public resource for a "beneficial use." Beneficial uses can include crop irrigation, wildlife habitat, power generation, snow making, municipal drinking water, and many other examples.

In Colorado, a water court determines if the water will be used beneficially. Once a water right is given, it is the responsibility of the Colorado Department of Water Resources (DWR) to administer the waters. The DWR is sub-divided into administrative units based on the major river basins of Colorado. Much like a watershed plan, these administrative units focus on water issues within a specified basin and use water districts to closely manage water rights under the hydrologic conditions of a particular time and place.

The Lower Arkansas River Watershed Plan is confined to DWR Division 2 and Water District 67. It is no coincidence that this watershed plan and Water District 67 overlap almost entirely; this area is geographically large and hydrologically connected through major tributaries. District 67 includes the major tributaries of Rush, Big Sandy, and Two Buttes Creeks as well as John Martin Reservoir. And although the DWR is specifically concerned with administering the state's waters on the basis of quantity, water quality should be included in any future discussions of water quantity administration. At the very least, the District and the DWR could support activities that lawfully use water resources (under prior appropriation and Arkansas River Compact obligations) and include water quality benefits. For a more detailed description on water administration in the watershed, see Chapter 4: Water Use.

3.2.3 Water Sources

It is presumed that much of the water flowing in the Arkansas River within the Lower Arkansas River Watershed originated far outside of the watershed. No studies exist as to the fraction of water from different climatological sources (i.e., snow vs. rain), but it is likely that most of the water in this watershed originated as snow in the headwaters region. The Lower Arkansas River Watershed is a closely managed river system, and the river, with its tributary groundwater connection, provides the largest source of water for beneficial uses in the watershed.

The Arkansas River headwaters region includes the tallest peak in the state, Mount Elbert, on the Continental Divide. From its source in Chaffee, Lake, and Fremont Counties, the Arkansas River flows approximately 127 miles before entering John Martin Reservoir and the Lower Arkansas River Watershed. Over the course of its journey from the headwaters, the river changes in many ways. Water quality, channel morphology, and riparian habitats change significantly as the river moves from the mountainous headwaters to the plains.

Many tributaries to the Arkansas River can be found near or below John Martin Reservoir: Big Sandy Creek, Two Buttes Creek, Caddoa Creek, Mud Creek, Wildhorse Creek, Cheyenne Creek and many others. The natural creeks, however, are not the only surface water sources returning water to the Arkansas River. Several irrigation drainage ditches also function similar to natural creeks by conveying water back to the river via open channels.

As mentioned above, the Lower Arkansas River Watershed is a closely managed river system. The largest reservoir in the watershed (and the only on-stream reservoir), John Martin, allows water managers the flexibility to store water in water accounts according to water user. John Martin Reservoir is also a critical and necessary tool for administering the Arkansas River Compact between Colorado and Kansas. And, it provides important wildlife habitat—the reservoir is a well-known migratory stop for several bird species—and is a world-class warm water fishery.

3.2.4 Hydrology

The Arkansas River is considered a "hard working" river: there are many water demands, mostly for agriculture, and typical hydrologic conditions of the basin are a limiting factor in the amount of water available for use. **In most years, and at certain times throughout the year, the Arkansas River is an over-appropriated river, meaning there is more demand for water than the river can supply.** Many of the water rights in the Lower Arkansas River Watershed are used for irrigated agriculture.

In addition to the surface water streams and alluvial aquifers, lakes and reservoirs fulfill a critical function for environmental and administrative water needs. The five largest reservoirs in the watershed are John Martin, Adobe Creek, Nee Noshe, Nee Sopah, and Nee Gronda. These reservoirs provide critical wildlife habitat for migrating bird species as well as riparian oases for terrestrial wildlife species. These lakes and reservoirs also boast world-class fisheries with some of the largest warm-water fish species found in Colorado (Colorado Parks and Wildlife, 2018). For a more detailed description of the surface water bodies please refer to the following subsections or Chapter 4: Water Use.

3.2.4.1 Main Stem of the Arkansas River

A 16-year average of streamflow (2000-2015) shows water levels in the Arkansas River vary greatly by reach. Immediately below John Martin Reservoir, average peak flow is 900 cubic feet per second (cfs) on July 1. Further downstream (near Lamar and Grenada), the river is reduced to average peak flows of roughly 425 cfs, also occurring in early July. This significant decrease in flow between John Martin Reservoir and Lamar is likely attributable to agricultural diversions for irrigation. This decrease in flow can also significantly impact water quality by reducing the rivers ability to accept pollutant loads and maintain water quality standards. More research is needed to quantify loading from subsurface groundwater sources within this reach.

3.2.4.2 Tributaries

The tributaries of Wild Horse Creek and Big Sandy Creek are monitored for flow by the USGS. Wild Horse Creek is monitored year-round while the flow gauge on Big Sandy Creek is monitored seasonally from April through November. In both tributaries, average annual flows from 2000-2015 show a significant hydrological response from large precipitation events, represented by large spikes in the hydrograph.

Big Sandy Creek is a major tributary watershed to the Arkansas River. The USGS flow station is located at the terminal part of the creek near its confluence with the Arkansas River. This watershed is 1,851 square miles, and Big Sandy Creek is 204.59 miles in length. This creek is typical of many high plains streams, with hydrological disconnection between segments at the surface resulting in partially ephemeral and perennial segments of the same stream (Martin and Noon, 2011). Flows in Big Sandy creek average 6-12 (median 6.7) cfs much of the year, with higher flows occurring during large rainfall events. Big Sandy Creek dries up routinely, with several days with no measurable flow. The highest flow value from 2000-2015 is 220 cfs. Firsthand accounts from residents of the upper Big Sandy watershed indicate the stream is dry most years, with some segments flowing seasonally and others only during large precipitation events.

Wild Horse Creek is a smaller tributary on the north side of the Arkansas River just above Holly, CO. This creek bisects the Amity Canal roughly eight miles north of Holly, CO, and runs adjacent to many irrigated agricultural fields until it meets the Arkansas River. The average annual hydrograph for Wild Horse Creek shows higher sustained flows during late May and early June (during the irrigation season), and again in late October and early November. The increased spring flow is likely a result of groundwater feeding the stream. A late season increase in flows could be a similar groundwater base flow signal from agricultural subsurface return flows. Both surface and subsurface agricultural irrigation return flows, including water seeping from the Amity Canal, could be a large contributor of water to this creek. This is only a hypothesis, and more research is needed to better understand the hydrologic characteristics of this creek.

3.2.5 Groundwater Sources

Groundwater in Colorado can generally be divided into two categories: tributary and non-tributary. Tributary and non-tributary groundwater are significant sources of water used in agriculture, as drinking water, or for augmentation supplies to fulfil water rights obligations.

Tributary groundwater is subsurface water that is “hydrologically connected” to a surface water source, either a stream or lake. The tributary aquifers of the Lower Arkansas River Watershed are typically shallow (Konikow and Bredehoef, 1974), ranging from 0-65 feet, or more in some cases (Gates et al., 2015). These shallow groundwater sources are replenished by natural rain events and inefficient irrigation practices that leach water below the root zone. These waters are a vital component to the Lower Arkansas River Watershed hydrologic system, and many water users depend on these subsurface flows returning to the river. Perhaps most importantly is that tributary groundwater is administered under the prior appropriation doctrine.

Therefore, changes in return flows from pumping and using this alluvial groundwater, including subsurface return flows, must be “augmented” (replaced) in timing and amount to ensure downstream water users are not injured (Figure 13).

Tributary sources of groundwater in the Lower Arkansas River Watershed create significant loading sources of selenium, uranium, and salts (Cain 1985, Mueller et al., 1991; Miller et al., 2010; Gates et al., 2015). The position of the groundwater in relation to

Table 3: Named creeks, streams, and ditches/canals with associated linear lengths in miles.

Stream Name	Stream Length (miles)	Ditch/Canal Name	Canal/Ditch Length (miles)
Adobe Creek	20.1	Adobe Creek Reservoir Outlet Ditch	0.8
Antelope Creek	12.6	Amity Canal	24.2
Arkansas River	76.3	Buffalo Canal	4.7
Big Sandy Creek	62.4	Chenoweth Lateral	1.5
Big Spring Creek	8.8	Comanche Canal	4.5
Brown Creek	5.9	Consolidated Ditch	2.7
Caddoa Creek	15.7	Consolidated Extension Ditch	2.3
Clay Creek	10.0	Deadman Ditch	2.2
Dry Creek	12.4	Fort Bent Canal	8.6
East Mud Creek	5.4	Fort Lyon Canal	28.5
	6.1	Fort Lyon Storage Canal	3.4
Granada Creek	7.6	Grenada Ditch	1.7
Horse Creek	5.1	Holly Ditch	3.5
Long Branch Creek	9.8	Jones Ditch	1.5
Long Creek	5.5	Keesee Canal	2.3
Middle Plum Creek	5.5	Kicking Bird Canal	9.5
Middle Rush Creek	11.6	Lamar Canal	6.3
Mud Creek	13.5	Las Animas Town Ditch	1.6
Muddy Creek	6.6	Lone Wolf Canal	1.2
Mustang Creek	22.5	Lubers Ditch	0.7
North Butte Creek	11.9	Lubers Drainage Ditch	0.9
North Rush Creek	13.6	Manvel Canal	3.2
Ou Creek	3.5	Marburg Ditch	2.7
Pass Creek	3.6	McClave Drainage Ditch	1.1
Plum Creek	7.2	North Grenada Ditch	1.8
Rule Creek	20.7	Pleasant Valley Drainage Ditch	1.5
Rush Creek	32.0	Riverview Ditch	1.6
Sand Arroyo - Adobe	11.1	Satanta Canal	3.8
South Rush Creek	15.2	Sisson Canal	1.5
Two Butte Creek	54.8	Sunflower Ditch	1.5
un-named	713.2	Swede Lateral	1.5
West Mud Creek	7.3	Vista Del Rio Ditch	3.8
Wild Horse Creek	22.3	West May Valley Drainage Ditch	4.0
Willow Creek	6.1	Wiley Drainage Ditch	3.1
Willow Gulch	5.9	X-Y Canal	4.6
Wolf Creek	11.0		

shale bedrock formations allows for the weathering of the bedrock and the release of these pollutants. The hydrologic gradient, or physical relationship among connected water bodies, often allows these contaminated waters to percolate towards, and ultimately connect with, the surface water bodies, including the Arkansas River.

Non-tributary groundwater resources also exist within the Lower Arkansas River Watershed. These groundwater aquifers are considered non-tributary because they are hydrologically disconnected from surface water sources. Non-tributary groundwater can be thought of as an underground reservoir, or bathtub, that accumulates and stores water. These groundwater resources can be deep below the surface of the earth and slow to recharge (Figure12, Colorado Groundwater Atlas).

3.2.6 Geology

The Lower Arkansas River Watershed is underlain with many different bedrock materials, most of which are Cretaceous sedimentary rocks made from a variety of parent materials. The most common formations are the Pierre, Carlile, Smoky Hill, and Graneros shales (Figure 15); the Fort Hayes and Greenhorn limestone; and the Dakota Sandstone (Scott 1968; Sharps 1976).

Most of the shale layers were formed during the Late Cretaceous Period (Colorado Groundwater Atlas, 2000) when an inland sea engulfed much of North America, including the present Lower Arkansas River Watershed, and the climate was subtropical-humid. These shale formations are a sedimentary byproduct of mud and fine particles that were cemented over time to form bedrock. These shale bedrock formations also contain the elements selenium and uranium and represent the largest source of these two elements into the waters of the Lower Arkansas River Watershed. Selenium, and likely uranium, are found in these formations because of the volcanic origins of this area (Ihnat, 1989).

Volcanic dusts and gases were deposited during cretaceous volcanic events (Miller, 2010). Selenium is the

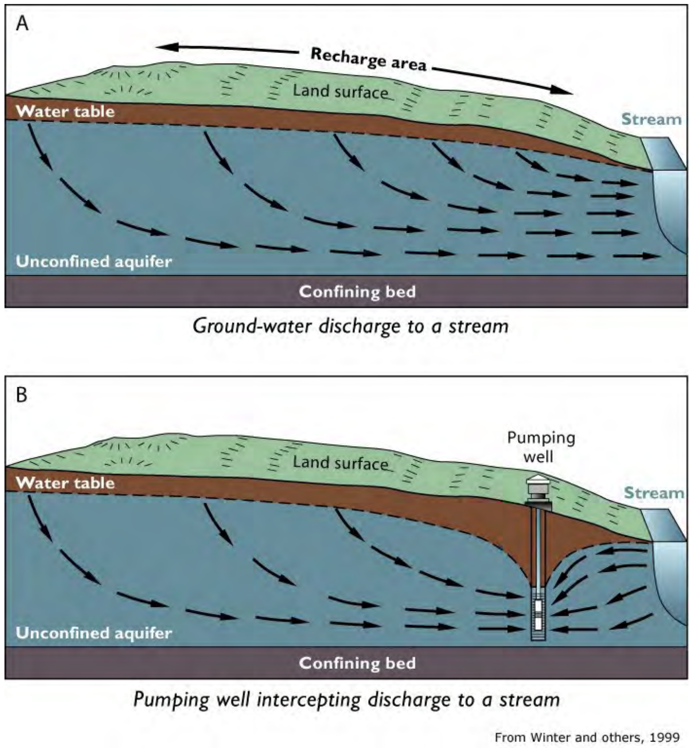

Figure 13: Influence of well pumping on tributary groundwater can create a cone of depression and, in some cases, significantly influences surface flows. Source: Winter et al., 1999 via the Colorado Groundwater Atlas.

most widespread water pollutant in this watershed, and it is widely believed that the source of this selenium is the various shale bedrock formations formed during the volcanic Cretaceous Period. As early as the 1940s, researchers were making links between the presence of Cretaceous sedimentary rocks and the elevated levels of selenium in soils derived from these parent materials (Lakin and Byers 1941).

Uranium, however, is not limited to shale formations and is often found in many different geologic formations, including igneous granite. Uranium levels have been observed as high as 60 parts per million (ppm) in the Pierre Shale (Landis, 1959). Some work has been done to explain the specific sources of uranium throughout the entire Arkansas River Watershed, however more research is needed to clarify the amount of selenium and uranium in each bedrock formation. It is likely that some formations would be considered

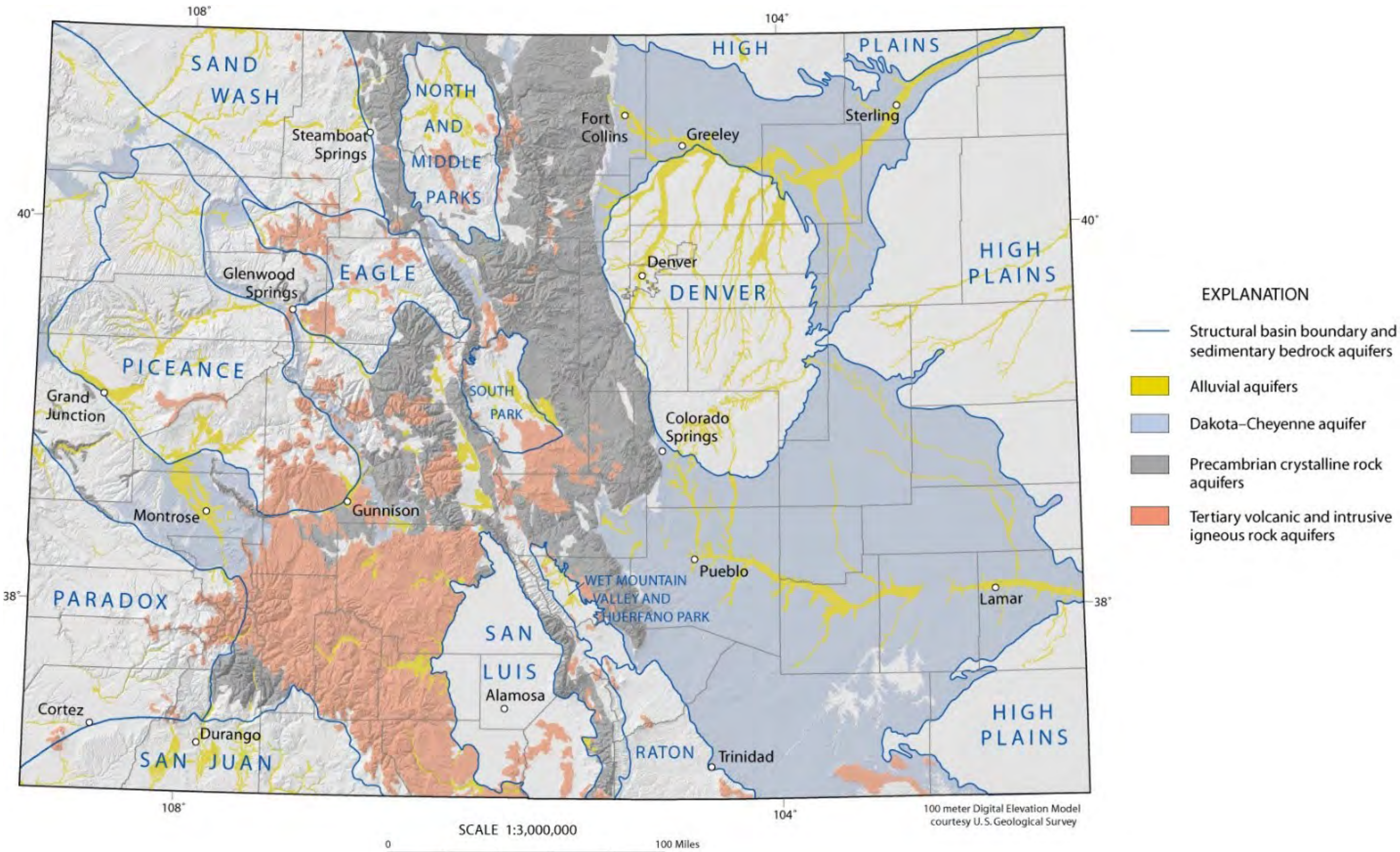

Figure 14: Locations of different aquifers in Colorado, including tributary groundwater aquifers. Source: Colorado Groundwater Atlas.

"hot," with higher concentrations of both selenium and uranium.

The northern- and westernmost areas of the watershed also contains part of the Fox Hills, Laramie, and Denver Formations, a mixture of sandstones and shales that hold water and serve as important water sources for rural water users in this area. These formations are part of the Denver-Julesberg Basin. This underground basin is considered a Designated Groundwater Basin by the state of Colorado, and the administration of water from this basin is closely regulated by the Division of Water Resources. Within the watershed, the Upper Big Sandy Ground Water Management District was formed in 1992 to oversee the permitted use of waters extracted from the designated groundwater basin. For more information on the regulations of pumping water in the Denver Basin, visit the Colorado Groundwater Commission website at **water.state.co.us/groundwater/CGWC/Pages/default.aspx.**

3.2.7 Geomorphology

The surface landscape geomorphology of the Lower Arkansas River Watershed is typical of many high plains landscapes with rolling hills, buttes, and stream valleys. Much of the Arkansas River Watershed, including parts of the upper watershed, overlie the Colorado Piedmont. The Colorado Piedmont is considered an "erosional inlier" (Madole, 1991), meaning it is a collection of Miocene rock formations and has a surface that is topographically lower than the surrounding regions (Madole, 1991). This formation is exposed because the Ogallala Formation (here used to describe a distinct rock formation, not a reference to the aquifer) was eroded by fluvial and Aeolian processes. All of the Arkansas River in Colorado

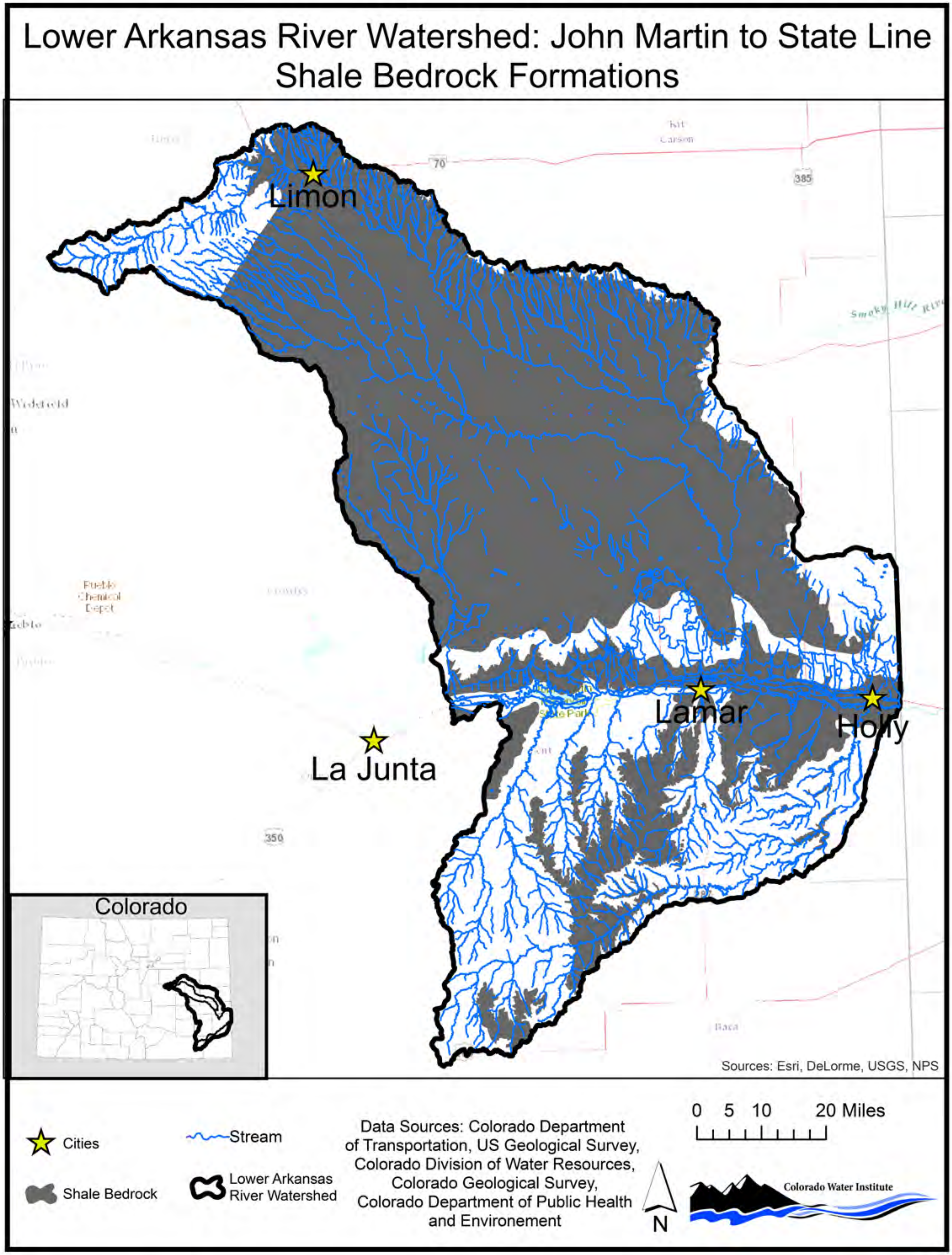

Figure 15: Spatial extent of shale bedorck formations as the primary rock type.

overlies the Colorado Piedmont. The Ogallala had once extended to the foothills of Colorado's Front Range, but erosion processes (including those by the Arkansas River) have stripped the Ogallala Formation from the Front Range region. It is estimated that the Arkansas River created the deepest erosional incision in the Ogallala formation, over 1,100 meters near present-day Rocky Ford, and now the surface is only Colorado Piedmont (Leonard, 2002).

3.2.7.1 Fluvial Geomorphology

The fluvial geomorphic features of the lower Arkansas River are driven by sediment transport, including deposition and erosion. Channel impediments are mostly in the form of woody debris; large boulders and cobble are less common in this plains watershed. The river inherits sediment from upstream sources, including Fountain Creek and the Apishapa and Purgatoire Rivers, but it also captures sediment eroded from within the Lower Arkansas River Watershed. The watershed contains sediment production (i.e., upper reaches of Big Sandy Creek), transfer (main stem of the Arkansas River), and deposition zones (floodplain). The sinuosity of the river increases as floodplain width increases, with the exception of bank stabilization efforts near cities, roads, and irrigation infrastructure. The river's floodplain meanders, and the current position of the river in the floodplain changes along the entire reach from John Martin Reservoir to Kansas.

Sediment transport and deposition can present problems for water administration in this watershed. First, landscapes with low elevation gradients (such as the Lower Arkansas River Watershed) are generally less prone to channel incision because the energy needed to incise the channel is dissipated when the floodplain widens. This allows sediment deposition to be a primary driver of channel placement within the floodplain. When sediment is a deciding factor in a channel's course, the river can migrate often and erode/deposit sediment, causing the channel to move.

This dynamic and migratory nature of channels in low-gradient elevations is problematic for fixed structures such as headgates, roads and bridges, water intake structures, and storm water infrastructure. Luckily, much of this impact is mitigated by John Martin Reservoir, which acts as a sediment sink.

Figure 16: Aerial view of John Martin Reservoir and Dam. Photo courtesy of Bill Cotton, Colorado State University.

John Martin Reservoir (JMR) has a large influence on the fluvial morphology of the Arkansas River. First, JMR can act as a sediment sink and, like most reservoirs, has a net increase in sediment over time. As of 2009, almost 102,000 acre feet of sediment had accumulated in JMR (USACE, 2018). Between 1942 and 1972, an estimated 81,756 acre feet of sediment was deposited in JMR, with approximately 58% of the total coming from the Purgatoire River. The dam's outlets are located near the bottom of the dam to make reservoir operations feasible in low water conditions, but the outlets themselves need occasional dredging, indicating the high amount of sediment JMR collects. Typically, the water coming out of JMR carries much less sediment, and turbidity is reduced as compared with the river above the reservoir. Personal conversations with large ditch/canal companies operating below JMR indicate this low-sediment water can be a problem because it more easily seeps through unlined ditches. However, turbidity increases downstream of JMR and requires some ditch/canal companies to dredge accumulated sediment.

3.2.8 Land Use and Ownership

A foundational piece of any watershed charac-

Figure 17: Cropping systems and livestock operations are closely connected in the Lower Arkansas River Watershed. Photo courtesy of Bill Cotton, Colorado State University.

terization is the analysis of land cover and working applications, sometimes called "land use." Land cover, the broad term used to analyze things happening on the land (both human-caused and natural), is a spatial depiction of the land use practices (i.e., irrigated agriculture or developed land in cities) and natural ecosystems (i.e., grassland or riparian forest). Land cover and climate could be considered the two primary drivers that make a watershed distinct. Many watersheds around the country, and even the world, share similar topographies and demographics, but land cover is unique because it is both a product of natural and man-made forces and activities.

Data to determine land cover in the Lower Arkansas River Watershed was gathered from two primary sources: 1) quantitative data was obtained from the National Land Cover Database (NLCD), and 2) qualitative data was obtained by current and historic photographs, anecdotal conversations with residents and land managers, and visual inspection.

3.2.9 Land Cover Descriptions

The most prevailing land cover classification in this watershed is the *Grassland/Herbaceous* cover type, which covers 5,358 square miles. This land cover type is typical for a high plains, shortgrass steppe ecosystem. This ecosystem consists of bunch and sod forming grass species such as blue and sideoats grama, buffalo grass, and western and wheatgrass, as well as many different forb species and succulent cacti. The second most prolific land cover classification, which also doubles as a "land use," is *Cultivated Crops*. This cover type includes both irrigated and non-irrigated crops and covers 1,400 square miles. Irrigated agriculture is only possible near perennial flowing streams, where water is diverted into ditches and canals, or by tapping into underground and hydrologically disconnected groundwater from the southern High Plains Aquifer, also known as the Ogallala Aquifer.

These two land cover types, *Grassland/Herbaceous* and *Cultivated Crops*, account for 86% of the entire watershed, or just over 6,750 square miles. In contrast, only 14 square miles are considered Developed in high, medium, or low densities (or in other words, cities).

Less widespread cover types include a diverse set of wetland classifications. Although wetlands only account for a fraction of the total watershed areas, *Woody Wetlands* (17.4 square miles, or 0.2%) and *Emergent Herbaceous Wetlands* (58 square miles, or 0.7%) are critical habitat for many species of wildlife, including hawks, deer, turkeys, and many migratory bird species. Wetlands are also a critical cover type because of the ecosystem services they provide, including the filtration and improvement of water quality. Improving and expanding wetlands, and riparian ecosystems in general, are one of the BMPs suggested to help improve water quality in this watershed. Two agencies, Colorado Parks and Wildlife and the Colorado Natural Heritage Program, both recognize and classify parts of the Lower Arkansas River Watershed as highly significant (or highly significant potential) for biodiversity (Figures 23 and 24).

3.2.10 Vegetative Communities

The vegetative communities of the Lower Arkansas River Watershed can be categorized under two main ecoregions: 1) the Southwest Tablelands and 2) the High Plains. According to the EPA, "Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources…" (Chapman et al., 2006).

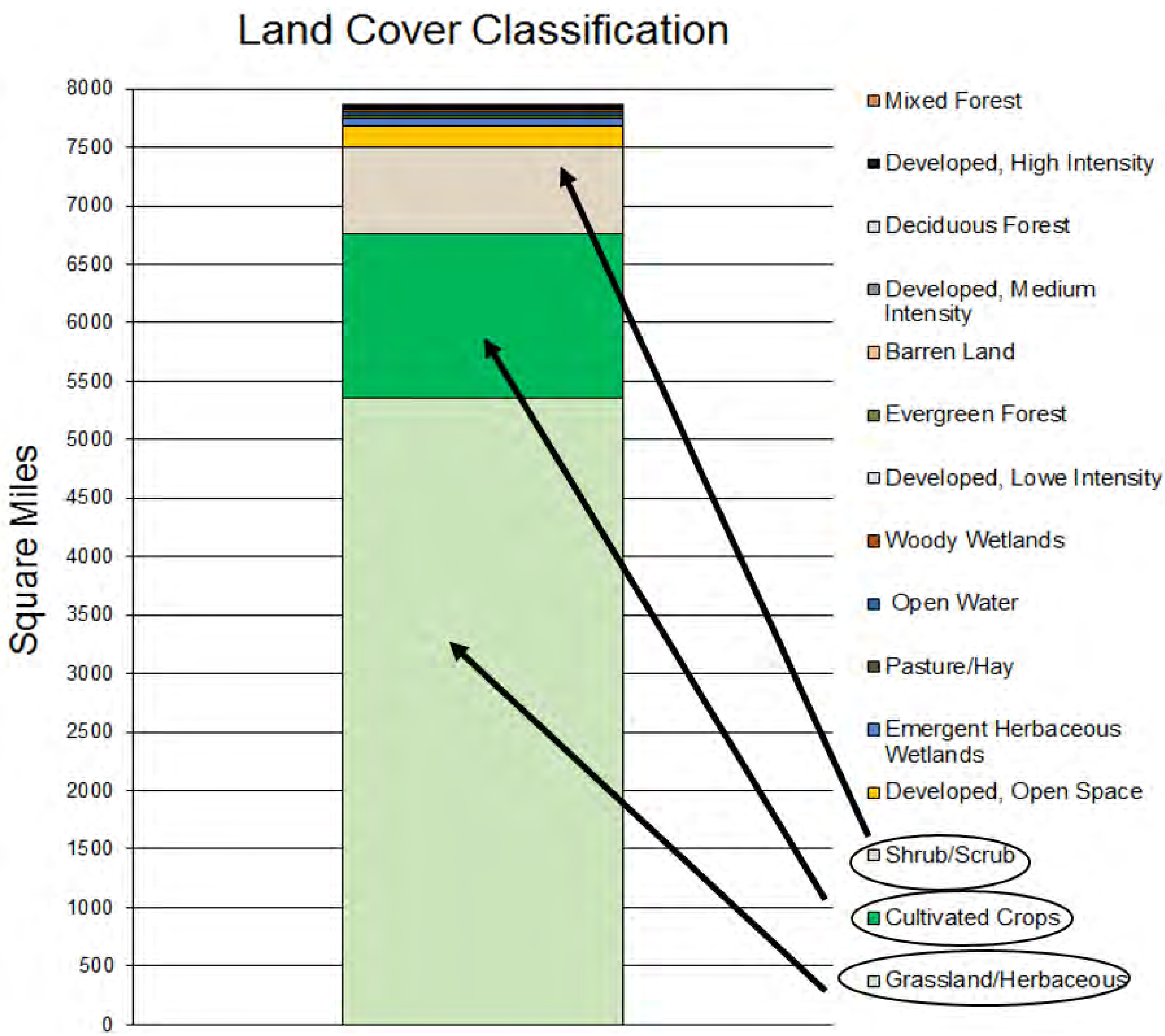

Figure 18: Breakdown of area, in square miles, of different land cover classifications in the Lower Arkansas River Watershed.

Most of the Southwest Tableland ecoregion can be further classified as Piedmont Plains and Tablelands, Sand Sheets, and a small section of Purgatoire Hills and Canyons. Common native plant species in this ecoregion include buffalo grass, blue grama, western wheatgrass, galleta, alkali sacaton, sand dropseed, sideoats grama, sand reed grass, switchgrass, little bluestem, needlegrass, sand sagebrush, and yucca (Chapman et al., 2006). The High Plains ecoregion of the watershed includes Flat to Rolling Plains, Moderate Relief Plains, and Rolling Sand Plains. Native plant species of this ecoregion include sand sagebrush, rabbitbrush, sand bluestem, prairie sand reed, Indian rice grass (Chapman et al., 2006).

A) *Bouteloua gracilis* (Blue Grama) – Source: National Park Service

B) *Boutelou curtipendulum (sideoats grama)* - Source: Flikr user 'lostinfog'

Figure 19: Two common native grass species; blue grama and sideoats grama.

The main drivers of vegetative communities in these ecoregions are climate, topography, and soil type. Numerous natural and man-made disturbances occur in the watershed, and they influence erosion and pollutant mobilization. These include residential and highway development, grazing management decisions, floods, and wildfires. Wildfires, both within and outside of the watershed, can significantly impact water quality by increasing sediment, nutrient, and in some cases, heavy metal loading to rivers and streams following heavy rain events. Wildfires can also change hydrologic properties within the soil, leading to increased flooding. Although wildfires are infrequent, the water quality impacts of wildfires in grass/range ecosystems should be monitored if an event takes place at a scale large enough to significantly impact water resources.

Native plants in the Lower Arkansas River Watershed have adapted to little rainfall, low humidity, high solar radiation, and high (100 °F +) and low (-30 °F) temperatures. These extreme environmental conditions, particularly relating to rainfall, have also allowed non-native species to establish and, in some cases, outcompete native species in some locations during times of plant stress, especially during drought. There are several non-native plant species found in the watershed, but the ones of greatest concern are Russian thistle, kochia, tamarisk, Russian olive, and Canada thistle.

3.2.10.1 Invasive Species

Invasive plant species plague parts of the watershed, most often in areas of disturbance such as roadway developments, agricultural fields, or overly-grazed rangelands. Invasive species are commonly called weeds, however the term weed does not apply to invasive species alone; some native "weed" species exist, such as white perennial astor, poison ivy, or stinging nettle. Non-native invasive species are legally described as "noxious weeds" and landowners are compelled to manage them according to the Colorado Noxious Weed Act (35—5.5-101-119).

Some invasive species and weeds outcompete native plants by using few resources, including little water, to grow and quickly reproduce. Other invasive plants are not as sparing of water resources, including the tamarisk (also called salt cedar) and the Russian olive. These plants are particularly problematic for water quantity and quality, using large amounts of water and bio-accumulating toxic ions and compounds. Tamarisk use an average of 4.2 acre feet of water per acre, per year (ARKWIPP 2008) and Russian olive trees can consume close to the same amount (ARKWIPP 2008).

Currently, multiple organizations focus on eradicating the two invasive tree species mentioned above, including RiversEdge West (Formerly the Tamarisk

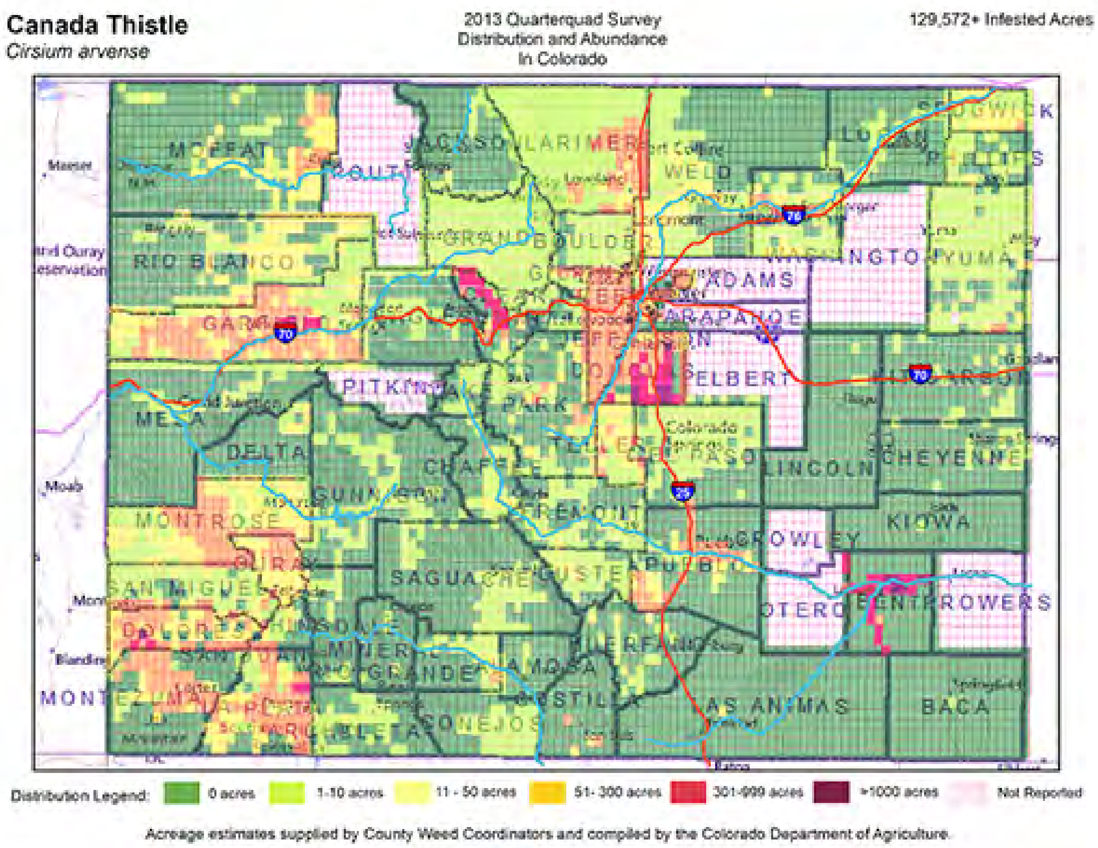

Figure 20: Canada thistle, a List B noxious weed, is common in disturbed and irrigated lands within the Lower Arkansas River Watershed. Source: Colorado Department of Agriculture.

Coalition) and the Purgatoire Watershed Partnership. Eradicating invasive species that use large quantities of water should be a priority, and projects including the eradication of these plants should be given priority regarding to any river restoration activities.

The water quality impacts from tamarisk and Russian olive are twofold: 1) they remove water from the river and in turn lower the river's ability to dilute pollutant concentrations, and 2) they add harmful pollutants, such as salts, to the riparian and aquatic environments. Tamarisk in particular can promote soil salinity; the trees bioaccumulate leaf salinity and then abscise plant material, depositing salts on the (Ladenburger et al. 2006). This process helps the salt-tolerant tamarisk by creating an environment conducive to tamarisk growth and inhibitive to the growth of less salt-tolerant native riparian vegetation. Creating saltier riparian soil conditions can have significant impacts on salt loading because of the close proximity of the salt deposits to the river.

3.2.11 Wildlife and Aquatic Life

The Lower Arkansas River Watershed is home to many diverse wildlife species, including several different species of resident and migratory birds, warm water fish, mammals, and amphibians. Good water quality is important to maintaining a healthy environment for both aquatic and terrestrial wildlife species. The Colorado Department of Public Health and Environment has established standard criteria for many pollutants to protect aquatic life. Aquatic life, including vertebrates and invertebrates, can be susceptible to slight changes in water quality. It is critical to maintain water quality standards, and regulatory agencies must use the best available science to inform these standards. Land management agencies also play a critical role in protecting wildlife habitats and ensuring habitat quality.

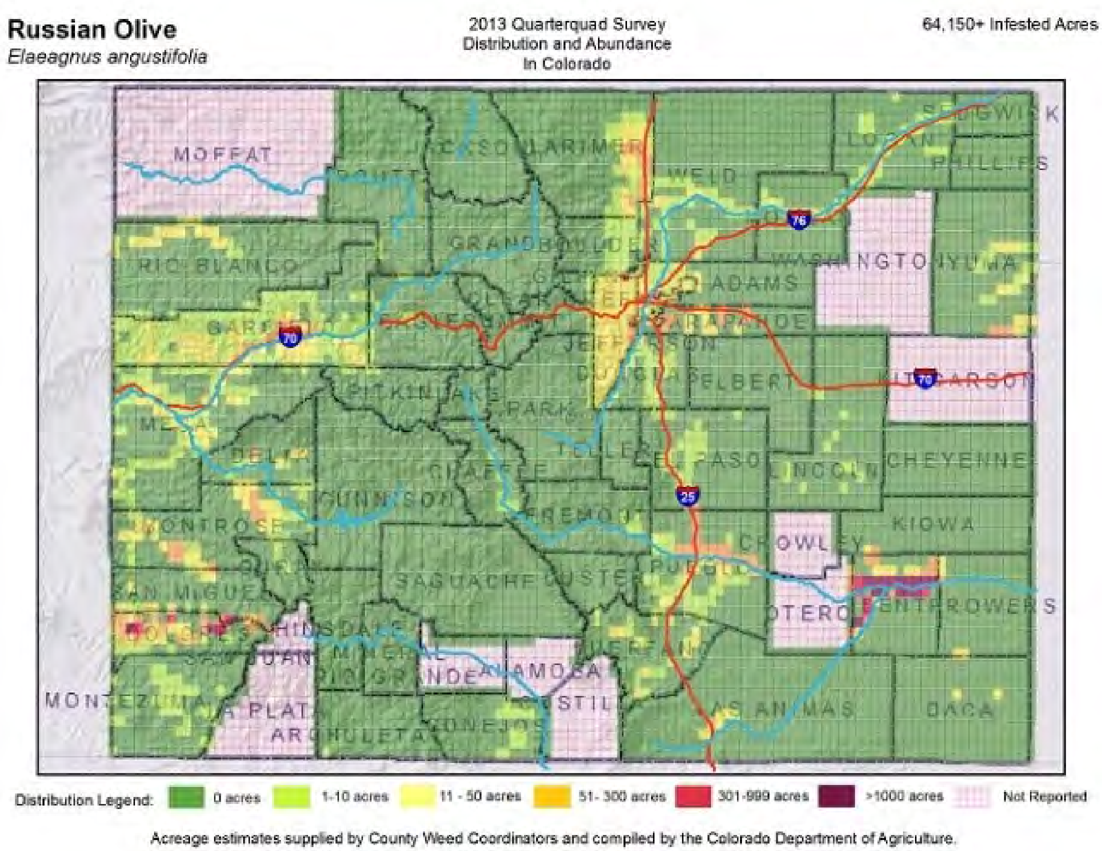

Figure 21: Russian olive trees are widespread throughout the Lower Arkansas River Watershed.

Colorado Parks and Wildlife (formerly Colorado Division of Parks and Colorado Division of Wildlife) operates many state park and wildlife areas in the Lower Arkansas River Watershed. One of the largest, John Martin Reservoir, is critical habitat for many wildlife species including osprey, bald eagles, catfish, bluegill, and bass, among others (Figures 23-26). Wildlife-related recreation, including hunting, bird watching and fishing, contribute significantly to the local economies of the Lower Arkansas River Watershed. The town of Lamar, CO, hosts the annual High Plains Snow Goose Festival, and Karval, CO, a town just outside the watershed, hosts the Mountain Plover Festival, while Rocky Ford, CO bills itself as the Dove Hunting Capital of Colorado.

Bird watching remains a big economic driver for many communities and supplements the income of some farms offering bird watching access. The Colorado Birding Trail lists two birding trails in the Lower Arkansas River Watershed: 1) the Two Buttes Trail and 2) the Snow Goose Trail. The Two Buttes trail is south and east of Lamar and includes stops in Lamar, Holly, and several state wildlife areas. Other private entities such as the 7K Ranch, Frank Ranch, and Taylor Ranch offer private property access to bird watchers for $5 per day (2018). The Snow Goose Trail is north of John Martin Reservoir and includes several reservoir sites, such as Nee Noshe and Queens, as well as private ranches with access for paying customers.

Much like bird watching, hunting interests should be dedicated to ensuring proper bird habitat, including adequate water quality. Hunting for many bird and mammal species, such as turkeys, white-tailed deer, pheasants, and pronghorn, is common in the watershed. These species rely heavily on riparian areas for cover, food, and water. Pronghorn venture further from riparian areas to feed in upland grasslands and often take advantage of stock watering tanks. These

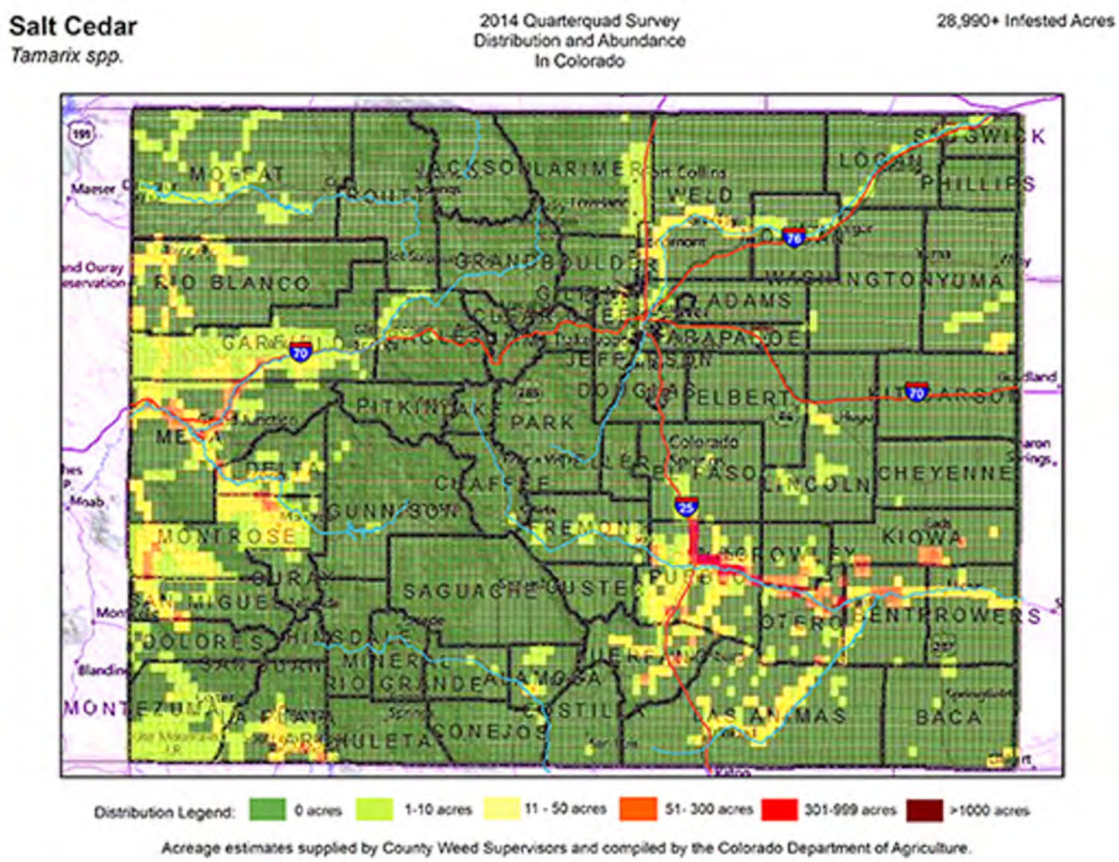

Figure 22: Salt Cedar, or Tamarisk, are also widespread throughout the Lower Arkansas River Watesrshed. The entire lower Arkansas River Valley has the highest density of Tamirisk in the state.

tanks are filled with groundwater that is pumped to the surface. In some cases, livestock watering tanks can be constructed on otherwise dry creek beds that collect water during rain events. More information on the legality of these livestock watering tanks can be found by contacting the Colorado Division of Water Resources.

Fish species are perhaps the most susceptible to changes in water quality. The entire aquatic food web of a warm water fishery has evolved with certain temperature requirements. Not only does temperature highly affect aquatic species, so too do dissolved oxygen levels and contaminant concentrations. Many primary heterotrophs at the bottom of the food web, such as small aquatic bug species, can be susceptible to changes in water chemistry and pH. Other animals, including fish and birds, can also be affected by aquatic chemistry. Selenium, for example, has been shown to cause birth defects in fish and incomplete incubation of eggs in migratory birds. The infamous Kesterson National Wildlife Refuge case of the early 1980s showcased the ill-effects of high selenium concentrations and their effect on fish and wildlife species. In short, the Kesterson Refuge is an artificial wetland created primarily from agricultural return flows, which contained high concentrations of pollutants such as salt ions and selenium (Presser 1994). Although the effects seen at Kesterson National Wildlife Refuge represent an extreme case of selenium toxicity, selenium can severely negatively impact aquatic and wildlife species (as well as livestock) if proper steps are not taken to mitigate the harmful effects of poor water quality.

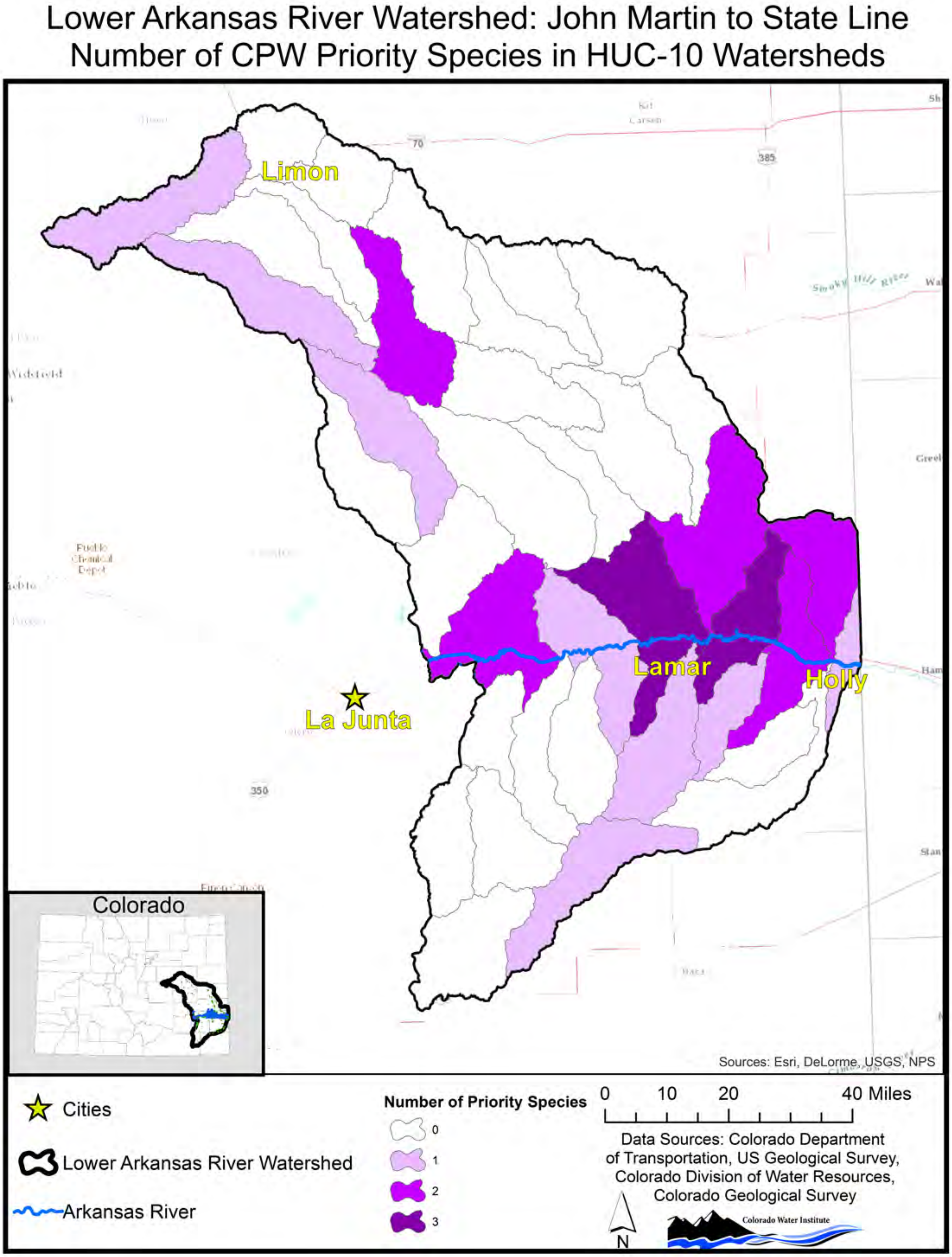

Figure 23: Total number of Colorado Parks and Wildlife Priority Species found in each "sub-watershed." Most of the priority areas are located along the main stem of the Arkansas River and near production agriculture.

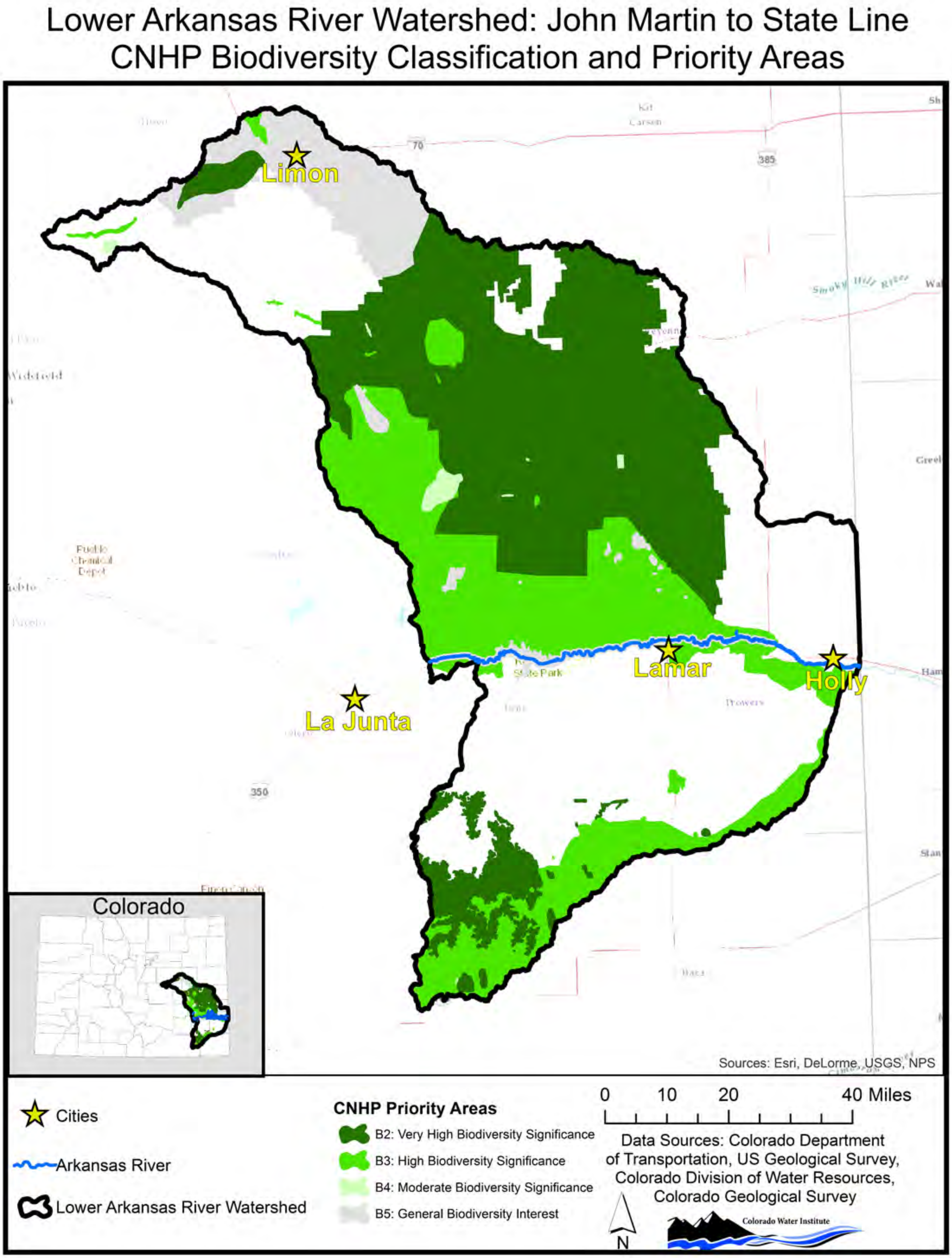

Figure 24: The Colorado Natural Heritage Program (CNHP) has delineated biodiversity classification areas that can be used by land managers and landowners to protect biologically diverse habitats.

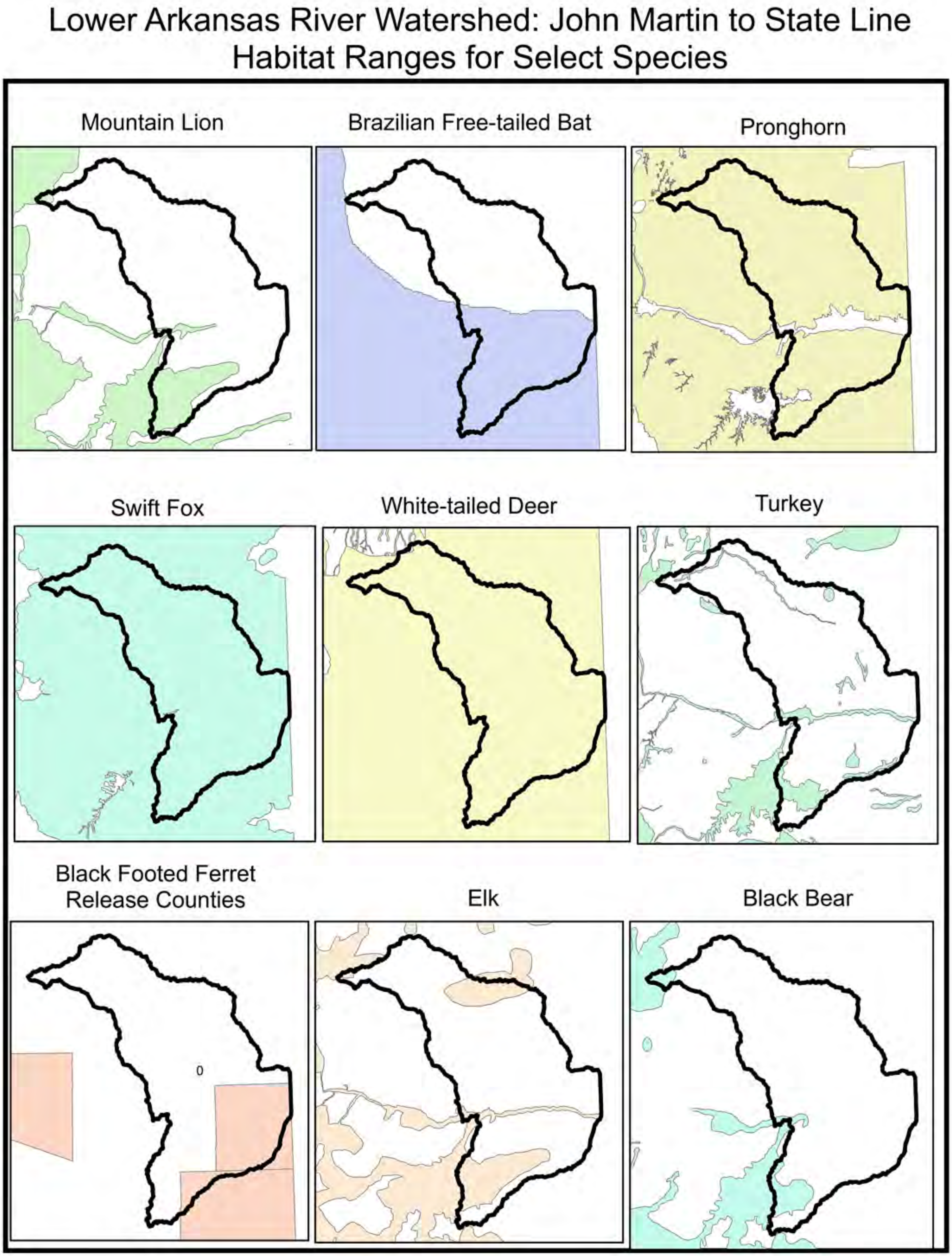

Figure 25: Habitat ranges for select wildlife species.

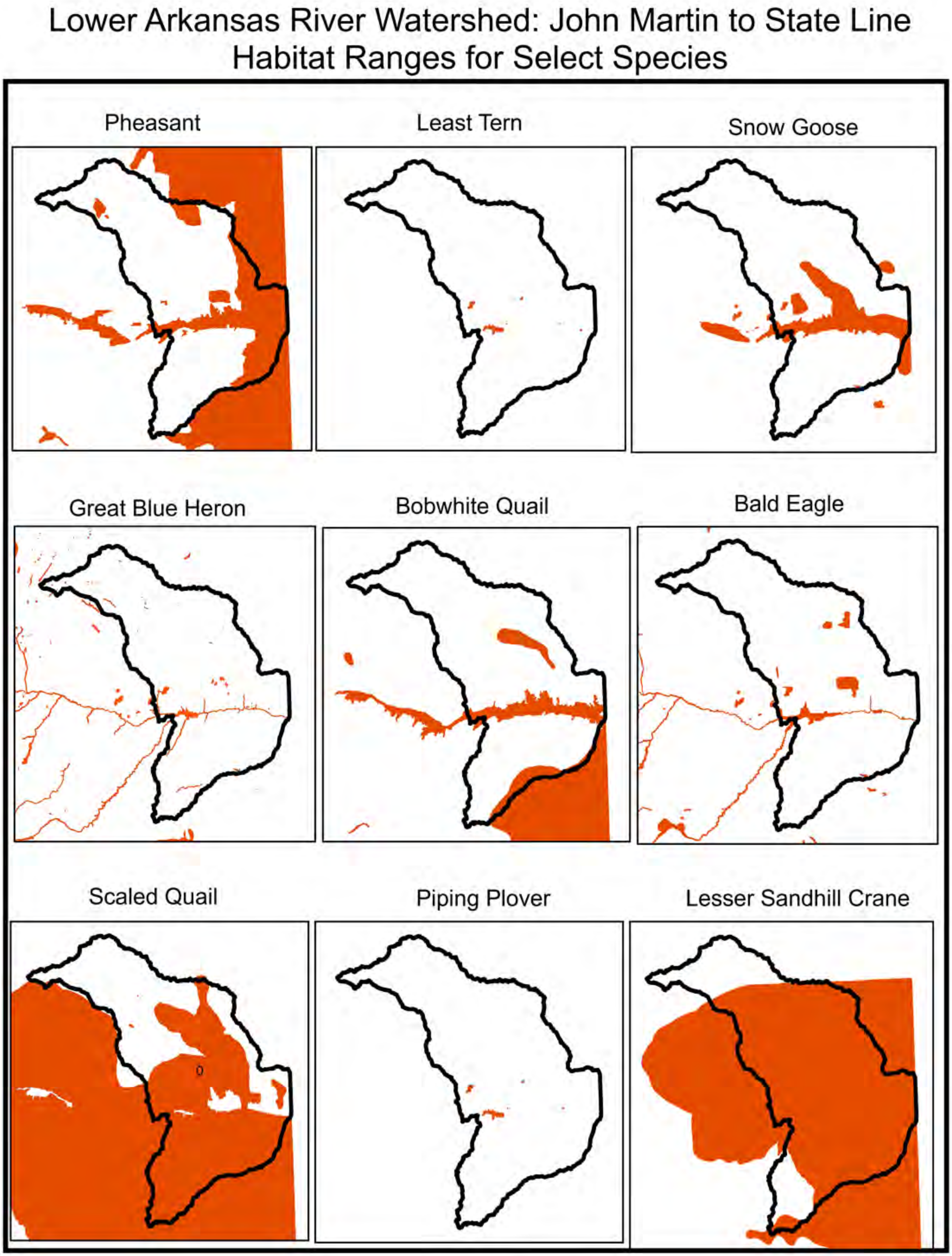

Figure 26: Habitat ranges for selected bird species.

3.3 Key Water Quality Issues

Water quality is the uniting force for many watersheds, including the Lower Arkansas River Watershed, because water quality is affected by most land uses and, in turn, it affects most water uses. Factors impacting water quality occur in many different magnitudes and durations, and the sources of water quality impairments are, too often, difficult to understand. For this reason, it takes a concerted and collaborative effort on the part of many stakeholders to improve water quality in a common resource.

The Lower Arkansas River Watershed is similar to many other watersheds: the greater the distance from the source, the worse the water quality. This happens because the lower parts of watersheds are taking in waters from a greater land area and, therefore, there is greater potential to pick up contaminants along the way. This is true of the Lower Arkansas River Watershed, as many of the water quality impairments are chemical in nature and easily dissolved into surface waters and groundwater. Total Dissolved Solids, or TDS, is a good indicator of water quality, and in the Lower Arkansas River Watershed from 2000-2004, TDS values averaged 2,208 mg/L directly below John Martin Reservoir (n=19) and 2,881 mg/L in Lamar, CO (n=38). TDS is a measure of all dissolved solids in the water sample, including ions and chemical compounds. TDS is a good indicator for general water quality issues, however, further analyses on individual contaminants is necessary to fully understand the water quality issues of this watershed.

A water quality problem can only be understood as a “problem” based on what is affected and the severity of those effects. For example, saline waters with sodium concentrations of 150 mg/L may be acceptable for humans and livestock to drink, but corn or melon yields may decrease due tothe stress these plants endure from the salty water. Too much sodium in the water can also affect soil structure through the Sodium Adsorption Ratio (SAR), which can lower infiltration rates and breakdown soil aggregates. Thus, salinity would be considered a problem for producers growing melons but not a rancher watering livestock. The example above illustrates how some water quality problems may affect only certain water uses. Similarly, the Colorado Department of Health and Environment has set “use standards” for different pollutant thresholds based on different water uses. The standard is lower for selenium concentrations that could impact aquatic life, such as aquatic invertebrates (4.6 µg/L), while the standards’ concentration for selenium in drinking water is higher (50 µg/L). The Lower Arkansas River Watershed has many different water body segments that have met or exceeded state water quality standards for some type of water use. Table 4 summarizes which segments are affected, which pollutant (or analyte) was evaluated, which water use standard has been exceeded, and the priority ranking for cleaning up that pollutant.

Selenium, uranium, and manganese are common water quality problems in the Lower Arkansas River Watershed, and the main water uses affected include domestic water supplies and aquatic life. Table 4 is not sufficient, however, to adequately identify all of the water quality problems of the Lower Arkansas River Watershed. Some water quality pollutants, such as salts and nutrients, cannot be listed on the state 303(d) list, yet they can cause serious problems for several different water uses.

As mentioned previously, salinity can have significant impacts on crop production (Mass and Gratten, 1999; Sutherland, 2002; Berrada and Halvorson, 2012). In several meetings with producers in the Lower Arkansas River Watershed, salinity was the foremost water quality concern among farmers. Therefore, it is important to expand the definition of water quality problems to include more than just the state list for impaired waters. See Appendix 1-A for a more thorough description of water quality analyses performed for this plan. The impairments analyzed include selenium, uranium, arsenic, manganese, iron, and E Coli, as well as other parameters of interest, including sulfate, nitrogen, and phosphorus.

3.3.1 Monitoring Locations - surface and ground water locations

A total of 19,699 individual water quality parameters were downloaded from the Water Quality Ex-

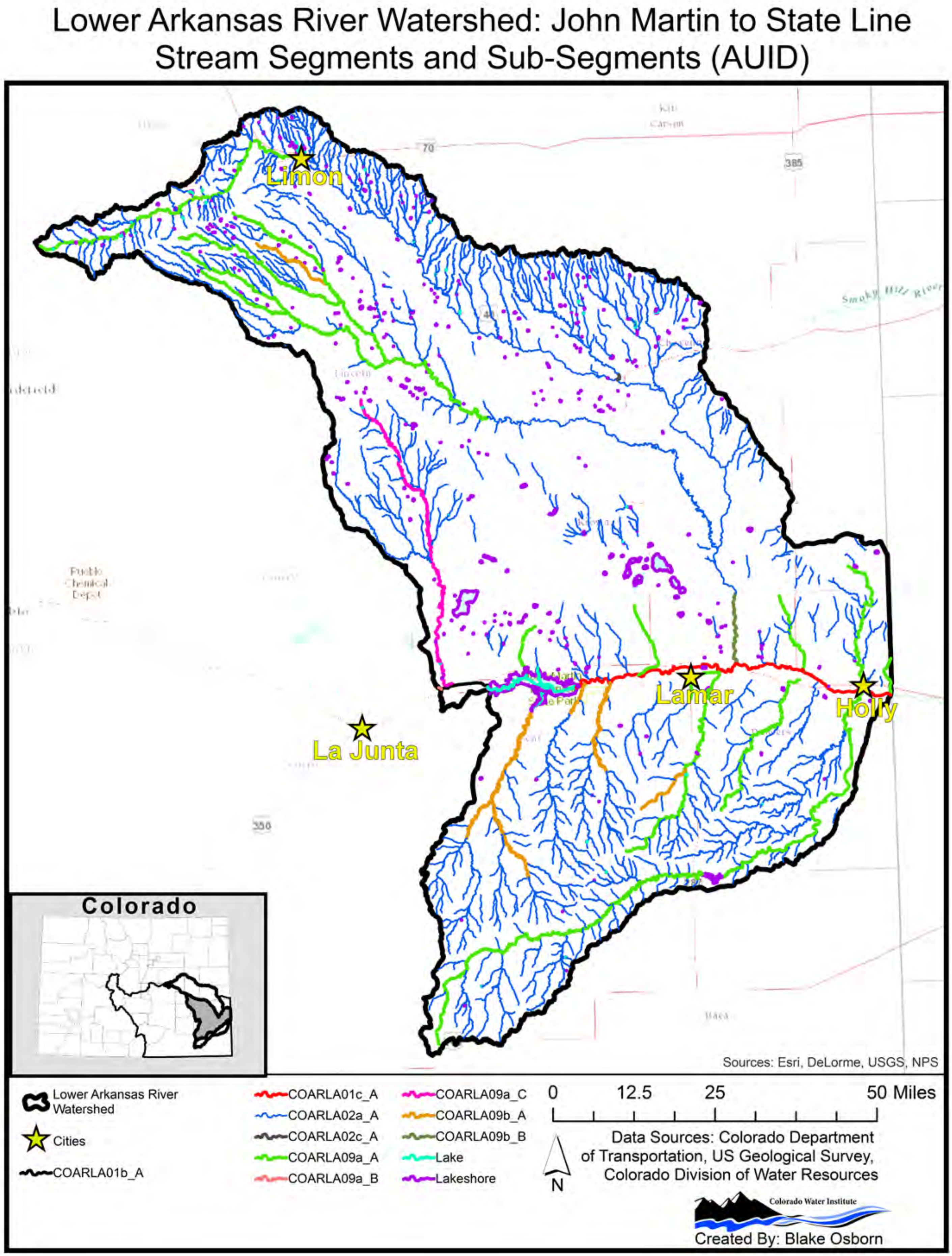

Figure 27: Stream segment classifications by CDPHE.

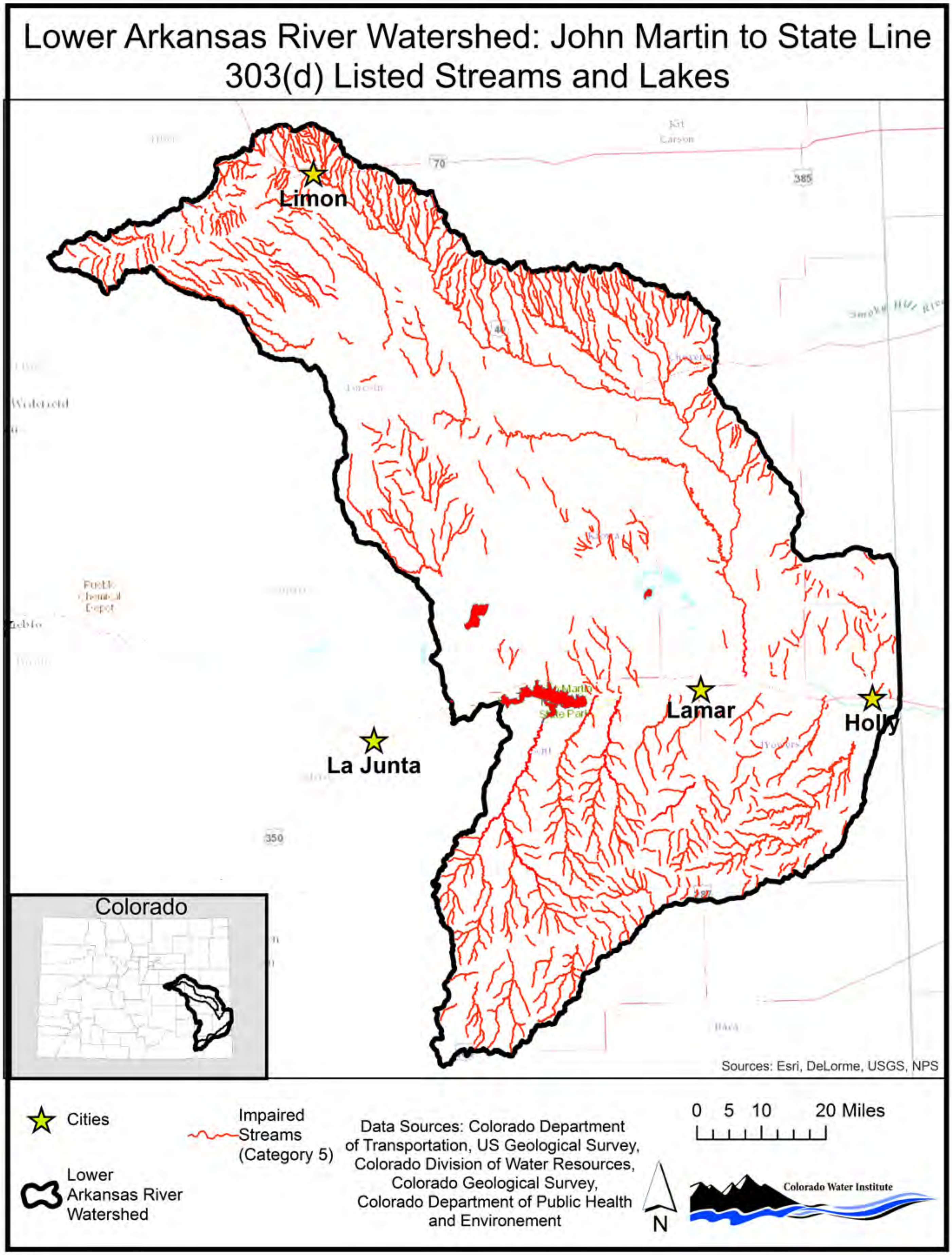

Figure 28: Location of streams listed as Impaired on the state 303(d) list.

Table 4: Complete summary of stream segements with impairments, affected uses, priority rankings, and descriptions of the waterbodies within the segment.

Segment	Analyte	Affected Use	Category	Priorty	Description
COARLAO1c_A	Temperature	Aquatic Life Use	M&E List	NA	Mainstem of the Arkanasa River from the outlet of John Martin Reservoir to the Colorado-Kansas border
	Selenium (dissolved)	Aquatic Life Use	303(d)	High	
	Arsenic (total)	Water Supply Use	303(d)	Low	
	Manganese (dissolved)	Water Supply Use	303(d)	Low	
	Uranium (total)	Water Supply Use	303(d)	High	
COARLAO2a_A	Manganese (dissolved)	Water Supply Use	303(d)	High	All tributaries to the Arkansas River, including wetlands, from the Colorado Cana head-gate to the Colorado/Kansas border, except for specific listings in segments 2b, 2c, 3a through 9b, and Middle Arkansas Basin listings.
	Sulfate	Water Supply Use	303(d)	High	
COARLAO9a_A	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	Mainstems of Adobe, Buffalo, Cheyenne, Clay, Gageby, Horse, Two Butte, Wildhorse, and Wolf Creeks from their sources to their confluences with the Arkansas River. Mainstems of the Chacuacho Creek, San Francisco Creek, Trinchera Creek, and Van Bremer Arroyo from their sources to their confluences with the Purgatoire River. Mainstem of Willow Creek from Highway 287 to the confluence with the Arkansas River. Mainstem of Big Sandy Creek from the source to the El Paso/Elbert county line. Mainstem of South Rush Creek from the source to the confluence with Rush Creek. Maintem of Middle Rush Creek from the source to the confluence with North Rush Creek. North Rush Creek from the source to the confluence with South Rush Creek. Mainstem of Rush Creek to the Lincoln County Line. Mainstem of Antelope Creek from the source to the confluence with Rush Creek; the West May Valley drain from the Fort Lyon Canal to the confluence with the Arkansas River.
	Arsenic (total)	Water Supply Use	303(d)	High	
	Manganese (dissolved)	Water Supply Use	303(d)	Low	
COARLAO9a_B	Sulfate	Water Supply Use	M&E List	NA	Mainstem of Horse Creek
	Uranium (total)	Water Supply Use	M&E List	NA	
	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	
	Arsenic (total)	Water Supply Use	303(d)	High	
	Iron (total)	Aquatic Life Use	303(d)	High	
	Manganese (dissolved)	Water Supply Use	303(d)	NA	
COARLAO9a_C	Selenium (dissolved)	Aquatic Life Use	M&E List	NA	Mainstem of Adobe Creek
	Arsenic (total)	Water Supply Use	M&E List	NA	
	Iron (total)	Aquatic Life Use	M&E List	NA	
	E. coli	Recreational Use	303(d)	High	

change portal and have been analyzed from a variety of locations throughout the Lower Arkansas River Watershed between 2000 and 2016. Most of the water quality samples collected from 2000-2016 in the Lower Arkansas River Watershed were from the main stem of the Arkansas River (n = 16,137). Most of the

COARLAO9b_A	Manganese (dissolved)	Water Supply Use	M&E List	NA	Mainstem of Apache Creek. Mainstem of Breckenridge Creek. Mainstem of Little Horse Creek. Mainstem of Bob Creek. Mainstem of Rule Creek from Bent/Las Animas County line. Mainstem of Muddy Creek from south boundary of Setchfield SWA. Mainstem of Caddoa Creek from CC Road. Mainstem of Cat Creek. Mainstem of Mustang Creek from the source to the confluence with Apishapa River. Mainstem of Chicosa Creek from source to the Arkansas River. Mainstem of Smith Canyon from Otero/Las Animas County line to confluence with Purgatoire River. Mainstem of Mud Creek from V Road to the confluence with the Arkansas River. Mainstem of Frijole Creek and Luning Arroyo from sources to confluence with Purgatoire River. Mainstem of Blackwell Arroyo from source to confluence with Luning Arroyo. Mainstem of San Isidro Creek from source with confluence with San Franscisco Creek.
	Sulfate	Water Supply Use	M&E List	NA	
	Temperature	Aquatic Life Use	M&E List	NA	
	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	
	Iron (total)	Aquatic Life Use	303(d)	Medium	
COARLAO9b_B	Manganese (dissolved)	Water Supply Use	M&E List	NA	Big Sandy Creek within Prowers County
	Sulfate	Water Supply Use	M&E List	NA	
	Temperature	Aquatic Life Use	M&E List	NA	
	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	
	Iron (total)	Aquatic Life Use	303(d)	NA	
COARLA10_B	Selenium (dissolved)	Aquatic Life Use	303(d)	NA	Adobe Creek Reservoir
	Arsenic (total)	Water Supply Use	303(d)	High	
COARLA10_B	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	Nee Gronda Reservoir
COARLA11_A	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	John Martin Reservoir
	Arsenic (total)	Water Supply Use	303(d)	High	

parameters were analyzed from surface water sources (48%), and fewer were samples from groundwater sources (3%). Over 8,900 samples (45%) do not list the water source (Figure 30).

3.3.2 Metals and Non-metals

Many of the water quality problems in the lower Arkansas Watershed stem from high concentrations of naturally occurring elements such as selenium, uranium, and variety of salt ions. Although these constituents are found to naturally occur in the watershed, management practices greatly influence their mobilization and movement into surface and sub-surface water bodies.

Metals, such as manganese and iron, pose health risks to aquatic and terrestrial life. The amount of exposure and the length of exposure are contributing factors to the toxic effects of the metals in question. Some metals are less toxic than others, however, almost all metals have a toxic threshold.

The toxicity of a metal may also be quite different in different biota. For example, the toxic effects of cadmium may cause problems at lower concentrations for mayflies, while catfish are unaffected. Similarly, humans may tolerate less dissolved manganese in our water compared to agricultural crops such as corn. Therefore, it is difficult to succinctly describe the toxicity of a given metal to each individual life form. When assessing the potential harmful effects from a water quality pollutant, the Colorado Department of Public Health and Environment uses research to determine toxicity standards for different life forms, such as aquatic life, agricultural applications (crops and livestock), and drinking water for humans. Common metals found in the Lower Arkansas River Watershed include uranium, iron, copper, zinc, and manganese.

Non-metals, such as sodium, sulfur, and nitrogen, can also pose water quality challenges if found in relatively high concentrations. Just like metals, non-metals can pose serious health risks. Elevated nitrate levels can be harmful to pregnant mothers and infants, high salinity can negatively affect crops, and phosphates can increase harmful algal blooms (HABs). Non-metal loading to streams and lakes can be significant when non-metal sources intersect management practices. For example, chemical fertilizers are used to supplement the nutrient demands of crops, and the timing, amount, and place of fertilizer application may not allow the nutrient sources to be retained in the soil for crop use. If too much is applied, or applied at the wrong time in the season, much of the easily dissolved fertilizer will be carried to surface and groundwater bodies. For the purposes of this watershed plan, selected metal and non-metal constituents have been analyzed and, in some cases, loading estimates are provided.

3.3.3 Selenium

The most widespread water quality impairment in the Lower Arkansas River Watershed is elevated levels of selenium. Selenium is a micronutrient essential for human growth and development, but at higher concentrations, the beneficial effects of selenium are replaced with harmful effects, such as kidney failure from selenium toxicity (National Institutes of Health, 2016). The National Institutes of Health (2016) list 55 micrograms (µg) as the upper recommended limit for human consumption. They also recommend a daily selenium intake of 20 µg for infants less than 1 year and 40 µg for children under the age of 13.

In the environment, selenium has been shown to be harmful to aquatic wildlife, including fish and waterfowl. One of the biggest environmental disasters involving irrigated agriculture started in the 1970s at the Kesterson Wildlife Refuge in the central valley of California. Elevated selenium levels in agricultural return flows caused fish and bird deaths and deformities and led to the term “Kesterson effect” (Presser,

Figure 29: Soil salinity experiments at the Arkansas Valley Research Station.Photo courtesy of Blake Osborn.

1994). Essentially, the Kesterson effect is the biogeochemical pathway of selenium from Cretaceous sedimentary rock formations into irrigation return flow, and ultimately into natural ecosystems and aquatic organisms.

This problem is not unique to Colorado. The Kesterson effect has also presented problems in North Carolina, Texas, California, Utah, Wyoming, and Idaho (Hamilton, 2004). The problem is not even unique to southeast Colorado; the Uncompahgre and Grand Valleys on Colorado’s Western Slope have been experiencing elevated selenium levels as a product of agricultural drainage and return flows. For this reason, the US Bureau of Reclamation has been working with private landowners, NGOs, and state agencies in the Gunnison and Grand Valleys to implement a Selenium Task Force (the Gunnison Basin and Grand Valley Selenium Task Force, 2018). In Colorado, the sources of selenium originated as byproducts of volcanic activity (Miller et al., 2010). Since its volcanic origins, selenium has been dispersed widely throughout the state and incorporated into bedrock material and soils. Therefore, it can be difficult to locate selenium sources and pinpoint management measures to remediate the release of the selenium into water sources.

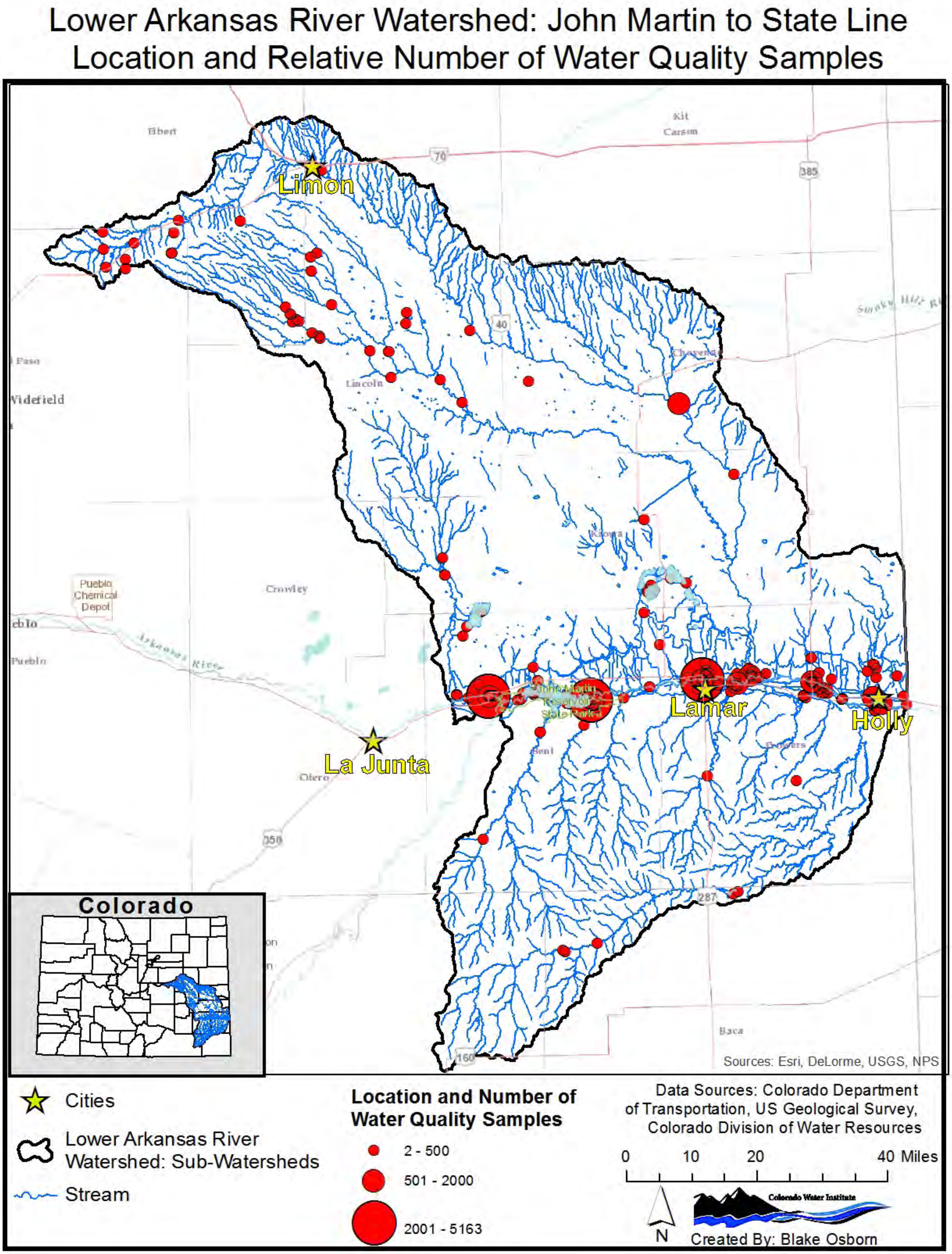

Figure 30: Location of sampling points and relative number of samples collected by all state and federal agencies between 2000-2016.

More recent investigations have been made by the Colorado Geological Survey and the US Geological Survey into the sources of selenium, especially in the Lower Arkansas River Watershed. It is commonly understood that much of the selenium in the Lower Arkansas River Watershed is trapped in shale bedrock formations and could also be sequestered in soils derived from these geological layers. Selenium is released from the shale formations when water is present, as in shallow groundwater systems near irrigated agriculture, and the rate of dissolution happens more easily and quickly with nitrogen-rich water. Therefore, because the selenium exists in great quantities in the natural environment of the Lower Arkansas River Watershed, it is not feasible to remove selenium from the system in quantities that are economically or technically feasible. Instead, management practices must be adapted to eliminate the release of the selenium into surface and groundwater bodies.

3.3.4 Uranium

Like selenium, uranium is also a byproduct of the weathering of old marine shale bedrock formations, and the source of the uranium is likely the same as that of selenium. But unlike selenium, uranium has not been shown to have any beneficial health properties, and the Centers for Disease Control lists it as potentially harmful to human health as a chemical agent, rather than from the radioactive properties commonly associated with it. However, a study conducted for the National Institutes of Health observed that elevated uranium concentrations in groundwater have been shown to increase the risk of certain cancers, primarily colorectal, breast, kidney, and prostate cancers (Wagner et al., 2011).

Many of the water quality standards for uranium can be difficult to understand, as the toxicity of uranium depends on the hardness of the water. The drinking water standard for uranium, as listed by the Colorado Department of Public Health and the Environment, is 16.8 µg/L. This is the chronic drinking water standard, and it became effective on January 1, 2011. The Water Quality Control Commission of CDPHE made this recommendation to protect people against the chemical toxicity of uranium. This concentration value does not account for the economic considerations of water treatment, which is not surprising given the chemically toxic nature of uranium. Further, CDPHE also follows a mandate by the EPA that drinking water should not exceed 30 µg/L in total radionuclides. This would include uranium and many other constituents such as radon, curium, americium, strontium, and plutonium.

Because uranium exists in the environment naturally, it is also not feasible to remove the uranium in quantities that would eliminate the threat of contamination to water sources. Like selenium remediation, management practices must be taken to reduce the ability of the uranium to dissolve from parent material.

General Nutrient Management BMPs

- Develop a yearly fertilizer plan for each field and crop.
- Test soil, plant tissues, and irrigation water.
- Analyze and credit nutrients from manure, compost, and biosolids.
- Establish realistic crop yield expectations
- Keep fertilizer records.
- Utilize a crop consultant.
- Manage irrigation application to avoid nutrient runoff and heavy leaching.
- Practice soil conservation and erosion management.
- Establish buffer zones around waterways.
- Identify and closely manage crop areas subject to erosion, runoff, or leaching.
- Follow the *4R* nutrient approach to fertilizer management:
  - Right *rate*
  - Right *time*
  - Right *place*
  - Right *source*

Figure 31: Nutrient Management BMPs recommended by Colorado State University. Source: coagnutrients.colostate.edu.

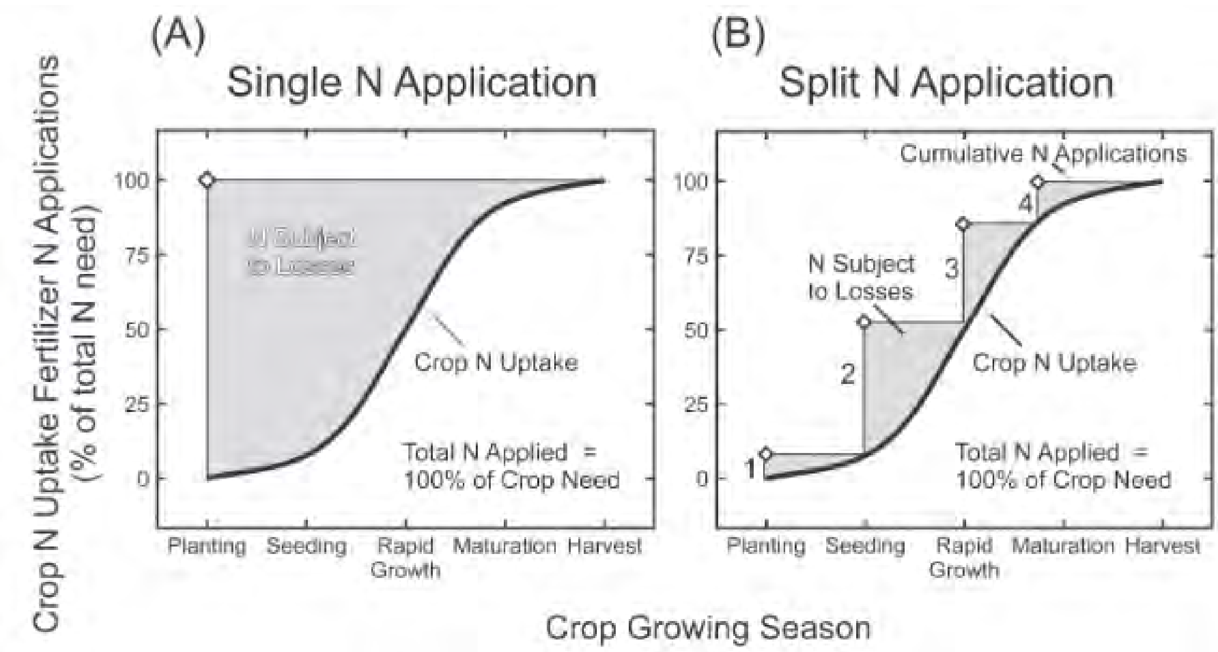

Figure 32: Split season nitrogen reduces the potential for excess nitrogen to leach into groundwater and runoff in surface waters. Image courtesy of Bauder et al.

3.3.5 Nutrients

For the purposes of this plan, nutrients are defined as nitrogen and phosphorus elements or their chemical compound derivatives. Nitrogen and phosphorus are common fertilizer inputs in irrigated agriculture, as well as byproducts in wastewater and animal manure. Most crops grown in the Lower Arkansas River Watershed are nutrient-limited, and therefore nutrients are supplied as organic or inorganic fertilizer. Non-organic nitrogen is most commonly in the form of nitrate, nitrite, or ammonium, while organic forms of nitrogen include animal waste (i.e., urea). Nitrogen, specifically nitrate, is highly soluble in water in all forms. If applied properly, these fertilizers can increase yields and create high return on investment. However, if nutrients are not applied carefully, they often end up in surface or groundwater.

Around the world, nitrogen sources can include chemical manufacturing, agricultural applications, natural fixation within environments, or atmospheric deposition. There are likely many sources of nitrogen and phosphorus within this watershed, including large amounts used in irrigated and dryland agriculture. Even native rangelands produce some nitrogen through nitrification in the soil. Animal feeding operations also produce large quantities of nutrients in animal waste. Colorado State University has developed materials to help producers implement BMPs that could help reduce the leaching of nutrients from agricultural fields into surface and groundwater. One example is applying nitrogen in “split applications,” meaning fertilizer is applied at multiple times throughout the season in smaller quantities (Figure 32). This reduces the total amount of fertilizer susceptible to loss through deep percolation or surface runoff. For more information on nutrient management visit **waterquality.colostate.edu**.

3.3.6 Sediment

Turbidity is a term used to describe the amount of suspended sediment in a water column and is measured using a Secchi Disk. Most data sources do not include measurements of turbidity at the temporal resolution necessary to perform water quality analyses. Therefore, no analyses have been performed in this watershed plan that specifically address turbidity.

However, sediment transport can be considered one of the bigger water quality issues facing the Lower Arkansas River Watershed. The flood plain of the Arkansas River has historically been wide and shallow, which is common in high plains watersheds, with the river regularly overtopping its primary channel bank and meandering throughout the flood plain. Sediment transport in the Lower Arkansas River Watershed has ranged from 10 mg/L to more than 6,000 mg/L with significant increases in sediment loads occurring after heavy rainfall events (Ortiz et al., 1998).

Over the past 100 years, the channel has changed considerably in some reaches as infrastructure was built and the hydrologic regime changed. In some cases, the river became narrower and less braided due to more sustained river flows that could support riparian vegetation (Nadler and Schumm, 1981). Conversely, some sections of the river have increased in sinuosity and begun to meander, often caused by higher suspended sediment loads (Nadler and Schumm, 1981).

3.3.7 Salinity

The word "salinity" is often used as a general term to describe water quality but is actually a measure of the number of salt ions dissolved in the water, including magnesium, sodium, calcium, potassium, chlorine, and others. Each of these elements form compounds like sodium chloride (NaCl) or potassium sulfate (KSO4), but most dissociate (or dissolve) in water leaving the positively or negatively charged ions (NA+, Cl-, K+, and SO4-).

The salts' ability to dissolve into positively and negatively charged ions makes it much easier to measure the "salinity" of the water by measuring the water's ability to transmit electricity. The more salt ions present in the water, the greater the waters ability to conduct electricity. This makes salinity measurements easier and cheaper to take, and the commonly reported measure of salinity is electrical conductivity (EC).

Electrical conductivity is the most commonly reported measure of salinity, and much research has been done to establish thresholds of salinity for certain water uses, all measured as EC. For example, the recommended soil salinity tolerance for corn is not to exceed 1.7 decisiemens per meter (ds/m; measure of electrical conductivity), alfalfa is 2.0 ds/m, and wheat is not to exceed 6.8 ds/m (Tanji & Kielen, 2002). Similarly, water with a salinity measurement of more than 8 ds/m should be limited in livestock watering (it is recommended that poultry not consume water with EC values greater than 5 dS/m) (Ayers and Westcot, 1985).

Salinity was listed as the highest water quality concern among the stakeholders participating in the watershed planning stakeholder meetings. Although salinity and salts are not a regulated pollutant, the Arkansas River and its tributaries suffer from elevated salt concentrations at certain locations and at specific times of the year. For example, below John Martin Reservoir (where salinity is measured as EC by the USGS in 15 minute intervals), EC values are lowest in Jun and July, when more water is in the river to provide a diluting effect. Conversely, the highest values of EC are typically seen in March and April, when river levels are low and irrigation return flows are contributing significant salt loading to the stream. EC values in the Arkansas River near Las Animas, CO, are as high 3.8 ds/m and as low as 0.52 ds/m (data from USGS gauge 07124000; data only available 10/1/2007-12/31/2016).

Typically, surface water salinity is much less than groundwater salinity. This is due in large part to the diluting effect of high river flows that begin as snowmelt upstream. Researchers from Colorado State University have observed EC values as high as 44 ds/m in groundwater within the watershed and average saturated soil EC values of 6.2 ds/m. These values represent maximums, but the implications of salt loading to the Arkansas River in quantities that can negatively impact crop production is, and should be, alarming to farmers and producers.

One point of hope is the understanding that many Best Management Practices that reduce selenium mobilization to rivers can also decrease the amount of salt loading to the same rivers. More information on these BMPs can be found in Chapter 5: Best Management Practices.

Chapter 4

Water Use

4. SUMMARY

Colorado subscribes to the doctrine of prior appropriation, meaning almost all of the consumptive water uses within the state require an adjudicated water right. This doctrine guides the administration of water used in agriculture, municipalities, industry, and other uses that need water to function. This water right, also called an absolute right, is given a permanent spot on the list of water users for a given stream based on the date the water is beneficially used for its specific purpose. The water right retains its priority date even if it is transferred through a sale or lease. This system creates a hierarchy of water uses where older water rights get fully satisfied before newer water rights can use water. Because of this system, water rights, and therefore consumptive water uses, are influenced by other water rights outside of the watershed, but still within the larger Arkansas River Basin of Colorado. Additionally, consumptive and non-consumptive water uses within the Lower Arkansas River Watershed are controlled by many factors upstream including mountain snowpack, upstream reservoir storage levels, and upstream senior water rights. This is typical of lower-order watersheds in states that adhere to the Doctrine of Prior Appropriation.

4.1 Water Uses and Water Rights

There are many types of consumptive and non-consumptive water uses within the Lower Arkansas River Watershed, including irrigating crops, municipal drinking water supplies, irrigation augmentation, and industrial manufacturing, among others.

Irrigated agriculture is the most significant water user and water consumer within the Lower Arkansas River Watershed, as is the case in most of Colorado's river basins. It is important to distinguish here the difference between water use and water consumption. Water is unique in that it can be used to perform a task (such as generate hydropower) but not be consumed (or lost to the atmosphere). There are many different types of water uses, including generating hydropower, instream flows, or minimum reservoir levels for fish habitat; whitewater boating parks; irrigating crops; providing drinking water; and many others. Some of these water uses do not consume any water, while some consume nearly all of the water. Most water uses are a hybrid model of use and consumption, meaning they require a certain amount of water to satisfy that use, but only a fraction of the water is actually consumed.

For example, an irrigator may have the right to divert 10 cubic feet per second (cfs) from the Arkansas River, however, not all 10 cfs of water will be consumed, or lost to the atmosphere, and taken out of the water system. It is common for some of the diverted water to seep from the earthen canal and feed water to the groundwater system, while some of the remaining water may run off the edge of the farmers' field and be transported back to the river through a drainage ditch. In many cases, only a fraction of the water (50%-60%) is actually consumed through evaporation or transpiration by the crops. This built-in inefficiency within the irrigated agricultural system is a critical factor that water administrators will always consider when determining when water users can use water, how irrigators can make efficiency improvements, and how much water an irrigator would have to "replace" by making an irrigation efficiency improvement and thus altering the amount of water, and its timing, getting back to the river.

4.1.1 Agriculture

Irrigated agriculture in Water District 67 makes up a large percentage of the total decreed water rights within the Lower Arkansas River Watershed. Data from the Colorado Department of Water Resources shows District 67 has a total filing of 2,364 water rights, including absolute rights and conditional rights. It is important to note that some agricultural water used within District 67 is diverted from the rivers and streams outside of District 67 boundaries. These water rights are not reflected in the amount listed above. Almost 44% of the adjudicated water rights can only be used for irrigation purposes, and over 57% of the rights contain some type of irrigation provision, meaning they have multiple decreed uses, of which irrigation is one. The next highest decreed use, in terms of total numbers of adjudicated rights, is stock watering, with 490 adjudicated rights.

Most irrigated farms are located in the alluvial valley near the river (Figure 33). Surface irrigation water is only available for lands served by ditches or canals,

Table 5: Ditches that have historically diverted water for multiple purposes			
Canal Name	Irrigated Acres	Number of Decrees	Total Allowable Diversion (CFS, including storage decrees)
Fort Lyon	91,300	5	2,437
Fort Bent	6,840	5	229
Keesee Ditch	1,900	3	28.5
Amity Canal	37,800	2	783.5
Lamar Canal	8,700	5	285.75
Hyde Ditch	970	1	23.44
Manvel Canal	750	1	54
X-Y Irrigating Canal	0	1	69
Buffalo Canal	5,000	1	67.5
Sisson-Stubbs Ditch	-	1	7
TOTAL	153,260	25	3,985

which transport the water from the river to the fields. The main ditch and canal systems serving the Lower Arkansas River Watershed have historically included the Fort Lyon Canal (most Fort Lyon farms are within the Lower Arkansas River Watershed, but not all), Fort Bent Canal, Buffalo Canal, Sisson Ditch (sold water in 1983), Keesee Canal, Amity Canal, Lamar Canal, Hyde and Manvel Ditches (sold water in 1993), X-Y Canal (sold water in 1996), and Graham Ditch. The Fort Lyon Canal, the largest ditch/canal in the entire Arkansas Basin, operates partially in the Lower Arkansas River Watershed below John Martin Reservoir. Roughly 92% of the farms irrigated by Fort Lyon Canal waters are within the boundaries of our watershed. Together, all of the ditches and canals (including the entirety of the Fort Lyon) have historically had the right to divert 3,985 cfs of water from the Arkansas River for use or storage (now excluding the Manvel Ditch, X-Y Canal, and Sissons-Stubbs Ditch, which each sold their water rights; Table 5).

Many of the water rights held by ditch and canal companies carry a senior priority, meaning they are entitled to water first when water supplies are scarce. The seniority associated with these water rights makes them very valuable. This high valuation of the water rights has caused other water users, such as municipalities or other farms, to pursue the acquisition of these senior water rights from willing sellers.

In the past, these valuable and expensive water rights have been bought by other water users and the water transferred to a new place of use. This can, and has previously, have severely negative impacts on the local communities that depend on agriculture as the main economic support structure. However, under new provisions from the Colorado legislature, it is now possible to temporarily transfer water from a farm to other users by using a lease agreement. This lease agreement has the potential to provide another tool for water users to share water without the fear of abandoning or lessening the value of the water right. In fact, one of the BMPs that will support water quality improvements is a Lease-Fallowing agreement that allows farms to be temporarily dried up and the water temporarily transferred to another use. See Chapter 5: Best Management Practices for more information on this BMP and others.

4.1.2 Non-consumptive water needs

Non-consumptive water uses in the Lower Arkansas River Watershed include recreational activities such as flatwater boating, fishing, and bird watching, as well as environmental needs that support aquatic wildlife habitat and riparian ecosystems. Rivers and lakes in the relatively dry eastern plains of Colorado, like the rest of the state, are important gathering places for wildlife. Rivers and lakes act as oases and provide critical, but limited, habitat. Livestock also benefit from these riparian area, and the shady river bottoms often provide stress relief for livestock during the hot summer months. Rivers and lakes can also provide many ecosystem services. Ecosystems services is a term used to describe processes, either naturally occurring or human-influenced, that benefit wildlife, livestock, or humans.

For example, riparian vegetation such as cottonwoods and willows stabilize river banks, which keeps the river

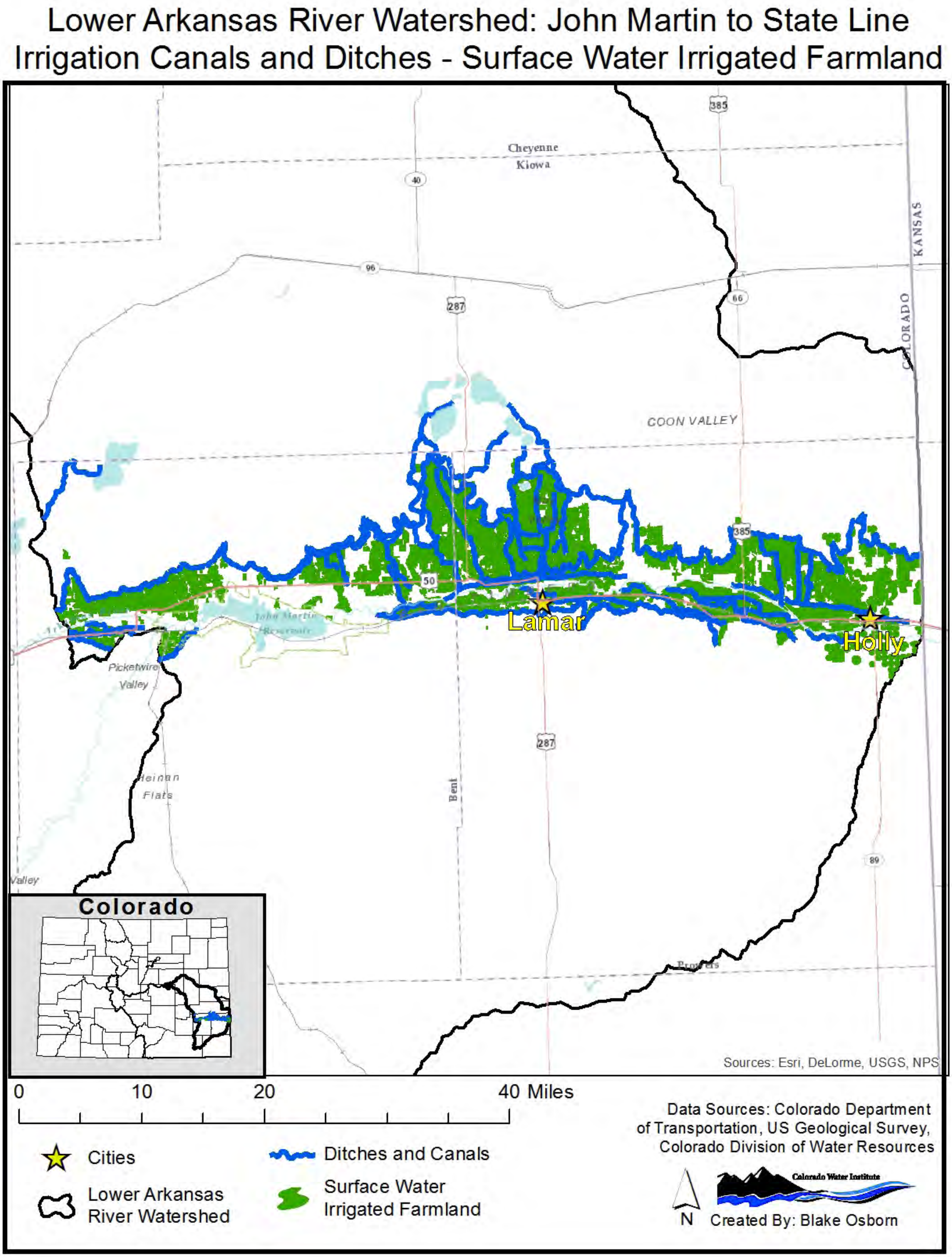

Figure 33: Irrigated farmland and ditch infrastrucutre in the Lower Arkansas River Watershed in 2016.

channel from migrating and eroding private and public lands. The value of riparian vegetation in preventing erosion is high, and the cost of replacing riparian vegetation with engineered levees or other streambank stabilization processes is also high. Another example of an ecosystem service is a grass waterway, or grass buffer strip, that can filter water that passes through it and simultaneously improve the water quality. Buffer strips are often placed at the edges of agricultural fields or along drainage ditches. When agricultural water runs off the field it can be filtered through this vegetation, and the processes that facilitate the growth of the plant (denitrification, microbial respiration, and oxidation) can remove pollutants from the water.

The Arkansas River Basin Roundtable Non-Consumptive Committee performed a GIS analysis of the entire Arkansas River Basin. That report shows significant non-consumptive uses in the Lower Arkansas River Basin that contribute greatly to the economy and provide valuable habitat and ecosystem services, including water quality benefits. In particular, the report identified much of the land around the reservoirs (John Martin Reservoir, Adobe Creek Reservoir, Nee Nosha and Nee Gronda Reservoirs, and Two Buttes Reservoir) as the land and waters containing the most important environmental and recreational places. Significant environmental and recreational classifications in the Lower Arkansas River Watershed include boating, fishing, waterfowl hunting, bird watching, threatened and endangered species protection, significant riparian and wetland communities, and Audubon-important bird areas.

4.1.3 Drinking Water

Municipal

Even though municipal drinking water is not the largest water use in the watershed, providing clean drinking water to the majority of the watershed's population is critical to ensuring a safe, healthy, and livable community. The population of this rural watershed, in 2018, is slightly over 26,000 people, with some of the population living in cities and many living outside of city limits. Within city limits, most residents are supplied with water from a water provider. The largest water providers in the watershed are the cities of Lamar, Limon, Eads, and Granada. Most of the water supplied to the citizens of these towns is derived from alluvial groundwater sources.

Water quality is a serious concern for municipal drinking water providers. Not only is it costly to treat water contaminated with pollutants, there are also stringent regulations on the pollutant concentrations that a drinking water provider can deliver to residents. Often, the most strict water quality standards exist to protect aquatic life, but municipal drinking water standards still can be some of the most stringent—not without reason. For example, following events in Flint, MI, and even Fountain, CO, providing safe drinking water is the responsibility of government entities (local, state, and federal), and failure to provide safe drinking water is damaging to human health and communities.

Arkansas Valley Conduit

As mentioned above, the cost to treat drinking water can be expensive, depending on the quality of the water source. Many small municipalities simply do not have enough resources (monetarily or otherwise) to purchase and use technology to adequately improve water quality. This is true of the Lower Arkansas River Watershed, which is composed of many small communities.

Currently, the Arkansas Valley Conduit is being proposed as a collective water source for smaller communities to bring cleaner water from upstream of the watershed to communities throughout the entire Lower Arkansas River Watershed. This water will be treated at a scale that makes the best use of resources and is financially viable for the small communities. In many ways, the conduit serves as a collaborative action model that harnesses the resources of small communities to scale treatment efforts to a point of financial and technical feasibility. Although the cost to transport cleaner water from upstream in the watershed is often prohibitive, the economies of scale and collective cost-sharing of the communities make it more feasible. Additionally, other government and non-government agencies are providing financial and technical assistance to offset the cost to the communities.

At the time of publication of this report, the Arkansas Valley Conduit is in the design and permitting phase, and the implementation of the conduit could be years in the future. Nevertheless, the idea and proposal of the Conduit underscores the critical point that water quality in the Lower Arkansas River Watershed is poor enough that a large and expensive project to pipe higher quality water from the upper watershed is the most efficient and cost-effective method for supplying healthy drinking water.

Non-Municipal

Many residents of the watershed do not live within a municipal service area and are required to supply their own drinking water. Where feasible, many rural homeowners drill wells to a variety of aquifers for a variety of domestic water uses. However, some rural homeowners must transport water to their homes, often from municipal water pumping stations. The latter method is costly and time-consuming but is often a homeowner's only option when groundwater is too deep and costly to access.

In most cases, rural homeowners get their water from a domestic well. These wells require a well permit, and the permit type is dependent on different factors such as lot size and the intended use of the water. The two most common water sources for homeowners with domestic wells are the Dakota Aquifer and Arkansas River alluvial groundwater. In some cases, and for some water uses, these wells may have to be augmented if they consume water within the river "system" out-of-priority. Some of the water quality issues common to the Dakota Aquifer include sulfates, salinity, alkalinity, and total dissolved solids.

4.1.4 Industrial

There are only two water rights in this watershed that are allowed to use water for strictly industrial uses. These two "industrial use only" rights are not located on the main stem of the Arkansas River, but rather on Middle Rush Creek in Lincoln County. This does not mean that these are the only two water rights in the watershed that use water for industrial purposes, but rather these are the only two water rights in the watershed that can only use water for industrial purposes. This illustrates that industrial water uses are not a major water use sector in this watershed.

In total, there are 46 water rights that can use water for industrial purposes, and these include a mix of absolute and conditional water rights. Most are multiple-use water rights, or decrees, where the water rights holder can use the water for multiple purposes. For example, a concrete company may have a water right to divert water from the Arkansas River for commercial or industrial uses. Similarly, a large canal company may have specific water rights that can be used for irrigation, industrial purposes, or even for municipal uses.

1.1.5 Water Quality Trading

Water quality trading has the potential to reduce pollutants in water bodies by focusing more attention and resources on feasible solutions that can be less expensive and more effective. Water quality pollutant trading can give flexibility to point-source dischargers that would otherwise spend large amounts of money to bring systems into compliance. The landscape of water quality trading is changing rapidly. The new memorandum on water quality trading released by the EPA on February 6, 2019, opens the door for pollutant trading in situations that did not previously exist. For this reason, water quality trading should be explored in the future when more certainty exists in the regulatory environment.

Water quality trading has the potential to be a market-based solution to address regional water quality issues in a way that financially supports producers and reduces costs to permitted dischargers. This market-based approach aligns with the feasibility expectations of many stakeholders in the Lower Arkansas River Watershed. Additionally, many of the point-source dischargers are small, and upgrading systems to meet water quality standards can be challenging. It may be more efficient to provide resources to nonpoint-source activities that have the potential to reduce pollutant loading significantly. If water quality trading is an option, it is absolutely necessary to measure, monitor, or model the exact load reductions from a BMP. This will ensure that both the integrity of the trading program and water quality benefits are realized.

4.2 Arkansas River Compact

Disclaimer: The author of this section is not a lawyer and none of the information presented below represents legal advice or legal interpretation.

The Arkansas River Compact (hereafter simply referred to as “the Compact”) is an agreement between the states of Colorado and Kansas and pertains to the rights and regulations of water administration for the Arkansas River. The Compact is a water sharing agreement, which became necessary to better manage the river using the prior appropriation system. Colorado, as a headwaters state, has many interstate river compacts, but the Arkansas River Compact is unique for many reasons.

Disagreements between Colorado and Kansas go back to the turn of the 20th century. As early as 1901, Kansas filed a lawsuit against Colorado in the Supreme Court of the United States claiming that Colorado and its citizens were responsible for “depriving and threatening to deprive the State of Kansas and its inhabitants of all the water heretofore accustomed to flow in the Arkansas River through its channel on the surface and through a subterranean course across the State of Kansas… (Kansas v. Colorado, 1902).”

This court case was substantial in that is gave the supreme court a new type of case law, one dealing with the interstate appropriation of natural resources “controlled and owned” by the public, but adjudicated to private entities. The Supreme Court’s decision takes a hard look at which branch of government (judicial or legislative) has the right to adjudicate or regulate such conflicts. In the end, the court saw this case as simply an adjudication plea by Kansas and ruled that the State of Kansas had not”…made out a case entitling it to a decree.” Also in the opinion is the suggestion for the two states to enter into an agreement, or compact, which allows for negotiations. Justice Brewer gave the opinion of the court.

In 1943, Colorado successfully sued Kansas in the US Supreme Court (Colorado v. Kansas, 1943). The ruling says Kansas users are not entitled to a specific apportionment of the waters of the Arkansas River (in second feet or acre feet), that further restraint should be exercised by Kansas with regards to litigation, and that not enough evidence was provided by Kansas to show that use has materially increased by Colorado to the detriment of Kansas.

The Compact was signed on December 14, 1948, and enacted in 1949. The major purpose of the compact is to “…settle existing disputes and remove causes of future controversy between the states of Colorado and Kansas, and between citizens of one and citizens of the other state, concerning the waters of the Arkansas River and their control, conservation, and utilization for irrigation and other beneficial purposes” (CO-KS Arkansas River Compact, 1949). One of the most substantial agreements in the Compact concerns the rules governing the operations of John Martin Reservoir (JMR). The Compact says storage potential in JMR can be used as an “account or pool” (or several different accounts) for the states of Colorado and Kansas to store water. However, when the water in the “conservation pool” drops below a certain quantity, Colorado is allowed 60% of the water flowing out of John Martin Reservoir (up to 600 cfs) and Kansas is entitled to 40% of the water flowing out of John Martin Reservoir (to a maximum of 400 cfs). The Compact specifies many other important water administration provisions, but this 60%-40% split is perhaps the most important. The Compact was signed by Henry C. Vidal, Gail L. Ireland, and Harry B. Mendenhall for Colorado and George S. Knapp, Edward F. Arn, William E. Leavitt, and Roland H. Tate for Kansas.

Unfortunately, the Compact has not been the perfect solution, and conflicts still exist between the two states regarding its interpretation. Moreover, the compact was written in a time when science and technology were developing, and we now have a better understanding of the hydrology of the system as well as better tools for using water more efficiently. As recently as 2015, the two states entered into an agreement on the methodology of a hydrologic model that simulates water allocation and water use. This model is a product of one of the more recent—and hotly debated—conflicts between the two states.

In 2003, the US Supreme Court was again involved in a dispute resulting from Kansas’ assertion that irriga-

Table 6: USGS stream monitoring gauges			
Monitoring Location	Agency and Station ID	Measured Parameter	Period of Record
Arkansas River at Grenada	USGS - 07134180	Discharge	1987 - present
		Gage Height	2018 - present
Arkansas River below John Martin Reservoir	USGS - 07130500	Water Temperature	2007 - present
		Discharge	1987 - present
		Gage Height	2018 - present
		Specific Conductance	2007 - present
Arkansas River at Lamar	USGS - 07133000	Discharge	1986 - present
		Gage Height	2018 - present
Arkansas River at Las Animas	USGS - 07124000	Water Temperature	2007 - present
		Discharge	1987 - present
		Gage Height	2018 - present
		Specific Conductance	2007 - present
Big Sandy Creek near Lamar	USGS - 07134100	Precipitation	2018 - present
		Discharge	1995 - present
		Gage Height	2018 - present

tion efficiency improvements were altering the natural hydrology of the river system. A special master for the court recommended that in fact, Colorado had been altering stream hydrology and therefore must develop a system to not injure Kansas users. This resulted in "use rules" being developed in 1997 and irrigation efficiency improvement rules being adopted in 2010. The rules regulate irrigation efficiency improvements, such as the conversion from flood irrigation to center pivot sprinklers, and require such conversions to acquire "new" water (augmentation water) that can be delivered to the stream at the same time, and in the same amount, as the previously inefficient system had been providing.

These rules have a substantial impact on water use, irrigation methods, and technology adoption by Colorado irrigators. The unintended consequences of these rules make it difficult to develop and implement irrigation efficiency improvements that have great potential for improving water quality. Many of the irrigation efficiency improvements would require new sources of water to augment return flows, and without anywhere to store this water, it will be difficult to support efficiency improvements to improve water quality. Therefore, to keep in accordance with the Compact Rules and still allow for efficiency improvements to help improve water quality, it is critical that more Lower Basin storage be considered as a place to store more augmentation water.

4. 3 Stream Flow Measurements

Proper management of the Arkansas River de-

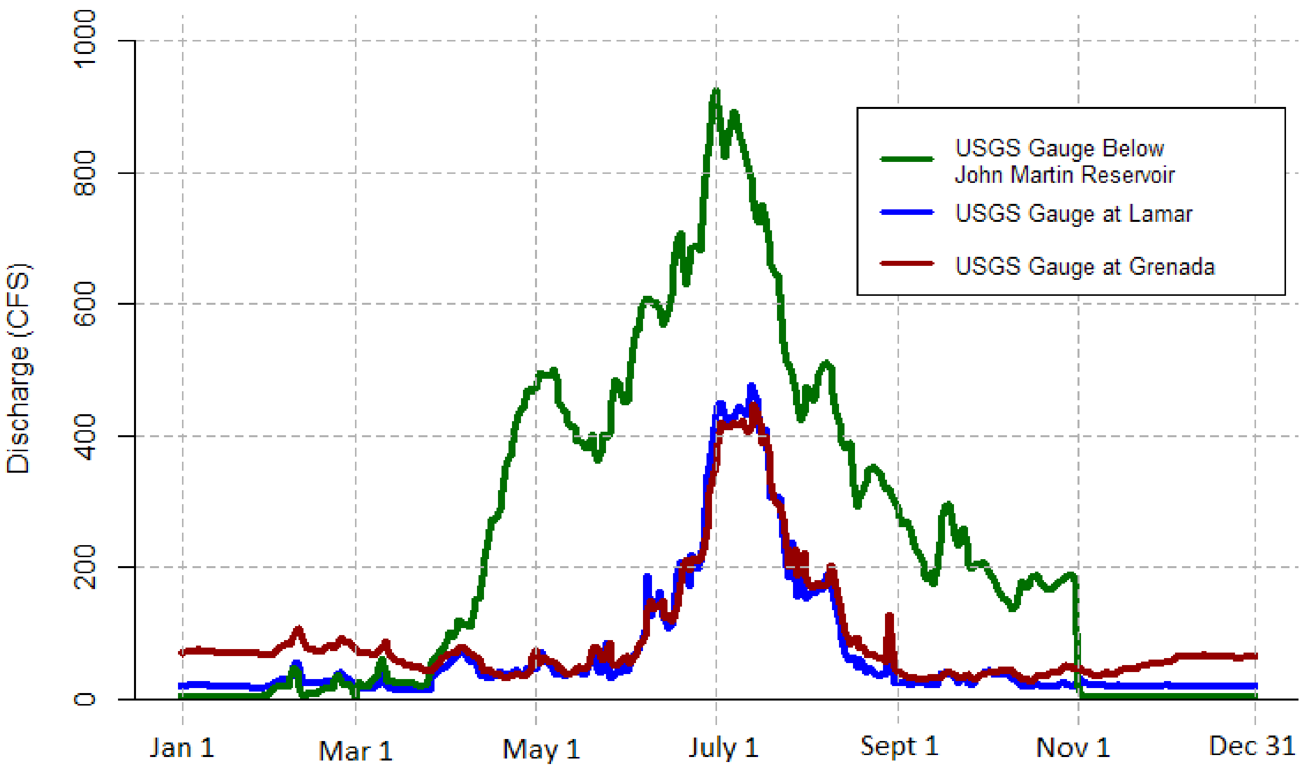

Figure 34: Hydrograph of the Arkansas River at three USGS streamflow gauging stations. The hydrograph represent daily average measurements from 2000-2015.

mands accurate measurements of the volume of water flowing in the river at several points. Water discharge in the Lower Arkansas River Watershed, reported in cubic feet per second (cfs), is measured by two entities, 1) the USGS and 2) the Colorado Department of Water Resources (CDWR). The USGS is the primary entity monitoring natural surface water sources, such as the main stem of the Arkansas River as well as major tributaries like Big Sandy Creek. As the administrative agency tasked with overseeing water rights, the Colorado Division of Water Resources has several water monitoring locations at major diversion points such as the Amity Canal and Lamar Canal. The CDWR also monitors lake levels in Adobe Creek and John Martin Reservoir.

4.3.1 Hydrographs

Hydrographs of river discharge are provided for three points along the main stem of the Arkansas River, as well as two tributaries that enter the river from the north. Each hydrograph was compiled from daily streamflow averages from 2000-2015. This period was chosen to coincide with the time period of water quality samples analyzed for this report. Due to river management decisions and changes in water administration, long-term hydrographs (30 year averages, or greater) may give different results.

4.3.1.1 Main Stem of the Arkansas River

The Arkansas River directly below JMR has the highest 30-year average streamflow, with peak flows occurring in early July at roughly 900 cfs (Figure 34). Major diversions to the Amity and Lamar Canals, as well as other smaller ditch systems, takes water from the river between JMR and Lamar, and this results in a lower average streamflows, as measured at Lamar. The 15-year average peak streamflow is 476 cfs, occurring in mid-July, which is similar to the 15-year average peak streamflow measured at Grenada, CO (448 cfs, mid-July). Return flows downstream from Lamar, either from agriculture or municipal discharge, contribute water to the river in non-irrigating months. This is represented as higher “base flows” during the months of November through March as measured at Grenada, CO.

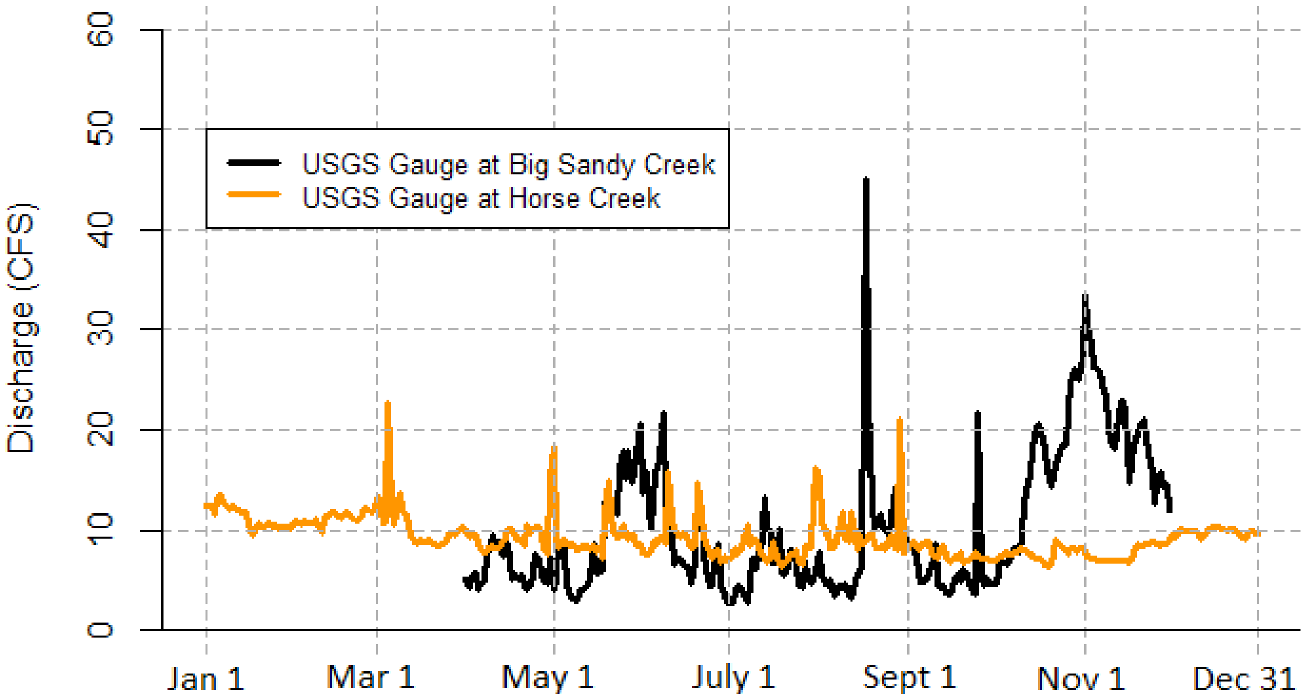

Figure 35: Hydrographs for two tributaries with USGS streamflow gauging stations: 1) Big Sandy Creek and 2) Horse Creek. Big Sandy Creek is monitored seasonally. Values represent daily averages from 2000-2015.

As mentioned previously, the Arkansas River below John Martin Reservoir is a closely monitored and administered system per the Arkansas River Compact agreement. A sign of this administration can be seen in the 15-year average hydrograph (2000- 2015) of the river directly below John Martin Reservoir. The reservoir releases little to no water from early November through mid-March. Water is only released from the reservoir during irrigating months.

This management strategy has benefits and drawbacks. It allows water users the ability to store all waters coming into JMR for later use in the irrigating season, thus securing more water for the water users when they need it the most. However, this management strategy is not suitable for the establishment or management of a fishery or other aquatic wildlife habitat. Regardless, JMR's position as an on-stream reservoir gives it the unique ability to store water for use later in the season.

Below JMR, significant diversions take water from the river to irrigate fields and augment the use of groundwater pumping. This can be seen in the smaller peak discharge averages in the river at Lamar and Grenada. Both locations' average peak discharge is around 450 cfs in mid-July, compared with over 900 cfs average peak discharge below JMR. River flows are highest in Lamar and Grenada from June 1 to September 1. During the winter and spring months, the river flows are typically marginal and only occur because of return flows from agriculture or municipal sources. At Lamar, the river averages 27 cfs December through February, while the river at Grenada averages 71 cfs for the same time period. This is most likely attributable to delayed agricultural return flows that return to the river as alluvial groundwater base flows. Surface return flows from agriculture, such as tailwater ditches and drains, are more instantaneous in their discharge of water and, therefore, would be less probable during the winter months. Additionally, no center-pivot sprinklers are pumping alluvial groundwater during the winter months, eliminating any pumping effect on base flows.

4.3.1.2 Tributaries to the Arkansas River

Two tributaries that provide significant contributions to streamflow below John Martin Reservoir are monitored for discharge. The first, Big Sandy Creek, enters the Arkansas River roughly 10 miles east of

Lamar. This gauge is only operated seasonally, beginning in April of each year and ending in November. The second, Wild Horse Creek, is monitored continuously. Both gauges are operated by the USGS.

Big Sandy Creek begins north and west of the town of Limon, CO. The total length of this creek is 204 miles. In most places the stream is ephemeral, only flowing when thunderstorms produce enough water to create flows. The terminal point of the creek enters the Arkansas River just east of Lamar, after having gone through intensively irrigated agricultural lands. The creek likely serves as a conduit for return flows from drainage ditches, or it could intercept shallow alluvial groundwater tables from over-irrigated farms, contributing to base flows.

Big Sandy Creek is monitored for flow near its confluence with the Arkansas River. This makes it difficult to understand flow conditions in the entire creek system, as this one sampling point may only represent conditions subject to land use practices such as agriculture. For this reason, the hydrograph can only be interpreted for information about mostly local conditions south of the Kiowa County line. The hydrograph still behaves like a thunderstorm-dominated discharge profile with sporadic, non-seasonal spikes in discharge that might be closely linked to heavy precipitation events. The hydrograph represents a 15-year average for each day of the year, and this graphical representation may not be sufficient to separate the effects of heavy rainfall from water uses.

Wild Horse Creek enters the Arkansas River near Holly, CO. This creek is monitored continuously by the USGS. The hydrograph of discharge on Wild Horse Creek implies a seasonality to water use in the adjacent agricultural lands, with lower flows in Wild Horse Creek during the irrigation season (May-November) and higher flows in the winter and spring months. This could be for two reasons: 1) one direct flow right exists on Wild Horse Creek (Wood Ditch), which may be taking water from the stream during irrigation season, or 2) agricultural return flows may be significantly contributing water to the creek during the winter and spring months via alluvial return flows. Either way, more water is available in Wild Horse Creek during winter months compared to summer months.

4.3.2 Impacts of Streamflow on Water Quality

We have all heard the phrase, “the solution to pollution is dilution.” Good, bad, or otherwise, this phrase does have scientific underpinnings that suggest the amount of water in a water body helps regulate the toxicity of pollutants in that water body. Sometimes, a water body can handle substantial amounts of a pollutant without creating concentrations that could harm living organisms.

Pollutant concentrations are dependent on water volume, and often, so is pollutant loading. Pollutant loading is the amount of a pollutant that enters a specific water body over a given time period. This is usually represented as pounds of pollutant per day, which has a direct correlation with pollutant concentrations. Pollutant concentrations are the values by which water quality standards are set, and the concentration determines the toxicity to living organisms. Concentrations represent the amount of pollutant in a standard volume of water, often represented as the amount of pollutant in one liter of water. Evaluating pollutant loading can be helpful for determining how much of a pollutant a water body can support without creating concentrations that are harmful to living organisms.

For example, if a stream is flowing at 50 cfs entering the Arkansas River with a selenium concentration of 10 µg/L, the total amount of selenium entering the river would be 2.7 pounds in a 24 hour period. If the stream has the same concentration of selenium (10 µg/L), but flows are elevated from a thunderstorm to 400 cfs, the total amount of selenium entering the river over a 24 hour period would be 21.6 pounds. This example is used as a basis to conceptualize the relationship between flow (in cfs) and pollutant concentration (in mass of pollutant per volume of water). In all likelihood, the pollutant concentration would dramatically decrease during a thunderstorm as more clean water is entering the stream and diluting the pollutant concentration. This would, of course, depend on the source of pollutant, as surface pollutants such as salts or nitrates could mobilized from the soil surface and actually increase concentrations. Selenium concentration from groundwater sources, on the other hand, would likely decrease in thunderstorm conditions.

Looking at this problem a slightly different way, let's assume the creek always contributes five pounds of selenium each day, regardless of streamflow. This could happen if water from alluvial groundwater enters the creek at a consistent rate with consistent concentrations of selenium. In the example above, the average daily concentration of selenium in the stream flowing at 50 cfs would be 25 µg/L, and the average daily concentration of selenium in the stream flowing at 400 cfs would be 3.1 µg/L.

Where this really matters is in the final concentration of selenium in the Arkansas River. In the first example, the selenium concentration was flow dependent, indicating a strong correlation with surface water loading. In the second example, the consistent addition of five pounds of selenium each day from groundwater inflow shows the "diluting" effect of higher stream flows. For a more detailed description of pollutant loading and to view analyses from data collected in the Lower Arkansas River Watershed, see Appendix 1-A.

4.4 Stream Flow Augmentation

Augmentation is the act of replacing water, in timing and amount, to a surface water body when a water user chooses to use water "out-of-priority." In this context, out-of-priority is used to describe when a water user is not allowed to use water because there is not sufficient water supplies in a river or stream to satisfy their needs and the needs of water users with more senior water rights. In this example, the more junior water user would not be permitted to use any water until streamflows increase to a level that all water rights holders with older water rights are satisfied. The variability in river flows creates uncertainty, and this is problematic for all water users, including irrigating farmers.

Most often, augmentation supplies are needed to replace depletions in alluvial groundwater from wells used to irrigate with center-pivot sprinklers. In 2011, to help consolidate and streamline the process of augmentation and reduce the engineering and administrative burden on farmers and ranchers, the Division of Water Resources created the *Compact Rules Governing Improvements to Surface Irrigation Systems in the Arkansas River Basin in CO*. For a more detailed description of these rules and their application, visit **water.state.co.us.**

To help address this uncertainty, a solution was created to allow more junior water rights the ability to still use water when they are out-of-priority by securing water, most often through a third party, to release back into the river so as to not impact more senior water rights holders. Commonly called "Rule 10," farmers or other water users can pay a third party with secured water rights (and most often water stored in reservoirs) to release some of the water to replace what the irrigator uses out-of-priority. This is a simplistic description; the concept of augmentation can be nuanced and subject to specific terms.

In Water District 67 of Division 2, a total of 44 water rights have the ability to be used for augmentation purposes. Of these 44 absolute rights, a total of 19,680 acre feet and 3,995 cfs can be used for augmentation purposes. One absolute water right is decreed for a total of 19,680 acre feet with a source water source of the Dakota Aquifer. All of the other absolute water rights are allocated in cfs, with the primary water source being the Arkansas River (39% of volumetric water flows), followed by the Pleasant Valley Drainage Ditch and the Wiley Drainage Ditch (17.5% each).

4.4.1 Augmentation and Water Quality

In the context of water quality, augmentation has the potential to greatly benefit water quality in two ways: 1) most of the water used in augmentation is derived from the Arkansas River, and typically is collected upstream of the point of use, and 2) augmentation gives water users the ability to be more efficient through the implementation of water quality BMPs.

The first benefit of augmentation applies the simple concept of dilution. In most cases, water is diverted upstream from the point of use and released to the system in timing and amount to replace for the out-of-priority use downstream. As discussed earlier,

Table 7: Summary statistics for water stored in John Martin Reservoir between 2000 and 2015					
	Minimum Value (year)	15th Percentile	Mean	85th Percentile	Maximum Value (year)
Water Volume in John Martin Reservoir (acre-feet)	2,534 (2006)	18,591	76,341	164,150	348,809 (2000)

water quality typically increases upstream, specifically when talking about the pollutant of concern for the Lower Arkansas River Watershed. Therefore, if higher quality water is captured upstream and released to the river to replace historic return flows (some of which would be degraded in water quality) pollutant concentrations would be reduced as the river finds chemical equilibrium between the more impaired local return flows and the less impaired augmentation waters.

The second benefit comes from the expansion of augmentation due to the implementation of BMPs to improve water quality. Two of the proposed BMPs that are already being implemented (irrigation efficiency improvements and canal/ditch sealing and lining) all require augmentation to replace historic return flows that will change with the implementation of the new BMPs. Augmentation supplies and equivalent storage capacity would need to be secured if BMPs are adopted at the scale needed to improve water quality to meet state standards. This also requires a close coordination with the Division of Water Resources to ensure the augmentation is appropriate and not infringing on compact obligations, as previously mentioned.

4.5 Water Storage

Securing augmentation water is one challenge, but securing the necessary storage capacity is another--and perhaps tougher—challenge. Augmentation depends on the ability to store water for release at a later date and, currently, there are finite locations to store water in the basin. However, the Lower Arkansas River Watershed is uniquely positioned to leverage the capacity of John Martin Reservoir as a possible storage vessel for future augmentation supplies. Between 2000 and 2016, JMR was only 22% percent full. The most water stored in JMR over that time period was 348,809 AF in 2000, and the least amount

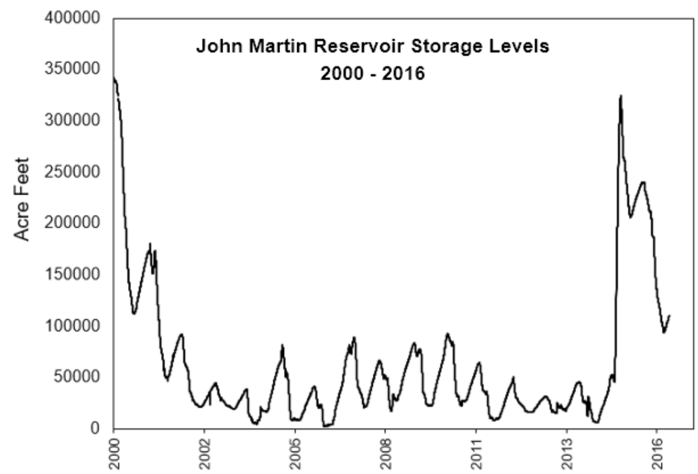

Figure 36: Storage levels in John Martin Reservoir 2000-2016 (in acre-feet).

of water was 2,534 in 2006 (Table 8). In total (and excluding flood control storage capacity), JMR can hold 340,771 AF of water. From average daily measurements taken from 2000-2016, John Martin Reservoir had 164,150 AF of water or less 85% of the time.

The biggest obstacle to storing water in JMR is not the lack of sufficient storage space in most years, but perhaps the effort of working out an agreement between many different water users that rely on JMR. This would include water users above and below JMR, but also the states of Colorado and Kansas, as well as the Army Corps of Engineers (the entity responsible for managing the reservoir, including the dam and outlets) and Colorado Parks and Wildlife (responsible for recreational activities in/around JMR). At the time of this writing, the Army Corps of Engineers is revising and releasing the John Martin Reservoir Master Plan. Challenges exist, but the opportunity to store excess augmentation water (with better water quality) in JMR is something that should be considered by all water users below JMR.

Chapter 5

Best Management Practices

5. BEST MANAGEMENT PRACTICES

Best Management Practices (BMPs) are recommended practices that have been scientifically assessed and field-tested to improve a resource of concern, economically evaluated to be cost effective, or validated through regulatory mechanisms to improve worker safety. In the context of water and land use, specifically agricultural land uses, BMPs can take many forms. For example, one BMP appropriate for the Lower Arkansas River Watershed is the installation of center pivot sprinklers. Irrigating crops is necessary in the Lower Arkansas River Watershed because water loss via transpiration greatly exceeds local precipitation. Historically, flood irrigation has been utilized as the main irrigation method, but the substantial water loss and labor costs associated with this method make it inefficient. Recent technological advances, such as center pivot or drip irrigation, have created alternatives that can increase the efficiency of irrigation applications and reduce labor costs. Therefore, reducing labor costs and water loss is advantageous, and the implementation of a center pivot would be considered a BMP.

Another example of a BMP is the enhancement and use of riparian buffer zones to improve water quality through chemical reduction, sorption to sediments, and volatilization of pollutants. Healthy riparian areas also provide ecosystem services such as bank stabilization and reduced erosion, nutrient regulation and mitigation, and wildlife habitat, among others. Healthy riparian areas help promote naturally appropriate stream morphology features. However, riparian vegetation consumes a significant amount of water—something water users in an over-appropriated system loathe. The result has been the removal of riparian vegetation, specifically woody tree species, and channel hardening to prevent stream migration and protect diversion structures. These interventions have unintended consequences, as many disturbed riparian areas have been invaded by tamarisk and Russian olive trees, two species with an incredible thirst for water. In other cases, weedy plants such as Russian thistle and kochia have colonized the disturbed soils along ditch banks or open drains. An appropriate BMP is to restore healthy riparian areas by removing invasive species and replanting native vegetation (trees, shrubs, and/or grasses). Restoring native riparian areas will help mediate water quality impacts from agriculture (specifically nutrients) and could also create conditions conducive to the removal of other harmful pollutants, such selenium (selenite) and nitrogen (nitrate) (Schultz et al. 2018).

These examples are just two BMPs that could be widely implemented throughout the watershed, but they may not be appropriate in all situations. Many other BMPs may be more desirable given local conditions, constraints, and opportunities. In total, 8 BMPs are preferable given the common environmental and economic conditions across the entire Lower Arkansas River Watershed. Details are listed below. These BMPs are not mutually exclusive, and several BMPs can be applied to agricultural operations to maximize water quality benefits. For example, increasing irrigation efficiency from flood irrigation to a center pivot allows for new water management opportunities, tillage treatments, and nutrient applications. This single change in irrigation method can expand opportunities to integrate soil health, nutrient management, and irrigation scheduling BMPs. In a larger context, applying different BMPs throughout the watershed is critical for capturing pollutants existing in different pathways of the hydrologic system (Shultz et al. 2017).

5.1 BMPs in LARW

Many efforts have been made over the years to identify appropriate BMPs with the best chance of improving water quality in the Lower Arkansas River Watershed. The most comprehensive effort to identify appropriate BMPs for this region has been from Colorado State University (CSU), specifically from the research and work of Dr. Timothy Gates and his many research partners and students, including Dr. Ryan Bailey. This team, led by Dr. Gates, has been working for more than 20 years to understand water quality problems in the Arkansas Basin, including extensive work below John Martin Reservoir. Their efforts have given water managers and water quality officials detailed understandings of where pollutants come from, how they get into subsurface and surface waters, and what actions can be taken to lessen the impacts from these pollutants. Attention has been given to the need to improve water quality not only to meet

Table 8: Since 2003, sprinkler irrigation has risen dramatically in the Lower Arkansas River Watershed. Flood irrigation is still the dominant irrigation method.					
	Year	2003	2010	2017	Percent Change (2003-2017)
Acres	Drip	0	425	0	0%
	Flood	130,344	191,600	101,317	-22%
	Sprinkler	1,459	36,206	38,857	2,564%
	TOTAL	**131,802**	**228,231**	**140,174**	**6%**
Number of Fields	Drip	0	11	0	0%
	Flood	4,985	7,197	4,772	-4%
	Sprinkler	27	437	504	1,767%
	TOTAL	**5,012**	**7,645**	**5,276**	**5%**

standards in groundwater and streams, but also to enhance crop productivity, namely to lower salinity.

The team from CSU has identified five major classes of BMPs with the potential to significantly improve water quality in the Lower Arkansas River Watershed. They include: 1) Irrigation Efficiency Improvements, 2) Canal Sealing and Lining, 3) Lease/Fallowing, 4) Nutrient Management Planning, and 5) Improved Riparian Buffers. Other BMPs, such as conservation tillage, irrigation scheduling, and soil moisture monitoring, can be considered “add-on” BMPs, as they can be used independently or in tandem with the five primary BMP’s to increase their effectiveness. The work of the CSU research team suggests that some BMPs will work better in specific parts of the watershed, and the net effect of using multiple BMPs greatly outweighs the use of only one BMP. This work has been critical and has set the stage for testing the implementation of these five BMPs, and a few others, to make meaningful water quality changes within the watershed. These BMPs still need further testing under a controlled conditions before money and effort are invested in scaling them to the watershed level.

In addition to the BMPs identified by the CSU team, other BMPs such as irrigation scheduling and conservation tillage are likely to play critical roles in improving water quality. These two BMPs have not been scientifically tested in the Lower Arkansas River Watershed, but they have been tested and verified in other parts of the watershed, state, and country. Their broad application makes them ideal BMPs to complement the five BMPs suggested by Dr. Gates’ team.

As an example, upgrading an irrigation system from flood to sprinkler allows for greater water management, using tools like the WISE irrigation scheduling tool or conservation tillage practices in the absence of field furrows. Center pivot sprinklers allow users to precisely control water applications, allowing for soil moisture monitoring to help make decisions about how much water the field and crops need at any given point in the growing season. The following is a discussion on the BMPs recommended for use in the Lower Arkansas River Watershed.

Many of the BMPs suggested below carry multiple benefits. This is deliberate, and feedback from stakeholders indicated that this was essential to successful implementation of water quality BMPs. Water quality was a concern for most stakeholders; however, improving water quality alone was not enough incentive for most stakeholders to change management activities and/or invest money in BMPs. This is especially true if the change could lead to greater risk in other aspects of

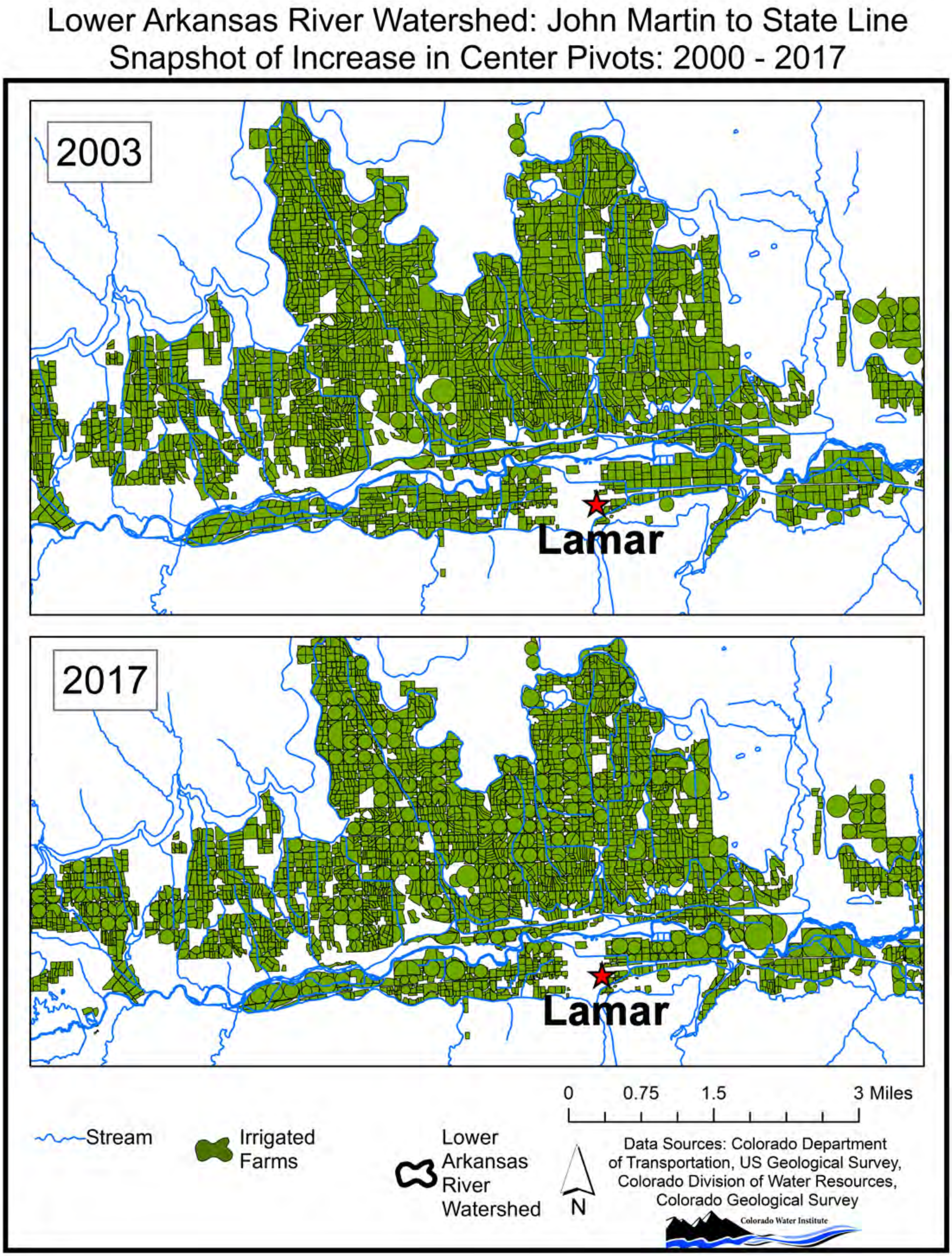

Figure 37: Sprinkler irrigation has increased dramatically in the Lower Arkansas River Watershed between 2003 and 2017.

their business—such as financial risk, safety concerns, or time management. Therefore, all the BMPs suggested below carry multiple benefits. It should be noted that most of the water management BMPs suggested below reduce climate/drought risks, as they can utilize alternative water sources, improve irrigation management, and/or reduce non-beneficial water losses.

5.1.1 Irrigation Efficiency Improvements

Irrigation efficiency improvements are most commonly the conversion of flood irrigation to center pivot sprinkler irrigation. Since 2003, there has been a 1,767% increase in the number of sprinklers in the Lower Arkansas River Watershed (Table 9, Figure 37).

Center pivot sprinklers can be considered a water quality BMP because they have the potential to reduce the amount of deep percolation and surface runoff compared with flood irrigation. The reduction in deep percolation is the primary benefit to water quality because less water is able to contact underground geologic formations that contain potential water quality pollutants such as selenium, uranium, and salts. This BMP is popular among stakeholders because it offers the chance to benefit water quality in addition to farming operations. It should be noted that not all center pivot installations will have the same water quality impact. Water quality benefits depend on the location of the center pivot in relation to water quality pollution sources and how water is applied and managed using the pivot.

Implementation of center pivots must be accompanied by a source of water to replace historical return flows that would occur via deep percolation from flood irrigation. This presents a hurdle; however, water supplies for augmentation are available through organizations such as the Lower Arkansas Water Management Association (LAWMA) and the Colorado Water Protective and Development Association (CWPDA). One of the critical and limiting factors to sprinkler implementation is the ability to store water for augmented release that corresponds with historic timing and at specific locations on the river. Storage and supply constraints must continue to be addressed by water management agencies.

An alternative to installing irrigation improvements is increasing the application efficiency of current surface irrigation systems. Physical attributes of each field (i.e., field length, slope, soil type, furrow design, etc.) contribute to the application efficiency. Increasing the application efficiency could lead to multiple benefits, such as increasing application uniformity, expanding water to historical acreages, and reducing water lost to deep percolation and surface runoff. This could be accomplished by altering field lengths, grading the land, changing set sizes to manage application rates to achieve rapid advance and minimize tailwater runoff and deep percolation, etc. Such improvements can result in substantial increases in efficiency, with lower costs than sprinklers.

Benefits

1. Increased application efficiency and the ability to carefully manage root zone soil moisture
2. Reduced labor costs of sprinklers as compared with flood irrigation
3. Technical support teams and cost-share programs exist to lessen financial burdens
4. Increased opportunity to implement other water saving BMPs, such as irrigation scheduling and conservation tillage
5. Better and more uniform crop yields
6. Ability to control nutrient applications through fertigation

Challenges

1. Sprinklers are expensive, both in up-front costs and potential repair costs
2. Technical learning curve
3. Salinity management and leaching fractions need to be managed
4. Need to secure and/or pay for augmentation water (or join a Rule 10 plan)

5.1.2 Lease-Fallowing

Lease fallowing is another water quality BMP, which, much like irrigation efficiency improvements, benefit water quality. By removing water temporarily from a field and transferring it to another place for use, there is no opportunity for water to percolate through the soil and contact bedrock materials containing water quality pollutants. This BMP is most appropriately applied by mutual ditch/canal companies to make enough water available for transfer to a new use. One example of a successful lease-fallow program is the Catlin Pilot project run by the Lower Arkansas Valley Water Conservancy District. Another example is the Town of Windsor and their agreement with the Cache laPoudre Ditch in Northern Colorado.

Lease-fallow agreements are relatively new to Colorado, and the details of such transactions are still being figured out. The Colorado Water Plan sets a goal to have 50,000 acres enrolled in lease-fallow projects by 2030 across the entire state. There are also hurdles around the methods of "exchanging" water that would normally be used further downstream to a new point of use upstream. For the Lower Arkansas River Watershed, this issue is critical as most of the water would likely be leased to users upstream. This highlights the need for additional storage lower in the Arkansas River Basin to accommodate such exchanges.

Benefits

1. Potentially creates income for producers without the costs of growing a crop
2. Does not necessitate the purchase of water rights for cities and the permanent dry-up of the fields
3. Can be done at scales, including cooperatives, that benefit farming communities and also cities

Challenges

1. Necessitates strict weed management on fallowed fields
2. Potential increase in erosion from lack of crop residue
3. Could reduce river flows if the historic compustive use water is transferred to an upstream user, potentially lessening the diluting effect

5.1.3 Nutrient Management Planning

The supplemental addition of nutrients via fertilizers or manure is critical to growing healthy and productive crops. Nitrogen, the most commonly limiting nutrients to plants, is most often applied to the surface of fields as manure or anhydrous ammonia. Nitrogen and its derivatives (nitrate, nitrite, ammonia, etc.) are water quality pollutants, and in some cases, they exceed state interim water quality standards. However, nitrogen (more specifically nitrate) has the chemical structure to facilitate the dissolving of selenium, uranium, and sulfur from parent materials, such as shale or shale-derived soils (Gates et al., 2016). For this reason, excess nitrogen has the potential to negatively impact water quality in two ways: 1) by excess amounts of nitrogen in surface waters and 2) through oxidation reactions with trace elements and salts, which allow these constituents to migrate from the bedrock material into surface and groundwater.

By managing the amount of nutrients applied, producers can realize benefits in the form of increased crop yields, decreased weed pressure, and decreased algal issues in ponds or ditches. One strategy for nutrient management is called "split season application." This BMP suggests producers apply nitrogen in four separate applications throughout plant growth stages, with enough nitrogen supplied to promote plant health in that stage without over-application. The over-application of nitrogen leads to nitrogen loss through runoff or deep percolation, and split season nitrogen application reduces the likelihood of that occurring. It also has the potential to reduce the total amount of nitrogen needed, therefore saving producers money. More information on split season nitrogen applications and nutrient management planning worksheets can be found in *Best Management Practices for Agricultural Nitrogen Application* (**waterquality.colostate.edu/documents/BMP_172_N.pdf**).

Benefits

1. Nitrogen management plans can be developed by farmers for free
2. Increases farmers' chances to save money on reduced fertilizer applications
3. Creates a more accurate understanding of nitrogen inputs and potential yield benefits
4. Most nitrogen applications are based on single yearly soil tests; more options exist for producers to manage nitrogen applications to help improve

yields, save money, and reduce the amount of nitrogen leaving the field

Challenges

1. Potential yield losses if not done properly
2. If applied by tractor, increased fuel consumption for split season nitrogen applications

5.1.3.1 Soil Health Practices

Understanding soil health means assessing and managing soil so that it functions optimally now and is not degraded for future use. – Natural Resources Conservation Service

Soil, like water, is a foundational component for any agricultural ecosystem. The term soil health is broad in its definition and mostly restricted to discussions on agriculture. The term soil "health" implies many factors are responsible for creating healthy soil, some of which include appropriate numbers and diversity of soil microbes, soil organic matter, soil nutrients, etc. Soil health is so encompassing that different scientific sources list soil health factors differently based upon empirical research. In general, soil health factors can be described and assessed against three main criteria: 1) physical properties of the soil, 2) chemical properties of the soil, and 3) biological properties of the soil.

Kibblewhite et al. (2007) make a great case for assessing soil health through two lenses: 1) a reductionist view, where each of the three soil health factors (physical, chemical, biological) are measured independently and used to quantify "soil health", or 2) an integrated approach, where all three factors are assessed for their interactions. The second approach (integrated) is considered a more holistic way of looking at the soil environment, whereas the first approach (reductionist) is more interested in quantifying the individual components within the soil (i.e. % organic matter, texture, field capacity, etc.). Both approaches are important, and understanding both approaches to assessing soil health is critical for managing soil—and water—resources.

In conventional, large-scale agriculture, soil health practices are dependent on two main BMPs: soil tillage practices and cover cropping. Cover crops are gaining more attention and tend to be evaluated from an "integrated" soil health perspective, but more work is needed to quantify the effects of cover crops on soil health properties. Tillage treatments have been studied for decades, and their impacts on soil health properties are well understood (Gebhardt et al., 1985). Conservation tillage utilizes a reductionist principle of reduced soil disturbance to help cultivate a healthier soil ecosystem. This includes consistent ground cover, incorporating nutrient-rich organic matter into soil, and reducing compaction, among others. Conservation tillage includes reduced-till, strip-till, and no-till practices.

Conservation tillage has many benefits, including reduced soil disturbance and compaction, enhancement of residue management BMPs (which help reduce evapotranspiration and soil loss from non-beneficial water use), and reduced operating costs of tractor use and maintenance. Residue management, and more specifically leaving crop residue in the field, limits the erosive impacts from wind and rain and reduces energy fluxes into the soil, which often account for increased soil evaporation. Conservation tillage and residue management are most easily practiced under center pivot or sprinkler irrigation; however, residue management and reduced tillage is possible in furrow irrigated systems. Wardle et al. (2015) published a technical report entitled Guidelines for Using Conservation Tillage Under Furrow Irrigation, which offers step-by-step guidance for implementing conservation tillage to improve soil health in furrow irrigated fields. There are several environmental and economic benefits from different conservation tillage practices, several of which are outlined in the report mentioned above.

Soil organic matter (SOM), one metric of soil health, has been studied extensively for its ability to retain water in the soil. Some studies have found that for each one-percent increase in SOM, an additional 2,850 gallons of water can be retained in the top 15 centimeters of soil covering one acre (Libohova et al. 2018). The greatest increase in water holding capacity is found when SOM is increased in sandy soils (Hudson, 1994; Libohova et al., 2018). Sandy soils lack the ability to hold water compared with clay and silty soils, so increasing the ability of the soil to capture water by adhering to SOM is more significant in sandy soils. Retaining more water in the soil would provide a water quality benefit by eliminating the movement of water (either surface or sub-surface), which carries nutrients, salts, and other pollutants to groundwater or streams. Improving soil health can also create conditions for increased nutrient retention and, therefore, less fertilizer would be needed.

Increasing SOM is only one metric of soil health, and measuring its impacts on water holding capacity is a way of assessing soil through a reductionist lens. However, SOM does more than just increase the water holding capacity: it also promotes microbial activity, which can increase nutrient concentrations, increase soil structure, and aggregate stability (Verhulst et al, 2010). Improving soil health could improve the overall effectiveness of nutrient management planning, another BMP suggested by this plan.

The practice of improving soil health and its effect on non-point source loading of pollutants such as selenium and uranium is not yet well understood. Most likely, soil health is indirectly related to non-point source loading by impacting the soil-water cycle and perhaps, to some degree, the enhancement of the microbial communities of the soil. Soil health, or more specifically conservation tillage treatments, have been shown to reduce non-point source loading of certain parameters such as sediment, nitrate-ammonia, and phosphate. More work is needed to better understand the relationship between soil health and non-point source loading of all parameters. The literature is not complete in its expected load reductions from broad-based soil health practices, and for this reason, it is difficult to estimate load reductions of this soil health BMP.

Benefits

1. Increasing soil organic matter can increase water holding capacity, to a point
2. Conservation tillage practices can inhibit surface runoff and promote infiltration
3. Soil aggregate stability is maintained with fewer tillage treatments
4. Soil microbes can provide benefits to plants by enhancing nutrient uptake

Challenges

1. Leaching fractions must be maintained to avoid salt accumulation in the root zone
2. Conservation tillage equipment is expensive and sometimes in short supply

5.1.4 Sealing/Lining On-farm Ditches

On-farm ditches, such as supply or tail water ditches, serve important functions in irrigation water management. These ditches are considered separate from "off-farm ditches" because they are used, managed, and operated by an individual farmer for the purposes of diverting water from the main canal for distribution and application to fields or for taking excess water to a return conveyance feature such as a creek or drain. In furrow irrigated systems, these on-farm ditches are necessary to bring water to fields, move water to points of use, and carry excess water to streams or drains. In many cases, farmers need flexibility in where the ditches are placed and how big they need to be constructed based on crop type grown, size of field, and soil types. For this reason, many carry-water ditches are simple earthen ditches built using tractor implements. These ditches are often unlined or sealed, leading to seepage losses, which in some cases can be significant.

This BMP carries both water quality and water quantity benefits. First, lining or sealing ditches reduces the amount of water percolating deep within the soil profile and, therefore, reduces the chance that water quality pollutants are mobilized from the soil or bedrock. Second, lining and sealing canals creates an added benefit by increasing the transportation efficiency and making more water available to be applied to a field, assuming the fields were "water-short" or unintentionally deficit irrigated before the ditch was lined. Though depletion of return flows (which results from seepage reduction when canals are lined and sealed) requires augmentation, on-farm ditch lining and sealing, as defined by the Irrigation Efficiency Improvement Rules (CDWR), does not.

Three BMPs can be employed to help reduce the amount of water seeping from on-farm ditches: 1) lining with concrete or pipe, 2) sealing with polyacrylamide, and 3) earthen ditch compaction. Significant progress has been made by using BMP #1 and installing gated pipe as a replacement for on-farm supply ditches. This BMP increases the transportation efficiency and replaces the practice of damming ditches and using siphon tubes. Concrete can also be used to line ditches on-farm. These two methods have higher initial costs compared with sealing using polymers, but the longevity and payback over several years make them most attractive. Polyacrylamide is an effective way to seal ditches but must be applied at least annually. All three methods, lining with concrete or pipe, and sealing with polyamers are available cost-share options for application to on-farm ditches with the Natural Resources Conservation Services Environmental Quality Incentives Program (EQIP) program. On the other end of the spectrum, earthen ditch compaction is the most cost effective but requires the most annual maintenance (Osborn et al., 2017). Currently, the Lower Arkansas Valley Water Conservancy District and the NRCS are implementing separate projects focused on on-farm ditch lining.

Off-farm ditches and larger canals experience significant and, in many cases, more seepage loss compared with on-farm ditches. Many of the strategies suggested for on-farm ditch lining/sealing can also apply to canals and off-farm ditches, however, the scale of these projects can be much greater. This requires much more effort, and costs can increase rapidly. Lining canals should be explored, where feasible.

Benefits

1. Decreased flow into groundwater with associated shallow groundwater (waterlogging and salinization) and dissolution and mobilization of pollutants in return flow to the river and tributaries
2. Sealing ditches with polyacrylamide is cheaper

Challenges

1. Maintaining lined ditches and protecting them from sedimentation
2. Lining ditches in concrete can be expensive
3. Polyacrylamide sealing is temporary and needs to be applied annually

5.1.5 Pond Lining

Much like lining carry-water ditches, lining or sealing

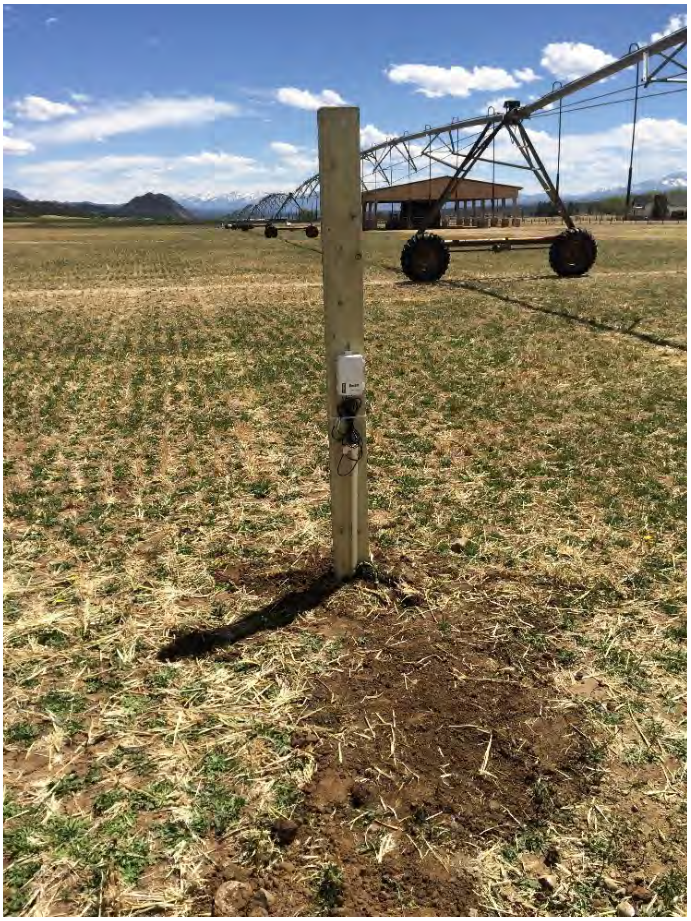

Figure 38: Soil moisture sensors and data loggers in a field outside of Buena Vista, CO. Photo courtesy of Blake Osborn.

ponds can be an effective way to reduce the amount of water lost to deep percolation. In terms of water quantity, the water lost to deep percolation can be a benefit, as it can be used to "replace" historic return flows as a source of "augmentation" water. However, this benefit can be outweighed by the negative water quality impacts the leached water creates if water quality pollutants exist in the subsurface soil or bedrock.

Ponds are often a necessary feature of installing irrigation efficiency improvements such as center pivot sprinklers. They allow sediment to settle and create stable "head," or gravitational pressure, which ultimately dictates water delivery rates to the center pivot. By stabilizing the head, the center pivot is guaranteed a steady supply of water at a constant pressure. Understanding the need for ponds, while also accounting for water quality impacts, will be

Table 9: Implementation table with recommended BMPs, details, financial and technical support partners, goals, and priorities.

BMP Name	Implementation Details [A]	Primary Implementation Partners	Technical Support Partners
Irrigation Efficiency Improvements	Increase application efficiency: • convert from flood irrigation to sprinkler or drip irrigation • land management practices such as leveling, conservation tillage, surge irrigation	Individual farmers	• NRCS (project design) [E,F] • Zimmatic (sprinkler support team; project design/support) • Augmentation groups (replacement water)
Lease/Fallow Project	*If given the option*, fallow fields that: • require longer-distance water transpot • are furthest from surface water sources • are least productive • exist over shale bedrock formations • encourage state legislation to expand lease/fallow options	• Individual farmers • Canal companies • Water management groups • Municipalities	• Colorado state legislature (legal authority) • Colorado Division of Water Resources (admistrative support) • Augmentation groups (replacement water)
Nutrient Management Planning	At the farm scale: • test for nutrients in irrigation water • develop nutrient management plans • visit coagnutrients.colostate.edu	Individual farmers	• Conservation Districts, CSU Extension, and NRCS (print materials, fertilizer recommendations) • Private crop consultants (nutritent testing and recommendations)
Sealing/Lining On-Farm Ditches	Increase transportation efficiency: • install underground transport pipe where feasible • install gated pipe • seal furrows with polyacrylamide	Individual farmers	• NRCS (technical project design) [E,F] • Conservation Districts (project coordination)
Pond Lining	Increase storage efficiency: • line ponds with synthetic or natural clay liners • use liners in head stabilization ponds or waste lagoons • require new irrigation improvements that need ponds to be lined	Individual farmers	• NRCS (technical project design) [E,F] • Augmentation groups (replacement water and rule compliance) • Conservation Districts (project coordination)
Riparian Buffer Improvements	Utilize ecosystem services: • use appropriate and native vegetation in riparian areas • develop maintenance plans for large woody plants • use appropriate weed-suppression techniques • work with RiversEdge West to eradicate tamarisk and Russian olive • open drainage ditches and grass waterways should be prioritized	• Individual farmers • Agricultural drainage districts • Colorado Parks and Wildlife • CSU	• NRCS (project design) [E,F] • RiversEdge West (project consultation) • CSU Extension and Colorado State Forest Service (project matierals, consultation) • Colorado Parks and Wildlife (project consultation) • Conservation Districts (project coordination)
Irrigation Scheduling	Increase application efficiency: • promote soil-based or ET-based irrigation scheduling • recommend easy-to-use smartphone apps from CSU (WISE) or Lindsay (FieldNET)	Individual farmers	• CSU Extension (host workshops, distribute free software) • Conservation Districts (provide demonstration or field-day opportunities)
Soil Moisture Monitoring	Increase application efficiency: • install soil moisture monitoring equipment under center-pivot sprinklers • accurately monitor soil moisture to optimize water conservation and plant health	Individual farmers	• CSU Extension (provide trainings and/or technical support) • Conservation Districts (provide demonstration or field-day opportunities)

A. *The Implementation Details are rough guidelines and further information should be gathered for each specific project.*
B. *Irrigation Improvement Rules of 2011*
C. *On-farm management practices such as land leveling or conservation tillage are not subject to augmentation.*

Goal	Subject to Augmentation?	Project Funding Source	Priority	Cost Category
1. Continue 15% annual increase in sprinklers installed in the watershed [D] 2. Create conservation tillage program with incentives	Yes [B,C]	• CDPHE (Section 319 funds) • NRCS (EQIP) • Public/private partnerships	High	$$
1. At least 1,000 cumulative acres in lease-fallow by 2025	Yes [B,C]	• Varies; private agreements between lessees and lessors	Medium	$ - $$$
1. 75% of farms within Conservation Districts will have nutrient management plans by 2023	No	• CSU Extension (provide free tools and training) • Conservation Districts (water quality testing) • Individual farmers (water quality testing)	Medium	$
1. 5,000 linear feet of on-farm transfer pipes will be lined each year	No	• CDPHE (Section 319 funds) • NRCS (EQIP)	High	$$
1. All new head stabilization ponds over shale bedrock formations will be lined	Yes [B,C]	• CDPHE (Section 319 funds) • NRCS (EQIP)	Medium	$$
1. Implement riparian buffer demonstration project/study 2. Install riprian buffer fencing (Adobe Creek) 3. Replant 6 hectares of historic riparian area per year with native species	No	• CDPHE (Section 319 funds) • CSCB (matching grant program) • CWCB (Watershed Restoration Grant Program, Healthy Rivers Fund, Water Supply Reserve Account) • NRCS (Conservation Stewardship Program [CSP], EQIP)	Medium	$
1. Require all new EQIP and Conservation District cost-share recipients to implement scheduling 2. 5% annual increase in existing pivot owners who use irrigation scheduling	No	• CSU Extension (provide free irrigation schedul-ing tools and trainings)	Medium	$
1. Grant 5 cost-share applications per year (Conservation Districts and NRCS) for soil moisture monitoring	No	• CSCB and Conservation Districts (matching grant program) • NRCS (EQIP)	Low	$$

D. From 2010-2017, the number of sprinkler pivots increase, on average, 15% per year.

E. efotg.sc.egov.usda.gov

F. NRCS National Engineering Handbook 650, Part 650 - Engineering Field Handbook critical when new irrigation efficiency improvements are installed. The locations of head stabilization ponds are most often dictated by topography and site suitability. By considering a pond's proximity to shale bedrock formations or soils with high potential for pollutant occurrence is part of the siting criteria, negative impacts to water quality can be avoided when new ponds are developed.

Benefits

1. Reduction in water lost to deep percolation
2. Assuming fields were being unintentionally deficit irrigated, more water may be available for field application

Challenges

1. Pond maintenance and dredging of accumulated sediment
2. Need to supply augmentation water to account for evaporative losses
3. Limited space within a field limits the location of their placement

5.1.6 Riparian Zone Improvements

Riparian zones are important ecosystems that provide critical services and functions that improve water quality, provide wildlife habitat, and regulate streamflow. Healthy riparian habitats can look different depending on the local topography, ecology, and water availability. For example, the riparian zone located along the main stem of the Arkansas River below John Martin Reservoir generally consists of a wide floodplain, with a meandering and sinuous stream channel and large woody plants along with shrubs and grasses. This area has relatively stable water supplies from the river and shallow alluvial aquifer associated with irrigation return flows, which allows for higher water-use vegetation to occur, such as cottonwood trees and willows. The riparian area of Graveyard Creek, however, is much different, with a narrower stream channel flowing through steeper slopes and less abundant water to support high water-use plants.

The historical context and functionality of many riparian areas is hard to determine because many of their features have been altered. Stream banks have been hardened to prevent erosion, and vegetation has been reduced by extended, unrested grazing or removal. In many cases, removal of native vegetation and disturbances of the riparian ecosystem have allowed non-native plants to colonize riparian areas, often with very harmful consequences. Tamarisk (or saltcedar) is a common riparian invader that uses large quantities of water and bio-accumulates salts in the leaves. When leaves fall and accumulate on the ground, these salts can then become a salt source to the adjacent stream. In other cases, all vegetation, including invasive species, has been removed to create more of a "ditch-like" condition on these natural streams. The unintended consequences of doing this includes higher streambank erosion, lower threshold for nutrient and trace element regulation, and increased water temperatures.

Restoring riparian areas to their original health and function can help promote conditions that have positive water quality benefits. Riparian vegetation can also help moderate stream flows by stabilizing channels and promoting sinuosity, which leads to greater "bank storage," or alluvial groundwater tables. More alluvial groundwater storage promotes greater sustained base-flows, which can help to regulate pollutant concentrations throughout the year. Productive riparian areas also help regulate nutrients and trace elements through chemical reduction, sorption, plant uptake, and microbial volatilization, which lowers potential pollutant transport to the river and tributaries.

Benefits

1. Nutrient and trace element filtration and regulation by plants and microbes
2. Provides wildlife habitat
3. Regulates streamflow

Challenges

1. Can be expensive to implement
2. Technical expertise needed to reclaim degraded riparian zones

5.1.7 Irrigation Scheduling

Irrigation scheduling is a strategy that consists of managing the timing and amount of irrigation water applications to fields to more accurately meet crop water requirements without excessive tailwater runoff

Table 10: Load reduction needed to obtain water quality standards.							
USGS Flow Station	Parameter	Statistical Description	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
7124000 (near Las Animas, CO)	Selenium	Load average (lbs/day)	35.7	12.74	6.93	2.6987	0.07947
		Average needed to achieve standard (lbs/day)	15.6	5.20	2.53	1.2380	0.4026
		Reduction needed to achieve standard (lbs/day)	20.1	7.54	4.40	1.4607	0.3921
		Percent reduction needed to achieve standard*	56%	59%	63%	54%	49%
	Nitrogen	Load average (lbs/day)	6769.1	2318.87	1762.01	190.9715	120.1482
		Average needed to achieve standard (lbs/day)	6678.7	2257.47	1105.62	540.9425	175.9183
		Reduction needed to achieve standard (lbs/day)	90.4	61.40	656.39	-349.9710	-55.7701
		Percent reduction needed to achieve standard*	1%	3%	37%	-183%	-46%
	Uranium	Load average (lbs/day)	50.7	26.66	15.29	9.2066	4.3851
	Manganese	Load average (lbs/day)	22.0	6.77	14.41	19.4200	5.8510
		Average needed to achieve standard (lbs/day)	631.3	213.39	104.51	51.1339	166291
		Reduction needed to achieve standard (lbs/day)	-609.3	-206.62	-90.10	-31.7139	-10.7781
		Percent reduction needed to achieve standard*	-2771%	-3051%	-625%	-163%	-184%
7130500 (immediately below John Martin Dam)	Selenium	Load average (lbs/day)	44.4	18.49	10.31	0.4519	0.0414
		Average needed to achieve standard (lbs/day)	26.9	12.53	3.66	0.2987	0.0273
		Reduction needed to achieve standard (lbs/day)	17.5	5.95	6.65	0.1532	0.0142
		Percent reduction needed to achieve standard*	39%	32%	64%	34%	34%
	Nitrogen	Load average (lbs/day)	3691.9	2829.28	1183.92	59.7891	11.4467
		Average needed to achieve standard (lbs/day)	11760.3	5476.51	1599.07	130.4977	11.9075
		Reduction needed to achieve standard (lbs/day)	-8068.4	-2647.23	-415.15	-70.7086	-0.4608
		Percent reduction needed to achieve standard*	-219%	-94%	-35%	-118%	-4%
	Uranium	Load average (lbs/day)	58.7	20.75	No Data	0.8231	0.1133
	Manganese	Load average (lbs/day)	488.8	231.03	37.47	14.2604	2.2535
		Average needed to achieve standard (lbs/day)	1111.7	517.94	151.11	12.2289	1.1256
		Reduction needed to achieve standard (lbs/day)	-622.9	-286.91	-113.64	2.0316	1.1279
		Percent reduction needed to achieve standard*	-127%	-124%	-303%	14%	50%
	Arsenic	Load average (lbs/day)	13.0	7.03	No Data	No Data	0.0157
		Average needed to achieve standard (lbs/day)	0.1	0.05	0.02	.0054	0.0003
		Reduction needed to achieve standard (lbs/day)	12.9	6.98	No Data	No Data	0.0154
		Percent reduction needed to achieve standard*	99%	99%	No Data	No Data	98%
7133000 (near Lamar, CO)	Selenium	Load average (lbs/day)	20.9	3.68	1.50	0.7853	0.3342
		Average needed to achieve standard (lbs/day)	13.5	1.26	0.47	0.2749	0.1397
		Reduction needed to achieve standard (lbs/day)	7.4	2.42	1.02	0.5105	0.1946
		Percent reduction needed to achieve standard*	36%	66%	68%	65%	58%
	Nitrogen	Load average (lbs/day)	3186.7	569.18	182.24	104.1839	53.9640
		Average needed to achieve standard (lbs/day)	5873.6	548.15	207.52	120.0383	60.9385
		Reduction needed to achieve standard (lbs/day)	-2686.9	21.03	-25.28	-15.8544	-6.9746
		Percent reduction needed to achieve standard*	-84%	4%	-14%	-15%	-13%
	Uranium	Load average (lbs/day)	63.2	9.52	4.29	3.0666	2.4578
	Manganese	Load average (lbs/day)	39.8	28.28	18.48	10.3478	4.2007
		Average needed to achieve standard (lbs/day)	555.2	51.81	19.62	11.3469	5.7604
		Reduction needed to achieve standard (lbs/day)	-515.4	-23.53	-1.13	-0.9991	-1.5597
		Percent reduction needed to achieve standard*	-1294%	-83%	6%	-10%	-37%
	Arsenic	Load average (lbs/day)	10.0	0.92	0.31	No Data	No Data
		Average needed to achieve standard (lbs/day)	0.1	0.01	0.00	No Data	No Data
		Reduction needed to achieve standard (lbs/day)	10.0	0.91	0.31	No Data	No Data
		Percent reduction needed to achieve standard*	99%	99%	99%	No Data	No Data

**Positive values indicate a reduction is needed, negative values indicate no reduction is needed.*

Table 11: Expected load reductions for each BMP given current conditions of water use and administration.							
BMP Name	Expected Load Reduction [1]						
	Selenium	Urnanium	Nitrate	Arsenic	Maganese	Sulfate	Iron
Irrigation Efficiency Improvements [2]	6.5-48.3	13.2-126	19.9-363	5.0-11.9	0-462	199.,056-497,642	0-4,177
Lease/Fallow Project [3.4]	2.5-18.3	5.0-47.9	7.6-137	1.9-4.5	0-386	75,7581-188,953	0-1,586
Nutrient Management Planning [7]	-	-	162,846 (total nitrogen)	-	-	-	-
Sealing/Lining On-Farm Ditches [5]	4.8-36.2	9.9-94.5	14.9-272	3.7-8.9	0-346	149,118-372,794	0-3,129
Pond Lining [2,6]	1.6-11.7	3.2-30.5	4.8-87.8	1.2-2.9	0-111	48,124-120,310	0-1,010
Riparian Buffer Improvements [8]	-	-	2,248 (total nitrogen)	-	-	-	-
Irrigation Scheduling [9]	2.7-19.9	5.4-52.1	8.2-150	2.1-4.9	0-420	37,300-93,250	0-1,725
Soil Moisture Monitoring [9]	2.7-19.9	5.4-52.1	8.2-150	2.1-4.9	0-420	37,300-93,250	0-1,725

1. Pounds per year
2. Assuming a 1% annual increase in total acres irrigated by sprinkler
3. Assuming a consistent annual increase of 142 acres per year
4. Amount of loading reduced per 142-acre increase in lease-fallow agreements
5. Assuming 0.5 CFS of water is newly transported by 8" PVC pipe (instead of earthern ditches) for six continuous months in each year. To meet goal of 5,000 feet per year of new pipe installation, 7.5 40-acre farms need to line head ditches (assuming a square 40 acres with 660 linear feet of pipe per farm).
6. Assuming all new sprinkler head stabilization ponds wlil be lined
7. Assuming 75% of farm acres are within Conservation District boundaries; half of farm acres are comprised of sorghum and corn; and application rates are similar to 2016 NASS estimates of 116 pounds per acre for corn and 25 pounds per acre of sorghum
8. Nitrogen uptake was asummed to be 170 kilograms per hectare per year (Dossky et al., 2010).
9. Irrigation Scheduling and Soil Moisture Monitoring are expected to achieve similar results based on the margin of error for each management technique.

and deep percolation. Irrigation scheduling becomes more useful if irrigation efficiency improvements, such as center pivot sprinklers, are in place. Irrigation scheduling is more difficult in flood irrigation systems because the application, and management of the water is more difficult to regulate and harder to measure than sprinkler or drip irrigated systems.

Irrigation scheduling can take many forms, from soil-based methods to advanced smartphone apps based on local weather data. At its most basic, irrigation scheduling is an estimation of soil moisture in the rooting zone and a management strategy that guides when plants need water. This can be done using many different metrics such as visual observations of plant stress, soil moisture estimations with ball probes or hand-feel methods, or more advanced sensing using local weather and soil information to estimate soil moisture in the root zone. This first example is the least accurate, and the last option the most accurate.

A tool developed by Colorado State University to help schedule irrigations using precise scientific data is called the Water Irrigation Scheduler for Efficient application (WISE) tool. This tool is a software application available on smartphones that uses local climate and soil conditions to estimate root zone soil moisture. The app automatically connects to the closest Colorado Agricultural and Meteorological Network (CoAgMET) station to obtain accurate weather measurements that most affect crop water use. These values calculate a daily water use, and a cumulative water balance is created for the root zone. Irrigators can then select a root zone soil moisture value that would "trigger" the need for irrigation, and when estimated soil moisture hits that trigger, this tells the irrigator when and how much to irrigate. This tool is designed to help create the most favorable conditions for soil moisture within the rooting zone and minimize loss through deep percolation and surface runoff. The tool does have a learning curve, however, but CSU is happy to provide hands-on training for irrigators.

Benefits

1. Most irrigation scheduling tools are free to use
2. Unlocks the full water savings potential of irrigation efficiency improvements such as sprinklers
3. Could help improve crop yields with better water management

Challenges

1. More advanced tools have a technical learning curve
2. Root zone soil moisture is estimated, not measured

5.1.8 Soil Moisture Monitoring

Soil moisture monitoring is a more advanced BMP than irrigation scheduling but the concept is the same. Improving water management through accurate measurements of root zone soil moisture can help improve water quality by limiting the amount of deep percolation and subsequent buildup of shallow water tables and pollutant dissolution and mobilization.

This BMP is a more expensive, but more accurate, way of managing root zone soil moisture compared with irrigation scheduling. One significant benefit of soil moisture monitoring is the ability to monitor root zone soil moisture in many locations in a single field and create prescriptive irrigation events for different locations. This concept could be called "precision agriculture," in that it uses multiple data points in a field to inform decisions about when and how much to irrigate. Farmers can use this technology, or crop consultants or other agricultural service professionals can be contracted to undertake this type of work. Expanding opportunities, technical support, and funding opportunities for irrigators to deploy low-cost soil moisture sensing technologies should be a priority.

Benefits

1. Accurate measurements of root zone soil moisture
2. Ability to monitor several points in a single field

Challenges

1. Can be technically challenging and costly if sensors are damaged or destroyed in typical farming operations

5.2 BMP Project Tables

The following tables attempt to provide a "first step forward" for implementing the proposed BMPs. Each BMP has a detailed implementation strategy, a realistic implementation goal, a list of technical and financial resources available, primary authorities responsible for implementation, and whether the BMP is subject to augmentation. The BMPs and their target goals were developed with significant input from the watershed stakeholder group and the technical advisory committee.

The expected load reductions are based on the successful implementation of each BMP to the goals and standards set forth in Table 10. Load reductions were evaluated with respect to the impairments eligible for regulation by the state and are classified as a range of potential reduction values. For BMPs relating to irrigation, this loading range was computed by evaluating the potential water savings of the BMP as it relates to the median pollutant concentration value (plus or minus one standard deviation). For example, the average expected reduction in deep percolation from converting roughly 1,880 acres of flood irrigated farms to sprinkler irrigated farms is 915 acre feet. With a median selenium concentration of 11 µg/L, this would equate to an estimated annual reduction in loading to the coupled stream/alluvium system of 27.3 pounds per year. One standard deviation, based on pollutant concentrations, was added and subtracted from this value to get the expected load reduction range.

It is extremely important to note that reductions in solute loading to the streams does not correlate proportionally to reduced pollutant concentrations. There are also several factors that contribute to loading, including surface-groundwater interactions, proximity to pollutant sources, and water application rates. In the Lower Arkansas River Watershed, groundwater is almost certainly the major contributor of pollutants to the stream system. The complexity of the surface-groundwaters system can add significant variability to the effectiveness of BMPs and their implementation across the landscape.

5.3 Funding

Financial support can be the most limiting factor to implementing solutions to improve water quality. It is important for all future water quality improvement efforts to be as efficient as possible with what funding is available. This includes sizing and scaling projects appropriately, investing resources in projects that give the greatest water quality return, and monitoring projects to ensure water quality benefits continue.

Several opportunities exist for partially or fully funding the management actions, research studies, and monitoring efforts needed to fully implement this watershed plan. These include local, state, and federal grants; private foundation grants; public-private partnerships; loans;, and self-funded options. Table 9 lists a few appropriate funding opportunities, but more funding opportunities must be explored and new creative solutions developed. One overarching financial support mechanism to help fund any of the BMPs proposed above is the Colorado Water Plan Grant Program. The Colorado Water Plan recognizes the need for all waters to support their classified uses, and this watershed plan advocates for the improvement of water quality of the Lower Arkansas River Watershed to support all its uses. Most of the BMP's discussed above have a water quality-quantity nexus, and assistance to identify and improve our understanding of these interactions is clearly stated in the Colorado Water Plan. The Colorado Water Plan Grant Program is a likely candidate for grants to address farm ditch/canal seepage, ATM's, and irrigation scheduling.

5.4 Reducing Pollutant Loading

It is challenging to quantify an exact loading reduction for specific BMPs because the scale of implementation for each BMP and site characteristics vary. Based on available data, it is easy to calculate the amount of loading that needs to be reduced to meet water quality standards. This is done by taking water quality data and the associated flow data of where and when the samples were taken. However, without a better understanding of the exact origin of non-point source loading at the sampling locations, these estimates can only be interpreted to mean a reduction in loading is needed from any non-point source upstream of the load estimation points, even those not located within the Lower Arkansas River Watershed. Basically, the amount of pollutant in the water could have entered the river far upstream from the watershed, and it is not feasible to require "in-watershed" BMPs to make reductions to account for upstream loading sources. Load reduction goals can be set and compared with water quality standards, and while the load reductions goals are specified at points within the Lower Arkansas River Watershed, it must be understood that loading from all upstream sources must also be accounted for.

Tables 10 through 12 show the amount of loading that needs to be reduced for each 303(d) water quality parameter. To better understand seasonality or flow/concentration dynamics, each parameter was evaluated under EPA flow classifications from High Flows to Low Flows. For a more detailed explanation of loading, see Appendix 1-A. Table 13 gives expected load reductions based on historic diversion records and the best available science concerning load reduction estimates. A range of load reduction is given to represent plus and minus one standard deviation from the actual expected load reduction.

Chapter 6

Measuring Success

6. SUMMARY

“Failure to plan, is planning to fail.” – Benjamin Franklin

This watershed plan is intended to provide a roadmap, and it lays out lofty goals that can only be achieved if multiple parties are willing to work together. Some are surprised to learn that this plan did not set out to only identify the causal relationships between management actions and reductions in water quality pollutants. This is important, surely, but a successful plan goes beyond the simplicity of making recommendations about land management techniques in the hope of reducing water pollution. The main goals of this plan are to create awareness of the water quality problems, facilitate partnerships to create actionable projects that can help improve water quality, identify a mechanism to keep the plan relevant and useful for stakeholders, and (*finally*) quantify the impacts of land management decisions on water quality.

Chapter 5 gives a more detailed description of the land management recommendations suggested by the stakeholder group. Chapter 6 is intended to describe ways to measure the success of the items recommended within the plan. Some of the successes will be quantitatively measured, while others will be more qualitative. For example, implementing a project to remove tamarisk trees and restore native riparian vegetation can be measured in acres treated, trees removed, etc. Other practices, such as elevating the knowledge of farmers about the impacts of selenium, are more challenging to quantify. The number of participants in workshops could be measured or their understanding before or after events can be surveyed, but getting a true and accurate measure of increased knowledge is challenging at the regional (or watershed) scale.

Measuring progress and setting milestones is best done by factoring in the local capacity to implement and monitor the effectiveness of the projects within this plan. These measurements, and all indicators of success, will be subjective to this principle.

6.1 Plan Implementation

This plan can be implemented at different scales, from an individual farmer/producer lining a headwater ditch, to a Conservation District organizing a riparian buffer improvement project across multiple acres. **The best results will be achieved when multiple partners work together from various perspectives: private landowners with infrastructure needs (i.e., center pivots), regional entities capable of coordinating projects (i.e., Conservation Districts), and state agencies with regulatory mandates and funding opportunities.** Table 9 is structured to identify a primary BMP implementation individual/group as well as any support groups that are needed to assist in making BMP implementation easier and more efficient.

We encourage organizations (local, regional, state, and federal agencies) to use this document to guide conservation priorities. This plan, or pieces of it, could be adopted into long-term strategic plans or short-term annual work plans. The priorities and project identified by this watershed plan have been carefully selected by a broad group of local stakeholders and analyzed for their effectiveness. It should provide a good foundation to build partnerships and lay the groundwork for future projects.

6.1.1 Interim and Measurable Milestones

Milestones are small celebrations on the path to reaching goals. Most of the goals set forth by this watershed plan are only achievable over longer periods of time. However, the direction and momentum of the efforts in the short-term is indicative of the potential for success in the long-term. It is important to define markers of success along the path to full implementation. Table 12 is a summary of implementation milestones that will help the implementation team determine the effectiveness of all the efforts outlined by this plan. This list was developed with the help of several different stakeholders within and outside of the watershed, as well as case studies from other watershed plans. The numbers were selected based on their feasibility of success given several different constraints to implementation.

Table 12: List of implementation milestones for each BMP.

BMP Name	Implementation Milestone		
	1 to 2 Years	2 to 5 Years	5 to 10 Years
Irrigation Efficiency Improvements	1. Establish programs to deliver conservation tillage education 2. Five new center pivots installed	1. All new center pivot cost share projects will also include mandatory conservation tillage 2. Thirteen new center pivots installed	1. 35% of all sprinklers in the watershed will employ conservation tillage methods 2. 30 new center pivots installed
Lease/Fallow Project	1. Explore partnerships and assess ATM needs at the regional scale	1. Execute lease-fallow agreement	1. 1,000 acres in lease-fallow agreement
Nutrient Management Planning	1. Assess current nutrient management planning by producers	1. Start program to encourage sampling of irrigation water 2. 50% of farms within Conservation Districts will complete annual nutrient management plans	1. 75% of farms within Conservation Districts will complete annual nutrient management plans
Sealing/Lining On-Farm Ditches	1. One pilot farm will be used to test effectiveness of polyacrilamide on different soil types	1. 20,000 feet of underground transfer pipe will replace earthen head ditches	1. Tile drain networks will be assessed and improvements made 2. 50,000 feet of underground transfer pip will replace earthen head ditches
Pond Lining	1. Establish guidelines for new pond locations and lining materials 2. Inventory existing ponds	1. All new irrigation pivots will have lined head stabilization ponds with bentonite	1. Up to three existing head stabilization ponds will be moved to acres where the probability of water contamination is lower
Riparian Buffer Improvements	1. Create restoration booklet for property owners with recommendations on successful reclamation techniques	1. Implement study to evaluate the effectiveness of bioremediation, species composition, etc.	1. Create demonstration project on state lands
Irrigation Scheduling	1. Calibrate irrigation scheduling tools	1. Deliver at least three workshops on irrigation scheduling	1. All new irrigation efficiency improvement projects wil be required to implement some type of irrigation water management system
Soil Moisture Monitoring	1. Develop a list of appropriate soil moisture sensing technology	1. Soil moisture sensors will be capable of linking with irrigation scheduling tools	1. Establish a pilot project with two producers to show the capabilities of irrigation scheduling

The implementation process, like the watershed planning process, can be iterative, and similar projects can be carried out at different locations in the watershed. Feedback and data from previous efforts must be used to make the best decisions about future projects. This necessitates an implementation strategy that outlines measurable milestones and short-term goals, which can in turn be evaluated from short- and long-term perspectives. This watershed plan makes every effort to contextualize the implementation milestones, given the constraints in funding, worker capacity, materials, jurisdictions, management boundaries, and land ownership. We recognize the need to create efficiencies in project development, implementation, and monitoring throughout a mostly privately-owned watershed. For this reason, Conservation Districts and federal agencies (such as the NRCS) are perfectly positioned to act as the "hub" for implementing parts of the watershed plan. The measureable milestones were developed using feedback from these agencies on capacity and limitations. The implementation, however, goes well beyond any one agency or individual. For it to be successful, implementation of this watershed plan will take a team of individuals and organizations.

Load reduction of selenium is a long-term goal in the area due to the size of the watershed and the magnitude of the issue. A modeling of selenium reduction through implementation of BMP (and combinations of BMPs) is underway to set ten-year reduction goals. These goals will be compared to the sampling results at certain locations along the Arkansas River, one of which should be the USGS sampling location at Holly, CO, since it is can best represent the location where the Arkansas River leaves the state.

6.1.2 Criteria to Measure Water Quality Improvements

Simply implementing BMPs does not guarantee success, and the effectiveness of each BMP will likely be different under different conditions. It may be possible, for example, that implementing the lining/sealing of on-farm ditches could lead to a reduction of 5.5 lbs/year of selenium loading to nearby Wildhorse Creek, while the same BMP implemented on a different farm could lead to a reduction in only 1.2 lbs/year of selenium loading to the Arkansas River. At the watershed scale, the implementation of the suggested BMPs has a high likelihood of improving water quality in the watershed, but the effectiveness of each BMP will be highly subjective to local conditions.

Table 13: List of indicators to measure progress towards achieving water quality goals.

Metals	1. Loading of Se, U, Ar, Mn, Fe from non-point sources at the watershed scale 2. Sampling at the field scale for constituents in applied water, tail water, deep percolation (shallow groundwater), etc. 3. Soil testing for heavy metals 4. Sampling riparian vegetation for bioaccumulation of metals 5. Sampling irrigation drains for metal pollutants 6. Fish and aquatic invertebrate tissue
Salinity	1. Field measurements of soil salinity 2. Irrigation return flows and shallow groundwater sampling 3. Crop yields 4. Lake salinity levels to measure evaporative effects
Nutrients	1. Agricultural soil sampling 2. Fertilizer sale records 3. NASS statistics
E. coli	1. Sampling Adobe Creek 2. Number of riparian sepcies from aerial photos (indicator of cattle grazing)

The information gathered from measuring the effectiveness of the BMPs is important data for adapting to meet the needs of each new project. This concept, often called adaptive management, gives flexibility in how projects are implemented, even if the projects appear to be very similar. In some cases, measuring success and BMP effectiveness will be similar among many different BMPs. One example is soil sampling in agricultural fields, in native grasslands, or from river and stream sediment. Soil sampling in an agricultural field, for example, will give results on soil salinity, nutrient deficiency/surplus, and metal accumulation (i.e., selenium, uranium, etc.). Sampling vegetation may be another measure of success for two different BMPs: 1) riparian buffer improvements and 2) irrigation efficiency improvements. Each BMP can be evaluated on its effectiveness of salt uptake by plants, which could be considered beneficial in riparian buffers, but not so beneficial for crops.

It should be noted that water quality data is notoriously hard to collect, synthesize, and interpret beyond the time of sampling. Statistical methods exist to take singular, time-specific data points and extrapolate them in space and over time. A major data gap for this region exists in the historical time series (2000-2016), which allows only a "snapshot" of water quality in the region. For this reason, water quality models are incredibly important for efficiently and scientifically estimating water quality impacts from implementing BMPs (Tavakoli-Kivi et al., 2018; Gates et al., 2019). Future water quality monitoring strategies should use a combination of modeling predictions and targeted physical sampling locations to capture changes in water quality when certain variables are changed or manipulated. This should be done in connection with standard water quality sampling points at strategic locations to monitor water quality standards and thresholds.

6.1.3 Monitoring Plan

6.1.3.1 Summary of Current and Past Water Quality Monitoring

Several organizations have been monitoring water quality in the Lower Arkansas River Watershed for several decades. From 2000-2016, the Colorado Department of Public Health and Environment (CDPHE) had over 50 unique sampling locations, the USGS had 6, and the EPA had 7 (mostly lakes or wetlands). Other groups have also collected extensive water quality data in the basin, including River Watch and Colorado State University. Each of these agencies is uniquely qualified to carry out water quality sampling because they have the proper training, protocols, and experience in collecting and analyzing water quality samples. Sampling for some water quality constituents can be technically difficult, and the integrity of the data depends on proper sampling. Most of the organizations listed above exclusively sample surface water sources (USGS excluded, in the Big Sandy sub-watershed). The biggest source of water quality data from groundwater sources is Colorado State University, which has almost two decades of experience in collecting data within the Lower Arkansas River Watershed. Recently, the Lower Arkansas River Water Conservancy District has begun "edge-of-field" water quality monitoring to determine the effectiveness of many different agricultural BMPs. This data will be critical for understanding how water quality pollutant concentrations respond to the implementation of BMPs.

Water quality sampling in the Lower Arkansas River Watershed can be difficult for many reasons: 1) access to water bodies, 2) intermittent flows, 3) river management operations, and 4) access to laboratories and supplies. For these reasons, it is difficult to get a complete picture of water quality issues within the watershed.

Numerous data gaps were observed within the data collected from 2000-2016. It is well understood, but not always documented, that the variability in hydrology leaves many of the streams in the Lower Arkansas River Watershed dry throughout most of the year. It is unclear how many of these data gaps exist simply because no water was flowing in a stream at the time of sampling. In other cases, there are large time gaps between sampling events at the same location. This could be caused by many factors including irregular hydrology, limited resources for sampling, or low priority sampling locations. Without a better understanding of why these gaps exist, it is difficult to recommend ways to fill them in future sampling designs.

The same is true for sampling locations. The main stem of the Arkansas River is by far the most sampled water body in the watershed, but the same is not true for its tributaries. Big Sandy Creek has abundant surface water data near its confluence with the Arkansas River, but nearly all of the data collected from Big Sandy Creek in the "headwaters region" near Limon, CO, is taken from groundwater. Two Buttes Creek has only two sampling locations, one near its confluence with the Arkansas River and the other near Two Buttes Reservoir. Metadata from some of the samples reveals that, at the time of sampling, no water was flowing, and the samples were collected from stagnant pools. Conversations with staff from the Water Quality Control Division at CDPHE revealed the challenges associated with creating a sampling design in sync with a highly variable hydrologic system. It is not uncommon for streams to flow seasonally, in response to precipitation events, or not at all. Clearly, it is very challenging to design a sampling plan for many of the streams in the watershed, as their flow is highly variable and often nonexistent.

The water body with the most consistent and predictable flows is the main stem of the Arkansas River, including John Martin Reservoir. Although the river flows fluctuate greatly and seasonally, the river almost always has enough water to sample at each river sampling location. The same is not true for most tributaries. However, water quality data collected from tributaries is critically important for understanding pollutant loading, and every effort should be made to collect appropriate and representative water quality samples from tributaries.

6.1.3.2 Future Sampling Needs

The lack of resources and sampling expertise is a limiting factor in the Lower Arkansas River Watershed. It is difficult, in the context of this watershed plan, to make actionable suggestions for sampling BMPs because many of the BMPs are relatively small in size and/or impact, and many different or combined BMPs will need to be implemented to enact meaningful water quality improvements at the watershed scale. Other Colorado watersheds with single, large non-point source contributions, such as abandoned mines, can develop a sampling plan that targets BMP projects to evaluate their individual effectiveness. And though it would give a wealth of information, monitoring individual BMPs in the Lower Arkansas River Watershed is not feasible outside of specific circumstances, such as research or implementation projects. Therefore, this sampling plan will make recommendations based on voluntary actions private landowners can feasibly take, as well as sampling efforts by state and federal agencies that help identify the effectiveness of BMP implementation. This plan will also make limited recommendations on how some of the water quality gaps can be filled by organizations or agencies that actively sample water quality in the watershed.

Currently, limitations also exist in giving farmers, water managers, and academic researchers, the tools needed to efficiently monitor and calculate the effects of water quality BMPs on pollutant loading to surface and groundwater. New tools need to be developed to better quantify the impacts of these BMPs from many different perspectives, such as water quality, economics, conservation efficiency, and crop production. These tools may include new monitoring equipment that is cost effective and easy to deploy in the field or technology-based software that can be designed as user-friendly “calculators” that help quantify water quality impacts from different management actions.

Soil Sampling

Soil sampling is a good way to evaluate the effectiveness of irrigation-related BMPs and nutrient management BMPs. Many landowners already take soil samples to inform fertility recommendations, soil texture, organic matter, and more. However, these soil samples could be expanded to include a more detailed analysis of soil salinity, which can then be used as a proxy for general field-scale water balances to measure the efficiency of irrigation practices. For example, if soil salinity is tested at three depths (10cm, 25cm, and 60cm, for example) each month during the growing season, the increase or decrease in salinity at any of these depths can be used to estimate deep percolation, an important contributor to shallow groundwater tables.

Soil sampling also provides critical information for managing nutrients applied to irrigated fields. Some crops, such as alfalfa, create environments for the natural “fertilization” and nitrogen-fixing processes that build soil nitrogen, which benefits existing and future crops. Fields coming off an alfalfa rotation may still carry “nitrogen credits” from residual nitrogen in the soil. This is only one example of the need to test soils for nutrient content (specifically phosphorus, potassium, and nitrogen) so as to not waste money on fertilizer treatments and lessen the chance for surface and groundwater contamination. Nutrient management plans rely heavily on the Four Rs: Right *rate*, Right *time*, Right *place*, and Right *source*. Soil testing can help address two of these Rs: rate and place. Soil rates depend on many factors, including soil type and residual soil nutrients, and the placement of fertilizers can be best accomplished by understanding the soil profile and soil textures. Many farms already use these techniques in determining appropriate nutrient inputs, and the application and idea of "precision agriculture" relies on accurate soil information. In general, soil sampling is a necessary component of farming, and carefully planned soil sampling campaigns can easily yield information that is critical to determining the effectiveness of several of the BMPs put forth by this plan.

Critical Stream Sampling Locations

Data should continue to be collected from strategic points along the main stem of the Arkansas River to give a broad understanding of "watershed health" and the combined effectiveness of BMPs at the watershed scale. When possible, data should continue to be gathered from sampling locations near flow gauges, including the four USGS gauges in the watershed.

Stream and surface water sampling should be expanded in the eastern region of the watershed and north of the Arkansas River, where significant loading of selenium and uranium is likely to occur. For example, selenium concentrations increase significantly from Lamar, CO, to Grenada, CO. Several tributaries and drainage ditches enter the river between these two towns, including Big Sandy Creek, Wolf Creek, Grenada Creek, Deadman Ditch, Smith Arroyo, Buffalo Creek, and Boggs Creek. As a major tributary, and one that flows through significant and large agricultural lands, Big Sandy Creek has the potential to contribute significant quantities of both water and pollutants.

Critical Groundwater Sampling Locations

The USGS has a robust groundwater monitoring network of four permanent groundwater sampling points in the headwaters of Big Sandy Creek near Limon, CO. In this reach of the stream, most of the water in the "stream network" exists as alluvial groundwater. Occasional rainstorms and seasonal patterns create streamflow in the creek, but most of the time the creek is dry. It is important to continue monitoring these locations, and if feasible, expand the monitoring network to better understand non-point source loading of nutrients from septic systems, agriculture, and natural deposition. In the Arkansas River Valley, more groundwater sampling is needed to better understand the stream-aquifer dynamic and potential "hotspots" for non-point source loading to the River. These locations should be selected based upon data generated by Dr. Tim Gate's research group. Maps and other data sources that can help identify pollutant "hot spots" can be found at **coloradoarmac.org**.

New Ideas for Sampling

Water quality sampling by agencies such as CDPHE, EPA, and USGS has provided valuable data to make inferences about non-point source loading at the larger watershed scale. However, several data gaps exist to pinpoint loading contributions at the sub-watershed scale and even at the field scale. For this reason, the state has pursued the use of computer models to estimate and extrapolate water quality data where none currently exists. Models are a good way to fill information gaps with scientifically-based estimates that are more efficient and cheaper to generate than physical water quality sampling. Current efforts by Colorado State University to create accurate computer models to fill data gaps are reaching a point of acceptance based on two decades of physical water quality sampling. These accurate and precise models will soon be able to forecast the effects of BMP implementation on water quality. In a watershed as large as the Lower Arkansas River Watershed, it will be very useful to run the models and make informed decisions on BMPs based on the model results. In the absence of expensive physical water quality samples, these model results should be used as the watershed plan is implemented.

Models can help bring more spatial resolution to water quality concentrations, but the best way to evaluate individual BMPs at the field scale will be through edge-of-field monitoring on fields where BMPs are implemented. These projects should be well-designed, and data collection should be robust. This data is valuable, but should be used carefully when expanded upon to make inferences about the same BMPs in different locations. Site-specific variables such as soil type, water source, crop types, and topography will likely have significant impacts on BMP effectiveness. However, with enough data and replication, trends may be identified that can help inform recommendations on how to best implement different BMPs. Of course, the goal is to move the ball in the right direction and improve water quality, but it is important to ensure financial resources, time, and effort are most efficiently directed to making the biggest impact for the least amount of money.

Often, another critical missing piece of information is data on flow conditions when the water quality sample is taken. When feasible, flow monitoring should accompany water quality monitoring, as this data is often a critical missing piece for estimating loading. Some things are still unclear, like the source of pollutants such as selenium and uranium between Lamar, CO, and Grenada, CO, and what mechanisms cause a significant increase in loading of certain parameters (such as selenium) between these two locations. More sampling is needed near the confluence of Big Sandy Creek, as well as some of the smaller creeks listed above.

Although Two Buttes Creek is often ephemeral, more information is needed to better understand the water and pollutant contributions to the Arkansas River. Two Buttes Creek enters the river less than five miles from the border with Kansas and just south of Holly, CO. Making management recommendations is difficult because few water uses exist on Two Buttes Creek. However, significant water uses from the High Plains Aquifer exist on the edges of the Two Buttes watershed, and there is the potential to have pollutant loading, especially nutrients. Big Sandy Creek, as mentioned earlier, should also be sampled more frequently, specifically where the creek flows through areas of heavy water use.

Appendix 1

Lower Arkansas River Watershed: Water Quality Analysis

CONTENTS

1. INTRODUCTION

A thorough water quality analysis is a foundational component of a defensible and actionable watershed-based management plan. The analysis must address stakeholder questions, consolidate existing data, use robust analysis methods, and present results to both technical and non-technical stakeholders.

In the Lower Arkansas River Watershed several organizations collect water quality data for a variety of objectives throughout the watershed, which creates a mosaic of data. The broad variety of water quality data necessitates a strategic approach to data compilation, management, and analysis. In this analysis, we compiled data from 2000 to 2016, collected primarily by US Geological Survey (USGS), Colorado Department of Public Health and Environment (CDPHE), and the Environmental Protection Agency (EPA). Additional details about data management practices are provided in Sections 5 and 6 below.

1.1 Report Purpose and Objectives

The overarching purpose of this analysis is to inform the Watershed Plan. The key objectives of the analysis are to:

1. compile, analyze, and describe surface water quality in the watershed;
2. identify water quality data gaps; and
3. identify areas where surface water quality may exceed water quality standards and, where possible, identify potential pollutant sources.

This report is intended for a technical audience; key information from this document will be summarized and incorporated into the Watershed Plan for use by the general public.

2. STUDY AREA

The Lower Arkansas River Watershed – John Martin Reservoir to the State Line with Kansas is the most easterly portion of the entire Arkansas River Watershed in Colorado and contains 7,879 square miles of land. The Lower Arkansas River Watershed extends north, following Big Sandy Creek to Limon, CO. The watershed's southerly extent is located in Las Animas County at the headwaters of Two Buttes Creek, approximately 50 miles east of Trinidad, CO. The majority of the watershed lies east John Martin Reservoir (JMR), however approximately 14.8 river miles above JMR is still within the watershed. The reason this area is included in the watershed is because the natural hydrological separation of the Arkansas River tributaries in the watershed extends slightly above JMR. The Arkansas River flows downstream from JMR and eventually reaches the Mississippi River and Gulf of Mexico, however the eastern extent of this watershed plan ends at the Kansas state line.

2.1 Sub-Basins

The large spatial area of the watershed—and the distribution of existing data throughout the watershed—made splitting it into smaller units necessary for the analyses. The entire watershed planning area consists of four smaller "sub-watersheds." These sub-watersheds include (with corresponding USGS Hydrologic Unit Code, or HUC, number):

- **Upper Arkansas-John Martin Reservoir (11020009)**
- **Big Sandy Creek (11020011)**
- **Rush Creek (11020012)**
- **Two Buttes (11020013)**

2.1.1 Upper Arkansas-John Martin Sub-Watershed

The John Martin sub-watershed's western boundary is just upstream of Las Animas, CO, and the eastern boundary is the border with Kansas. From Las Animas, CO, to John Martin Reservoir, the watershed lies predominantly along the north side of the river (Figure 1-A). This sub-watershed includes many reservoirs, including John Martin Reservoir, Adobe Creek Reservoir, and Nee Gronda Reservoir. The majority of irrigated agriculture is within this sub-watershed. Between 2000 and 2016, more than 80% of all water quality data collected in the watershed was collected in this sub-watershed and, therefore, most of the data analyses were performed using data from this sub-watershed.

2.1.2 Big Sandy Creek Sub-Watershed

The Big Sandy sub-watershed, a major tributary watershed to the Arkansas River, has a predominant north-south orientation that extends from Limon, CO, in the north to the main stem of the Arkansas River just downstream of Lamar, CO, in the south. Previous water quality sampling efforts by CDPHE and USGS have occurred in two main locations within the watershed: near the "headwaters" or first order streams upstream of Limon, CO, and near the terminal point in the watershed where it merges with the Arkansas River. For the purposes of the data analyses, the upstream region is called the "headwaters," and the downstream section is called the "outlet." Groundwater is the source for all of the samples collected in the headwaters. All of the samples collected in the outlet section are sourced from surface water.

2.1.3 Rush Creek Sub-Watershed

The Rush sub-watershed is an 8-digit Hydrologic Unit Code (HUC) located within the watershed planning area. This is the only 8-digit HUC sub-watershed that does not contribute water directly to the Arkansas River, but instead this sub-watershed terminates into Big Sandy Creek near the town of Chivington, CO. The Rush Creek sub-watershed is dominated by native rangeland and shrubland, and the dominant land use is grazing. There are areas of irrigated agriculture, mostly in the upper reaches of the sub-watershed. All water quality samples for Rush Creek have been taken within the upper reaches of this sub-watershed in the counties of Lincoln and Elbert. All samples were taken from surface water sources, and all data was collected by CDPHE and the EPA.

2.1.4 Two Buttes Creek Sub-Watershed

This sub-watershed contains the least amount of usable data. Excluding a small subset of biological invertebrate data, only 90 water quality samples exist for the period of record, which include all constituents. For example, there are only one uranium sample and three selenium samples. There is simply not enough data to perform the type of robust analyses helpful for this report.

3. FACTORS THAT AFFECT WATER QUALITY

Water quality conditions are the result of complex interacting factors that vary through time and throughout the watershed. This section provides a brief overview of the natural and anthropogenic factors that can affect water quality. Site-specific water quality conditions are a result of multiple interactive factors.

3.1 Land Use and Ownership

Land cover types are similar throughout the watershed, however most of the irrigated agriculture occurs along the main stem of the Arkansas River, where ditches and canals can deliver water. Some irrigated agriculture exists further north and south of the river but much of the agriculture located away from the main stem is dryland agriculture. Most of the watershed is covered by grassland/herbaceous cover types (68%), cultivated crops (17%), and shrubland (9%).

The majority of land in this watershed is privately held. This presents a challenge—but also an opportunity—to improve water quality using a private/public partnership structure. Recognizing the largest water users and landowners are private citizens and businesses, this watershed plan strongly encourages the use of voluntary incentive programs to help build and fund projects that will improve water quality.

3.2 Geology

The topography of the Lower Arkansas River Watershed – John Martin to State Line is driven by Cretaceous geologic formations, including rolling hills and flatter tablelands. In places, such as the area near Kiowa, CO, bedrock formations rise to the surface, while in other areas, such as the Arkansas alluvium, bedrock can be 60 feet or more below the surface. Much of the bedrock material is made up of sedimentary rocks, including shales, sandstones, and limestone. Many of these formations developed during the Cretaceous Period and contain remnants from the history of that period. One such example is the Pierre Shale. The material for this formation was deposited during a time when a vast inland sea covered much of North America. The

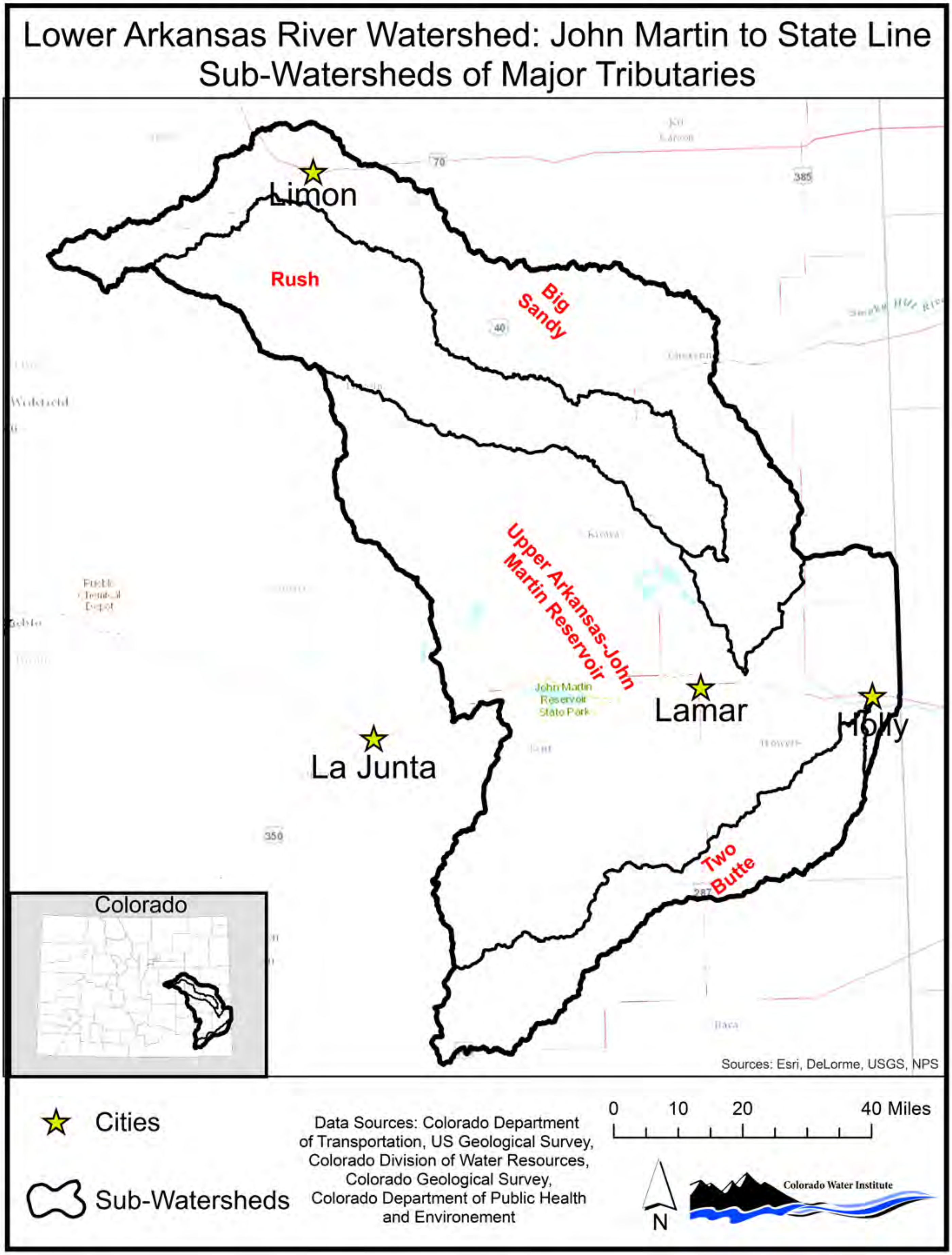

Figure 1: Four sub-watersheds make up the Lower Arkansas River Watershed: 1) Upper Arkansas-John Martin Reservoir, 2) Big Sandy, 3) Rush, and 4) Two Butte.

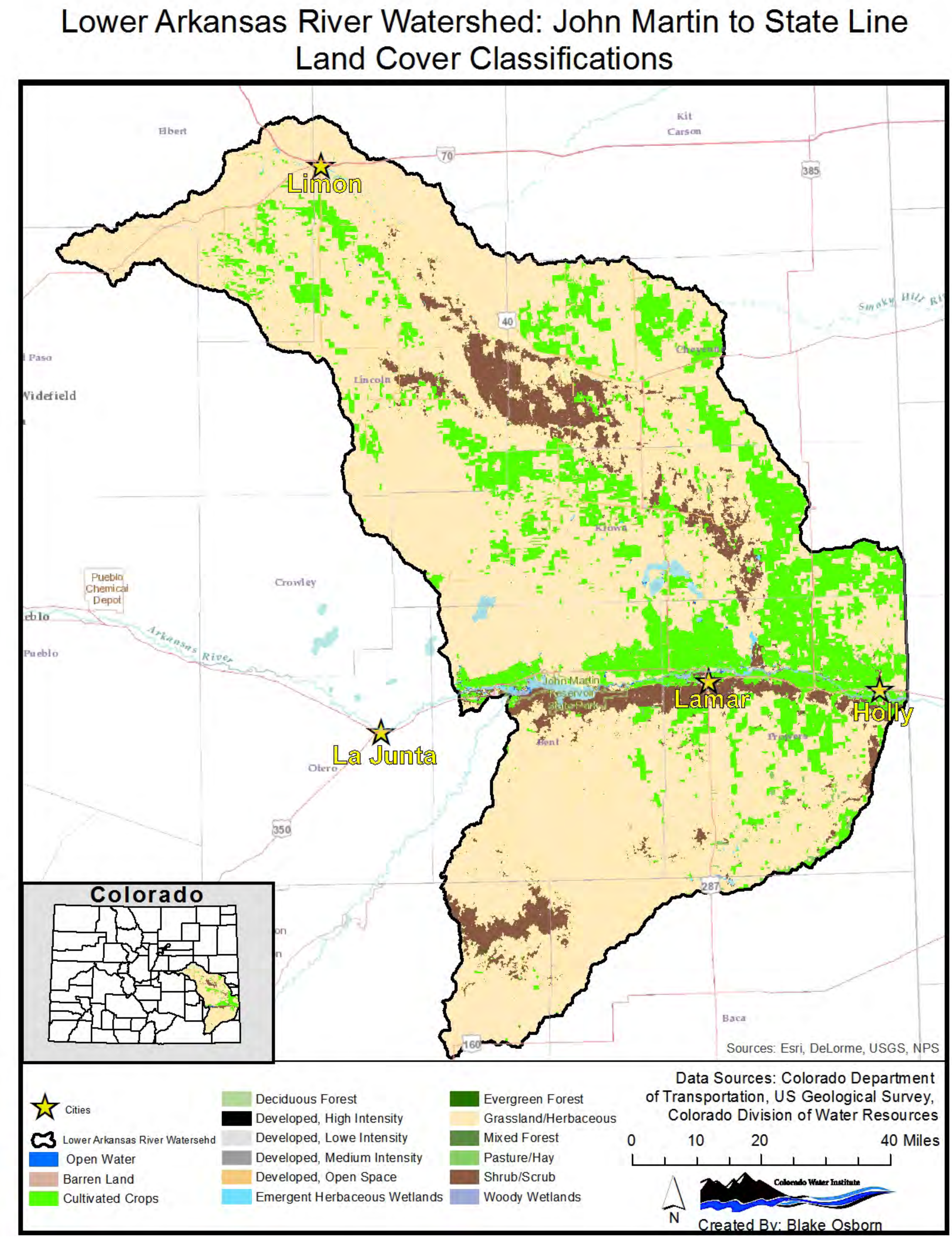

Figure 2: Land use classifications in the Lower Arkansas River Watershed.Two Butte.

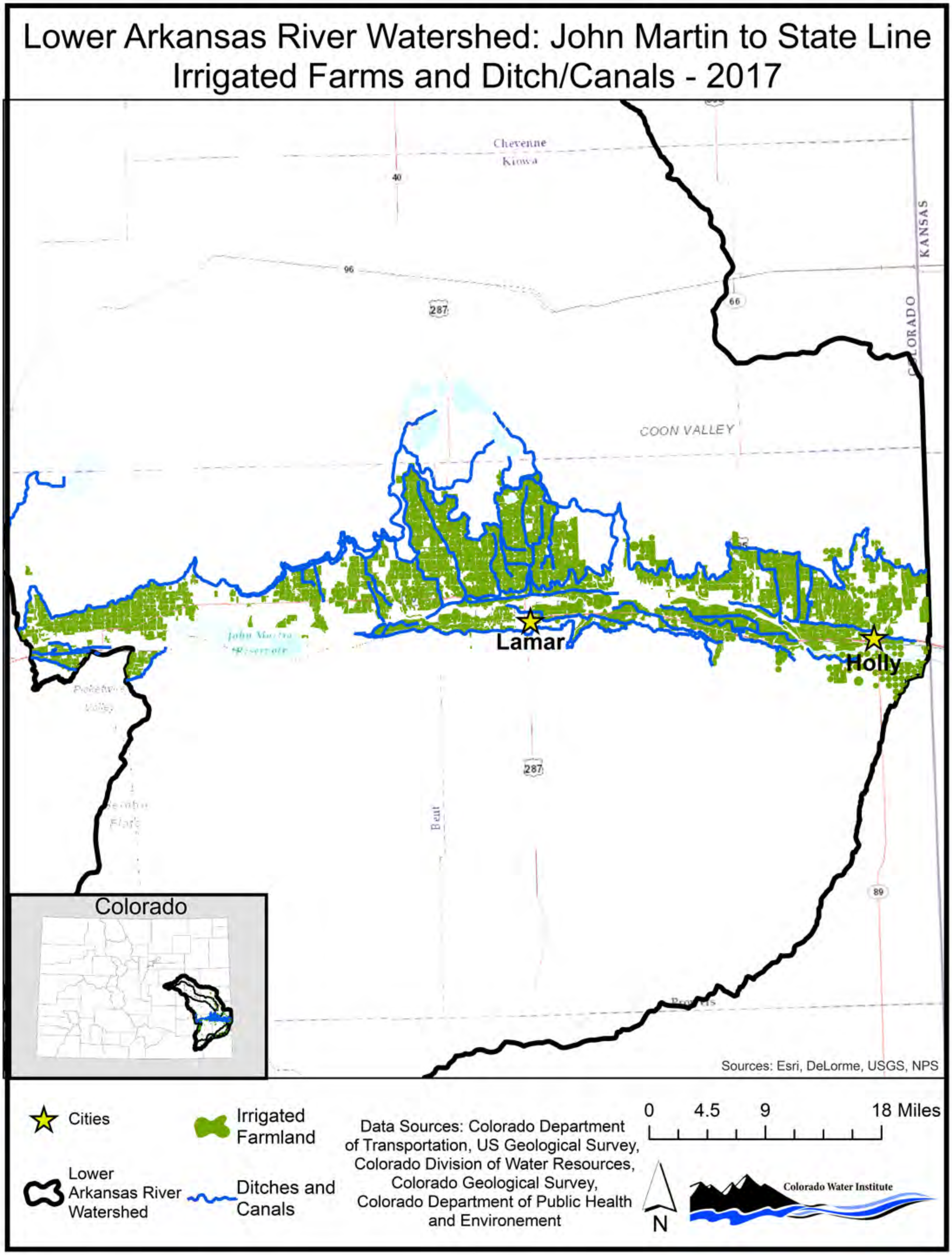

Figure 3: Location of irrigated agricultural fields and major ditch/canals (2017).

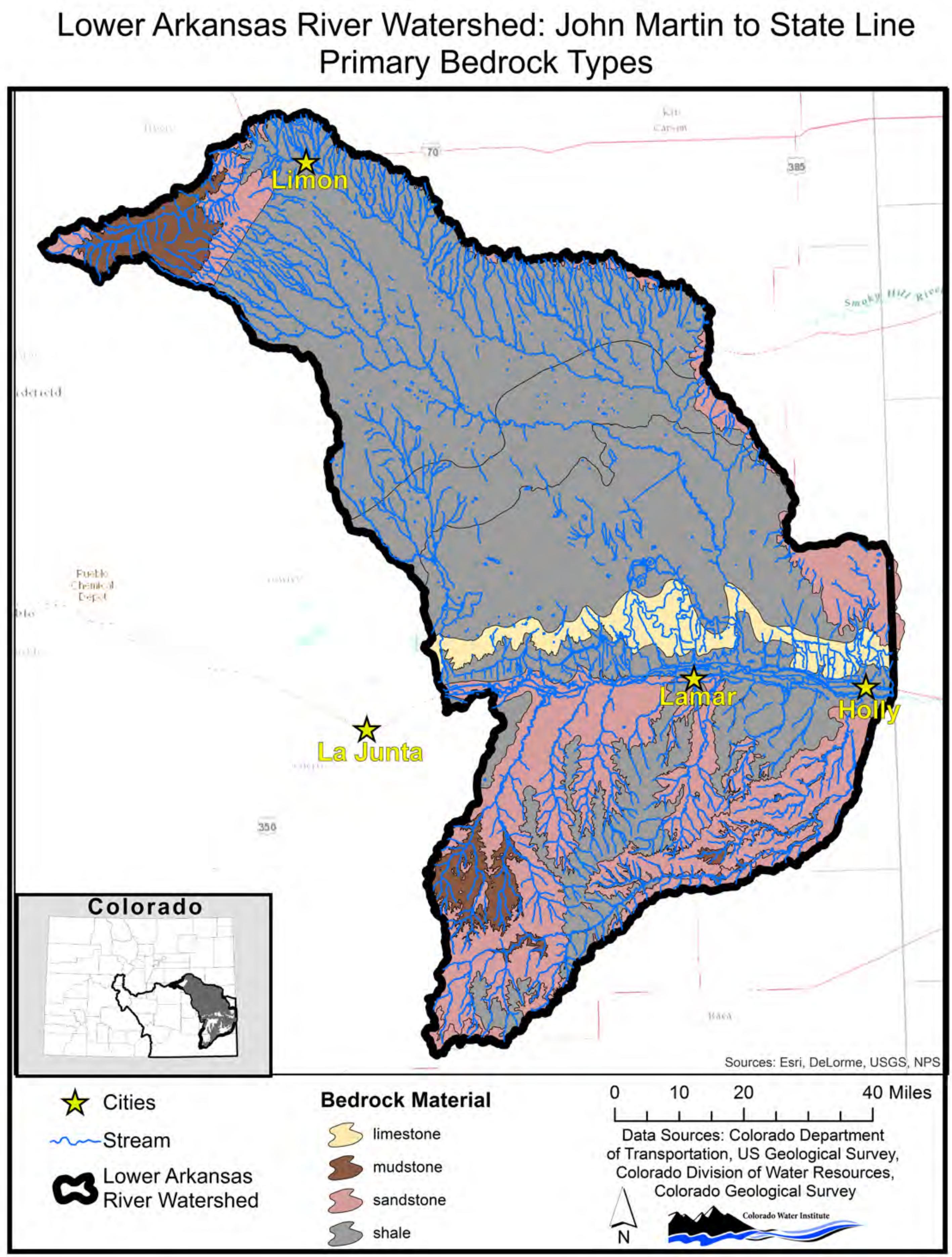

Figure 4: Location of primary bedrock types in the Lower Arkansas River Watershed.

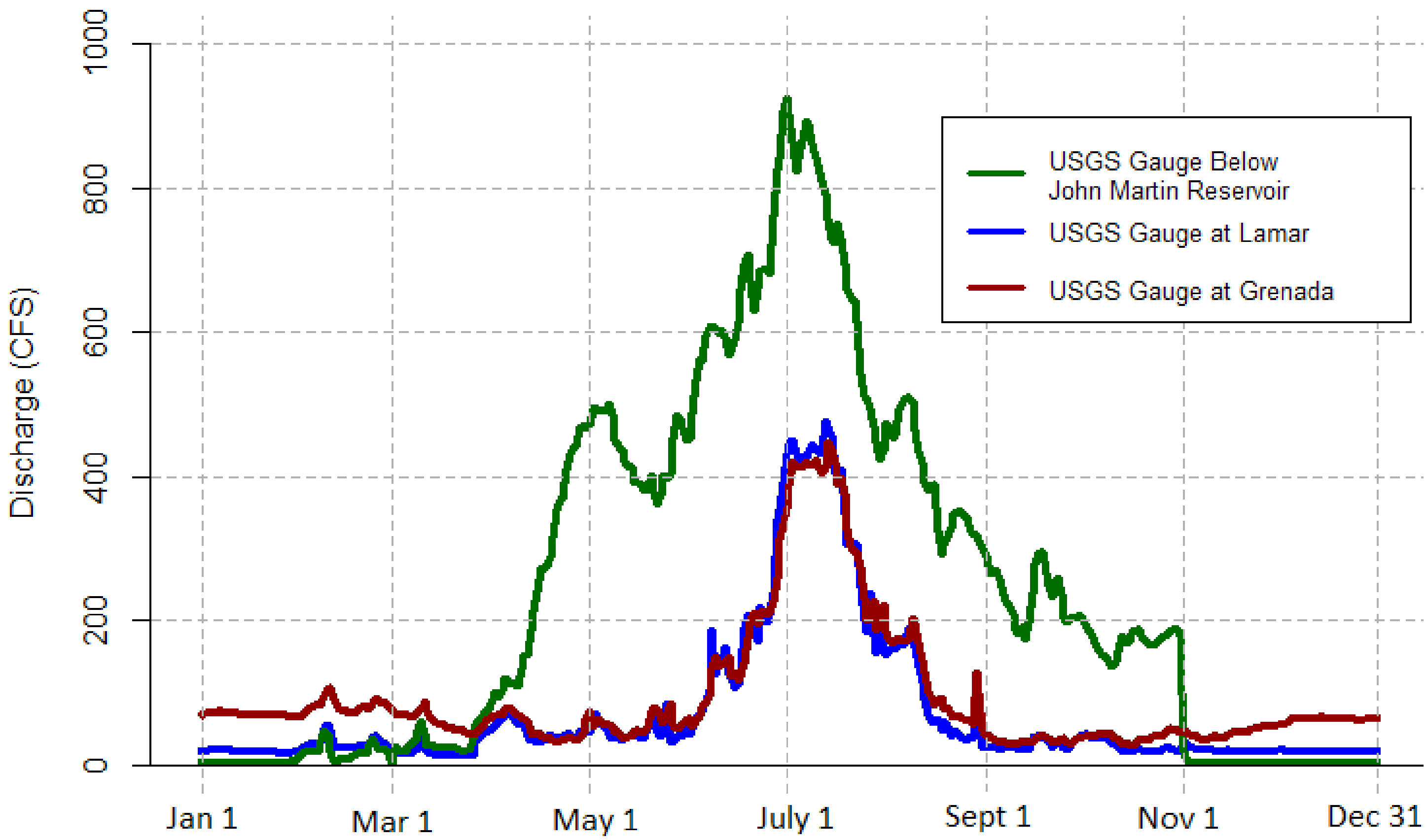

Figure 5: Average daily (2000-2016) streamflow hydrograph at three USGS locations on the Arkansas River.

sediment accumulated many different elements present in the sea at that time, including uranium, selenium, sulfates, and a variety of salt ions. When exposed to certain weathering processes, such as chemical weathering, these elements can be released into our waterbodies either as pure forms of the element (Se, U, N) or as new compound constituents (SO4, Na2O4Se). The presence of oxygen greatly speeds up the dissolution processes, and this commonly occurs under saturated or partially saturated conditions.

3.3 Hydrology

The main stem of the Arkansas River is closely managed below John Martin Reservoir in Water District 67. The presence of John Martin Reservoir as an on-stream storage vessel allows water users above and below the reservoir to manage and use water in accordance with prior appropriation doctrine and our interstate compact obligations. Peak flows occur around the first of July, averaging roughly 900 cfs. Early and late season (November through April), average flows below the reservoir are less than 10 cfs (Figure 5). Two large ditches, the Amity and Lamar Canals, between JMR and the town of Lamar, CO, take water from the river and reduce annual average flows to around 450 cfs during the peak runoff date in early July (Figure 5).

John Martin Reservoir has the ability to store water in wet years, and release them during dry years. However, water coming into and through John Martin Reservoir is administered through the prior appropriation doctrine and the Colorado-Kansas Compact. Water availability can have significant impacts on the administration of the waters from John Martin Reservoir (Figure 6). A combination of factors such as inadequate upstream storage, higher than average precipitation, or significant tributary flows can contribute to significantly higher streamflows below JMR in wet years. In dry years, water users below JMR are not immune to

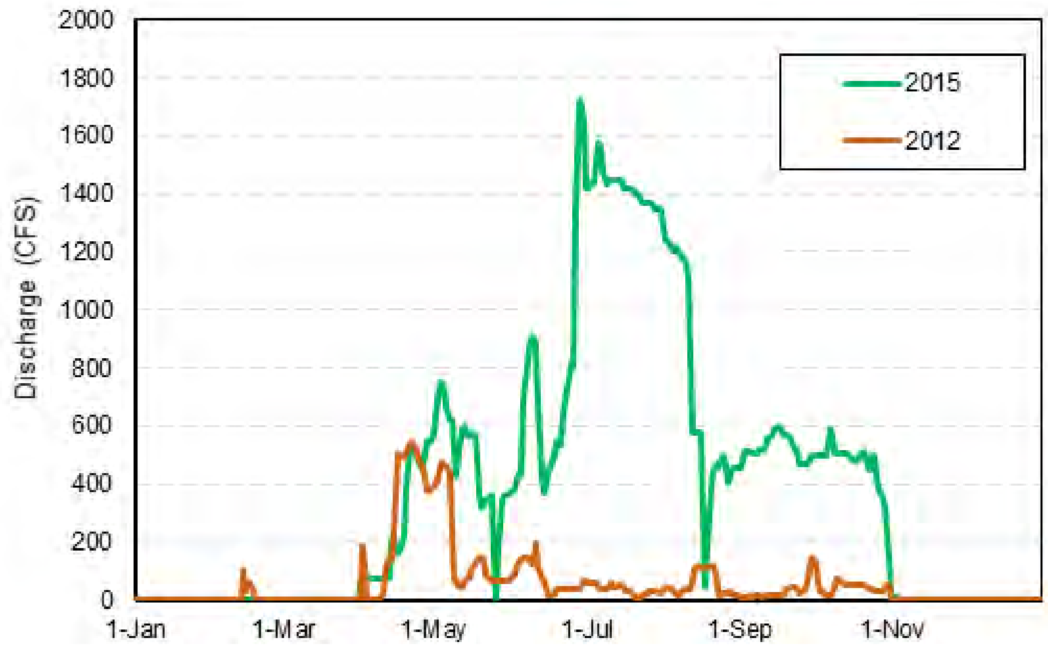

Figure 6: Discharge from John Martin Reservoir in a low water year (2012) and a high water year (2015).

low river flows and low water allocations if water is not also available in the water user's storage accounts.

Big Sandy Creek, the largest tributary to the Arkansas River within this watershed, shows a highly variable hydrograph with apparent and strong responses to thunderstorms in the spring and summer months. The creek is monitored for flows near its outlet not far from the Arkansas River. Because this long stream is ephemeral in places and perennial in others, the hydrograph only gives us information for creek flows within the lower part of the sub-watershed. Average flows are generally less than 15 cfs, with the lowest flows occurring in mid-July, presumably because of irrigation withdrawals (Figure 6).

3.4 Water Management

Water management happens at different scales within this watershed: 1) the statewide scale (Arkansas River Compact), 2) the regional scale (Colorado Division of Water Resources [CDWR] Division 2), 3) the local scale (Water District 67), and 4) the field scale.

The Arkansas River Compact of 1949 established a criteria for water use between the states of Colorado and Kansas (see Chapter 5 of the main report for more information). John Martin Reservoir serves as a critical water management feature that helps meet the needs of Colorado and Kansas farmers, cities, and ecosystems. JMR serves eleven ditches in Colorado and five in Kansas. These entities, and others, are allowed to store water in JMR in different "water accounts."

Currently, there is a permanent pool account established to maintain the integrity of ecosystems supporting fish and wildlife, as well as other accounts for irrigators to store water, including the conservation storage account, Article II accounts (conservation storage), an offset account (well augmentation), Article III accounts (Non-native water, not subject to compact), and transit loss from Article III accounts. With a capacity slightly over 330,000 acre-feet, John Martin Reservoir rarely fills. Improving water quality in the Arkansas River relies on increased storage capacity to offset changes in irrigation efficiency improvements, and JMR is perfectly positioned to allow for this increase in storage capacity. JMR is an established facility, which could streamline permitting and reduce regulatory hurdles. Every attempt should be made to allow more

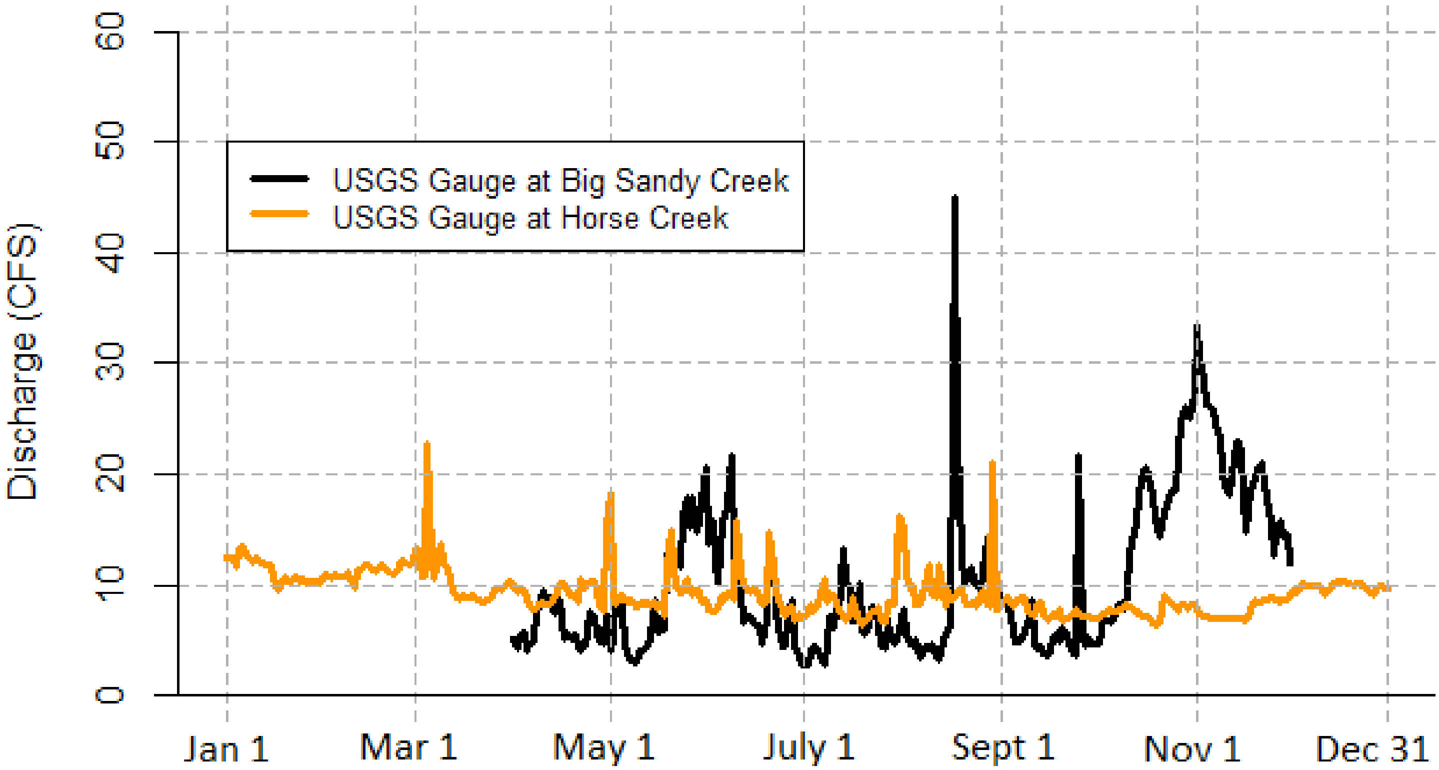

Figure 7: Sixteen year average annual flows (2000-2016) for Big Sandy and Horse Creeks.

water to be stored in JMR so that compact obligations are met and irrigation efficiency projects can be implemented to improve water quality.

At the regional and field scales, water is managed similar to other agricultural regions of Colorado. Water is diverted according to priority and used to irrigate crops. Eleven ditches take water from the river below John Martin Reservoir, with the Amity Canal being the largest. Each ditch/canal has its own water administration procedures, and water is delivered to farm head gates or, in some cases, incorporated into lateral ditches with many farms/shareholders sharing the lateral. Improvements made to water conveyance infrastructure are subject to augmentation under certain circumstances.

Augmentation is also a critical water management strategy at the regional and field scales. Off-farm improvements in water conveyance, such as piping a ditch, will need to supply augmentation water to replace the historical return flows from water seeping from the previously un-piped ditch. Augmentation is required for individual farmers improving on-farm irrigation efficiency, such as converting from flood irrigation to sprinkler irrigation, and augmentation groups, such as the Lower Arkansas Water Management Association and the Arkansas Groundwater Users Association, procure and administer augmentation plans for irrigators making efficiency improvements or pumping groundwater from out-of-priority wells. These groups need access to more water storage options to ensure that enough water can be augmented in the future if irrigators make efficiency improvements to improve water quality.

4. STATE WATER QUALITY STANDARDS AND REGULATIONS

The agency responsible for establishing and enforcing water quality standards is the Colorado Department of Public Health and Environment (CDPHE).

This agency uses many tools, both regulatory and non-regulatory, to maintain or improve water quality.

4.1 Statewide and Basin-Specific Water Quality Regulations (Regulations 31 and 32)

CDPHE typically develops water quality standards on a statewide basis (Regulation 31). The standards are applied on a site-specific basis for each basin in the state in Regulations 32-38. Regulation 32 identifies the segments, water uses, and standards applied to waterbodies in the Arkansas River Basin, including the Lower Arkansas River Basin. Regulation 32 also documents changes made to water quality standards to better reflect local conditions.

CDPHE will often assign standards specific to the local water uses within each segment. For example, some of the most common water uses in the Arkansas River include agricultural, fisheries, municipal, augmentation, and storage. These specific water uses each carry a specific water quality standard based on research into the effects of water quality pollutants on each specific water use.

Each parameter, such as selenium, pH, or nitrate, has the potential to impair each use (agricultural use, aquatic life, water supply, etc.) at different concentrations. For example, aquatic life in the Arkansas River are exposed to selenium. Because of this exposure, CDPHE has adopted two standards to protect aquatic life in the Arkansas River. The chronic standard (the level not to be exceeded by the concentration for either a single representative sample or calculated as an average of all samples collected during a thirty-day period) is 4.6 micrograms per liter (µg/L), and the acute standard (the level not to be exceeded by the concentration for either a single sample or calculated as an average of all samples collected during a one-day period) is 18.4 µg/L. Water from the Arkansas River is also used for agriculture. The agricultural use standard for selenium is 20 µg/L. If selenium concentrations exceed 20 µg/L, livestock that consume the water may have health, growth, or reproductive problems. Note, the agricultural use standard does not account for a specific agricultural operation or

Aquatic life water quality criteria are typically expressed in two forms, with different recommended magnitudes and durations.

1. **ACUTE** criteria protect against mortality or effects that occur due to a short-term exposure to a chemical.

2. **CHRONIC** criteria protect against mortality, growth and reproductive effects that may occur due to a longer-term exposure to a chemical.

- EPA Water Quality Standards Handbook (2017)

practice. The drinking water standard for selenium in the Arkansas River is 50 µg/L. The standard with the lowest concentration, which happens to be the chronic standard to protect aquatic life, is the effective standard. If the chronic aquatic life standard is attained, the standards associated with all the other water uses will also be attained. Also, the water can only be impaired for the uses it is designated for by CDPHE; not all waters support all uses.

Water quality standards are evaluated and may be revised every five years. The Arkansas River Basin standards were revised in 2018. This was an opportunity for CDPHE, permittees, and other interested parties to review existing standards and/or propose new standards, including site-specific standards. The review process also allowed the public to comment on existing and proposed standards.

4.2 Nutrients in Surface Water Bodies (Regulation 85)

Regulation 85, adopted in 2012, is a nutrient control regulation put forth by the Water Quality Control Commission (Commission). The regulation is intended for point and non-point sources of pollutants and is focused on reducing the amount of nutrients (such as total nitrogen, ammonia, phosphorus, etc.) in surface water bodies.

The regulation was intended to allow a ten-year time window for point source dischargers and non-point sources to reduce the amount of nutrients entering surface water bodies. In 2017, the Water Quality Control Commission delayed the implementation of certain parts of Regulation 85, specifically the adoption of nutrient standards for warm water lakes and all surface water streams. In 2017, the Commission determined that sufficient progress had been made by agricultural producers to voluntarily implement BMPs that have the potential to reduce nutrient loads to surface waters from non-point sources and that the issue would be reevaluated at a hearing in 2020. Therefore, no nutrient regulations are currently enforced by the State of Colorado for non-point sources.

4.3 Process to Address Water Quality Impairments

Because most waters within the state support multiple uses (i.e., recreation, wildlife habitat, drinking water, agriculture), the state will list a stream as impaired if the lowest water quality standard is not met. For example, if the concentration of selenium in the Arkansas River does not meet the standard for municipal drinking water (and if the drinking water standard for selenium is the lowest concentration standard among all uses) the stream will be listed on the 303(d) list.

4.3.1 The 303(d) List and Regulation 93

The Clean Water Act (1972) requires states to publish a biennial list of rivers, streams, and lakes not meeting the standard(s) associated with the designated use on the segment. This includes a 305(b) report and a list commonly called the 303(d) list. In Colorado, this list is also known as Regulation 93. A surface water body can be listed on the 303(d) list in two ways: 1) the water body often exceeds the limit of certain pollutants and is listed as impaired (as determined by a specific 303(d) listing methodology), or 2) the water body does not meet the requirements to be listed as *impaired*, but instead a pollutant is of concern and

Listed Impaired or Threatened Waters (CWA 303(d) List)

- **Category 5:** impaired (or threatened) without a TMDL completed
- **Category 5-alternative (5-alt):** impaired without a TMDL completed but assign a low priority for TMDL development because an alternative restoration approach is being pursued

Not Listed but STill Impaired Waters

- **Category 4a:** impaired with an approved TMDL
- **Category 4b:** impaired without a TMDL but with an appropriate 4b plan
- **Category 4c:** impaired due to pollution

Unimpaired or Restored Waters (i.e., meets water quality standards)

- **Category 1:** meets all designated uses
- **Category 2:** meets some designated uses

Figure 8: If a stream is listed on the 303(d) list it will enter the Category 5 protocol. This prioritizes a TMDL, unless an Alternative Restoration Approach is used.

Table 1: Stream segment descriptions and pollutant type listed as impaired or monitored and evaluated (M&E).

Segment	Analyte	Affected Use	Category	Priorty	Description
COARLAO1c_A	Temperature	Aquatic Life Use	M&E List	NA	Mainstem of the Arkanasa River from the outlet of John Martin Reservoir to the Colorado-Kansas border
	Selenium (dissolved)	Aquatic Life Use	303(d)	High	
	Arsenic (total)	Water Supply Use	303(d)	Low	
	Manganese (dissolved)	Water Supply Use	303(d)	Low	
	Uranium (total)	Water Supply Use	303(d)	High	
COARLAO2a_A	Manganese (dissolved)	Water Supply Use	303(d)	High	All tributaries to the Arkansas River, including wetlands, from the Colorado Cana head-gate to the Colorado/Kansas border, except for specific listings in segments 2b, 2c, 3a through 9b, and Middle Arkansas Basin listings.
	Sulfate	Water Supply Use	303(d)	High	
COARLAO9_A	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	Mainstems of Adobe, Buffalo, Cheyenne, Clay, Gageby, Horse, Two Butte, Wildhorse, and Wolf Creeks from their sources to their confluences with the Arkansas River. Mainstems of the Chacuacho Creek, San Francisco Creek, Trinchera Creek, and Van Bremer Arroyo from their sources to their confluences with the Purgatoire River. Mainstem of Willow Creek from Highway 287 to the confluence with the Arkansas River. Mainstem of Big Sandy Creek from the source to the El Paso/Elbert county line. Mainstem of South Rush Creek from the source to the confluence with Rush Creek. Maintem of Middle Rush Creek from the source to the confluence with North Rush Creek. North Rush Creek from the source to the confluence with South Rush Creek. Mainstem of Rush Creek to the Lincoln County Line. Mainstem of Antelope Creek from the source to the confluence with Rush Creek; the West May Valley drain from the Fort Lyon Canal to the confluence with the Arkansas River.
	Arsenic (total)	Water Supply Use	303(d)	High	
	Manganese (dissolved)	Water Supply Use	303(d)	Low	
COARLAO9_B	Sulfate	Water Supply Use	M&E List	NA	Mainstem of Horse Creek
	Uranium (total)	Water Supply Use	M&E List	NA	
	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	
	Arsenic (total)	Water Supply Use	303(d)	High	
	Iron (total)	Aquatic Life Use	303(d)	High	
	Manganese (dissolved)	Water Supply Use	303(d)	NA	
COARLAO9_C	Selenium (dissolved)	Aquatic Life Use	M&E List	NA	Mainstem of Adobe Creek
	Arsenic (total)	Water Supply Use	M&E List	NA	
	Iron (total)	Aquatic Life Use	M&E List	NA	
	E. coli	Recreational Use	303(d)	High	

COARLAO9b_A	Manganese (dissolved)	Water Supply Use	M&E List	NA	Mainstem of Apache Creek from the source to the confluence with the North Rusk Creek. Mainstem of Breckenridge Creek from the source to the confluence with Horse Creek. Mainstem of Little Horse Creek from the source to the confluence with Horse Creek. Mainstem of Bob Creek from the source to Meredith Reservoir. Mainstem of Big Sandy Creek within Prowers County. Mainstem of Rule Creek from the Bent/Las Animas county line to John Martin Reservoir. Mainstem of Muddy Creek from the south boundary of the Setchfield State Wildlife Area to the confluence with Rule Creek. Mainstem of Caddoa Creek from CC Road to the confluence with the Arkansas River. Mainstem of Cat Creek from the source to the confluence with Clay Creek. Mainstem of Mustang Creek from the source to the confluence with Apishapa River. Mainstem of Chicosa Creek from the source to the Arkansas River. Mainstem of Smith Canyon from the Otero/Las Animas country line to the confluence with the Purgatoire River. Mainstem of Mud*
	Sulfate	Water Supply Use	M&E List	NA	
	Temperature	Aquatic Life Use	M&E List	NA	
	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	
	Iron (total)	Aquatic Life Use	303(d)	Medium	
COARLAO9b_B	Manganese (dissolved)	Water Supply Use	M&E List	NA	Big Sandy Creek within Prowers County
	Sulfate	Water Supply Use	M&E List	NA	
	Temperature	Aquatic Life Use	M&E List	NA	
	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	
	Iron (total)	Aquatic Life Use	303(d)	NA	
COARLA10_B	Selenium (dissolved)	Aquatic Life Use	303(d)	NA	Adobe Creek Reservoir
	Arsenic (total)	Water Supply Use	303(d)	High	
COARLA10_B	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	Nee Gronda Reservoir
COARLA11_A	Selenium (dissolved)	Aquatic Life Use	303(d)	Low	John Martin Reservoir
	Arsenic (total)	Water Supply Use	303(d)	High	

requires more *monitoring and evaluation*. A TMDL is developed based on the amount of pollutant a water body can support and assigns a maximum pollutant load from point sources and non-point sources. Once a quantifiable “load” is determined, the amount of pollutant (usually in pounds per day) is divided among point sources and non-point sources, with a margin of safety included to account for uncertainties in the data/conditions that cannot be accounted for given the limited nature of data itself.

TMDLs exist on the Arkansas River upstream, mostly in the upper Arkansas River Watershed above Pueblo, CO, and mostly for pollutants such as lead, zinc, cadmium, and other byproducts of mining. The closest TMDL to the Lower Arkansas River Watershed is on Boggs Creek, a tributary to Pueblo Reservoir. This TMDL is most significant to the Lower Arkansas River Watershed because the TMDL was developed to reduce loading of selenium and uranium. These two pollutant elements are the highest priorities for TMDL development in the Lower Arkansas River Watershed.

The entire Lower Arkansas River Watershed from Pueblo, CO, to Kansas has impaired water bodies and TMDL needs. A TMDL is currently being developed for the segment of river and its tributaries immediately above the Lower Arkansas River Watershed – John Martin to State Line. This includes the Arkansas River from the Colorado Canal headgate to John Martin

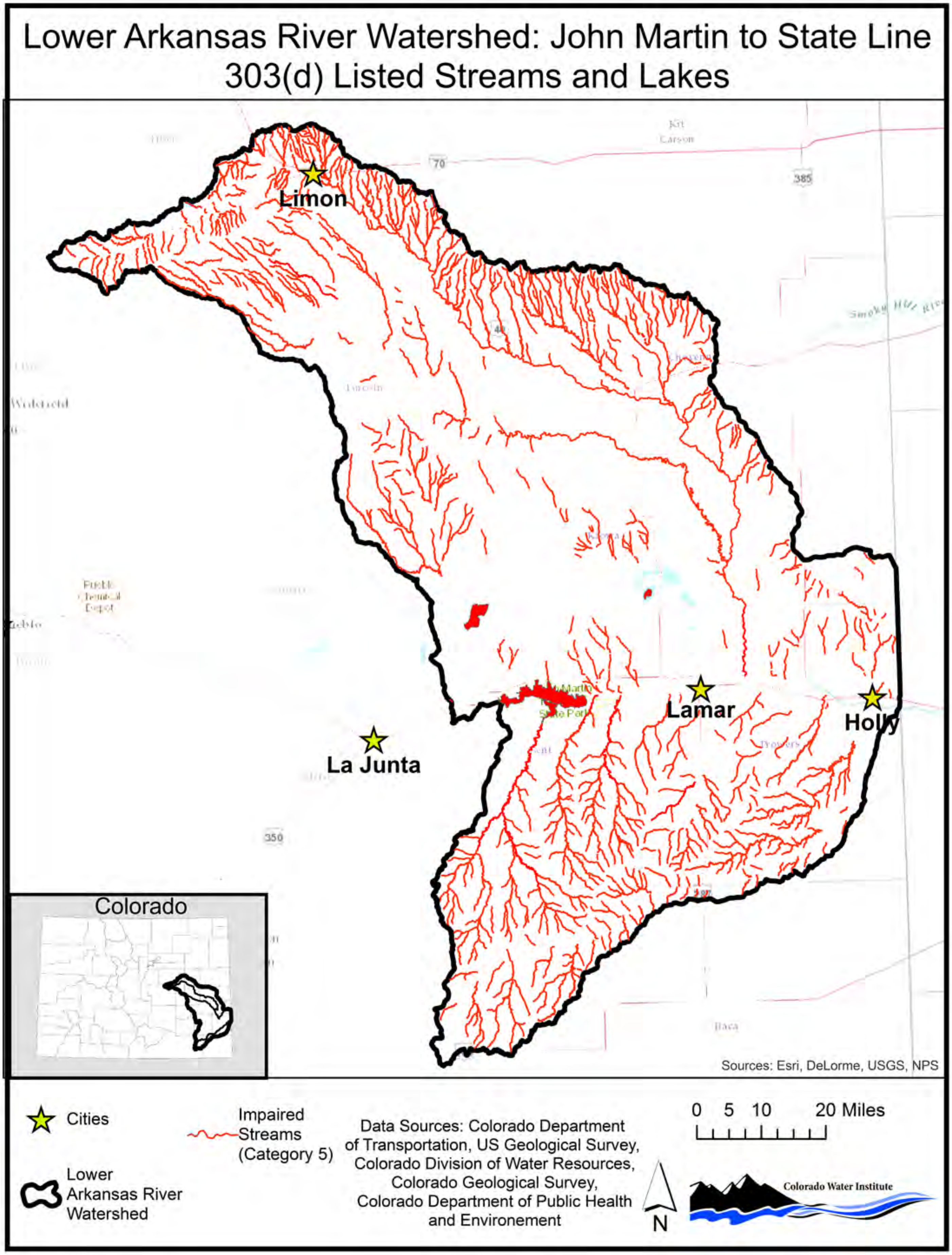

Figure 9: Stream segments listed as "impaired" on Colorado's 303(d) list.

Reservoir. Presently, there are no TMDLs for any surface water bodies located in the Lower Arkansas River Watershed – John Martin to Stateline.

The development of a TMDL is the most common administrative way to clean up pollutants that are impairing surface waters. However, the federal government allows states to postpone the development of a TMDL for impaired waters and use the *Alternative Restoration Approach*. This approach allows local stakeholders the opportunity to implement practices with a high likelihood of improving water quality. For example, preliminary research conducted by Colorado State University shows lining and sealing ditches and canals can reduce seepage to shallow groundwater tables and reduce selenium loading to the river. This theory needs to be tested, and therefore pilot projects need to be implemented to monitor the effectiveness of this practice on actual selenium load reduction. This watershed plan, along with robust and scientifically sound pilot projects, will provide the implementation steps to improve water quality in the Lower Arkansas River basin and serve as the *Alternative Restoration Approach*.

4.3.2 Resolving Water Quality Issues and De-listing

A water body can be removed from the 303(d) because "new information is developed, which indicates that water quality standards are being met and/or designated uses are being attained" (WQCD, 2016), including:

a. More recent or more accurate data

b. More sophisticated analysis using a calibrated model

c. Identification of deficiencies in the original standards

d. Changes in standards, guidance, or policy

To know if the criteria or water quality standard is being attained, one would have to have a) or b) on the list above.

4.3.3 303(d) Listed Waterbodies in the Watershed

Table 1 describes the impaired river segments within the watershed, and Figure 11 shows the location of a 303(d) listed stream, current as of 2017.

4.3.4 Monitoring and Evaluation Segments (Regulation 93)

Occasionally, streams are not listed as impaired under category 5 (Figure 9) but do show symptoms of pollution that could lead to listing the stream for that pollutant on the 303(d) list. These streams will still be listed in Regulation 93 and classified as Monitoring and Evaluation (M&E) segments for specific water quality parameters. For example, the main stem of the Arkansas River from JMR to Kansas is listed on the 303(d) list as impaired for selenium, uranium, manganese, and arsenic. The same segment of river is also being monitored and evaluated for temperature. If the future data suggest temperatures in this segment of river exceed the standards for a specific use, the segment could be listed on the 303(d). However, at this time, more data is needed to make this determination. Another example is Adobe Creek. The creek is listed on the 303(d) list for E. coli, but the stream is also on the M&E list and closely monitored for selenium, iron, and arsenic.

5. DESCRIPTION OF THE DATA

This section describes the data sources used in this analysis.

5.1 Data Sources

Collecting water quality data can be challenging, time-consuming, and expensive due to strict handling procedures and expensive lab analysis costs. For this reason, all of the data used in this water quality analysis was gathered from existing data sources. These data sources include:

- Water Quality Exchange and Storage and Retrieval database(WQX/STORET)
- Colorado Department of Agriculture

Several agencies utilize WQX/STORET as a primary data hub for public access. These agencies include

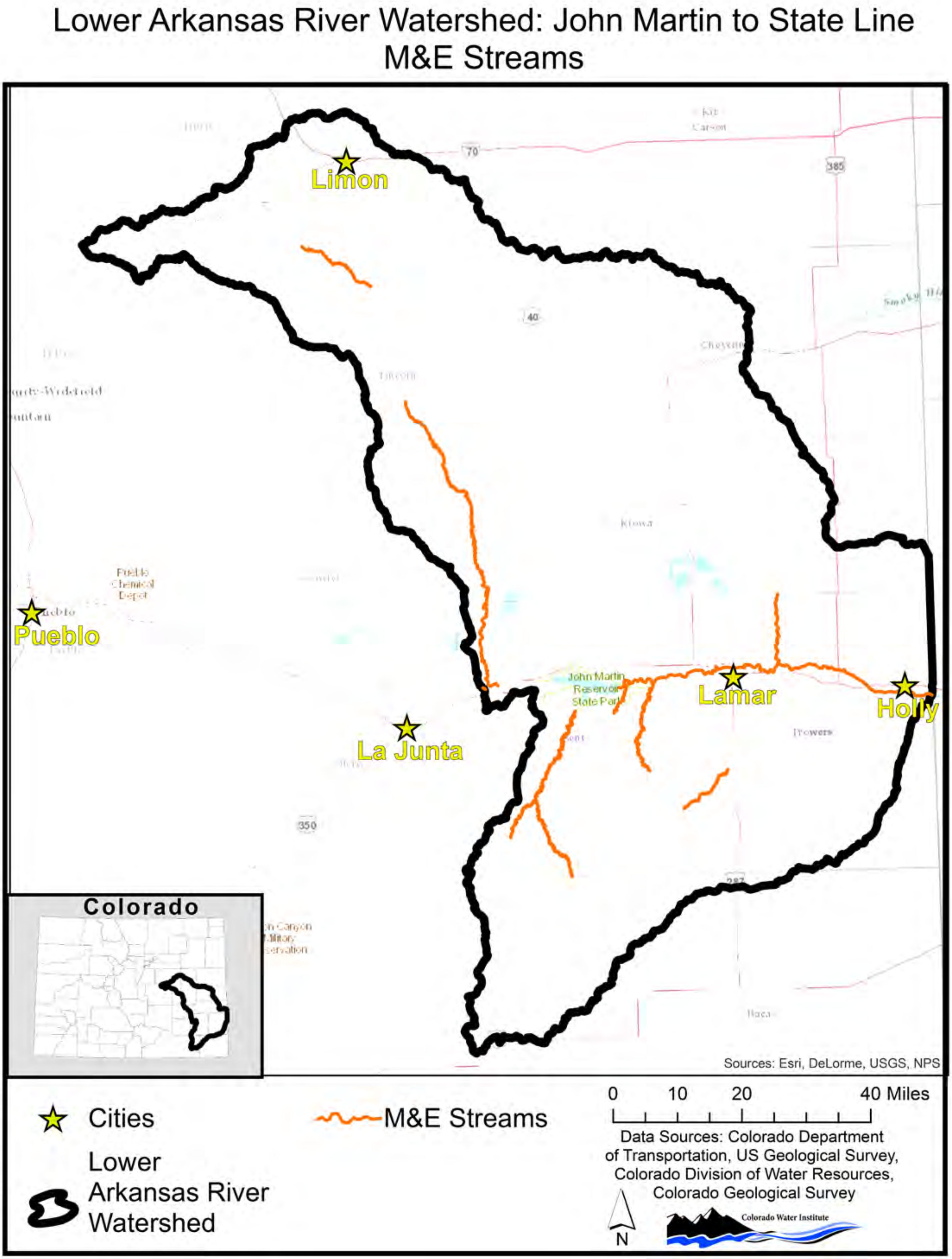

Figure 10: Location of streams listed as "Monitored and Evaluated" on Colorado's 303(d) list.

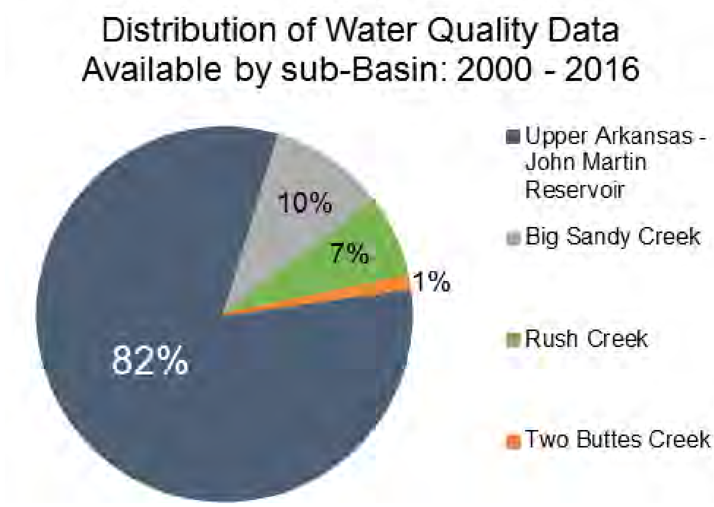

Figure 11: Percentages of water quality samples taken in each sub-watershed.Colorado's 303(d) list.

the Environmental Protection Agency, the Colorado Department of Public Health and Environment, and the US Geological Survey. With the exception of load analyses, the data used in this plan are from the agencies mentioned above, including a small amount of data from the Colorado Department of Agriculture.

This analysis uses data collected from 2000-2016. This period of record was selected for the following reasons: 1) frequent and large changes to water administration, 2) the sale and purchase of water rights, and 3) changes in land use. The Colorado Division of Water Resources implemented irrigation improvement rules of 2011—one example of changing water administration that greatly affected water uses, principally in agriculture. Additionally, water rights have been transferred within and outside of the watershed and have corresponded with changes in the acreage of irrigated land.

All three of these "hydrologic adjusters" can have direct and significant impacts on stream flow, water use, and water quality. The selected period of record, 2000-2016, also allows for a more detailed analysis given the project's timeline and budget. The compiled water quality data set includes 19,967 unique records.

Most of the data was collected from the main stem of the Arkansas River. A limited number of samples were collected from the Big Sandy, Rush, and Two Buttes sub-watersheds. For this reason, most of the water quality analyses were performed on data within the Upper Arkansas-John Martin Reservoir sub-watershed. Due to the limited number of results from the Big Sandy and Rush sub-watersheds, this analysis only provides summary statistics of selected water quality parameters. The Two Buttes sub-watershed lacks data, and summary statistics are not provided.

The Upper Arkansas-John Martin sub-watershed contains 82% of the results (Figure 13). Further, most of the results are from the main stem of the Arkansas River. As a perennial river, the Arkansas River has been sampled more than its tributaries, which may flow on an intermittent or ephemeral basis. Summary statistics and loading analyses were performed using Microsoft Excel.

Site-specific variance plots were created using the statistical and graphing software R with the ggplot2 package (Wickham, 2009).

Loads were calculated from paired concentration and flow data. For this reason, only a select number of sampling locations could be used. Most of these locations are on the main stem of the Arkansas River near a USGS flow gauge. At these sites, load duration curves were developed.

5.2 Load Duration Curves

Load duration curves are helpful for determining the pollutant load a stream can accept and still meet the applicable water quality standard. This method is preferred when evaluating pollutant loading and standards in moving water bodies, such as rivers and streams, because it accounts for flow by using flow percentiles from historical flow measurements. A simple calculation can turn flow (in cfs) and concentration data (in mg/L or µg/L) into pounds of pollutant per day passing a single location on the stream. An example equation for determining the flow-adjusted selenium standard load is as follows:

$$\frac{\text{700 cubic feet}}{\text{1 second}} \times \frac{\text{864,000 seconds}}{\text{1 day}} \times \frac{\text{28.3168 liters}}{\text{1 cubic foot}} \times \frac{\text{4.6 micrograms}}{\text{1 liter}} \times \frac{\text{1 pound}}{5.563e^{8}\ \text{micrograms}} = \frac{\text{17.37 pounds}}{\text{1 day}}$$

In the example above (Equation 1), a well-mixed stream flowing at 700 cfs could accept a maximum load of 17.36 pounds of selenium in one day and not exceed the chronic standard concentration of 4.6 µg/L. Load duration curves are helpful in TMDL planning, as they set a quantifiable limit of pollutants that can then be allocated between point sources and non-point sources.

In Figure 12, selenium loading was calculated from water quality samples and compared with the maximum loading limit the flow regime could support and still meet the water quality standards. The load duration curves were developed using methodology established by the EPA (Environmental Protection Agency, 2007), which analyzes loading by flow categories based on the probability of a particular flow occurring at a certain point on the river. For example (from Figure 12), high flows were calculated as the top 10% of flows that occurred in the Arkansas River at Las Animas, CO, during the study period of 2000-2016. The same is true for the other flow conditions:

- Moist Conditions (flows equaled or exceeded 10-40% of the time)
- Mid-Range Flows (flows equaled or exceeded 40-60% of the time)
- Dry Conditions (flows equaled or exceeded 60-90% of the time)
- Low Flows (flows equaled or exceeded 90%-100% of the time)

For convenience, each break point between the flow classifications contains a corresponding cfs value. From Figure 12, 10% of the flow measurements at Las Animas, CO, between 2000 and 2016 were greater than 422 cfs, and 90% of the flow measurements were above 23 cfs. The yellow line in Figure 12 is the maximum acceptable loading value of selenium for all flow conditions while still maintaining an acceptable concentration of 4.6 µg/L or less of selenium (assuming constant loading of selenium and a well-mixed river). You can see in Figure 12 the estimated loading values (in pounds of selenium entering the river per day, y-axis) from selenium concentration data under various flow conditions exceed the state standard in each sample. Therefore, selenium loading is continuously high, suggesting a large influence from groundwater sources that supply water to the system continuously throughout the year. Analyzing other pollutants might reveal seasonal trends, such as spikes in nitrogen loading during low flow conditions during winter months. More detailed explanations of loading can be found in Section 6.

5.3 Analysis Parameters

The sections below introduce the parameters included in this analysis and provide justification for their inclusion.

5.3.1 Selenium

Selenium is necessary for growth and development; humans and animals need selenium as a micro-nutrient. However, high concentrations of selenium can lead to neurological conditions such as alkali poisoning.

Selenium is a naturally occurring element commonly found in marine shale formations throughout Colorado. Shale bedrock formations contain selenium (or commonly selenate) within the rock structure. Selenium is naturally released as precipitation percolates through selenium-rich soils and rock formations. In areas with selenium-rich soils and rock formations, natural weathering processes can elevate selenium concentrations in groundwater. Several types of water use, including irrigation, septic drain fields, and water storage in unlined ponds, create deep percolation and the accumulation of shallow groundwater tables. In areas with selenium-rich geology, deep percolation increases selenium concentrations because of the natural redox reactions that occur when the bedrock is wetted and exposed to other chemical constituents. Practices to reduce or eliminate deep percolation, such as deficit irrigation or lining ponds, can be effective practices to reduce the manmade component of selenium loading.

The presence of certain elements or compounds, specifically nitrate, can accelerate the release of selenium into groundwater. This may lead to higher concentrations of selenium in groundwater of certain

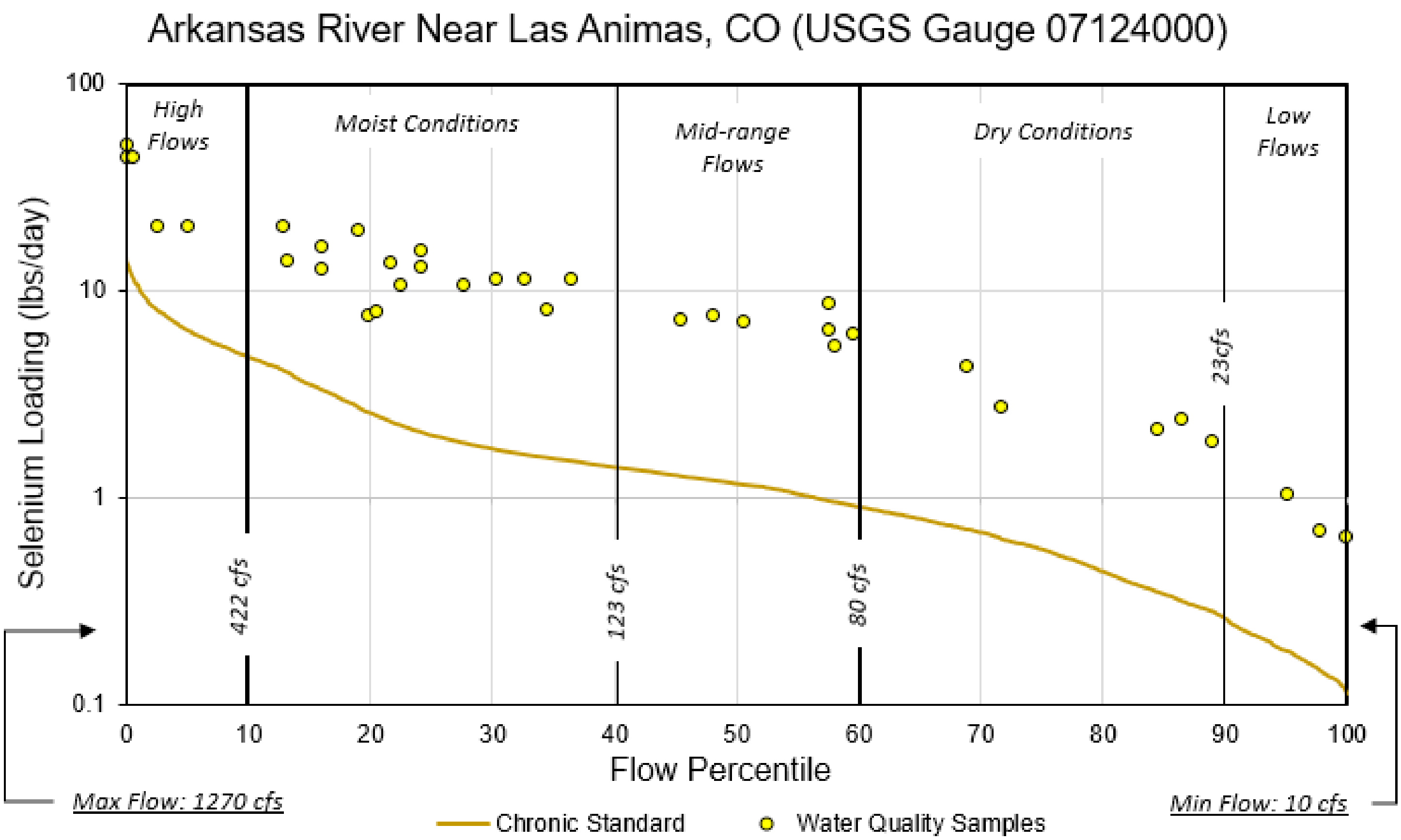

Figure 12: Example of a load duration curve for selenium.

areas within the watershed where shale bedrock formations exist.

5.3.2 Uranium

Uranium is a radioactive element that can be used to generate electricity through nuclear fusion, but it also poses a health risk because of its radioactive properties. The radioactive decay of uranium emits radiation, which has been proven to increase the risk for cancer and other health problems. However, the US Center for Disease Control says health problems associated with the ingestion of uranium are a byproduct of chemical toxicity and not radioactive toxicity. Nevertheless, uranium is considered a great health risk to people and animals because of its bio -accumulative nature, which can lead to kidney failure.

Much like selenium, uranium is commonly found in marine shale bedrock formations. Many of the same processes that mobilize the release of selenium from the bedrock also mobilize uranium. The chronic and acute standards for uranium are hardness-dependent as the toxicity of uranium is dependent upon the hardness of the water. The chronic and acute standards are calculated using the equations provided in Regulation 31. Because water hardness data is not included in all water quality samples, the EPA's radionuclide standard of 30 µg/L was used.

6. ANALYSIS METHODS

The methods used in this analysis are outlined below.

6.1 Method Detection Limit

The Method Detection Limit (or MDL) can be thought of as the "sensitivity factor" of the instruments or procedures used to analyze water quality samples. The MDL is not reported as an actual measured value, but rather a value that can be represented with a high degree of confidence. Some laboratory water quality analyses, standards, and practices can accurately and precisely detect water quality parameters at much lower concentrations, while other laboratory methods are not as robust at detecting small amounts of the analyte. For example, some methods used to detect sulfate can accurately and precisely detect sulfate concentrations above 0.2 µg/L, while other methods can only detect sulfate concentrations greater than 2 µg/L. If a water quality sample was analyzed using each of the methods described above, it is likely the first method would produce a more accurate reading of sulfate concentrations. Not all of the water quality data analyses included information on the MDL of each individual sample.

6.2 Method Reporting Limit

The Method Reporting Limit (MRL) is a threshold value that represents the lowest quantifiable concentration of a water quality parameter that can be replicated using standard laboratory methods and procedures. The MRL is different than the Method Detection Limit (MDL) in that the MDL is the minimum detectable concentration of an analyte that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results (EPA, 2016). Results can still be reported as non-zero values if the value is above the MDL but below the MRL. In the analyses, results below the MRL were treated as zeros.

6.3 Data Summarization Methods

Data was summarized spatially along the main stem of the Arkansas River and tributaries to the north and south, including Big Sandy Creek and Rush Creek. Summary statistics were compiled using methods consistent with the Colorado Department of Public Health and Environment (i.e., 85th percentile). The minimum, mean, and maximum values are reported for all parameters independent of the number of samples. Only percentile statistics (i.e., 85th, 15th) are reported for parameters with more than five samples.

7.0 UPPER ARKANSAS-JOHN MARTIN RESERVOIR SUB-WATERSHED

The Upper Arkansas-John Martin Reservoir sub-watershed contains the entire main stem of the Arkansas River analyzed under the scope of this watershed plan. It also contains the most significant water uses in the watershed, with large amounts of water diverted for irrigated agriculture and the largest source of drinking water in this watershed, as well as critical habitat for fish and migratory birds.

The John Martin Hydrologic Unit Code (HUC) western boundary is near Las Animas, CO, and the eastern boundary is the border with Kansas. From Las Animas, CO, to John Martin Reservoir, the watershed lies predominantly along the north side of the river. The majority of irrigated agriculture is within this sub-watershed. Between 2000 and 2016, more than 80f% of all water quality data collected in the watershed were collected in this sub-watershed and, therefore, most of the data analyses were performed using data from this sub-watershed. There are 48 sampling locations within this sub-watershed: 37 location are monitored by the Colorado Department of Public Health and Environment; five locations are monitored by the EPA National Aquatic Resource Survey; and six locations are monitored by the USGS. All of the USGS monitoring sites are located on the main stem of the Arkansas River.

The locations of the samples taken by the EPA National Resource Survey and CDPHE are a mixture of sites located on the main stem of the Arkansas, its tributaries, and lakes/reservoirs, included four effluent discharge points. In total, over 16,000 water quality parameters were measured within the sub-watershed from 2000-2016. This includes all data parameters, such as specific conductance (EC), total dissolved solids (TDS), biological parameters, dissolved constituents (i.e., selenium), and even some measurements of flow. Much of this data was not used because the analyses focused on parameters commonly listed on the 303(d) list.

Finally, in an attempt to reveal the source of some pollutants, this sub-watershed was further divided,

Table 2: Summary statistics for parameters of interest in the Upper Arkansas-John Martin Reservoir sub-watershed.

Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	199	169	32	0	5	12	12	19	53
Dissolved Uranium (µg/L)	135	(D)	(D)	6	14	32	37	62	97
Dissolved Arsenic (µg/L)	134	78	0	0.00	0.00	0.93	1.29	1.80	3.00
Total Recoverable Arsenic (µg/L)	23	23	0	1.40	2.26	3.30	3.33	3.80	6.80
Dissolved Manganese (µg/L)	185	112	(D)	0.0	14.0	90.0	197.2	203.5	1600.0
Nitrite (mg/L)	13	1	-	0.000	0.000	0.020	0.083	0.034	0.930
Nitrate (mg/L)	12	-	0	0.590	0.794	1.200	1.460	2.335	2.600
Total Nitrogren (mg/L)	347	20 (A)	-	0.000	0.185	0.780	0.895	1.605	3.400
E. coli (#/100mL)	112	23	-	0	1.0	28.2	115.1	141.4	1558.1
Sulfate (mg/L)	173	172 (B)	-	41	762	1500	1452	2100	2700
Dissolved Phosphorus (mg/L)	174	7 (C)	-	0	0.016	0.030	0.057	0.070	1.500
Dissolved Oxygen (mg/L)	120	18	-	0.87	5.00	6.84	7.04	9.72	14.05
Total Recoverable Iron (µg/L)	160	-	12	0	75	320	991	1100	43000

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 µg/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.
D. Indeterminate due to lack of data.

and analyses were performed in the following areas: 1) main stem of the Arkansas River, 2) tributaries to the north of the Arkansas River, 3) tributaries to the south of the Arkansas River, 4) Adobe Reservoir, 5) Nee Gronda Reservoir, and 6) John Martin Reservoir.

7.1 Maps

Figures 13-17 show the locations and names/identifiers of water quality sampling points within the Upper Arkansas-John Martin Reservoir sub-watershed.

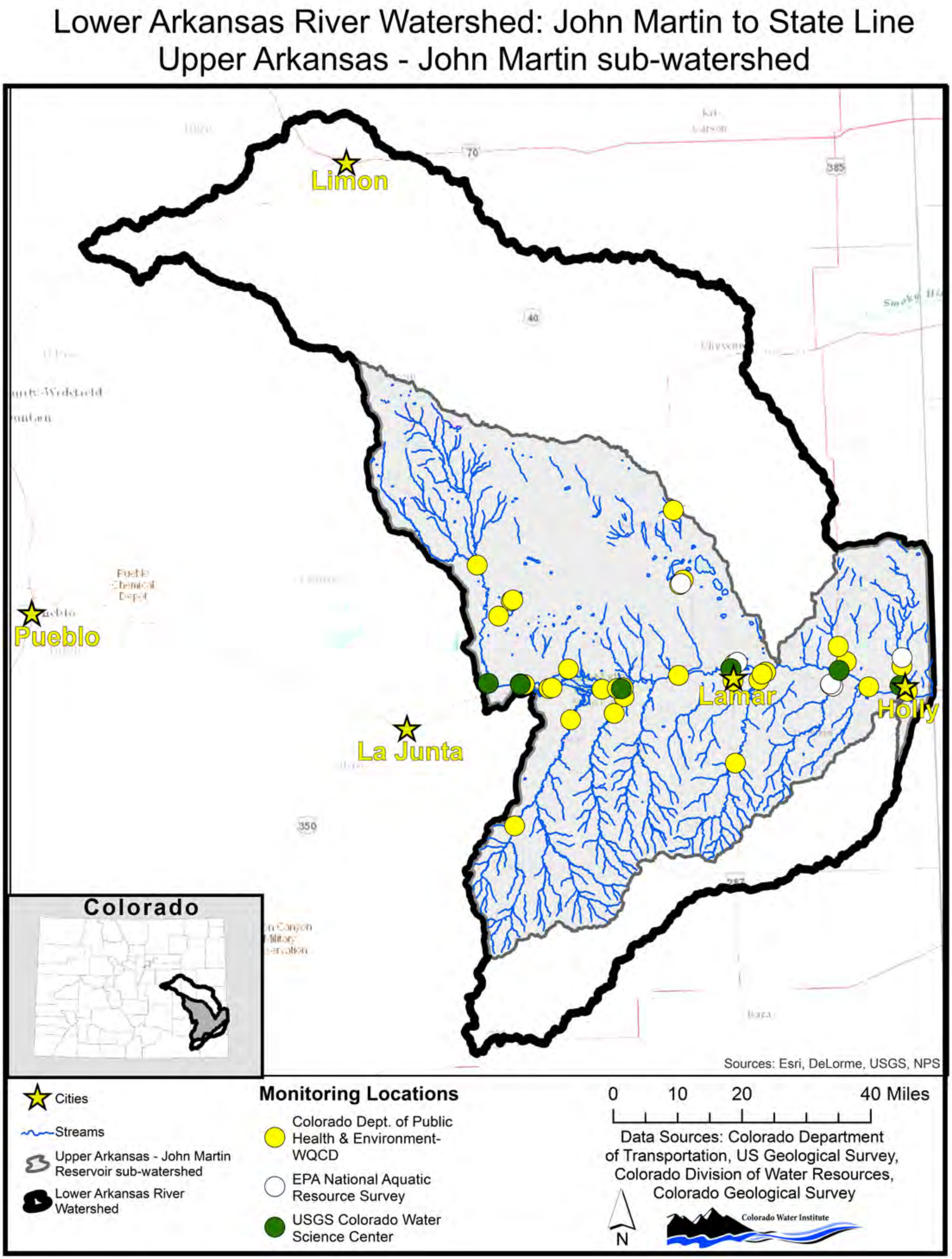

Figure 13: Sampling locations and agencies responsible for taking samples taken in the Upper Arkansas-John Martin Reservoir sub-watershed.

Lower Arkansas River Watershed: John Martin to State Line
Upper Arkansas - John Martin sub-watershed Sample Distribution

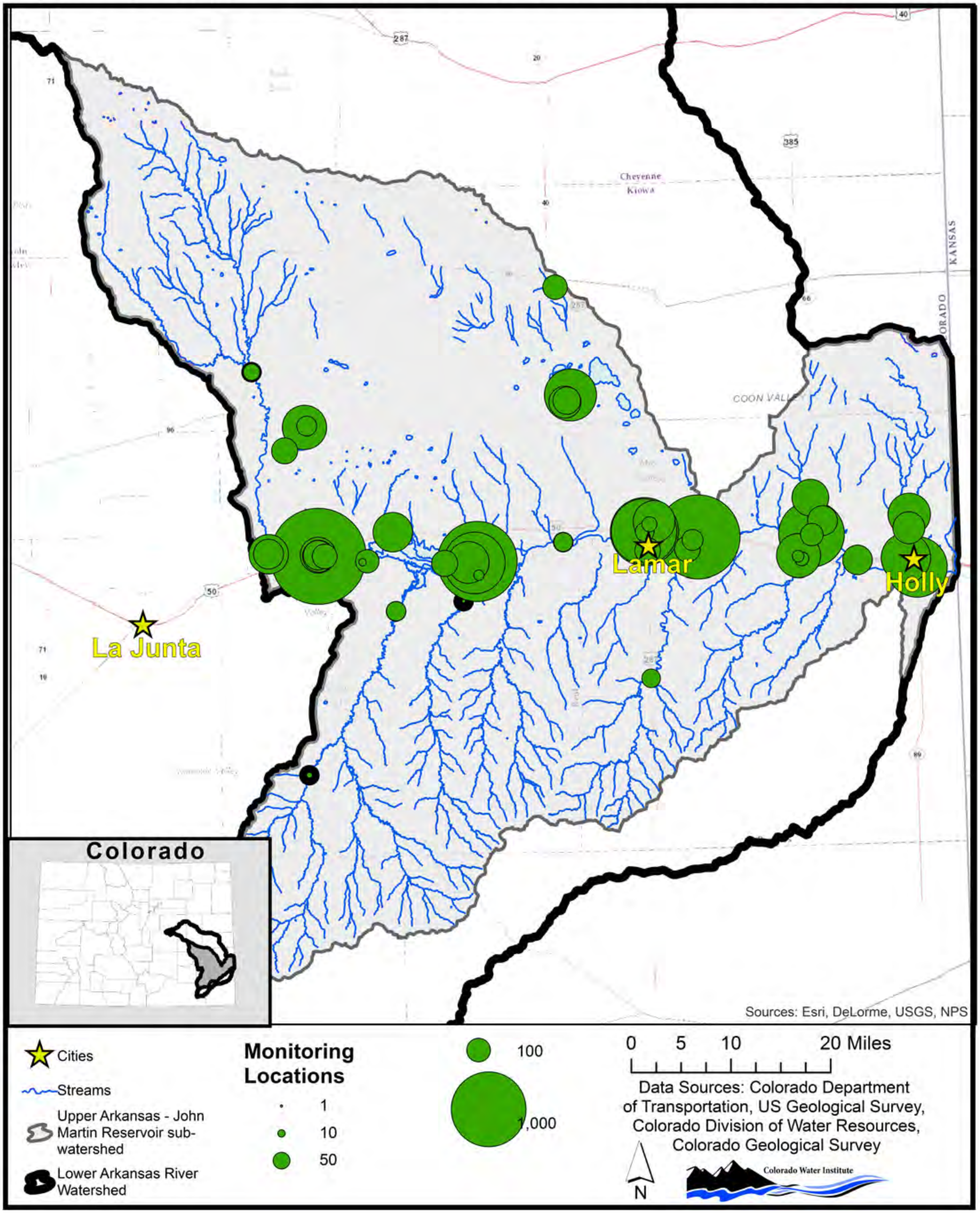

Figure 14: Sampling locations and relative number of samples taken in the Upper Arkansas-John Martin Reservoir sub-watershed.

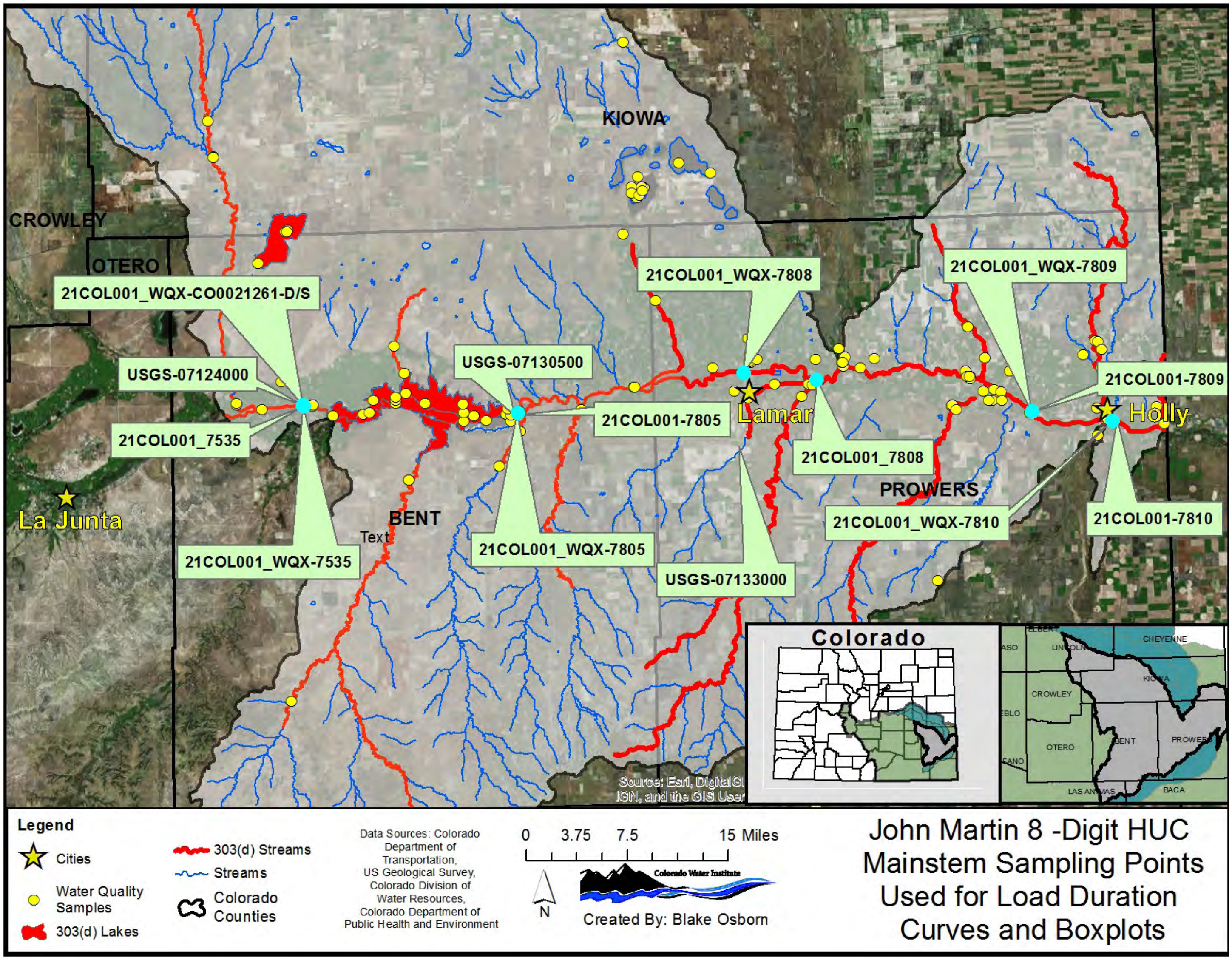

Figure 15: Sampling locations on the main stem of the Arkansas River.

7.2 Analysis and Discussion: Main stem of the Arkansas River

The parameters of interest analyzed on the main stem of the Arkansas River include: selenium, uranium, arsenic, manganese, nitrite, nitrate, total nitrogen, E.coli, sulfate, phosphorus, dissolved oxygen, and iron. This section of river, the Arkansas River from a point near Las Animas, CO to the Colorado-Kansas State Line (COARLA01c) is on the 303(d) List for dissolved selenium, total uranium, total arsenic, and dissolved manganese.

7.2.1 Arkansas River Main Stem: Dissolved Selenium

Selenium concentrations ranged from <MRL to 53 µg/L (Monitoring Location 21COL001-7807; Date 2/7/2006) in 190 samples. The average selenium concentration was 12 µg/L, and the average selenium concentration measured in the main stem of the Arkansas River is nearly three times higher than the chronic aquatic life standard of 4.6 µg/L. Seventy percent of the samples contained greater than 5 µg/L of dissolved selenium, but less than 19 µg/L. Dissolved selenium concentrations in 169 samples exceeded

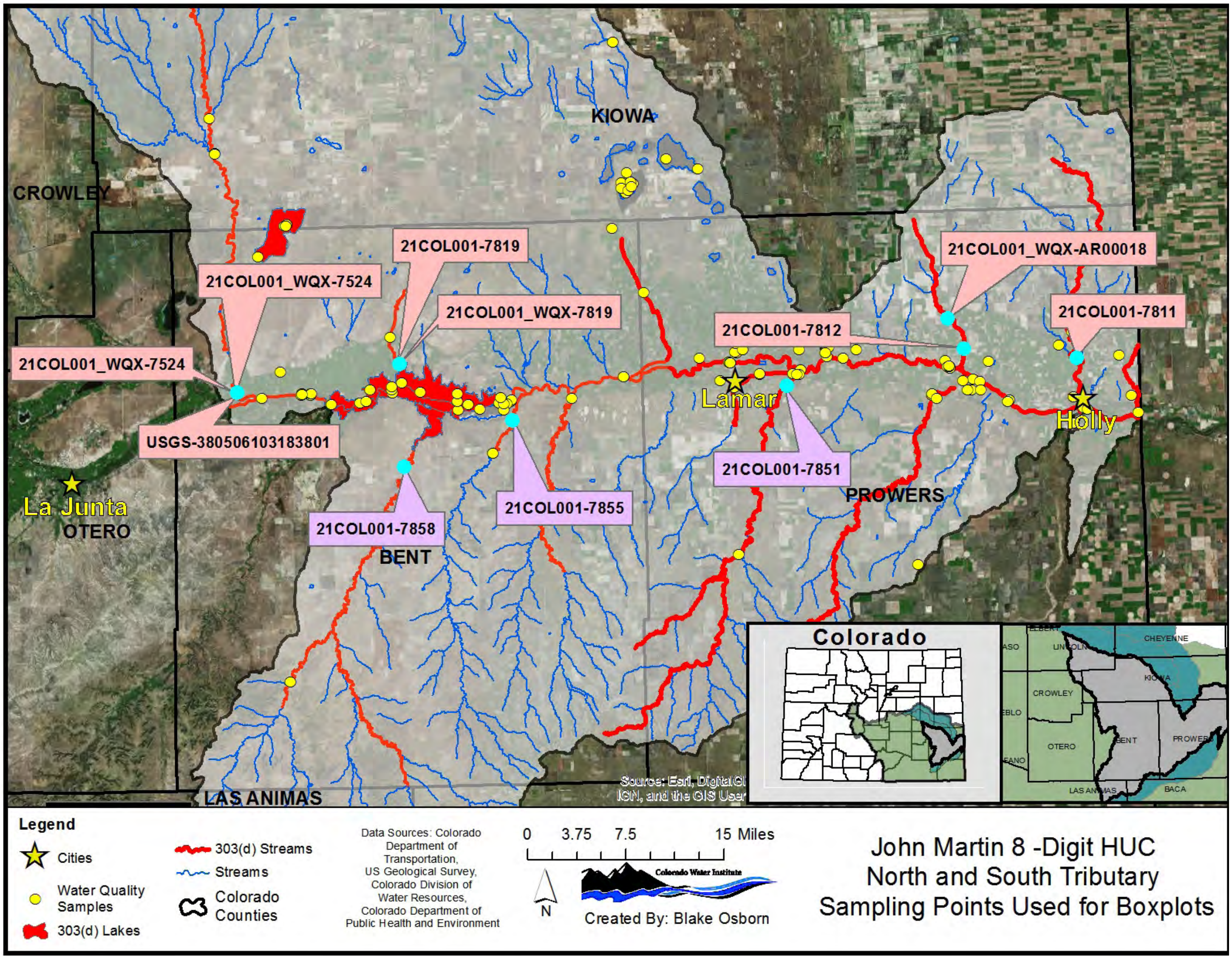

Figure 16: Sampling locations on north (peach) and south (purple) sides of the Arkansas River; Big Sandy Creek and Two Buttes Creek are excluded.

the chronic aquatic life standard of 4.6 µg/L, and concentrations exceeded the acute aquatic life standard of 18.1 µg/L in 32 samples.

7.2.2 Arkansas River Main Stem: Dissolved Uranium

The main stem of the Arkansas River has the highest observed uranium concentrations for all waterbodies in the John Martin sub-watershed. This could be a product of sample design, as most water quality samples collected in the watershed take place on the main stem of the Arkansas River. However, water quality sample analyses performed on tributaries also included uranium, and none of the sampled tributaries had concentrations exceeding values observed on in the river. 135 samples collected from the main stem of the Arkansas River show dissolved uranium concentrations ranging from zero to 97 µg/L (Monitoring Location 21COL001-7808; Date 2/10/2003). The average concentration was 37 µg/L. Eighty five percent of the samples had concentrations greater than 14 µg/L, and 85% of the samples had a concentrations less than 62 µg/L. The water supply standard, and the effective standard, for uranium is 30 µg. Seventy-eight

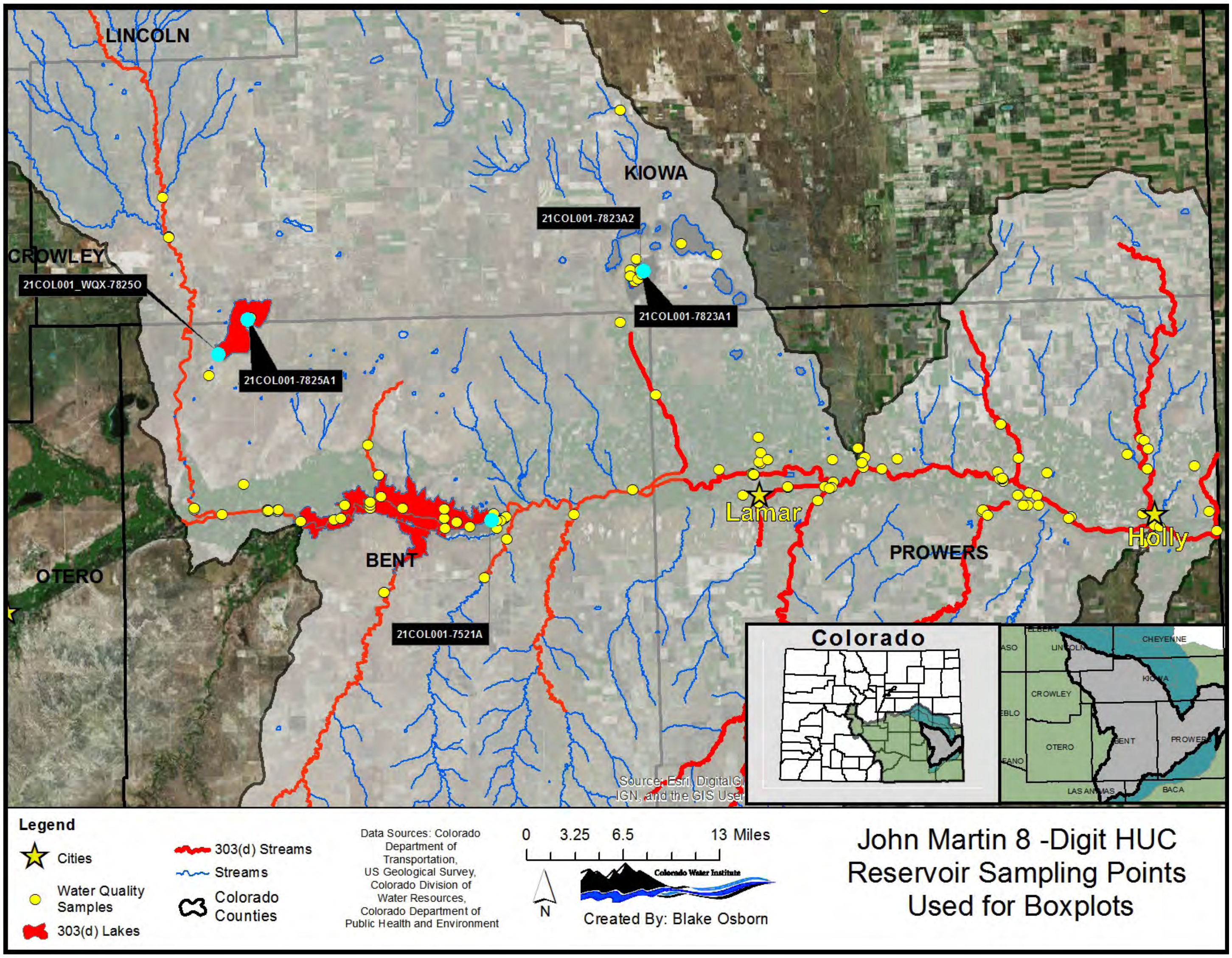

Figure 17: Sampling locations for reservoirs in the Lower Arkansas River Watershed.

of the 135 samples (57%) had a uranium concentration greater than 30 µg/L.

7.2.3 Arkansas River Main stem: Nutrients

Generally, nutrients (including nitrogen and phosphorus) do not exceed water quality standards, except at a few locations and during certain times of the year. More information on the relationship between nitrogen and river flows/timing can be found in the load duration curves in sub-section 7.3.5. To evaluate standard exceedances, the chronic standard for total nitrogen was set to 2.01 mg/L and 170 µg/L for phosphate (for warm water Tier 1 streams). Nitrate and nitrite were evaluated against standards set by Regulations 31 and 32.

Nitrogen

Nitrogen analyses were performed on individual parameters, nitrate and nitrite, as well as total nitrogen. Nitrate and nitrite concentrations were always below the standards set by Regulation 32 of 10 mg/L and 1 mg/L, respectively. Total nitrogen had an average concentration of 1.16 mg/L, a maximum of 15.2 mg/L, and a minimum values of 0.07 mg/L. The main stem of the Arkansas River is the most-well-mixed waterbody in this sub-watershed, and concentrations are likely to be higher in water at or near agricultural fields, or in groundwater.

Phosphorus

Phosphorus does not significantly negatively impact streams in this watershed, as more than 85% of the samples had concentrations equal to or less than 70 µg/L, well below the chronic standard of 170 µg/L. Only seven samples, or 4% of all phosphorus samples, exceeded the interim standard. Phosphorus levels are more important for lake environments with slower moving/mixing waters. See section 7.5 for a discussion on water quality in John Martin Reservoir.

Other Listed Parameters

The main stem of the Arkansas is listed as "impaired" for selenium, uranium, arsenic, and manganese. CDPHE lists selenium and uranium as high priorities for TMDL and development and restoration, while manganese and arsenic are listed as lesser priorities.

All samples tested for arsenic exceeded the standard concentration of 0.02 µg/L. According to Regulation 32, the chronic arsenic standard used for analysis is taken from the acceptable levels for fish as well as domestic water supplies. The human health standard is a two-part standard. The first part of the standard is used to protect human-health (0.02 µg/L), and the second part of the standard is the maximum contaminant level (10 µg/L) for raw water supplies. Although arsenic values were observed as high as 3 µg/L, this concentration is well below the 100 µg/L standard for agricultural uses and less than the chronic biological standard of 150 µg/L.

Thirty six percent of the samples collected and tested for manganese had concentrations above the chronic biological standard of 50 µg/L. The highest observed concentration of manganese was 1600 µg/L (Monitoring Location 21COL001-7805; Dates 2/26/2001 & 1/22/2002), with an average concentration of 248.2 µg/L.

7.3 Pollutant loading analysis for the main stem of the Arkansas River

Loading analyses are critical for identifying the original source regions where contaminants are entering a waterbody. By creating load duration curves, we can calculate the contributions of specific pollutants from certain regions. Load duration curves and the changes in concentrations of pollutants are best analyzed on a reach basis.

For the purposes of this watershed plan, stream reaches were divided by segments between USGS flow gauges. Flow data is critical for the calculation of loading, and three USGS flow gauges provide the most adequate flow data available for the watershed. The flow gauges are identified as 07124000 above John Martin Reservoir near Las Animas, CO; 07133500 located within a mile of the John Martin Reservoir outlet; and 07133000 located near the town of Lamar, CO. The gauges are ideally positioned on the river system to evaluate loading occurring upstream of the watershed, processes in John Martin Reservoir that elevate or reduce constituents, and finally the contribution of certain land use practices (especially farming practices) that might contribute loads below John Martin Reservoir and Lamar.

Loading analysis is only feasible if paired water quality and flow data exist. Luckily, CDPHE has chosen sampling sites located near (less than a mile from) these flow stations. Pairing flow data with the corresponding water quality samples allows us to analyze pollutant concentrations under a variety of flow conditions.

The following information on pollutant loading in the Lower Arkansas River Watershed is arranged by USGS flow station, starting with the westernmost upstream station (07124000) and ending with the easternmost downstream station (07133000). Each graph represents a variety of flow conditions on the x-axis (shown as both flow percentile and as absolute flow values at each "condition" break) and pounds of pollutant passing by the flow gauge in a given day, represented on the y-axis. The value of pounds per day was extrapolated from water quality concentration data and combined with flow data to estimate a loading value under the assumption that flow and concentration was static for 24 hours after the flow and concentration measurements were taken. Because the amount of

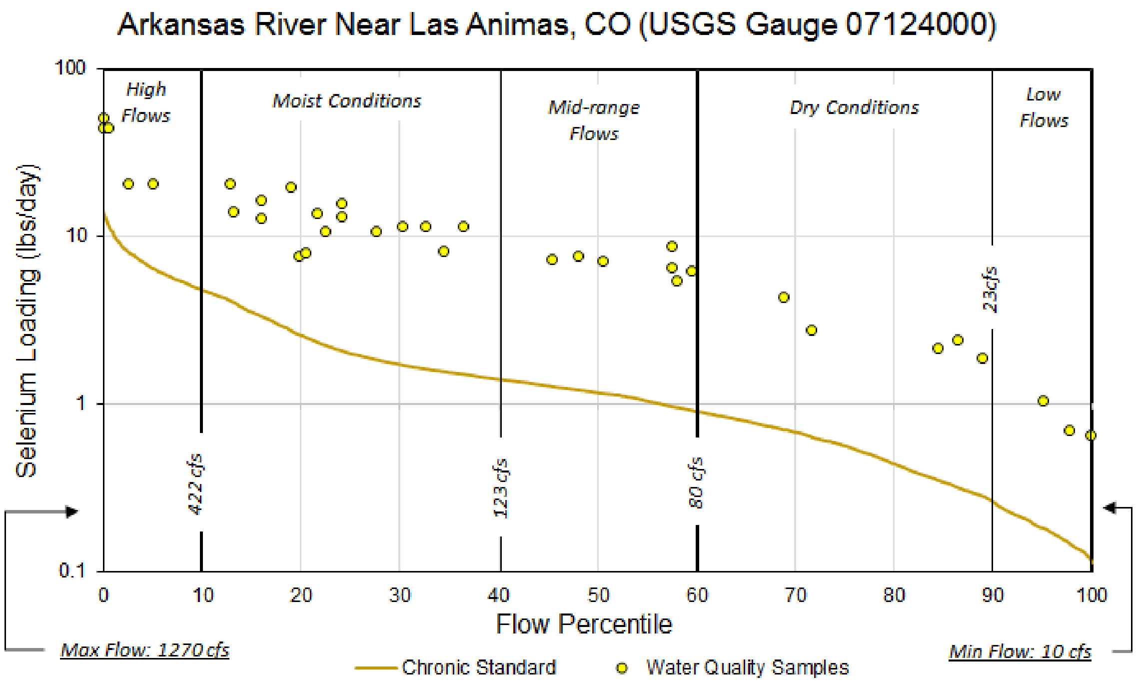

Figure 18: Selenium loading for USGS Gauge 07124000.

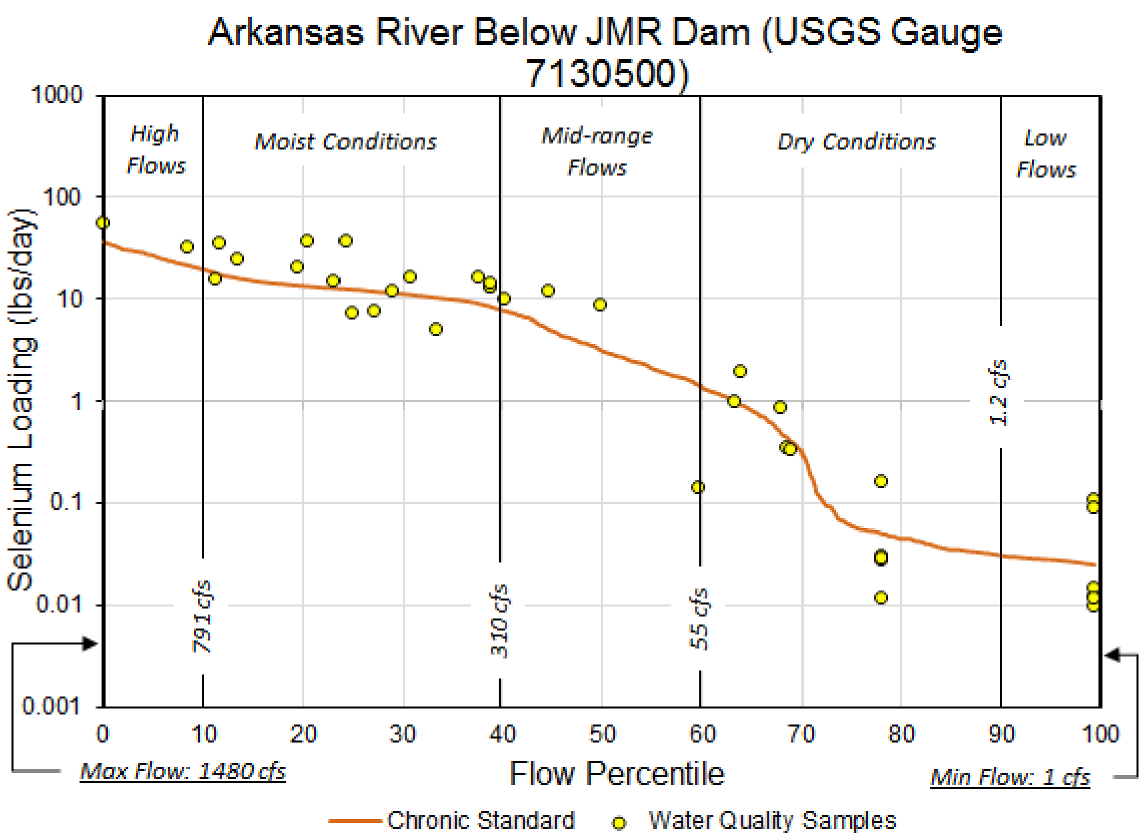

Figure 19: Selenium loading for USGS Gauge 07130500.

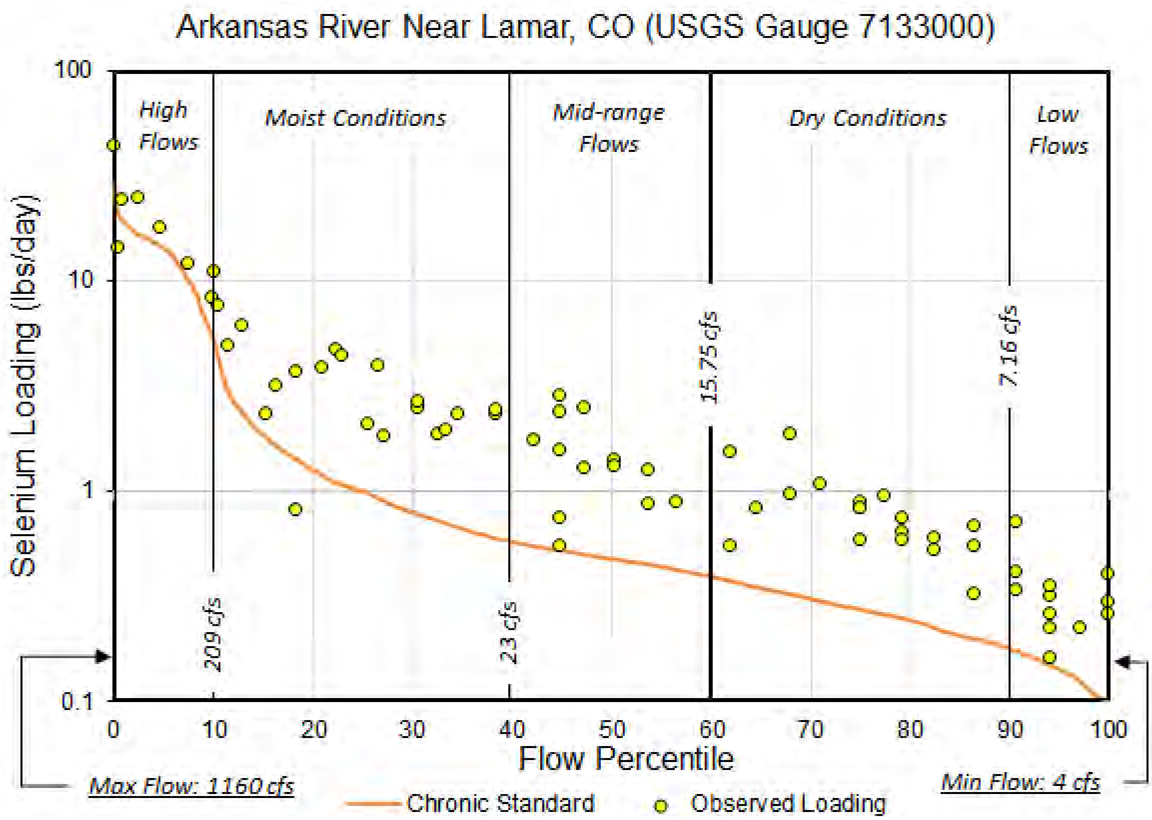

Figure 20: Selenium loading for USGS Gauge 07133000.

pollutant typically increases linearly, and we can compare flow measurements 07124000, from 1 cfs to over 1000 cfs, pollutant loading is shown on a log transformed y-axis. Values are often one or two magnitudes different between low flow and high flow conditions.

Load duration curves are presented for three sites along the main stem of the Arkansas River. USGS flow gauge 07124000 is located just below Las Animas, CO, and provides a good framework for evaluating the loading from waters entering the watershed from upstream sources. USGS flow gauge 07130500 is located on the main stem of the river just below John Martin Reservoir. USGS flow gauge 07133000 is located in Lamar, CO. Data is presented by constituent, and graphs are arranged with flow gauges 07124000 first, followed by 07130500, and finally 07133000. This represents an upstream-to-downstream evaluation of loading.

7.3.1 Selenium

Figures 18-20 illustrate selenium loading for gauges 07124000, 07130500, and 07133000.

Discussion

Each water quality sample analyzed for selenium at monitoring locations near 07124000 indicate pollutant loading much higher than sustainable levels for the Arkansas River to meet the water quality standard. This means the quality of the water entering the watershed is already elevated in selenium and carrying a selenium load that elevates concentrations above the water quality standard. The sources of selenium upstream of the watershed is likely the same as within the watershed. Point sources, such as municipal wastewater, and non-point sources, such as irrigation upstream of the watershed, are likely contributing significant selenium loads to the river. Selenium loading is most consistent above John Martin Reservoir and above our watershed, which indicates flow-independent processes are responsible for selenium loading to the river.

Selenium loading just below John Martin Reservoir is sometimes less than the maximum acceptable load to meet water quality standards. This important finding

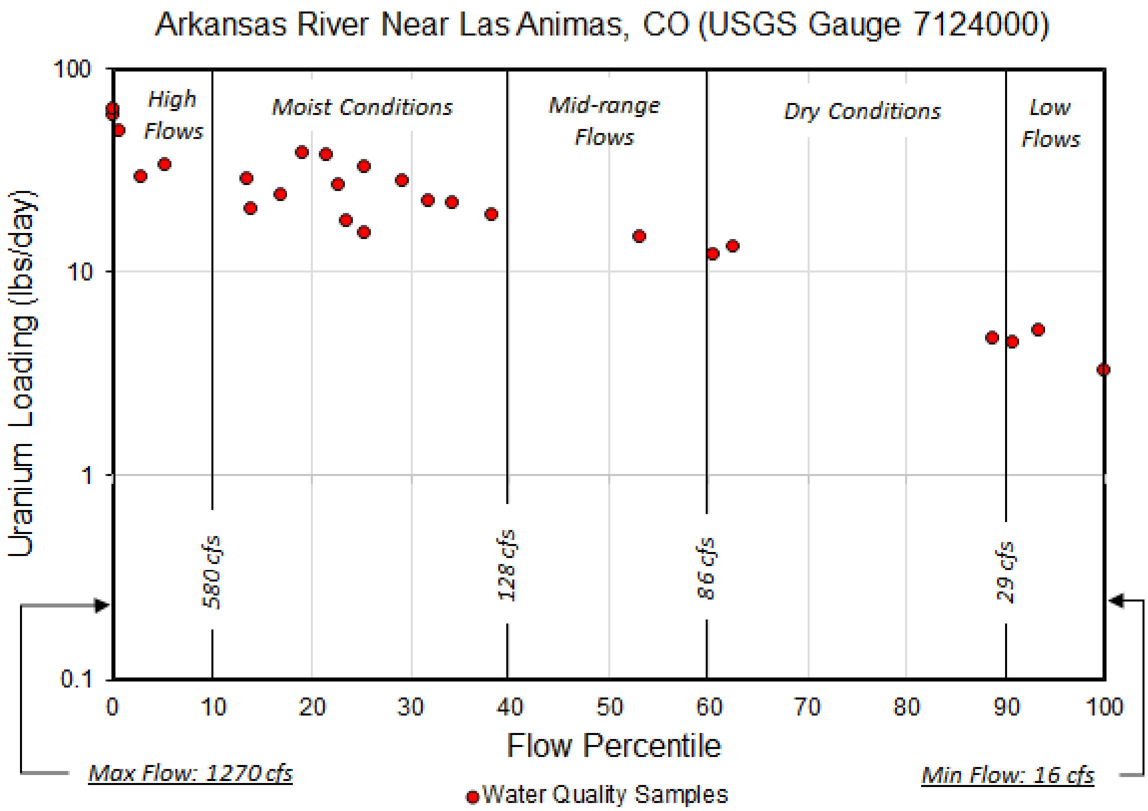

Figure 21: Uranium loading for USGS Gauge 07124000.

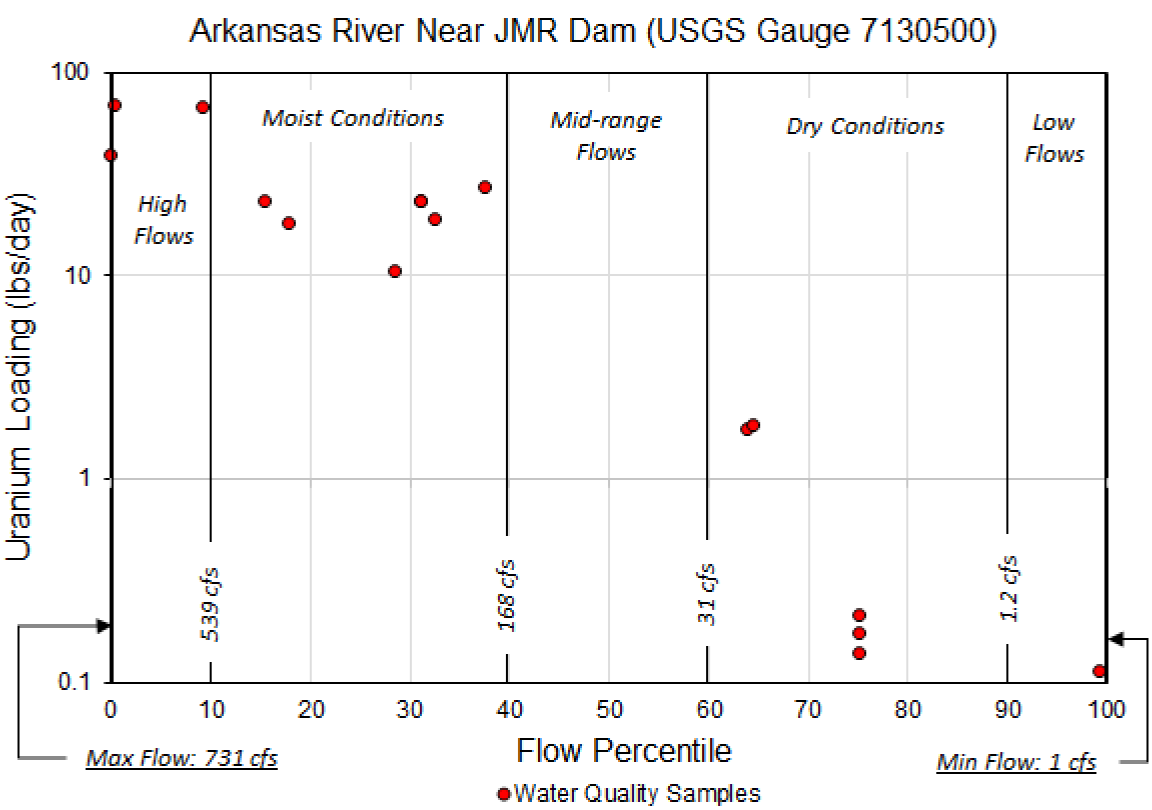

Figure 22: Uranium loading for USGS Gauge 07130500.

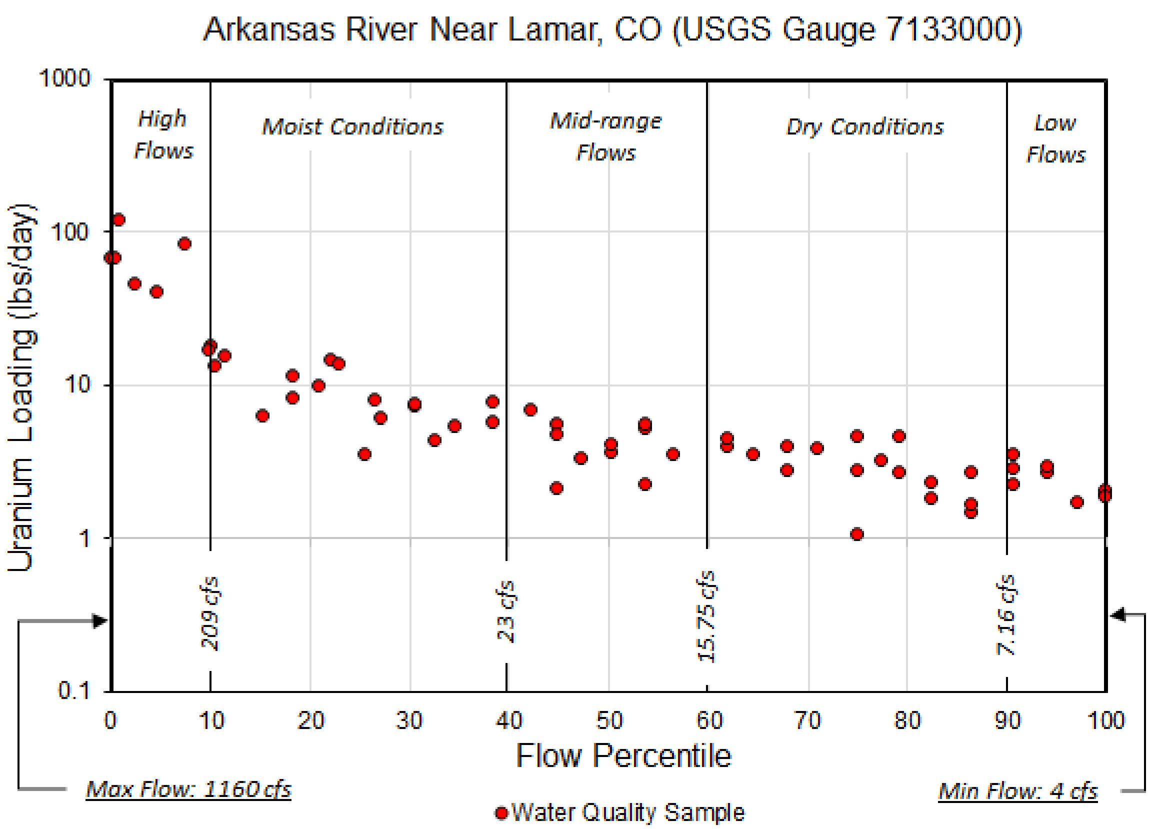

Figure 23: Uranium loading for USGS Gauge 07133000.

is consistent with other research efforts by Colorado State University that suggest processes in John Martin Reservoir act to reduce the amount of selenium in the Arkansas River.

Selenium loading increases again between John Martin Reservoir and Lamar, CO, and only two water quality samples indicate daily stream loading below acceptable levels to meet the chronic water quality standard.

7.3.2 Uranium

Figures 21-23 illustrate uranium loading for gauges 07124000, 07130500, and 07133000.

Discussion

Uranium loading follows a similar trend to selenium loading. In the most extreme case, and under high flow conditions (770 cfs), uranium loading exceeded 120 pounds per day from sources upstream of USGS flow station 07133000 (near Lamar, CO). Even under low flow conditions (less than 7 cfs), 1.5 pounds of uranium were added to the river upstream of USGS flow station 07133000.

Under the same flow conditions, uranium loading to the stream is similar at USGS flow stations 07124000 and 07133000. Less data exists for uranium loading between flow stations 07124000 and 07130500. This is most likely because of John Martin Reservoir and the reduced chances for non-point source loading, but it does seem evident that dissolved uranium (unlike selenium) is not being chemically reduced into non-toxic forms. Loading of uranium into the waters of this watershed could present a health risk, and efforts need to be made to reduce the amount of uranium in the water.

7.3.3 Manganese

Figures 24-26 illustrate uranium loading for gauges 07124000, 07130500, and 07133000.

Discussion

Manganese loading does not follow the same

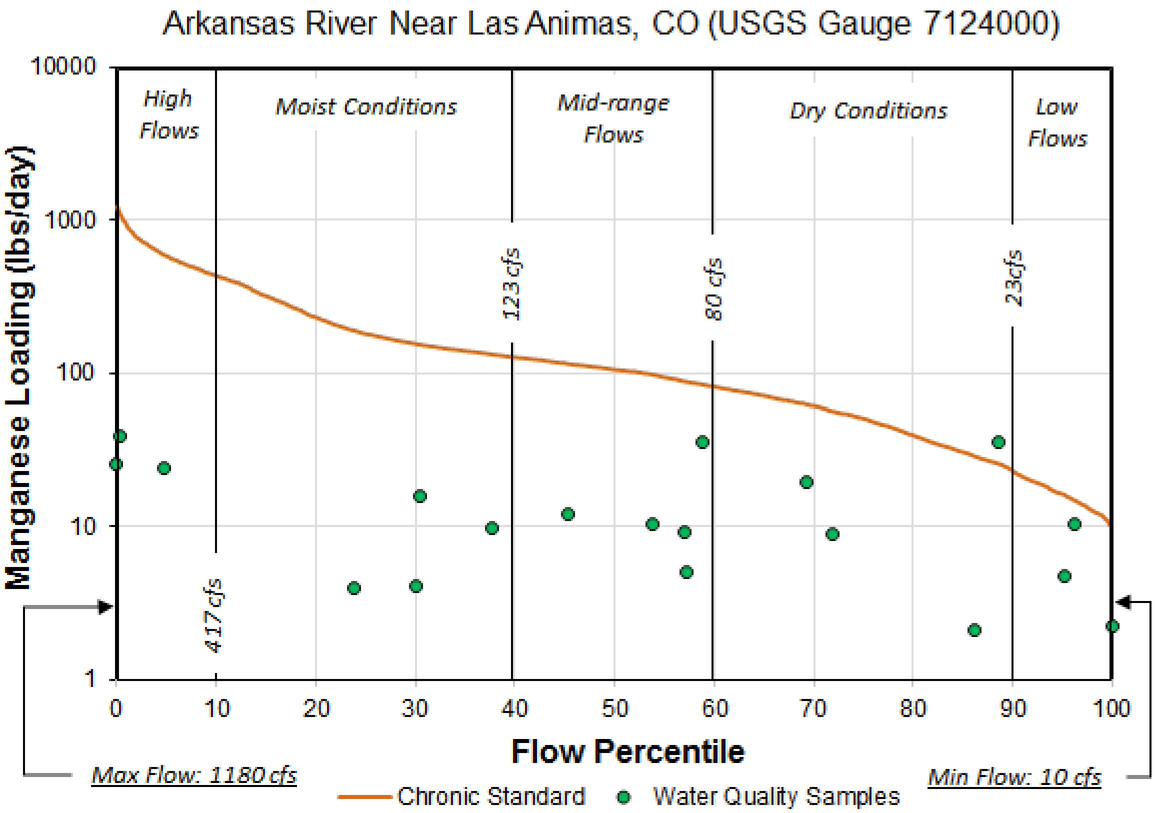

Figure 24: Manganese loading for USGS Gauge 07124000.

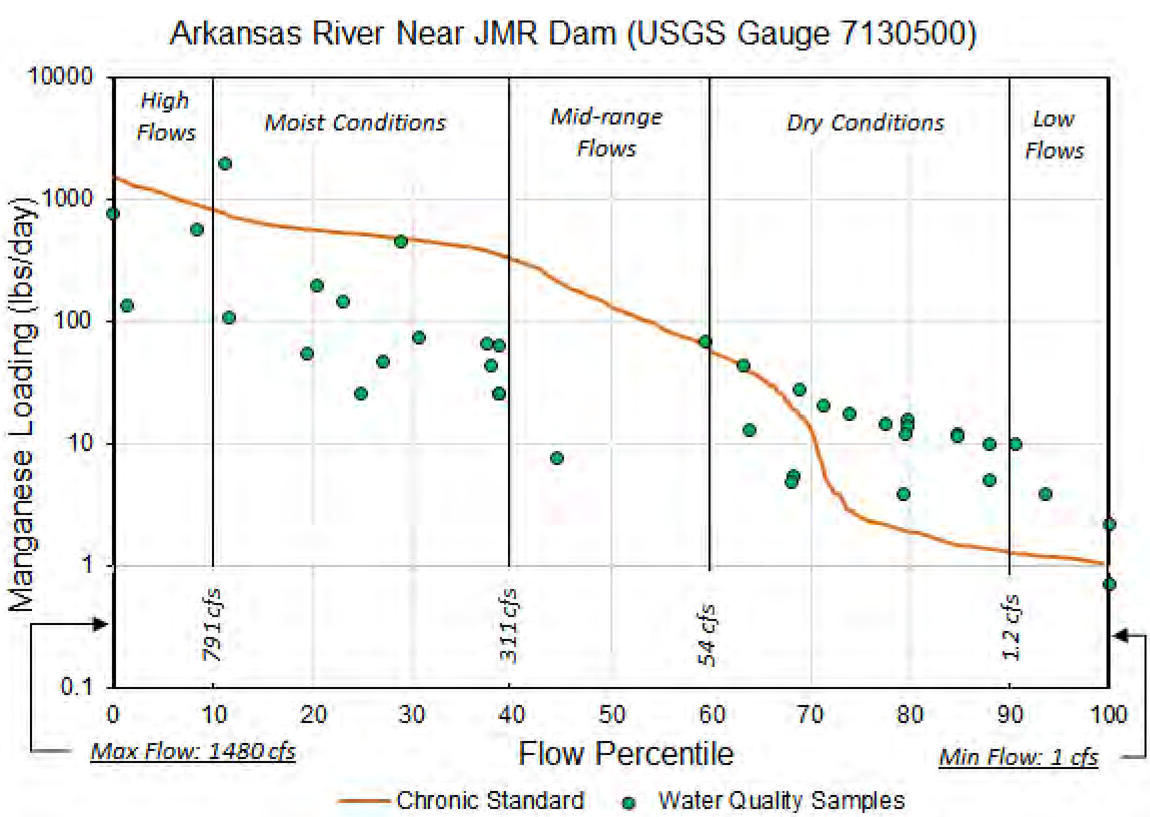

Figure 25: Manganese loading for USGS Gauge 07130500.

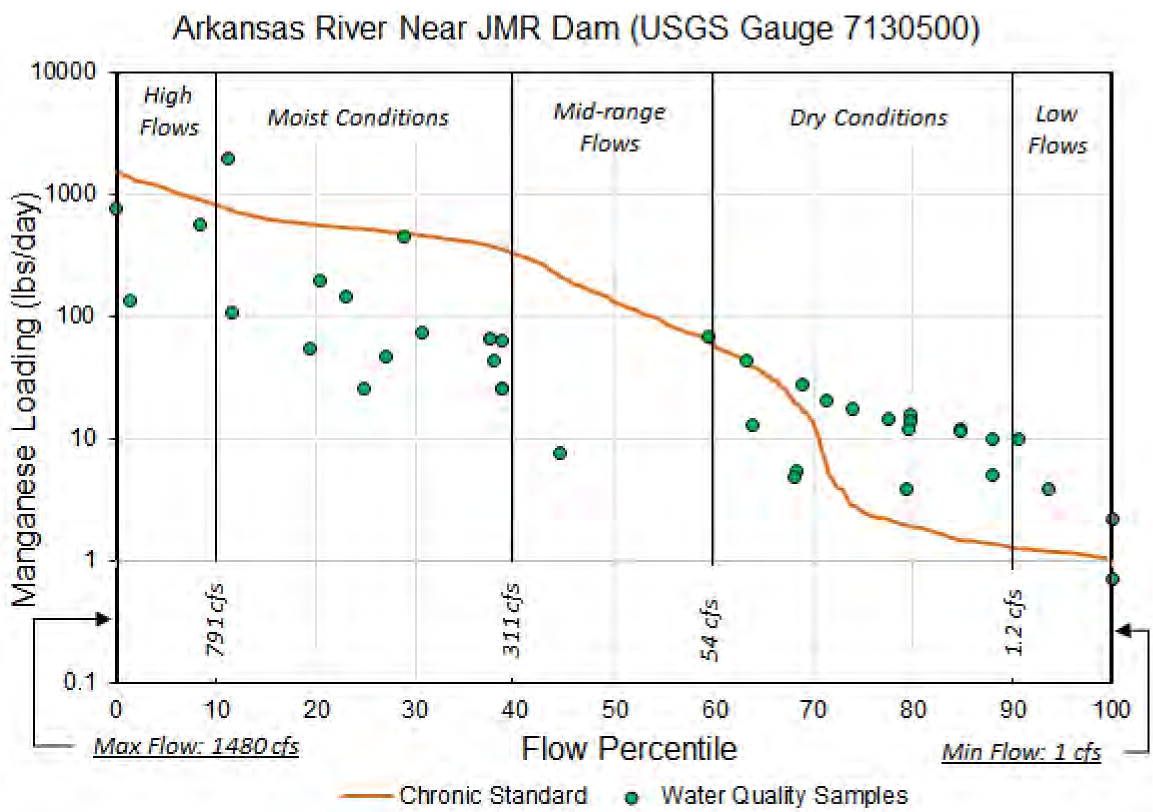

Figure 26: Manganese loading for USGS Gauge 07133000.

trend as selenium and uranium loading. Instead of a linear relationship between loading and flow, manganese loading appears to be non-linear and most problematic during low flow conditions. Manganese loading above USGS flow stations 07124000 and 07130500 is generally not enough to exceed water quality standards when flows are above 10 cfs. However, the river cannot support the amount of manganese entering the river when flows are below 10 cfs, and thus water quality standards are exceeded.

Much more data exists from the Arkansas River near Lamar, CO. Under the typical flow conditions for the river at this point, manganese loading is often too high, and water quality standards are often exceeded as a result (except for high flows).

7.3.4 Arsenic

Figures 27 and 28 illustrate arsenic loading for gauges 07130500 and 07133000. No data was collected near USGS Gauge 0712400.

Discussion

The main stem of the Arkansas River is listed as impaired for arsenic, and most water quality samples are two (or even three) magnitudes of difference greater than the standard. Part of this could be due to the relatively low chronic standard for Arsenic of 0.02 µg/L.

7.3.5 Nitrogen

Figures 29-31 illustrate arsenic loading for gauges 0712400, 07130500, and 07133000.

Discussion

In the upper part of the watershed, near Las Animas, CO, loading is most significant during mid-range and moist condition flows. During these flow regimes, nitrogen loading caused concentrations to slightly exceed the interim standard of 2.01 mg/L. Caution must be used with this limited data set, but nitrogen generally does not greatly exceed the state standard in the river near USGS station 07124000.

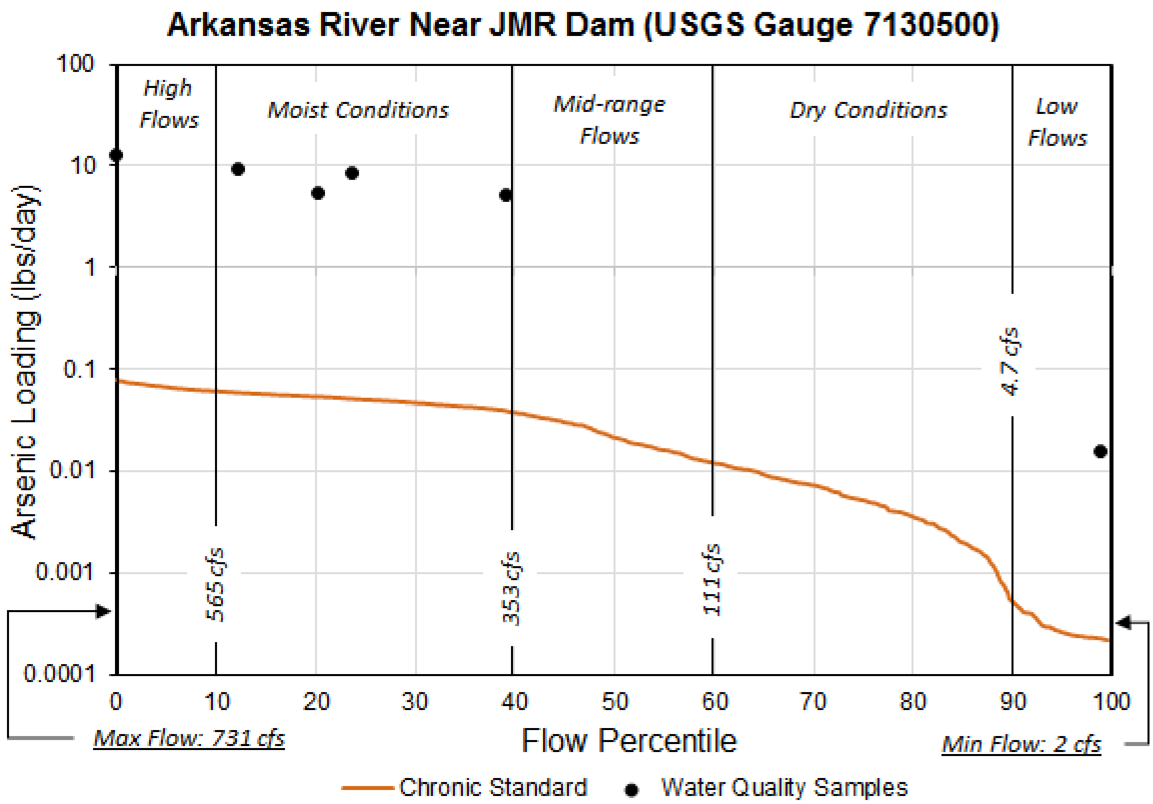

Figure 27: Arsenic loading for USGS Gauge 07130500.

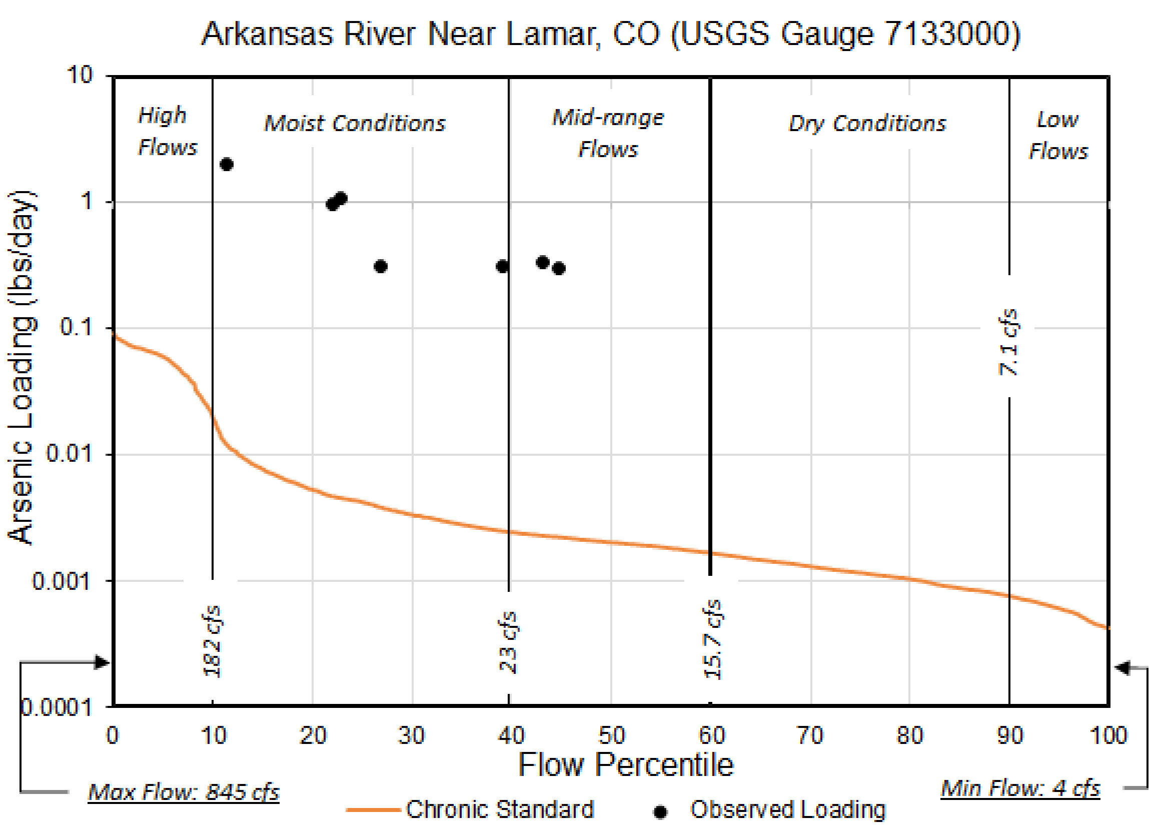

Figure 28: Arsenic loading for USGS Gauge 07133000.

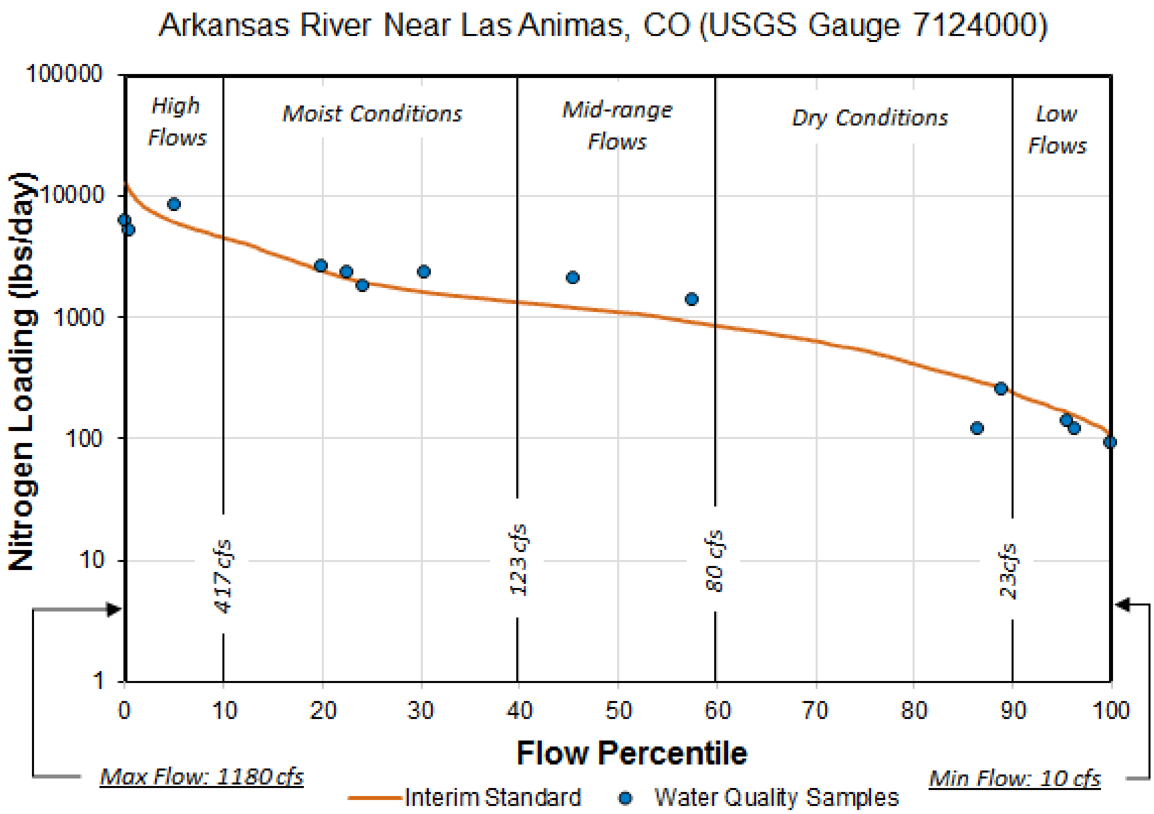

Figure 29: Nitrogen loading for USGS Gauge 07124000.

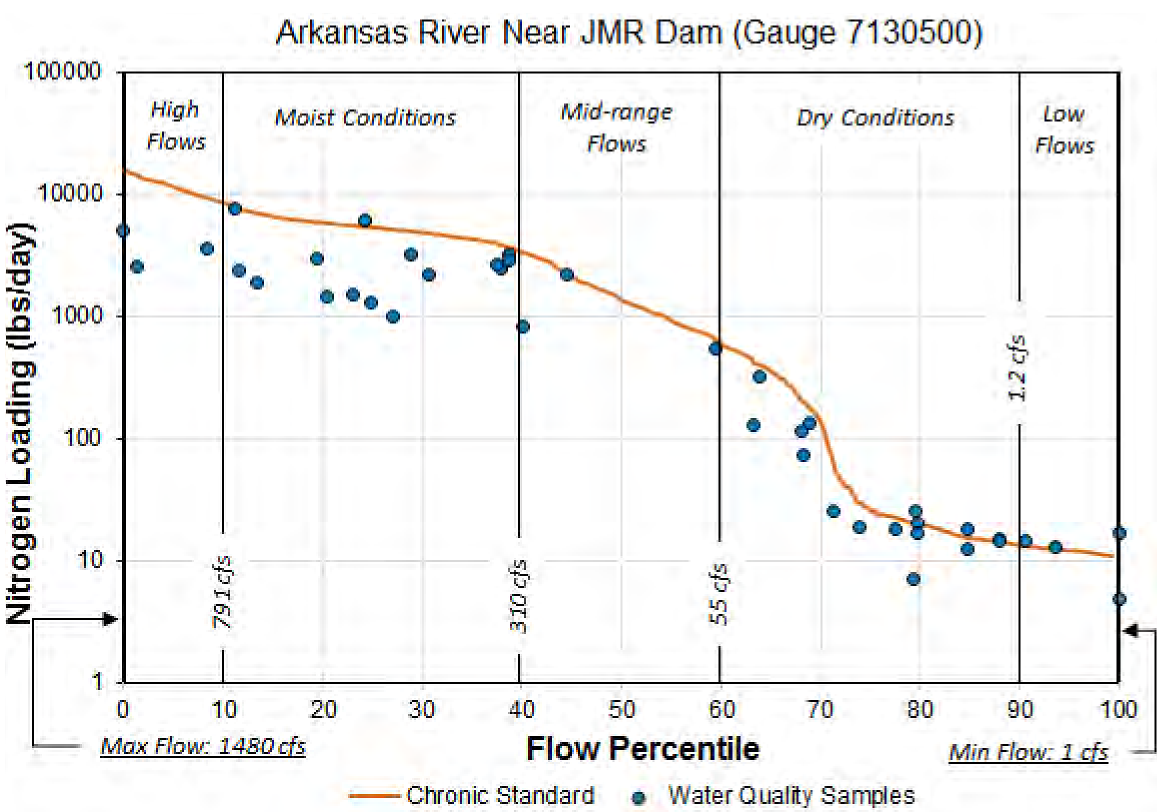

Figure 30: Nitrogen loading for USGS Gauge 07130500.

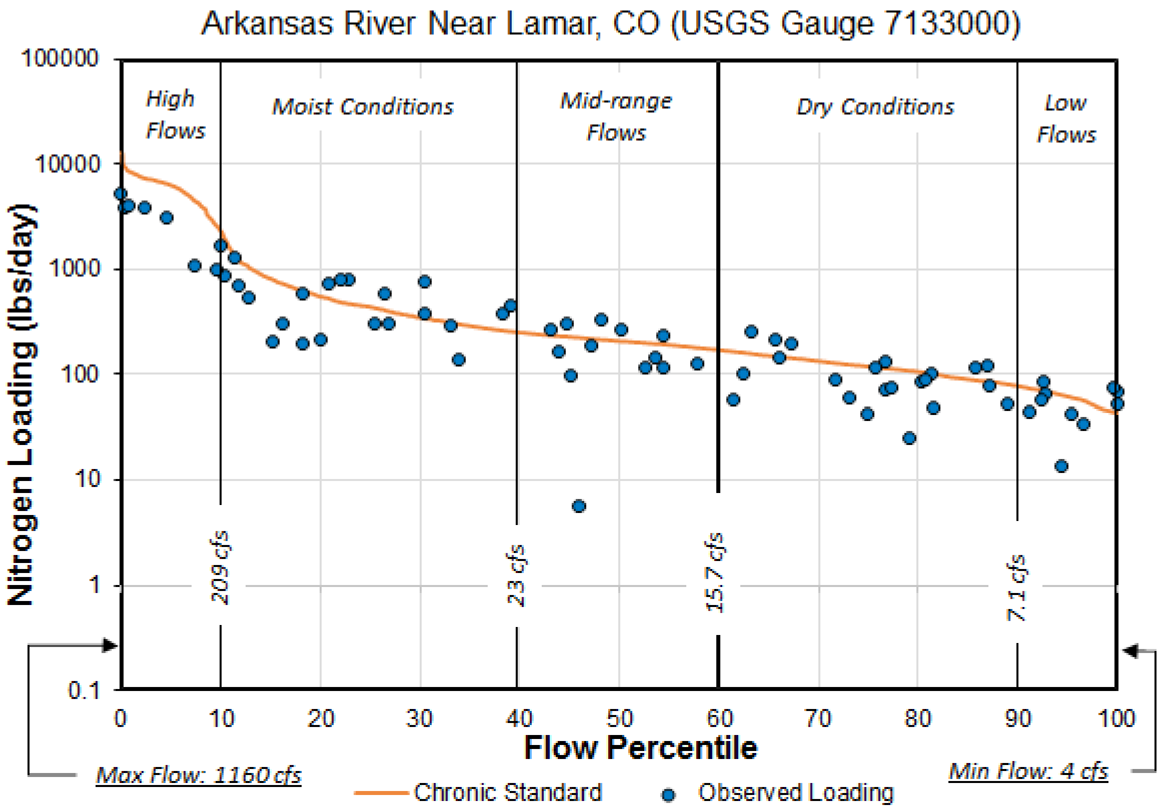

Figure 31: Nitrogen loading for USGS Gauge 07133000.

Directly below JMR Dam, near USGS gauge 07130500, nitrogen loading is not considered significant, as most of the water quality sample concentrations (n=32) are below the interim standard. JMR, like many other reservoirs and lakes, creates unique changes in water quality by slowing river water, which has big implications for water temperature. Reducing the velocity of the water and increasing the temperature creates an environment favorable to aquatic organisms and anaerobic bacteria. These organisms can utilize dissolved nutrients (such as nitrogen in the form of nitrate or ammonia) to grow and reproduce. For this reason, nutrient concentrations, including total nitrogen, are lower in water released from JMR.

Further downstream, near Lamar, CO, nutrient concentrations increase again, and nitrogen concentrations exceed the interim standard under almost all flow conditions except high flows. Samples collected near this flow gauge are downstream of large agricultural operations. It is unclear exactly where the nitrogen sources are located, but we can assume the increase in nitrogen is contributed by a mix of agricultural sources, septic systems, stormwater discharges, and some point sources. . Most water quality samples are still below the interim standard for total nitrogen, and reducing nitrogen loading to meet water quality standards is likely attainable.

7.4 Summary Statistics for Tributaries and Select Reservoirs

To better understand the likely sources of contamination and loading of pollutants to the main stem of the Arkansas River, summary statistics were determined for the following locations: 1) all tributaries north of the Arkansas River (excluding Big Sandy and Rush Creeks), 2) all tributaries south of the Arkansas River (excluding Two Buttes Creek), 3) John Martin Reservoir, 4) Adobe Creek Reservoir, and 5) Nee Gronda Reservoir.

The analyses performed on the tributaries to the north and south of the river use the same statistical methodology described in Section 6.3 of this report. All data collected from north tributaries was pooled, and summary statistics were determined for each parameter. The same was done with data from tributaries south of the river and each of the reservoirs.

7.4.1 Analysis and Discussion: North Tributaries

Many tributaries to the north of the Arkansas River overlay shale bedrock deposits, a likely source of selenium or uranium, and traverse most of the irrigated agriculture in the watershed. The tributaries serve multiple purposes: as sources of irrigation water, conveyance mechanisms for tail water (surficial drains), ecological habitats, and potential buffer strips for water quality remediation.

When analyzing all of the North Tributaries as one unit, 87% of samples had a selenium concentration that exceeds the chronic standard of 4.6 µg/L. The average selenium concentration in the 53 samples was 20.1 µg/L, while the median concentration was 12.0 µg/L. The highest concentration of 80 µg/L was observed at monitoring station 21COL001-7812 on March 15, 2006. Samples collected from monitoring stations 21COL001-7811 and 21COL001_WQX-AR0018 show significant selenium concentrations with a median concentration of 52 µg/L and an average concentration of 49 µg/L, while 85% of the samples were less than 55 µg/L (n=14).

Other constituents of concern include: uranium, manganese, sulfates, and arsenic. Median and average uranium concentrations are slightly above the EPA radionuclide standard of 30 µg/L, with a maximum observed concentration of 79 µg/L (21COL001-7811; April 11, 2006). Manganese concentrations exceeded the water quality standard in 55% of the samples collected, with a maximum concentration of 530 µg/L observed at monitoring location USGS-380506103183801 (Adobe Creek) on March 8, 2001. Sulfate concentrations exceeded the state drinking water standard of 250 µg/L in all of the water quality samples. The maximum observed concentration of sulfate, 3200 µg/L, was observed at monitoring location 21COL001_WQX-AR0117 on October 5, 2015. Arsenic also exceeded the state standard for total recoverable arsenic of 0.02 µg/L in each sample collected.

7.4.2 Analysis and Discussion: South Tributaries

Tributaries to the south of the Arkansas River are generally not as close in proximity to shale formations compared with tributaries north of the River. Additionally, much fewer irrigated acres exist south of the river within this watershed, with the exception being near Lamar, CO, where the Lamar Canal and a few smaller ditches feed some irrigated acres south of the river. Much less water quality data exists for tributaries south of the Arkansas River compared with tributaries to the north. For this reason, some of the summary statistics (such as arsenic and E. coli) lack robustness due to small sample sizes (n = 4 and 8, respectively). Only three monitoring stations exist with enough data to be used to calculate summary statistics.

Although it is generally understood that less shale bedrock material exists south of the Arkansas River (Figure 5), selenium and uranium concentrations still remain elevated in tributaries to the south of the River. This could be from several factors, including unknown shale deposits, seliniferous soils deposited from shale parent materials, or the importation of selenium from higher in the watershed. The median (6 µg/L) and average (14 µg/L) concentrations of selenium in samples from south tributaries is less than that of north tributaries, however the maximum observed value (74 µg/L)is similar to that of northern tributaries (21COL001-7851; January 10, 2006).

Uranium, arsenic, manganese, and sulfate are also a concern in the southern tributaries. Average (35 µg/L), median (29 µg/L), and maximum (84 µg/L) uranium concentrations are similar to values observed in the main stem of the Arkansas River as well as the north tributaries. Also similar to the other surface water bodies, total dissolved arsenic concentrations exceeded the site-specific chronic standard of 0.02 µg/L in most of the samples (66.6%). Similar to northern tributaries, sulfates are a concern. Sulfates exceed the state drinking water standard in 92% of the samples (n=12), with a maximum values of 1800 mg/L observed at monitoring location 21COL001_WQX-7843 on

Table 3: Summary statistics for pollutants of interest in tributaries to the north of the Arkansas River.									
Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	53	46	17	2.3	5.0	12.0	20.1	44.6	80.0
Dissolved Uranium (µg/L)	33	(D)	(D)	8	14	31	34	69	79
Dissolved Arsenic (µg/L)	28	21	0	0.00	0.00	1.40	1.28	1.40	3.30
Total Recoverable Arsenic (µg/L)	12	12	0	2.10	2.16	3.45	3.61	4.61	6.80
Dissolved Manganese (µg/L)	58	32	(D)	0.0	11.6	70.5	104.8	203.5	530.0
Nitrite (mg/L)	0	-	-	-	-	-	-	-	-
Nitrate (mg/L)	0	-	-	-	-	-	-	-	
Total Nitrogren (mg/L)	80	20 (A)	-	0.000	0.231	0.795	1.169	2.411	2.900
E. coli (#/100mL)	21	8	-	0.0	1.0	38.1	173.8	378.4	866.4
Sulfate (mg/L)	44	44 (B)	-	660	915	1400	1443	1982	3200
Dissolved Phosphorus (mg/L)	44	1 (C)	-	0.010	0.016	0.036	0.055	0.070	0.560
Dissolved Oxygen (mg/L)	27	1	-	3.65	5.49	8.69	8.33	10.91	12.77
Total Recoverable Iron (µg/L)	44	-	7	43	127	395	641	1400	2700

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.
D. Indeterminate due to lack of data.

September 13, 2010. Dissolved manganese concentrations exceed the state chronic standard for aquatic life in 56% of the samples (n=16), with a maximum values of 280.0 µg/L observed at monitoring location 21COL001_WQX-7850 on April 5, 2011.

7.5 Analysis and Discussion: John Martin Reservoir

John Martin Reservoir, the largest reservoir in the entire Arkansas River Basin, is an on-channel reservoir used for several purposes including wildlife hab-

Table 4: Summary statistics for pollutants of interest in tributaries south of the Arkansas River.

Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	14	10	2	1	4	6	14	18	74
Dissolved Uranium (µg/L)	10	(D)	(D)	2	9	29	35	67	84
Dissolved Arsenic (µg/L)	6	4	0	0.00	0.00	1.00	0.83	1.25	2.00
Dissolved Manganese (µg/L)	16	9	(D)	0.0	29.0	90.5	109.1	207.5	280.0
Nitrite (mg/L)	0	-	-	-	-	-	-	-	-
Nitrate (mg/L)	0	-	-	-	-	-	-	-	
Total Nitrogren (mg/L)	22	1 (A)	-	0.000	0.000	0.120	0.528	0.643	6.400
E. coli (#/100mL)	8	1	-	0.0	0.2	12.3	51.1	48.0	298.7
Sulfate (mg/L)	12	11 (B)	-	200	420	1300	1139	1470	1800
Dissolved Phosphorus (mg/L)	12	0 (C)	-	0	0.015	0.020	0.031	0.054	0.082
Dissolved Oxygen (mg/L)	17	5	-	1.86	3.51	6.36	6.38	9.38	10.93
Total Recoverable Iron (µg/L)	11	-	0	130	140	220	265	385	540

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.
D. Indeterminate due to lack of data.

itat, recreation opportunities, and as a storage vessel for waters subject to the Arkansas River Compact. This important reservoir has a capacity of 603,500 acre-feet and a flood storage pool of 261,000 acre-feet (US Army Corps of Engineers, 2018). As of April 2018, the US Army Corps of Engineers (USACE) is finalizing the newest version of the John Martin Reservoir Master Plan. This plan, similar to a watershed plan, sets goals and management objectives for the resources of John Martin Reservoir, including ecological, recreational, and cultural goals. The most recent version of the Master Plan states specifically that the plan "does not address the specifics of regional water quality." All water quality data used in this analysis was collected by the Colorado Department of Public Health and Environment or the EPA.

Table 5: Summary statistics for pollutants of interest in John Martin Reservoir.									
Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	12	7	1	3	3	5	7	11	20
Dissolved Uranium (µg/L)	7	(D)	(D)	8	8	12	12	15	16
Total Recoverable Arsenic (µg/L)	8	8	0	0.00	0.35	1.00	1.10	2.00	2.00
Dissolved Manganese (µg/L)	12	0	(D)	0.0	2.0	5.5	10.3	20.7	29.0
Nitrite (mg/L)	5	0	-	0.010	0.016	0.030	0.024	0.030	0.030
Nitrate (mg/L)	5	-	0	0.000	0.030	0.090	0.194	0.414	0.420
Total Nitrogren (mg/L)	19	0 (A)	-	0.000	0.000	0.000	0.213	0.523	1.400
E. coli (#/100mL)	2	0	-	1.0	-	-	9.0	-	16.9
Sulfate (mg/L)	12	12 (B)	-	400	453	590	575	701	740
Dissolved Phosphorus (mg/L)	11	1 (C)	-	0	0.012	0.030	0.037	0.055	0.095
Dissolved Oxygen (mg/L)	38	0	-	5.04	6.67	9.12	9.44	12.10	15.71
Total Recoverable Iron (µg/L)	12	0	-	130	140	470	609	903	2100

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.
D. Indeterminate due to lack of data.

John Martin Reservoir is currently listed on the 303(d) list as impaired for selenium. Based on available data, the average selenium concentration in JMR was 7 µg/L with a maximum value of 20 µg/L (August 11, 2005 at 21COL001-7524A), and 85% of the samples were below 17 µg/L. (n=12). Approximately 58% of the samples (n=12) exceed the states chronic selenium standard for aquatic life. Uranium values are typically much lower in John Martin Reservoir compared to the main stem, with the maximum observed uranium concentration being 16 µg/L (August 11, 2005 at 21COL001-7521A), however, JMR has roughly 5% of the amount of data available as compared with the main stem.

The most tested parameters in JMR include dissolved oxygen, nitrogen, phosphorus and sulfates. These constituents are often the most problematic for lakes and reservoirs, especially warm water reservoirs near agricultural areas. From 38 samples collected, dissolved oxygen exceeded 5 mg/l (the site-specific chronic standard) in all samples and, therefore, dissolved oxygen is not an issue in JMR. Total nitrogen, nitrate, and nitrite were all well below chronic and acute standards set for this reservoir. Phosphorus generally met the state water quality standards with only one instance of exceedance. Sulfate exceeded the state standard in each sample collected. This is not uncommon in the watershed as sulfates appear elevated in all surface water bodies to varying degrees.

Although the water quality in JMR reflects similarities with other surface water bodies in the watershed (elevated selenium, arsenic, sulfates, etc.), the data analyses of the Arkansas River show JMR to be acting as a “water quality sink.” This is a valuable ecosystem service JMR provides. More research is needed to discern and quantify the effects and the conditions under which the reservoir retains, or releases, water quality pollutants.

7.6 Analysis and Discussion: Adobe Reservoir

Adobe Reservoir is an off-channel reservoir in the context of the Arkansas River main stem. Water in the reservoir is managed by the Fort Lyon Canal Company and transported from the Arkansas River just upstream of Rocky Ford, CO, via the Fort Lyon Storage Canal. Adobe Reservoir serves multiple objectives including wildlife habitat, recreation (angling, wildlife viewing), and irrigation water storage. Water quality in Adobe Reservoir is generally better than the other reservoirs in the watershed because the source waters are typically of better quality.

Selenium concentrations are generally lower in Adobe Reservoir compared with other surface water bodies, specifically streams. However, Adobe Reservoir (along with several other reservoirs in hydrologic unit COARLA10) is listed on the 303(d) list as impaired for selenium. The median concentration of selenium from this data set is 3 µg/L, with a maximum concentration of 50 µg/L (August 10, 2005; 21COL001-7825B). This value of 50 µg/L appears to be an outlier in the dataset, as all of the other samples were below 5.5 µg/L. Nonetheless, only two samples out of 16 exceeded the chronic standard for aquatic life.

Uranium concentrations are similar to other water bodies in the watershed. The median uranium concentration in this dataset was 17 µg/L, and the maximum observed value was 25 µg/L (August 10, 2005 at 21COL001-7825A1 and 21COL001-7825B1). Like John Martin Reservoir, dissolved oxygen was never less than 5 mg/L, the chronic standard for this waterbody. Total nitrogen, nitrate, nitrite, and phosphorus all generally did not exceed the chronic or acute standards. The only exception being two instances of total nitrogen exceeding the state interim water quality standard of 2.01 mg/L (n=22). Also similar to John Martin Reservoir, and all water bodies in this watershed, sulfate concentrations exceed the state’s drinking water quality standard of 250 mg/L.

7.7 Analysis and Discussion: Nee Gronda Reservoir

When full, Nee Gronda Reservoir, located in the Queens State Wildlife Area, can be more than 70 feet deep. Water is transported to Nee Gronda via the Kicking Bird Canal, and water stored in the reservoir includes water owned by the Amity Canal Company. The reservoir is managed and used by both the Colorado Parks and Wildlife and the Amity Canal Company. Nee Gronda Reservoir is listed on the 303(d) list as impaired for selenium. Additional water quality issues, like many warm water reservoirs, stems from temperature, nutrients, and dissolved oxygen concentrations. In 2010, an unusually cold winter created thick ice cover and lower lake levels, while nutrient-rich waters that created a low oxygen environment, the combination of which resulted in a total fish kill. Existing data was used to analyze water quality parameters, including those listed above, that most likely exceed state standards.

The source water supply for Nee Gronda Reservoir is the Kicking Bird Canal, which branches out from

Table 6: Summary statistics for pollutants of interest in Adobe Creek Reservoir.									
Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	16	2	1	0	2	3	6	4	50
Dissolved Uranium (µg/L)	14	(D)	(D)	8	10	17	17	20	25
Dissolved Arsenic (µg/L)	14	14	0	1.00	1.76	2.40	2.36	3.01	3.30
Total Recoverable Arsenic (µg/L)	4	4	0	2.90	-	-	4.13	-	5.50
Dissolved Manganese (µg/L)	16	7	(D)	0.0	7.3	47.5	50.8	94.8	100.0
Nitrite (mg/L)	8	0	-	0.007	0.011	0.020	0.017	0.020	0.020
Nitrate (mg/L)	8	-	0	0.000	0.000	0.000	0.006	0.019	0.030
Total Nitrogren (mg/L)	22	2 (A)	-	0.000	0.000	0.635	0.837	1.640	3.700
E. coli (#/100mL)	6	1	-	0.0	0.0	1.5	51.1	35.2	131.4
Sulfate (mg/L)	16	16 (B)	-	330	403	900	1064	2000	2300
Dissolved Phosphorus (mg/L)	16	0 (C)	-	0.030	0.030	0.046	0.053	0.092	0.100
Dissolved Oxygen (mg/L)	43	0	-	6.03	7.86	9.75	9.64	11.05	12.98
Total Recoverable Iron (µg/L)	16	0	-	97	118	675	664	922	1900

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.
D. Indeterminate due to lack of data.

the Fort Lyon Canal approximately two miles north of John Martin Reservoir. The Fort Lyon Canal Company diverts water from the Arkansas River between Swink, CO, and La Junta, CO. Although some dryland farming exists within a few miles of Nee Gronda, it is likely the source of much of the selenium in the reservoir comes two places: 1) the Arkansas River source water and 2) dissolution of selenium from local sediments, soils, and bedrock materials. The average selenium concentration (n=15) from 2000-2016 in Nee Gronda

Table 7: Summary statistics for pollutants of interest in Nee Gronda Reservoir.									
Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	15	7	5	0	1	3	14	38	45
Dissolved Uranium (µg/L)	12	(D)	(D)	22	22	23	24	26	28
Dissolved Arsenic (µg/L)	11	11	0	2.00	2.00	3.00	3.09	4.00	4.00
Dissolved Manganese (µg/L)	16	2	(D)	0.0	0.0	0.0	9.9	6.3	71.0
Nitrite (mg/L)	7	0	-	0.003	0.004	0.007	0.007	0.010	0.010
Nitrate (mg/L)	7	-	0	0.000	0.000	0.000	0.011	0.040	0.040
Total Nitrogren (mg/L)	25	1 (A)	-	0.000	0.000	0.970	0.826	1.340	2.400
E. coli (#/100mL)	4	0	-	7.40	-	-	57.33	-	104.60
Sulfate (mg/L)	16	16 (B)	-	1400	1500	1500	1600	1775	1800
Dissolved Phosphorus (mg/L)	16	0 (C)	-	0.010	0.011	0.025	0.026	0.032	0.070
Dissolved Oxygen (mg/L)	91	0	-	5.29	7.43	9.91	9.73	11.58	16.46
Total Recoverable Iron (µg/L)	16	0	-	47	57	82	101	150	210

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.
D. Indeterminate due to lack of data.

Reservoir was 14 µg/L, with a maximum concentration of 45 µg/L (August 11, 2005 at 21COL001-7823B2).

Uranium concentrations have been relatively consistent with a minimum concentration of 22 µg/L (August 11 and 31, 2005 at 21COL001-7823B2, 21COL001-7823B1, and 21COL001-7823A2) and a maximum concentration of 28 µg/L (July 13, 2006 at 21COL001-7823A1 and 21COL001-7823A2). Only one sample analyzed for total nitrogen exceeded the interim standard for total nitrogen, and no samples exceed the standards for nitrate and nitrite. Similarly, no samples fell below the state standard of 5 mg/L of dissolved oxygen, signaling success in keeping fish habitat protected from fish kill conditions. Phosphorus concentrations did not exceed state standards in any of the samples, while sulfates exceeded state standards for all samples. Like the rest of the watershed, the state standard for sulfates is reflected as the drinking water standard f 250 mg/L, which may not be the most appropriate standard for this reservoir.

8. BIG SANDY CREEK

The Big Sandy sub-watershed, a major tributary watershed to the Arkansas River, has a predominant north-south orientation that extends from Limon, CO, in the north to the main stem of the Arkansas River just downstream of Lamar, CO, in the south. Previous water quality sampling efforts by CDPHE and USGS have occurred in two main locations within the watershed: near the "headwaters" or first order streams upstream of Limon, CO, and near the terminal point in the watershed, where it merges with the Arkansas River.

The Big Sandy sub-watershed was broken into two distinct regions for the purposes of this report; 1) the "headwaters region" located near Limon, CO, and 2) the "outlet" region located from the Kiowa, CO/Bent County line to the Arkansas River. Groundwater is the source for all of the samples collected in the headwaters. All of the samples collected in the outlet section are sourced from surface water. These two regions are where the majority of the water quality data has been collected.

8.1 Summary Statistics

Summary statistics were performed using the same methodology as the analyses of water quality data in the Upper Arkansas-John Martin Reservoir HUC.

8.2 Maps

Figures 32 and 33 show sampling locations for the Big Sandy Creek sub-watershed.

8.3 Big Sandy Creek Headwaters Region

The headwaters region of Big Sandy Creek includes the lands and waters west of Aroyo, CO. This includes the towns of Limon, Simla, and Hugo, CO. Although Big Sandy Creek intersects these small towns, the ephemeral nature of the creek makes it an unreliable surface water source. These towns rely mostly on sub-surface groundwater as the main source of municipal drinking water. All of the data collected and analyzed for this watershed plan are from wells. This watershed plan is mostly concerned with the water quality of surface water sources; however, the interconnected nature of alluvial groundwater and the use of this water as a drinking water source compels us to perform basic analyses and give a general description of water quality conditions. The parameters of highest concern for this part of watershed include selenium, manganese, and nutrients (nitrogen [N]and phosphorus [P]).

8.4 Pollutant Loading

Loading analyses are only possible when concentration data and flow data are spatially and temporally explicit. Flow and concentration data is limited in the Big Sandy watershed. Big Sandy Creek is ephemeral and in many cases disconnected, making it difficult to analyze flows or pollutant loading. Furthermore, all the samples collected and analyzed in the headwaters region of Big Sandy Creek are collected from groundwater. This prohibits any loading analysis in this region, and very limited data is available in the outlet region of this sub-watershed. Therefore, no loading analysis could be conducted for the Big Sandy Creek watershed.

Selenium was not detected in any of the four samples taken in the headwaters region of Big Sandy Creek (Table 8). All four samples were taken on different days in 2005, and a significant data gap exists. However, the non-appearance of selenium in any of the samples is a significant sign. Because the waters being analyzed are from a headwaters region, the absence of upstream land and water management practices that may contribute to the mobilization of selenium is of significance.

Nitrogen and phosphorus did not exceed state standards in the limited number of samples taken (n=4 and n=4, respectively) Dissolved manganese was also below the standard in each sample (n=4). Dissolved arsenic was not detected in any of the samples (n=4), and there is no data available for sulfate. In general, very little data exists in the Big Sandy Creek headwa-

Lower Arkansas River Watershed: John Martin to State Line
Big Sandy Creek sub-watershed Sample Distribution

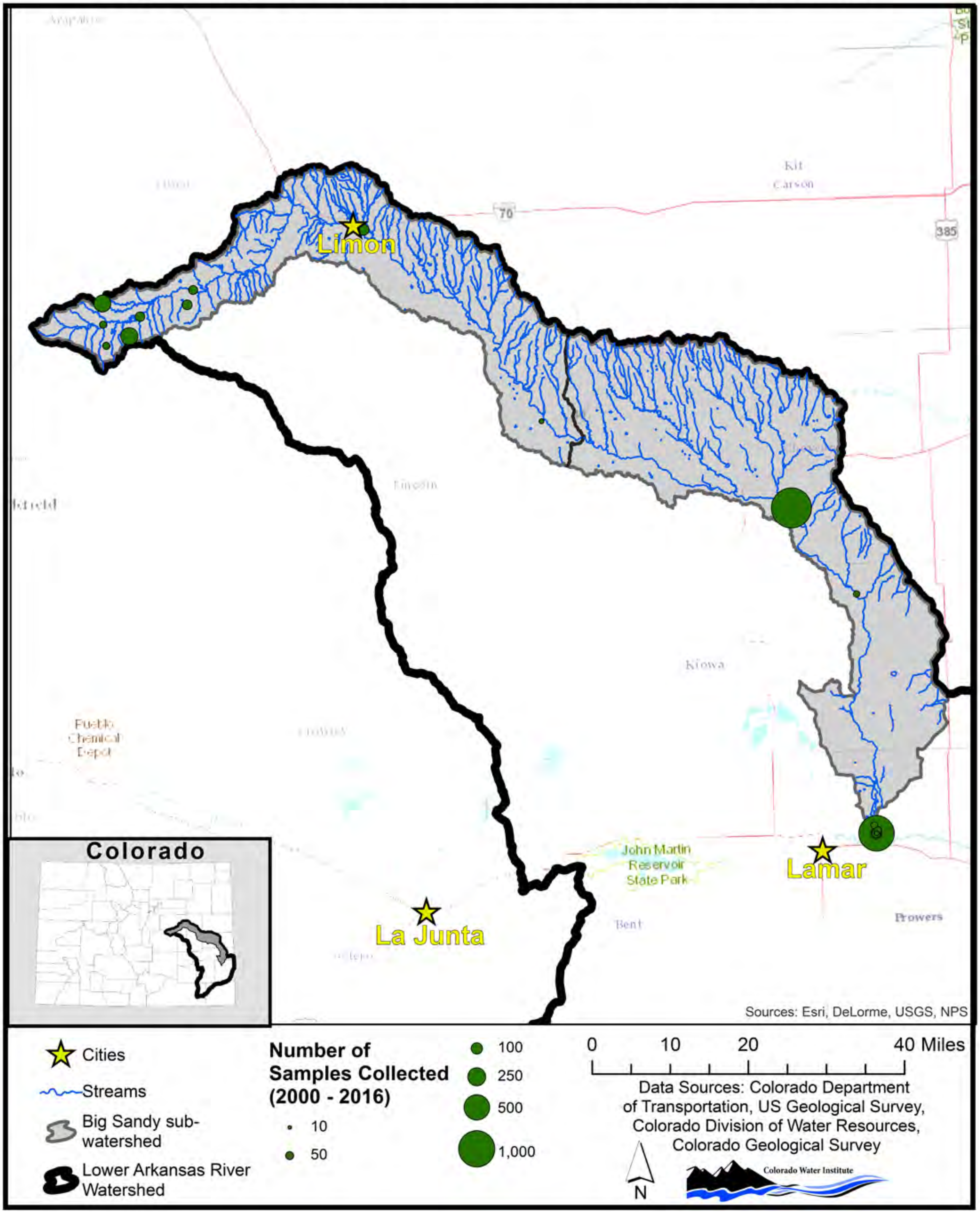

Figure 32: Sampling locations and relative number of samples taken in the Big Sandy Creek Watershed.

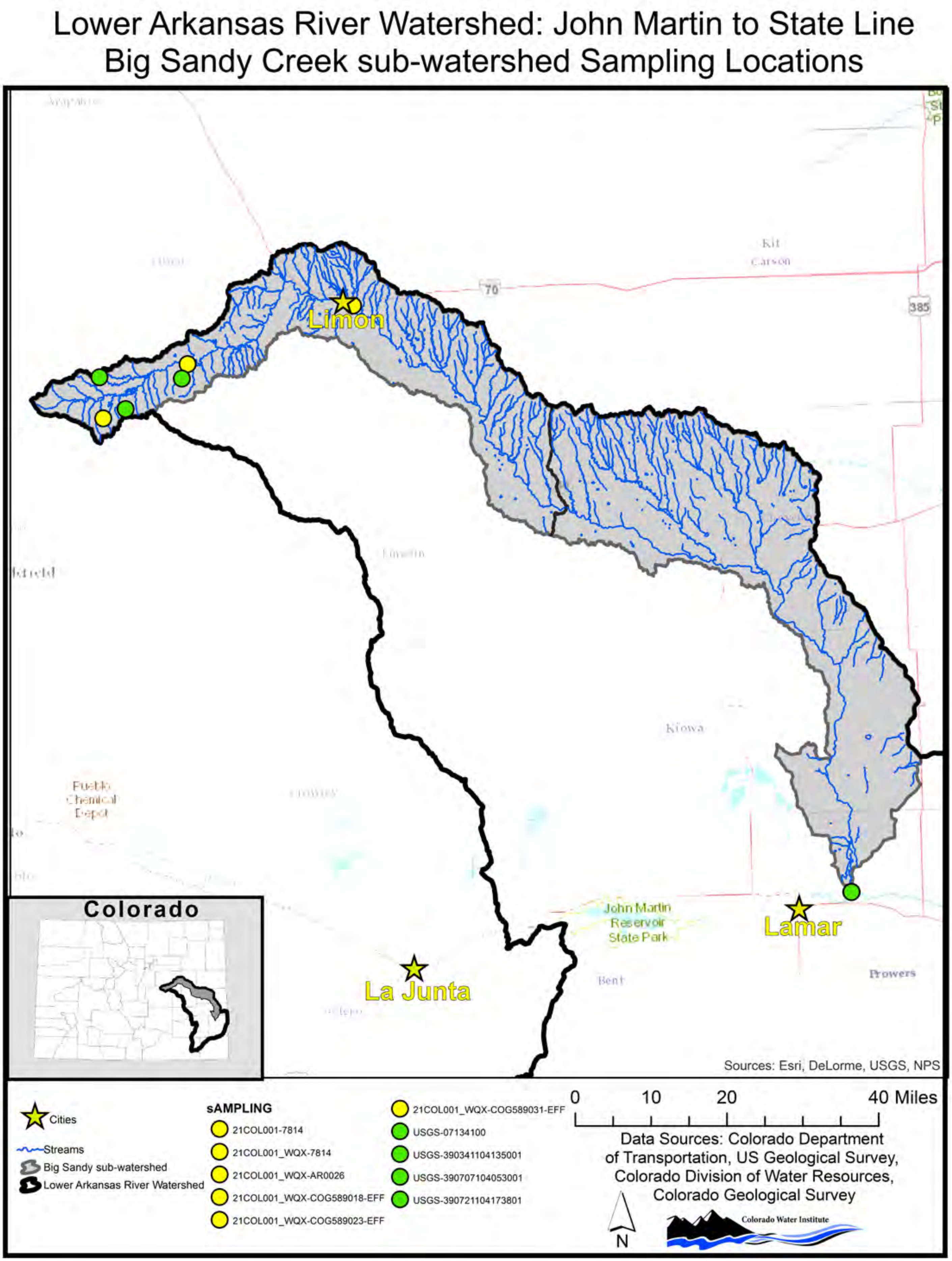

Figure 33: Sampling locations and agencies responsible for sampling in the Big Sandy Creek Watershed.

Table 8: Summary statistics for pollutants of interest in the Big Sandy Creek Headwaters Region.

Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	4	0	0	0	0	0	0	0	0
Dissolved Arsenic (µg/L)	4	0	0	0	0	0	0	0	0
Dissolved Manganese (µg/L)	4	0	-	3.8	5.2	6.9	7.0	9.0	10.6
Total Nitrogren (mg/L)	4	0 (A)	-	0.290	0.273	0.300	0.303	0.314	0.320
Sulfate (mg/L)	0	(B,D)	-	-	-	-	-	-	-
Dissolved Phosphorus (mg/L)	4	0 (C)	-	0.041	0.058	0.094	0.113	0.138	0.150
Dissolved Iron (µg/L)	10	0	-	0	1	4	7	14	18

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.
D. Indeterminate due to lack of data.

ters region, and more sampling is needed to adequately characterize the water quality of this region.

8.5 Big Sandy Creek Outlet Region

The outlet region of Big Sandy Creek includes the lands and waters south and of Aroyo, CO. This includes site of the Sand Creek Massacre east of Eads, CO. Aerial imagery suggests very little crop production exists within this part of the Big Sandy sub-watershed, either irrigated or dryland; some dryland crops are grown in the southeast part of this sub-watershed. This part of the watershed is likely used for grazing livestock, and significant water uses could include wildlife habitat, livestock watering, and household wells. Big Sandy Creek continues to be ephemeral in this sub-watershed. This region is listed on the state 303(d) list as impaired for iron.

The only available data for this sub-watershed is located near the terminal segment of Big Sandy Creek, near its confluence with the Arkansas River. USGS gauge 07123100 and CDPHE sampling points 21COL001_WQX-7814 and 21COL001_WQX-AR0026 are the only sampling points. All sampling points sample surface water from Big Sandy Creek. The parameters of highest concern for this part of watershed include selenium, iron, manganese, and nutrients (N and P).

Contrary to samples analyzed in the headwaters region (Table 8), all seven samples analyzed for selenium in the outlet region (Table 9) exceeded the acute standard of 18.2 µg/L (n=7). The average selenium concentration was 36 µg/L, and the maximum concentration was 60 µg/L (September 14, 2005 at 21COL001-7814). Selenium samples have only been collected in 2005, 2006, 2010, and 2011, leaving significant data gaps.

Table 9: Summary statistics for major pollutants in the Big Sandy Creek Outlet Region.									
Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Selenium (µg/L)	7	7	7	19	22	29	36	55	60
Arsenic (µg/L)	2	1	0	0.00	0.15	0.50	0.50	0.85	1.00
Manganese (µg/L)	7	3	-	13.0	20.2	44.0	56.3	99.2	110.0
Total Nitrogren (mg/L)	7	6 (A)	-	2.100	2.352	3.270	3.683	5.128	5.380
Sulfate (mg/L)	7	7 (B)	-	1900	1990	2100	2128	2220	2400
Total Phosphorus (mg/L)	6	0 (C)	-	0.018	0.038	0.049	0.070	0.130	0.130
Total Iron (µg/L)	7	3	-	97	118	330	1495	3650	5000
Dissolved Iron (µg/L)	5	0	-	11	12	13	15	14	18

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.

This is concerning as Big Sandy Creek could be a significant source of selenium loads entering the Arkansas River at the confluence of the two water bodies.

Arsenic exceeded the chronic standard in one instance (n=2), and manganese exceeded the acute standard three times (n=7). Total nitrogen exceeded the state interim standard of 2.01 mg/L in six out of seven samples, with an average values of 3.6 and a maximum values of 5.3 (September 14, 2005 at 21COL001-7814). Phosphorus did not exceed standards in any of the samples, however, sulfate exceeded the chronic standard 100% of the time (n=7). Iron is reported as dissolved iron (n=5) or total recoverable iron (n=7). Dissolved iron did not exceed the chronic water quality standard for domestic drinking water, while total recoverable iron exceeded the chronic standard for aquatic life in three instances (n=7).

9. RUSH CREEK

The Rush Creek sub-watershed is an 8-digit HUC located within the watershed planning area. This is the only 8-digit HUC sub-watershed that does not contribute water directly to the Arkansas River, but instead this sub-watershed terminates into Big Sandy Creek near the Town of Chivington, CO. The Rush sub-watershed is dominated by native rangeland and shrubland, and the dominant land use is grazing. There are areas of irrigated agriculture, mostly in the upper reaches of the sub-watershed. All water quality samples for the Rush Creek have been taken within the upper reaches of this sub-watershed in the counties of Lincoln and Elbert. All samples were taken from surface water sources, and all data was collected by CDPHE and EPA.

9.1 Maps

Figures 34 and 35 show sampling locations for the Rush Creek sub-watershed.

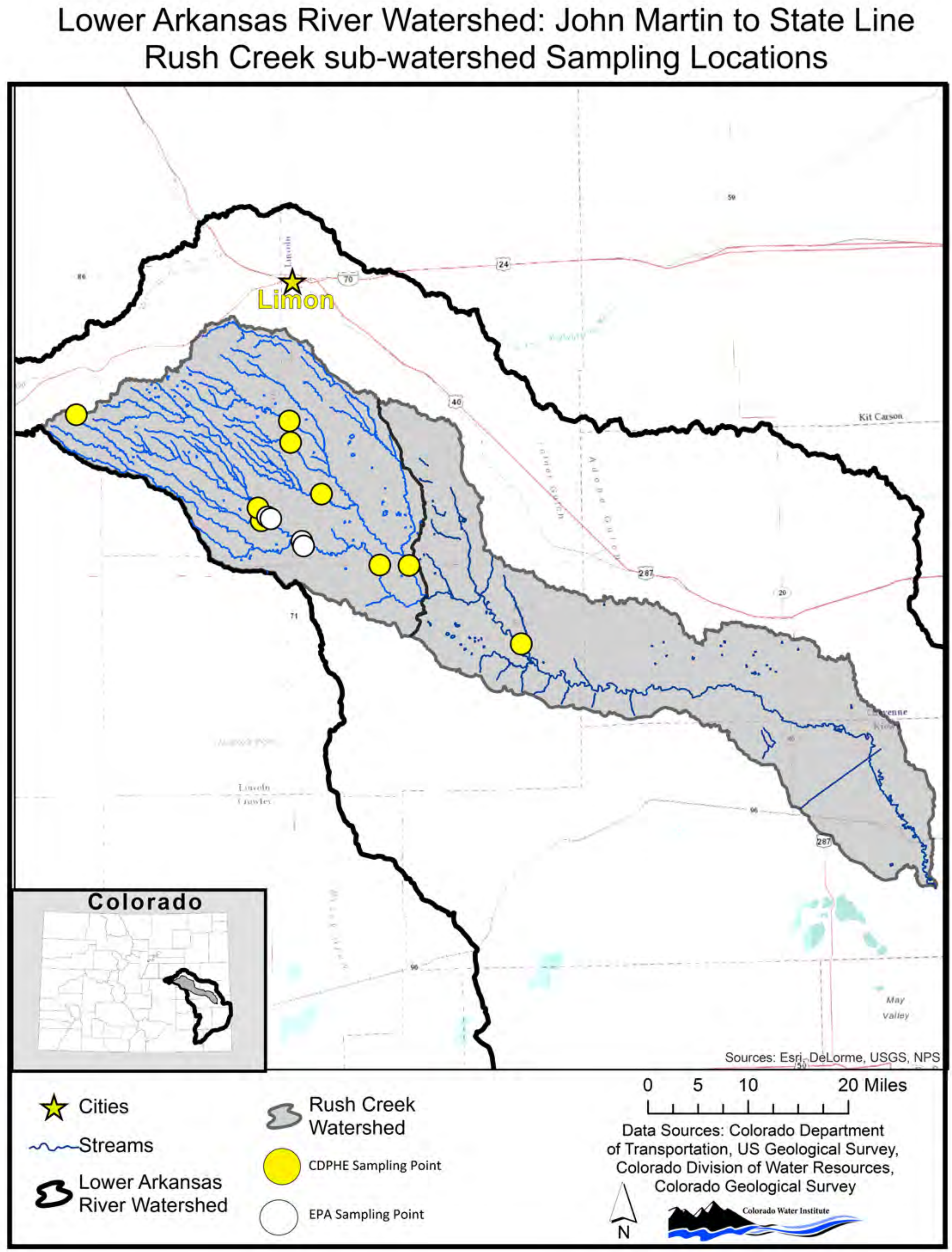

Figure 34: Sampling location and agency's responsible for sampling in the Rush Creek Watershed.

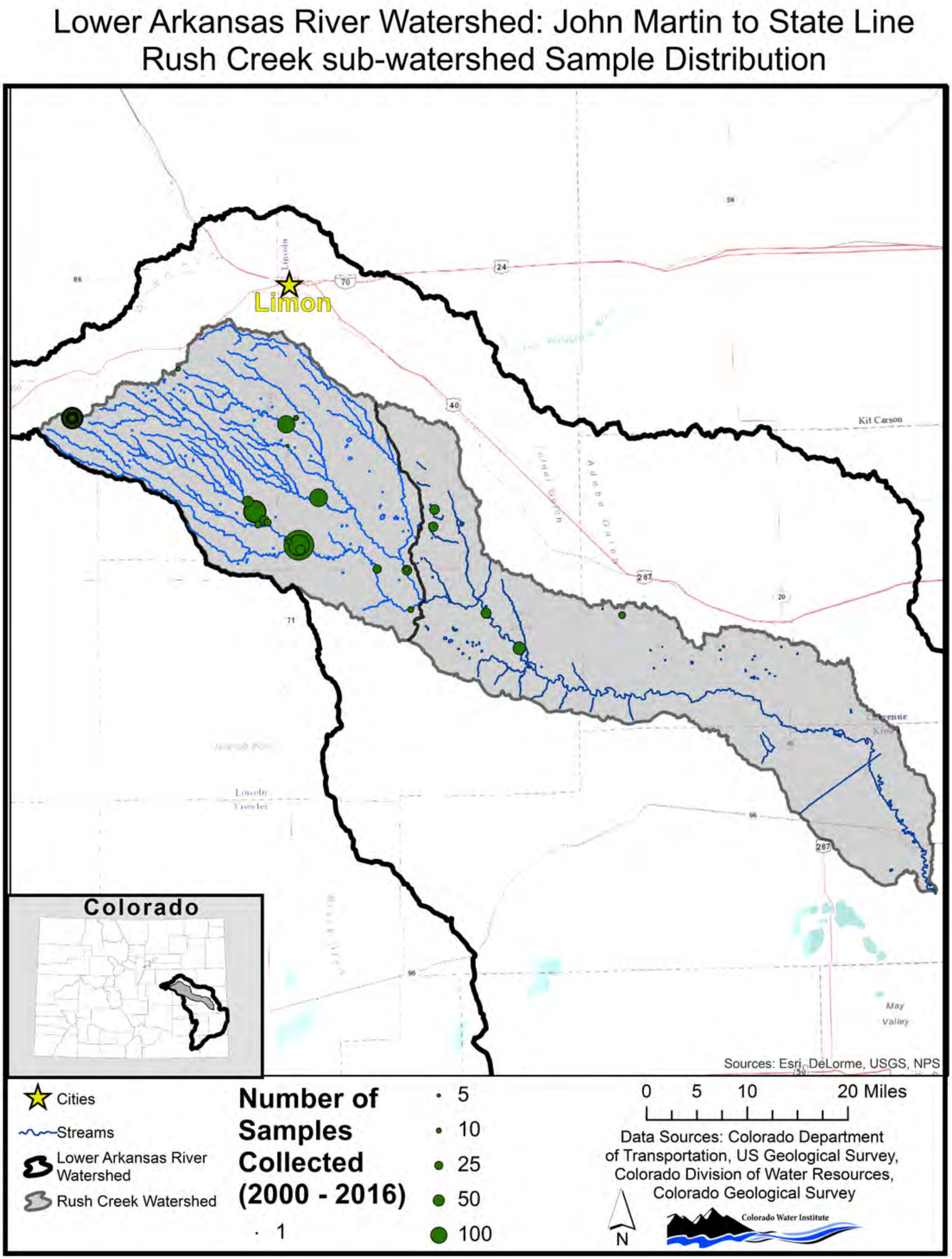

Figure 35: Sampling locations and relative number of samples taken in the Rush Creek Watershed.

Table 10: Summary statistics for major parameters in the Rush Creek Watershed.

Parameter	# of Samples	# of samples above chronic standard	# of samples above acute standard	Minimum Value	15th Percentile	50th Percentile	Mean	85th percentile	Maximum Value
Dissolved Selenium (µg/L)	20	0	0	0.00	0.31	0.46	1.44	3.23	3.70
Dissolved Uranium (µg/L)	13	-	-	1	1	2	2	3	8
Dissolved Arsenic (µg/L)	14	0	0	0.9	1.4	2.5	2.7	3.9	5.4
Dissolved Manganese (µg/L)	15	3	-	4.2	17.3	24.0	38.0	63.8	120.0
Total Nitrogren (mg/L)	13	1 (A)	-	0.180	0.254	0.647	0.989	1.548	3.630
Sulfate (mg/L)	16	2 (B)	-	45	47	89	167	231	610
Total Phosphorus (mg/L)	16	2 (C)	-	0	0.027	0.047	0.320	0.107	2.500

Determination of Standard Exceedances

A. The interim standard for warm water streams of 2.01 mg/L was used as a chronic standard.
B. Chronic standard set to 250 mg/L sulfate, which is the CDPHE chronic standard for sulfate in drinking water.
C. The interim standard of 170 ug/L for warm water rivers and streams was used; values are report in mg/L to remain consistent with federal and state agency reporting.

9.2 Pollutant Loading

Similar to Big Sandy Creek, reliable flow data does not exist. Therefore, it is difficult to evaluate pollutant loading to surface water sources. This creek, much like Big Sandy Creek, is also ephemeral and contains large sections of sandy wash with no flowing surface water.

9.3 Summary Statistics

Summary statistics were performed using the same methodology as the analyses of water quality data in the Upper Arkansas-John Martin Reservoir HUC and Big Sandy HUC.

Although not much surface water data exists for Rush Creek, it is clear that dissolved selenium is not an issue. No sample analyzed for selenium exceeded the chronic standard of 4.6 µg/L (n=20). It is unclear why selenium concentrations do not exceed standards in at least one instance, which is in stark contrast with the other surface waters analyzed in the watershed, but one determining factor for this could be the land uses within this sub-watershed. The source of Rush Creek is located south of Limon, CO, and is in an area with considerable acres of crop production, however, most of the crop production appears to be dryland. Without reliable surface water for irrigation, crop production must rely on natural precipitation. This constrains the local hydrology to “natural conditions” and, therefore, does not artificially elevate the water table and catalyze the dissolution of selenium from the shale bedrock. The average selenium concentration was found to be 1.44 µg/L with a maximum observed value of 3.7 (October 5, 2015 at 21COL001_WQX-7995).

Similar to selenium concentrations, the concentration of uranium in Rush Creek at the time of sampling is much lower than most waters within the Lower Arkansas River Watershed. The average dissolved uranium concentration was 2 µg/L, with a maximum observed concentration of 8 µg/L (May 18, 2015 at 21COL001_WQX-7896). In some cases, other parameters analyzed exceeded chronic standards, such as manganese (20% of the time, n=15), total nitrogen (7%, n=13), sulfate (12%, n=16), and phosphorus (12%, n=16). In general, and at the time samples were taken, the water quality of Rush Creek's available surface water does not often exceed water quality standards and represents some of the best water in the Lower Arkansas River Watershed.

10. TWO BUTTES CREEK

The Two Buttes sub-watershed is an 8-digit HUC located within the watershed planning area. This sub-watershed contains the least amount of usable data. Excluding a small subset of biological invertebrate data, only 90 water quality samples that include all constituents exist for the period of record. For example, there is only one uranium sample and three selenium samples. There is simply not enough data to perform any water quality analyses.

10.1 Pollutant Loading

Pollutant loading cannot be analyzed for this watershed, as no flow data exists.

10.2 Summary Statistics

Summary statistics cannot be analyzed for the lack of water quality data.

10.3 Maps

Figures 36 and 37 show sampling locations for the Two Buttes Creek sub-watershed.

11. FINAL REMARKS

For the purposes of this watershed, most of the water quality analyses focused on areas with adequate data. Most water quality samples have been taken from the main stem of the Arkansas River or the three largest reservoirs in the watershed: Nee Gronda, Adobe Creek, and John Martin. Water quality coming into the watershed, as measured near Las Animas, CO, is already above state water quality standards in many cases. However, clear patterns of non-point source pollution loading are evident within the Lower Arkansas River Watershed, where seasonal and spatial factors are considered.

For most pollutants, John Martin Reservoir acts as a "sink." Although this sink provides a water quality benefit at the moment, the volatile nature of water levels in JMR could act to mobilize pollutants. Further, the "sink effect" from John Martin Reservoir is not a long-term solution to improve water quality, and the risk of remobilization of pollutants in short, high concentration events or slow elevated concentration conditions still poses threats to downstream water users, including fish and wildlife.

The sources of many pollutants in the Lower Arkansas River Watershed (such as selenium, uranium, and salts) come from natural sources, including shale bedrock formations. Based on the data and the consistency of measured values at certain sampling locations, it is clear that keeping all of the pollutants "in-situ" is not realistic, even under natural conditions. The hydrologic cycle and geochemical makeup of the landscape will inevitably allow for the chemical weathering of soils and bedrock formations. However, the alteration of the hydrologic cycle to support activities such as agriculture and municipal water use acts as a catalyst and undoubtedly contributes to elevated pollutant loading for some constituents.

To make the best decisions about how to co-manage for agricultural productivity and healthy water quality, it is critically important that we have the most robust dataset possible. Data gaps exist, both spatially and temporally, and every effort should be made, within reasonable financial and technical constraints, to fill data gaps. The water quality analyses presented above are a first step at taking raw data and using it to identify water quality problem areas and potential data gaps. At the watershed scale and under current water-use conditions, it is clear that some water

Lower Arkansas River Watershed: John Martin to State Line
Two Buttes sub-watershed Sampling Locations

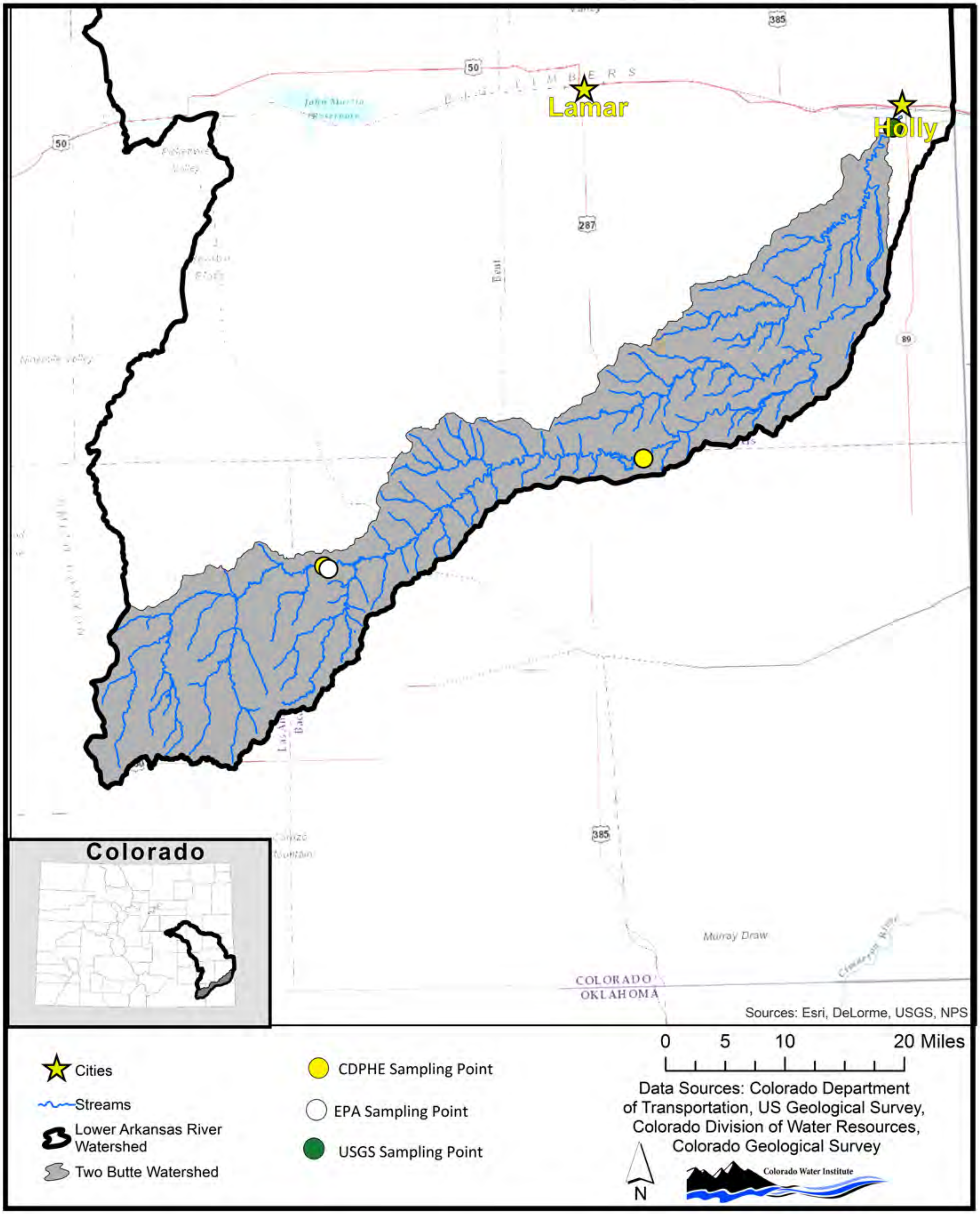

Figure 36: Sampling locations and agency's responsible for data collection in the Two Buttes watershed.

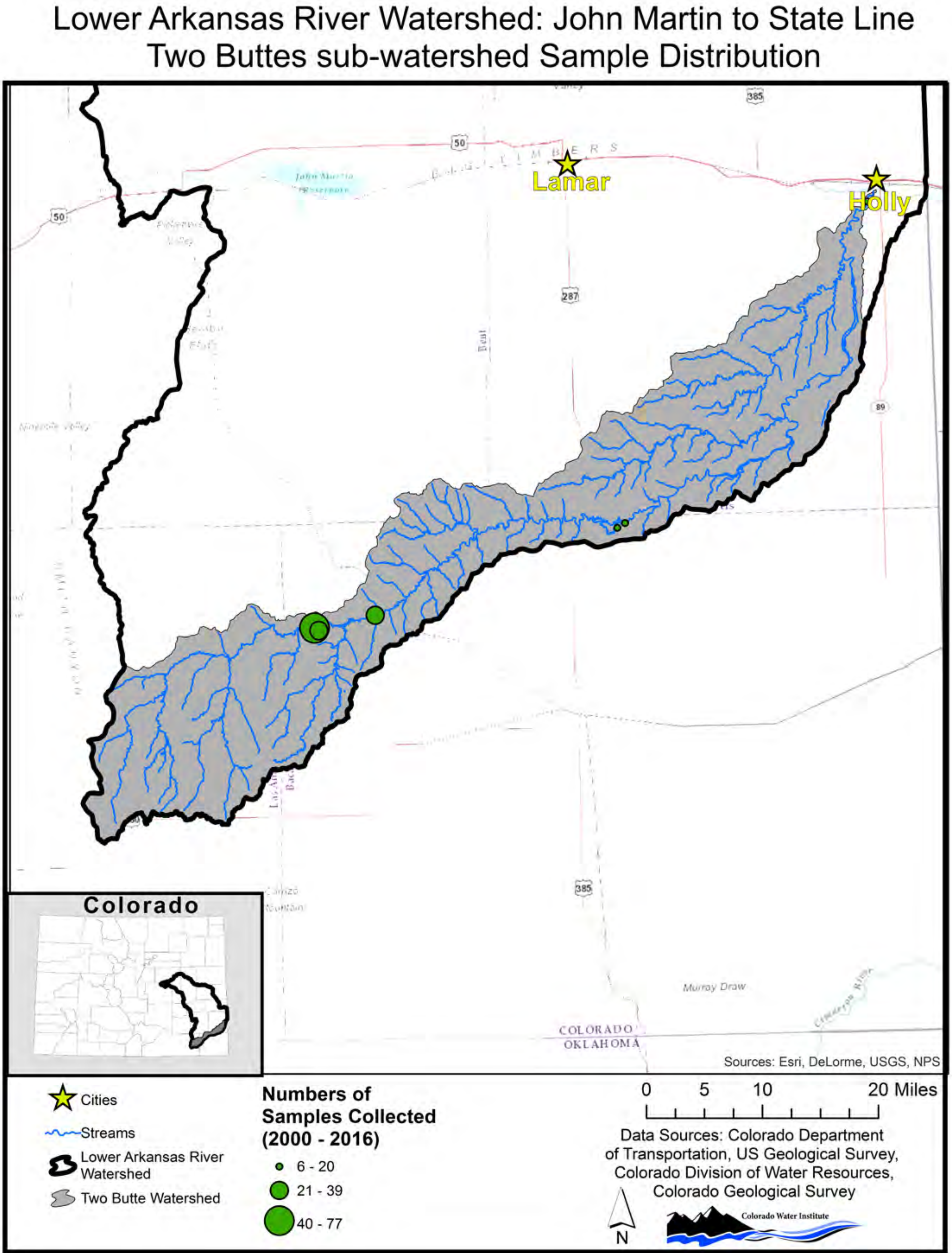

Figure 37: Sampling locations and relative number of samples taken in the Two Buttes Watershed.

quality pollutants exceed state water quality standards regularly (i.e., selenium, uranium, arsenic). In the future, land and water managers would benefit from a more detailed understanding of baseline water quality conditions and the impacts of alternative land and water management techniques on water quality.

The data collection and sampling procedures should focus on this need while also collecting water quality samples that represent the entire watershed, sub-watersheds, or stream segments of interest. One of the main goals of this watershed plan is to help identify data gaps and needs, as well as to identify water quality BMPs. Now is the time to merge these two techniques and test land and water management practices with robust and scientifically defensible data collection. It is recommended that any regulatory or funding agency adhere to robust standards for data collected internally and by external groups. Good data is valuable, and bad data is counterproductive.

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