Red River

Stakeholder Discovery Project Report

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INTRODUCTION

The impacts of a changing climate—increased temperatures, longer droughts, increased flood events, and sea level rise—pose a challenge to nearly all natural and human systems. The United States Geological Survey (USGS) Climate Science Centers have been tasked with pursuing "actionable science": science that is immediately useful to stakeholders who work to manage natural resources under the growing changes, constraints, and risks posed by a changing climate.

South Central Climate Science Center (SC CSC) has taken the call for actionable science in earnest. Its staff members and affiliated researchers recognize that pursuing actionable science must begin with obtaining a deep understanding of what is happening in their area of interest, including what stakeholders in that area have identified as pressing, needed, and most important.

SC CSC selected the Red River basin within their designated geography as a natural resource that supports a multitude of conservation and human uses. They have chosen to focus on this resource over the coming years because the Red River basin is projected to experience shifts in precipitation patterns, leading to longer droughts and more severe flooding, with a host of resultant consequences.

SC CSC contracted DJ Case & Associates (DJC), a conservation consultancy, to conduct a discovery project to understand what is happening in the Red River basin. The primary goal was to discern areas of research for SC CSC to pursue that will be immediately useful to stakeholders focused on natural resource management. The particular focus of this research is that it be co-produced—in other words, that researchers involve stakeholders from conception to completion of any given project.

This report summarizes the approach and methods for this discovery project, and then describes work that is currently happening in the region, followed by needs that were identified in talking with stakeholders across the basin. Lastly, it lists potential projects of need identified for SC CSC to consider pursuing in a collaborative fashion with the stakeholders identified.

THE RIVER

The Red River begins on the eastern edge of New Mexico with an ephemeral stream, Tierra Blanca Creek (see Figure 1).[1] This creek joins Palo Duro Creek to form the Prairie Dog Town Fork located just southeast of Amarillo, Texas. Prairie Dog Town Fork, together with North

[1] Note, we were not able to speak with anyone in New Mexico about this project and did not find anything in our media review about the headwaters in New Mexico. This is not to say there are not issues in that area as well, but they may have been less apparent in light of the large number of issues farther downstream.

Fork, are two major branches that form the beginnings of the Red River. The river runs east, forming the boundary between Oklahoma and Texas. Near Sherman, Texas, the river passes through Lake Texoma—the twelfth-largest reservoir in the US—passes briefly through southwest Arkansas, and then enters Louisiana. The river becomes navigable at Shreveport with a series of five locks and dams (see Figure 2). Finally, it merges with the Atchafalaya River southeast of Alexandria, near Simmesport, Louisiana.[2]

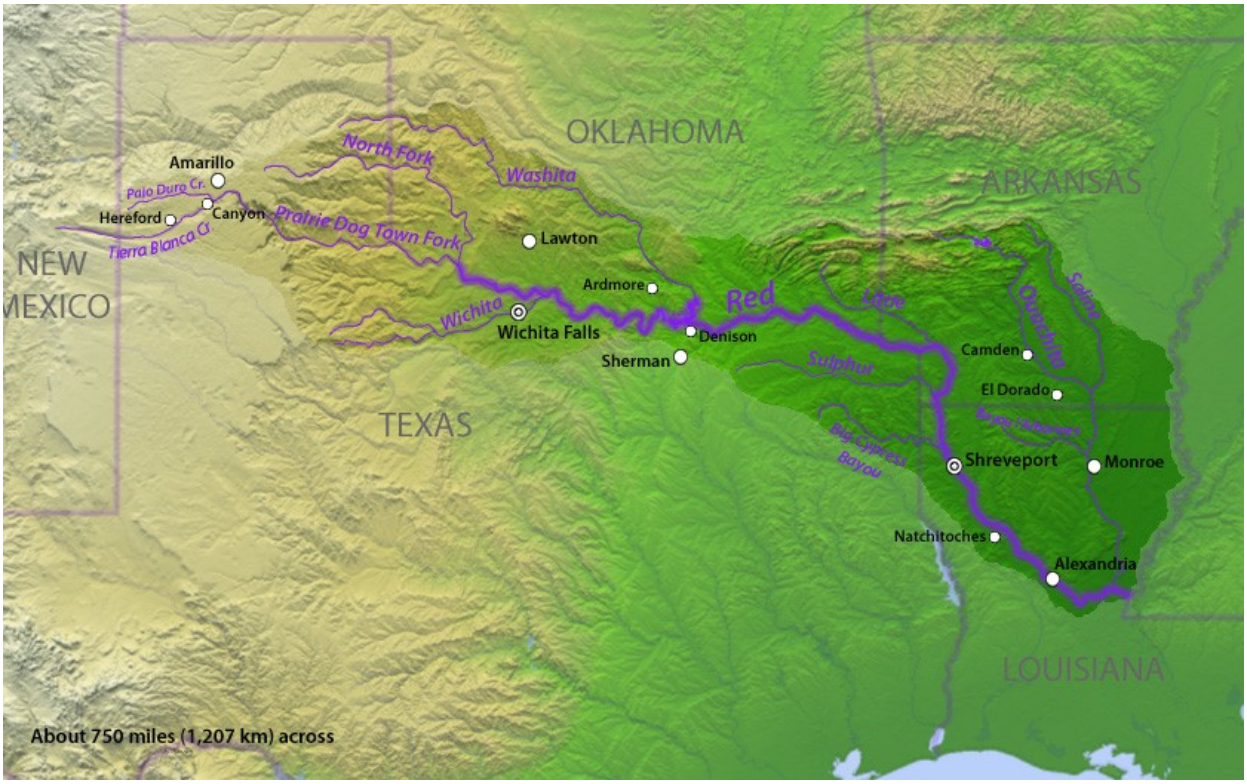

Figure 1. Red River Basin.

The western edge of the river's basin is dry, with precipitation of approximately 20 inches annually around Amarillo, Texas. As the river flows between Oklahoma and Texas, precipitation gradually increases to 35–45 inches per year. The shrub and scrub land (grassland and savannah) gradually change to piney forest in the river's eastern section (east Texas, Arkansas, and Louisiana). Precipitation increases to about 50 inches annually in Shreveport.

The uses of the river's water change drastically across the basin. The very western sections (especially on the North Fork) flow through areas where hydraulic fracturing is prevalent. Wheat farming occurs along the Prairie Dog Town Fork. The Washita River is especially

[2] The Red River used to flow into the Mississippi River. The US Army Corps of Engineers changed the course of the river so that it now flows into an outflow channel from the Mississippi River to join the Atchafalaya, which then flows into the Gulf of Mexico. Water flowing from the Mississippi River into this outflow is regulated by the Army Corps at the Old River Control Structure.

biodiverse, and attracts hunting and birding. Various types of recreation happen on and around Lake Texoma, including boating, fishing, hunting, and wildlife viewing. Shipping and navigation, irrigation, and steel manufacturing occur in the Louisiana stretch.

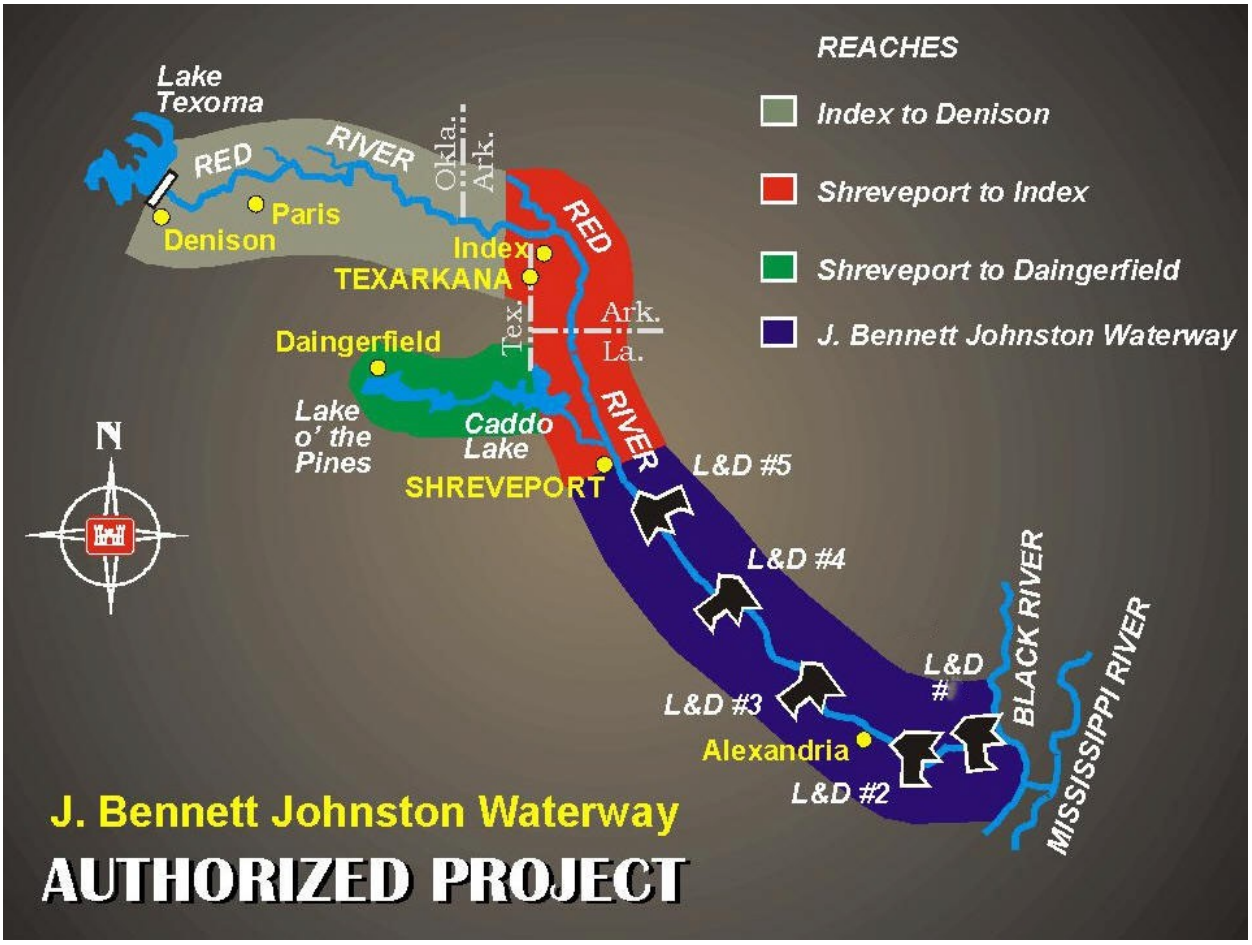

Figure 2. Locks and Dams near Shreveport, Louisiana.[3]

PROJECT APPROACH

In this project researchers at DJC approached the Red River basin both with culture and geography in mind, recognizing that both interact in complicated ways with ecology throughout the Red River basin. Maintaining a cultural-geographic approach revealed where issues of concern converge and where they diverge in the basin.

A cultural-geographic visualization was created as a way to summarize issues of concern and potential research projects along the basin. This visualization can be found at http://redriver.djcase.com, and much of this report corresponds with items in that visualization.

[3] Source: http://www.finsntales.com/wp-content/uploads/2012/02/rrauth_edited-1.jpg. See also http://www.redriverwaterway.com/forms/Full-Map.pdf.

Our research began by conducting a media review of pieces along the Red River basin published over the last 10 years. This report can be found in Appendix A (Media Review). The review was more sensitizing than exhaustive, providing the researchers with the background material necessary to enter into conversations with stakeholders from a position of knowledge rather than deficit. It also provided the researchers with fodder for topics that warranted pursuing in the conversations with stakeholders. Items of particular interest found in the media review were also linked to the visualization as a way to show the location of salient issues to stakeholders.

The DJC team also conducted a review of social science literature. If SC CSC is to pursue engaged, actionable science, then an understanding of relevant entities and the relationships among them is needed. The literature review turned up little social science research on the Red River basin proper. As a result, the review covered many of the broad theoretical underpinnings that will help to frame multi-disciplinary work in the future, including social vulnerability to climate change, perception of environmental risk, social networks and the diffusion of information, power relationships, and the role of culture in action. That review can be found in Appendix B (Social Science Literature Review: Relevant Social Processes and Mechanisms in the Red River Basin).

Upon completion of the media and literature reviews, we engaged with particular stakeholders. We chose a personal approach that focused on individual contacts and personal interactions, attempting to minimize the group processes that can derail discovery efforts conducted in large-group settings. Speaking to individuals alone or in small groups in informal settings created an atmosphere in which stakeholders could speak frankly and openly: there was little opportunity for dominant personalities to sway whole conversations in one direction or another. While this approach was more time-consuming, it was more apt to reveal issues of concern and priorities for actionable research. To that end, the research team conducted phone calls and face-to-face conversations with as many stakeholders as possible, given typical constraints of time and budget. While these conversations were not exhaustive, we are confident they were sufficient, particularly because we began to observe convergence in the themes of concern and needs identified.

Our first round of conversations entailed phone calls conducted with individuals from groups explicitly focused on conservation issues. From there we included government employees from various municipal, state, regional, and federal agencies and offices. To identify these people, we relied on the expertise of SC CSC personnel and groups and individuals who appeared regularly in our media review. We further used a snowball sampling method, asking those we interviewed who else they would recommend that we contact.

After the first round of phone conversations, we then set up in-person discussions with individuals and small-group listening sessions to increase our understanding of the river and its basin. These in-person conversations took place in local settings for our respondents in Louisiana, Oklahoma, and Texas.

All conversations, either in person or over the phone, were conducted in a way to uncover concerns and needs, and what groups were already doing to address some of the issues along the Red River basin. We emphasized in all of these conversations that this report would be shared for collaborative purposes. It is our aim that this document is only one step in this collaborative process and that those affiliated with the SC CSC continue to strengthen these relationships after this discovery phase ends.

Twenty-three conversations were held with a total of 41 different individuals over a three-month time span in late summer and early fall of 2016. A listing of all organizations represented in those meetings by meeting type can be found in Appendix C (Contacts).

RESULTS

The Red River basin is already the site of a large amount of research efforts, conservation efforts, and human infrastructure projects. We found that these efforts are not necessarily coordinated; that there is a great need for better communication, data sharing, and collaboration; and that there is still much to do, particularly in the face of a changing climate, growing human population, and pressing socio-ecological issues across the span of the basin.

In what follows we first provide an overview of what is occurring. We briefly describe the different projects we heard described under several different topic areas. Much of the work overlaps between groups, states, and topic areas.[4] The review of ongoing work in the region is in no way exhaustive, nor is it meant to be. Rather, it demonstrates the breadth and scope of work already under way and provides fodder for thinking about how future projects could link with existing research and resources.

Water quantity

Given that the Red River runs much of its course through areas that experience frequent droughts, it is not surprising that there is a large amount of work on water quantity issues already occurring. These fall under several sub categories, including work on groundwater modeling; surface water modeling; water access, rights, and needs; issues of water loss, often due to human infrastructural breakdowns; ecological flows related to times when water quantity is low; and changes in water quantity in relationship to climate change projections.

[4] Note that these descriptions are meant to provide a broad overview: we are not content experts in the many fields of study represented by the 41 individuals with whom we spoke. Every person we contacted is willing to participate in follow-up conversations should more detail on a particular project be needed.

Water quantity and the law

In general, three major legal frameworks affect water quantity issues from the perspective of apportionment and ownership. For the river as a whole, the Red River Compact was negotiated in the late 1970s among Oklahoma, Texas, Louisiana, and Arkansas to ensure equitable apportionment of the waters of the Red River and its tributaries (see http://apps.csg.org/ncic/Compact.aspx?id=165). A nine-member commission meets annually to discuss water distribution and, increasingly, water quality. The compact contains flow requirements for the Red River, and some are concerned that these requirements are not always being met. This compact is relevant for human and non- human water use in the basin. The second major framework consists of tribal treaties. Contention over the ownership and control of water in the river basin has been a prominent issue in Oklahoma, with major court cases decided or settled recently. The third major framework consists of intra-state regulations concerning water rights and permitting of groundwater discharge.

Water quantity and ecology

USGS Water Science Centers have been collecting a vast amount of data on water quantity (and quality) going back many years. They have gages in many of the tributaries that feed the Red River. These gages collect water temperature and stream flow. One of the uses of these data is to better predict floods, flood levels, droughts, and drought levels. Data for the gages can be found at water.usgs.gov. Gages located in Oklahoma can be found at ok.water.usgs.gov (click on the streamflow data tab). The numbers for gages along the Red and its tributaries in Oklahoma begin with 073000–07339000.[5]

The USGS Water Science Center in Oklahoma is also working on modeling aquifer and stream interaction on the North Fork, Salt Fork, and reaches of the Washita River down to Lake Texoma, to better understand the impacts of water withdrawals on the system as a whole. The data for this study was just arriving as of this writing.

One large-scale project is the Red River Water Availability and Use and Ecological Characteristics Focus Area Study. Multiple Water Science Centers are involved (Oklahoma, Texas, Arkansas, New Jersey, and Louisiana), and the center in Texas is leading the effort. This project is examining historic water use, refining water-use estimates, and identifying the flows of water necessary to support selected aquatic species. It is also modeling ground water and surface water flows and the impacts of changes in use in order to generate a combined model that more accurately describes the interactions of these waters. Alongside this effort, the Bureau of Reclamation is looking at risk assessments due to climate change along the Red River. These projects are both ongoing, and represent large-scale, total- system projects.

[5] Staff members at Oklahoma Water Science Center offered their services in accessing and understanding the data available.

Ecological flows are an important focus of research on water quantity.[6] Oklahoma Department of Wildlife Conservation (ODWC) has begun a Streams Management Program, focusing on instream habitat and restoration work. One of its projects examines ecological flow requirements for white bass recruitment and striped bass spawning. ODWC is conducting long term monitoring of the basin, looking at species distributions over time, and comparing this to historical data to understand change in species ranges. In particular, ODWC is looking at the life history of broadcast spawners, as these species have very specific needs and little is known about them. ODWC is also working on the population dynamics of several other aquatic species, including the blue sucker, and looking at nuisance species to understand where they are recruiting and how they are spreading. This work dovetails with the Oklahoma Conservation Commission's work on water quality (discussed in a later section).

Great Plains Landscape Conservation Cooperative (LCC) has a project on fish community connectivity and genetic integrity. This LCC is linking this research to historical data to determine native fish priority habitats. (See Appendix D: GCPLCC Progress Report.)

Still another group working on fisheries and connectivity in combination with water management strategies is the Gulf Coast Prairie LCC. Their project seeks to understand how connectivity happens and how connectivity changes due to changes in precipitation.

Habitat changes and restoration work are also directly impacted by changes in water quantity. The Gulf Coastal Plains and Ozarks LCC is working on identifying priority habitat for forest wetland restoration as part of their Conservation Blueprint, version 1, with a second version underway in 2017: http://gcpolcc.org/blueprint-1-0.

The Nature Conservancy (TNC) in Oklahoma is also examining water quantity. It recently acquired 3,000 acres of native prairie close to the Blue River, with the goal of recharging some of the Arbuckle Aquifer, part of which underlies the land. There are several unique species in the area, and TNC is also working on restoration of the land. TNC is further creating and studying models for sustainability and climate change that take water pumping, flows, and ecosystem and human communities under consideration to account for changes in use into the future.

The Army Corps of Engineers at Lake Texoma has had both direct and indirect effects on the quantity of water that flows downstream. It recently completed a major project to fix leaks in the dam's conduits, which then affected downstream fisheries because less water flowed through. The Corps does not have minimum flow authorization of a certain amount; however, because of the Operations Master Plan, it attempts to maintain a release of at least 50 cubic

[6] We understand that Texas Parks and Wildlife works on ecological flows in the panhandle portion of the Red River Basin and they are also working to preserve native prairie habitat in that region. However, we were not able to meet with this group.

feet per second (c.f.s.) from July 1 to October 1. Clear guidelines around minimum flows, informed by clear ecological needs and balanced with human-use needs, will be needed, especially during periods of prolonged drought.

Water quantity and human demands

Landowners throughout the Red River basin are also quite concerned about water quantity and quality.[7] The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) is working with landowners in Oklahoma to develop water access for livestock via the building of wells in order to mitigate drought. The overarching goal of NRCS is to help farmers better prepare for extremes. NRCS also supports farmers on projects of grade stabilization, farm ponds, and erosion control as a way to be better prepared for and mitigate flooding. In addition, NRCS is involved in efforts to restore wetlands in the southeast part of the Red River.

Dealing with drought is leading to some innovative projects. The Red Bayou project, created in Caddo Parish near Hosston and Gilliam by the Louisiana NRCS, has been operational for three years. It was created to help mitigate extremes and to provide a steadier supply of irrigation water for the area. The bayou diverts some water from the river and holds it, acting as a source of water during drier periods. This restored wetland has economic, ecological, and social impacts and is an example others could consider.

Another way to help farmers mitigate water-supply extremes is to help them implement practices leading to better aquifer recharge and ecosystem health. For this reason, NRCS is working on soil health as a way to work with the land in a more sustainable way (see these links for more information: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/ and https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_043902.pdf). Oklahoma Conservation Commission is also promoting soil health with landowners to deal with water quantity, water quality, and carbon sequestration.

Tarrant Regional Water District (TRWD) provides water to the Fort Worth, Texas, metropolitan area, a large and growing area with high water demands. It is currently working on water efficiency and leak detection as well as public outreach to reduce water consumption. If current efforts continue, the district anticipates not needing more water capacity for at least a decade. TRWD also has created a large wetland for water storage and aquifer recharge from Richland Creek. The George W. Shannon Wetlands were created from

[7] See media pieces linked throughout the visualization, particularly in the western reaches of the Basin, covering issues of water quantity and access during periods of drought.

land originally owned by Texas Parks & Wildlife Department. The 2,022 acres provide habitat for birds and other wildlife and help with water filtration.[8]

Oklahoma Department of Environmental Quality is also working on water loss monitoring. A recent report found that the majority of communities had up to 50 percent water loss, and some were losing up to 90 percent (Appendix E). Updating human infrastructure and finding ways to reduce waste could go a long way in alleviating water quantity issues in the region, especially in the face of predicted changes to the intensity and length of droughts.

Texas Commission of Environmental Quality (TCEQ) fulfills a number of responsibilities, one of which is ensuring water distributions from the Red River align with the Red River Compact. The Department of Water Availability within TCEQ uses ground and surface water models in its determination of what new permits can be issued. The determination of how much water various users can extract relies on the following general process: TCEQ examines gage flows on the Red River, which reveal the amount of water flowing; water rights holders take out water according to their priority order, which is largely determined by Supreme Court cases decided in Texas and in the US.

TCEQ has also worked with the town of Wichita Falls, Texas, on direct potable reuse, something many municipalities have begun considering due to the five-year drought that ended in 2015, when water shortages were felt across the western stretches of the Red River.

Oklahoma Water Resources Board permits water use in Oklahoma and oversees surface and groundwater rights in the state. (See Appendix F: Water for 2060, from Oklahoma Water Resources Board). It grants loans to communities for infrastructure needs and for conducting water quality monitoring. The agency is currently very supportive of projects that support regionalization as a way to deal with water shortages moving into the future. The 1973 Oklahoma Water Law requires that the board investigate the state's (groundwater) aquifers to determine the Maximum Annual Yield of fresh water that is permitted to be withdrawn from each groundwater basin, and the amount of water that may be withdrawn from each acre of land overlying a basin. The board recently completed two groundwater studies, on the North Fork and Salt Fork of the Red River, respectively. These studies are planned to be released in March 2017 and 2018 or 2019, respectively. (See http://ok.water.usgs.gov/projects/saltforkred/ and http://ok.water.usgs.gov/projects/northforkred/.)

Agriculture in southwest Oklahoma is heavily dependent on the Red River. Early in 2015, lake levels in that area were less than 20 percent of the normal capacity, and some were less than 10 percent of the normal capacity. Irrigation districts had not been able to have releases since

[8] Water from the Richland-Chambers Reservoir is pumped to customer cities, where it is treated and used. After use, the water is treated and discharged to the Trinity River. A pump station diverts water from the river into the wetland system for treatment. Once treated, the water is pumped to the reservoir, where it is re-used.

2010. By May of 2015, some lakes went from 10 percent of capacity to over 100 percent capacity in a month due to record rains. Some irrigation districts are looking at efficiencies since most farmers still use furrow irrigation (because of the cost of installing drip irrigation); one potential source of water conservation is to use water of marginal quality on non-food crops such as cotton. Conservation of water or the use of effluent indirect potable reuse of water for these sorts of agricultural purposes would help to alleviate water shortages.

Throughout the basin, the regionalization of water supplies emerged in several sessions. Such a move would help many communities to better address issues of extended drought; it would also save money by combining infrastructure and maintenance/construction costs. Yet communities big and small fight back against this idea, with municipal and other leaders tending to see having their own water system as part of their independence. Even if that is not most salient concern, what respondents often called "political forces" seemed to make this idea untenable. Understanding the complicated socio-political issues behind regionalization will become increasingly important in the years to come, as regionalization offers opportunity to mitigate water shortages.

Water quality

Closely related to water quantity is water quality. Primary considerations are the provision of potable water for human consumption, in addition to the irrigation of crops and the water needs of livestock. Due to both geological history and modern day erosion, the Red River tends to contain high levels of chlorides (salts). As a result, various components of the ecosystem have evolved accordingly; meanwhile, the use of water for human consumption and irrigation requires low levels of chlorides. Protecting ecosystems while also meeting human needs sometimes creates tension, and numerous attempts to alter the chloride levels in the river itself have ended without action taken.

Human behavior across the landscape is affecting water quality in the lakes, rivers, streams, and groundwater within the basin. Activities from agriculture, the oil and gas industry, certain municipalities, and septic fields impact water quality. Many groups, such as the Oklahoma Conservation Commission, NRCS's across the states, as well as state-level Departments of Environmental Quality and Water Resource Boards, are working to track these issues and find ways to mitigate and lessen some of the pollutants entering the system.

Water quality and ecology

The Oklahoma Biological Station at Lake Texoma is often called in to assess water quality issues, particularly as relates to fish kills. Staff members are using existing data and remote surveying as a way to reconstruct water quality through time. Oklahoma Biological Station is also working on several projects focused explicitly on Lake Texoma, where water quality (and potentially warmer temperatures) is exacerbating blue-green algal blooms. (The lake is

also susceptible to golden-algal blooms.) The Oklahoma Biological Station is studying these in order to reduce the resultant fish kills from such blooms.

Oklahoma Conservation Commission conducts several rotating surveys of streams and tributaries throughout the state to determine water quality issues and make recommendations. A summary report for Jackson and Tillman Counties is in Appendix G and, as is evident, many of the waterways in that area are impaired. (See Appendix G: Rotating Basin Site Summary, Jackson, and Tillman Counties, from Oklahoma Conservation Commission.) Also, in Appendix H is the entire summary report for cycle 2 of the Lower Red River Basin. (See Appendix H: Basin 5 (Lower Red River), Cycle 2, Final Report, from Oklahoma Conservation Commission.) Summaries and reports are made available on the Conservation Commission website as they are completed (found at http://www.ok.gov/conservation/Agency_Divisions/Water_Quality_Division/ or here). The commission also works specifically on non-point source pollution issues. Similar to the NRCS, staff members interface directly with land owners on soil health as a way to promote water quality and carbon sequestration. Some of their success stories can be found in Appendix I: Non-point Source Pollution Success Stories, from Oklahoma Conservation Commission.

Water quality and human needs

Both the Caddo Nation and Fort Sill Apache are working on several issues related to water quality and quantity as well as vulnerability assessments to climate change, mitigation, and adaptation work. The Caddo Nation just completed a groundwater/surface water study with USGS (see the cultural geographic visualization at http://redriver.djcase.com). Analyses of water quality in their area revealed troubling levels of pesticides in the water supply of some residents.[9]

Drought and flooding

The incidence of drought and flooding in the Red River basin is not new. However, droughts are lengthening in duration, and flooding is becoming more frequent and severe, as predicted by climate change models. Mitigating and adapting to these extremes must be addressed over the coming years. It is important to note that climate change (especially its exacerbation of flooding) is directly related to other issues. One particular issue is the accumulation of sediment in various portions of the river—especially groins and dikes and locks and dams—which means that the river tends to crest higher with each flood, even if the actual amount of precipitation has not changed.

Projects to help deal with the extremes of flooding and drought are occurring all across the basin. Work focused on drought mitigation is more common in the western reaches of the river. Work focused on flooding is more common in the eastern reaches of the river. Lake

[9] Environmental Protection Agency water quality standards can be found at https://www.epa.gov/wqs-tech.

Texoma experiences both issues equally; however, Congressionally Authorized Mandates direct the Army Corps of Engineers there to prioritize flood control.

At the federal level, NOAA has a considerable amount of data available online, particularly for looking at drought. Figure three shows the drought monitor for the Red River basin as of December 6, 2016 (map created using NOAA Climate Viewer). These tools will be helpful for many projects moving forward as a way to tap into a wealth of already existing data.

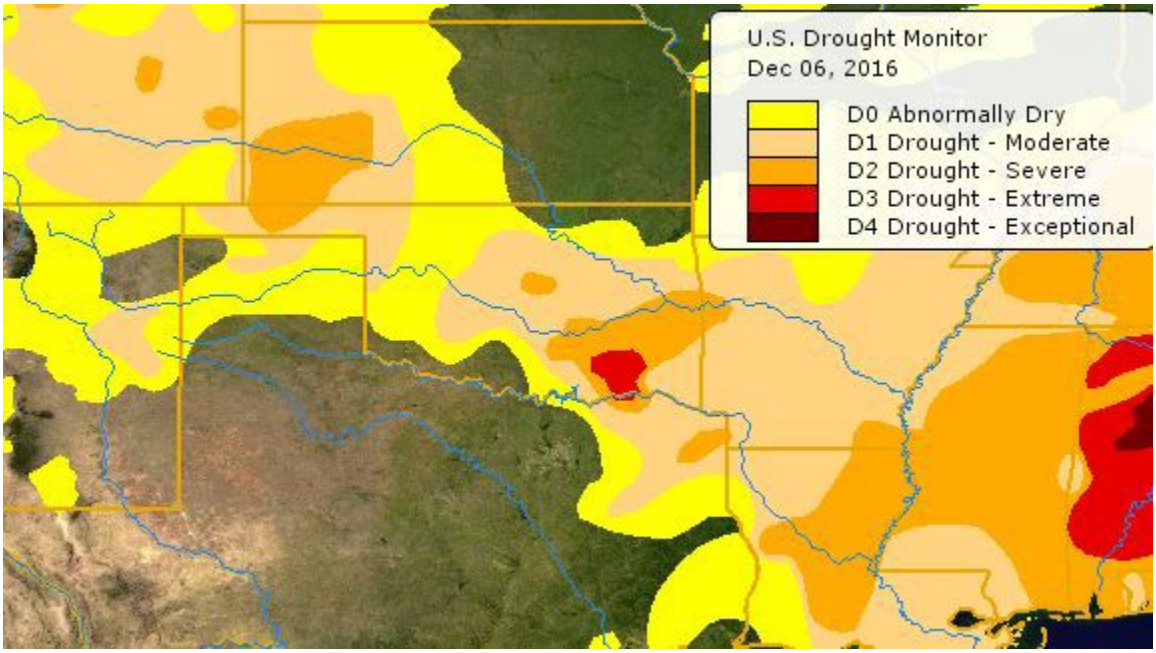

Figure 3: NOAA Climate Viewer output example

Lake Texoma

Lake Texoma is a significant geographic area along the Red River with distinct, complex issues, and a number of projects are occurring in that area.

Oklahoma Biological Station has projects to understand the interaction between invasive species and water quality (especially salinity) to see if this is a limiting factor for some invasive species. (This is also a topic of interest to ODWC.) The station is also attempting to understand, via climate model projections, how climate change may impact the lake. Chickasaw Nation is also working with the U.S. Fish and Wildlife Service on invasive species issues in Lake Texoma.

The Army Corps of Engineers manages the lake. According to its five Congressionally Authorized Mandates, its primary focus is preparedness for and relief from flooding and drought. The lake has experienced drought for the last five years, with 2015 lake levels at their lowest in recent memory, and reservoirs or upstream lakes having dried or at record lows. In combination with drought, however, is intense flooding: two flood events went over

the spillways in 2015. In January of the same year, there was an 8-hour flood watch, which was highly unusual for that time of year.

One reason for the exacerbation of flooding is deltaic formation upriver on the Red and the Washita rivers. Certain areas have accumulated sediment, grown trees (cottonwoods and willows in particular), and as a result channelize flood waters toward the lake. The release of sediment into the river is largely a natural process, given the geology of the area and given that the stream systems feeding the lake change course frequently. However, the release of sediment is also augmented by climate change (due to increases in flooding), and augmented by the fact that most of the land upriver is privately owned, operated for agriculture, and increasingly converted into cropland (thus helping to increase erosion).

Given that the size of the basin is about 40,000 square miles—the size of the state of Indiana—bank stabilization and erosion control would be a massive undertaking involving multiple disciplines, myriad landowners, and new sources of incentives.

Droughts affect human access to the lake and activities such as fishing and wildlife viewing. The lake is also aging, and the accumulation of sediment is producing a number of consequences: Western portions of the lake have become ponds, with shifting ecosystems; the boundaries of the lake have changed; certain formerly lakeside communities are no longer near the water; formerly deep sections are now shallow. Dredging is not effective, as one major flood could return more sediment than could be removed in a year's time. Yet during each drought, local residents pressure the Army Corps to dredge marinas and docks to restore access to the water. Drought and flooding, especially as they affect sedimentation, will only continue to have greater impacts as their intensity increases with climate change.

The ecosystem on the upper (western) reaches of the lake—pelagic reaches and open-water reaches—is also changing rapidly. Certain areas have developed small lakes and sustain their own fisheries. There are some 20–30 lakes (the exact number is unclear). Some lakes have their own boat ramps and support recreational activities like fishing and wildlife viewing.

The exact lifespan of Lake Texoma is currently unknown. In the coming several decades, it could transition into a wildlife refuge, or a flood plain, or a wetland as sedimentation continues to accumulate. Each of these would lead to different human uses and different ecologies.

Navigation, locks, and dams

Those with interests in navigation have a particular concern with drought and flooding, and these concerns must be considered in combination with ecological concerns. The Red River Waterway Commission owns 28,000 acres (see cultural geographic visualization at http://redriver.djcase.com) that they manage for fishing. The Commission also works with the Army Corps (especially in Louisiana and Arkansas) to keep navigation open during flood

events. (The Army Corps operates 15 locks and levies upriver from the locks in Shreveport.) However, the use of the river for navigation is not fully accounted for in the Army Corps' plans for flood control since the plan was implemented in the early 1990s and dredging for navigation finished in 1993. Indeed, when the plan was written, there had been merely one flood event in the prior 30 years. Respondents in Louisiana were concerned that the Army Corps has not taken into account changes—urbanization, increases in impervious surfaces, locks and dams, and dikes—in terms of what they do and how they operate.

The cities and towns of Shreveport, Bossier, and Alexandria are especially at risk of floods on the Red River. The river has seen five flood events in the 18 months from 2015 to mid-2016. Flood crests are exceeding high water marks of previous periods. Major problems include siltation in locks and dams—a result of high silt flows from upriver in Oklahoma, Texas, and Arkansas—which requires dredging. Urbanization between the levies in Louisiana, permitted by parishes and cities, has contributed to flooding and sedimentation accumulation by channelizing, or artificially narrowing the course of the river. Sedimentation in the river is blamed for some of the increased flooding issues occurring in Louisiana. This directly affects the navigation of the river. Mitigating future flooding (for example, by raising the height of levies) will require knowing the level of siltation.

Where and how the rain falls affect the river greatly. Hence, one concern surrounding climate change in Louisiana is not only the amount of precipitation, but also its location. In general, if heavy rain falls north of Interstate 30, it is distributed into the river, which floods and then impacts navigation. However, if the rain falls along the Interstate 20 corridor, the precipitation occurs outside the levies. As a result, the water cannot reach the river, and the communities outside the levies flood. (For example, some 1,000 homes in Bossier City and some 1,000 in Shreveport flooded during a recent "backwater" flood, since the water did not have a place to go, and the bayous could not handle the 30 inches of rain in two days.) The existing bayous were built some 50–60 years ago, and they have not been improved to handle the tens of thousands of additional houses constructed since then. One infrastructure need, then, is more storage for additional water to go during these backwater floods.

The Red River Waterway Commission has also worked with towns, such as Bossier City to help create and maintain stable pools of water as Bossier City obtains 100 percent of its water from the river and so must have a stable source available.

Five locks and dams exist on the Red River from Shreveport to Baton Rouge. From upriver to downriver—roughly north to south—these are Joe D. Waggoner, Jr. Lock & Dam #5, Russell B. Long Lock & Dam #4, Lock & Dam #3, John H. Overton Lock & Dam #2, and Lindy C. Boggs Lock & Dam #1.

Stabilizing the river by installing levies, dikes, and locks has produced greater recreational opportunities. When the river is stable, there are five lakes above (upriver of) the locks and

dams, which are popular sites for fishing. Because of the locks and dams on the river, 20 recreation sites now exist (including a national wildlife refuge), up from zero sites prior to the locks and dams. In total these sites receive some two million visitors per year. Additional recreational opportunities include dragon boat and power boat races, a riverfront theater (in Alexandria), a shopping complex (in Shreveport), a recreational vehicle (RV) park (in Natchitoches), and trails along the river (in Bossier City and Shreveport)—all created as a result of stabilizing the river. Dredging the river has also created bass fishing opportunities.

Depending on respondents' priorities, the creation of five locks and dams around Shreveport have been either good or bad overall. Those who argue in their favor note that historically the river in Louisiana was essentially a long logjam, and these locks and dams mimic the river's original state. Those who argue against them note that the river is now highly channelized and has fewer ox bows than it did, thus giving excess water and sediment few places for relief.[10]

Other ongoing work

Water quality, water quantity, and the extremes of flooding and drought are a focus of much of the work happening in the basin. These projects span the fields of ecology, biology, hydrology, climate science, economics, sociology, and the law.

The Bureau of Indian Affairs will release an environmental impact statement in 2017 that covers Texas, Oklahoma, and Kansas. This report will include air and water quality as well as other environmental impacts on tribal members in those states.

The Bureau of Land Management is primarily concerned with the area of disputed land on the Texas side of the Red River (see cultural geographic visualization at http://redriver.djcase.com). While helping to address the problem of disputed boundaries is not within the purview of the CSC, it is important to be aware of such contentious issues as they impact the reception of individuals representing government agencies on other projects.

NEEDS

The previous section provides cause for optimism: good work is happening on a number of fronts in the Red River basin. Nevertheless, much more remains to be done. This section details the needs identified by different groups and individuals. The following (and final) section provides recommendation for potential future projects the SC CSC or others could pursue along the Red River basin.

Collaboration

Many of the needs listed below involve (or ought to involve, according to those with whom we spoke) *collaboration*. Collaboration, of course, is already occurring in many locations. As

[10] Three major oxbows are located at the following places: the Red River National Wildlife Refuge, one located near Louisiana State University–Shreveport, and one located south of Shreveport.

an example, Oklahoma Water Resources Board (OWRB) is conducting a study with Bureau of Reclamation on the Rush Springs Aquifer, which feeds the Washita River, which drains into the Red River. USGS is contributing the groundwater flow models, since groundwater affects how much water flows into creeks (note, USGS is also working with the Apache Ft. Sill on ground water modeling of the Rush Springs Aquifer); OWRB is doing the surface water flow models. Bureau of Reclamation is taking these two models, adding a run-off component, and adding in different climate scenarios. This will provide estimated total flows into the Fort Cobb Reservoir under different groundwater pumping scenarios. Bureau of Reclamation wants to do same project in upper Red Basin region, and OWRB has entered in agreement with them. As of this writing, OWRB has five contracts with USGS, a direct result of the state's Comprehensive Water Plan. Similarly, in 2015 the SC CSC forged a partnership with and funded a project with the Chickasaw Nation to look at impacts of water availability along the Red River under different climate scenarios (see "Impacts of Climate Change on Flows in the Red River Basin" under Projects on the http://redriver.djcase.com cultural geographic visualization).

These types of projects are exactly the sorts of collaborations needed to understand and address changes across a large spatial scale in such a complex cultural-ecological system. Nevertheless, respondents described the need for two types of collaboration. The first type is collaboration across different sections or reaches of the Red River, including across state lines. The most obvious state line of interest (given its size) is between Oklahoma and Texas, with information, accessibility to information, and priorities differing between the two states. The second type is collaboration across agencies, especially between federal and state agencies.

For respondents, collaboration did not necessarily need to mean formal involvement on a project (in the sense of providing funding or personnel). Rather, collaboration might include simple awareness that a project in a particular geographic area or a particular subject matter were occurring. Some participants described hearing about projects that were already underway or that had been completed without their consultation or knowledge. In particular, respondents described the need for collaboration among *scientists at the mid-level*, not only at the executive level.

One strategy that could help facilitate collaboration is a database of projects—perhaps represented as a spatial visualization—that have been completed, are currently underway, or are planned for the future. The template created for this project (http://redriver.djcase.com) could easily be extended to host this sort of additional information.

Another strategy is for an in-person conference or meeting of water scientists throughout the river basin. This event could be sponsored by the relevant Climate Science Centers, Water Science Centers, Landscape Conservation Cooperatives, and/or Joint Ventures as appropriate. Such a gathering would prioritize the creation of interpersonal and inter-organizational

relationships across agencies and state lines, which in the long term would help to facilitate information-sharing and other types of collaboration. Several groups mentioned in the report already have regularly scheduled meetings: For example, the Red River Waterway Commission meets monthly; the Red River Valley association, several times throughout the year; the Red River Compact Commission, at least once per year.

Data sharing, ease of use, translation

A major need is the connection of data gathering and reporting across various groups and agencies. One source of disconnection is the relatively little amount of communication between federal-level and state-level agencies and organizations. To be sure, some collaboration is already occurring via stakeholder meetings and advisory committees. This sort of collaboration can be expanded so that all relevant members of organizations understand what is happening across the river and in other agencies. Some respondents (such as Oklahoma Water Resources Board and the Oklahoma Conservation Commission) are eager to be involved from the beginning of projects that involve their jurisdiction. These agencies and organizations (as well as others) do not necessarily need to be a major player in each effort or initiative, but they bring a wealth of expertise that should be tapped into before efforts are conducted. Many of the organizations we interviewed already sit on one another's boards as a way to consult with one another. However, easier avenues for communication, consultation, and collaboration – particularly across state lines and across organizations at state, federal, and county and city levels – was something we heard time and again from those we interviewed as needed. What this looks like precisely should arise out of a collaborative process to be sure that the structure of such a connective network is truly useful to these different organizations. Inclusion of stakeholder representatives at all levels is important for science to be truly actionable, on the ground and interacting with lived experience.

Although respondents agreed on the need to think of the river and its basin as a whole, one major complication is that the river varies significantly from its beginnings in New Mexico to its end in Louisiana. Although something like the Red River Watershed Management Institute (located in Shreveport, Louisiana) is able to accomplish much with its limited budget, its staff are able to focus on only a small section of the river.[11] Creating and funding one institute for each segment, with an inter-institute coordinator, could be one way to increase data sharing and to increase thinking of the river as a whole. The South Central Climate Science Center or a Water Science Center could perform such a task. The coordinators of the three relevant Landscape Conservation Cooperatives—Gulf Coastal Plains and Prairie Ozarks, Gulf Coast Prairie, and Great Plains—may also be able to play this role.

[11] The Red River Watershed Management Institute is housed at Louisiana State University–Shreveport. Started in 2001, the institute brings together LSUS faculty; local, state, and federal agencies; and community stakeholders. It consists of a 585-acre wetland on the Red River adjacent to the university's campus, water monitoring technology, GIS laboratory, and environmental assessment and monitoring laboratory.

Hydrology

Very little is known or tracked along the river regarding water withdrawals of groundwater and surface water. This includes both the quantity of water withdrawn alongside its use. Several respondents noted that understanding the whole hydrological system—let alone one particular tributary or fork of the river—requires identifying where water is drawn, not where it is used. As mentioned in the prior section, some projects focusing on these interactions are happening (e.g., The Red River Water Availability and Use and Ecological Characteristics Focus Area Study mentioned previously, conducted by the USGS Texas Water Science Center), but these could be expanded. Understanding where saturation is and best practices for aquifer recharge would be beneficial, particularly to those who work directly with landowners to implement best practices. These efforts would also benefit from coordination as well as data sharing to understand these hydrological interactions across the basin and how projected changes in precipitation will impact these interactions.

The role of wetlands in recharge is important. There are several groups working on wetland restoration (such as the Tarrant Regional Water District wetland restoration and recharge efforts mentioned previously): these wetlands impact habitat quality and aquifer recharge. Using models of existing restored areas to understand broader impacts may be a good way to move forward on other restoration projects.

Social science

Many of the problems the region is facing and will continue to face will require cultural understanding and sensitivity. For example, persuading ranchers and farmers to make investments in water efficiency, pollution reduction, or erosion control requires nuanced understanding of the issues at stake, the legitimacy of the organizations and agencies involved, what is required to build trust, appropriate modes of interaction, perceptions of risk, and so on. Streamlining infrastructural needs or fixing aging systems to conserve water in the face of drought requires nuanced understanding and strategy of the political landscape. Providing residents with easily interpretable information and forecasts requires strategic communications and extensive user testing. Identifying sites of social and ecological vulnerability requires mapping not only habitats, but also indicators of social health. Many of these situations call for not only the provision of more information, but also mediators and cultural translators who can work out avenues for compromise. Linking the social with the ecological is something that few are doing, but it was identified by several stakeholders as desperately needed in the region. This work is essential for outreach and communication efforts to be successful.

As an example, the area around Lake Texoma is being parceled into small(er) fragments and owned by people with different understandings of land management than farmers and ranchers in the past. In addition, there are high levels of poverty as well as high concentrations of wealth in the Lake Texoma region, which are often related to water access

and the location of the shoreline. These issues point to the need for socio-cultural assessment that complements environmental assessments.

Combining macro- and micro-level empirical data with relevant social theories and concepts, some of which are laid out in Appendix C (Social Science Literature Review: Relevant Social Processes and Mechanisms in the Red River Basin) as a way to harness the social science to address pressing socio-ecological issues is needed in the basin.

Ecological flows

While there are a number of different groups working on ecological flows, most of those are focused on fish communities. There is the need to move beyond fish to other species in this area. Collaborative work between conservation-focused groups and the Army Corps could help to create better pulse releases to support species-specific ecological flows downriver of Lake Texoma.

Identifying the minimal flows downstream to support species such as the pallid sturgeon (which is endangered) is a specific research need. Other aquatic species of interest include broadcast spawning fish species, the Red River pup fish, alligator gar, and paddle fish. This work should be linked with best practices for maintaining needed ecological flows. Such a need grows even more in light of more intense droughts.

Water quality and quantity

Across the river many groups are concerned with sedimentation and the need for bank stabilization. For groups working on navigation in Louisiana, sedimentation and bank erosion are major issues. Groups such as the Red River Waterway Commission and the Red River Valley Association struggle to handle the high sediment load carried by the Red, which leads to increased flooding and decreased navigability of the river. However, most were skeptical that control of sedimentation is possible, especially given that existing efforts have proven expensive and limited in their impact. New approaches to sedimentation control would be welcomed by those dealing with navigation as well as flooding issues in Louisiana. While others recognize the role of that sediment further downstream at the mouth of the Mississippi building deltas in the Gulf of Mexico, balancing these concerns is a difficult issue, but one that merits more research.

Sedimentation in Lake Texoma is changing the lake in dramatic ways that need to be better understood. The lake's holding capacity is changing; communities that had been lakeside now look over wetlands and have lost access to the lake. Also, land ownership patterns around the lake are changing, and this too is impacting the system in ways that are not yet understood. Ultimately, it is an aging lake that is eutrophying and filling in. This impacts the ecology and the economics of the area in profound ways. These issues are further compounded by toxic algal blooms (a result of nutrient loading and potentially worsened by warming temperatures). A multi-disciplinary project is needed to address these complex and

interacting issues: such a project could include bathymetric mapping of the lake bottom to understand how sediment is impacting the basin, as well as economic evaluations and human needs assessments. This work should also include future projections and the interactions between social, climactic, and ecological changes.

There is also a regularly arising issue of salinity and chlorides in the Red River and Lake Texoma specifically. More research may provide avenues through which middle grounds and compromises could be met. Conservationists tend to oppose desalinization, while those working to meet human consumption needs tend to see desalinization as a potential solution. This is a complicated topic, and one that merits further investigation. Investigations that look at biological needs of species as well as human community needs may work best for determining a middle ground that is suitable for conservation and human needs. This research is needed in preparation for increased drought.

Nutrient loading in the basin from fertilizers, the oil and gas industry, septic fields, and municipalities, as well as the specific impacts of irrigation on water quality, are major issues that need solution-driven research. These are complicated issues with major impacts on water quality and habitat integrity that intersect with large industries. One particular area for further research is how regulations might be better placed to limit the multiple sources of nutrient loading on the river. Many respondents also expressed the need for more water quality monitors and the need to monitor contaminants that are currently measured only sporadically, such as hormones from birth control often found in human waste.

Invasive species

Another complex change happening in the basin's ecosystems is the influx of invasive species, especially Asian carp and zebra mussels. As of yet, there does not seem to be good baseline data on Asian carp (e.g., where they are breeding, and what is their tolerance for salinity?). Furthermore, will these species fair better or worse when flows are interrupted due to drought? These are currently unknown, and answering them would help with management decisions across the basin.

Legal

Water rights will continue to be an issue that generates heat and tension, especially with changes in precipitation patterns. Great Plains LCC plans to start focusing on this issue, and there is much to be done. Tribal rights to water are particularly unclear. While the Chickasaw and Choctaw case helped to lay a roadmap for sustainable use models that protect tribal sovereignty and water rights, tribes do not currently hold federal water rights. (See Appendix J: Findings of Fact and Conclusions of Law, from Chickasaw and Choctaw Nations.) Treaties rarely contain explicit information on water, and many respondents had reason to believe that tribes take precedent for water rights on their sovereign land. Those who understand the

complexity of water law will be in high demand in a future where water becomes more limited.

Land use, historic changes, and access

The use of four-wheelers along the Red River and the creation of makeshift bridges came up in several discussions. These bridges are illegal, and the four-wheelers may be running on land that is not open to public use. In addition, these vehicles often damage river and stream banks and habitats where they operate. Several groups interviewed desire to use modern technology, such as LiDAR and drones, to better understand land use changes along the river and to identify these problem areas more completely. In general, maps from different time periods could be used to better understand human-induced changes to land use, as well as other changes happening to the river and its tributaries.

Integration of data for decision making

Much of the data currently being collected could benefit from greater integration across different organizations and sciences. The data need further interaction with real-world applications. Using ecosystem services modeling approaches would be one way to engage in strategic land use planning that accounts for multiple priorities and values on the landscape in a way that attempts to find commensurate ways to account for variability in values, particularly those that may not correspond to direct market valuation. (One widely used tool is called InVEST, or Integrated Valuation of Ecosystem Services and Tradeoffs: http://www.naturalcapitalproject.org/invest/.) Accounting for multiple values in the river basin produces greater understanding of which habitats, resources, and wildlife may be vulnerable in the future. Doing so also provides a common means through which groups with competing priorities can begin to find mutually acceptable adaptation and mitigation strategies. Linking the social, economic, ecological, and hydrological is needed, and these models may provide one way to achieve this integration.

It is crucial that any projection models account for four particularly important factors affecting water availability. One is increasing water demands due to a growing human population. Another is increased evaporation due to climate change. A third is changes in land use as a result of urbanization. A fourth, and closely related, is socio-economic shifts in the basin.

Economic assessments in combination with ecological understanding are needed in many areas, but perhaps most particularly around Lake Texoma. Some communities are losing their lake access due to sedimentation. The counties surrounding the lake are already some of the poorest in the area, and changes in the lake will change one of the major economic drivers in the area. Again, integration across the social and ecological is needed to understand and make holistic management decisions.

There are multiple jurisdictions managing the flow of the Red and there is a need to bring these together in a more concerted way. Integrating across these jurisdictions and finding ways to better share data across these entities would take management of the basin a long way. This integration would also require a critical understanding of how different sciences approach and understand problems. Through this, collaborations will move beyond talking past one another to truly working together.

RESEARCH OPPORTUNITIES

Based on the wide-ranging description above, we describe opportunities for research specifically related to climate change. Two elements that underlie the potential research projects listed are 1) the need for collaboration and 2) the possibilities of using new technologies (such as drones or decision support tools) in this geographic area.

Monitor water flows

Those interviewed expressed the view that in comparison to other large rivers the Red River is relatively understudied in terms of *ongoing* examination of the flows of ground and surface water. Some tributaries are un-gaged, and there is little accounting for run-off from agricultural uses and impervious (urban) surfaces.[12]

Potential research projects:

- Identify particular geographic or hydrologic areas that could benefit from greater frequency of water monitoring not only to detect water shortages ahead of time, but also to assess the effects of climate change.
- Determine what it would take to improve the accuracy of gages and the predictive models that use their data along the Red River and its tributaries especially during flood events. This may help to improve the accuracy of initial predictions during flood events.
- Make data more accessible and understandable, not only to members of the public, but also to those whose job involves working on or with the Red River.
- Improve forecasts, especially the Quantitative Precipitation Forecasts, which professionals involved with drought and flood control use. Doing so could have a variety of benefits, especially in better predicting flood events.
- In addition, given the size of the river and its basin, it may be worthwhile for one group to coordinate data-gathering efforts. This may or may not be a role the USGS—via the SC CSC or a Water Science Center—would consider playing. Potentially, this

[12] To be sure, the USGS in partnership with Bureau of Reclamation and Oklahoma Water Resources Board, are conducting a ground water and surface water flow study of the entire Red River basin from 2016 to 2018. This will provide comprehensive evaluation of water-resource availability, refine water-use estimates, and characterize aquatic ecology and stream flows needed to support selected aquatic species. This sort of project could be updated on a regular basis.

role could be played by two or three US Fish & Wildlife Service Landscape Conservation Cooperatives.

Potential organizational partners:

USGS; Red River Watershed Management Institute; tribes; Red River Waterway Commission; Red River Valley Association; major universities; LCCs and JVs.

Identify water use

Given projections of increased drought, and given the increased uses of the Red River for agriculture, navigation, and drinking water, data on water use is minimal. (Most data consist of where water is used, not from where it is extracted.) Clearer data on this could help with water conservation efforts, which in turn would help to alleviate shortages exacerbated by climate change. Oklahoma seems to be a bit behind Texas in terms of understanding and monitoring of water use. Respondents suggested that Texas has a much better handle on actual amounts of water out as well as groundwater/surface water interactions. We cannot assess if this is true, but there does seem to be the need for more groundwater and surface water modeling, as this relates to water withdrawals and even water quality for communities that rely on surface or groundwater.

Potential research project:

- Monitor where water is taken (and for what it is ultimately used).

Potential organizational partners:

Oklahoma Water Resources Board; Tarrant Regional Water District; other water districts as appropriate; Oklahoma Department of Environment Quality; Texas Department of Environmental Quality; Texas Commission on Environmental Quality; USGS; tribes; major universities.

Understand ecological flows

The issue of understanding ecological flows, beyond fish populations, was raised by several of the more conservation-focused groups. Ecological flows are severely impacted by extended droughts as well as flooding events. While the USGS is doing a large-scale study of the Red River that includes a component looking at ecological flows, these flows are being studied through modeling of extant data.

Potential research projects:

- Collect greater and more frequent on-the-ground ecological data
- Combine this data collection with modeling land-use change on different parts of the river

Potential organizational partners:

USGS; Oklahoma NRCS; Oklahoma Conservation Commission; Texas Department of Wildlife; LCCs and JVs (in region where work is conducted); The Nature Conservancy.

Assess socio-environmental vulnerability

Social scientists across a range of disciplines—geography, sociology, political science, and psychology—have developed indices of vulnerability to environmental change and have applied them to countries around the world, including the United States. Analyzing vulnerability includes more than mapping the direct physical consequences of an event, such as reduced yields or shortages of drinking water or loss of reservoirs and rangeland. Fully analyzing vulnerability means tracing the causal role of social organization above and beyond the causality of "nature." Hence, vulnerability analysis examines physical processes alongside social, political, and economic ones. The goal is then to respond to *all* of these causes of impacts so as to reduce vulnerability.

These analyses are rooted in the reality that both the physical features and the social features—especially the presence of poor and socially marginal populations—of a geographic locality affects the damage to human residents. Furthermore, underdevelopment undermines the coping abilities and resilience of certain populations more than others.

Potential research projects:

- Use existing or adjusted measures of social vulnerability to flooding and drought in portions of the river especially susceptible to both.
- Pair these assessments with identification of the social causes of vulnerability, including community context, economic inequality, flows of information, and power dynamics.
- Particular attention could be paid to the area around Lake Texoma, a major economic driver, yet one that is undergoing substantial transformation—many of which are directly or indirectly associated with climate change: warmer waters, accumulation of sediment, increases in invasive species, and prolonged drought. In addition, the upper (western) portions of the lake are becoming shallower, deltas are forming, and portions of the shoreline are expanding. This creates ponds, which changes the habitat for birds, fish, and other wildlife. It also changes the opportunities available for fishing. Furthermore, this cuts existing communities off from the water, which decreases property values and changes the composition of the human population and surrounding communities. All of this is happening at the same time that there is promising development on the north side of the lake being pursued by the Chickasaw Nation. Additionally, the area has other tribal land holdings as well as there likely being rich historical and archaeological sites (as is true along much of the Red). It is unclear how these different pieces across different portions of the lake will affect downriver ecosystems or the surrounding human communities. A project that engages

with landowners and stakeholders in the area and focuses on an environmental economics study of the area could be very beneficial to many of the stakeholders in that region.
- Engage with stakeholders in different segments of the river (especially around Lake Texoma), potentially using the tool InVest as a way to illustrate residents' interactions with the landscapes, identify goals for the future, show how climate change may impact these goals, and provide avenues for engagement that are solution-driven.
- Another way to engage landowners in particular is via decision support tools that would provide clear recommendations and guidance depending on specific landowners' goals or objectives.

Potential organizational partners:

Army Corps of Engineers; Chickasaw Nation (if focus is Lake Texoma are); other Tribes (depending on geographic focus); USDA NRCS; Oklahoma Conservation Commission; Texas Department of Wildlife; USFWS via the Hagerman National Wildlife Refuge; municipalities in the area; North Texas Municipal Water District

Monitor and understand sedimentation

Flooding on the Red is not only caused by high levels of precipitation, but also by buildup of sedimentation and the channelization of the river. (That is, artificially narrowing its banks through, say, a downtown area, as in Shreveport, Louisiana.) Some along the Red are skeptical that anything could even be done to reduce the buildup of sedimentation; others are convinced that there is no other option except to do something about it. Understanding the impacts of tributaries, upstream damming, as well as how land-use change impacts sedimentation is important to Lake Texoma and to those further down river as well.

Potential research projects

- Deploy innovative technologies such as multi-band LiDAR or drones to better assess the impacts of sedimentation on the river.
- Use novel technologies to assess where sedimentation will accumulate.
- Compare historical imagery with present-day imagery to see how the river has changed.
- Identify sites that are especially prone to erosion and support bank stabilization efforts there.

Potential organizational partners:

Army Corps of Engineers; USDA NRCS; various Soil Conservation Districts, depending on where work is focused; Chickasaw Nation; Red River Watershed Management Institute; municipalities

Assess land-use changes

Along the whole of the Red River basin is the need to assess land-use changes. Several departments in Oklahoma and Texas are working on soil health as a way to promote healthy ecosystems as well as needed carbon sequestration. The relationship to climate change is, of course, land-use changes can be a major driver for carbon emissions.

Potential research projects:

- Model the relationship among different land-use strategies and carbon sequestration, aquifer recharge, water quality, and drought mitigation.
- Evaluate the ecological and economic impacts of incorporating wetland restoration or construction into flood and land-use models and planning on appropriate areas of the river.

Potential organizational partners:

Oklahoma Conservation Commission; USDA NRCS; LCCs and JVs (in region where work is done); Caddo Nation; Apache Ft. Sill Nation; other tribes