

The Role of Citizen Science in Ecosystem Management: A Case Study of the Middle Rio Grande Bosque Ecosystem Monitoring Program

by

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Abstract

Rapid advances in technology, especially smart phones, have changed citizen science around the world. Citizen science-generated data are growing exponentially, so there is increasing interest about what is happening with all this data. Some research suggests that governmental agencies are not using citizen science data to make ecosystem management decisions, although other studies contradict this finding. Regionally, the Middle Rio Grande bosque ecosystem extends for 162 miles along the Rio Grande in New Mexico. The Bosque Ecosystem Monitoring Program, or BEMP, was founded in 1996 following the efforts of the Bosque Initiative and the development of the Bosque Biological Management Plan in 1993. The objective of this research is to understand how BEMP data are incorporated into the ecosystem management framework. Interviews were conducted with known BEMP data users at local and federal agencies who are responsible for managing natural resources in the study area to learn more about how managers are applying BEMP data to their decision-making processes. A review of publicly available ecosystem management plans that cover the extent of the ecosystem supports this investigation. Interview findings suggest that BEMP data plays a strong role in ecosystem management decisions and is widely used across the ecosystem by various management agencies, specifically related to restoration projects. Recommendations are offered to the State and BEMP to improve MRG bosque ecosystem outcomes and citizen science program efficiency.

Introduction

Rapid developments in internet and personal-use technologies like smart phones in recent decades has led to an explosion of Citizen Science (CS) related activities globally. All types of CS data have seen increases including long-term ecological monitoring data, which is a critical resource to ecosystem managers. Long-term monitoring of natural resources is imperative for increasing the understanding of ecosystem processes, services, and how to manage those ecosystems to maintain or improve function (O'Donnell et al., 2021). The Bosque Ecosystem Monitoring Program (BEMP) is one CS program that has been conducting long term ecological monitoring for twenty-six years across a large riparian ecosystem in central New Mexico. BEMP was founded in 1996, in response to the 1993 Bosque Biological Management Plan (BBMP). The BBMP is a biological management plan covering the entire extent of the Middle Rio Grande (MRG) bosque ecosystem, which is also the reach of BEMP data collection activities. The MRG is also the extent of the study area of this research.

The BBMP plan provides ecosystem management information, guidance, and recommendations. The original recommendations in the BBMP defined a major shift in vision around long-term management of the MRG ecosystem. The plan emphasizes “an integrated management approach, with special emphasis being placed on communication and coordination.” The BBMP was published one year prior to the listing of the endangered Rio Grande silvery minnow, which is a federally protected in-stream species inherent to the study area that plays a strong role in the way the river is managed today. BEMP was originally formed to begin monitoring the ecology of the MRG bosque ecosystem and to engage and educate the public about their home ecosystem. BEMP continues to collect data in its twenty-seventh year

in 2023. This research seeks to discover the role CS is playing, if any, in ecosystem management (EM) in the study area, utilizing BEMP as a case study.

Interviews were conducted with all known ecosystem managers in the study area that use BEMP data or have in a past role. The field of CS has been expanding and with it the net of data available to managers and to the public, but our understanding of the role of CS data in EM is still somewhat ambiguous. This research seeks to understand the role of CS by placing the program within the EM framework of the study area, so if the reader finds the chapters on the study area and associated EM plans denser, relative to sections covering the interviews, it is because those sections are meant to support and provide context to the interview data. Interview questions were crafted in a way to 1) develop understanding of the role that CS is playing in the EM framework in the study area, 2) improve understanding of how efficient BEMP's long term ecological monitoring CS data are at meeting the intended use of managers, and 3) consider EM challenges and how CS supports managers in meeting those challenges. The sections ahead cover background information about CS, BEMP, and EM; followed by sections on the interview research process and findings (methods, results/discussion, and conclusion). Final recommendations are made to BEMP and the State.

The appendices contain reference information relevant to this ecosystem. Appendices include relevant information about the history, ecology, climate, EM plans, and a series of new canopy maps. It became clear through management literature review and interviews that the comprehensive plan for this ecosystem is dated and that there is not a public agenda for this ecosystem, so the appendices offer a reference for relevant information to the study area and provide meaningful context to this research. Comprehensive planning provides partners and the public with a consensus on priorities being set for the ecosystem and for what reason. Setting

an agenda to address comprehensive priorities for an ecosystem like this is challenging for many reasons, and a few of those challenges are presented in the sections ahead.

I. Citizen Science

Citizen science is the participation of non-professional scientists within scientific research helping to generate new knowledge and information (Lee et al., 2020). CS is increasingly recognized as a distinct field of research (Haklay, 2016). The field of CS focuses on the collaboration of motivated volunteers (citizen scientists) with professional scientists to generate new knowledge and information (Lee et al., 2020). The past decade has seen a rapid increase in the number of CS projects and their scale (Hecker et al., 2018). Earth Science-related CS projects are the focus of this research. Earth Science-related CS projects aim to inform, build awareness, and improve resilience to various environmental issues (e.g., geohazards, environmental monitoring). CS programs have seen a progression from small pilot studies to large data collection Earth Science initiatives where data support and underpin modelling (Lee et al., 2020). A range of approaches has arisen for collecting CS environmental data (i.e., community-based monitoring, volunteer monitoring, and crowdsourcing) from the local to international level (Miller-Rushing et al., 2012; Chandler, 2017). Volunteers are typically provided information about the ecosystem of interest and the research goal. While the awareness of CS has significantly increased in recent years, the direct impact of CS on policy and decision-making is still limited (Lee et al., 2020).

Earth Science-related CS programs offer participants the opportunity to improve their scientific understanding of the local ecology and provide individuals with a sense of place (Lee et al., 2020). The acknowledgement of these kind of individual impacts has led to an increase

in popularity of Earth Science-based CS programs as an effective means to produce ecological data while also advancing public ecological knowledge (Krabbenhof, 2020). The most effective CS programs are those with small infrastructure costs that maintain active and regular sampling by motivating volunteers, often those living in or near the ecosystem of interest (Krabbenhof, 2020; Cooper et al., 2007).

CS data has contributed to regional and global assessments of biodiversity, habitats, and impacts of global change (Amano et al., 2016) as well as provided input for management (Newman et al., 2016; Chandler, 2017). CS programs offer an opportunity to expand the scope of monitoring spatially and temporally, and at lower cost in terms of data points gathered per dollar (Gardiner et al., 2012). Long-term ecological monitoring data are critical for ecosystem managers to make the best-informed decisions towards adaptive management by improving ecosystem models and forecasts (Giron-Nava, 2017). This research considers the role of one Earth Science-based CS organization providing long term ecological monitoring data sampling across a large riparian ecosystem along the MRG of central New Mexico, the Bosque Ecosystem Monitoring Program (BEMP).

One recent publication that focused on BEMP in the study area is titled, *'Bringing citizen monitoring into land management: a case study of the Bosque Ecosystem Monitoring Program'* (Converse et al., 2016). Converse et al. says that “despite the rapid expansion of CS monitoring, data from these programs remain underutilized by natural resource managers, perhaps due to quality and comparability issues.” Converse et al. recommends the creation of a five-year plan including scientific goals and financial solvency strategies prior to establishing a citizen science program and offering multiple platforms for data-sharing and dialogue, to maximize potential for partnerships with managers.”

In 2015 a University of New Mexico thesis was published by Cameron Weber, *Citizen Science Ecological Monitoring: For Whom?* (Weber, 2015). Weber's research investigated the 'barriers to use' of BEMP's CS data in the same study area as defined in this research. Weber's research begins on the presumption that "bosque land managers are not using the available citizen science ecological monitoring information to the extent they could, to inform their decisions." The primary data for the study came from 18 semi-structured in-depth interviews with land and water resource managers, biologists, and policymakers representing 17 entities with a stake in planning and management of the Middle Rio Grande bosque. Interviews were conducted in person during the 2015 summer; each lasted for 45 to 90 minutes.

Weber's study found that the barriers have something to do with the "decision-making context and whether monitoring data are simultaneously available and useful for management objectives; and that monitoring data derived from CS is not an inherent barrier to its use." Weber's research identified five barriers to the use of CS data by EM managers as: the lack of time or staff; priorities driven by funding; lack of requirement to make evidence-based decisions; lack of immediately useful information; and the uncertainty of leadership priorities (Weber, 2015). Where Weber chose to survey a broad range of managers on barriers to use, this research goes directly to the known BEMP data users who are involved in managing the ecosystem and asks them to expand on which BEMP data they actually use and what they are using it for. This research builds on Weber's and Converse's respective work on this topic by considering the EM framework of the study area that BEMP operates within, identifying specifically what types of BEMP data are relevant to managers and how/why the data are being applied to their decision-making process. The goal is to understand the role that BEMP plays in EM in the study area.

II. Case Study: The Bosque Ecosystem Monitoring Program (BEMP)

BEMP was the only CS program identified in the study area collecting long term ecological monitoring data utilized by managers to make EM decisions in the study area. Comprehensive bosque ecosystem management recommendations were presented thirty years ago in the BBMP (Crawford et al., 1993), many of which are still not fulfilled today (see Appendix E for those 1993 recommendations). The MRG Bosque Initiative and BBMP collaborative efforts led to the formation of BEMP in 1996. The Middle Rio Grande Bosque Initiative was “an ongoing, congressionally supported interagency EM effort with the objective of protecting, enhancing, and restoring biological values by addressing ecological functions within the Middle Rio Grande.” The Bosque Initiative was led by the Bosque Improvement Group (BIG), an informal non-exclusive think-tank and forum with federal, tribal, state, city, county, and local government agencies, educational institutions, private industry, non-profit organizations, and private individuals. Information about the Bosque Initiative or BIG was challenging to find and it appears that these are not active organizations at this time.

BEMP continues to generate data from thirty-three active collection sites along 270 miles of the MRG, producing around one million data points annually that range on a spectrum from conventional to informal (see BEMP site map in Figure 1). Nature’s Notebook is another CS organization collecting long term ecological monitoring data in the study area that contributes

to the national phenology database.¹ The role of Natures Notebook in EM is not included in this research.

In 1997 BEMP originally began monitoring and collecting data at three sites: Alameda, Rio Grande Nature Center, and Los Lunas. The BEMP website details early days of the organization and identifies the late Dr. Cliff Crawford as the original team lead (University of New Mexico, Department of Biology). Supporting members of the team included Dr. Crawford's then-graduate student Lisa Ellis and Dan Shaw from the science program at the Bosque School. The group tasked themselves with bringing community members together to collect local ecological information, i.e., “conduct community science in the Albuquerque community to both enhance scientific research capabilities and to educate local citizens about their bosque.” In 2023, the BEMP website says that BEMP data helps answer questions like “What are the results of management decisions and actions?” or “What are the best management practices for bosque restoration?”

The BEMP website states that BEMP data-use occurs across state, local, tribal, and federal natural resource management agencies; and has been utilized to inform large-scale bosque management projects. BEMP identifies its lead science partner as the Department of Biology at the University of New Mexico. The primary ecosystem managers known by BEMP to utilize BEMP data include the Army Corps of Engineers (Corps), Save Our Bosque Taskforce (SOBT), Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA), U.S.

¹ These datasets do not have the same relevance to local ecosystem managers as BEMP data. Nature's Notebook data contributes to the National Phenology database, as discussed on the group's website https://www.usanpn.org/natures_notebook and is linked on the BEMP website www.bemp.org.

Bureau of Reclamation (BOR), U.S. Fish & Wildlife Service (USFWS), and City of Albuquerque Open Spaces (CABQ).

BEMP Data

These are the categories of long-term ecological monitoring datasets (monthly monitoring) listed on BEMP's website:

- Depth to Groundwater
- Precipitation
- Litterfall
- Arthropods
- Vegetation
- Water Chemistry and Water Quality
- Tamarisk Leaf Beetle
- Temperature²
- Phenology
- Woody Debris (Historical)

BEMP datasets are summarized on the website <https://bemp.org/about-bemp-science/>, while the raw datasets are available on the organization's GitHub page linked on the BEMP website https://github.com/BEMPscience/bemp_data.

² **Temperature Data** BEMP collects temperature data at several of its sites using LogMaster. The temperature data are not technically citizen science because it is collected by BEMP staff and interns. Temperature Loggers. At sites where temperature is monitored, three loggers are installed: one in the tree canopy to capture air temperature, and two subsurface loggers to capture ground temperature (one under tree canopy cover and one out in the open). Data points are recorded hourly, giving us great resolution of temperature data for our sites. Once a year, BEMP staff and interns go out into the field with ladders, shovels, and a laptop to retrieve all the data and re-deploy the loggers. This network of temperature loggers across BEMP sites and in various areas within sites helps us understand how temperatures fluctuate in different areas, how microclimates might behave, and how the canopy cover in the bosque might affect ground temperatures. With increasing aridity and heat becoming a pressing climate change impact, especially across the southwest, gathering data that can help us monitor these shifts is crucial to conservation and management of our bosque.

BEMP Data Collection and Management

Data Collection

BEMP data are primarily collected by K-12 students and teachers. BEMP staff guide data collection and data processing activities in the field and in the lab.

Site Selection

When BEMP was asked during the interview how the organization determines which sites will be monitored the interviewee responded, “Initially, it was really based on proximity to schools that were interested in participating. Selected sites were near research sites that some of us were working on as grad students. So, there was a layering of data. But most of our sites, two thirds to three quarters of our sites have been put in, in specific locations at the request of an agency that's addressing individual project data demands.” Data collection started at three sites in 1997 and has grown over time to thirty-three sites in 2023. The organization maintains several long-term core datasets, while there is natural variability in the linear data richness across all sites due to the layering on of sites over time. View a map of BEMP’s data collection reach in Figure 1.

Site Setup

The methods for site setup described here can be found in the science section of BEMP’s website:

“Each BEMP study site is set up as a rectangle with a north/south length of 200 meters and an east/west width of 100 meters. Sites, typically located between the river and the levee, should be representative of the forest composition in the area. To minimize disturbances and the potential for vandalism, study sites should be selected in areas of low human impact, though this is not always possible. Some sites are set up to monitor specific land management practices, treatments, or other aspects; these areas are predetermined and may not conform

to the above criteria. Study sites are set up using the same design; this makes it possible to make valid comparisons among sites. All sites are monitored using the same methods and during the same week on a monthly basis. Following standard procedures is critical to the success of the program. Each study site is comprised of 10 vegetation plots, 10 litterfall tubs, 20 pitfall traps, five wells and two rain gauges (see image 1). Some sites have three temperature loggers.”

Monitoring Schedule

An explanation for the monitoring schedule design can also be found in the science section on the organization’s website:

“BEMP is designed to gather information from a series of sites along the Rio Grande. As any scientific study, it is critical to limit variables so comparisons can be made among the sites. For this reason, data are collected at all sites in the same way and during the week or season. The week of the third Tuesday every month, BEMP collects data at: five groundwater wells, ten litterfall tubs, and two precipitation gauges. The first week of May, fourth week of June and fourth week of September, they collect pitfall traps/surface active arthropods. Additional datasets are collected as determined by funding. These are some examples:

Every Monday: river quality monitoring and E. coli collections in partnership with the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) mid-Rio Grande Stormwater Quality team and Middle Rio Grande Conservancy District (MRGCD) each winter: woody debris

Three times a year: (around high river flow, after high flow and first week of November for base flow): groundwater, ditch and river chemistry

Seasonally: frequency determined by funding: ditch chemistry and E. coli”

Github

BEMP data is publicly available to any interested user. To request current raw data, data analysis, and/or effects of land management strategies at various BEMP sites, an interested party can contact BEMP’s Data Manager. That contact is available on the organization’s website on the Science page. All available data for download has recently moved, in 2023, from the BEMP main page to the organization’s GitHub page

(https://github.com/BEMPscience/bemp_data). All available data is downloadable through the GitHub, which allows BEMP to keep track of downloads. Data entry and the Github page are managed by BEMP staff.

Getting Involved

Those interested in getting involved with BEMP, supporting their activities, or learning more about the organization or the data can go to the ‘contact us’ link on the website and reach out through the portal there.

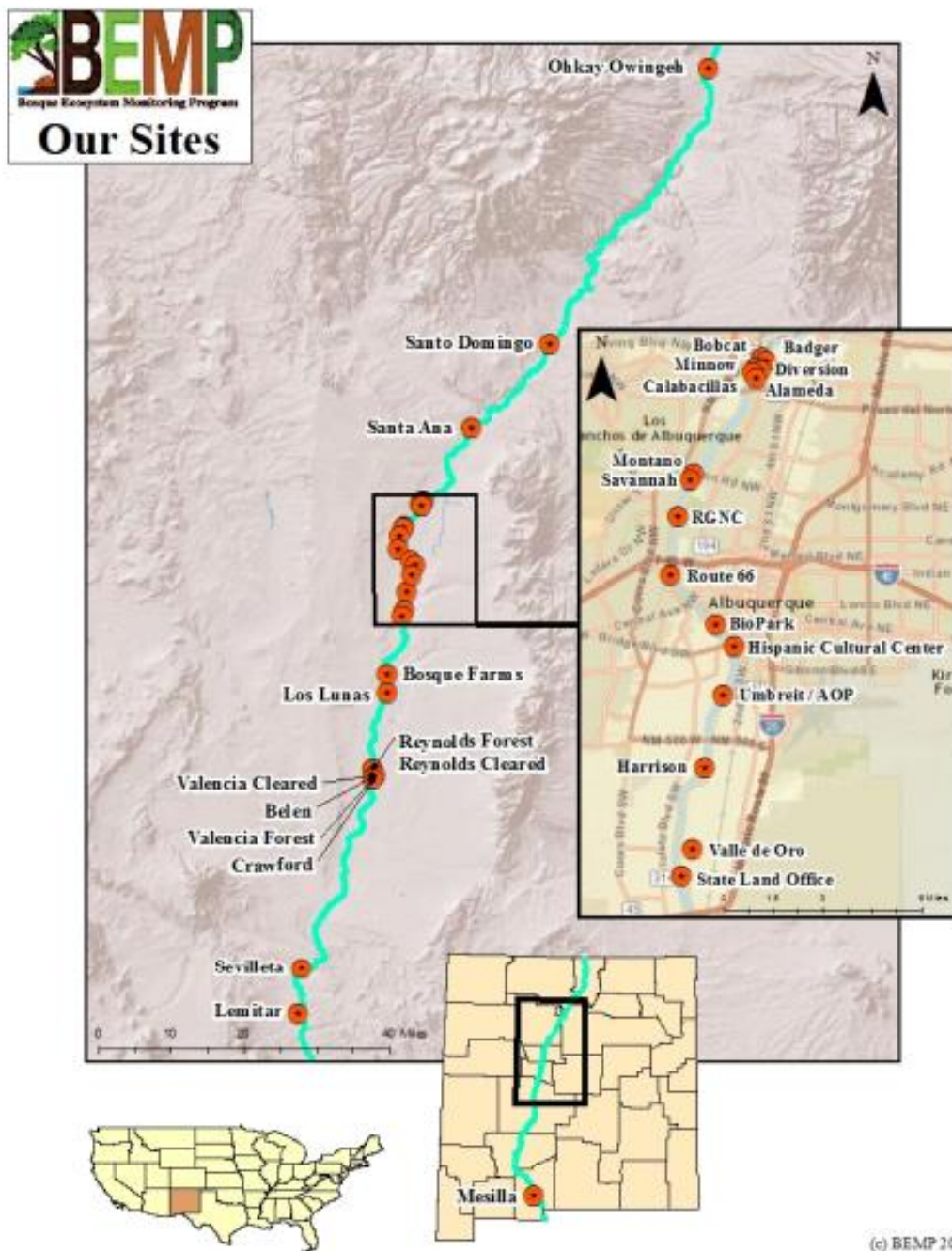


Figure 1: Extent of BEMP's data collection reach including 30 permanent monitoring sites in the Middle Rio Grande Valley in New Mexico, across approximately 300 miles of Rio Grande from Ohkay Owingeh Pueblo to Mesilla Valley Bosque State Park in Las Cruces. Albuquerque, the most populous city in New Mexico, houses sixteen sites.

III. Study Area

The MRG riparian forest, or bosque, represents the largest cottonwood gallery in the southwestern United States. The MRG extends from Cochiti Dam, north of Albuquerque, downstream 162 miles to San Marcial, New Mexico. The Rio Grande is regulated for water supply (primarily irrigation) and flood control. The system reflects a flood-regulated and hydrologically departed riparian ecosystem (Carton et al., 2008; Crawford et al., 1993). Historical channel modifications have shaped the hydrology of this ecosystem. Legacy flood control engineering developments were implemented originally to meet historic irrigation, flood, and sediment control objectives. For more information about historical channel modifications see Appendix I. The extent of the operating area for BEMP and the extent of the study area for this research is the MRG bosque ecosystem, as defined above.

Water is a scarce resource in the arid Southwest, with riparian ecosystems making up only about two percent of landscapes (Cartron et al., 2008). Riparian ecosystems contain immense biological diversity (Cartron et al., 2008). According to the World Wildlife Fund, the most endangered river system in the North American continent and one of the World's top 10 rivers at risk, is the Rio Grande, which even in its impaired state is still globally important for freshwater biodiversity (Karatayev et al., 2012). The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) website states that today 70% of municipal drinking water is sourced from the Rio Grande. Approximately 40% of the state's population lives within the study area. The MRG population is projected to grow by 50 percent by 2040 (Metropolitan Transportation Board, 2015).

A. Overarching Water Resource Administration

This definition of New Mexico water resource administration from the BBMP (1993) is still relevant today and is provided here for context to the EM framework of the study area:

There are many institutional and individual interests involved in the management of Rio Grande water, not only within the middle valley but also upstream and downstream. Water in New Mexico is managed under state law as administered by the New Mexico State Engineer, and under federal and international law. Because the Rio Grande is an interstate and international resource, mechanisms for allocating its waters were determined to be necessary. A treaty between the United States and the Republic of Mexico was signed in 1906 which guarantees a minimum annual delivery of water to Mexico. In 1939, 10 years after ratification of an interim agreement, the federal government, Colorado, New Mexico, and Texas ratified the Rio Grande Compact, which allocates water between the three states. In addition to the New Mexico State Office of the State Engineer, other principal water management entities active in the study area include but are not limited to: MRGCD (irrigation water delivery), Bureau of Reclamation (water delivery), Army Corps of Engineers (flood control), Rio Grande Compact Commission, and the International Boundary Water Commission. Obviously, those individuals and entities holding the rights to use water (pueblos, City of Albuquerque and other municipalities, wildlife refuges, etc.) are also critical participants in the Middle Rio Grande Valley water management community and the larger citizenry, represented by various interest groups, is becoming increasingly involved in water management decisions.

So, in short, water resource management is complex in this study area. River management became more complicated in 1994 with the listing of the endangered Rio Grande silvery minnow, fundamentally shifting the focus of EM in the study area. Just recently in the summer of 2022, a 5-mile stretch of the Rio Grande in Albuquerque ran dry for the first time in 40 years (Pratt, 2022). Downstream near Los Lunas, twelve miles of the river ran dry, and thirty-two miles in Socorro County had also dried up (Pratt, 2022). Drought conditions in the study area have triggered a lawsuit from the WildEarth Guardians regarding the management of the river

and the minnow. On November 30, 2022, the WildEarth Guardians issued the following press release (Timmons, 2022) related to the lawsuit:

In November 2022, the WildEarth Guardians filed a lawsuit seeking to hold federal agencies accountable for the continued decline of imperiled species in the Middle Rio Grande, including the endangered Rio Grande silvery minnow. The lawsuit was filed in the federal District of New Mexico, alleging that the Bureau of Reclamation and the U.S. Fish and Wildlife Service are in violation of the Endangered Species Act and seeks a court order compelling the federal agencies to reassess the effects of water management activities on threatened and endangered species along the Rio Grande. If successful, the lawsuit would require federal agencies to develop enforceable measures to ensure that dams and diversions in the Middle Rio Grande do not jeopardize the survival or recovery of imperiled species.

The complexity in water administration in the study area cannot be understated. It is important for readers to have an approximate understanding for water administration complexity because BEMP operates within this context and framework, and it might explain why it has been challenging to follow through with an agenda to achieve comprehensive EM goals for this study area.

B. Middle Rio Grande Conservancy District

This summary of the Middle Rio Grande Conservancy District (MRGCD) was sourced from its website and from the Middle Rio Grande Conservation Action Plan (MRG-CAP) (Muldavin et al., 2015). More detail is provided about the MRG-CAP in the EM chapter. The MRG-CAP states that MRGCD oversees management of about 30,000 acres of bosque and 1,200 miles of waterways and conveyance channels (a complex system of irrigation canals) that deliver irrigation water to approximately 60,000 acres of farmland outside the riparian corridor. The agricultural areas are intermixed with growing urban areas that include

Albuquerque and the Rio communities with a population approaching a million people. The MRGCD operationally divides the MRG into four divisions from north to south corresponding to each of the major irrigation diversions: Cochiti, Albuquerque, Belen, and Socorro (see Figure 2 for map). Most MRGCD-managed riparian lands are in the Albuquerque, Belen, and Socorro Divisions. Reach one, Cochiti Division, is primarily in Pueblo ownership. District divisions not only reflect where MRGCD diverts and manages its water; they also correspond roughly to sub-reaches with differing channel and floodplain characteristics and tend to have differing trends in hydrological conditions. The sub-reaches may also reflect different ecological characteristics, and as necessary, these differences are specified in the MRG-CAP.

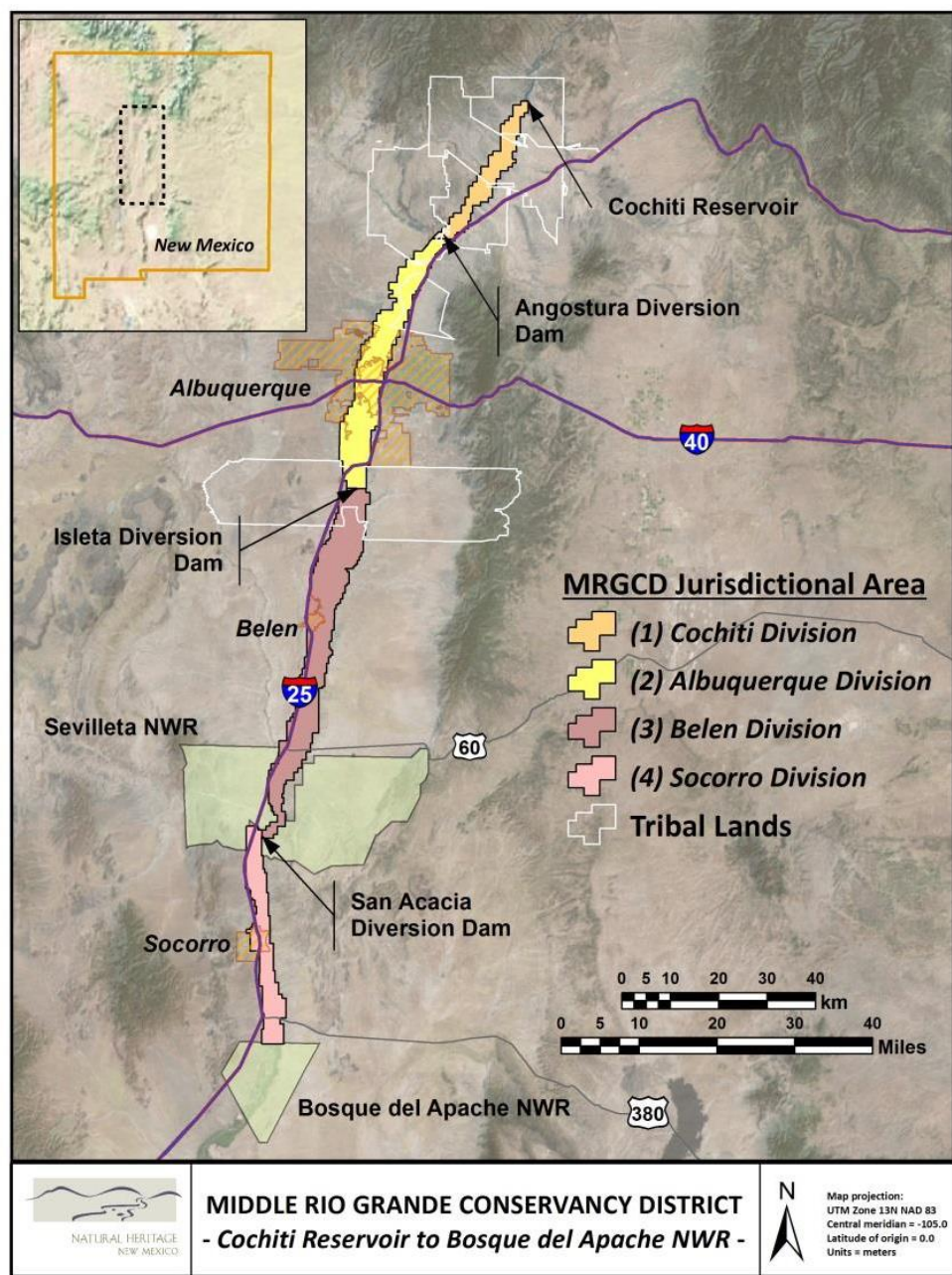


Figure 2: Middle Rio Grande Conservancy District extent map (Muldivin et al., 2015)

C. Historical Rio Grande Stream Flows

Historical USGS streamflow graphs provide data trends of historic stream channel flows and flood regimes. The USGS Otowi stream gage, is located twenty miles upstream of Cochiti Dam, feeding into the study area. The Otowi flow graph records ‘total annual flow’ from 1900

to 1990, in acre feet per year and confirms a significant flood event around 1941, which is considered the timeframe when most of the monoculture cottonwood gallery was established (see Figure 3). The USGS San Felipe gage, is located twenty miles downstream from Cochiti Dam. The San Felipe graph reflects the ‘annual peak streamflow’ from 1928 to 2012 in cubic feet per second (see Figure 4). Circled on the San Felipe graph are potential overbank-flooding events in the 1940s reflecting that same flood event in Figure 3 (Crawford et al., 1993; Howe, 1991). The red line in Figure 4 reflects the completion of Cochiti Dam, where thereafter the annual peak flow does not exceed 10,000 cfs.

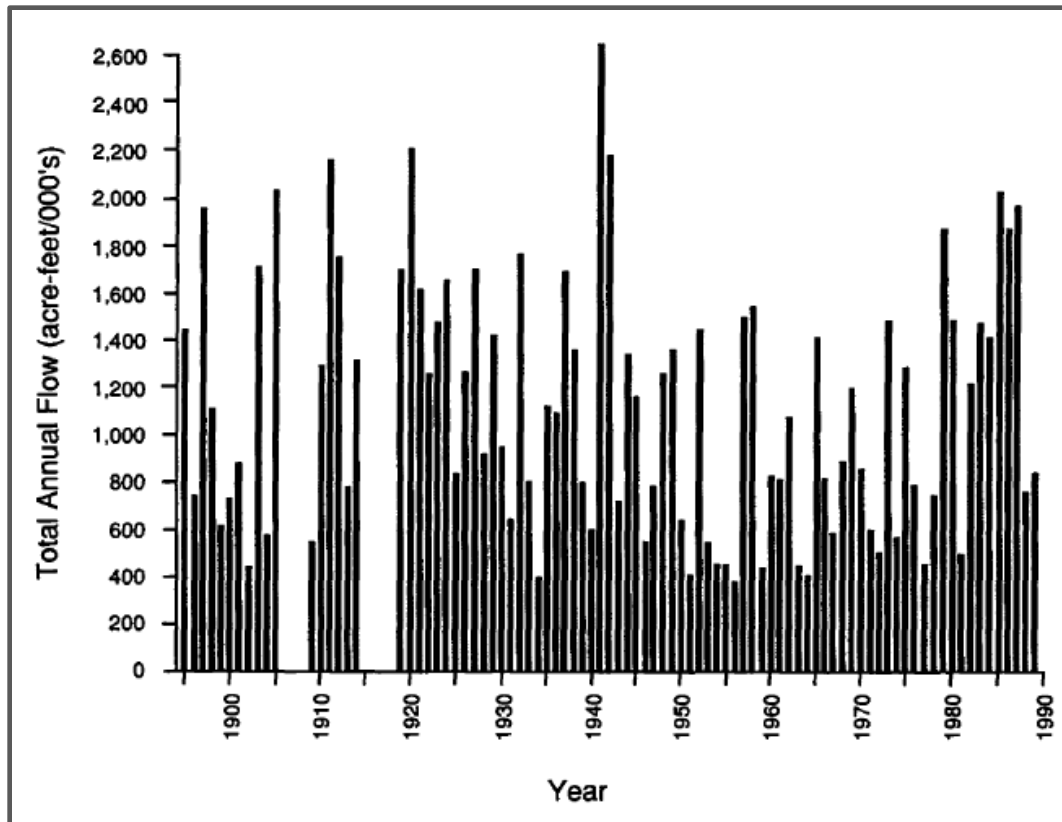


Figure 3: Total annual stream flow for the Rio Grande upstream from Cochiti Dam at the Otowi Bridge USGS stream gage from 1900 to 1990. Stream flow units are in acre feet. Source: 1993 BBMP (Crawford et al., 1993).

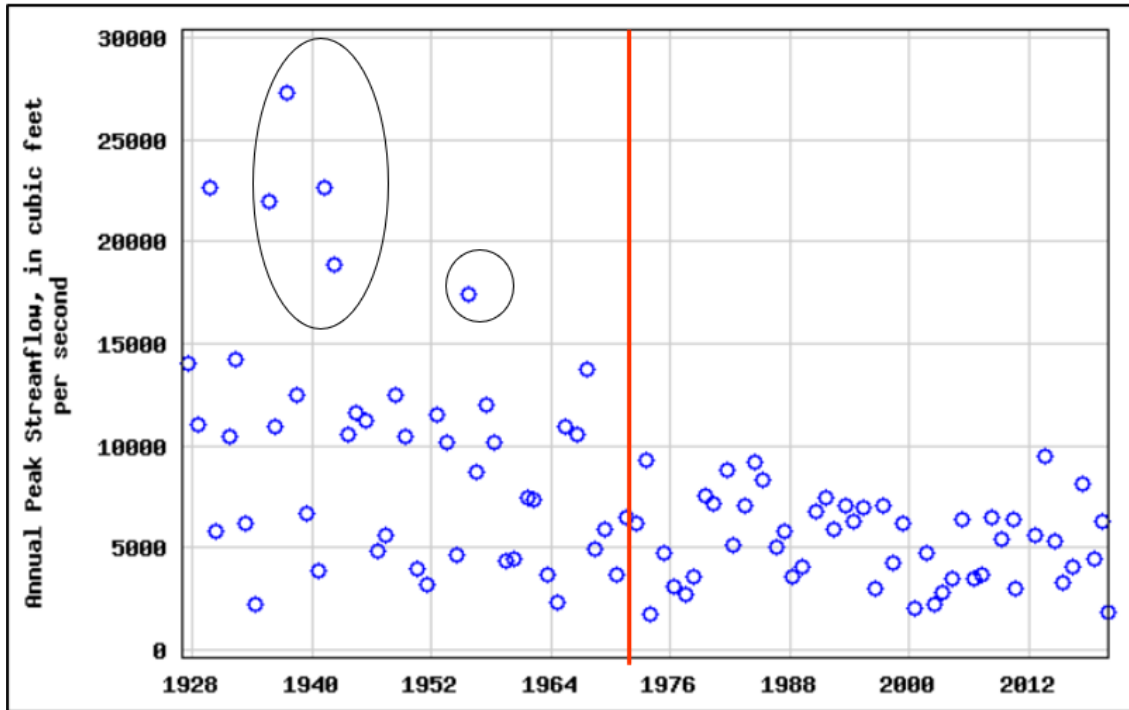


Figure 4: Rio Grande annual peak streamflow at San Felipe gauge. Streamflow measured in cubic feet per second (cfs). The red line reflects the completion of Cochiti Dam in 1973. Courtesy of the U.S. Geological Survey

D. Changing Climate

Gutzler (2020) provides a summary here of projected changes for New Mexico’s climate over the next half-century. See Appendix F for more information about climate trends for New Mexico.

“Consider that a downward trend in streamflow, with continued large natural variability, makes drought periods more severe. I do not expect New Mexico to dry up due just to a slow decline in streamflow as the climate warms. Instead, I am concerned that future drought periods, whenever they occur in the decades to come, will be hotter and drier than droughts of the past. Increased severity of multi-year droughts poses a major risk for humanity and ecosystems in New Mexico.”

E. Bosque Ecosystem Services

A changing climate and its effects on ecosystem services across the Southwest will have broad impacts, but not all individuals and communities will be equally impacted

(Borchers, 2021). For readers concerned about socioeconomic risks and vulnerabilities due to changes in our ecology in this region, a regional assessment from the USDA is available to the public, *Socioeconomic Vulnerability to Ecological Changes in the Southwest: An All-Lands Assessment* (Borchers et al., 2021). The report extends existing vulnerability reporting focused on national forests, to all lands, regardless of ownership in Arizona and New Mexico. The assessment of vulnerability identifies communities and geographic areas where climate-change-driven ecological changes have the potential to adversely affect human well-being due to changes in the provision of ecosystem services. See Appendix J for a list of ecosystem goods/services and how they may be affected.

V. Ecosystem Management

Ecosystem management is the preferred approach to managing natural resources and defined as “the application of ecological and social information, options, and constraints to achieve desired social benefits within a defined geographic area and over a specified period” (Lackey, 1998). Lackey suggests that there is no ‘right decision’ in EM, but rather ‘decisions that seem to best respond to the current and future needs of society, as determined through a decision-making process.’ Lackey insists that while there are not exactly ‘right decisions’ in EM there are wrong ones and that includes a decision not to act. Of course, there are instances in EM where taking no action can be the right thing to do as well. EM projects exist across the study area administered by various entities with varying objectives, scopes, scales, and levels of planning. This research finds that an updated comprehensive EM plan for the study area does not exist and that there is no agenda associated with the existing plans.

Lackey identifies seven pillars of EM as follows:

- (1) EM reflects a stage in the continuing evolution of social values and priorities; it is neither a beginning nor an end.
- (2) EM is place-based, and the boundaries of the place must be clearly and formally defined.
- (3) EM should maintain ecosystems in the appropriate condition to achieve desired social benefits.
- (4) EM should take advantage of the ability of ecosystems to respond to a variety of stressors, natural and man-made, but all ecosystems have limited ability to accommodate stressors and maintain a desired state.
- (5) EM may or may not result in emphasis on biological diversity.
- (6) The term *sustainability*, if used at all in EM, should be clearly defined—specifically, the time frame of concern, the benefits and costs of concern, and the relative priority of the benefits and costs.
- (7) Scientific information is important for effective EM but is only one element in a decision-making process that is fundamentally one of public and private choice.

Existing EM Plans for the Study Area

A. Bosque Biological Management Plan (BBMP) (1993, 2005)

The most relevant and comprehensive EM plan referenced by managers for the study area is the BBMP (Crawford et al., 1993). The document turned thirty years old this year and was originally authored by the MRG Biological Interagency Team consisting of Clifford S. Crawford, University of New Mexico (lead); Anne C. Cully, U.S. Fish & Wildlife Service; Rob Leutheuser, U.S. Bureau of Reclamation; Mark S. Sifuentes, Army Corps; and James E. Knight, New Mexico State University. An update was published in 2005 by Lisa Robert with Rio Grande Restoration, and in cooperation with the MRG Bosque Initiative and the Bosque Improvement Group. Selected excerpts from the BBMP on bosque ecology, hydrologic regime, ESA habitat, and trends can be found in Appendix G. Information about the 2005

BBMP update can be found in Appendix H. This plan is the primary comprehensive plan that interviewees referenced and reflects the shared goals of primary ecosystem administrators in the study area. While the document is thirty years old, many of the recommendations have yet to be fulfilled (see those recommendations in Appendix E).

B. Middle Rio Grande - Conservation Action Plan (MRG-CAP) (2015, 2019)

While the BBMP is referenced heavily as a primary EM resource for managers in the study area, it is not updated. A recent comprehensive ecosystem assessment was published in 2015 led by MRGCD titled, *Middle Rio Grande-Conservation Action Plan* (MRG-CAP) (Muldavin et al., 2015). The framework and status assessment were the focus of the initial document. An update was published in 2019 (Muldavin et al., 2019). The overall goal of the planning process is “to provide a foundation for developing strategies that can be applied to meet conservation goals in collaboration with the MRGCD’s many partners and stakeholders.” The first steps of the planning process were intended to 1) develop an ecologically based framework for stewardship, 2) identify conservation targets, and 3) provide an initial assessment of the targets’ present and desirable future status based on measurable indicators. Additionally, major threats or stressors to the conservation targets were identified and evaluated with respect to the severity of their potential impacts.

The MRG-CAP provides valuable new data and ratings for the ecosystem. The plan assesses thirty-six individual indicators, which are rated from poor to very good. The overall system is rated as follows: 60% of indicators rating at fair; 15% as poor, and 20% as good or very good. The overall current conditions in 2015 were rated as fair with a desired condition of good as a target for the coming ten years. Downward trends are mostly rated as mild, suggesting strategies can be developed that can lead to further improvement and achieving a

good rating over the next decade. While the plan rates the overall system as fair, it also states that “the identified threats and their potential impacts indicate that the ecosystem as a whole is imperiled.” It is not clear how the system can be fair and imperiled at the same time.

The cottonwood age class rating is a red flag regarding overall ecosystem health (see table in Appendix K). The rating for this indicator was poor, with 90% of cottonwood stands rated as mature or old. The rating includes trends for this indicator towards a strong decline. That means a regenerating rate of only about 10% of total forest density (see Appendix K). The future projection for cottonwood age class still receives a good rating, which is confusing considering that most of the trees will die over the next couple of decades (Appendix L). A new series of comprehensive canopy density maps of the study area developed for this research by New Mexico Forest and Watershed Restoration Institute (NMFWR) and available in Appendix D.

VI. Methods

As described in the Introduction section, the purpose of this research is to explore the role of CS in EM in the study area by interviewing environmental managers who use BEMP data. Interview questions were crafted in a way to 1) develop understanding of the role that CS is playing in the EM framework in the study area, 2) improve understanding of how efficient BEMP’s long term ecological monitoring CS data are at meeting the needs of managers, and 3) reflect on EM challenges and how CS supports managers in meeting those challenges. Primary data came from six semi-structured in-depth interviews with ecosystem managers representing all known entities in the study area that utilize BEMP’s long term ecological monitoring data. An interview was also conducted with BEMP. Interviews were conducted to

hear from EM managers who are known (by BEMP) to utilize BEMP's CS data to inform their management decisions. Interviewees were asked to reflect on the significance of BEMP data in their work and the role that BEMP plays in the EM framework. Interviewees were also asked to identify their greatest EM challenges to help understand the significance of CS data in supporting managers in facing those challenges.

A. Interviewee Recruitment

A list of all known BEMP data users was provided by BEMP. The list included representatives from five natural resource management agencies and a nonprofit organization operating in the study area including: the City of Albuquerque Open Spaces (CABQ), US Fish and Wildlife Service (USFWS), Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA), Save our Bosque Taskforce (SOBT), Army Corps of Engineers (Corps), and the Bureau of Reclamation (BOR). BEMP personnel were also included in interviews. All individuals on the list provided by BEMP responded and participated, except MRGCD because the district said it does not use BEMP data itself. All interviewees are existing or past funding partners of BEMP, except the SOBT, which is a nonprofit operating in the San Acacia reach of the study area. A brief description of each of the organizations interviewed can be found in Appendix B. It is important to make the distinction here that this small list of interviewees does not reflect the entire body of ecosystem managers operating in the study area. It is also relevant to reflect again on the complexity of the administration of this ecosystem and how many interests and authorities influence natural resource outcomes in the study area. The agencies represented by interviewees are a few of the most influential authorities to ecosystem outcomes in the study area. The self-selection bias is acknowledged in this research due to the only interviewees chosen are those who are already known to utilize BEMP data.

B. Interview Timing and Venue

Interviewees were initially contacted via email and/or telephone. The questionnaire was provided in advance of interviews. This report only references the agency when reporting results or quoting rather than reporting individual interviewee names. Interviews were conducted online through zoom, over the phone, or received as a written response. Each live interview was recorded and lasted between 45 minutes to an hour.

C. Questionnaire

The original interview questionnaire is in Appendix A. The original questionnaire included some questions that produced data that, although analyzed, were not found relevant to understanding the research question and were not included in the results. A separate set of questions was developed for the interview with BEMP with a focus on confirming what was learned from interviews with managers. The questionnaire for BEMP is also in Appendix A. The questions that produced the most relevant data to inform the research question were these:

Interview Questionnaire

1. Which specific BEMP datasets did you utilize most?
2. What was the goal or intended use for the data?
3. Have you utilized BEMP long term ecological monitoring data in your academic publications or management plans?
4. Was the data effective in achieving the intended goal (sufficient in extent and quality)?
5. Are there any BEMP datasets that do not exist that you wish were available?
6. Does your organization support BEMP, either through funding or by providing in-kind support (staff, access, equipment, mentoring, advisors)?

7. Do you have any additional comments regarding your experience accessing or applying BEMP data or working with BEMP as a partner?
8. What are your main concerns and challenges regarding EM in the study area?

D. Data Analysis

Prior sections that discuss the study area and EM information and plans, provide context to the challenges that ecosystem managers are experiencing in achieving favorable outcomes in the bosque ecosystem regardless of the availability or utilization of CS data. Information about the planning framework and ecology of the study area also places CS within the larger framework of ecology and EM.

The interviews produced qualitative data. The recorded interviews were transcribed digitally using Otter software. The transcripts were coded by hand into a singular theme revolving around data priorities; data applications; significance of BEMP as a data source; and challenges to EM. Results were organized into sections: 1) data priorities, 2) data applications and significance, and 3) EM challenges.

VII. Results and Discussion

Several interviewees referenced experience in prior roles where they partnered with BEMP. For example, one interviewee working for an environmental consulting firm does not utilize BEMP data as a consultant, but rather referenced over a decade of experience working with BEMP while employed at the Corps. The interviewee speaking on prior experience at USFWS, spent multiple decades working on the river in the MRG, but has since retired from that role and in now 2023 is supporting an environmental NGO in the study area. Responses

from the Corps came from two individuals who had both worked there previously and now one is working in the private sector. Two interviewees had extensive timelines working at the Corps, so the data from the Corps are more robust. The interviewee representing the BOR with prior experience at the Corps, stated that the BOR utilizes BEMP data in much the same way as the Corps. Table 1 below organizes key interview details regarding the interview venue, funding partner status, and approximate number of years of experience working with BEMP. The column regarding the funding partner status is related to whether the organization has ever been a funding partner in the past.

Table 1. Interviewee Experience, Interview Venue, Funding Partner Status			
Interviewee	Years with BEMP	Interview venue	BEMP funding partner?
Army Corps	20+	Zoom	Y
BOR/Army Corps	20+	Zoom	Y
CABQ Open Spaces	5+	Phone	Y
U.S. Fish & Wildlife	20+	Zoom	Y
AMAFCA	10	Zoom	Y
SOBT	5+	Email	N
BEMP	27	Zoom	N/A

A. Data Priorities

Ecosystem managers utilize various kinds of long-term ecological monitoring data to meet their management purposes. The Corps/BOR and SOBT utilize BEMP data most extensively. Stream flow data are usually sourced from the U.S. Geological Survey (USGS) national surface water database. USGS also offers national vegetation and land cover data. The Natural Resource Conservation Service (NRCS) provides national soil maps and data. USGS

and Audubon provide national bird survey data. BEMP data provides local managers with a variety of monthly monitored data types specific to the study area, filling in data gaps when managers really need to see recent trends.

When interviewees were asked about their primary BEMP data interests, the primary data types of interest were depth to groundwater and vegetation. Certain managers were narrower in their data interests, like AMAFCA, who is only interested in water quality related data. The only agency that mentioned interest in the historical fuel load data was CABQ, which they used in the past, when it was available, to inform fuel load reduction projects to reduce wildfire risk. See the table below for the details of which BEMP monthly monitoring datasets are being utilized by interviewees (Table 2).

Table 2. Interviewee BEMP Data Priorities						
	Corps	BOR	CABQ	USFWS	AMAFCA	SOBT
Depth To Groundwater	X	X	X	X		X
Precipitation	X	X				X
Litterfall	X	X				X
Arthropods	X	X				X
Vegetation	X	X	X	X		X
Water Chemistry and Water Quality	X	X			X	X
Tamarisk Leaf Beetle	X	X				X
Temperature	X	X			X	X
Woody Debris (Historical)	X	X	X			X

i. Data Requests

Interviewees had three primary data requests for BEMP that they thought might be within the organization's capacity. Interviewees acknowledge that BEMP is likely already operating at capacity, but expansion of the primary data interests of depth to groundwater and vegetation are of interest. Introduction of soil data would also really support managers in implementing revegetation projects, but those data are not currently part of the BEMP data palette. One interviewee said that the national soil survey data that they utilize is a bit dated, which makes it less relevant to managers when planning and implementing restoration projects on the ground and in real time.

B. Data Applications and Significance

Army Corps and BOR

The most common response to the broader question of why interviewees access BEMP data was related to bosque restoration project management or planning. The Corps/BOR said BEMP data are utilized for all their restoration projects in the bosque, many of which are large scale. All BEMP datasets inform baseline data for new Corps/BOR projects and provide a data source for the various project phases, i.e., planning, construction, and post-construction monitoring. Corps/BOR said that BEMP data goes into agency planning/management documents like environmental assessments and feasibility studies, which inform managers about what is possible in terms of realistic project goals.

The largest Corps project in the study area that utilized BEMP data was one thousand acres in total and spanned the whole reach of the bosque in Albuquerque. There were two smaller projects in the bosque in and around Central Ave. The Tingley Beach ponds and bosque wetlands were also a Corps project that utilized BEMP data. BEMP data also plays a significant role in post project assessments in determining the overall success of intended project goals. Both Corps/BOR interviewees reflected that the data played a huge role in their decision-making process and that the data does meet quality standards and is very useful. They also both acknowledged the powerful policy role BEMP plays through public education and outreach in the study area.

SOBT and CABQ

The SOBT used BEMP's monitoring protocol to develop their own monitoring protocol in the San Acacia reach. BEMP protocol was utilized because the San Acacia Reach

required consistent monitoring protocol between bosque monitoring programs. This reach of the bosque is particularly challenged with wildfire management issues and illegal dumping. The SOBT also uses BEMP reports and datasets when designing large-scale plans for future restoration in the San Acacia reach and for specific restoration projects.

The CABQ interviewee discussed challenges around forestry management goals regarding where to prioritize efforts between wildfire mitigation work and revegetation/restoration work. CABQ has a limited staff to oversee the 4,000 acres of bosque that it manages, so staff time and budgets can only tackle so many objectives at once. BEMP data are meaningful to CABQ because it relieves management challenges associated with obtaining meaningful data that supports ongoing management objectives.

AMAFCA and USFWS

AMAFCA is only interested in the *E. coli* and Field Water Quality dataset. The interviewee from AMAFCA said BEMP data was utilized in a publication, *Riverbed Sediments Control the Spatiotemporal Variability of E. coli in a Highly Managed, Arid River* (Fluke et al. 2019). BEMP data was not explicitly cited in the paper though. AMAFCA utilized the paper to support their hypothesis that *E. coli* levels in the study area were due to natural processes, not storm water, influencing water quality standards for the MRG. This interviewee also mentioned that UNM graduate students have published papers that utilized BEMP data in efforts to better understand the surface water - groundwater interactions in the hyporheic zone of the bosque (Heller, 2018; Rodriguez, 2021).

The interviewee representing USFWS reflected on the importance of BEMP's vegetation datasets and groundwater level datasets in informing all revegetation projects in the

bosque, saying that the importance of visualizing data trends over time is critical to agency restoration work. The USFWS interviewee also mentioned that in the southern reaches of the river the groundwater levels fluctuate quite a bit, and BEMP data are particularly helpful in those areas.

BEMP

The interview with BEMP explored the same question about the significance of their organization and data in the EM framework of the study area. BEMP affirmed that their primary purpose is to provide long term ecological monitoring and public outreach and education in the MRG bosque ecosystem, which the organization proves through their robust program activities and data utilization by public agencies involved in EM in the study area. BEMP provides a scientific community focused on understanding the bosque ecosystem, with opportunities for all ages to volunteer in data collection and processing. BEMP has also started to identify more with the role of stewardship (beyond data collection and public education), as described by BEMP during the interview:

“By involving students in ecosystem monitoring and having them outdoors in their local environment and invested in understanding the science, we are beginning to identify more with a third role of stewardship.”

C. Ecosystem Management Challenges

AMAFCA focuses primarily on water quality management. The interviewee said that the MRG has had consistent or persistent violations of two or three water quality parameters in recent years, transient violations of dissolved oxygen and temperature, and fairly frequent violations of the *E. coli* standard. When asked if they think that the cottonwood population

decline is a challenge for water quality, they said they do not think it has any impact on the water quality but mentioned that around 20% of water in the Rio Grande is lost to ET by the cottonwood forest. They said that the variability and rapid changes in water resources are a primary challenge for water quality management in the area. One of the interviewees representing the Corps summarized the dynamic of this heavily managed ecosystem engineered for flood control necessitating more/further management efforts that account for existing and forthcoming water demands (of humans and ecologies). All interviewee responses regarding various EM challenges seem to be echoed within this quote from one of the Corps interviewees:

“The bosque evolved with flood as the major disturbance regime. Without that it is taking on a whole new life. Sadly, it seems like now (2023) fire has taken over as the primary disturbance regime. That is not something that the current bosque bounces back from without a lot of help. When you have drought in such a managed system, you must manage even more. That is going to be one of the greatest challenges – for anybody to do restoration projects, to have them be self-sustaining, but I do not think that is a completely realistic picture in such a heavily managed system, with such intense climate issues.”

The interviewee with an almost thirty-year career with the USFWS, discussed how there was more comprehensive EM planning leading up to the 1990's with the Bosque Initiative and Cliff Crawford's efforts with the BBMP. They felt that after the silvery minnow was listed as endangered that really reshaped how money, time and efforts would be directed; legalistically driving EM efforts in the study area after that point with too much primary focus on the minnow and not enough on whole system improvements. According to the interviewee, “It's the kind of system that must be managed, because you don't have big floods anymore.”

All interviewees seemed to express some challenge with balancing various management goals and activities like recreation and restoration, or whether to spend money on

restoration or mitigation. Responses to the question of EM challenges generally suggested a sense of discontinuity across management agencies creating a gray area between partners about what is really happening across the ecosystem and what is plausible for EM goals, in terms of restoration or just understanding future potentials for bosque species composition, density, and health. One interviewee from the CABQ mentioned the challenge of the dynamic of public driven versus science driven EM actions, i.e., what is mandated versus what is logical or ethical. CABQ also has limited staff to manage a large, forested area of several thousand acres of bosque, so staff and funding are challenges as well. The SOBT originally formed to address concerns about degradation of the ecosystem along the San Acacia Reach due to dumping of trash, off-road vehicle use, illegal fuelwood cutting, and wildfire. These are still concerns of the organization for this reach of the river.

BEMP is concerned about already overallocated water resources in this arid climate, dwindling water resources, and increased fire risk and management challenges in the bosque. BEMP is also concerned about inconsistent sense of urgency across diverse groups and individuals involved in bosque ecosystem outcomes, perhaps coming from “a disparity in understanding or lack of strong dialogues between scientists, managers, owners and policy/decisionmakers.” Securing long-term funding for BEMP has also been a challenge. Initially funded by the National Science Foundation (NSF), BEMP has continued to receive various sources of federal grant support. BEMP is primarily funded by federal grants in 2023. Cuts from NSF and Corps funding during the Trump administration have been impactful. BEMP is working on diversifying funding opportunities.

VIII. Conclusions

The CS literature presents uncertainty about the use of CS data by government agencies in general, and specifically in the study area of this research. The literature also describes uncertainties about perceived confidence in the quality of CS data for use by government agencies. Responses from interviewees in this study suggest that government agencies find CS data provided by BEMP to be a critical resource when conducting restoration work throughout the study area and meeting their data quality and assurance requirements. Results suggest that CS data are being used to inform environmental assessments, baseline project assessments, feasibility studies, planning, monitoring, and was even used in a publication that supported agency assertions regarding the cause of a particular water quality problem in the study area (Fluke et al., 2019). The primary role that BEMP plays in EM in the study area appears to be the utility role of data production, informing ecosystem managers of existing and trending ecological conditions throughout the study area. All interviewees suggested that the role BEMP plays in public education and outreach is also equally important to its utility role. BEMP is also beginning to identify more with the role of stewardship; a subtle distinction of the role of public education producing similar nuanced impacts on overall EM outcomes.

The research suggests that BEMP continues to be a critical data resource for managers to make the best-informed decisions in this hydrologically engineered and highly variable ecology. Climate change brings increases in surface temperatures and evaporation/evapotranspiration and decreases in snowpack in the winter, yielding less spring runoff for the river. EM challenges mentioned by interviewees are related to a disconnected floodplain; cottonwood decline-related issues; wildfire mitigation; nonnative species dynamics; endangered species; data shortages; variability in stream flow; and lack of agenda-

driven comprehensive planning. The role and relevance of CS data in EM is guided by the EM framework, which research suggests has fundamental challenges requiring additional leadership.

The monoculture stand of cottonwood forest across the study area is quickly approaching a sharp decline with 90% of trees in the ‘mature’ age class in 2015 (Muldavin et al., 2015). Upon review of all EM plans it is still unclear the extent, in acres, that the bosque ecosystem encompasses today. The MRG-CAP says MRGCD manages “some 30,000 acres of bosque”, but the table from the BBMP (1993) records indicate the bosque extent was approximately 20,000 acres in 1990. The MRG-CAP (2015) assessment does not map out or report on the extent in acres of the bosque. The research suggests that fundamental problems in comprehensive EM and planning limit the relevance and role of CS data, or any data, in addressing ongoing EM challenges.

Most interviewees discussed a need for better future planning for restoration projects, to better assure self-sustaining projects in terms of water. This is impossible without good data, which BEMP plays a critical role in providing for managers. Three interviewees mentioned that cottonwood may not be the resilient species in the bosque in the future, so making consensus decisions about what species of trees to plant in restoration projects would be much better guided by good data and comprehensive planning.

Cultivating a more resilient ecosystem in the MRG is an effort that interviewees and many others have been working on for decades. Regardless of foundational management and planning challenges inherent to the ecosystem, BEMP, as a CS program and data source, does provide critical understanding to managers and the public about their changing ecosystem. BEMP provides long-term data that allows managers to see trends for different variables in the

system that make it possible for them to make the best-informed decisions while contending with so many EM challenges. This research acknowledges that BEMP holds a unique position politically in the EM framework, as it is connected to the bosque through science and education and through data production and resource managers. Climate change and the cottonwood decline are larger contextual challenges that managers have no control over. A shift in the management framework that reflects a sense of urgency and sets an agenda to achieve consensus priorities is something that managers and administrators should consider, to improve the efficiency in EM activities and guide CS data collection priorities.

IX. Recommendations

The study results suggest future work for BEMP. Like one interviewee said “BEMP is a great organization that is probably operating at maximum capacity and efficiency.” Based on interview findings, this seems to be the case. Interviewees reflected strong confidence in the quality of data that BEMP produces. BEMP is also seen as a strong partner by interviewees. One important recommendation to consider has to do with finding a meaningful way to educate and inform the public about the forest shift that is unfolding and what that means for future bosque ecologies. The role of stewardship that BEMP is starting to identify should mean instigation of more dynamic dialogue about what the data and literature says, particularly considering cottonwood dynamics. Based on interviewee feedback, BEMP could consider expanding data collection sites for depth to ground water and adding a category of soil profile data collection to future activities, if possible.

The findings of this study lead to several recommendations that warrant consideration by the state of New Mexico. The study area is lacking consensus priorities through comprehensive

planning. The BBMP is 30 years old and lacks a clear agenda for achieving comprehensive management objectives. The MRG-CAP is still in the early planning stages and also lacks a clear agenda for achieving desired comprehensive management objectives. Research suggests that additional leadership may be necessary to implement a comprehensive management plan with an agenda. The monoculture cottonwood forest is quickly approaching expiration, with only about 10% of cottonwood trees regenerating and the maturation date approaching in coming decades. The bosque is an important public resource that does not have a clear agenda. A clear agenda to the public regarding this resource would be helpful. Consider different approaches to addressing this imbalance. The MRG is no longer a flood-prone zone and management concerns are shifting towards those related to deforestation and wildfire. The mission of organizations in the study area like MRGCD and AMAFCA with missions associated more closely with management challenges of the past should be reconsidered by the appropriate authority. In the development of comprehensive planning with an associated agenda, remember the unique networking position that BEMP holds in the EM framework, as BEMP could offer leadership in more than one area of planning and management efforts.

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Appendix A : Interview Questionnaires

ORIGINAL INTERVIEW QUESTIONS

1. Does your employer/organization utilize BEMP (Bosque Ecosystem Monitoring Program) ecological monitoring data to inform policy or management decisions impacting the management of the bosque ecosystem?
2. Does your employer utilize any other citizen science data to inform policy or management decisions that impact the bosque ecosystem?
3. Have you utilized BEMP ecological monitoring data in your academic publications?
4. How does your entity access BEMP data?
5. Which specific BEMP datasets were used?
6. What was the goal or intended use for the data?
7. Was data analysis and interpretation necessary before utilizing the data for your purposes?
8. If data analysis was necessary, who performed the analysis?
9. If data analysis was needed, what was the cost of that analysis (time and money)?
10. Was the data effective in achieving the intended goal (sufficient in extent and quality)?? If not, please explain why it wasn't effective.
11. Are there any BEMP datasets that do not exist that you wish were available? If so, what type, extent, and quality are you looking for?
12. Can you recommend any other entities that are utilizing BEMP data or other citizen science ecological monitoring data that are connected to the management of the bosque ecosystem?
13. Does your organization support BEMP, either through funding or by providing in-kind support (staff, access, equipment, mentoring, advisors)?
14. Do you know of other non-profit organizations that are involved in citizen science initiatives?
15. What are the technical limitations of data generated by BEMP that limit the utility of the data generated by this program or other citizen science groups?

INTERVIEW QUESTIONS – BEMP

1. What role(s) do you see BEMP data playing to inform water and/or ecosystem policies and management in the study area?
2. Which specific data types do you see as most frequently utilized?
3. Which dataset types do you see as least utilized?
4. What do you see as the primary goal or intended use for key datasets?
5. Does BEMP conduct data analysis and interpretation in house?
6. Do you feel like BEMP data are effective in achieving the intended goals of data users that are decisionmakers in the ecosystem?
7. Are there any BEMP data types or extents that do not currently exist that you think data users would like to see?
8. What do you see as the primary challenges to water resources and ecosystem management in the study area?
9. How do you see your relationship with partners?
10. One interviewee mentioned that BEMP is still seeking long term funding. Can you respond to the challenges you are facing in securing long-term funding?

Appendix B: Interviewee Organization Profiles

Detailed profiles of each of the organizations represented by interviewees are included in this appendix. Information was gathered primarily from the respective organizations' websites.

US Army Corps of Engineers - Albuquerque District

Today, the district continues several regional civil works projects. In addition, it now provides extensive design and construction services to three New Mexico military bases: Kirtland Air Force Base in Albuquerque, Holloman Air Force Base in Alamogordo, and Cannon Air Force Base in Clovis. As the US struggled in the throes of the Great Depression, a new USACE district was created in New Mexico. Although flood control and irrigation projects were not economically feasible in 1929, widespread unemployment in the early 1930's helped to convince President Roosevelt to approve the building of Conchas Dam. USACE established the Tucumcari District on August 2, 1935, to construct a dam for irrigation, flood control, and water supply. The Tucumcari District personnel later transferred to Caddoa, and on December 4, 1939, the organizational name was officially changed to USACE, Caddoa District. In early 1942, the district headquarters transferred to Albuquerque, changed name, and given a new mission, switching from civil works projects to wartime activities (with a peak workforce of 3,039). The Albuquerque District performed real estate and construction services supporting various regional military projects (including those at Los Alamos National Laboratory). After WWII, the district resumed civil works construction and completed John Martin Dam. Several other USACE major dam projects followed, in chronological order: Jemez Canyon Dam, Abiquiu Dam, Two Rivers Dam, and Cochiti Dam in New Mexico; Trinidad Dam in Colorado, and Santa Rosa Dam in New Mexico.

Albuquerque Metropolitan Arroyo Flood Control Authority

The Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) was created in 1963 by the New Mexico Legislature with specific responsibility for flooding problems in greater Albuquerque. AMAFCA's purpose is to prevent injury or loss of life, and to eliminate or minimize property damage. AMAFCA does this by building and maintaining flood control structures throughout the Albuquerque area. AMAFCA is also concerned with protecting the quality of water for Albuquerque and its surrounding areas. Structures which catch debris and protect the Rio Grande from pollution are often modeled in the UNM Hydraulics Lab before being built by AMAFCA. This web pages (Projects) provides more details on recent AMAFCA models.

U.S. Fish & Wildlife Service

In compliance with a U.S. District Court order, the U.S. Fish and Wildlife Service has designated critical habitat for the endangered silvery minnow in New Mexico. The designation covers 163 miles of the Rio Grande River channel downstream of Cochiti Dam to the headwaters of Elephant Butte Reservoir near San Marcial, New Mexico. The designation identifies areas where federal agencies are required to consult with the Service on actions they carry out, fund, or authorize that may adversely modify that critical habitat. Federal agencies have been consulting with the Service since the species was listed in July 1994, to ensure that their actions do not jeopardize the continued existence of the minnow. Because these two consultation requirements are so similar, the Service does not anticipate the critical habitat designation will result in any further restrictions to existing water management practices. The U.S. Fish and Wildlife Service is the principal Federal agency responsible for conserving, protecting, and enhancing fish, wildlife and plants and their habitats for the continuing benefit

of the American people. One hundred and fifty miles, or 92 percent of the critical habitat area, are within the administrative boundaries of the MRGCD.

City of Albuquerque Open Spaces

Albuquerque Open Space is mostly composed of lands acquired by the City of Albuquerque. Open Space also includes properties owned by other entities and co-managed by the Open Space Division. Each piece of land contains several areas that provide the public with a variety of facilities and uses: Aldo Leopold Forest, Boca Negra Canyon, East Mountain Open Space, Elena Gallegos Open Space, Montessa Park, Open Space Farmlands, Paseo de la Mesa Trail, Paseo del Bosque Trail, Petroglyph National Monument, Piedras Marcadas Canyon, Rio Grande Valley State Park (bosque), Sandoval County Open Space, Volcanoes, and West Mesa Open Space.

Save Our Bosque Taskforce

The SOBT was formed as a nonprofit corporation in 1994 by citizens of Socorro County, New Mexico, concerned about degradation of the ecosystem along the Rio Grande bosque due to dumping of trash, off-road vehicle use, illegal fuelwood cutting, and wildfire. There are three law enforcement agencies and five land management agencies with law enforcement authority in the Socorro area. The agencies coordinate efforts to curb illegal activities within the Bosque. The Socorro Police Department, Socorro County Sheriff Office, and NM State Police patrol lands and roads under their jurisdiction and assist other agencies with their law enforcement duties. The land management agencies of the MRGCD, Bureau of Land Management, US Fish and Wildlife Service, NM State Forestry, and New Mexico Department of Game and Fish patrol their lands and neighboring lands. Ongoing goals include:

1) Improving agency coordination to protect the Bosque (cross-commission, joint patrols, information sharing); 2) Working with local and district court systems to support appropriate prosecution of illegal activities; 3) Developing policies and regulations to assist law enforcement efforts (Bosque access policy for cooperating land management agencies, fuel wood permits); and 4) Improving cooperative response for emergencies and closures (bosque closures, wildfires).

Bureau of Reclamation – Upper Colorado Basin - Albuquerque Area Office

The Albuquerque Area Office is one of the largest in Reclamation reaching from the Alamosa area of southern Colorado through most of New Mexico and into west Texas. Staff manage delivery of water on the Rio Grande, Rio Chama, Pecos, and Canadian rivers from the main office in Albuquerque and six field offices in Alamosa, Colorado; Alamogordo, Chama, Elephant Butte, and Socorro, New Mexico; and El Paso, Texas. The Albuquerque office is responsible for overseeing the management of nine major dams with a combined reservoir storage capacity of over 3.5 million acre-feet, supplying water for more than 439,000 acres of irrigated land and several municipal drinking water projects. It oversees hydropower production at Elephant Butte Dam, and research and testing at the Brackish Groundwater National Desalination and Research Facility.

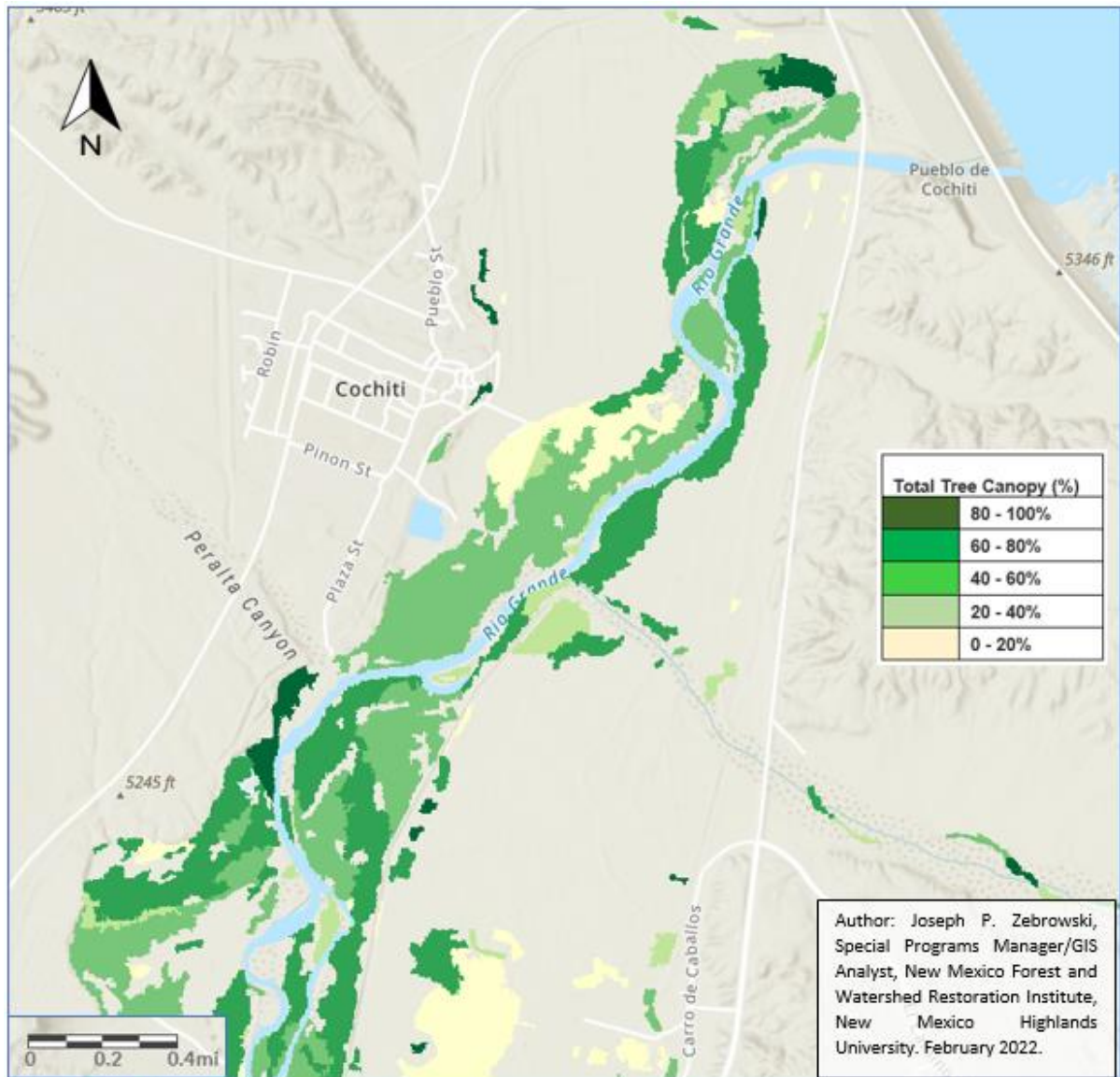
Appendix I contains a historic timeline and key explanations of, The Middle Rio Grande Project, as recounted by a BOR employee in 2013 (Gahan, 2013). The history provides details on the series of pervasive flood control and channelization engineering projects rendering impacts that fundamentally changed the ecology of the study area – in conjunction with Cochiti Dam. The Rio Grande Project budget was initially about 1- million dollars (1950's dollars). This project history does not include the details of the construction of the Cochiti Dam

project, because the dam was an Army Corps of Engineers project with a then, 1-billion-dollar price tag, completed in 1973. Cochiti Dam is the north boundary of the study area.

Appendix C: Glossary

ABCWQUA	Albuquerque Bernalillo County Water Quality Utility Authority
AMAFCA	Albuquerque Metropolitan Arroyo Flood Control Authority
BBMP	Bosque Biological Management Plan
BEMP	Bosque Ecosystem Monitoring Program
BOR	Bureau of Reclamation
Bosque	Riparian Forest
CABQ	City of Albuquerque Open Spaces
Corps	Army Corps of Engineers
ESA	Endangered Species Act
MRG	Middle Rio Grande
MRG – CAP	Middle Rio Grande Conservation Action Plan
MRGCD	Middle Rio Grande Conservancy District
NMFWRI	New Mexico Forest and Watershed Restoration Institute
UNM	University of New Mexico
USDA	US Department of Agriculture
USFWS	US Fish & Wildlife Service
USGS	United State Geological Survey

Appendix D: Canopy Density Maps of the Study Area (series of 42)

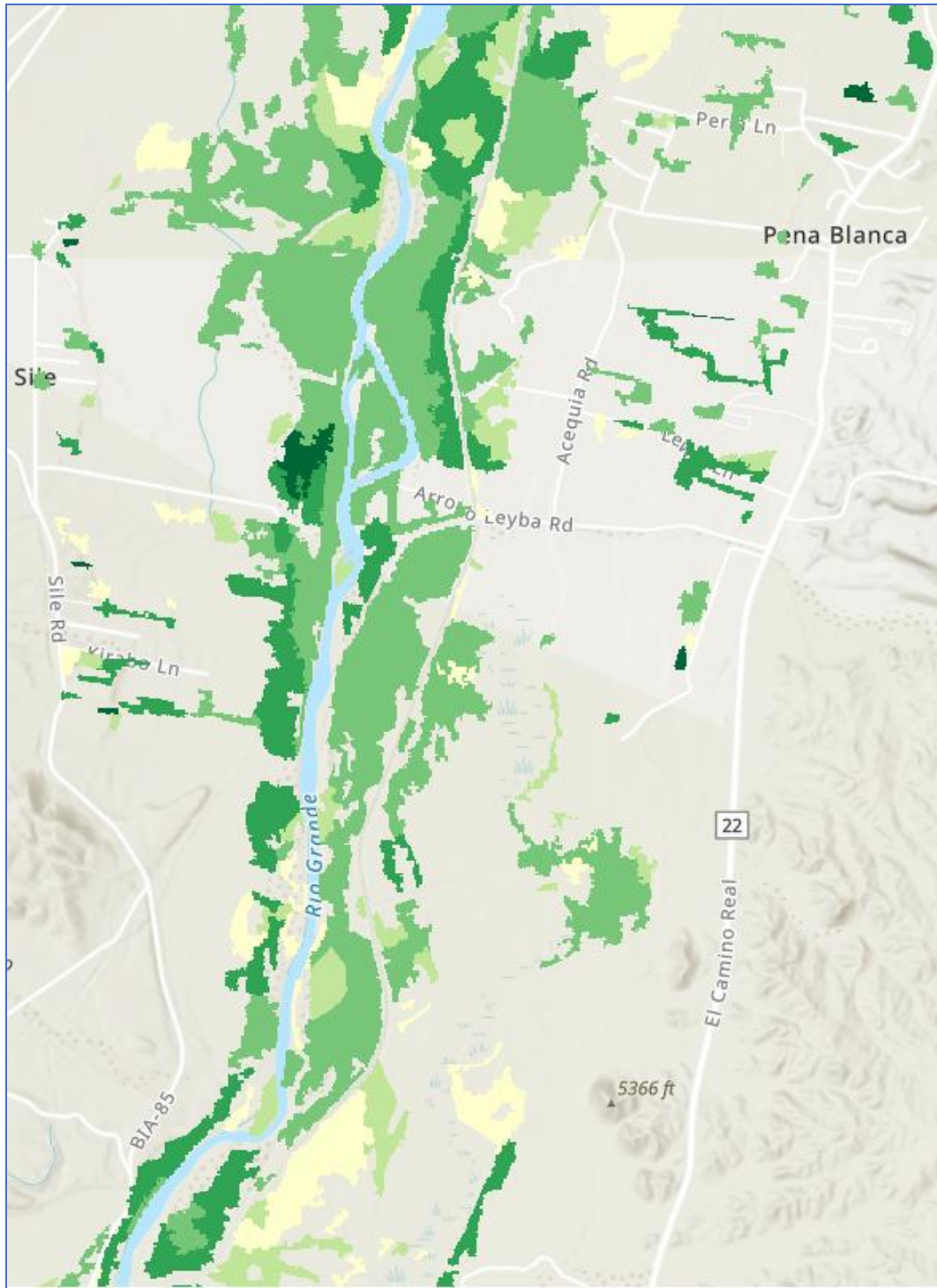


1) Cochiti Dam

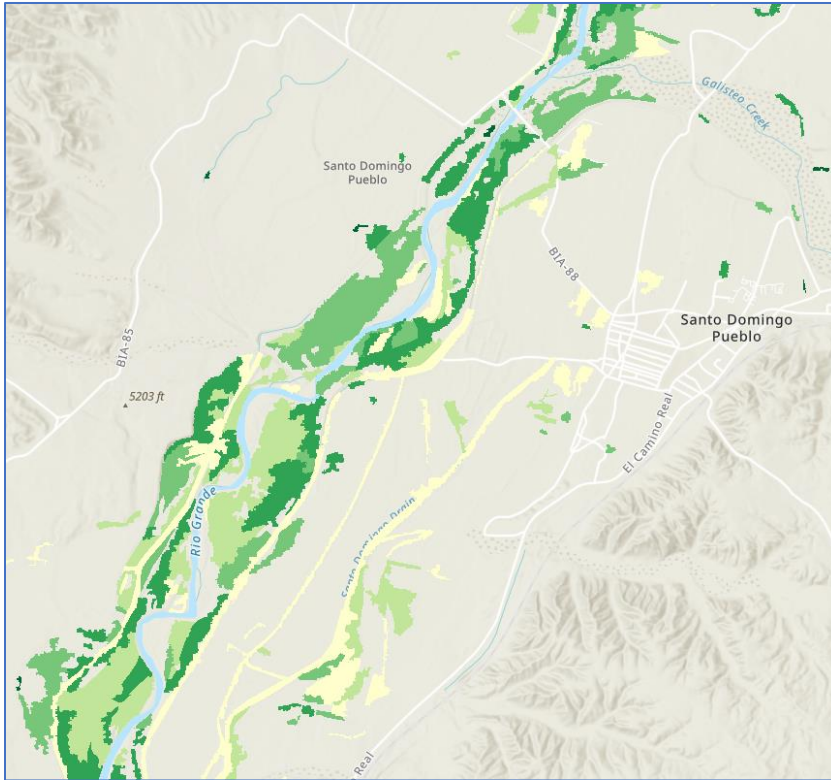
The canopy cover density map of the study area was created by New Mexico Forest and Watershed Restoration Institute (NMFWRI), New Mexico Highlands University, Joe Zebrowski, Special Programs Manager/GIS Analyst, February 2022. Maps convey the percent of canopy coverage across the extent of the study area, utilizing NMRipMap³ data. The map was broken up into viewable sections, as a series of forty-two maps found below. The first section of the map (Cochiti) contains key map components that can be applied to the rest of the series. All map sections were created in the same scale as the Cochiti map section.

NMFWRI provides state-of-the-art information about forest and watershed restoration to the public, federal and state agencies, tribes, and private landowners in New Mexico. NMFWRI collaborates with citizen stakeholders, academic institutions, NGOs, and professional natural resources managers to establish a consensus concerning prescriptions and monitoring protocols for use in the restoration of forests and watersheds in an ecologically, socially, and economically sound manner. NMFWRI promotes ecological restoration and forest management efforts in ways that: 1) Keep New Mexican homes and property safe from wildfire; 2) Lead to a more efficient recharge of New Mexican watersheds; 3) Provide local communities with employment and educational opportunities.

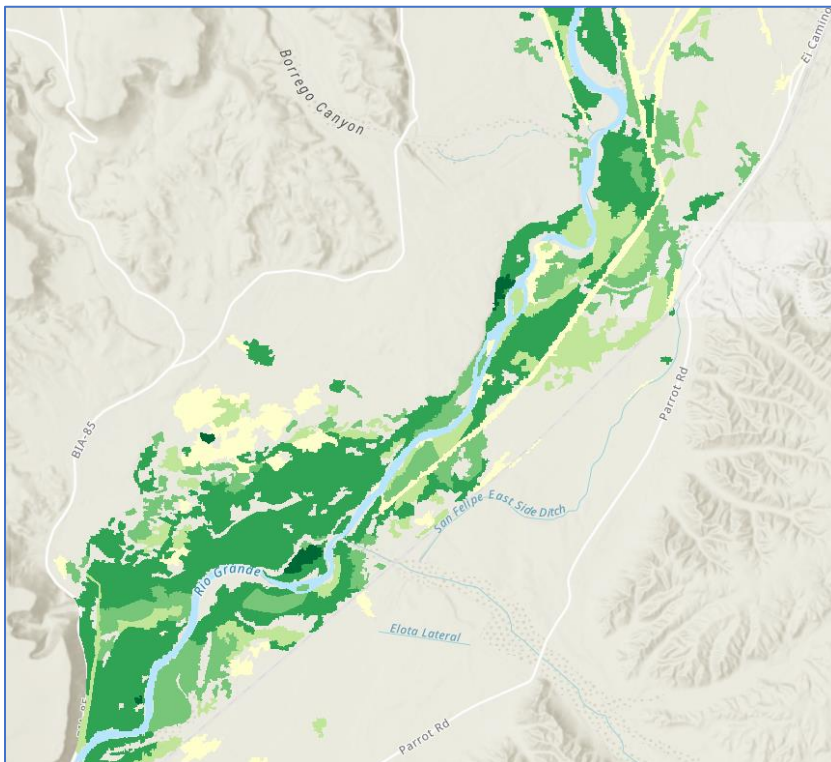
³ NM Rip Map Metadata: NMRipMap is a key element of the New Mexico Conservation Information System (NM-CIS), where it is linked to habitat descriptions in the NM State Wildlife Action Plan (SWAP) and it serves as an information layer in the New Mexico Environmental Review Tool (ERT) and New Mexico Crucial Habitat Assessment Tool (NMCHAT) to further support wildlife management and conservation in New Mexico. NMRipMap is a core resource for USDA Forest Service planning and management activities, and in supporting the Southwestern Region's recently adopted Riparian and Aquatic Ecosystem Strategy (USDA, 2019). The NM Riparian Map, as a whole, is based on the 2016 four-band National Agriculture Imagery Program (NAIP) ortho-photography at 1-meter resolution - in combination with Light Detection and Ranging (LiDAR) data, where available. LiDAR provides the capacity to define vegetation structure directly (vegetation height and cover). Where possible, 'leaf-on and leaf-off' imagery was used, along with coarser resolution from Planet imagery - to discern evergreen from deciduous trees and shrubs. Ancillary environmental datasets were also compiled, such as soils, geology, landform, and topography - to aid the modeling of environmental envelopes of vegetation types, to further constrain their distribution (e.g., elevation and geographic limits) (Muldavin et al., 2020).



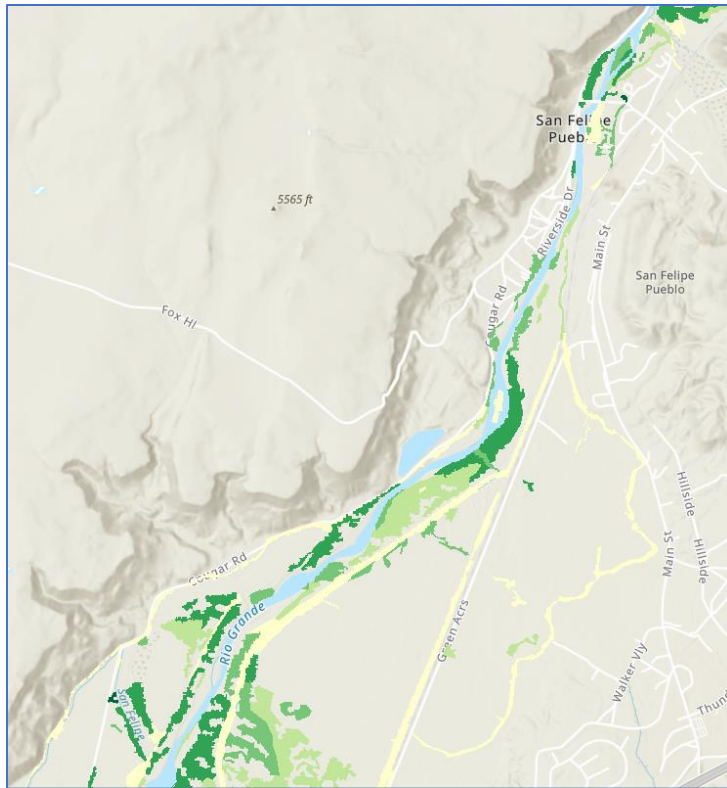
2) Pena Blanca



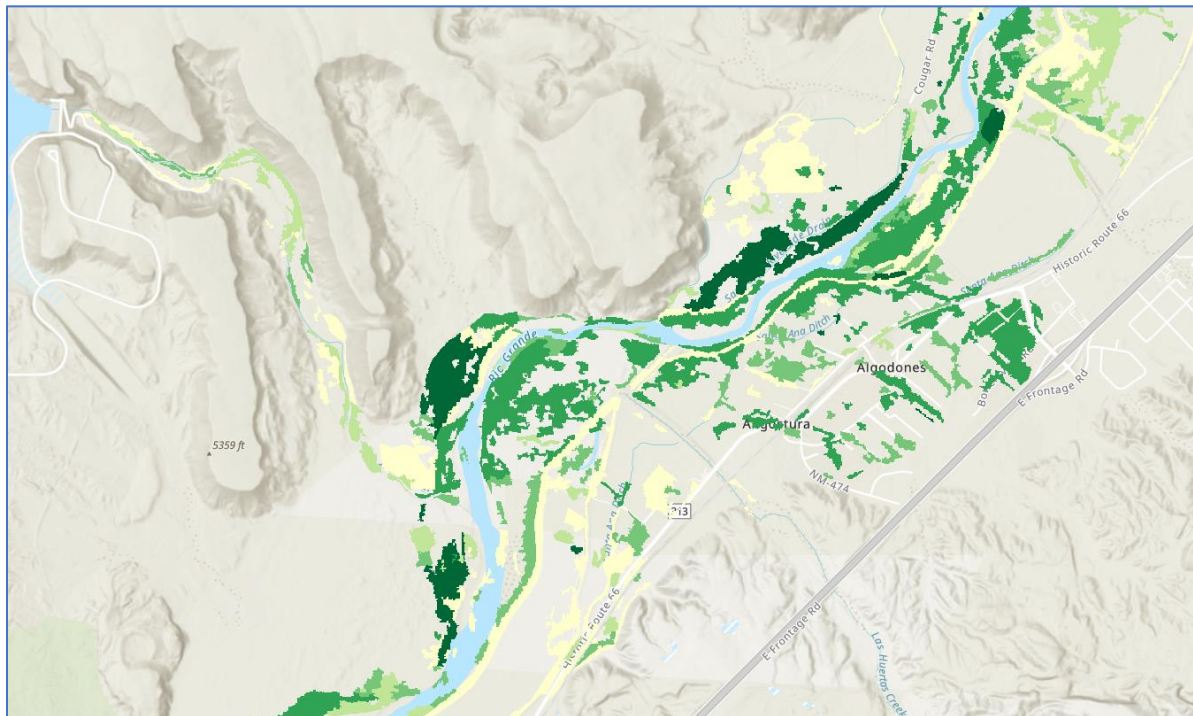
3) Santo Domingo Pueblo



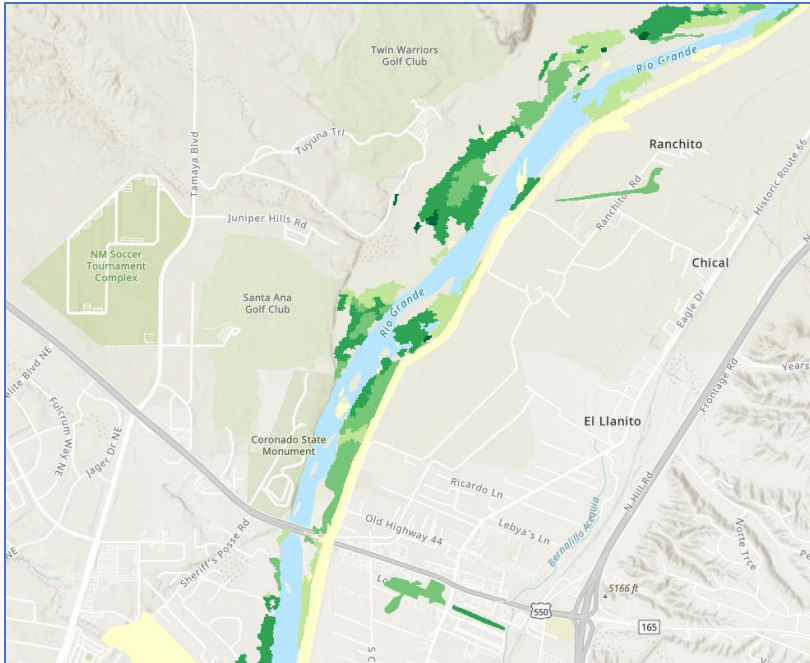
4) South of Santo Domingo Pueblo



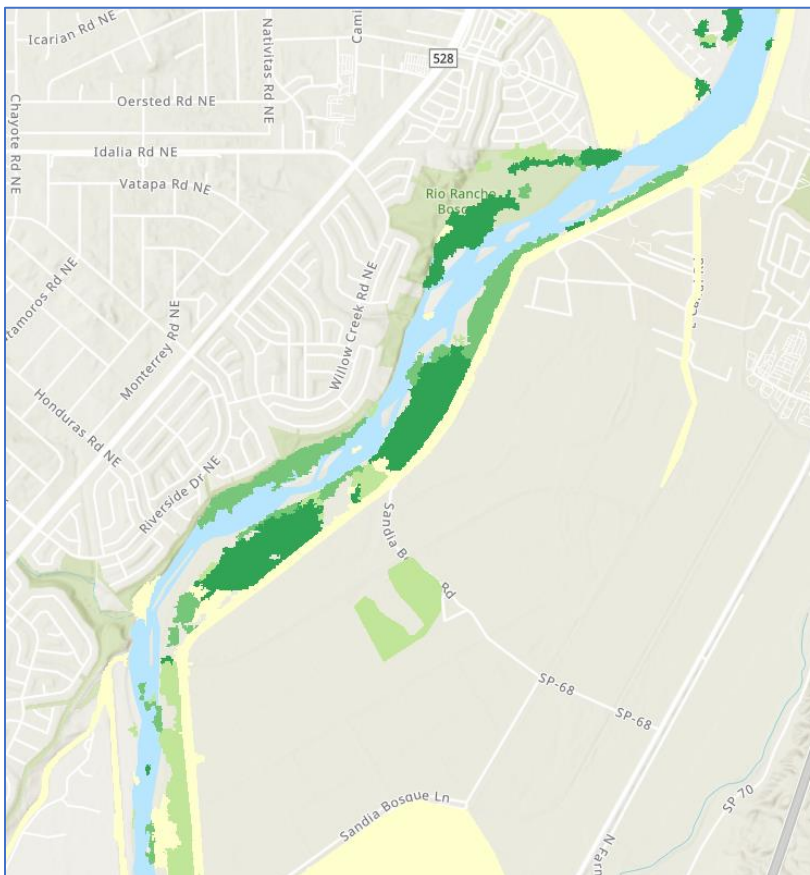
5) San Felipe Pueblo



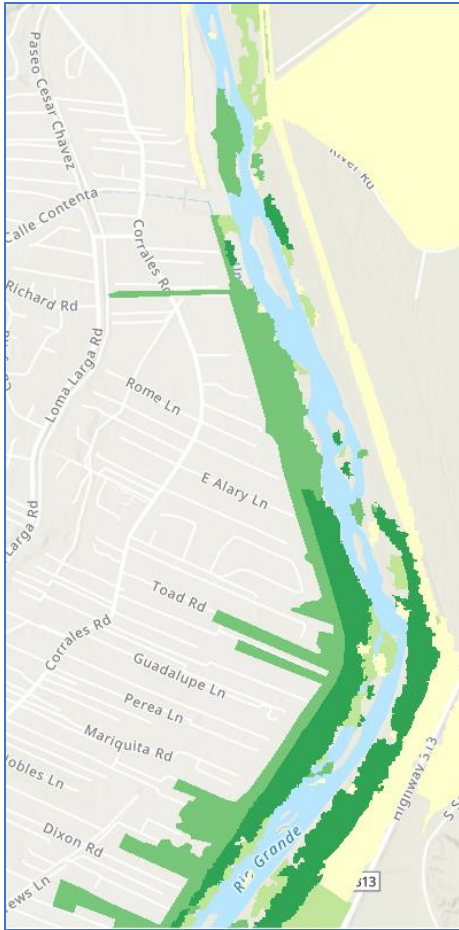
6) Algodones



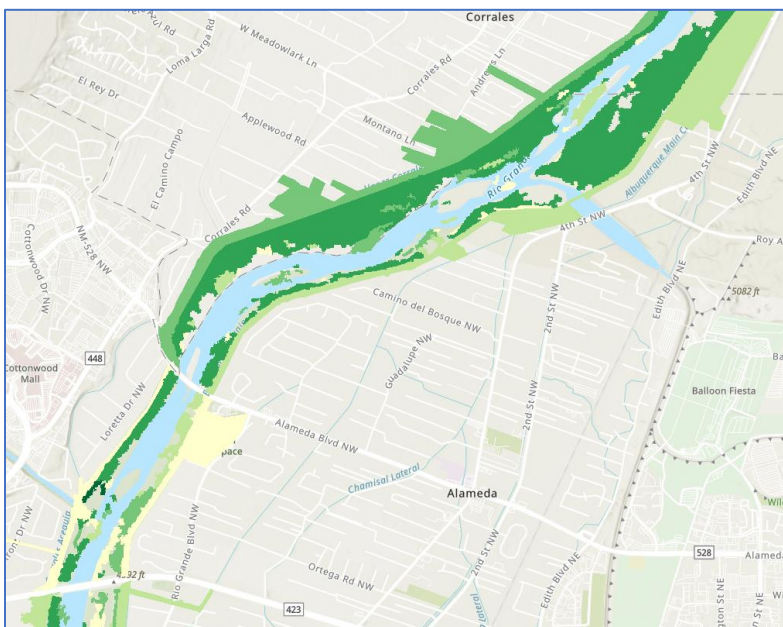
7) El Llanito



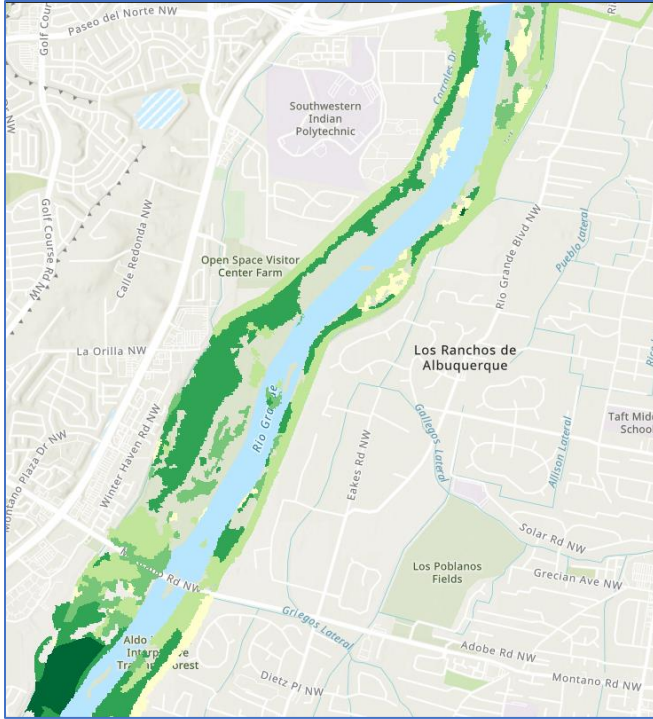
8) Rio Rancho



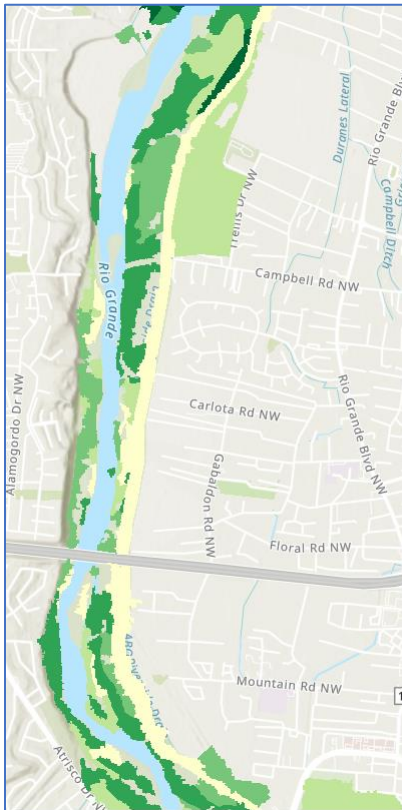
9) Corrales



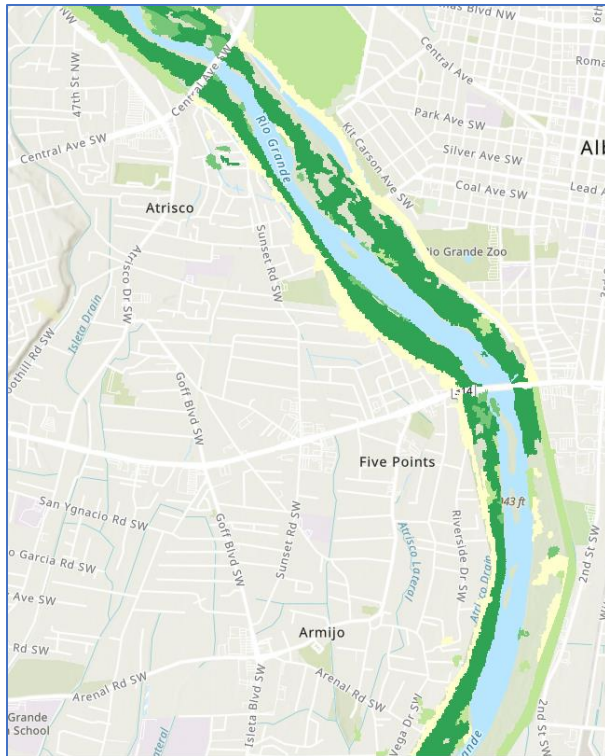
10) Corrales/Rio Rancho



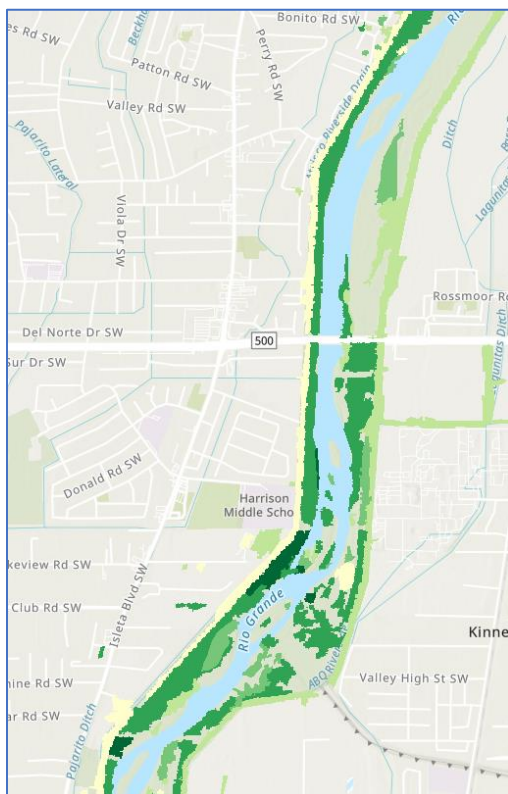
11) Los Ranchos de Albuquerque (North Albuquerque)



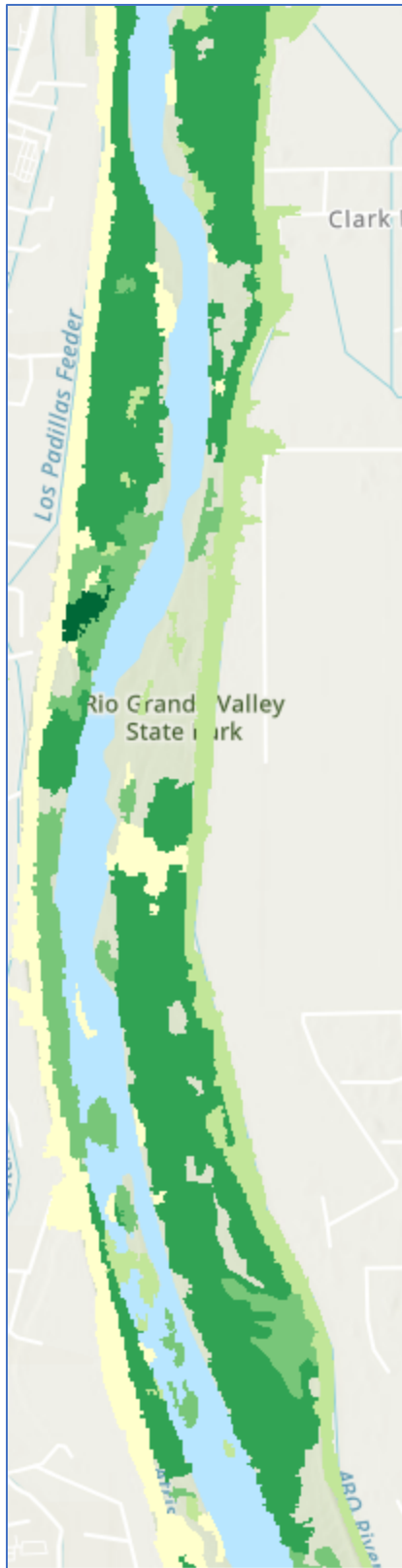
12) Albuquerque (North)



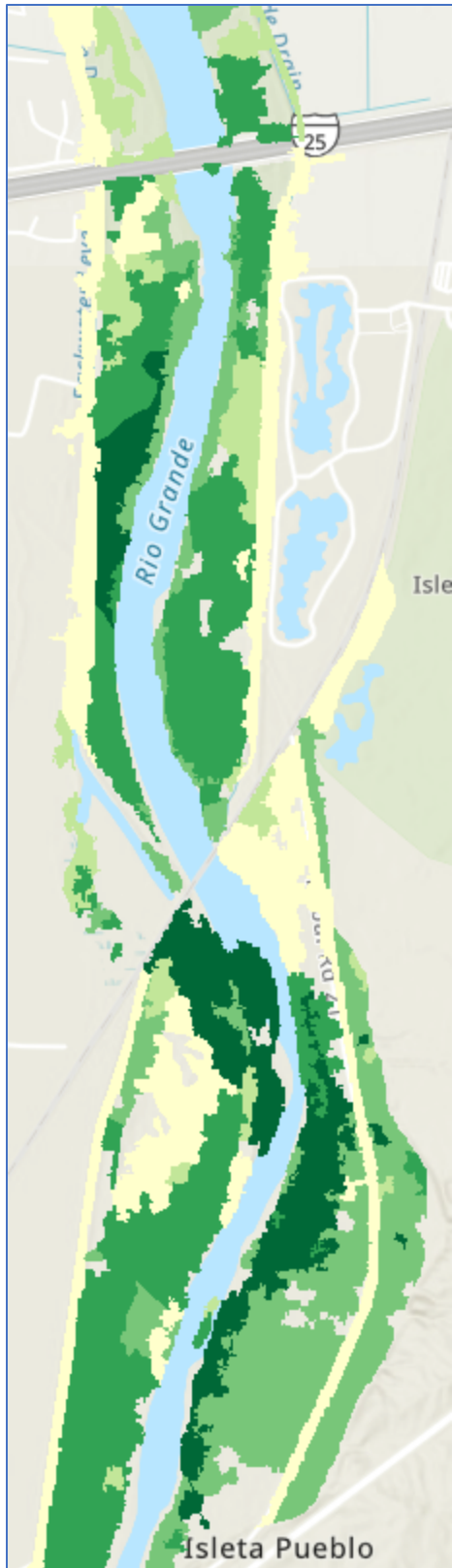
13) Albuquerque (Central)



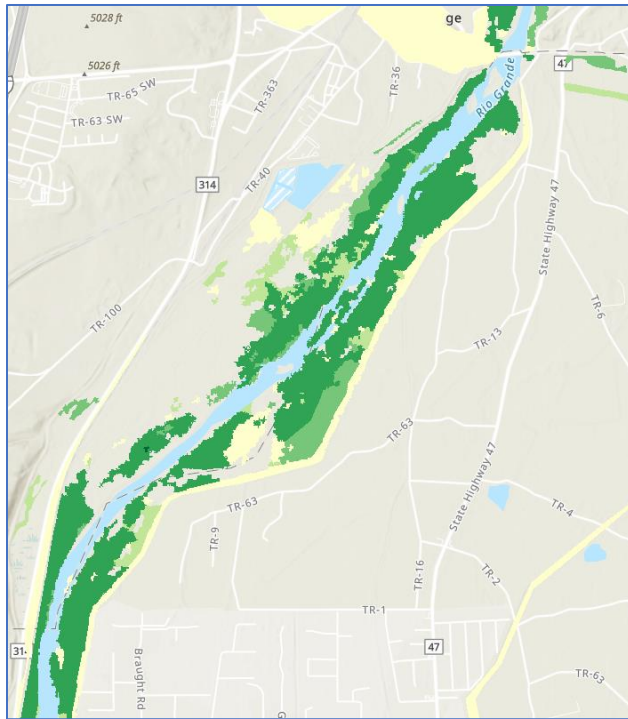
14) Albuquerque (South)



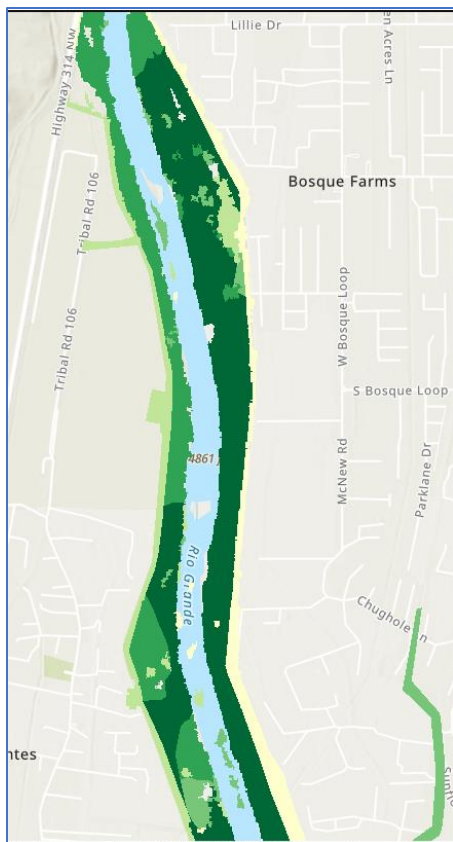
15) South Albuquerque (Rio Grande Valley State Park)



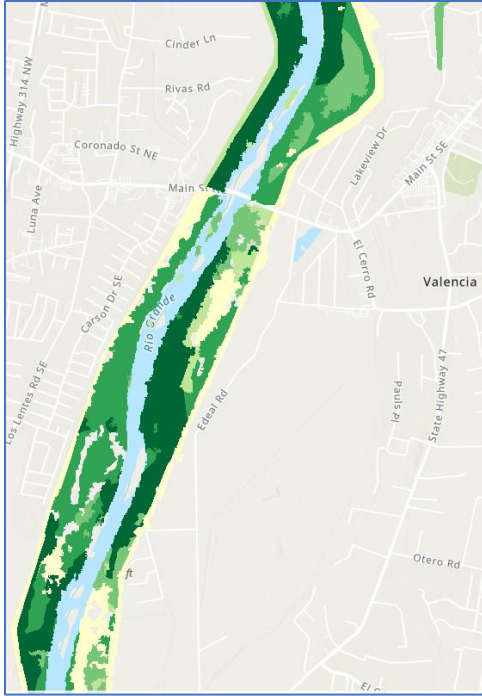
16) Isleta Pueblo (North)



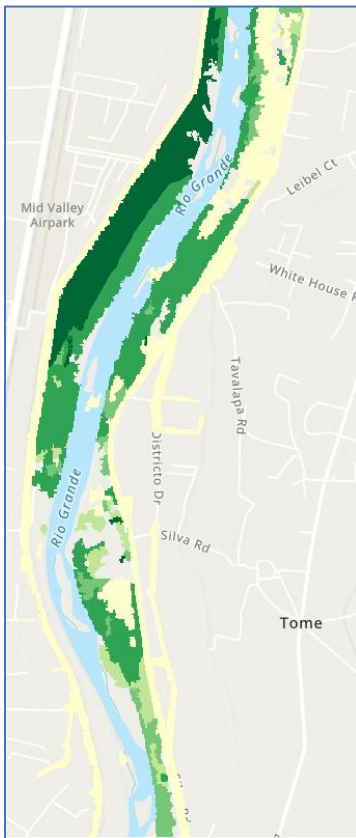
17) Isleta Pueblo (south)



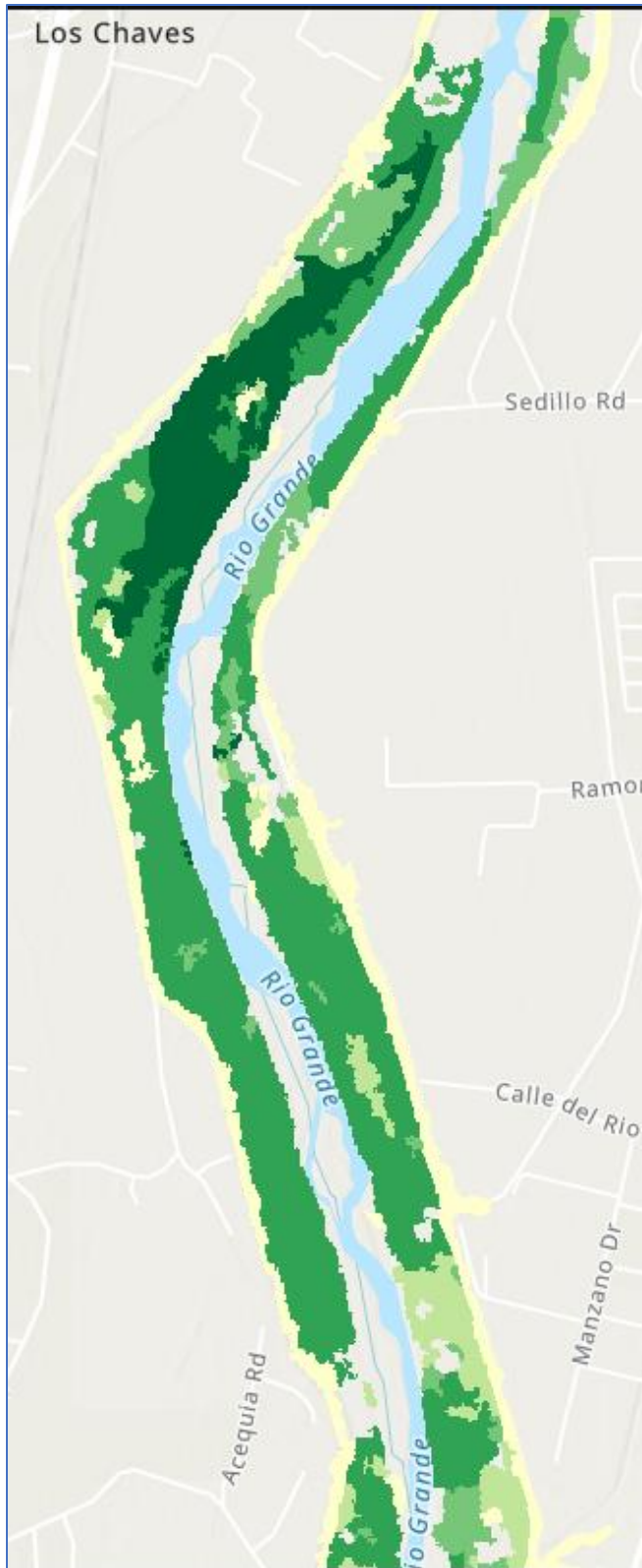
18) Bosque Farms



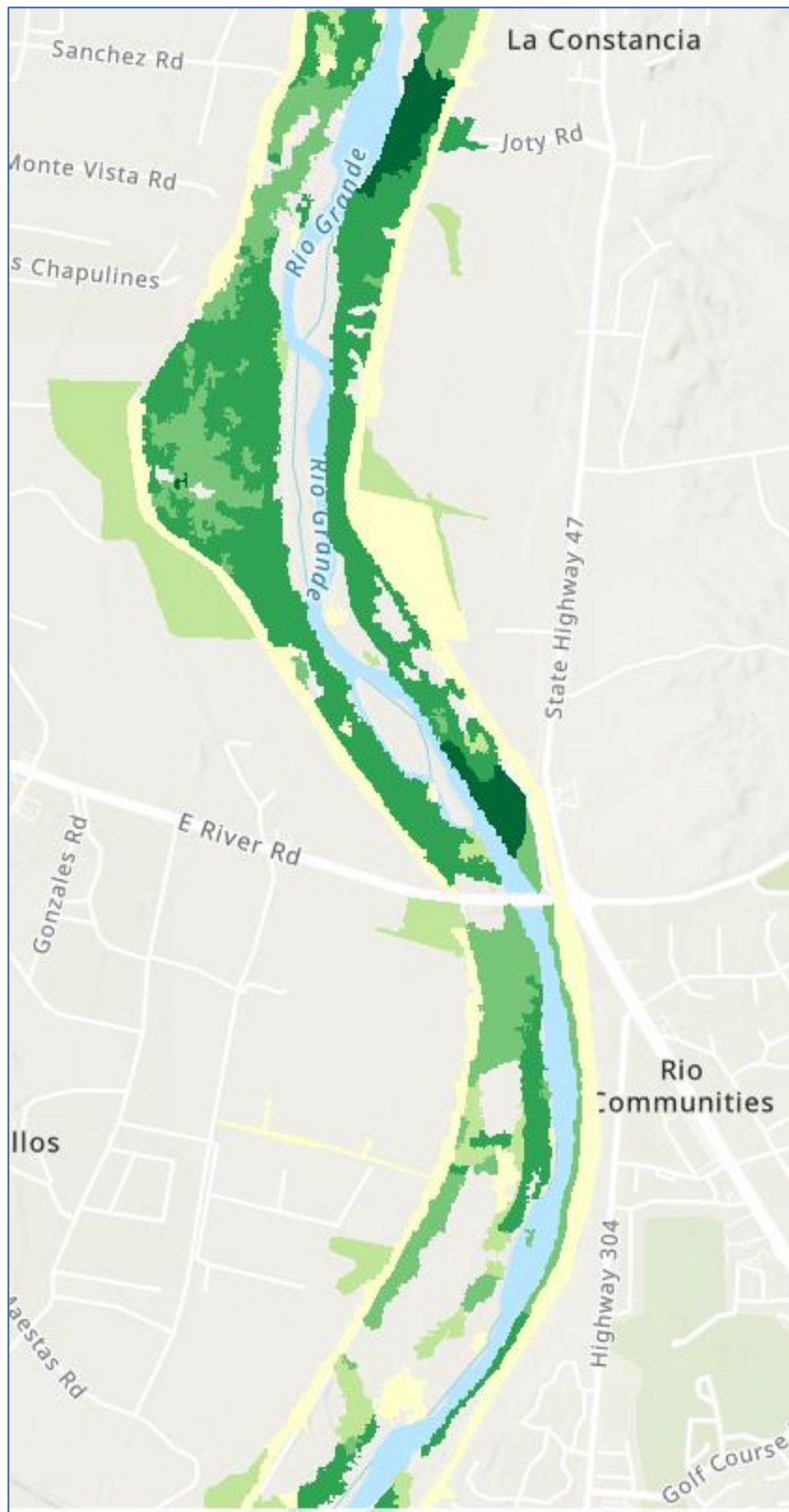
19) Valencia



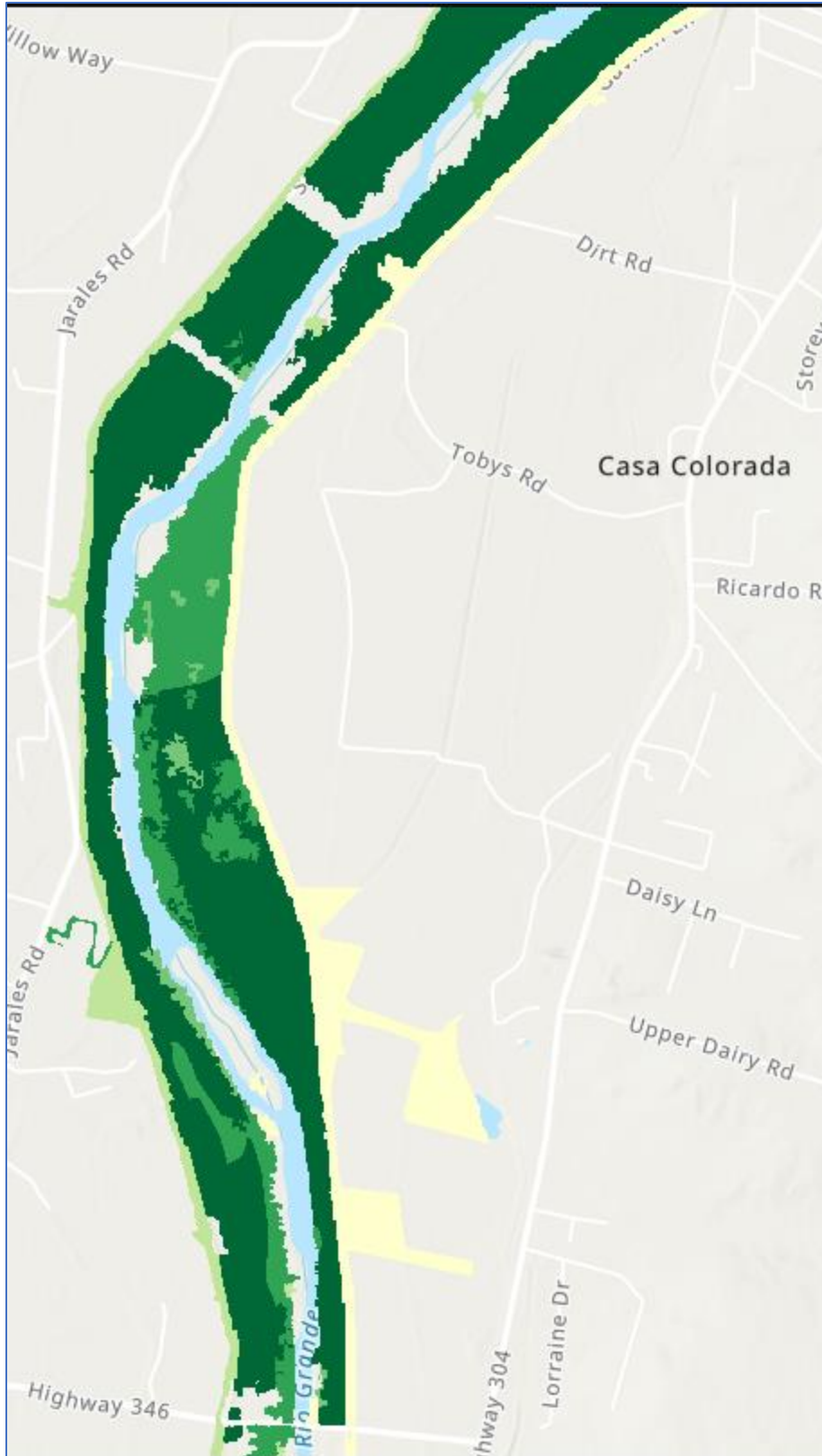
20) Tome



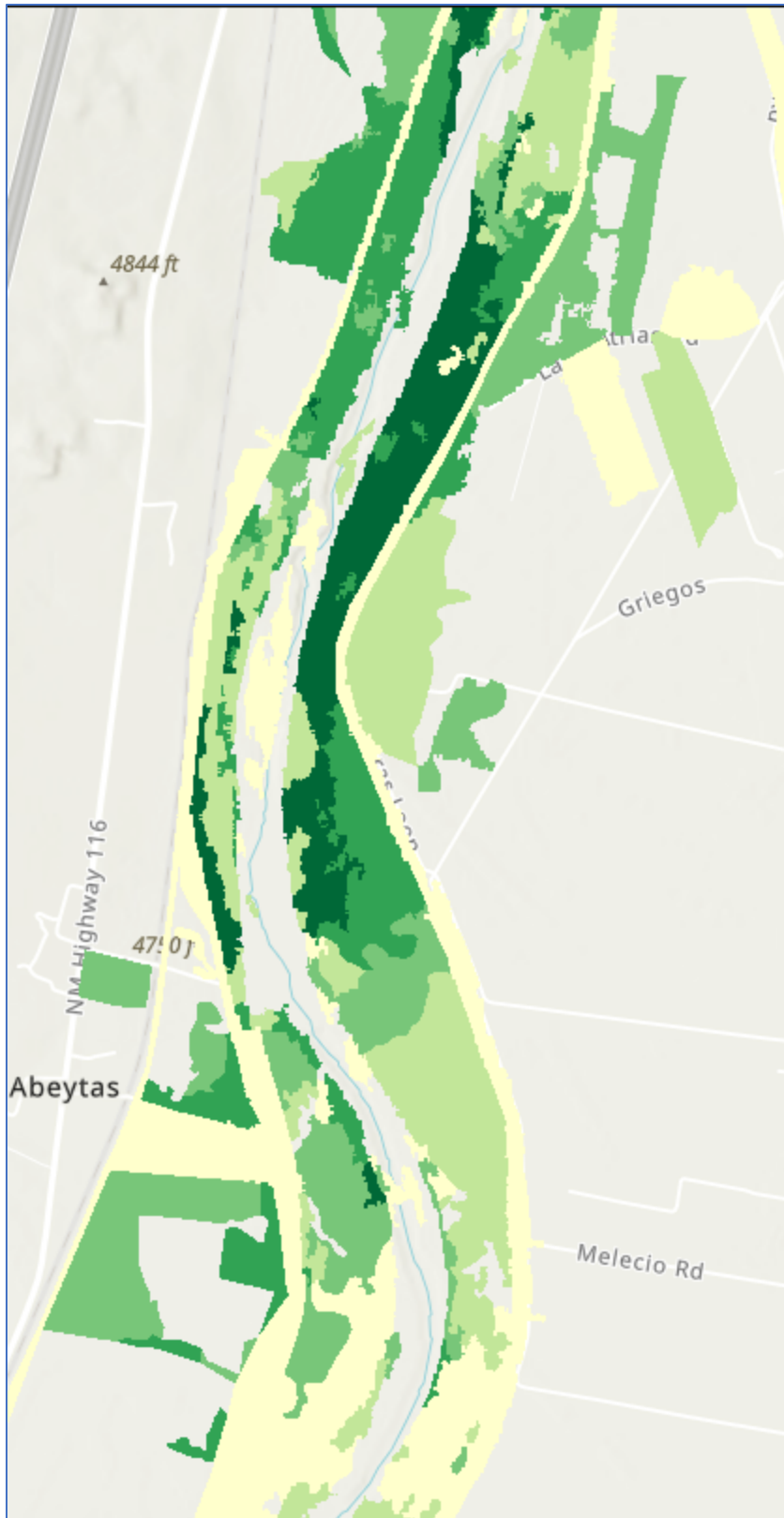
21) Los Chaves



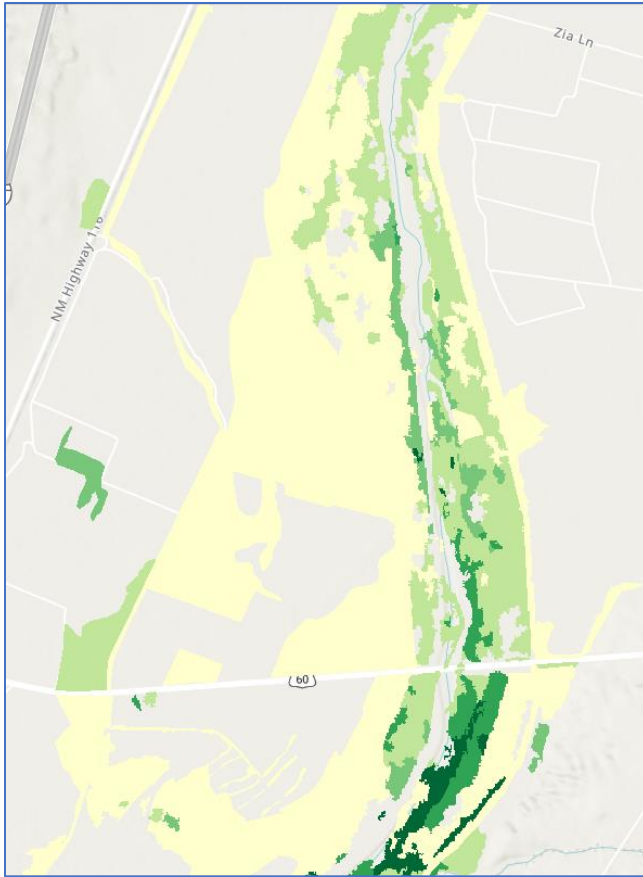
22) Rio Communities



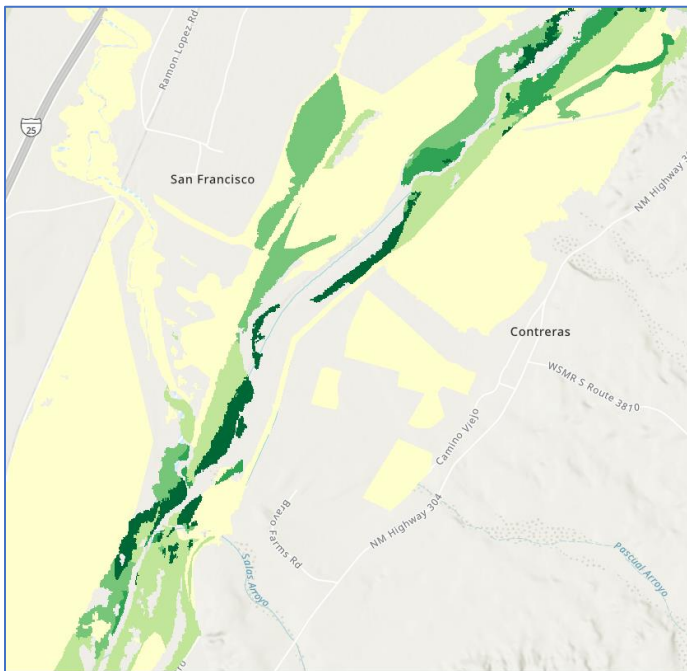
23) Casa Colorada



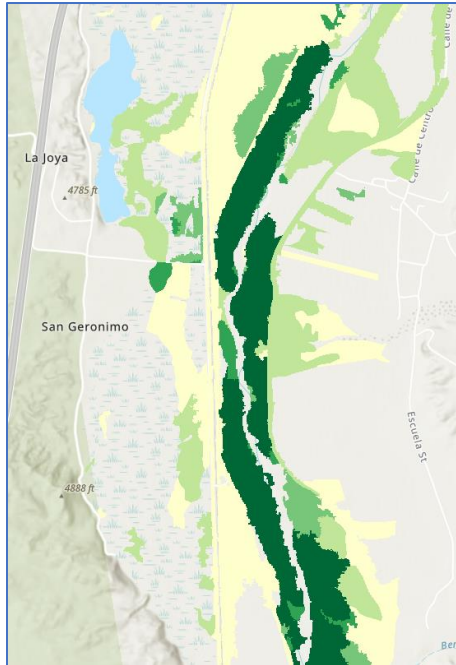
24) Abeytas



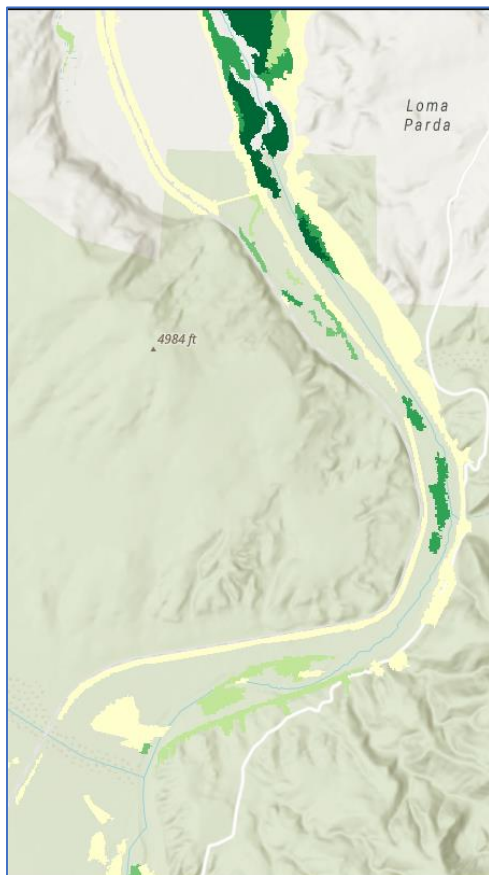
25) North of San Francisco / Contreras



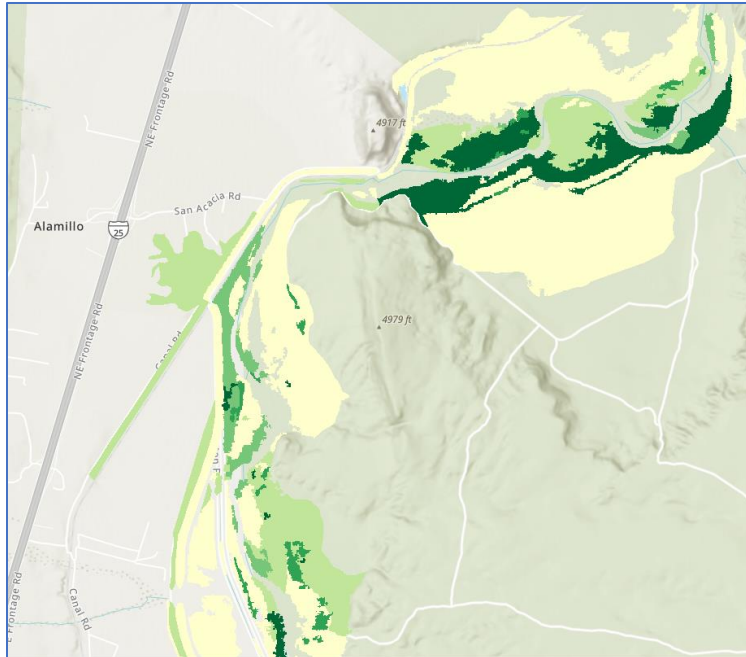
26) San Francisco / Contreras



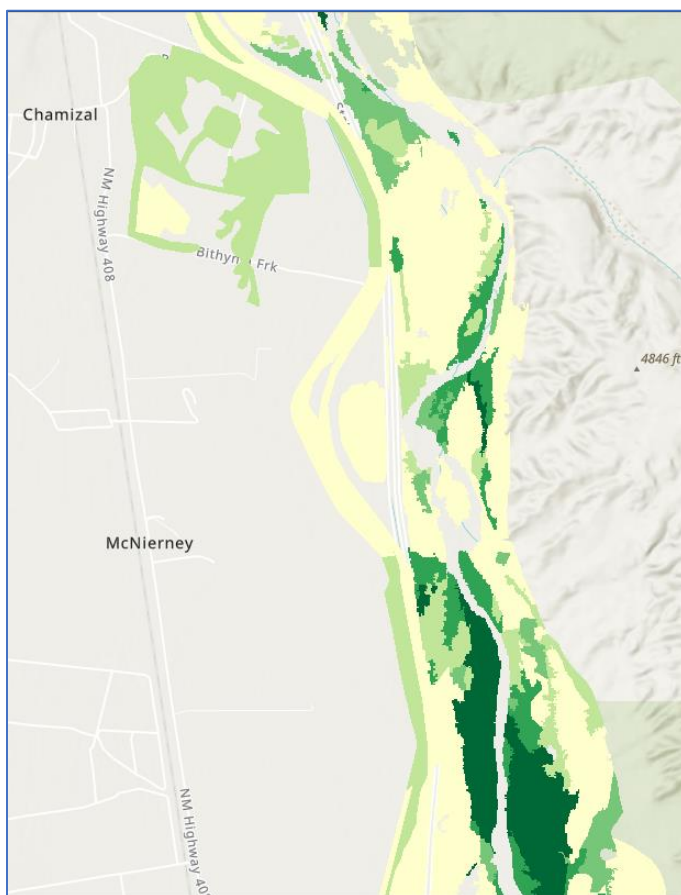
27) San Geronimo



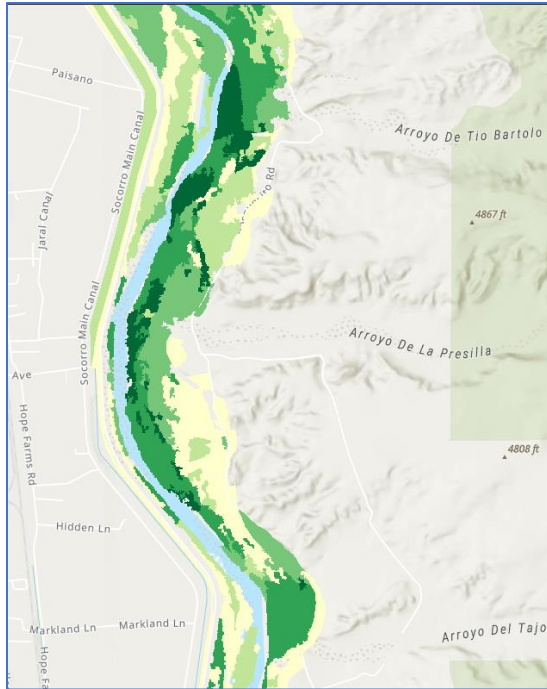
28) Loma Parda



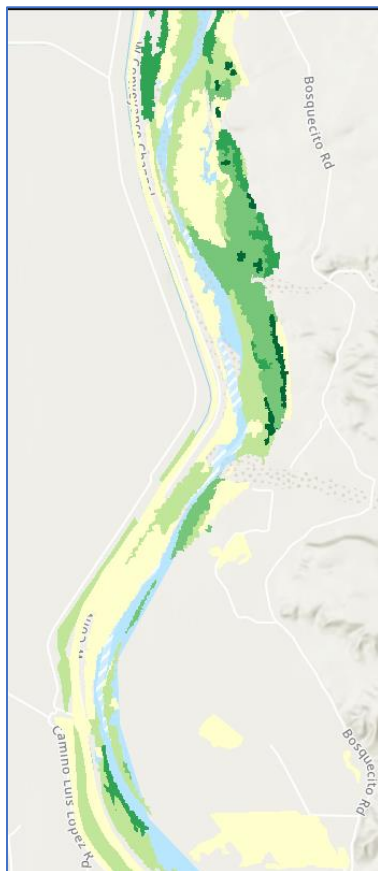
29) Alamillo



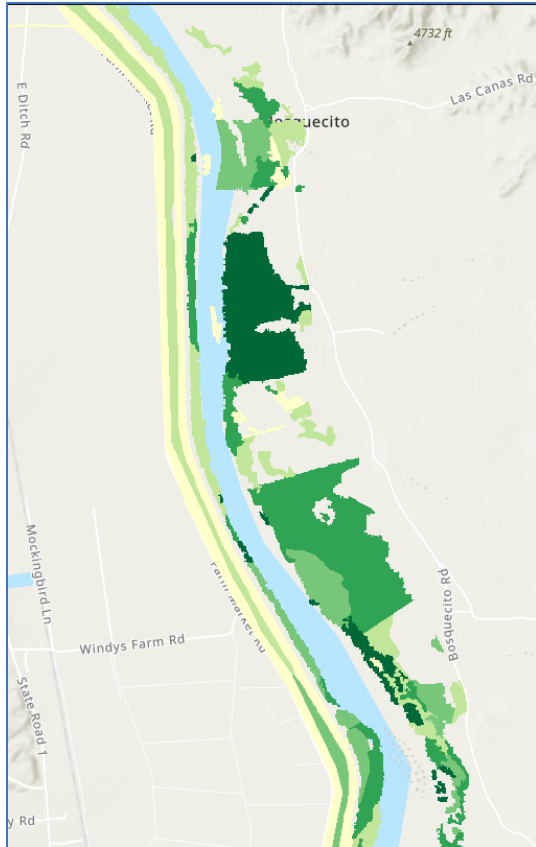
30) McNierney



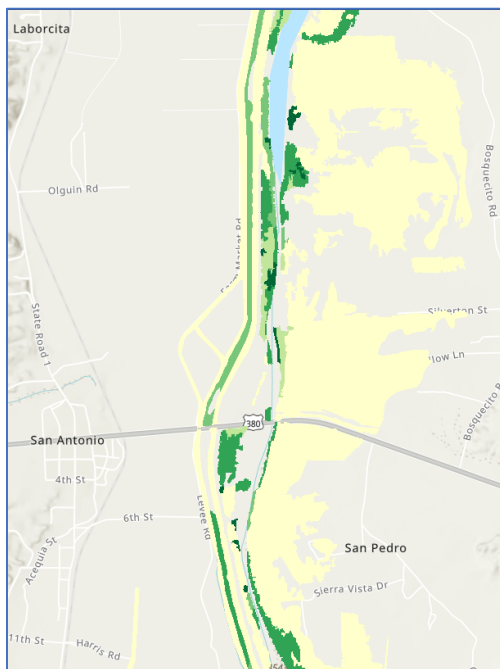
33) South of Lemitar (B)



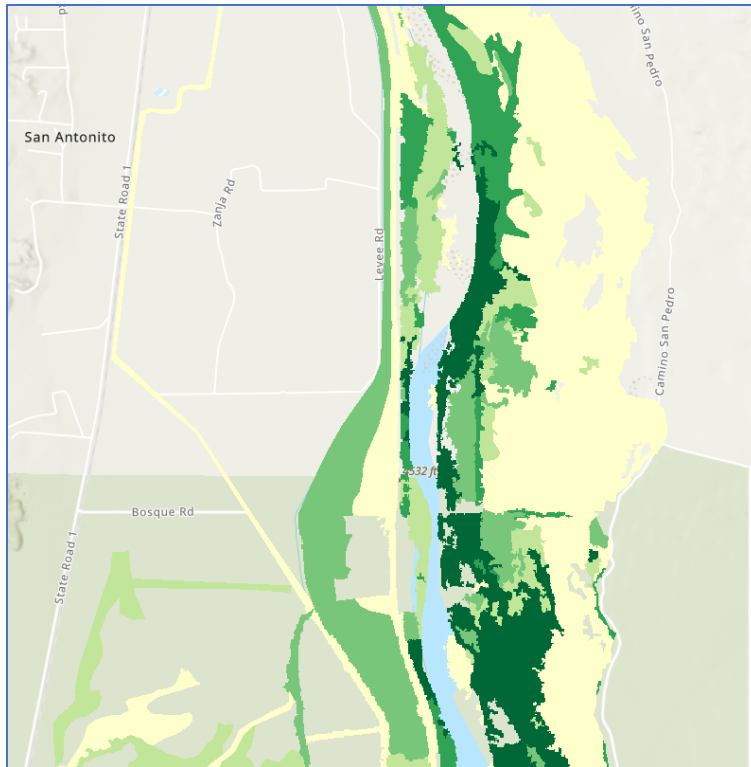
34) North of Bosquecito



35) Bosquecito



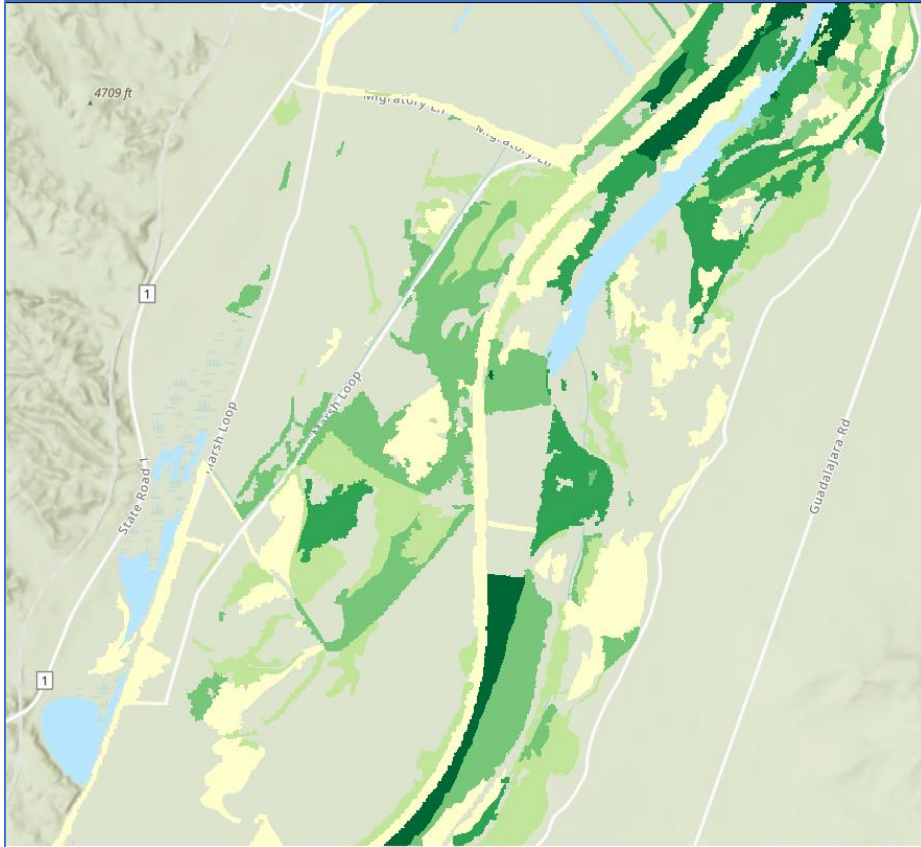
36) San Pedro



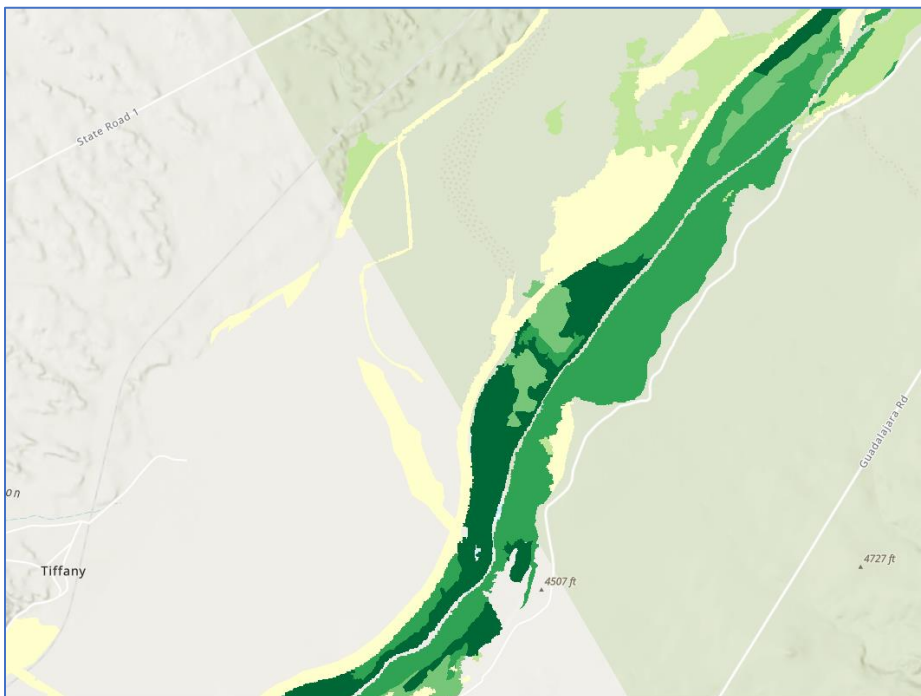
37) San Antonio



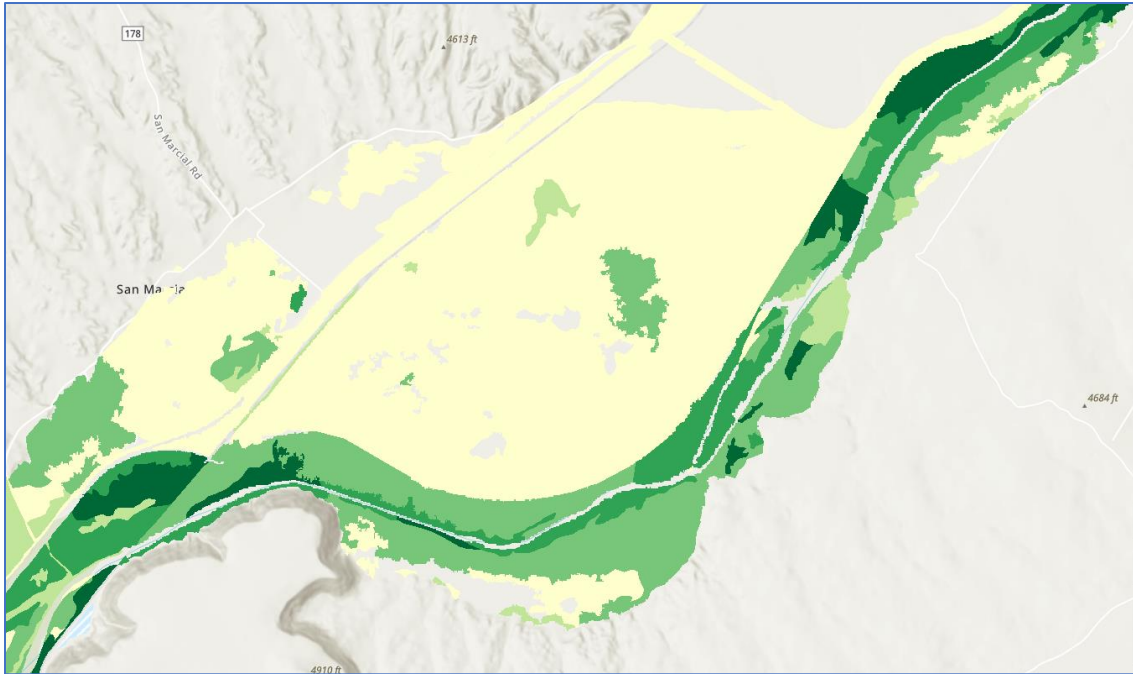
38) Bosque del Apache



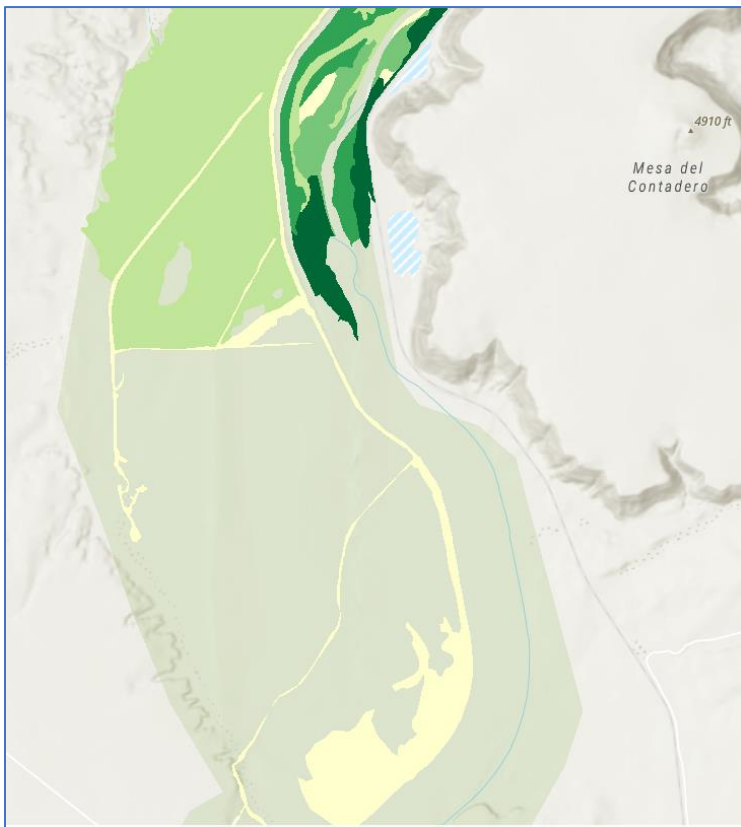
39) Bosque del Apache



40) North of San Marcial



41) San Marcial



42) South of San Marcial

Appendix E: MRG BBMP 1993 and 2005 Update: All Recommendations

The team foresees the boundaries of the Middle Rio Grande bosque as not only being protected from development but also expanded in the future. In addition to protection, the restoration and maintenance of ecosystem processes are fundamental to this biological management plan. We envision a perennial Rio Grande whose flows mimic the natural hydrograph to the maximum extent possible, and a river channel that is permitted maximum freedom within the floodway. The attainment of these basic conditions will facilitate the achievement of all other recommendations to enhance the biological quality and ecosystem integrity of the bosque.

Hydrology

Water is the key variable that drives the processes of the riparian ecosystem. Prior to the extensive human changes in the river system, water performed the work of providing habitat, moisture, and nutrients for riparian organisms' reproduction and survival. We believe that water can be managed to allow it to continue to do as much of this work as possible with minimal human interference. Whenever water cannot do its work, people will have to attempt to replace vital, missing functions and processes in the ecosystem. The following three recommendations are closely interrelated and deal with management of surface and ground water in the Middle Rio Grande:

1. Coordinate Rio Grande water management activities to support and improve the bosque's riverine and terrestrial habitats, with special emphasis placed on mimicking typical natural hydrographs.

2. Implement measures to allow fluvial processes to occur within the river channel and the adjacent bosque to the extent possible.
3. Reintroduce the dynamics of surface-water/ground-water exchange, manage groundwater withdrawal, and restrict contamination.

Aquatic Resources

Recommendations about aquatic resources overlap and are related to those for hydrology but focus on communities and species that are primarily dependent on the presence of surface water either throughout or at critical times during their life history. Water must also be of high enough quality to enable organisms ranging from single-celled to more complex plants and animals to use the resource without toxic effects. In addition to this, recommendations relating to aquatic resources consider habitat and the introduction of nonnative species into the waters of the Rio Grande and associated wetlands. The recommendations are as follows:

4. Protect, extend, and enhance the structure of the aquatic habitat to the benefit of native communities.
5. Protect and enhance surface-water quality.
6. Integrate management of nonnative and native fish species in all aquatic environments in the Middle Rio Grande riparian ecosystem including wetlands, canals, and drains.

Terrestrial Resources

Recommendations affecting terrestrial resources in the riparian ecosystem focus on protection, enhancement, and restoration of communities and habitats in the riparian zone and

the floodplain. Human activities have severely impacted these portions of the riparian ecosystem. The effect of water in important ecosystem processes (e.g., disturbance, nutrient cycling, reproduction of native species, etc.) has been reduced by dams and levees that protect a highly developed floodplain. In addition, introduced species have entered plant and animal communities and become major components of the ecosystem. It is in the terrestrial portion of the ecosystem that there are the most visible needs for management, in order to replace the ecosystem processes that have been eliminated or diminished in force and scale and to protect the remaining communities from detrimental human activities. The following recommendations address management needs:

7. Protect the geographic extent of the Rio Grande bosque and avoid fragmentation of the riparian ecosystem and component habitats.
8. Protect, extend, and enhance riparian vegetation in noncontiguous areas in the floodplain.
9. Manage the buffer zone of the contiguous bosque to protect ecosystem processes, enhance wildlife habitat values and maintain rural and semirural conditions.
10. Manage livestock grazing activities in a manner compatible with biological quality and ecosystem integrity.
11. Manage activities that remove dead wood in a manner compatible with biological quality and ecosystem integrity.
12. Manage recreational activities in the bosque in a manner compatible with biological quality and ecosystem integrity.
13. Prevent unmanaged fires in all reaches of the bosque.
14. Use native plant species and local genetic stock in vegetation establishment and management efforts throughout the bosque.

15. Protect, enhance, and extend (create) wetlands throughout the Middle Rio Grande riparian zone.
16. Sustain and enhance existing cottonwood communities and create new native cottonwood communities wherever possible throughout the Middle Rio Grande riparian zone.
17. Contain the expansion of existing large stands of nonnative vegetation in the Middle Rio Grande riparian zone. At the same time, study the ecology of these stands and develop creative ways of maximizing their biological values.

Monitoring and Research

Monitoring to determine the effects of management actions is vital to the implementation of all recommendations included in this document. In addition, monitoring studies are needed to assess the ecological trends in the bosque over a long period of time as well as to provide information about the life histories of individual species. Monitoring information can be used in developing research goals that specifically address management problems. Research related to management questions should be pursued, but research addressing purely scientific goals should also be encouraged. Both research approaches will generate information that can be applied to management issues. We have made two recommendations relating to these topics:

18. Develop a coordinated program to monitor biological quality (with emphasis on diversity and abundance of native species) and ecosystem integrity (with emphasis on restoring the functional connection between the river and riparian zone) of the Middle Rio Grande ecosystem.

19. Develop a coordinated research program to study the ecological processes and biotic communities that characterize the Middle Rio Grande riparian ecosystem.

Implementing and Revising the Biological Management Plan

Management of the Middle Rio Grande as an ecosystem requires an integrated approach. The key factors in this approach are communication among agencies and other management entities and coordination of activities that have to do with the river, riparian zone, and floodplain. Monitoring and research generate data that needs to be compiled and analyzed for application to future management activities, management plan revisions, and guidance for research.

20. Regularly review and update the Middle Rio Grande Ecosystem: Bosque Biological Management Plan.

The Middle Rio Grande—Part of a Larger Riparian System

The Middle Rio Grande is only a portion of the total river system and includes a small fraction of the entire watershed. This part of the river is dependent on what enters the system upstream, and how we manage our section affects the river downstream. While we have attempted to take an ecosystem approach to management of the Middle Rio Grande, we recognize that to be truly comprehensive, the whole river and its watershed should be included. The final recommendation deals with how this management plan could be readily adapted to fit into a larger management scheme for the entire Rio Grande.

21. Integrate resource management activities along the Rio Grande and within the contributing watersheds to protect and enhance biological quality and ecosystem integrity.

Public Outreach and Education (added to 2005 Update)

22. Develop outreach initiatives through public education programs and events, and community participation activities and projects, to broaden public understanding of and generate more active interest in bosque restoration and river EM in the Middle Rio Grande.

Appendix F: Climate Change & Water Resources in New Mexico

From *Climate Change and Water Resources in New Mexico* (Gutzler, 2007):

A. Implications For Water Management

Climate change is hardly the only important factor in the development of sustainable water resources in New Mexico. State water managers must plan for increasing population, economic development, ongoing depletion of ground water reservoirs, and the desire to maintain a healthy riparian environment, as they administer water rights within the established legal framework. The state of New Mexico has an overarching legal obligation to satisfy annual downstream delivery requirements to the neighboring state into which each of our major rivers flows. The state's consumptive use of water from the Rio Grande, for example, is limited by an agreement called the Rio Grande Compact. New Mexico's annual delivery obligation to Texas depends on the stream flow that passes the Otowi gage below Los Alamos. During years with low flows both the downstream delivery requirement and New Mexico's allowed depletion are reduced, so the pain of drought is shared between New Mexico and Texas. The extra water flowing past Otowi during high flow years (anything more than 1,250,000 acre-feet per year) all goes to Texas.

The changes in climate predicted for the 21st century would cause an overall decrease in flow in New Mexico's snow-fed rivers. The annual flow at Otowi is highly correlated with snowpack in southern Colorado. As snowpack decreases in a warmer climate, we should anticipate that future Otowi index flows will decrease substantially. Low annual Otowi flows (less than 750,000 acre-feet per year) have occurred during almost half of the years since the Rio Grande Compact was negotiated. It is likely that the warming trends cited above will shift

most of the future Otowi flows into the low flow category, with a significant overall downward trend during the 21st century. Superimposed on this trend, we should anticipate intermittent severe drought episodes, during which flows are even lower.

The implications for water management in all of New Mexico's major river valleys are potentially profound. Consider the water budget for the Middle Rio Grande valley downstream from Otowi. The principal inputs of water to the Middle Rio Grande are inflows from snowpack in southern Colorado and from tributary inflows. These inputs are predicted to decrease in a warmer climate. The principal depletions include evaporation from open water (in the river and in reservoirs, including Elephant Butte), transpiration from plants, and withdrawals by people. All of these depletions will likely increase, especially considering the new extraction and treatment plant now under construction by the city of Albuquerque. But the downstream delivery obligations to Texas are not changing. So, each of the predicted climate-forced trends in this budget will exacerbate water management challenges within the Middle Rio Grande valley. Although this discussion has focused on the Rio Grande, all of New Mexico's major snow-fed rivers (including the Pecos, Canadian, Gila, and San Juan Rivers) will experience similar climatic effects, leading to predictions of lower flows. Will we have the foresight to plan for shortages of water during severe droughts and lower river flows in the years to come?

B. Hard Choices for New Mexicans

Most of the scenarios used by climatologists for 21st-century predictions assume that per capita greenhouse gas emissions will decrease over the coming decades, but we don't really know how this will be achieved. Presumably some mix of conservation, increased efficiency, alternative energy development, and carbon sequestration will move us toward a lower-

emissions future. Accomplishing this while maintaining the energy supplies required for a healthy economy will be a huge challenge. Several western governors (including ours) have promoted a regional effort to decrease greenhouse gas emissions. On the national level, however, government policy to date can only be characterized as inaction based on willful disregard of our best science.

From *New Mexico's Climate in the 21st Century - A Great Change is Underway* (Gutzler, 2020):

Projected Change Over the Next Half-Century:

“Consider that a downward trend in streamflow, with continued large natural variability, makes drought periods more severe. I do not expect New Mexico to dry up due just to a slow decline in streamflow as the climate warms. Instead, I am concerned that future drought periods, whenever they occur in the decades to come, will be hotter and drier than droughts of the past. Increased severity of multi-year droughts poses a major risk for humanity and ecosystems in New Mexico.”

Appendix G: Middle Rio Grande Ecosystem Bosque Biological Management Plan (1993)

Selected excerpts from the BBMP on bosque ecology, hydrologic regime, ESA habitat, and trends for the ecology under current management at that time and still relevant today.

1. Ecological Processes

Lack of active change in management would continue to affect several ecological processes, including decomposition and nutrient cycling. As stated earlier in this report, introduced Russian olive fixes nitrogen, and produces leaf litter that has significantly more nitrogen than cottonwood leaf litter. As a result, soils beneath Russian olive contain more nitrogen than soils beneath cottonwood. A nearly complete takeover of the northern bosque by Russian olive would therefore add increased nitrogen to the apparently nitrogen-limited decomposer community in the non-flooded riparian forest there and increase the amount of nitrogen available for plant life. Continued absence of overbank flooding in the northern reach of the Middle Rio Grande riparian zone would allow litter build-up to continue. This would have several consequences. One will be enhancement of fire potential particularly in dry years and decades. Another will be the continued build-up of a soil horizon with an increasingly deep layer of leaf litter above it. While horizon buildup will enhance that habitat for many invertebrates, it will also inhibit the germination of seeds covered over by dead leaves as is now the case. Another consequence of the lack of flooding would be the continued limiting of storage water in the riparian forest soil (Reily and Johnson 1982 cited in Scott et al. 1993) and recharge of the alluvial aquifer (Johnson et al. 1976 cited in Scott et al. 1993). This will continue to affect the decline of native riparian vegetation.

2. Hydrologic Regime - Effects on the Riparian Vegetation

Present conditions in the Rio Grande include levees, dams, and channelization. Cochiti Dam has had a major impact on the river and riparian zone below it by reducing peak flows and sediments in the system. The timing and duration of releases of peak flows may not be suitable for germination and establishment of native species (Fenner et al. 1985, Szaro 1989). Levees have restricted the lateral movement of the river, and channelization has occurred along some reaches. The consequence of all these actions for native riparian vegetation, once areas have become vegetated, is a drastic reduction in numbers of sites and opportunities for further recruitment (Fig. 29; Howe and Knopf 1991, Milhous et al. 1993).

As stated, probably as a result of the construction of Cochiti Dam, the northern reaches (Cochiti and Albuquerque) of the Middle Rio Grande are now degrading. Because sediments are trapped at the dam, released waters have high potential for erosion and the channel is deepening. Vegetation is stabilizing the riverbanks, enhancing the narrowing, and deepening of the channel. Comparison of 1935 to 1989 aerial photos indicates that the riverine, or river channel portion of the Middle Rio Grande, has been reduced by 49% (8,920 ha [22,032 acres] in 1935 to 4,347 ha [10,736 acres] in 1980; see Fig. 30). For native riparian plant species, there is little or no recruitment, except for banks and bars adjacent to the main channel of the river that are exposed after high flows. These areas may be scoured by the next high flows and are often subject to mowing to maintain the floodway. This lack of recruitment is a consequence of the presence of existing riparian vegetation and the absence of high magnitude flows to remove established vegetation and create barren areas for colonization.

In the southern reaches (Belen and Socorro) of the Middle Rio Grande, large amounts of sediment are introduced into the system at the confluences of the Rio Puerco and Rio Salado

(Lagasse 1980). Some areas are without levees, and waters spread out there and deposit sediments. In these reaches, decreases in peak flows prevent sediments in the channel from being moved downstream. At the southern end of the Middle Rio Grande, Elephant Butte Dam has caused the base elevation to rise upstream enhancing deposition, channel widening, river braiding, and aggrading in some areas. Sediment deposition creates substrate for recruitment of native cottonwoods and willows and introduced salt cedar.

Fragmentation is occurring on the Middle Rio Grande at the plant community level. Marsh and wet meadow habitat have been fragmented and reduced in size, thereby causing a reduction of wildlife species that depend on this habitat (i.e., leopard frog, New Mexican jumping mouse). The anticipated continued decline in Rio Grande cottonwood-willow communities would lead to significant loss and fragmentation of this plant community in the foreseeable future. Fragmentation of the entire riparian ecosystem by private residential development is a concern. Wilcove et al. (1986) summarized the management implications of fragmentation with the following conclusions: "Finally, we believe that over the long run virtually all temperate zone reserves will require active management to prevent or overcome the ecological imbalance created by fragmentation and human activity. A good reserve design will lessen but rarely eliminate the need for management. Such management may take several forms, including controlled treatment of the vegetation to preserve particular successional stages; the elimination of foreign species; or the culling of populations of 'nuisance' animals (cowbirds). Conservationists must realize that the battle is not over once the land has been saved. Indeed, it has just begun."

3. Habitats for Special Status Species

Currently (1993) there are about twenty species of plants and animals in the management area that, because of their apparent rarity or declining population trend, have state and federal designations such as "endangered" and "threatened." In addition, there are several species which are designated as candidates for federal listing or have been determined by us to need special management considerations. The federally listed species are protected by the Endangered Species Act (Act). The initial stated purpose of the Act is "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved." Likewise, a goal of listing State of New Mexico endangered species, under the Wildlife Conservation Act, has been to protect habitats. Although most of the focus of implementing these Acts has been toward individual species, the overall long-term intent is to protect national and regional biodiversity.

4. Trends for Hydrologic and Riparian Conditions under Current Management Conditions

Northern (Cochiti and Albuquerque) Reaches of Middle Rio Grande

These reaches will continue to be sediment-poor because of Cochiti and Jemez Canyon dams. The continued restriction of high flows would prevent major floods from scouring large areas and removing vegetation. Bank stabilization by vegetation would continue causing the channel to continue to deepen rather than to broaden. Bed armoring has been observed along some stretches of river in the north, indicating that equilibrium between sediment input and sediment load has been attained. There would be little or no recruitment of native plant species that require open substrate and periodic flooding for germination and growth. There would continue to be senescence and death of cottonwoods and tree willows, with exotic species such as Russian olive, Siberian elm, white mulberry, and others that have potential for germination in the understory, becoming dominant species. Native species in the northern reaches of the

Middle Rio Grande Valley would eventually be replaced by Russian olive, Siberian elm, and other nonnative trees.

Southern (Belen and Socorro) Reaches of Middle Rio Grande

This part of the system would continue to be sediment-rich because of input from tributary streams. Because of water controls upstream, there will be a lack of high flows to move those sediments downstream. There will be continued aggradation of the stream channel, resulting in formation of substrate for native and introduced species and burial of young colonies by sediments. Depending on the time of high water, native or introduced species will become established on the open substrate. While this area has the highest potential for large-scale recruitment of new cottonwood and willows, it also has high potential, under current water management, for the continued expansion of salt cedar.

Appendix H: BBMP Update (2005)

All text in this section was sourced directly from the document.

“The sound-bite version of what needs to be done? Protect the existing levees but remove jetty jacks wherever you can. Level off the banks wherever possible to facilitate overbank flooding. Get peak flows back up, with a flood every three to four years. Look for places to return sediment to the system. Thin the riparian forest—remove non-natives and even dying cottonwoods—and open it up to native cover like Saltgrass. It would also be good to identify potential wet meadow areas, and eventually do moist soil management up and down the valley.”

Paul Tashjian, Hydrogeologist, U.S. Fish & Wildlife Service

“We must provide overbank flooding potential. If you don’t have high flows on a regular basis, you can’t maintain the river. Sandbars will become vegetated, armored, and channel capacity will be reduced. You have to have channel-forming discharges. You can recreate all the quality there used to be within the levees. It will be scaled down, but you can achieve it. The restoration projects that are in the works are steps in the right direction, but you’ve got to have higher flows. We need to educate people about the dangers of living right on the banks of the river. There are half-million-dollar homes with absolutely no respect for potential floods, and they constrain the higher flows needed by the system.”

Dick Kreiner, U.S. Army Corps of Engineers

An Ecosystem Approach

The listing of the Rio Grande silvery minnow as an endangered species in 1994 resulted in a schism in thinking relative to environmental restoration in the Middle Rio Grande. The legal mandate to protect a single species took immediate precedence over the more encompassing approach represented by the Bosque Biological Management Plan. Divergence from a holistic perspective eventually polarized public opinion, initiated a chain reaction of lawsuits that set resource agencies against each other, and exhausted critical reserves of water to effect uninterrupted river flows.

We are beginning to recognize that the focus on single species restoration has sent us on a costly ten-year detour, and that rather than doctoring the symptom—i.e., trying to halt the decline of one or two species—the wiser course is to protect the system’s natural hydrologic processes, for they are key not only to the health of the river, but to the well-being of all of its attendant species. Although endangered species concerns are still driving ecological appropriations and efforts, the actions currently (2005) being proposed for recovery of the silvery minnow are starting to echo the strategies charted in 1993 to revive the Rio Grande bosque: U.S. Fish & Wildlife Service’s Biological Opinion now proposes both water and non-water solutions, including the restoration of riparian habitat along the river. Gradually, inexorably, we are moving toward an ecosystem approach.

Getting Real

These are broad stroke directives guiding managers toward bosque resilience-planning with recommendations from 2005, yet to be fulfilled.

Since 1993, researchers, agency representatives, river restorationists and water managers in countless combinations and forums have been making recommendations about what must happen if ecological integrity is to be returned to the Middle Rio Grande. Their thinking has served, again and again, to underline exactly what the authors of the Bosque Biological Management Plan suggested more than a decade ago: to effect real healing we must consider hydrologic, morphologic, biologic, sociologic, legal, and administrative processes, as well as the river’s capacity to adapt to change. That means cultivating an active connection between the river and the aquifer; providing variations in flow; and ensuring that the stream has sufficient lateral movement to transport sediment and distribute nutrients and biotic

communities across its floodplain. In a populated river basin, though, it also means respecting the carrying capacity of the region, assuring the safety of its residents and property, guarding water quality, and guaranteeing that enough flow passes downstream to meet compact deliveries and vested water rights.

Priorities for ecosystem restoration fall into three general categories, two of which can be addressed through the existing recommendations of the Bosque Biological Management Plan. The first category is anchored to the re-establishment of a more naturally functioning river system through a mimicked hydrograph, attention to fluvial processes, and the interaction of groundwater and surface water. The second category addresses the need for integrated management along the Rio Grande and within its contributing watersheds, and involves data archiving, project monitoring, peer review, cooperative funding, and an active/adaptive approach to resource management. Finally, Recommendation #22 has been added to the management plan's original twenty-one, proposing the development of an outreach program to promote a comprehensive water conservation ethic, better communication with media and decision-makers, and ways to involve community in ecosystem restoration. These suggestions represent the wisdom of many thoughtful people, and the gold panned from thousands of hours of fieldwork and discussion. They reflect not only the difficult recent past, but also a more hopeful future.

Appendix I: Middle Rio Grande Project History (Bureau of Reclamation)

A selection of relevant sections from *A History of the Bureau of Reclamation, Middle Rio Grande Project*, by Andrew Gahan (BOR), 2013. The sections below provide a timeline and explanation of the series of extensive flood control and channelization engineering projects rendering legacy impacts on the ecology of the study area. The Rio Grande Project was initiated with a million-dollar contract (1950's dollars). The BOR project history does not include the details of the construction of the Cochiti Dam, because it was an Army Corps of Engineers contract with a 1-billion-dollar price tag, completed in 1973. Cochiti Dam sits at the north boundary of the MRGCD.

1. Location

Located in the north-central part of New Mexico, the Middle Rio Grande Valley extends from the Colorado-New Mexico state line to the backwaters of Elephant Butte Reservoir. Elevations within the Rio Grande drainage area vary from over 14,000 ft. to 4,100 ft., while annual precipitation varies from 4 to 18 inches. The Bureau of Reclamation, Middle Rio Grande Project, is located within the boundaries of the MRGCD. District property runs north-south along the Rio Grande for 145 miles and varies in width from one to five miles. The district encompasses 277,760 acres with 123,000 acres of irrigable land, of which roughly 60,000 acres are irrigated. The Middle Rio Grande Project exists in Bernalillo, Sandoval, Socorro, and Valencia counties and includes the major urban center of Albuquerque. Conservancy district responsibilities also consist of delivering water to six Pueblo communities: Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta, serving over 8,000 irrigable acres.

2. Middle Rio Grande Conservancy District – 4 Divisions

The MRGCD consists of four divisions (Cochiti, Albuquerque, Belen, Socorro) encompassing about 150 river miles from Cochiti Dam to the northern boundary of Bosque del Apache National Wildlife Refuge (Figure 2). The study area also included the Low Flow Conveyance Canal (LFCC) and irrigation channels within Bosque del Apache National Wildlife Refuge. Data collected in these two systems (Bosque del Apache National Wildlife Refuge and LFCC) were grouped and analyzed as Socorro Division data. About 834 miles of irrigation canals, laterals, and acequias and 386 miles of interior and riverside drains provide a network of irrigation systems throughout the Middle Rio Grande Valley (Shah 1992).

Cochiti Division originates directly below Cochiti Dam and extends downstream through Cochiti, Santo Domingo, and San Felipe pueblos, terminating at Angostura Diversion Dam. Irrigation water is transported on both the east and west sides of the Cochiti Division. Human encroachment into the Rio Grande riparian corridor is minor relative to downstream divisions. There is only one drainage return in this Division. Angostura Diversion Dam marks the head of the Albuquerque Division, which includes Santa Ana and Sandia pueblos and continues downstream to Isleta Diversion Dam (IDD), Isleta Pueblo. Numerous municipalities, including Bernalillo, Corrales, and Albuquerque are served by the irrigation system of this division. Flows of the Atrisco Feeder Canal are conveyed from the east to the west riverbank via the Corrales and Atrisco Siphons. There were five drainage returns in this Division.

The development of the MRGCD irrigation system is greatest in the Belen Division. Rio Grande mainstem flows are diverted by IDD to irrigation systems that deliver water to irrigable lands stretching about forty-seven river miles downstream to just upstream of San

Acacia Diversion Dam (SADD). Irrigation returns to the Rio Grande are most numerous within this division. Drain Extension 7, which originates just south of the Rio Puerco levee at San Francisco, NM, is the northern boundary of the Socorro Division (Shah 1992). About 70% of the Socorro Division's irrigation demand is supplied by Drain 7 Extension, with additional flow provided by water diverted into the Socorro Main Canal at SADD. The LFCC originates at SADD and conveys flow about fifty-five miles downstream to its Rio Grande confluence in Elephant Butte State Park. There are no drainage returns to the Rio Grande in this division, as all interior drains discharge into the LFCC.

3. Middle Rio Grande Project History – 1948 Project Authorization

On June 30, 1948, Congress authorized the Middle Rio Grande Project as part of the Flood Control Act of 1948. In its authorization Congress provided an initial appropriation of \$3,500,000 and eliminated Chiflo Dam from the project. Congress also directed the secretary of the interior to acquire the conservancy district's debt and take possession of agricultural lands within the project owned by the state to be sold or leased to settlers for agricultural purposes. New Mexico Senator Dennis Chavez inserted an amendment stating that the federal government gives preference "to former owners who had lost title by reason of tax sales, their children, or war veterans." To emphasize the idea that the Middle Rio Grande Project was a water conservation effort, Congress directed Reclamation to find methods of controlling or eliminating invasive plant species "to reduce nonbeneficial consumption of water." The legislation also included a proviso that the operation of project works conforms to the Rio Grande Compact.

4. Project Construction – 1951 Breaking Ground

Contract Details: Construction of the Middle Rio Grande Project began in the late summer of 1951 when Reclamation awarded a \$940,115.00 contract to McGinnis Bros., Inc., for channelization of the Rio Grande from Elephant Butte Narrows to San Marcial. Prior to starting construction, Bureau of Reclamation officials met with the Corps of Engineers to develop a policy for coordinating studies of the Rio Floodway Project. Reclamation also met with representatives from the Bureau of Indian Affairs “to discuss the extent of their participation in the project, and to arrange a future meeting to consider agreements concerning contract items with regard to Indian lands.” As a final piece to the preconstruction picture, a repayment contract between Reclamation and the conservancy district was signed on September 24, 1951.

4 Divisions: Cochiti, Albuquerque, Belen, and Socorro: Reclamation divided its portion of the project into four divisions: Cochiti Division, Albuquerque Division, Belen Division, and Socorro Division. The Cochiti Division extended 22 miles from Cochiti Diversion Dam south to Angostura Diversion Dam. There are two canals in this division serving 12,675 acres of both Indian and non-Indian lands. The Albuquerque Division extended 41 miles south from Angostura to Isleta Diversion Dam. This division consists of four main canals serving 34,933 acres of irrigable lands. The Belen Division ran 64 miles from Isleta Diversion Dam to the confluence of the Rio Puerco and the Rio Grande. According to one source, “Lands in this division are served by the Belen Highline and Peralta canals. Irrigable lands in this division total 21,000 acres.” Finally, the Socorro Division extends south from the mouth of the Rio Puerco to the entrance of the Bosque Del Apache Grant and includes the San Acacia Diversion Dam. The Socorro Main Canal supplies irrigation water to about 8,500 acres.

5. Construction details from 1952 to the Project end in 1964

For the first few years of construction, Reclamation's efforts focused on channelization. This task was an attempt to repair damage to river flows brought on by decades of sediment entering the river and increasing upstream diversions. One contemporary observer noted that these conditions "resulted in raising the bed of the Rio Grande until now it is higher than downtown Albuquerque," which in turn raised underground water levels, waterlogging agricultural lands. Re-channelization took the highest priority because completion of flood and sediment control dams was well into the future. Reclamation officials estimated that 143,000-acre feet of water was lost as a result of the aggraded river channel and vegetation growth "between the south boundary of Bosque Del Apache and the Narrows of Elephant Butte Reservoir" alone.

1952: Nevertheless, project histories noted that during 1952 contractors had completed 21 miles of channelization work, and by 1953, sixty-nine percent of the second 10-mile reach of river channelization was completed, saving estimated 84,800-acre feet of water.

1954: By 1954 Reclamation had made significant progress, and the overall work effort had become routine. Contractors were nearing completion of rehabilitation work on El Vado Dam and Isleta Diversion Dam, along with nearly 140 miles of drainage works.

1955: In 1955 new work began on siphon and canal structures in the Socorro, Belen, and Albuquerque divisions. Also, that year Reclamation, at the request of MRGCD, took over control of all district operation and maintenance obligations. This agreement made Reclamation responsible for ensuring compliance with the Rio Grande Compact.

Coincidentally, the Southwest was experiencing drought conditions which severely limited water allocations from El Vado Reservoir.

In 1957 rehabilitation work on San Acacia Diversion Dam was complete and work began on Angostura and Cochiti diversion dams. Reclamation also reported completion of all project drainage works. On the Socorro Division contractors began working on rehabilitating laterals, acequias, and canals along with channelization of four sections of the river. Similar progress was made on irrigation features for the Belen and Albuquerque divisions.

In 1958 Reclamation completed rehabilitation work on Angostura Diversion Dam and began operations for “enlargement of the Rio Grande channel and installation of jetties for levee protection at and above Angostura Diversion Works.” The Angostura channel work was just part of a larger effort on channelization throughout the project where Reclamation was overseeing over fifty miles of channel improvements.

By the end of 1959 almost eighty-nine percent of irrigation rehabilitation and eighty percent of channelization work had been completed.

By the end of 1960, ninety-five percent of the rehabilitation of irrigation features and eighty-six percent of channelization had been completed.

In 1964 the final channelization job on the Belen Unit was completed, bringing the entire project’s major construction to an end.

In 1994 - The Endangered Silvery Minnow Legalities Begin

Another more complex and long-lasting controversy arose in 1994 when the U.S. Fish and Wildlife Service listed the Rio Grande silvery minnow as an endangered species. Fish and

Wildlife maintained that the designation of the silvery minnow, which was “once one of the most widespread and abundant species in the Rio Grande basin,” was the result of dam construction, water diversions, channel rectification, and removal of “aquatic plants and snags.” In other words, all the “improvements” accomplished by the Middle Rio Grande Project for the benefit of valley water users. These followed years of litigation and negotiation attempting to bring competing uses of Rio Grande water into harmony.

Late 1990's During the late 1990s, the Rio Grande basin was in the middle of a severe drought creating water shortages. These conditions led to a drastic reduction in the number of silver minnow. In 1999 the secretary of the interior issued a Rio Grande silvery minnow Recovery Plan wherein the Fish and Wildlife Service designated a critical habitat for the silvery minnow consisting of 163 miles of the Rio Grande's mainstem from Cochiti Dam south to Elephant Butte Reservoir. In November environmental groups filed suit against the Bureau of Reclamation and the Corps of Engineers over their role in diversion and storage of Rio Grande water, under the name Rio Grande Silvery Minnow et al v. Keys. The environmentalists claimed that “federal defendants” failed “to consult with FWS as required by the ESA [Endangered Species Act] jeopardized the extinction of the minnow.” A major issue in the case was the release of San Juan-Chama Project water to raise sustainable flows, which the environmentalists demanded, and Reclamation refused on the grounds that that water “was not native to the Rio Grande Basin, and the endangered species is in the Rio Grande.” As the litigation continued to drag on, Congress passed legislation restricting the use of San Juan-Chama water to meet ESA obligations on the Rio Grande.

In the meantime, Reclamation worked with basin water interests and other federal agencies to help in sustaining the silvery minnow population. Efforts continue to be made in

restoring minnow habitat and creating sanctuaries. Reclamation introduced measures to purchase water from willing sellers to maintain sustainable water flows. In 2002 Bureau of Reclamation signed a memorandum of understanding with multiple state and federal interests, including the conservancy district, “to strive for the survival and recovery of threatened and endangered species in the Middle Rio Grande while simultaneously protecting existing and future water users in compliance with state and federal laws, including compact delivery obligations.” This program, the Middle Rio Grande Endangered Species Act Collaborative Program, seeks to prevent extinction by improving habitat and conducting scientific analysis, while developing “flexible” methods of water use that serve to protect endangered species under the ESA and still serve current water users. Program projects include the Albuquerque Biological Park Refugium for rearing and breeding minnows, widening river channels, clearing bosque vegetation, and developing designs in diversion dams to aid fish migration upstream.

6. Conclusion

The silvery minnow controversy is a microcosm of the intense competition for water resources throughout the West. Water use on the Rio Grande reflects these divergent interests and the growing pressures for water on an over-appropriated river. Still the silvery minnow problem is just one representation of multiple issues concerning the Rio Grande. As Ira Clark wrote in his masterful tome on the history of New Mexico water in 1987, the issue is multifaceted:

Resolution of the problems of the Middle Rio Grande ... would impinge upon virtually every controversial water-use issue. It could arouse smoldering interstate and international conflicts over the use of the river's water, and the potentially explosive interstate rivalry between the Middle Rio Grande and Elephant Butte Irrigation District. Existing appropriative and community ditch rights, and those of the Middle Rio Grande pueblos, would have to be reconciled to the overall development plan. Urban and rural interests, and a

wide variety of competing uses, would be pitted against one another in shaping that plan.

As Clark's statement points out, multiple issues and interests encompassed Rio Grande water development. In the middle valley, the Bureau of Reclamation encountered a well-entrenched irrigation culture that goes back over three hundred years. In essence, the Middle Rio Grande Project was an attempt to rectify problems those long years of irrigation practices produced.

Appendix J: USDA All Lands Vulnerability Assessment (climate impact on ecosystem goods and services)

Climate Impacts on Ecosystem Goods and Services in SW Region

Ecosystem good or service	Description	Pathways that may affect provision	Scope of beneficiaries
Water supply	Municipal, agricultural, commercial, and in-stream uses	Direct – Reduced precipitation and increased temperatures; Disturbance regimes – Increased incidence and severity of wildfires and erosion events	Within region; onsite; downstream users (e.g., Texas and Mexico)
Recreation opportunities	Site access and availability for onsite recreation opportunities	Direct – Reduced snowpack for skiing; Vegetation vulnerability – Suitable habitat for game mammals, fish; Disturbance regimes – Degradation or enhancement of sites due to wildfire	Benefits derived onsite, but could accrue to local and non-local beneficiaries
Forage for livestock	Forage availability and appropriate for grazing	Vegetation vulnerability – Changes in range or extent of suitable forage; Disturbance regimes – Incidence and severity of invasive plants	Onsite use by within-region livestock operations
Forest products – commercial use	Commercial timber and biomass	Vegetation vulnerability – Changes in range and extent of certain plant species; Disturbance regimes – Increased bark beetle mortality; increased incidence and severity of wildfire	Wood product market participants, ranging from local to global
Forest products – personal use	Fuelwood, food, and forage	Vegetation vulnerability – Changes in range and extent of certain plant species; Disturbance regimes – Increased bark beetle mortality; increased incidence and severity of wildfire	Mostly residents within the region, particularly those close to forests
Air quality	Forests as a source (dust, smoke) and a sink for emissions	Disturbance regimes – Increased smoke from wildfires	Local and regional residents within regional airshed
Climate regulation	Forests as a carbon sink and carbon sequestration option	Vegetation vulnerability – Reduced biomass/carbon sequestration; Disturbance regimes – Increased emissions from wildfire; loss of biomass due to bark beetle mortality	Global
Biodiversity and non-use species	Plant and animal genetic resources; non-use values for plant and animal species (e.g., cultural, spiritual, and existence values); biomass input for forest products and recreation opportunities	Direct – Loss of aquatic habitat due to reduced surface water flows; change in climate conditions for certain species; Vegetation vulnerability – Change in range or extent of habitat; Disturbance regimes – Wildfire; invasive plants; bark beetle mortality	Values accrue to residents within and outside the region
Spiritual, cultural, and historic significance	Sites, species, and landscape characteristics that hold spiritual, cultural, or historic value	Vegetation vulnerability – Change in range or extent of plants or habitat for animals for cultural and spiritual uses; Disturbance regimes – Damage to cultural sites from wildfire	Spiritual site users (within region); residents within and outside the region with cultural and historic ties to forests in the region
Offsite amenities	Viewsheds and landscape characteristics that hold aesthetic value that can be enjoyed offsite	Vegetation vulnerability – Change in vegetation composition of land adjacent to private properties; Disturbance regimes – Effects of wildfire on desirable viewsheds	Residents adjacent or close to forests

Source: (Borchers, 2021)

Appendix K: Cottonwood Age Class Rating

Riparian and Wetland Vegetation Communities - Cottonwood age class indicator rating

Key Attribute	Indicator	Poor	Fair	Good	Very Good	S ¹	R ²	Current ³	Trend ⁴	Future ⁵
Dynamic Patch Mosaic (DPM) - Vegetation	[11] Cottonwood age classes	90% of stands mature or old age classes.	70% of stands mature or old age classes.	50% of stands mature or old age classes; 50% of stands advanced or regeneration (poles) or saplings.	All age classes present and each representing approximately 25% of the stands.	Exp	3	Overall: P R1: U R2: P R3: F R4: P	SD	G

¹ S= Ratings Source

Est = Estimated; Exp = Expert Knowledge; Res = Onsite Research

² R = Current Indicator Measurement Reference

1= Stream gauge data; 2= GIS analysis of Hink and Ohmart MRG vegetation maps from 2002; 3= Tree ring studies (ages of most trees exceed 50 years because of synchronous reproduction events with channel stabilization with jetty jacks beginning in the 1950s); 4= Current amount >40% (ERM & MH NHHM); 5 = Hink and Ohmart Transects (HAI, USACE); 6= GIS analysis of ownership: federal wildlife refuges and state parks reflect protection (as of 2014, 34% or 2720 ha out of 7640 ha).

³ Current = Current Viability Rating

VG = Very Good; G = Good; F = Fair; P = Poor; U = Unknown

Sub-reaches designated R1 through R4, where R1 = Cochiti Division, R2 = Albuquerque Division, R3 = Belen Division, R4 = Socorro Division (refer to map on page 3 for locations of divisions).

⁴ Trend = Trend in Viability Rating

F = Flat; MD = Mild Decrease; SD = Strong Decrease

⁵ Future = Future Desired Rating

VG= Very Good; G = Good

⁶ Estimate based on limited mapping

⁷ Rated as Very Good but vegetation includes exotic species

⁸ Includes tribal lands

Riparian and Wetland Vegetation Communities section. Cottonwood Age Class Viability Assessment. Indicator is cottonwood age class*. Red = 'poor' overall current rating. Green = 'good' future rating. *2015 Cottonwood Age Class Metadata: Cottonwood age class viability ratings are based on 4 types of data: 1) stream gauge data; 2) GIS analysis of MRG vegetation maps from 2002; 3) Tree ring studies (ages of most trees exceed 50 years because of synchronous reproduction events with channelization stabilization with jetty jacks beginning in the 1950's); and 4) Current amount >40%

Appendix L: Cottonwood Ecology

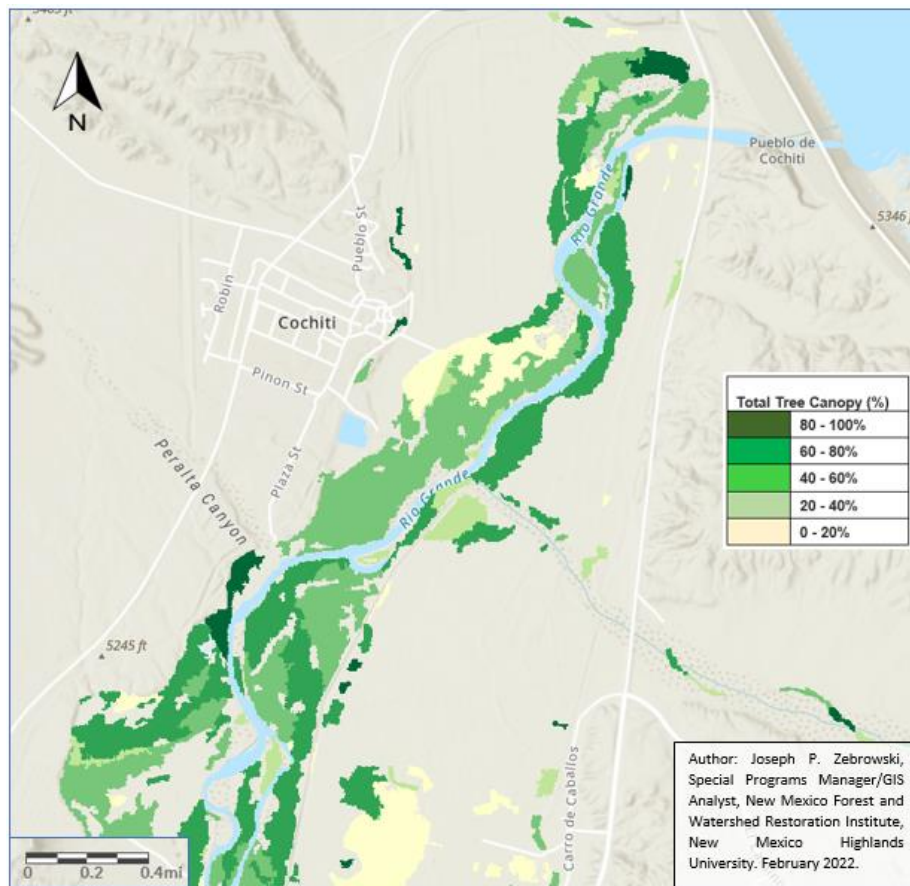
The dominant overstory tree species in this ecosystem is the Rio Grande cottonwood, with a lifespan of about one hundred years (Cartron et al. 2008; Whitney, 1996). Cottonwood regeneration requires conditions provided by overbank flooding for seeds to germinate naturally (Howe, 1991; Whitney, 1996; Cartron et al., 2008; Crawford et al., 1993; Muldavin et al., 2015). The conditions for natural cottonwood germination are not being met in this ecosystem (Cartron et al., 2008; Howe, 1991; Muldavin et al., 2015). In 1991 an article was published in the *Southwestern Naturalist*, by Howe and Knopf, On the Imminent Decline of Rio Grande Cottonwoods in Central New Mexico. The Howe article was published in the years leading up to the BBMP publication and listing of the endangered silvery minnow. Howe predicted trends of significant decline in cottonwood species in the study area, with predicted increases in nonnative species dominance (Russian olive and salt cedar):

The combination of a paucity (scarcity) of cottonwood regeneration... the rapid colonization during this century of Russian-olive (*Elaeagnus angustifolia*) and salt cedar (*Tamarix chinensis*) into the valley, and current river channel management practices suggests that the Rio Grande riparian woodland will become dominated by the exotic shrubs over the next 50 to 100 years. To assure the continued survival of the cottonwood riparian community along the Rio Grande, resource managers need to implement strategies to enhance cottonwood regeneration and survival and to control the spread of exotics.

Cottonwood Canopy Density

The current tree canopy density of the study area can be viewed as a series in Appendix D. The first map section below conveys forest canopy density along the first few miles of the study area, at the northern boundary with Cochiti Dam and Cochiti Pueblo. This map series was developed in 2022 for this study by New Mexico Forest and Watershed Restoration Institute (NMFWRI). These maps provide a current view of the extent of remaining bosque

canopy resources in the study area. The study area is too large to effectively view on an 8x10 page frame, so it is presented as a series. This is the most comprehensive canopy cover density map of the study area known to be available publicly at this time. The NM Riparian Map (NMRipMap) was the data source.



Historical Comparison of Canopy Density in the Study Area - 1918 versus 1982/1989

A historic comparison of cottonwood population canopy density trends in the study area from 1918 to 1982/1989 can be reviewed in Figure 6 (Crawford et al., 1993). The table illustrates a historical comparison of the areal extent in hectares (and acres) of cottonwood, Russian olive, salt cedar, Saltgrass meadow, and marsh for selected reaches and periods. One stark statistic from this table is the bosque losing over 40% of cottonwood canopy density in

the decade following the completion of Cochiti Dam (1973); a decline of cottonwood population from 37,000 acres to 20,000 reflects a huge initial impact to the ecology of the study area (Crawford et al., 1993).

The 1918 data was originally sourced from U.S. Reclamation Service Maps from 1992. Data for the 1982 and 1989 numbers originally came from a publication by Hink and Ohmart (1984) and the U.S. Bureau of Reclamation (1993 b). Note that the acreages from '82/'89 excluded 6,323 acres of low shrub and herbaceous vegetation (mostly salt cedar and predominantly in the Bernardo to San Acacia Reach) because this vegetation class may not have been identified in the 1918 survey.

	Cottonwood Dominated Timber and Brush	Russian Olive	Salt Cedar	Saltgrass Meadow	Marsh/ Standing Water
1918					
Cochiti to Bernardo	7,053 (17,422)	---	---	↓	1,392 (3,439)*
Bernardo to San Acacia	353 (872)	---	---	19,677 (48,603)	59 (146)
San Acacia to San Marcial	7,354 (18,165)	---	---	↑	1,089 (2,689)
Total	14,760 (36,459)* 15,312 (37,821)†	---	---	19,677 (48,603)	2,540 (6,274)* 1,346 (3,324)†
1982, 1989					
Cochiti to Bernardo	6,543 (16,162)	335 (828)	660 (1,629)	---	267 (659)‡
Bernardo to San Acacia	137 (338)	119 (294)	605 (1,494)	---	262 (647)
San Acacia to San Marcial	1,548 (3,823)	---	5,955 (14,710)	---	1,028 (2,538)
Total	8,228 (20,323)	454 (1,122)	7,220 (17,833)	---	1,557 (3,844)
* Planimetering by Biological Interagency Team.					
† Burkholder (1928).					
‡ Includes 91 ha (224 acres) of wet meadow.					

Figure 6: Historical comparison of areal extent in hectares (acres) of cottonwood, Russian olive, salt cedar, Saltgrass meadow, and marsh for selected reaches and periods across the study area (BBMP, 1993; p. 35).