Evaluation of Hydrologic Alteration and Opportunities for Environmental Flow Management in New Mexico

October 2011

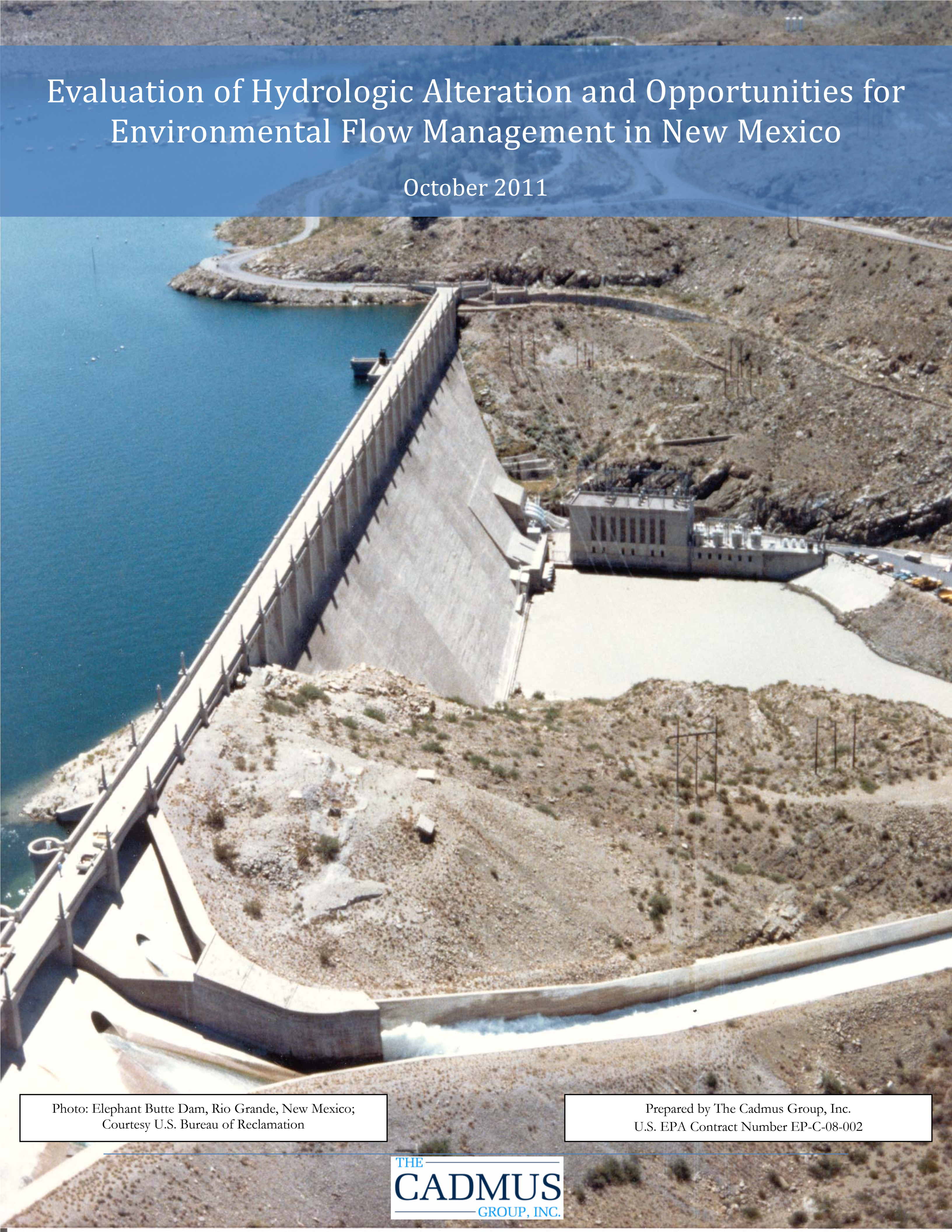

Photo: Elephant Butte Dam, Rio Grande, New Mexico;
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Executive Summary

The people of New Mexico rely on the state's streams and rivers for a variety of services. From small mountain headwaters to major river systems, these waters act as a source of drinking water, irrigate crop and pasture lands, and provide a multitude of recreational opportunities for residents and visitors. The use of such services has not come without costs. Municipal, agricultural, and industrial water use in the state has led to significant modification of New Mexico's rivers through the construction of: diversions that direct water away from natural channels; dams and reservoirs for short- and long-term water storage; and levees and other channelization structures to prevent flooding and maximize water delivery. Additionally, river modifications, groundwater pumping along river corridors, and land use changes have contributed to major changes in the natural flow pattern, or hydrologic alteration, of New Mexico's streams and rivers, such as the loss of peak flows or reduced low (base) flows.

The ecological implications of hydrologic alteration are diverse. New Mexico's sensitive riparian and wetland ecosystems are shrinking and under increasing stress from water shortages, with native vegetation outcompeted by invasive species such as saltcedar. Populations of native fish species have dwindled as a result of habitat degradation, loss, and fragmentation. Rivers such as the Rio Grande and Pecos River, which once supported a diverse array of habitat and wildlife, have been reduced to simplified pipelines for the transport of water from one user to the next. These issues are compounded by water quality changes caused or aggravated by hydrologic alteration (e.g., concentration of salts, sediment, and other pollutants). Together, these impacts can affect state and local economies, and the well-being of New Mexico's residents, through increased costs for addressing polluted waters or endangered species, and the loss of recreational opportunities.

Though hydrologic alteration has been well-documented for several of the state's largest rivers, a comprehensive review of hydrologic alteration in New Mexico has not been undertaken. This report offers a first step towards that goal by presenting an analysis of hydrologic alteration for 32 New Mexico stream sites. Trend analysis of long-term flow records was completed to identify changes in eight streamflow metrics that characterize the magnitude, frequency, duration, and timing of high and low flow conditions. Study sites span the breadth of the state and cover a range of hydrologic conditions, including high-elevation headwater streams, perennial and ephemeral snowmelt-dominated rivers, ephemeral desert washes, and major river systems.

28 of the 32 study sites included in the hydrologic alteration analysis demonstrate change in at least one flow regime component. A number of sites display patterns in the type and direction of streamflow change that are consistent with known effects of upstream river management activities. These include reductions in high and low flow magnitude for sites downstream of diversions and groundwater wells, and flow stabilization (increased low flow magnitude, decreased high flow magnitude) downstream of dams. However, hydrologic alteration exhibits variability across sites with similar types of human influence, and the application of more sophisticated analysis methods may help to explain this variability.

Overall, results of the hydrologic alteration analysis indicate that: 1) hydrologic alteration is a widespread issue throughout New Mexico; 2) a broad range of stream types have been affected; and 3) alteration is not limited to streams impacted by large-scale water management projects. When considered in conjunction with known and potential impacts of hydrologic alteration on stream ecology, these data paint a bleak picture for the health of New Mexico's waters. Watershed restoration and protection efforts have the potential to mitigate or prevent many of the negative ecological effects of flow alteration. Such efforts can be greatly aided by an improved awareness of the role of hydrologic alteration in the biological, chemical, and geomorphic degradation of watersheds by those involved; and so this report includes a discussion of known relationships between hydrologic alteration and watershed health.

The long-term viability of ecosystem restoration and protection in New Mexico is tied to the restoration and protection of ecologically-relevant components of the natural flow regime, termed environmental flows. The final sections of this report include discussion of innovative environmental flow programs that have been undertaken in New Mexico, such as the San Juan River Basin Recovery Implementation Program, and provide recommendations for future environmental flow initiatives. These recommendations relate to:

- Standardized classification of New Mexico's surface waters to streamline environmental flow analysis for individual stream reaches.
- The use of reach-scale biological and habitat data to develop flow alteration-ecological response (i.e., flow-ecology) relationships that are robust and transferable to similar stream reaches.
- The use of modeled or reference-site hydrologic data, or other methods, to account for climate variability when evaluating hydrologic alteration and developing environmental flow recommendations.
- The need to account for "confounding factors" (i.e., factors that drive ecological degradation regardless of flow alteration) when developing flow-ecology relationships.

The above recommendations are relevant to any environmental flow initiative, regardless of its scope (e.g., river, watershed, or state scale). The success of future initiatives depends on the ability to develop practical and ecologically relevant flow recommendations, and to identify sources of water for environmental flow management. This requires scientifically-sound analysis and effective communication between scientists, policymakers, water users, and other stakeholders so that New Mexico's streams and rivers can continue to meet the many needs of the state's plants, wildlife, and people.

1. Introduction

Look onto a river on a clear day and you will likely see water flowing calmly by. Look at the same river following an intense thunderstorm and you may see a raging torrent, or a small trickle during prolonged drought. These observations reflect the dynamic nature of freshwater flow in streams and rivers. For a given stream reach, the variability of flow takes on a characteristic pattern in time, referred to as the stream's *natural flow regime*. Aquatic, riparian, and floodplain ecological communities are shaped by the natural flow regime, and individual species have evolved to depend on the variability of freshwater flows for critical ecological functions (habitat creation and maintenance, spawning and migration cues, etc.). Conversely, humans have largely become disconnected from water use constraints imposed by the natural flow regime through river impoundment, regulated water releases, and transbasin water transfers. These and other activities, such as diversion of water to offsite users, have the potential to drive *hydrologic alteration*, or changes to the natural flow regime.

The natural flow regime is characterized by the magnitude, frequency, duration, timing, and rate of change in baseflows, high flows, floods, and other hydrologic events (Poff, et al., 1997) (Figure 1). Its role in maintaining the ecological integrity of streams, riparian areas, wetlands, and floodplains has come into focus in recent years. A nationwide assessment of hydrologic alteration conducted by the U.S. Geological Survey (USGS) identified flow alteration in 88% of assessed streams and highlighted hydrologic alteration as the primary variable responsible for biological degradation of fish and macroinvertebrate communities (Carlisle, Wolock, & Meador, 2010). Other studies have linked hydrologic alteration to invasion by non-native species and shifts to upland species in riparian and floodplain areas (Poff & Zimmerman, 2010). The U.S. Environmental Protection Agency (EPA) has identified hydrologic modification of streams from water management activities as the second leading source of designated use impairments across the U.S. (U.S. Environmental Protection Agency, 2009).

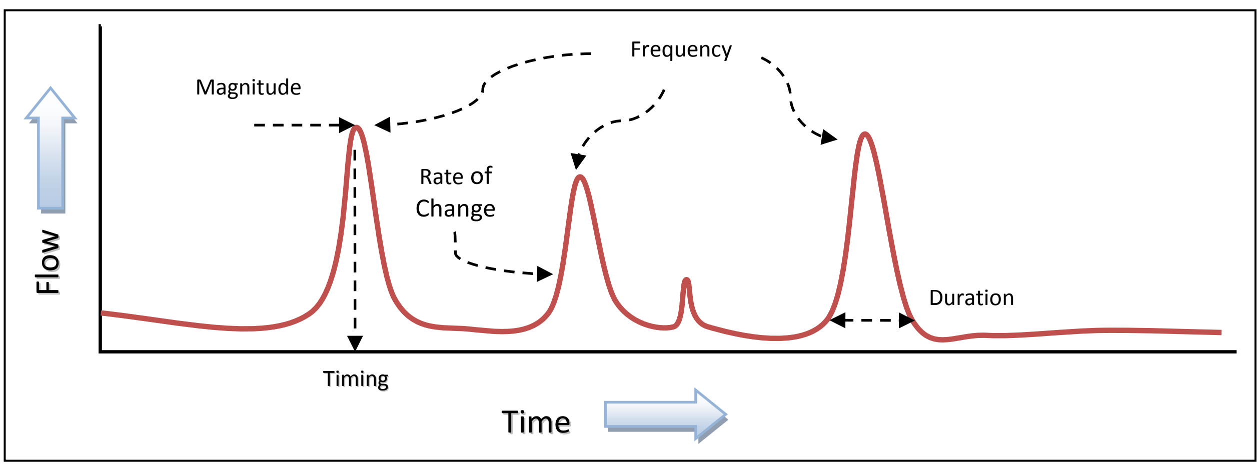

Figure 1. Illustration of the 5 characteristics of the natural flow regime (magnitude, frequency, duration, timing, and rate of change) for high flow events.

Improved understanding of the extent and consequences of hydrologic alteration has spurred many scientists, water resource managers, and policymakers to call for the integration of *environmental flow standards* into the existing water quality management framework (Arthington, Bunn, Poff, & Naiman, 2006; Poff, N L, et al., 2010). Environmental flow standards are intended to maintain the ecologically important components of the natural flow regime that allow humans to optimize the benefits of a healthy stream. Environmental flows programs are increasingly being viewed as a key mechanism for conserving or restoring the ecological function of stream systems.

Arid and semi-arid climate conditions predominate throughout the State of New Mexico, and a high demand for water exists relative to supply. Much of the state's population and industry depend on surface flows to meet water needs. All of New Mexico's surface water is fully appropriated through water rights claims and interstate compacts, and additional demand is met through extensive groundwater pumping. Until recently, the effects of water use on the natural flow regime have been overlooked or disregarded. Research and monitoring have begun to uncover the extent of the issue, identifying hydrologic alteration on portions of the state's largest rivers, including the Rio Grande (Molles, Crawford, Ellis, Valett, & Dahm, 1998) and San Juan River (Graf, 2006). Such studies have linked flow alteration to the disappearance of New Mexico's sensitive riparian and wetland ecosystems and native fish populations. The reduced ability of streams with altered flow regimes to support aquatic life has contributed to the designation of multiple streams as "impaired waters" on the state's Clean Water Act 303(d) list. In total, hydromodification and flow alteration are identified as sources of impairment on over 1,200 miles of the New Mexico's streams and rivers (New Mexico Environment Department, 2010).

In 2010, the New Mexico Environmental Flows Workshop brought together scientists, policymakers, and stakeholders with a vested interest in the development of environmental flow standards in the State of New Mexico. At this event, attendees embarked on the process of evaluating the condition of New Mexico's streams and rivers to identify opportunities for environmental flow restoration and protection. The need for a statewide assessment of hydrologic alteration was a key outcome of the 2010 workshop. This report presents results of hydrologic alteration analyses for 32 New Mexico stream sites and discusses the ecological significance of these results. This document is intended to serve as a resource for those interested in the scientific basis for environmental flows policy in New Mexico and other states, and as a source of information for future assessments of watershed health.

EPA's Healthy Watersheds Initiative

This report was made possible through a grant from EPA's Healthy Watersheds Initiative. The Healthy Watersheds Initiative is an effort launched by EPA to protect high-quality aquatic ecosystems through:

- A systems-based approach to watershed assessment;
- A renewed focus on maintaining healthy waters and ecological integrity;
- Collaboration between federal, state, tribal, local, and non-governmental organizations;
- Technical assistance that supports healthy watershed assessment and conservation.

A major component of watershed assessment under the Healthy Watersheds framework is the characterization of the natural flow regime and evaluation of hydrologic alteration. This report describes relationships between hydrologic alteration and watershed health parameters identified at the New Mexico Environmental Flows Workshop. Additional information on this and other healthy watersheds topics can be found on the Healthy Watersheds Initiative website (http://www.epa.gov/healthywatersheds).

2. Hydrologic Alteration Analysis Study Design

What Sites Are Assessed?

New Mexico's surface waters are divided among five USGS-defined hydrologic regions (Figure 2). The bulk of the state's land area is part of the Rio Grande Region (Region 13) and its two major river basins, the Rio Grande basin and the Pecos River basin. The northeastern portion of New Mexico is predominantly drained by the Canadian River, part of the Arkansas-White-Red Region (Region 11). Northwestern New Mexico sits within the Upper Colorado Region (Region 14) and is entirely drained by the San Juan River. The New Mexico portion of the Lower Colorado Region (Region 15) includes the headwaters of the Little Colorado River and one of its major tributaries, the Gila River, in the southwest. Additionally, the headwaters of the Texas-Gulf Region (Region 12) extend into a small portion of eastern New Mexico.

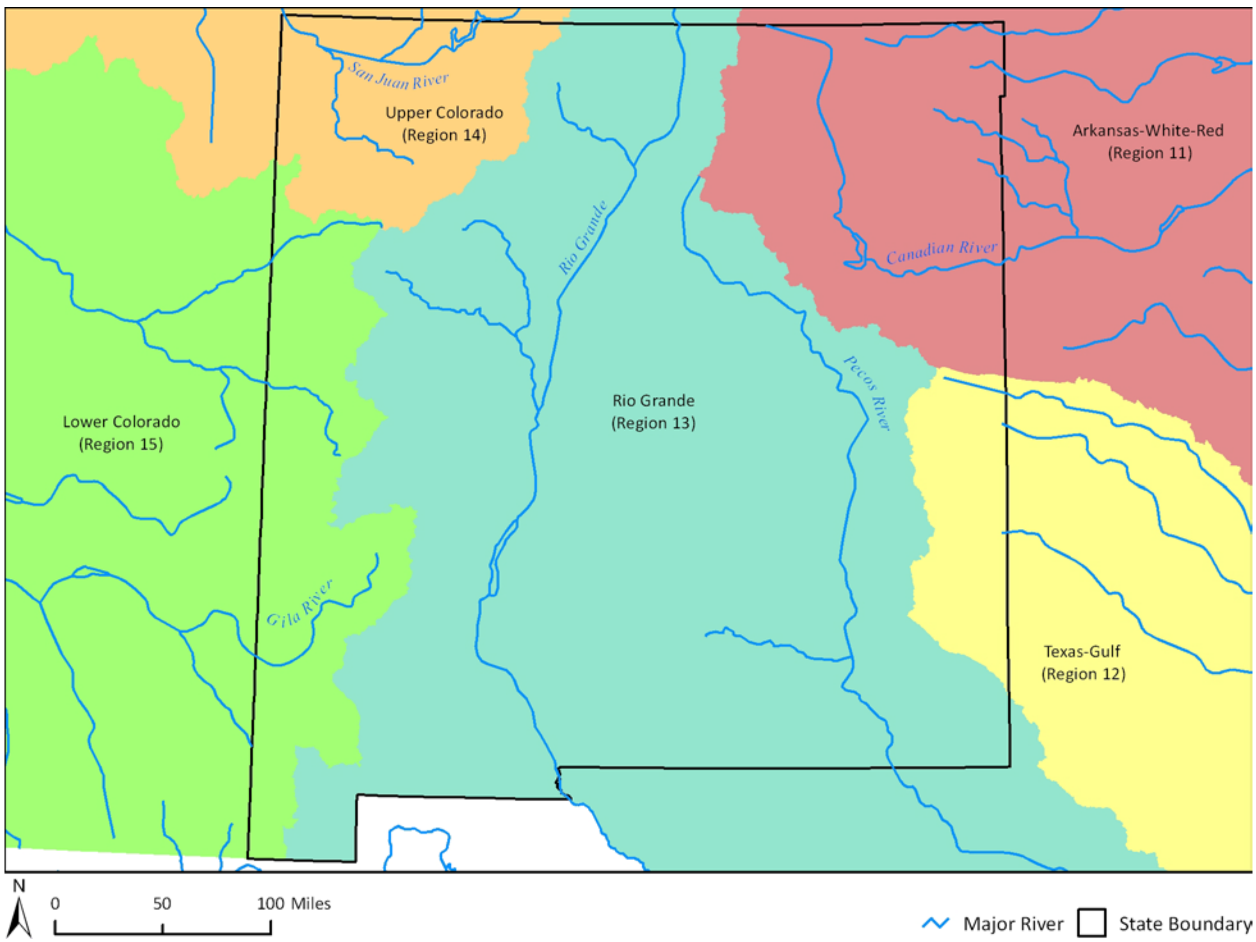

Figure 2. USGS hydrologic regions of New Mexico.

Hydrologic conditions within New Mexico reflect the state's topographic and climatic variability (Figure 3). High elevation headwater regions receive the majority of annual precipitation in the form of snow. A deep snowpack develops over the winter months and melts with the onset of spring, driving a surge in stream and river flows through the summer. Meteorological and ecosystem conditions play a major role in determining flow characteristics (e.g., snowmelt volume and timing, peak flow) within a given year. High elevation forests in part regulate snowpack depth and melt through interception of falling snow and shading by the canopy, and drive atmospheric loss of water through evapotranspiration (ET).

Dramatic precipitation and air temperature gradients exist between New Mexico's mountains and deserts. Average annual precipitation in desert regions is as low as 6 inches (compared to over 40 inches in upper elevation areas), with much of this occurring as intense rainfall during the summer monsoon season. Consistently high temperatures allow for high ET rates, and intermittent to ephemeral flow conditions dominate in low elevation streams. Groundwater inputs to streams and rivers are variable and can support perennial reaches in otherwise arid landscapes.

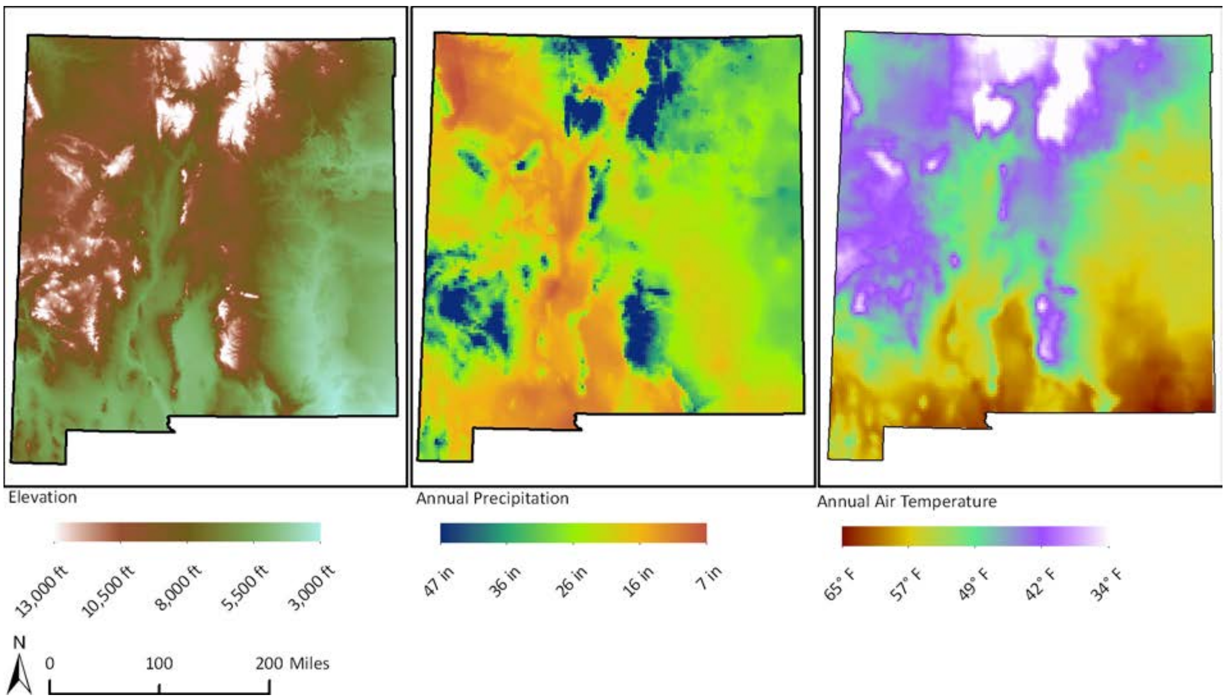

Figure 3. Topography and climate of New Mexico.

The USGS set up its first streamflow monitoring station in the late 1800s on the Rio Grande. Today, hundreds of monitoring sites are maintained throughout New Mexico as part of the USGS National Water Information System (NWIS). For this project, 32 New Mexico stream gaging sites with long-term, high-quality data were considered for analysis of hydrologic alteration[1]. Study sites are located in four of the state's five hydrologic regions within the Rio Grande, Pecos River, Canadian River, San Juan River, and Gila River watersheds and are representative of the broad range of hydrologic conditions throughout New Mexico (Figure 1; Table 1). The following is a brief description of study sites by major watershed.

[1] See comment 1 in Appendix A. Notes on Analysis Methods for additional details regarding site selection.

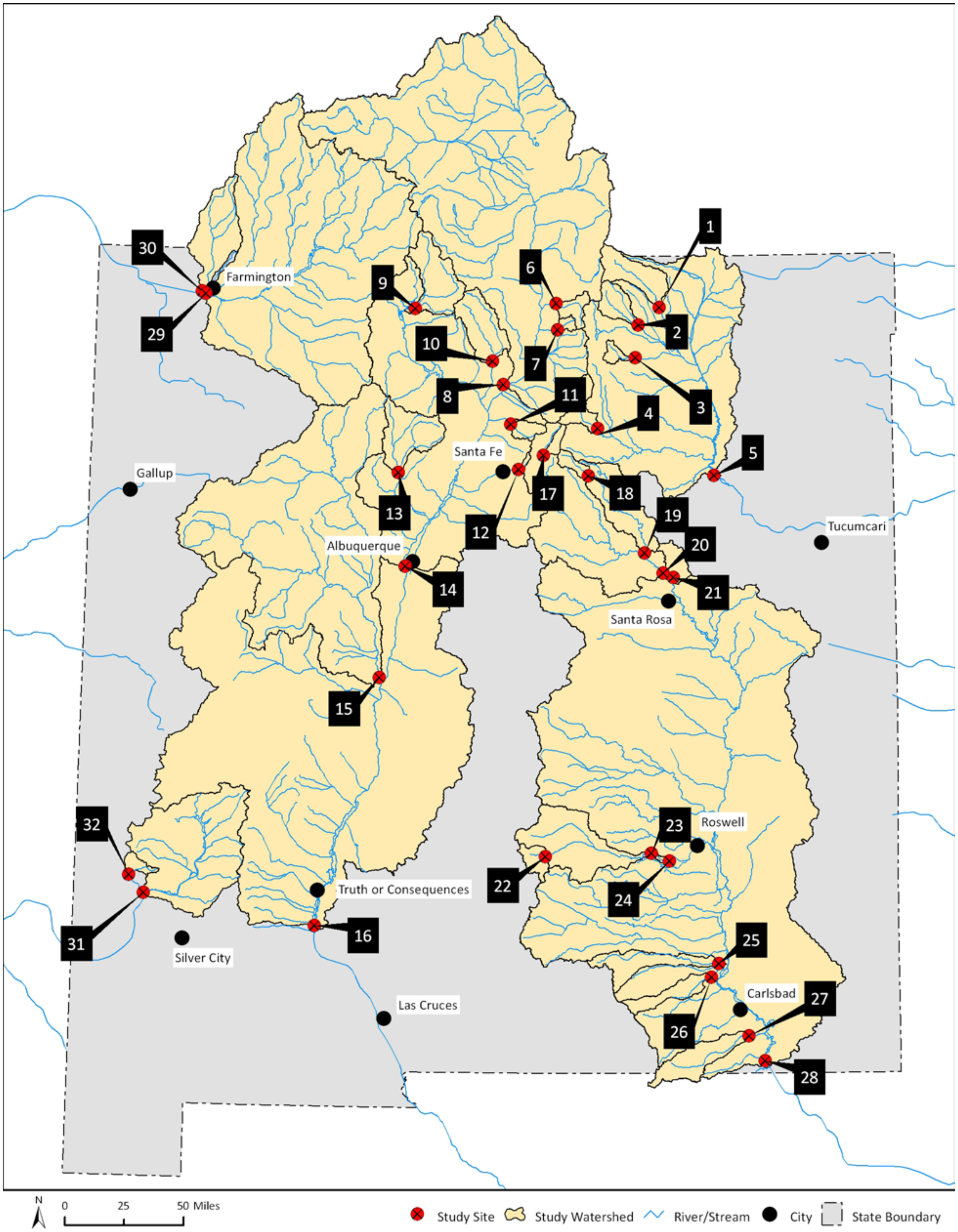

Figure 4. Map of study sites.
Label values correspond to those in the "Map Label" column of Table 1.

Table 1. Physical, hydro-climatic, and streamflow data record characteristics of study sites.

USGS Station #	Site Name	Map Label	Major Watershed	Period of Record	Missing Data	Drainage Area (mi.^{2})	Gage Elevation (ft.)	Average Annual Air Temp. (°F)[a]	Average Annual Precip. (in.)[a]	Average Annual Streamflow (in.)
07203000	Vermejo River near Dawson, NM	1	Canadian	1928 - 2010	0%	301	6,360	44	19	1
07207500	Ponil Creek near Cimarron, NM	2	Canadian	1951 - 2010	0%	171	6,630	43	18	1
07208500	Rayado Creek near Cimarron, NM	3	Canadian	1931 - 2010	0%	65	6,720	40	24	3
07215500	Mora River at La Cueva, NM	4	Canadian	1932 - 2010	0%	173	7,025	42	24	2
07221500	Canadian River near Sanchez, NM	5	Canadian	1937 - 2010	0%	5,712	4,500	47	17	<1
08265000	Red River near Questa, NM	6	Rio Grande	1931 - 2010	<1%	113	7,452	37	25	6
08267500	Rio Hondo near Valdez, NM	7	Rio Grande	1935 - 2010	0%	36	7,650	37	26	13
08279500	Rio Grande at Embudo, NM	8	Rio Grande	1913 - 2010	0%	7,460	5,789	40	17	2
08284100	Rio Chama near La Puente, NM	9	Rio Grande	1956 - 2010	0%	480	7,083	39	27	10
08289000	Rio Ojo Caliente at La Madera, NM	10	Rio Grande	1933 - 2010	0%	419	6,359	43	18	2
08291000	Santa Cruz River near Cundiyo, NM	11	Rio Grande	1933 - 2010	0%	86	6,460	40	24	5
08316000	Santa Fe River near Santa Fe, NM	12	Rio Grande	1914 - 2010	1%	18	7,720	41	23	6
08324000	Jemez River near Jemez, NM	13	Rio Grande	1954 - 2010	0%	470	5,622	42	22	2
08330000	Rio Grande at Albuquerque, NM	14	Rio Grande	1943 - 2010	0%	14,500	4,946	43	17	1
08353000	Rio Puerco near Bernardo, NM	15	Rio Grande	1941 - 2010	0%	6,220	4,722	51	11	<1
08362500	Rio Grande Below Caballo Dam, NM	16	Rio Grande	1939 - 2010	0%	27,760	4,141	47	14	<1
08377900	Rio Mora near Terrero, NM	17	Pecos	1964 - 2010	0%	53	7,890	38	37	9
08380500	Gallinas Creek near Montezuma, NM	18	Pecos	1927 - 2010	0%	84	6,880	43	25	3
08382500	Gallinas River near Colonias, NM	19	Pecos	1952 - 2010	0%	610	4,940	50	17	<1
08382650	Pecos River above Santa Rosa Lake, NM	20	Pecos	1977 - 2010	0%	2,340	4,760	49	17	1
08382830	Pecos River below Santa Rosa Dam, NM	21	Pecos	1981 - 2010	0%	2,430	4,640	49	17	<1
08387000	Rio Ruidoso at Hollywood, NM	22	Pecos	1954 - 2010	0%	120	6,420	47	25	2
08390500	Rio Hondo at Diamond A Ranch Near Roswell, NM	23	Pecos	1940 - 2010	0%	947	4,190	51	19	<1
08390800	Rio Hondo Below Diamond A Dam Near Roswell, NM	24	Pecos	1964 - 2010	0%	963	3,950	51	19	<1
08400000	Fourmile Draw near Lakewood, NM	25	Pecos	1952 - 2010	1%	265	3,299	58	14	<1
08401200	South Seven Rivers near Lakewood, NM	26	Pecos	1964 - 2010	2%	220	3,280	60	14	<1
08405500	Black River above Malaga, NM	27	Pecos	1948 - 2010	0%	343	3,070	61	14	<1
08407500	Pecos River at Red Bluff, NM	28	Pecos	1938 - 2010	0%	19,540	2,850	56	14	<1
09365000	San Juan River at Farmington, NM	29	San Juan	1931 - 2010	0%	7,240	5,230	45	19	4
09367500	La Plata River near Farmington, NM	30	San Juan	1939 - 2010	1%	583	5,215	47	15	1
09430500	Gila River near Gila, NM	31	Gila	1928 - 2010	<1%	1,864	4,655	50	20	1
09430600	Mogollon Creek near Cliff, NM	32	Gila	1968 - 2010	0%	69	5,440	52	22	6

[a] Average values for the period 1951-2006 (PRISM Climate Group, Oregon State University, Created 4 Feb 2007)

RIO GRANDE WATERSHED

The Rio Grande is New Mexico's largest river, flowing south from its headwaters in the southern Colorado Rockies through the length of the state and eventually emptying into the Gulf of Mexico. Major tributaries to the Rio Grande are (from north to south) the Rio Chama, Jemez River, and Rio Puerco. Three study sites are located along the main channel of the Rio Grande. The drainage area of the upper site (USGS station # 08279500; near the town of Embudo) includes subalpine forest[2], subalpine grasslands, mid-elevation woodlands, and semi-arid shrublands. The middle Rio Grande site (USGS station # 08330000; near Albuquerque) lies approximately 100 miles downstream, below the Rio Chama and Jemez River confluences. An additional 150 miles downstream is the lower Rio Grande site (USGS station # 08362500; below Caballo Dam), which includes the Rio Puerco drainage and several smaller watersheds drained by ephemeral streams.

Study sites on major tributaries of the Rio Grande are the Rio Chama (USGS station # 08284100; near La Puente), Jemez River (USGS station # 08324000; near the town of Jemez), and Rio Puerco (USGS station # 08353000; near Bernardo) sites. Stream gaging stations on the Rio Chama and Jemez River are located on the upper reaches of each river, and subalpine forest and mid-elevation woodlands dominate both watersheds. The Rio Puerco site, located approximately 3 miles upstream of the Rio Grande confluence, captures most of the Rio Puerco drainage, which includes a major semi-arid shrubland component.

The remaining sites in the Rio Grande watershed are relatively small drainages that flow directly into the Rio Grande or one of its major tributaries. All are dominated by subalpine forest and mid-elevation woodland vegetation.

PECOS RIVER WATERSHED

The Pecos River originates in the Sangre de Cristo Mountains of north-central New Mexico and flows south through the state, meeting the Rio Grande at the Texas-Mexico border. Three study sites are located on the Pecos River. The upper Pecos River sites (USGS station # 08382650 & 08382830) are situated immediately upstream and downstream of the Santa Rosa dam and reservoir in Guadalupe County. Land cover in these watersheds is predominantly montane woodlands and prairie. Upstream of these sites are the Gallinas River (USGS station # 08382500; near Colonias), Gallinas Creek (USGS station # 08380500; near Montezuma), and Rio Mora (USGS station # 08377900; near Terrero) sites. The Gallinas Creek and Rio Mora are small, headwater watersheds dominated by subalpine forest, subalpine grassland, and mid-elevation woodland ecosystems. The Gallinas River is a major tributary of the Pecos River, and the monitoring site (located two miles upstream of the Pecos River confluence) captures flow from the majority of the Gallinas River drainage.

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[2] In this section, "subalpine forest" collectively refers to subalpine spruce-fir, lodgepole pine, and mixed conifer forest types. "Mid-elevation woodlands" refers to pinyon-juniper, ponderosa pine, and mixed woodland types. Watershed land cover descriptions are based on the Southwest Regional Gap Analysis Project (SWReGAP) land cover dataset (USGS National Gap Analysis Program, 2004).

The lower Pecos River site (USGS station # 08407500; at Red Bluff) is located among Chihuahuan desert vegetation, 10 miles from the Texas border, and includes nearly the entire New Mexico portion of the Pecos River watershed. Between the upper and lower Pecos River monitoring stations are six sites representing a variety of stream types. The Rio Hondo (USGS station # 08390500 & 08390800; upstream and downstream of Diamond A Dam), Fourmile Draw (USGS station # 08400000; near Lakewood), and South Seven Rivers (USGS station # 08401200; near Lakewood) sites are ephemeral tributaries of the Pecos River that drain semi-arid woodlands, grasslands, and desert scrub. The monitoring station on Rio Ruidoso (USGS station # 08387000; at Hollywood), a tributary of Rio Hondo, is located on an upper perennial reach among mid-elevation woodlands. The Black River (USGS station # 08405500; above Malaga) is a perennially flowing tributary of the Pecos River that drains mid-elevation woodlands and desert scrub.

Note that the Rio Hondo study sites in the Pecos River watershed are part of a stream system that shares its name with a stream in the Rio Grande watershed and that a distinction must be made between these sites and the Rio Hondo near Valdez site (USGS station # 08267500).

CANADIAN RIVER WATERSHED

The headwaters of the Canadian River lie in mountains of northeastern New Mexico and the river flows south and east through the state's high plains region, ultimately entering Texas and Oklahoma and joining the Arkansas River. The Canadian River site (USGS station # 07221500; near Sanchez) includes approximately half of the total Canadian River drainage in New Mexico. The area upstream of the monitoring site mainly consists of shortgrass prairie and woodland vegetation. The four additional study sites in the Canadian River watershed are headwater streams that feed tributaries of the Canadian River or are located on upper reaches of Canadian River tributaries. Land cover in these watersheds is predominantly mid-elevation woodlands with subalpine forest and grassland cover in upper elevation areas.

SAN JUAN RIVER WATERSHED

The San Juan River drainage encompasses the northwestern corner of New Mexico. The river forms in the San Juan Mountains of southern Colorado, flows south into New Mexico, west to the Four Corners region, and meets the Colorado River in southern Utah. The San Juan River site (USGS station # 09365000; at Farmington) includes approximately half of the total San Juan River drainage in New Mexico and is comprised of subalpine forest, mid-elevation woodland, and semi-arid shrubland cover types. The La Plata River joins the San Juan River two miles downstream of the San Juan monitoring station. The La Plata River site (USGS station # 09367500; near Farmington) is located near the confluence of the two rivers and drains an area dominated by mid-elevation woodlands and semi-arid shrublands.

GILA RIVER WATERSHED

The Gila River is the lowermost large river tributary of the Colorado River. Its headwaters are located in the mountains of southwest New Mexico, flowing south and west into Arizona. The Gila River site (USGS station # 9430500; near the town of Gila) drains the upper portion of New Mexico's Gila River watershed, an area dominated by mid-elevation woodlands. Mogollon Creek joins the Gila River approximately one mile downstream of the Gila River monitoring station. The Mogollon Creek site (USGS station # 09430600; near Cliff) lies on an upper reach of the stream and drains subalpine forest and mid-elevation woodlands.

What Drives Hydrologic Alteration?

A variety of human activities can drive hydrologic alteration. These can be grouped into four general classes:

1. Diversion of free flowing surface water.
2. Impoundment of surface flow (dams) and other channel modifications (e.g. channelization, dredging).
3. Discharge of stormwater or wastewater, or surface water/groundwater delivered across basin boundaries.
4. Offstream activities that modify natural surface and subsurface hydrologic processes (e.g., groundwater withdrawals, urban development, etc.).

Examples of each class can be readily identified for New Mexico streams (Figure 5). Water rights laws allow surface flow to be diverted or impounded for domestic, municipal, agricultural, industrial, and recreational purposes. Large dams have been constructed on the state's rivers for water supply and flood control purposes since the early 20th century, often accompanied by levee construction and channelization. Discharge of stormwater and wastewater are common in urban areas and from large-scale agricultural and industrial operations. Additionally, water management projects (such as the San Juan-Chama Project and Closed Basin Project on the Rio Grande) discharge surface and groundwater across natural watershed and aquifer boundaries. Riparian and floodplain development, and groundwater pumping, occur in populated areas of the state and can affect the natural flow regime by altering infiltration and recharge, groundwater flow characteristics, and surface water-groundwater connections.

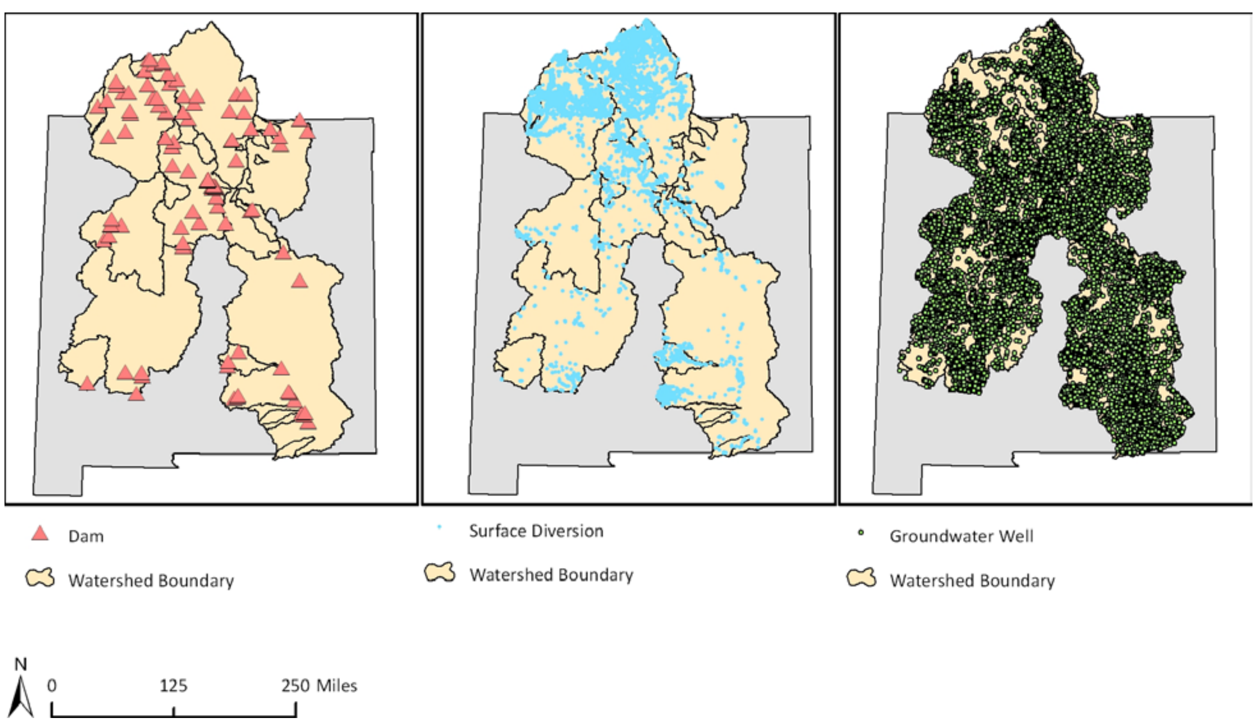

Figure 5. Location of dams, surface diversions, and groundwater wells within study watersheds.

The following is a review of potential drivers of hydrologic alteration for each study site. Table 2 summarizes this information and displays relative differences in the presence of a major dam, and the density/location of surface diversions and groundwater wells in each watershed.

Table 2. Potential drivers of hydrologic alteration upstream of study sites. Green, orange, and red markers correspond to low, moderate, and high upstream presence, respectively.

Site Name	Major Watershed	Major Dam(s)[a]	Surface Diversions[b]	Groundwater Wells[b]
Vermejo River near Dawson	Canadian		● (green)	
Ponil Creek near Cimarron	Canadian		● (green)	
Rayado Creek near Cimarron	Canadian			
Mora River at La Cueva	Canadian		● (orange)	● (orange)
Canadian River near Sanchez	Canadian		● (orange)	● (red)
Red River near Questa	Rio Grande		● (orange)	● (orange)
Rio Hondo near Valdez	Rio Grande			
Rio Grande at Embudo	Rio Grande		● (red)	● (red)
Rio Chama near La Puente	Rio Grande		● (red)	● (red)
Rio Ojo Caliente at La Madera	Rio Grande		● (orange)	
Santa Cruz River near Cundiyo	Rio Grande		● (green)	
Santa Fe River near Santa Fe	Rio Grande	● (red)		
Jemez River near Jemez	Rio Grande		● (orange)	● (orange)
Rio Grande at Albuquerque	Rio Grande	● (red)	● (red)	● (red)
Rio Puerco near Bernardo	Rio Grande		● (orange)	● (red)
Rio Grande Below Caballo Dam	Rio Grande	● (red)	● (red)	● (red)
Rio Mora near Terrero	Pecos			
Gallinas Creek near Montezuma	Pecos		● (orange)	● (orange)
Gallinas River near Colonia	Pecos		● (orange)	● (orange)
Pecos River above Santa Rosa Lake	Pecos		● (orange)	● (red)
Pecos River below Santa Rosa Dam	Pecos	● (red)	● (orange)	● (red)
Rio Ruidoso at Hollywood	Pecos		● (orange)	● (red)
Rio Hondo at Diamond A Ranch Near Roswell	Pecos		● (red)	● (red)
Rio Hondo Below Diamond A Dam Near Roswell	Pecos	● (red)	● (red)	● (red)
Fourmile Draw near Lakewood	Pecos			● (green)
South Seven Rivers near Lakewood	Pecos			● (green)
Black River above Malaga	Pecos		● (orange)	● (orange)
Pecos River at Red Bluff	Pecos	● (red)	● (red)	● (red)
San Juan River at Farmington	San Juan	● (red)	● (red)	● (red)
La Plata River near Farmington	San Juan		● (red)	● (red)
Gila River near Gila	Gila		● (green)	
Mogollon Creek near Cliff	Gila			

[a] Source: National Inventory of Dams (National Atlas of the United States, 2006)

[b] Source: Water rights data for New Mexico (New Mexico Office of the State Engineer, January 2011) and Colorado (State of Colorado Division of Water Resources, August 2010)

RIO GRANDE WATERSHED

- **Red River near Questa:** The Red River monitoring site is located downstream of the Town of Red River and the eastern extent of the Town of Questa. Low and high density urban development cover a small portion of the total watershed area (~1%). Water is diverted for irrigation on agricultural lands located upstream and downstream of the stream monitoring site and groundwater wells are present throughout the upper portions of the watershed. Major human disturbances in the watershed result from the Molybdenum Corporation of America (Molycorp) mine and refinery, which began open pit operations in the mid-1960s. The open pit mine and waste rock dump are large, disturbed areas adjacent to the Red River. The refinery diverts surface water and pumps groundwater for refining operations, and discharges waste slurry in tailings ponds downstream of the monitoring site.
- **Rio Hondo near Valdez:** The Rio Hondo monitoring site is part of the USGS Hydro-climatic Data Network (HCDN), a collection of streamflow monitoring sites with low human influence. The watershed contains no surface diversions and scattered groundwater wells. The uppermost portion of the watershed is the site of the Taos Ski Valley.
- **Rio Grande at Embudo:** The upper Rio Grande monitoring site is located downstream of a number of small dams, surface diversions, and groundwater pumping wells. Agriculture makes up approximately 11% of the total watershed area. The watershed includes a number of small towns and communities, though urban land cover totals less than 1% of the total watershed area. Flows at this station have been augmented since the early 1990s by the Closed Basin Project, which discharges pumped groundwater into the upper Rio Grande.
- **Rio Chama near La Puente:** The Rio Chama monitoring site is located downstream of several surface diversions and groundwater wells that supply water for agricultural activities and domestic use. The major settlement is the village of Chama in the upper portion of the watershed. Note that this site is located upstream of the major water management projects in the Rio Chama watershed, including Heron Reservoir, El Vado Reservoir, and Abiquiu Reservoir.
- **Rio Ojo Caliente at La Madera:** The Rio Ojo Caliente monitoring site is located downstream of multiple surface diversions and scattered groundwater wells that supply water for agricultural activities and domestic use within the watershed. Riparian and floodplain areas in the vicinity of the monitoring site are major agricultural corridors within the watershed.
- **Santa Cruz River near Cundiyo:** The Santa Cruz River monitoring site is part of the USGS HCDN. The watershed includes a small number of surface diversions and scattered groundwater wells and minimal developed and agricultural lands.
- **Santa Fe River near Santa Fe:** The Santa Fe River monitoring site is located downstream of McClure Dam and Reservoir (constructed in 1926), which stores water for irrigation and municipal use downstream of the monitoring site. Upstream diversions, groundwater pumping, and urban/agricultural development are minimal within watershed boundaries.
- **Jemez River near Jemez:** The Jemez River monitoring site is downstream of several surface diversions and groundwater wells that provide water for domestic and agricultural use. The monitoring site is part of the USGS HCDN.
- **Rio Grande at Albuquerque:** The middle Rio Grande monitoring site is located downstream of the Cochiti Dam and Reservoir (constructed in 1973), a large impoundment that provides flood control. The watershed contains a number of surface diversions and groundwater wells, and several large dams have been constructed on major upstream tributaries, including the Rio Chama and Jemez River. Since the early 1970s, flow at the monitoring site has been augmented by water transported across basin boundaries

from the San Juan River to the Rio Chama (the San Juan-Chama Project). The monitoring site is within the limits of New Mexico's largest city, Albuquerque.

- **Rio Puerco near Bernardo:** The Rio Puerco monitoring site is located downstream of multiple small dams, diversions, and groundwater wells that provide water supplies for irrigation, mining, domestic use. Agricultural and developed lands are generally located in the upper portions of the watershed.
- **Rio Grande below Caballo Dam:** The lower Rio Grande monitoring site is located downstream of two major dams, Elephant Butte (constructed in 1916) and Caballo (constructed in 1938). The watershed contains many surface diversions and dense groupings of groundwater wells which provide domestic and irrigation water to a number of users.

PECOS RIVER WATERSHED

- **Rio Mora near Terrero:** The Rio Mora monitoring site is part of the USGS HCDN and the USGS Hydrologic Benchmark Network (HBN), a collection of streamflow monitoring sites with minimal human influence. The watershed contains no surface diversions, few groundwater wells, and no agricultural or developed lands. The majority of the watershed lies within the Pecos Wilderness Area of the Santa Fe National Forest.
- **Gallinas Creek near Montezuma:** The Gallinas Creek monitoring site is located downstream of multiple surface diversions and groundwater wells that provide water for irrigation and domestic use. Developed lands make up a small portion of the watershed area and the monitoring station is part of the USGS HCDN.
- **Gallinas River near Colonias:** The Gallinas River monitoring site is located downstream of multiple small dams, surface diversions, and groundwater wells. The majority of these are located in the vicinity of the City of Las Vegas, NM, in the upper portion of the watershed.
- **Pecos River above Santa Rosa Lake:** The upper Pecos River (above Santa Rosa Lake) monitoring site is located downstream of multiple surface diversions and groundwater wells that provide water for irrigation and domestic use.
- **Pecos River below Santa Rosa Lake:** The upper Pecos River (below Santa Rosa Lake) monitoring site is located downstream of Santa Rosa Dam (constructed in 1980), which stores water for irrigation, flood control, and sediment control.
- **Rio Ruidoso at Hollywood:** The Rio Ruidoso monitoring site is located downstream of multiple surface diversions, and a dense grouping of groundwater wells that provide water for municipal and domestic users. The monitoring site is immediately downstream of the village of Ruidoso.
- **Rio Hondo at Diamond A Ranch:** The Rio Hondo (at Diamond A Ranch) monitoring site is located downstream of a several surface diversions and groundwater wells that provide water for irrigation and domestic use. A few small dams are present in the upper watershed. Large agricultural corridors exist within the river valley in the middle portion of the watershed.
- **Rio Hondo Below Diamond A Dam:** The Rio Hondo (below Diamond A Dam) monitoring site is located downstream of Diamond A Dam (constructed in 1963) and Two Rivers Reservoir, a dry reservoir that provides flood control for downstream communities. Two Rivers Reservoir receives water from Rio Hondo and Rocky Arroyo, a Rio Hondo tributary that would otherwise naturally join the Rio Hondo downstream of the dam. When the reservoir is full, water can be discharged to the Rio Hondo and Rocky Arroyo channels.

- **Fourmile Draw near Lakewood:** The Fourmile Draw monitoring site is located downstream of scattered groundwater wells. The watershed contains no surface diversions and no major human development.
- **South Seven Rivers near Lakewood:** The South Seven Rivers monitoring site is located downstream of scattered groundwater wells. The watershed contains no surface diversions and no major human development.
- **Black River above Malaga:** The Black River monitoring site located downstream of multiple surface diversions and groundwater wells that provide water for irrigation and domestic use.
- **Pecos River at Red Bluff:** The lower Pecos River monitoring site is located downstream of 2 major dams, Brantley Dam (constructed in 1991) and Avalon Dam (constructed in 1907). Historically, McMillan Dam (constructed in 1908) was the main impoundment on the lower Pecos River and was decommissioned following completion of Brantley Dam. The Pecos River watershed contains many surface diversions, small dams, and groundwater wells. A large city, Carlsbad, and extensive agricultural lands are present immediately upstream of the monitoring site.

CANADIAN RIVER WATERSHED

- **Vermejo River near Dawson:** The Vermejo River monitoring site is part of the USGS HCDN. The watershed contains few surface diversions, scattered groundwater wells, and limited human development.
- **Ponil Creek near Cimarron:** The Ponil Creek monitoring site is part of the USGS HCDN. The watershed contains few surface diversions, scattered groundwater wells, and limited human development.
- **Rayado Creek near Cimarron:** The Rayado Creek monitoring site is part of the USGS HCDN. The watershed contains no surface diversions, scattered groundwater wells, and limited human development.
- **Mora River at La Cueva:** The Mora River monitoring site is located downstream of scattered surface diversions and multiple groundwater wells. A portion of diverted water is transported downstream for irrigation via the La Cueva canal. Agricultural lands are concentrated in the region immediately upstream of the monitoring site.
- **Canadian River near Sanchez:** The Canadian River monitoring site is located downstream of multiple surface diversions and groundwater wells. Human development in the watershed is low and is generally limited to the upper and middle portions of the watershed. Note that the monitoring site is located above the major dams on the Canadian River (Conchas Dam, Ute Dam).

SAN JUAN RIVER WATERSHED

- **San Juan River at Farmington:** The San Juan River monitoring site is located downstream of the Navajo Dam (constructed in 1962). The Navajo Reservoir is New Mexico's second largest lake and provides water storage for irrigation and recreational use. The watershed contains many surface diversions, small dams, and groundwater wells for irrigation of lands located upstream and downstream of the monitoring site. The Cities of Farmington and Bloomfield, and large agricultural communities, are located immediately upstream of the monitoring station.
- **La Plata River near Farmington:** The La Plata River monitoring site is located downstream of many surface diversions and groundwater wells. Development areas within the City of Farmington are present immediately upstream of the monitoring site. Large agricultural areas are found throughout the upper and middle portions of the watershed.

GILA RIVER WATERSHED

- **Gila River near Gila**: The Gila River monitoring site is located downstream of surface diversions and scattered groundwater wells that provide water for irrigation and domestic uses. The watershed contains limited human development and the monitoring site is part of the USGS HCDN.
- **Mogollon Creek near Cliff:** The Mogollon Creek monitoring site is part of the USGS HCDN and HBN. The watershed contains no surface diversions or groundwater wells and lies within the Gila Wilderness Area of the Gila National Forest.

How Is Hydrologic Alteration Assessed?

A general first step for assessing hydrologic alteration is to translate raw streamflow time series data into metrics that describe the flow regime (e.g., the number of high flow events for each year of the data record). This can be completed manually using data analysis software or using a program specifically designed for this purpose. One well-established resource is The Nature Conservancy's Indicators of Hydrologic Alteration (IHA) software package. IHA characterizes the streamflow regime using 33 ecologically relevant flow metrics (The Nature Conservancy, 2009). These describe the magnitude of monthly flows and the magnitude, timing, duration, and frequency of high and low flow conditions. Additional metrics can be computed for distinct hydrologic events termed Environmental Flow Components (EFCs), such as extreme low flows or large floods.

The wide variety of streamflow metrics available to characterize the flow regime complicates interpretation of hydrologic alteration data. For this reason, hydrologic alteration assessment often focuses on a subset of flow metrics computed by IHA or similar software. Selection of streamflow metrics can be based on an evaluation of those that are highly informative and non-redundant, and entire studies have been devoted to identifying such metrics (Olden & Poff, 2003). Alternatively, analysis may be centered on metrics that are relevant to specific study objectives (those that affect populations of a particular fish species, for example). As a broad-scale overview of hydrologic alteration and ecological condition in New Mexico, this project focused on eight IHA metrics that have demonstrated ecological significance (Table 3) (Poff & Zimmerman, 2010). It should be noted that metrics which best describe the ecological value of the natural flow regime for individual streams and rivers likely vary by stream class. A complete stream classification for the State of New Mexico would facilitate identification of the most relevant IHA metrics for each ecological setting. Such a classification was beyond the scope of this project, but is included as a potential next step for environmental flow initiatives (see Section 6).

Table 3. Hydrologic metrics considered for assessment of hydrologic alteration. Annual (water year) values of each metric are used for hydrologic alteration analysis.

Flow Regime Component	Metric Considered	Ecological Relevance
High Flow		Increase aquatic habitat area; recharge soil moisture and groundwater; limit establishment of upland vegetation; provide spawning and reproduction cues.
Magnitude	Maximum average daily flow	
Frequency	Number of high flow pulses[a]	
Duration	Median duration (days) of high flow pulses	
Timing	Date of maximum average daily flow	
Low Flow		Fragmentation, reduction, or loss of aquatic habitat; balance stress tolerant and intolerant species.
Magnitude	Minimum average daily flow	
Frequency	Number of low flow pulses[b]	
Duration	Median duration (days) of low flow pulses	
Zero Flow		
Frequency	Number days with zero flow	

[a] High flow pulses are quantified as daily values above 1.25 times the long-term median daily flow.
[b] Low flow pulses are quantified as daily values below 0.75 times the long-term median daily flow.

A number of quantitative methods can be applied to streamflow data to evaluate the presence and severity of hydrologic alteration. The selection of an appropriate quantitative method for hydrologic alteration analysis in part depends on characteristics of available streamflow data and the motivation for analysis. USGS streamflow records often include data that are subject to increased human influence over time. For these data, an assessment of changes to the streamflow regime over time can be performed using trend analysis techniques. If distinct "pre-impact" and "post-impact" time periods exist in the flow record (such as before and after construction of a major dam), statistical methods that compare two distinct datasets can be applied. An example of these methods is the Range of Variability (RVA) approach (see below). Two-sample analysis methods can also be applied using a reference dataset collected from an undisturbed site in place of pre-impact data or with simulated reference data generated through hydrological modeling. See Pyron & Neumann (2008), Graf (2006), Poff et al. (2006), and Carlisle et al. (2010) for examples of how these methods have previously been applied.

For this report, IHA trend analysis output is used to evaluate hydrologic alteration of study sites. IHA trend analysis consists of linear regressions of annual flow metric values with time[3]. Note that RVA analysis was completed for the five study sites that had distinct pre- and post-impact periods in their data record and RVA results are provided in 7.Appendix B. (IHA Output). These data are not discussed in the main body of this report due to the lack of distinct pre- and post-impact record and inability to perform RVA analysis for all 32 study sites.

[3] Additional discussion of trend analysis is provided in comment 2 in Appendix A. Notes on Analysis Methods.

IHA's Range of Variability Approach

Assessment of hydrologic alteration is often carried out to guide the design of environmental flow standards or evaluate an established environmental flow program. For these purposes, Richter (1997) suggested the Range of Variability Approach (RVA). RVA is useful for comparing two distinct datasets (such as pre-impact and post-impact flow data) and RVA algorithms are built into IHA software. RVA includes three steps: 1) characterize variation in pre-impact flow data by grouping data points into high, middle, and low magnitude ranges; 2) calculate the expected frequency that post-impact flows should fall into each RVA range based on data record length and pre-impact frequency; and 3) quantify differences between observed and expected post-impact frequencies using Hydrologic Alteration Factor (HAF) statistics. Positive HAFs correspond to increased post-impact frequency and range from 0 to infinity. Negative HAFs correspond to reduced post-impact frequency and have a lower limit of -1. An example of RVA data is provided in Figure 6, which illustrates a pronounced post-impact decrease in high flow magnitude for the San Juan River at Farmington site (reflected by downward median shift, negative high HAF, positive low HAF) following dam construction in 1962.

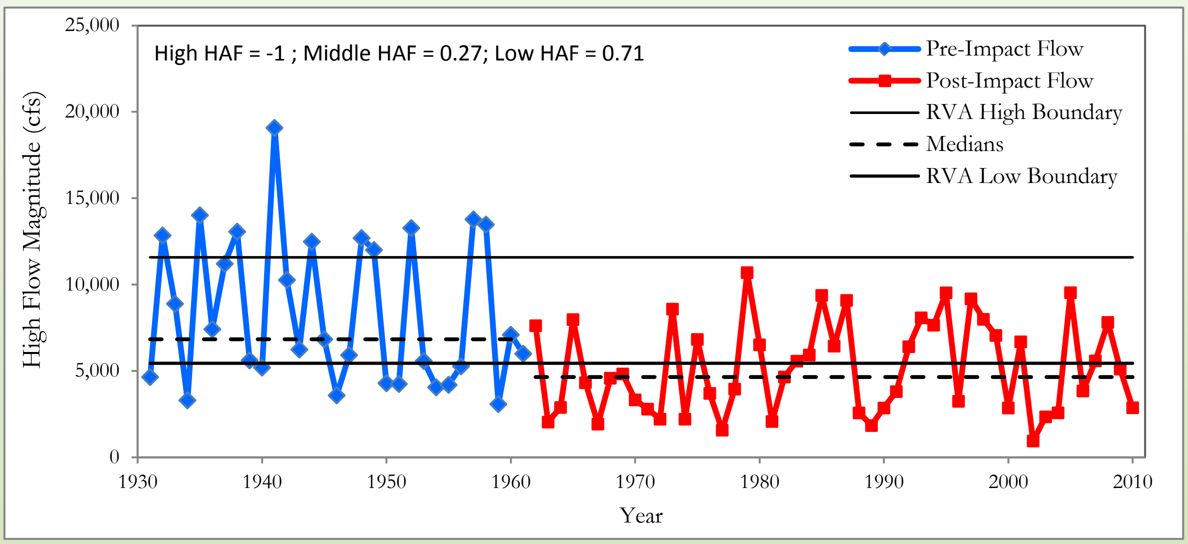

Figure 6. Example of Range of Variability (RVA) data for San Juan River high flow magnitude.

Five study sites are well-suited for RVA analysis and HAF values for these sites are provided in Appendix B. (IHA Output).

3. Results of Hydrologic Alteration Analysis

Alteration of High Flow Events

High flow conditions generally develop during the spring snowmelt or summer monsoon seasons in the streams and rivers of New Mexico (Figure 7). Periods of high flow provide increased habitat area for aquatic species, replenish soil moisture stores for riparian and floodplain vegetation, limit the establishment of upland species, and recharge aquifer systems. Further, high flow conditions play a major role in shaping channel and bank morphology and regulate nutrient exchange between the stream, adjacent wetlands, and the floodplain.

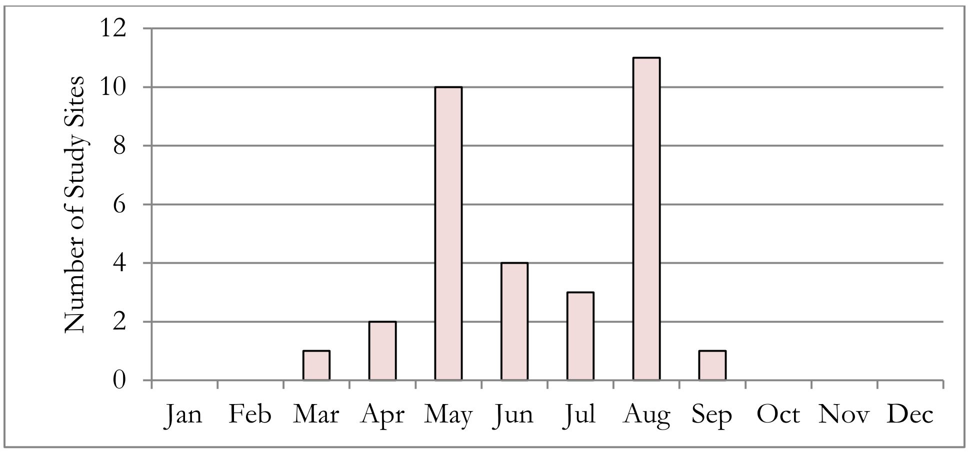

Figure 7. Number of study sites with median date of annual peak flow in each calendar month. For most sites, peak flow occurs during the spring snowmelt and summer monsoon seasons.

Table 4 summarizes hydrologic alteration analysis for four metrics that characterize high flow events: annual maximum average daily flow (magnitude); the annual number of high flow pulses (frequency); the annual median duration of high flow pulses (duration); and the date of the annual maximum average daily flow (timing). Note that a high flow pulse was defined to occur when daily flow exceeded 1.25 times the median daily flow over the period of record.

KEY POINTS:

- Overall, the presence and direction of change in high flow metrics over time is highly variable. Variability is observed within and between sites, and for each type of human influence.
- Several (10) sites with upstream surface and groundwater use show reduced peak flow magnitude over time. Three sites with a major dam display reduced peak flow magnitude.
- In some cases, a decrease in peak flow magnitude is accompanied by less frequent high flow pulses (Rio Grande at Embudo; San Juan River near Farmington).
- The increase in the frequency of high flow pulses for the Rio Grande below Caballo Dam site may be related to flow regulation by Caballo Dam.
- The presence of trends in sites with minimal human influence, and variability in the presence/direction of trends, underscores the fact that trend analysis results can be influenced by climate variability as well as human impacts.

Table 4. Direction of trend for high flow metrics with a statistically significant trend (at p ≤ 0.1). A (▲) symbol corresponds to an increasing trend, a (▼) symbol corresponds to a decreasing trend. For high flow timing, a (▼) symbol corresponds to a trend of delayed high flow, a (▲) symbol corresponds to a trend of earlier high flow.

Site Name	Human Influence[a]	High Flow			
		Magnitude	Frequency	Duration	Timing
Vermejo River near Dawson	S				
Ponil Creek near Cimarron	S				▲
Rayado Creek near Cimarron,					
Mora River at La Cueva	S, G	▼			
Canadian River near Sanchez	S, G	▼			
Red River near Questa	S, G	▼			▼
Rio Hondo near Valdez					▼
Rio Grande at Embudo	S, G	▼	▼		
Rio Chama near La Puente	S, G				
Rio Ojo Caliente at La Madera	S		▼		
Santa Cruz River near Cundiyo	S				
Santa Fe River near Santa Fe	D	▼			
Jemez River near Jemez	S, G				
Rio Grande at Albuquerque	D, S, G				
Rio Puerco near Bernardo	S, G	▼			
Rio Grande Below Caballo Dam	D, S, G		▲	▼	
Rio Mora near Terrero					▲
Gallinas Creek near Montezuma	S, G				
Gallinas River near Colonias	S, G	▼	▲		▲
Pecos River above Santa Rosa Lake	S, G				
Pecos River below Santa Rosa Dam	D, S, G	▲			
Rio Ruidoso at Hollywood	S, G				
Rio Hondo at Diamond A Ranch Near Roswell	S, G		▼		
Rio Hondo Below Diamond A Dam Near Roswell	D, S, G	▼			▲
Fourmile Draw near Lakewood	G				
South Seven Rivers near Lakewood	G	▼			
Black River above Malaga	S, G	▼			
Pecos River at Red Bluff	D, S, G			▼	▼
San Juan River at Farmington	D, S, G	▼	▼	▲	
La Plata River near Farmington	S, G	▼			
Gila River near Gila	S	▲		▲	
Mogollon Creek near Cliff					

[a] Primary human influence type(s) (see Table 2). D = Major Dam; S = Surface Diversion; G = Groundwater Wells

Alteration of Low Flow Events

Low flow conditions develop during periods with little or no precipitation or when precipitation is stored on the landscape in the form of snow, and are largely reflective of local and upstream groundwater conditions. During these periods, aquatic habitat is limited and species that depend on large quantities of water are stressed. Naturally occurring low flow periods maintain a balance between stress tolerant and intolerant wildlife and vegetation. In extreme cases, portions of streams can run dry, temporarily eliminating aquatic habitat and resulting in a disconnection of upstream and downstream reaches.

Table 5 summarizes hydrologic alteration analysis for four metrics that characterize low flow events: annual minimum average daily flow (magnitude); the annual number of low flow pulses (low flow frequency); the annual median duration of low flow pulses (duration); and the number of days per year with zero flow (zero flow frequency). Note that a low flow pulse was defined to occur when daily flow was less than 0.75 times the median daily flow over the period of record.

KEY POINTS:

- Like trends for high flow metrics, observed changes to low flow metrics over time vary within and between sites, and between types of human influence.
- Trends of increased low flow magnitude (11 sites) dominate over low flow magnitude decreases (3 sites). A number of sites with increased low flow magnitude also show less frequent low flow pulses. These changes may be related to return flow of diverted/pumped water or other dry-weather discharges.
- For sites downstream of major dams or other water management projects (Rio Grande at Albuquerque, San Juan River at Farmington), larger minimum flows and less frequent low flow pulses may be a result of flow regulation or augmentation.
- Flow regulation and upstream water use may contribute to the observed decrease in low flow magnitude for the Mora River at La Cueva , Red River near Questa , and Santa Fe River near Santa Fe sites.
- Flow regulation and upstream water use may contribute to the observed increase in the number of zero flow days for the Santa Fe River and Pecos River below Santa Rosa Dam sites.
- Trends in the duration of low flow pulses for sites with large dams (shorter duration for San Juan River at Farmington, longer duration for Santa Fe River and Pecos River Below Santa Rosa Dam) suggest that dam operation decisions play a large role in determining the effects of dams on the flow regime.
- Observed trends of increased low flow magnitude, decreased low pulse frequency, and decreased zero flow days for sites with low human influence underscore the fact that trend analysis results can be influenced by climate variability as well as human impacts.

Table 5. Direction of trend for low flow metrics with a statistically significant trend (at $p \leq 0.1$). A (▲) symbol corresponds with an increasing trend, a (▼) symbol corresponds with a decreasing trend.

Site Name	Human Influence	Low Flow			Zero Flow Frequency
		Magnitude	Frequency	Duration	
Vermejo River near Dawson	S	▲	▼		▼
Ponil Creek near Cimarron	S	▲	▼		▼
Rayado Creek near Cimarron,		▲	▼		
Mora River at La Cueva	S, G	▼			▼
Canadian River near Sanchez	S, G				
Red River near Questa	S, G	▼			
Rio Hondo near Valdez					
Rio Grande at Embudo	S, G				
Rio Chama near La Puente	S, G	▲			
Rio Ojo Caliente at La Madera	S	▲	▼	▲	
Santa Cruz River near Cundiyo	S	▲			
Santa Fe River near Santa Fe	D	▼		▲	▲
Jemez River near Jemez	S, G				
Rio Grande at Albuquerque	D, S, G	▲	▼		▼
Rio Puerco near Bernardo	S, G				▼
Rio Grande Below Caballo Dam	D, S, G				
Rio Mora near Terrero					
Gallinas Creek near Montezuma	S, G	▲	▼		
Gallinas River near Colonias	S, G				▼
Pecos River above Santa Rosa Lake	S, G				
Pecos River below Santa Rosa Dam	D, S, G		▲	▲	▲
Rio Ruidoso at Hollywood	S, G	▲			
Rio Hondo at Diamond A Ranch Near Roswell	S, G				
Rio Hondo Below Diamond A Dam Near Roswell	D, S, G				
Fourmile Draw near Lakewood	G				
South Seven Rivers near Lakewood	G				
Black River above Malaga	S, G				
Pecos River at Red Bluff	D, S, G				
San Juan River at Farmington	D, S, G	▲	▼	▼	
La Plata River near Farmington	S, G	▲	▼	▲	▼
Gila River near Gila	S		▼	▲	
Mogollon Creek near Cliff					

[a] Primary human influence type(s) (see Table 2). D = Major Dam; S = Surface Diversion; G = Groundwater Wells

Ecological Implications of Hydrologic Alteration in New Mexico

The majority of sites included in hydrologic alteration analysis demonstrate change in at least one flow regime component. Observed types of flow alteration include shifts in peak flow magnitude and timing, minimum flow magnitude, and/or the frequency and duration of high and low flow events. Many of the observed flow alteration types are consistent with those expected for sites subject to upstream diversions and groundwater withdrawal. These include reduced high flow magnitude and frequency, reduced low flow magnitude, and increased low flow duration. Observed types of flow alteration for sites located downstream of a major dam include flow stabilization (decreased high flow magnitude/frequency, increased low flow magnitude; San Juan River at Farmington) (Figure 8) and an across-the-board decrease in flow (reduced high and low flow magnitude, increased low flow duration and zero flow frequency; Santa Fe River at Santa Fe) (Figure 9).

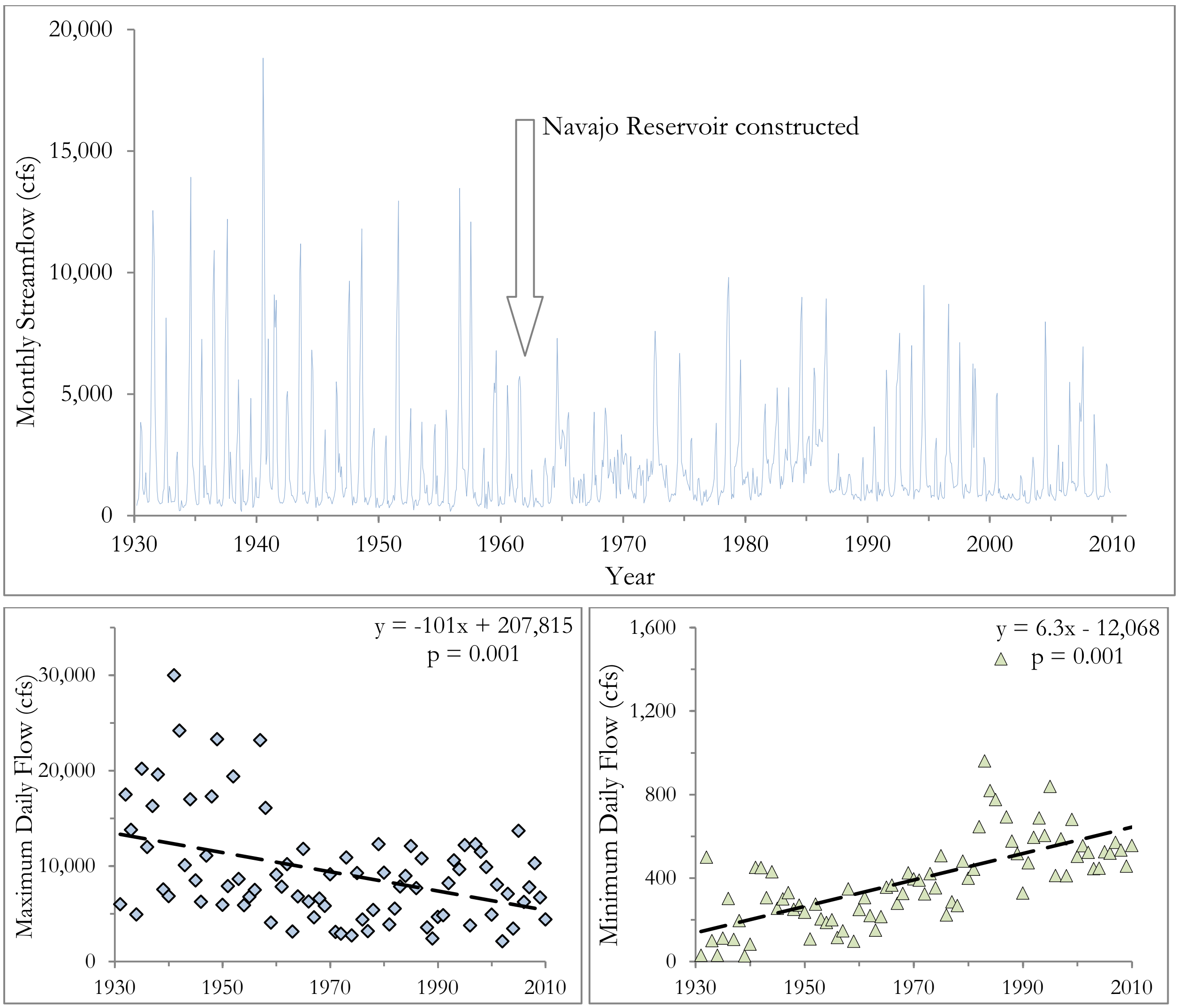

Figure 8. Monthly streamflow (top), annual peak flow (bottom left), and annual minimum flow (bottom right) for the San Juan River near Farmington site. These plots demonstrate the stabilization of San Juan River flows identified from hydrologic alteration analysis. The site lies downstream of Navajo Reservoir, which regulates river flows for downstream users.

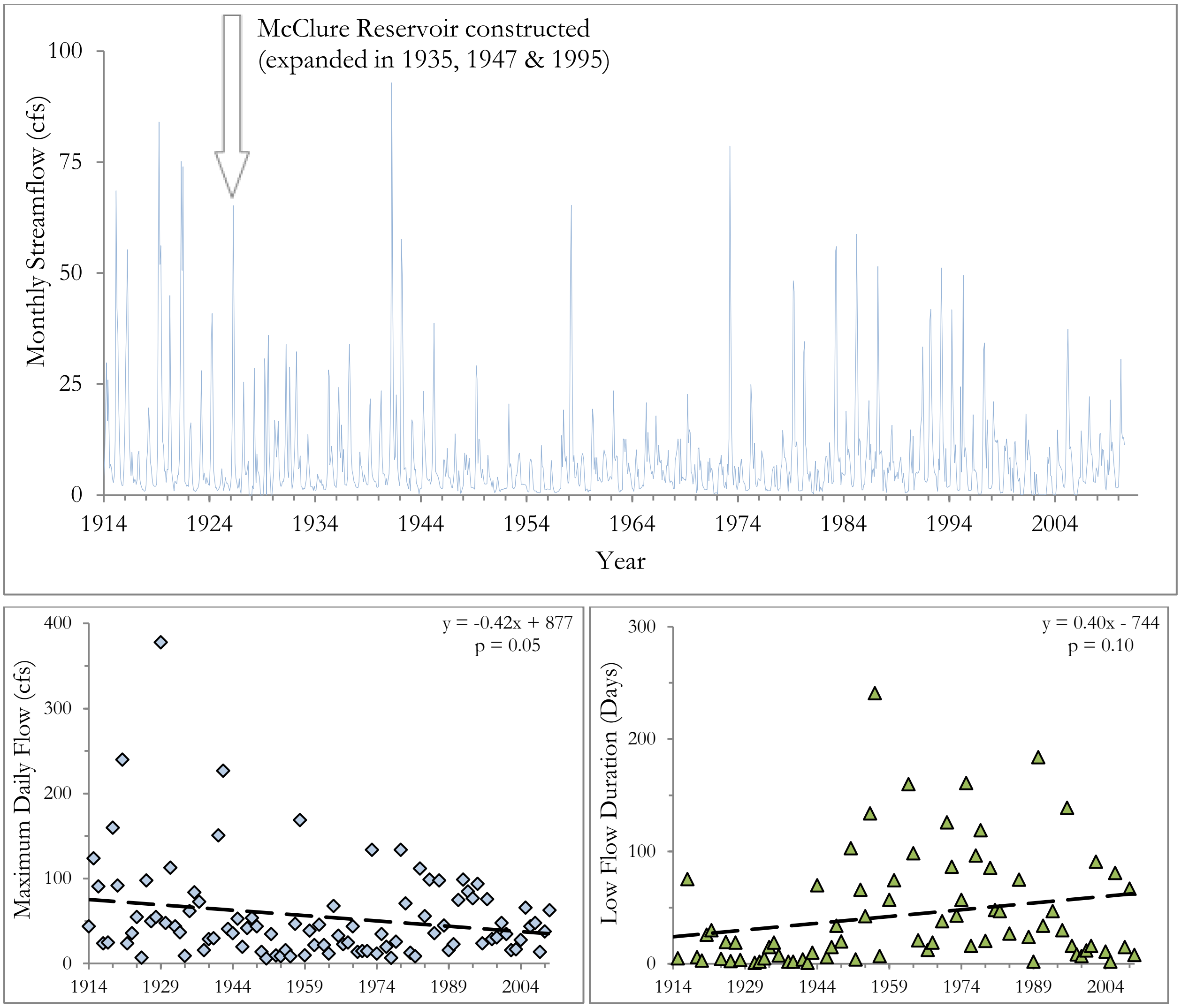

Figure 9. Monthly streamflow (top), annual peak flow (bottom left), and annual low flow duration (bottom right) for the Santa Fe River near Santa Fe site from 1914-2010. These plots demonstrate the overall decrease in Santa Fe River flows identified from hydrologic alteration analysis. The site lies downstream of McClure Reservoir, a key source of water for the city of Santa Fe, NM.

The types of hydrologic alteration detected for New Mexico streams have potential ecological implications that are significant and diverse. Table 6 outlines study sites demonstrating various flow alterations and potential ecological responses that have been associated with each flow alteration type. Ecological responses are generally related to changes in species composition, species diversity, life-cycle disruption, and invasion by non-natives. This information is derived from a review of 165 hydrological alteration-ecological response case studies (Poff & Zimmerman, 2010).

Table 6. Common ecological responses to hydrologic alteration. Adapted from Poff & Zimmerman (2010)

Flow Component	Flow Alteration	Sites Affected	Organism(s) Studied	Common Ecological Responses
Magnitude	Stabilization	San Juan River, La Plata River	Aquatic	Loss of sensitive species; Reduced diversity; Altered assemblages & dominant taxa; Reduced abundance; Increase in non-natives
	Greater magnitude high and/or low flows	Rio Grande (at Albuquerque), Vermejo River, Ponil Creek, Rayado Creek, Rio Ojo Caliente, Rio Chama, Santa Cruz River, Gallinas Creek, Rio Ruidoso, Gila River, Pecos River (below Santa Rosa Dam)	Aquatic	Life cycle disruption; Reduced species richness; Altered assemblages & relative abundance of taxa; Loss of sensitive species
	Loss of peak flows	Mora River, Canadian River, Rio Grande (at Embudo), Rio Puerco, Red River, Santa Fe River, San Juan River, Gallinas River, Rio Hondo (below Diamond A Dam), Black River, South Seven Rivers, La Plata River	Riparian	Altered recruitment (failure of seeding establishment); Terrestrialisation of flora; Increased success of nonnatives; Lower species richness; Vegetation encroachment into channels; Increased riparian cover; Altered assemblages
Frequency	Decreased peak flow frequency	Rio Grande (at Embudo), Rio Ojo Caliente, Rio Hondo (at Diamond A Ranch), San Juan River	Aquatic	Seasonal reproduction; Reduced reproduction; Decreased abundance/extirpation of native fishes; Decreased richness of endemic & sensitive species; Reduced habitat for young fishes
			Riparian	Shift in community composition; Reductions in species richness; Increase in wood production
Duration	Decreased high flow duration	Pecos River (at Red Bluff), Rio Grande (below Caballo Dam)	Aquatic	Decreased abundance of young fish; Change in juvenile fish assemblage; Loss of floodplain specialists
			Riparian	Reduced growth rate or mortality; Altered assemblages; Terrestrialisation/desertification of species composition; Reduced vegetation cover
Timing	Shifts in peak Flow	Ponil Creek, Red River, Rio Hondo (near Valdez), Rio Mora, Gallinas River, Rio Hondo (below Diamond A Dam), Pecos River (at Red Bluff)	Aquatic	Disruption of spawning cues; Decreased reproduction & recruitment; Change in assemblage structure

Many of the ecological responses outlined in Table 6 have already been observed for streams and rivers included in this report. Several streams with high and low flow alterations (Mora River, Canadian River, Rio Grande, Santa Fe River, Gallinas River, Pecos River, San Juan River, La Plata River, and Gila River) are listed as impaired due to their inability to adequately support aquatic life (New Mexico Environment Department, 2010). Specific ecological effects of flow alteration have been well-documented for several of these rivers:

- **Rio Grande**: The Rio Grande is a highly managed river system, with multiple large dams, diversions, and levees dotting its length. Because it is so important to the well-being of New Mexicans, the ecological effects of water management in the Rio Grande have been studied in-depth relative to other waterways. Molles et al. (1998) describe the changes caused by flood management on the river, transforming a rich mosaic of braided channels, wetlands, and riparian cottonwood forests that teemed with life during the spring floods into a simplified, single-channel system surrounded by the non-native saltcedar and upland desert habitat. The loss of wetlands due to reduced overbank flows has restricted populations of several animal species, including the Western painted turtle, leopard frog, and New Mexico garter snake (New Mexico Department of Game and Fish, 2006). Geomorphic changes associated with flood management, and flow reductions due to diversions, are commonly associated with declines in populations of multiple fish species, including the Rio Grande silvery minnow (a state and federal endangered species), blue sucker (a state endangered species), gray redhorse (a state threatened species), and Rio Grande bluntnose shiner (now extinct).
- **Santa Fe River**: The Santa Fe River originates in the mountains of the Santa Fe National Forest. Prior to reaching its confluence with the Rio Grande, the river is impounded at two locations, forming McClure Reservoir and Nichols Reservoir. These reservoirs, and remaining flow in the river, serve as a source of water for the City of Santa Fe and surrounding communities. Water use has increased as the population of the region has grown, and hydrologic alteration analysis of the Santa Fe River near Santa Fe site shows a distinct reduction in flow across multiple metrics (see Figure 9). In 2007, the Santa Fe River was designated as "America's Most Endangered River" due to water management practices that effectively "turned off" the river (American Rivers, 2007), resulting in a loss of native riparian ecosystems and instream habitat. The City of Santa Fe has recognized that improved water management strategies can restore aquatic and riparian systems, provide recreation opportunities for residents, and boost the local economy, and has committed to providing water to maintain minimum flows (Borchert, Drypolcher, & Lewis, 2010).
- **Pecos River:** Riparian conditions along the lower Pecos River have transformed dramatically as it has shifted from a meandering, diversified system to a highly eroded, channelized river (Audobon New Mexico, 2009). These changes corresponded to flow reductions following dam installation, groundwater pumping, and surface diversion. Today, the lands adjacent to the Pecos River are choked with the non-native saltcedar, while populations of native fish such as the Pecos bluntnose shiner (a state and federal threatened species) have dwindled (New Mexico Department of Game and Fish, 2006).
- **Canadian River**: The Canadian River is a key source of water for northeastern New Mexico. The upper portion of the Canadian River watershed (above Ute Reservoir) includes the historic range of the suckermouth minnow, a state-listed threatened fish species (New Mexico Department of Game and Fish, 2006). Flow reductions (such as the peak flow reduction identified for the Canadian River near Sanchez site) are believed to contribute to the degradation, fragmentation, and desiccation of suckermouth minnow habitat. Reduced flow has also been associated with a decline in native riparian vegetation and

increase in populations of invasive shrub species, including saltcedar and Russian olive (Colfax Soil and Water Conservation District, 2004).

- **San Juan River**: Operation of the Navajo Dam and Reservoir on the San Juan River through the early 1990s resulted in a loss of peak flows during the spring snowmelt season and augmentation of low flow conditions during the late summer and winter months (Figure 8). These changes were linked to declines in the populations of two native fish species, the Colorado pikeminnow and razorback sucker (both federally endangered species). Additional discussion of the ecological effects of flow alteration, and environmental flow management, on the San Juan are provided in Section 5 of this report.
- **Gila River:** Wetland habitat, which once extended throughout large portions of the middle and lower portions of the Gila River, have effectively disappeared due to extensive groundwater pumping and surface water withdrawals (New Mexico Department of Game and Fish, 2006). These practices have also contributed to dewatering of the Gila River mainstem during dry periods. As a result, several fish species are in decline, including the Gila chub (a state endangered species) and Gila trout (a state and federal threatened species), while others, such as the Gila topminnow and roundtail chub, are no longer found in the New Mexico portion of the Gila River.

Results of hydrologic alteration analysis provide evidence that: 1) hydrologic alteration is a widespread issue throughout New Mexico; 2) a broad range of stream types have been affected; and 3) alteration is not limited to streams impacted by large-scale water management projects. When considered in conjunction with known and potential impacts of hydrologic alteration on stream ecology, these data paint a bleak picture for the overall health of New Mexico's waters. Watershed restoration and protection efforts that are currently underway have the potential to mitigate or prevent many of the ecological effects of flow alteration. Integral to their success is the recognition of the role of hydrologic alteration in ecosystem degradation. The next section discusses relationships between hydrologic alteration and watershed health with the intention of informing those involved in watershed management activities of the importance of incorporating environmental flow considerations.

4. Hydrologic Alteration and Watershed Health

Since the passage of the Clean Water Act in 1972, the management of water resources has gradually shifted from a focus on restoration of individual sites and components of the environment to a comprehensive watershed approach for improving the nation's waters. The watershed approach was born from the recognition that water resources management must occur across political and administrative boundaries and that individual components of the natural and developed environment are fundamentally connected. EPA's Healthy Watersheds Initiative emphasizes the benefits of the watershed approach for the protection of healthy ecosystems in addition to the restoration of degraded systems.

A first step in watershed management planning is the assessment of the current and historic condition of ecological resources within a watershed. The Healthy Watersheds Initiative bases this assessment on the six Essential Ecological Attributes (EEAs) presented in the *Framework for Assessing and Reporting on Ecological Condition* (U.S. EPA Science Advisory Board, 2002) (Figure 10). Included in an EEA-based assessment of watershed condition is an evaluation of the flow regime of surface waters within a watershed.

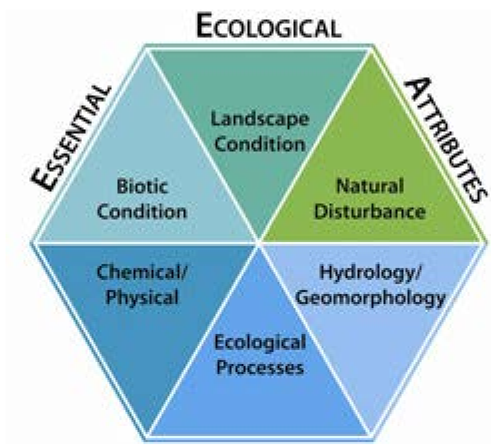

Figure 10. Essential Ecological Attributes presented in the *Framework for Assessing and Reporting on Ecological Condition* (U.S. EPA Science Advisory Board, 2002).

The main entity responsible for coordinating watershed management actions within the State of New Mexico is the Watershed Protection Section of the New Mexico Environment Department (NMED). In 1999, the NMED Watershed Protection Section released the *New Mexico Nonpoint Source Management Program* (updated in 2009), which prioritized New Mexico watersheds according to water quality restoration needs and called for the development of watershed plans in the form of Watershed Restoration Action Strategy (WRAS) reports. WRASs have been generated for 30+ watersheds throughout the state, including several study watersheds in this report. A review of existing WRASs indicates that recognition of the link between hydrologic alteration and watershed health by watershed managers and planners is currently lacking. This section is intended to augment understanding of this connection so that well-informed watershed protection and restoration decisions can be made.

For the State of New Mexico, Eight Key Parameters of Watershed Health were identified by participants at the 2010 New Mexico Environmental Flows Workshop for the purpose of evaluating the condition of New Mexico's rivers. Each of these parameters is tied to hydrologic alteration, representing both drivers of, and responses to, hydrologic alteration. Below is a review of the Eight Key Parameters and their relationship to hydrologic alteration. To describe conditions within study watersheds, several watershed health metrics are discussed that relate to the Eight Key Parameters[4]. Environmental flows and watershed management programs can be greatly aided by robust quantitative relationships between watershed health parameters and flow alteration metrics. Statistical analysis of these data indicates that the development of such relationships is complicated by issues of scale, data availability, and confounding factors. The implementation of targeted monitoring studies to quantify flow alteration-ecological response relationships for New Mexico streams is therefore included as a recommended next step for environmental flow initiatives in the state (see Section 4).

Aquatic Species of Concern

The biological diversity of riverine ecosystems is largely a function of habitat condition and diversity, and is directly related to the variability of streamflow in space and time. Changes to the natural flow regime can adversely affect populations of aquatic species and reduce biological diversity (see Table 6 for example flow alteration-biological response relationships). The *Comprehensive Wildlife Conservation Strategy for New Mexico* (CWCS) (New Mexico Department of Game and Fish, 2006) details the current state of biological diversity within New Mexico through an assessment of wildlife population and habitat data. In it, 452 species are defined as Species of Greatest Conservation Need (SGCN), based on their ecological, recreational, and economic value, and vulnerability to population declines. A common threat to aquatic SGCN is habitat fragmentation, degradation, and loss due to low and high flow reductions or other flow regime change.

Aquatic SGCN are present in all study watersheds included in hydrologic alteration analysis (Figure 11). High SGCN counts are found for large rivers with major upstream human disturbance (26 SGCN for Pecos River at Red Bluff; 16 SGCN for Rio Grande below Caballo Dam). These rivers also contain multiple state- and federally-listed threatened and endangered species. Recovery plans for these species have noted the connection between hydrologic alteration and threatened/endangered status, and have called for a return of relevant components of the natural flow regime to improve survival potential. For example, the *Rio Grande Silvery Minnow Recovery Plan* (U.S. Fish and Wildlife Service, 2010) discusses several options for improved flow management of the Rio Grande to protect and restore Rio Grande Silvery Minnow habitat, and public-private partnerships such as the Middle Rio Grande Endangered Species Collaborative Program have made progress toward implementing flow management strategies that benefit the Rio Grande Silvery Minnow and other threatened/endangered species.

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[4] See Appendix C. Watershed Health Metrics for methods used to quantify watershed health metrics.

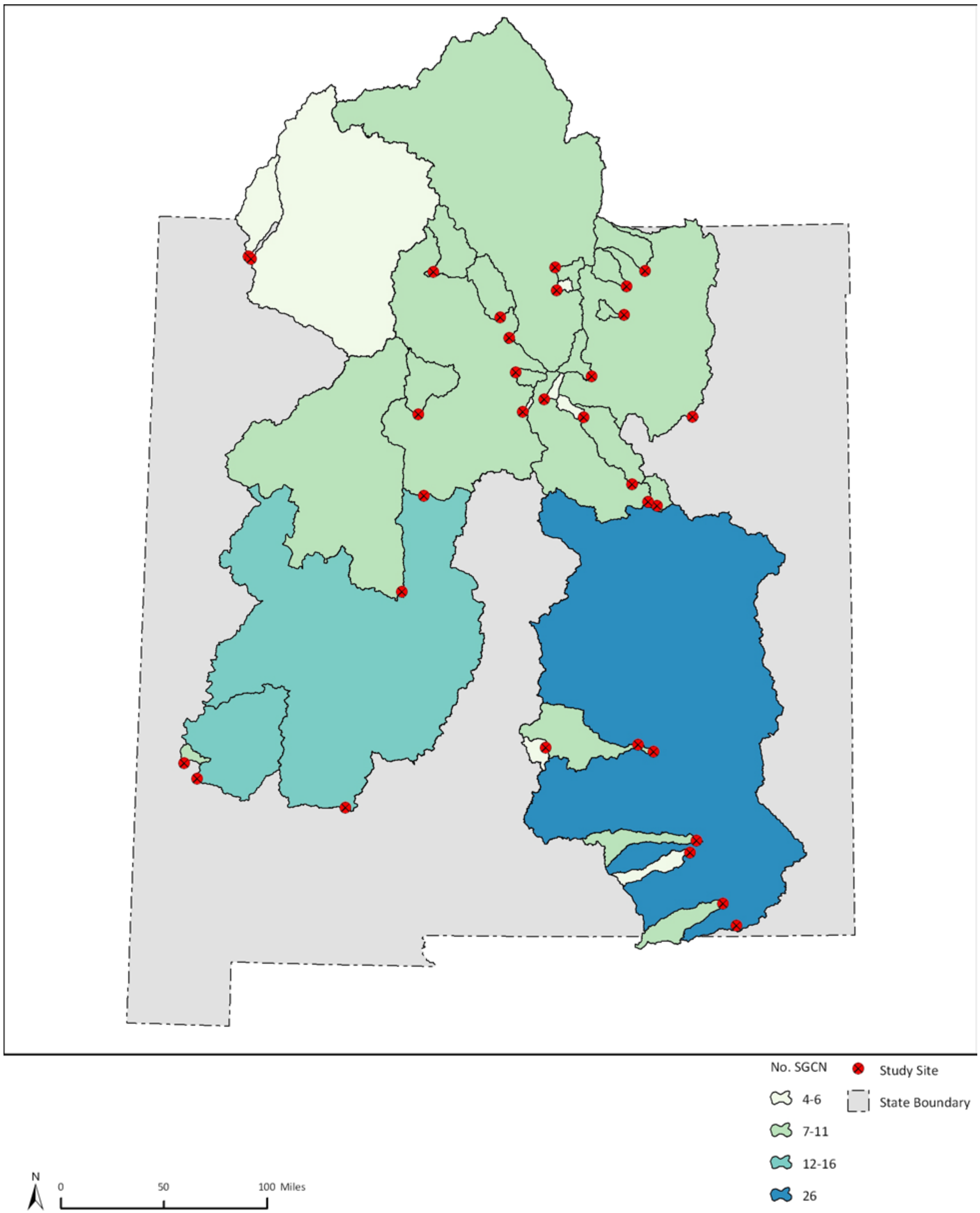


Figure 11. Number of Species of Greatest Conservation Need (SGCN) within study watersheds (New Mexico Department of Game and Fish, 2006).

Clean Water Act (CWA) Impaired Waters

Since 1998, the State of New Mexico has conducted ambient water quality monitoring to assess the ability of streams and rivers to achieve their designated uses. Results of this assessment are published biennially in the *State of New Mexico Clean Water Act 303(d)/305(b) Integrated Report*. The 2010-2012 Integrated Report (New Mexico Environment Department, 2010) identifies several causes of designated use impairments throughout the state and their ultimate source(s). Flow alteration is listed as a direct cause of impairment on 194 miles of river and stream segments, and as a source of causes that are chemical or physical in nature (e.g., water temperature changes or nutrient contamination) on more than 700 miles of rivers and streams. Further, hydrologic alteration is associated with a number of other impairment sources (dams/impoundments, industrial and municipal permitted discharges, channelization, irrigated crop production, mine tailings, etc.).

NMED's 2010-2012 Integrated Report demonstrates that water quality issues are prevalent throughout the State of New Mexico. 25 of the 32 study sites included in this project are located on reaches that are listed as impaired (Figure 12). Five study sites are located on reaches that currently support all designated uses. These are generally subject to a few human impacts and exhibit minimal hydrologic alteration (e.g., Rio Hondo near Valdez; Santa Cruz River near Cundiyo; Rio Mora near Terrero). This information supports the connection between degraded water quality and hydrologic alteration and the assertion that improved flow management can be an integral part of regulatory-driven water quality management efforts.

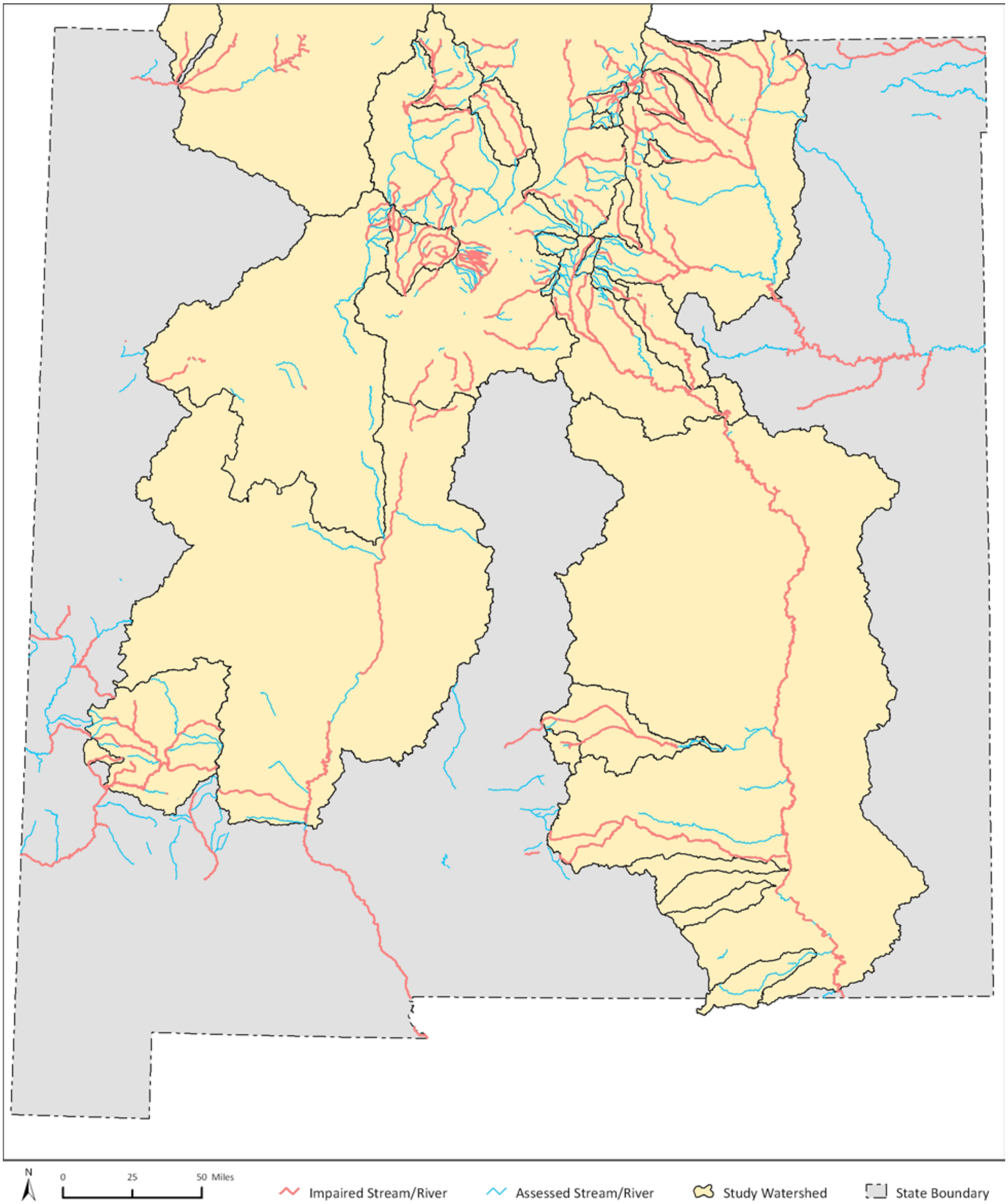


Figure 12. Impaired waters of New Mexico (New Mexico Environment Department, 2010). Rivers and streams that were assessed for the *2010-2012 State of New Mexico Clean Water Act 303(d)/305(b)* and deemed fully supportive of designated uses are also shown.

Watershed Condition

Widespread land cover change can alter hydrologic processes and drive water budget changes at the watershed scale. A primary cause of long-term land cover change is human development of natural lands for residential, commercial, industrial, or agricultural use. Following development, changes to the flow regime can include increased high flow magnitude, frequency, and duration due to increased impervious cover and storm runoff. Alternatively, water demand increases that parallel development can act to reduce high and low flows. In the arid southwest, the effects of increased water use have been found to outweigh those of increased impervious cover, with reduced high and low flow magnitude, and reduced high flow duration, associated with urban and agricultural development (Poff, Bledsoe, & Cuhaciyan, 2006).

New Mexico ranks among the top 5 states in the U.S. in land area and among the bottom 15 in population. Vast expanses of undeveloped land are found throughout the state and within study watersheds (Figure 13). Developed lands make up at least 10% of total watershed area for a single study site only (Rio Grande at Embudo). Though the total land area affected by human development is relatively small in these watersheds, the hydrologic footprint of development can be considerable. Multiple sites with developed lands in the vicinity of streamflow monitoring site locations exhibit flow alterations that are consistent with the expected effects of increased water demand, including reduced peak flow magnitude and reduced frequency of high flow pulses (e.g., Rio Grande at Embudo, Rio Ojo Caliente at La Madera, Mora River at La Cueva), and increased duration of low flow pulses (La Plata River near Farmington, Rio Ojo Caliente at La Madera).

As discussed in Section 2, forest and woodland cover types dominate the landscape in many study watersheds. Recently, forests of the western U.S. have been affected by widespread tree mortality that has been associated with climatic stress (drought and high temperatures) (Allen, et al., 2010) and past forest management decisions. Forest ecosystems play a major role in regulating the quantity and timing of streamflow due to interception of snow and rain by the forest canopy, protection of the snowpack by the canopy, and transpiration by forest vegetation. Changes to forest cover may therefore drive streamflow change in areas that are important sources of water for downstream users. Forested areas that are vulnerable to mortality events were identified as part of The New Mexico Statewide Resources Assessment (ENMRD Forestry Division, 2010). Nearly 1 million acres of New Mexico's forests are classified as high priority forests due to their susceptibility to insect and disease outbreaks Several study watersheds contain high priority forest (Figure 14) and these areas should be a focus for evaluation of the ecohydrologic impacts of landscape change by watershed managers.

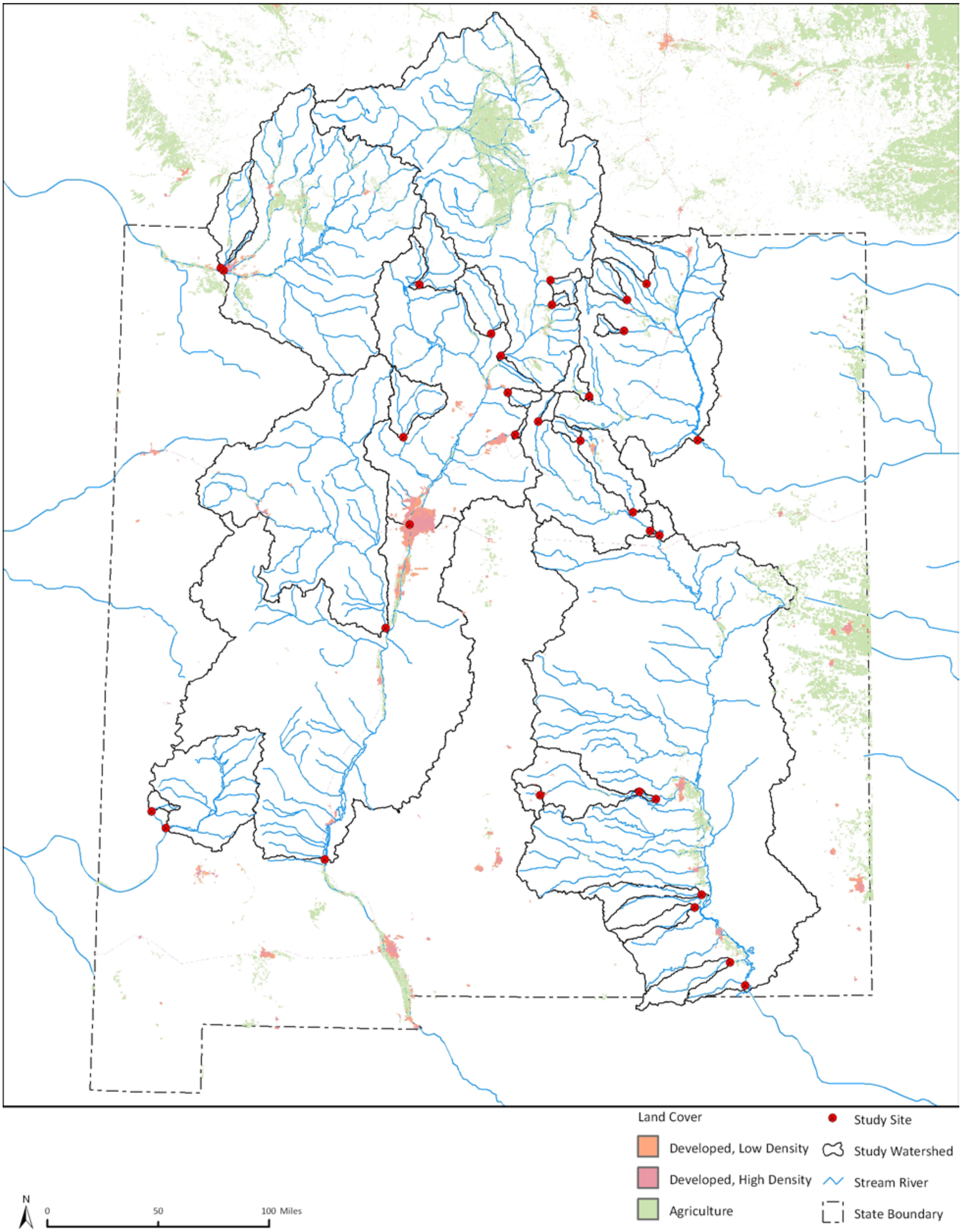


Figure 13. Developed lands within study watersheds (USGS National Gap Analysis Program, 2004).

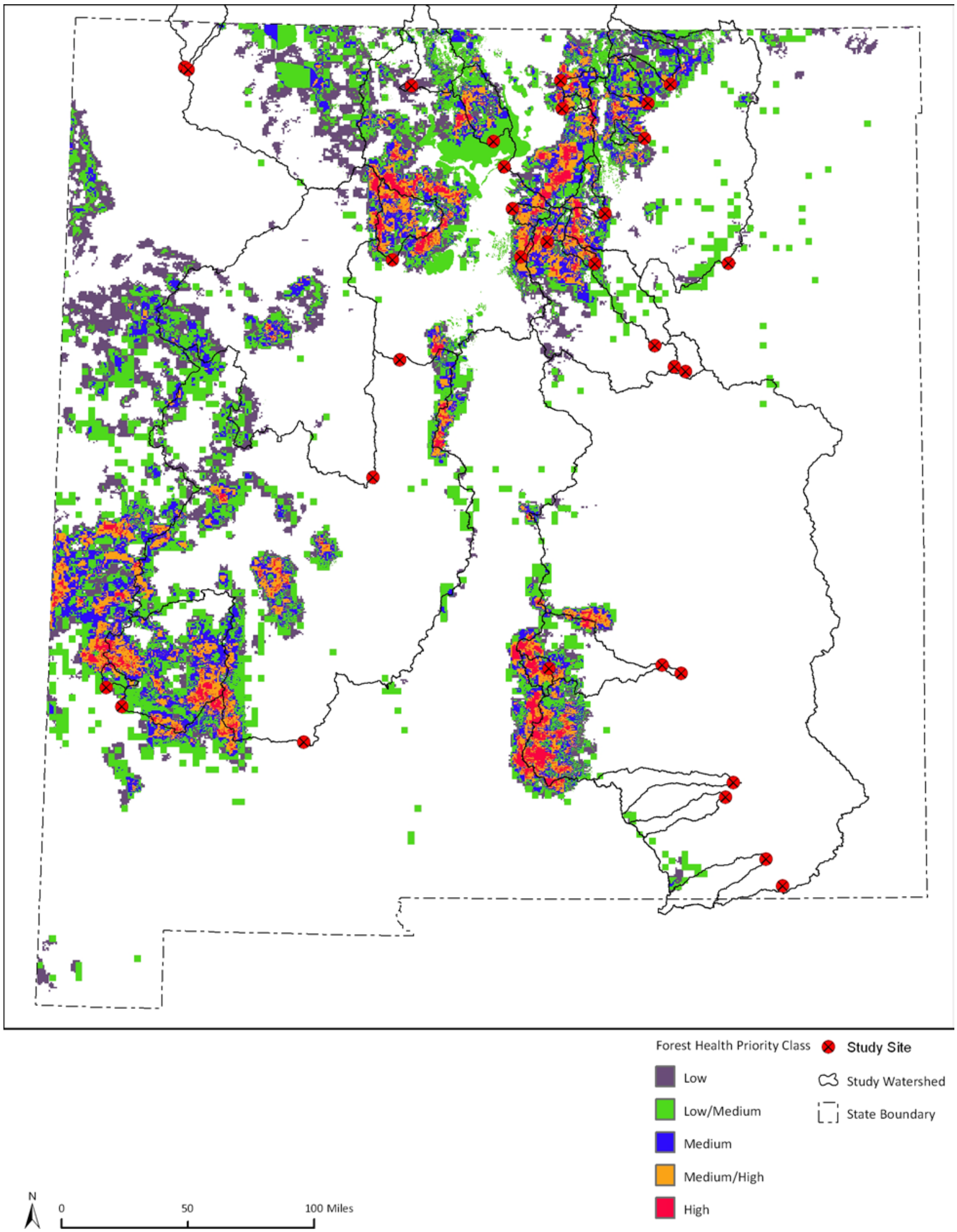


Figure 14. Priority areas for protection of forest health (ENMRD Forestry Division, 2010).

Riparian Condition

Riparian areas represent transitional zones between terrestrial and aquatic ecosystems. As such, they provide habitat for phreatophytic and wetland vegetation, amphibious wildlife, and species that otherwise depend on large quantities of water during all or part of their life cycle. From a water quality perspective, riparian vegetation naturally filters surface and near surface runoff as it enters streams and rivers, prevents erosion through streambank stabilization, and stabilizes water temperature.

Relationships between hydrologic alteration and riparian health are diverse. As discussed above, human development and hydrologic alteration are closely tied, and development within a watershed often extends into riparian areas (Figure 15). Beyond the physical changes associated with human development, riparian ecosystems are highly sensitive to various types of flow regime change (Stromberg, 2001). Reductions in the spatial extent of riparian areas have been associated with extreme reductions in flow magnitude due to diversions, flow regulation, and groundwater pumping. Rivers subject to high flow reductions by flood control structures have seen decreases in plant diversity and dominance by one or a small number of species otherwise controlled by flood disturbance, especially the non-native tamarisk/saltcedar. Groundwater pumping or flow reductions that drive water table declines have led to die-off of phreatophytic vegetation and loss of riparian cottonwood forests.

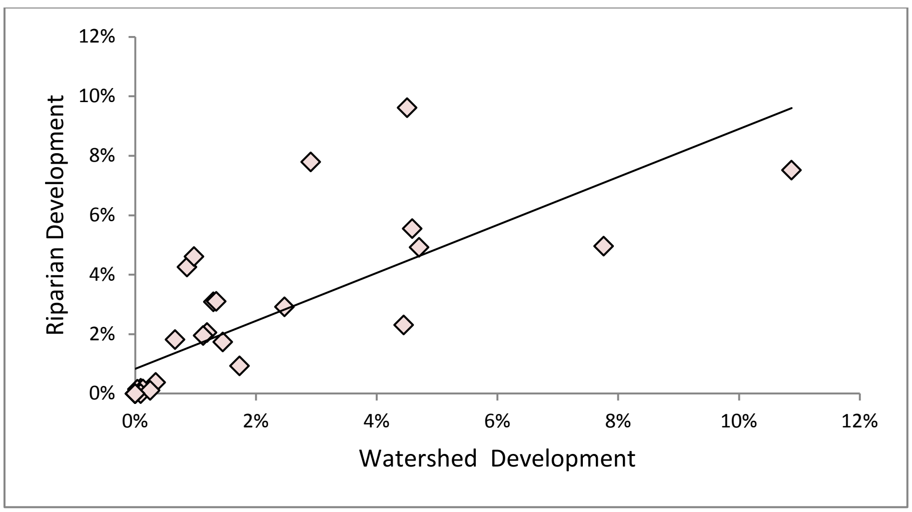


Figure 15. Comparison of riparian development and total watershed development within study watersheds. Development includes urban and agricultural land cover types.

Several study sites have riparian restoration plans in place to meet watershed management goals. The connection between surface flows and riparian condition underscores the need to consider hydrologic alteration and environmental flow management as part of future riparian restoration initiatives (Molles, Crawford, Ellis, Valett, & Dahm, 1998; Stromberg, Beauchamp, Dixon, Lite, & Paradzik, 2007). These initiatives could be aided by quantitative flow alteration-ecological response relationships. Riparian health data specific to stream reaches where flow is monitored could allow for the development of such relationships and would complement riparian data currently collected by NMED.

Geomorphic Condition

Channel and floodplain geomorphology are fundamentally shaped by streamflow characteristics. Changes to the natural flow regime can significantly affect channel geometry, physical properties, and floodplain connectivity. The geomorphic effects of large dams have been especially well-studied; with flow regulation associated with larger low flow channels, smaller high flow channels, and smaller floodplains relative to unregulated upstream reaches (Graf, 2006). Increases in bed erosion and incision, and bank instability have also been documented following hydrologic alteration (Poff, Bledsoe, & Cuhaciyan, 2006; Juracek & Fitzpatrick, 2009). On the Rio Grande, flow regulation following the construction of the Cochiti Dam in 1973 drove the shift from a wide, braided channel to the simplified, deepened channel present today (Richard & Julien, 2003).

Watershed management plans for study sites outline several geomorphic restoration projects to reduce bed and bank erosion and reconnect stream channels with the natural floodplain. The long-term success of these projects is tied to the restoration or maintenance of key components of the natural flow regime. NMED has collected geomorphic data for select stream monitoring stations throughout the state, and additional, targeted monitoring of streamflow and geomorphology across watersheds may reveal quantitative relationships that outline streamflow needs for various geomorphic restoration objectives which are relevant to specific stream and river reaches.

Groundwater-Surface Water Connection

Groundwater is a major part the New Mexico water supply and is vital to the health of aquatic, riparian, and wetland ecosystems. In New Mexico, groundwater recharge-discharge dynamics vary dramatically between river reaches and over time for a single river reach. Where and when discharge does occur, it serves to maintain the baseflows and subsistence flows (extreme low flows) that sustain aquatic and riparian species. Excessive pumping of groundwater and water table drawdown can reduce groundwater discharge, reverse natural gradients, or increase channel losses in areas where recharge occurs naturally. These changes can affect low flow components of the natural flow regime to the detriment of aquatic and riparian wildlife and vegetation.

For a particular stream system, the relative importance of groundwater outflow contributions is demonstrated by the annual baseflow index (BFI; the ratio of annual baseflow to total annual flow). Figure 16 illustrates the average annual BFI within study sites. Streams in 60% of study watersheds receive at least one-half of their total annual flow from groundwater sources, with decreasing groundwater contributions occurring at lower elevations. BFI, groundwater seepage, and water table data collected at the reach scale is useful for evaluating sensitive areas where aquifer development can increase the frequency and duration of low flow events or where small changes in groundwater dynamics can lead to zero flow or extreme low flow conditions.

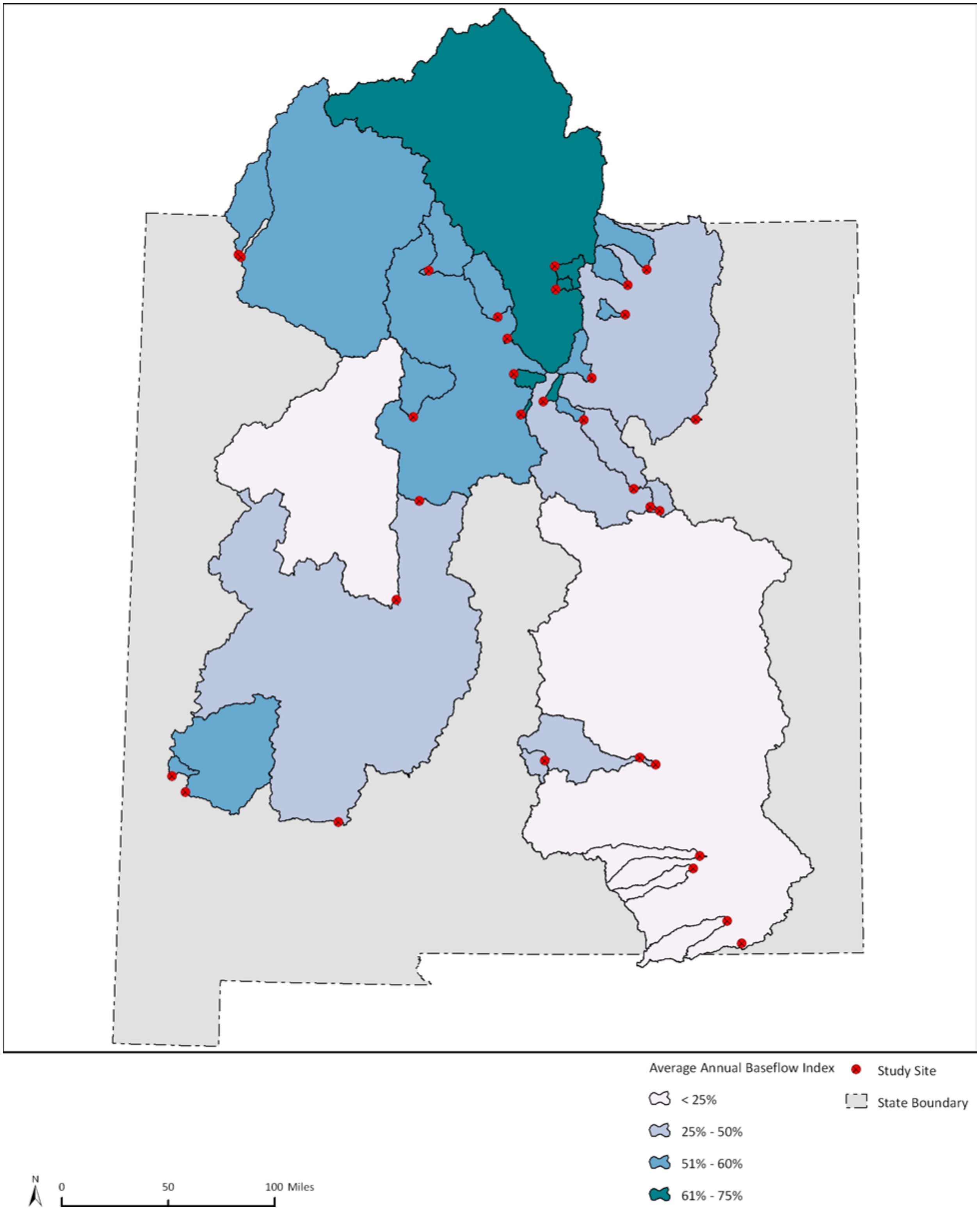


Figure 16. Average annual baseflow index for study watersheds (Wolock, 2003).

Agro-Ecosystem Health

Agricultural ecosystems, or agro-ecosystems, include anthropogenic (crops, livestock) and natural (soils, air, water) components. Their health is relevant to the quality-of-life of all human populations. Productive and efficient food supplies require prudent natural resource management, including the maintenance of a clean and reliable water supply, and policy approaches that recognize the importance of agricultural economies.

While agro-ecosystems are themselves drivers of hydrologic alteration (primarily due to irrigation), feedbacks between hydrologic alteration and agro-ecosystem health can compromise the productivity of farmed lands. For example, reduced flows may reflect groundwater drawdown and aquifer depletion that can have substantial implications for the long-term viability of agricultural production. Not only an effect of sustained pumping, groundwater drawdown can result from short-term groundwater use to supplement surface supply shortages (e.g., under drought conditions). The hydrologic implications of groundwater pumping during multi-season droughts is a topic requiring additional research and is particularly relevant in light of expected increases in drought frequency and severity under global climate change. Expanded groundwater use during such conditions may push already reduced flows beyond ecological thresholds and greatly reduce the ability to procure irrigation supplies.

Flow alteration also affects agricultural productivity when water of degraded quality is applied to irrigated croplands. Flow reductions can result in water supplies with high concentrations of salts and sediment. Issues of high soil salinity in agricultural lands are already present throughout multiple study watersheds (Figure 17) and the management of low flows for improved water quality may improve or maintain the health and productivity of agro-ecosystems. Alternatively, high flow changes due to stormwater discharge can result in increased transport of natural and anthropogenic pollutant loads in water used for irrigation, and create flooding issues for agricultural lands located in floodplains.

Overall, changes in high and low flow conditions can affect agricultural productivity. These issues must be addressed by water managers and the agricultural community to protect the economic viability of local producers and ensure that sustainable water use practices are designed.

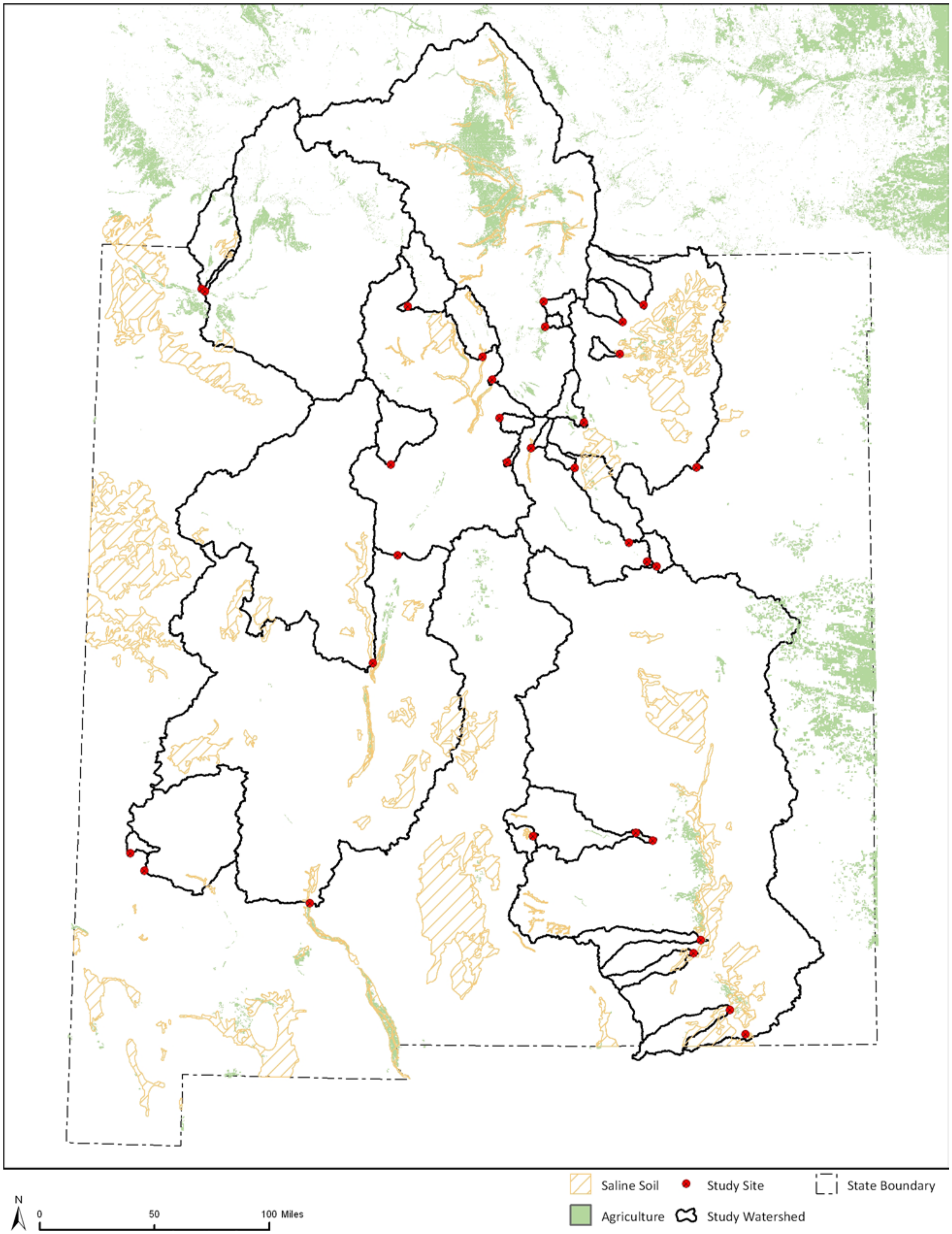


Figure 17. Location of saline soils in study watersheds (U.S. Department of Agriculture, Natural Resources Conservation Service, 2006).

Drought & Climate Change Vulnerability

Hydrologic alteration of New Mexico streams will likely increase in the coming years, both in terms of the number of streams affected and the severity of change. Over the last 50 years, the state has experienced dramatic population growth, doubling since 1960 to 2 million residents. With increased growth comes increased water demand. Recent estimates of surface and groundwater use indicate that a large proportion (up to 70%) of available water is used for municipal, domestic, agricultural, and industrial purposes in New Mexico's major watersheds (Figure 18) and remaining surface flows are appropriated to downstream users.

Continued growth is projected for the state, with 3 million residents predicted by 2060 (Bureau of Business and Economic Research, 2008). A water supply increase is not expected to offset the demand increase associated with a growing population over this period. Rather, climate projections through 2050 suggest that annual precipitation will decrease over much of the state and annual temperature will increase across the entire state (Figure 19). Drought periods are expected to become more frequent and severe and annual runoff is expected to decrease (State of New Mexico Agency Technical Workgroup, 2005). These projections represent a dual threat to streamflow, with the effects of increased water use compounded by those of climate change.

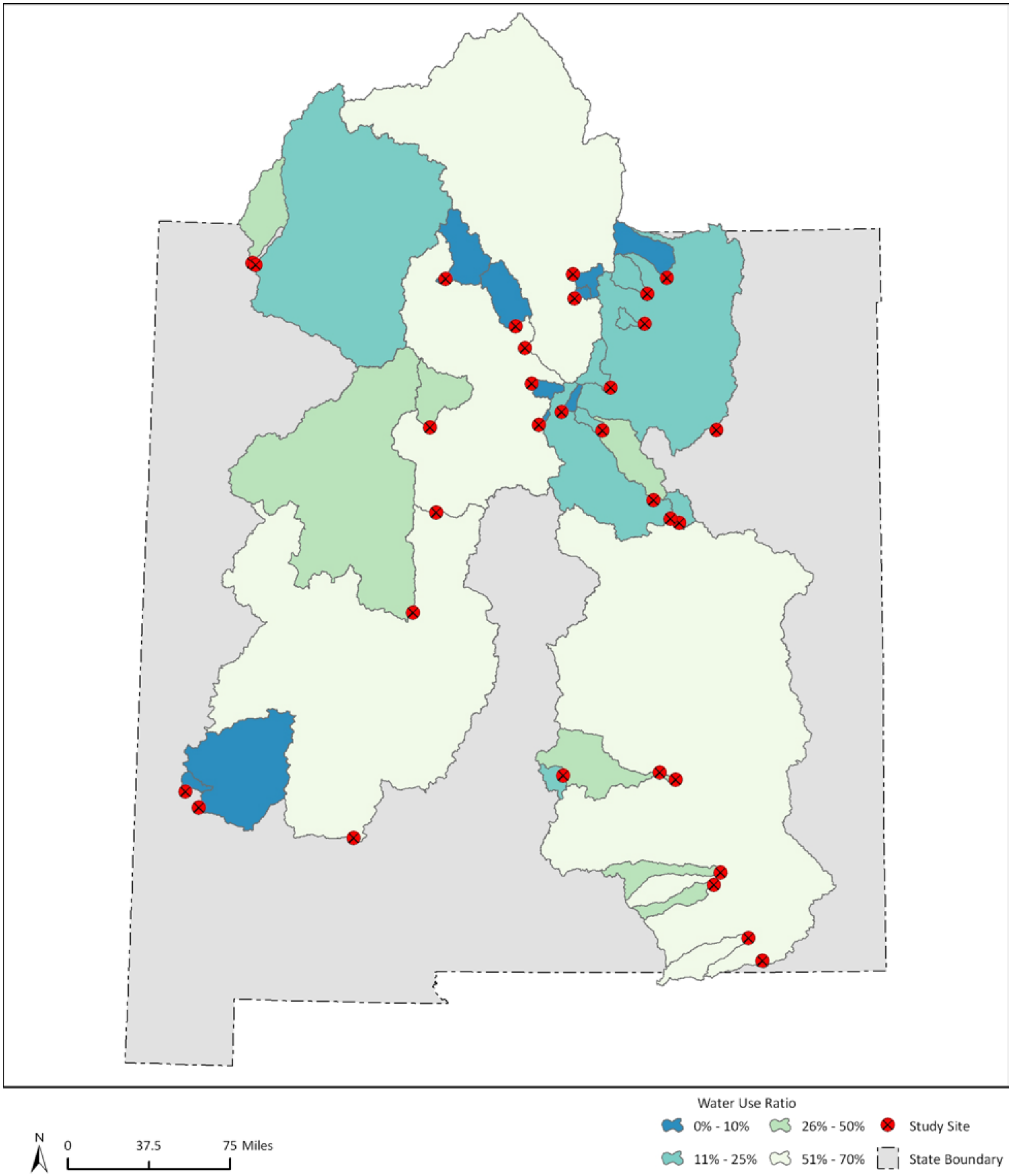


Figure 18. Ratio of water use to water availability (water use ratio) within study watersheds. Water use estimates are based on USGS data for the year 2000 (Hutson, Barber, Kenny, Linsey, Lumia, & Maupin, 2004). Water availability estimates are based on long-term average annual runoff (Gebert, Graczyk, & Krug, 1987).

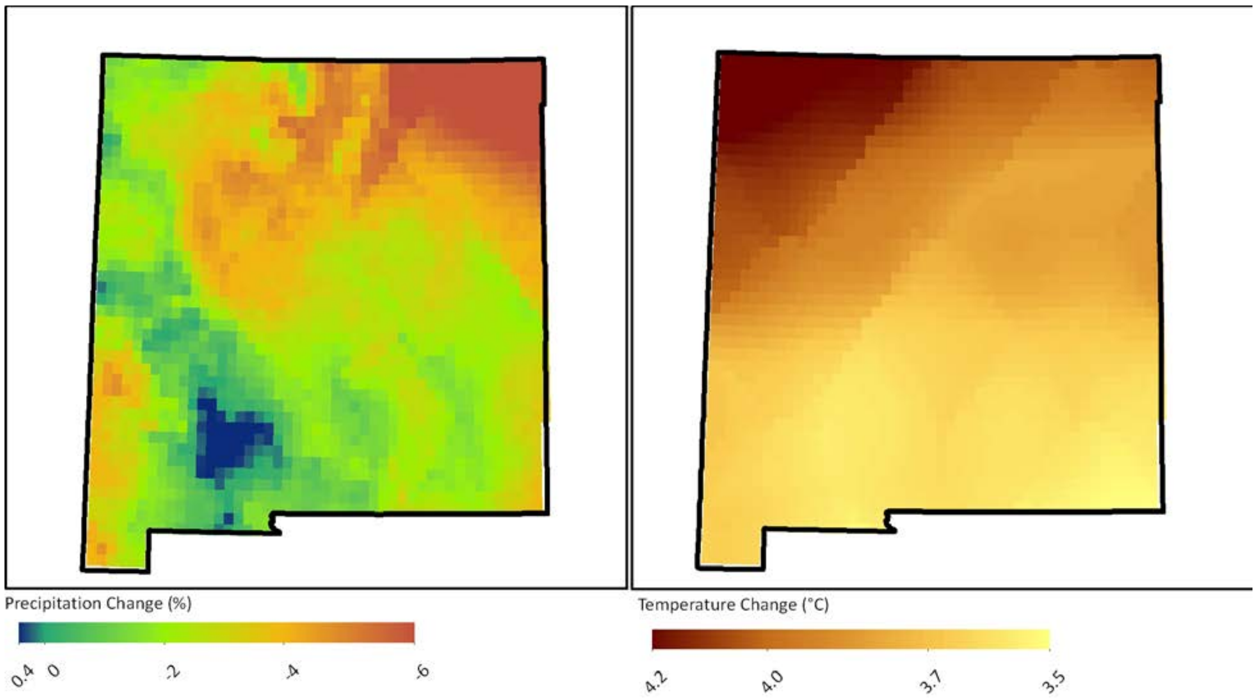


Figure 19. Projected changes in precipitation and temperature in New Mexico through 2050 (Maurer, Brekke, Pruitt, & Duffy, 2007).

5. Environmental Flow Management in New Mexico

The ecological problems posed by hydrologic alteration in New Mexico can have cascading local and statewide economic and cultural impacts. These impacts can be traced to the degradation of water quality and loss of recreational opportunities that often accompany flow alteration. Water quality impairments that are caused or aggravated by flow regime change often must be addressed through the TMDL process, a potentially complex and expensive method, and may affect the productivity of local agricultural lands. Impacts on recreation include reductions in fishing, swimming, and boating/rafting areas, and reduced birding opportunities from riparian and wetland habitat loss, among others.

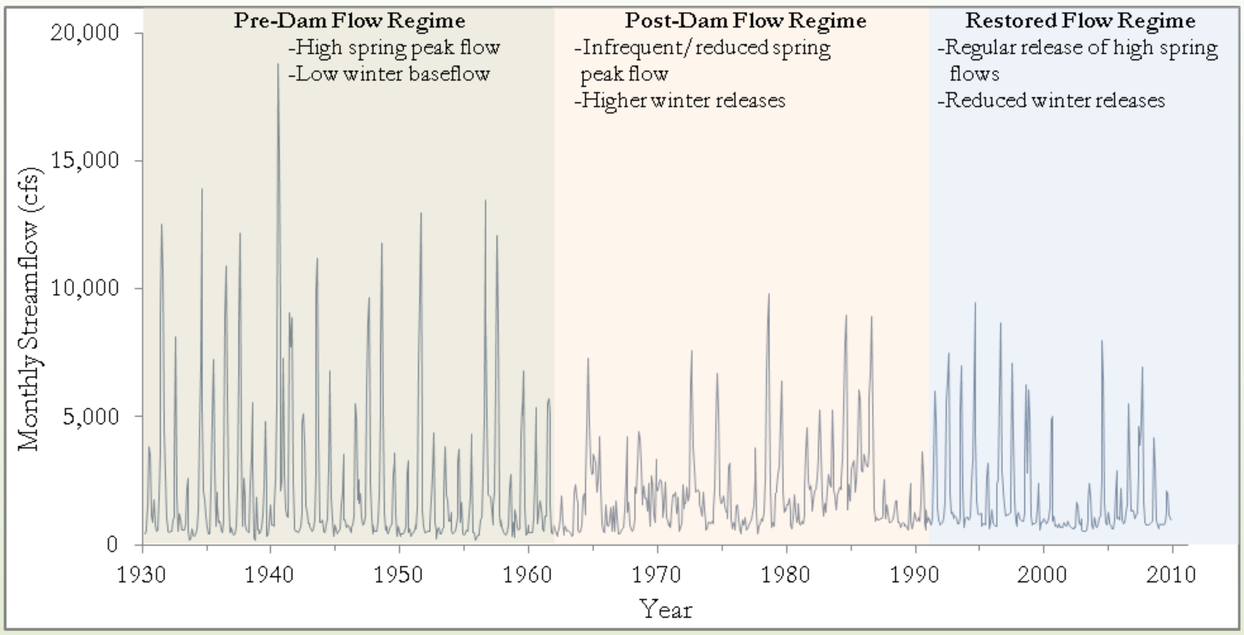
A number of organizations and communities have recognized the ecological, economic, and social implications of hydrologic alteration, and have devised innovative solutions that move away from the tenets of traditional water management (Environmental Flows Workshop, 2010). Examples include:

- Facing substantial dewatering of the Santa Fe River, the City of Santa Fe has set aside unused appropriated water for environmental flow releases and has created a fund to purchase additional water for river flows using contributions from water users.
- The Strategic Water Reserve (SWR), a program designed and implemented by nonprofits, local and state governments, and other stakeholders, allows the state's Interstate Stream Commission to acquire water rights to comply with interstate compacts/court orders and benefit wildlife species. SWR acquisitions have been used to augment flows on the Rio Grande and Pecos Rivers.
- The New Mexico Office of the State Engineer has encouraged environmental flow initiatives by authorizing water rights acquired specifically for environmental flow purposes, and by protecting "retired" water rights placed in an approved Conservation Water Project from forfeiture.
- The San Juan River Basin Recovery Implementation Program developed flow recommendations for the San Juan River to aid in the recovery of two endangered fish species, the Colorado pikeminnow and the razorback sucker. Flow recommendations have been implemented by operators of Navajo Dam to restore key components of the natural flow regime. The San Juan River Basin Recovery Implementation Program is featured as an exemplary environmental flow program on the following page.
- The Rio Chama Flow Optimization Project, initiated in 2011, is comprised of a partnership between land managers, scientists, and non-governmental organizations with the goal of enhancing the ecological condition of Rio Chama, a federally-designated Wild and Scenic River, through environmental flow management. The project aims to gain an intricate understanding of natural and engineered river conditions to optimize Rio Chama management using input from water users and other stakeholders.

The expansion of these and similar environmental flow programs would help to improve the condition of degraded waters and prevent future impairment of high-quality stream systems. Critical to the success of such programs is the involvement of water users throughout the program planning and implementation phases. This involvement should extend beyond traditional water conservation outreach to engage domestic, agricultural, and industrial users when addressing questions related to the location of future river restoration projects, environmental flow guidelines, and water availability for environmental flow management.

The San Juan River: A Case Study for Environmental Flow Management & River Restoration

The Problem: Water development on the San Juan River and its tributaries is extensive, consisting of multiple large dams, diversions for irrigated lands, and interbasin water transfers. The construction of the Navajo Dam and Reservoir in 1962 had a particularly large impact on the San Juan's natural flow regime and river ecology. Dam operations through the early 1990s emphasized the stabilization of outflows to maximize reservoir storage, effectively eliminating the natural snowmelt-driven flow regime downstream of the dam (see hydrograph below). The reservoir also acted as a sediment trap, and regulated water releases had the capacity to transport substantial amounts of sediment below the dam, resulting in major geomorphic modifications to the river channel (New Mexico Department of Game and Fish, 2005). These changes contributed to the designation of two native fish species, the Colorado pikeminnow and the razorback sucker, as endangered species by the U.S. Fish and Wildlife Service (USFWS).



San Juan River (at Farmington) monthly streamflow over the period 1930-2010.

The Solution: In response to the listing of the Colorado pikeminnow and razorback sucker as endangered species, the USFWS formed the San Juan River Basin Recovery Implementation Program (the Program). The Program, consisting of a partnership between multiple state governments, federal agencies, and native tribes, is intended to direct and facilitate the recovery of these species in conjunction with continued water development in the San Juan watershed. In 1991, the Program initiated a seven-year study that included modified Navajo Dam operations to better mimic natural conditions and direct environmental flow recommendations that were ultimately adopted by the U.S. Bureau of Reclamation (the dam operator) (Holden, 1999).

Lessons for Future Initiatives: The San Juan River Basin Recovery Implementation Program is noteworthy for several reasons. First, it readily recognized the role of hydrologic alteration in the ecological degradation of the San Juan River. Moreover, the Program took a direct and deliberate approach to addressing the issue, implementing a study to investigate flow-ecology relationships, and working across political boundaries to implement flow recommendations. The Program has also worked with water users to secure environmental flow supplies during periods of drought and continues to perform ecological monitoring of the San Juan River to evaluate the effectiveness of environmental flow management for native fish recovery.

6. Recommendations for Future Environmental Flow Initiatives

This report is the result of an initial attempt to gather streamflow data, evaluate hydrologic alteration, and assess ecological relationships at the statewide scale. During this process, several observations were made that may enhance the value of future environmental flow analyses:

- A standardized classification of New Mexico's surface waters may streamline the identification and assessment of ecologically-relevant streamflow metrics for individual streams. Such a classification may also be useful for the development of robust and transferable flow-ecology relationships. Stream classification is a vital step in the Ecological Limits of Hydrologic Alteration (ELOHA) process, the recently developed framework for large-scale environmental flow planning proposed by Poff et al. (2010).

- Reach-scale ecological data are often required for the development of flow-ecology relationships that serve as the basis for environmental flow management. Such data were available for just a few sites included in this report. A comprehensive review of reach-scale biological and habitat data availability near existing stream gaging locations is needed for the state, and expansion or adjustment of stream sampling may be needed.

- Many streamflow datasets for New Mexico do not include true "pre-impact" hydrologic data, as the state's oldest water rights were established prior to the onset of extensive streamflow monitoring. Therefore, assessment of hydrologic alteration may be improved through the use of baseline data generated through hydrologic modeling or obtained from suitable reference sites.

- Evaluation of hydrologic alteration over time is complicated by climate variability and directional climate change. The development of environmental flow recommendations without considering climate variability or fundamental changes to water and energy inputs to hydrologic systems due to climate change is likely to lead to unrealistic and inappropriate management guidelines. This provides further justification for the use of modeled or reference site data for environmental flow analysis rather than historical data.

- It is important that a process for evaluating flow alteration and ecological response consider confounding factors that drive ecological degradation despite minimal flow alteration. Controlling for these confounding factors allows for isolation of flow alteration effects on fish, macroinvertebrate, and riparian communities and for the development of clear, quantitative linkages between flow alteration and ecological response.

A central question arising during the early phases of a large-scale restoration or protection initiative is how to prioritize future actions. For a statewide environmental flow assessment, this question is complicated by the sheer scale of the undertaking. At the time of this report, 142 streamflow monitoring stations are actively maintained on New Mexico's streams and rivers by the USGS and many more unmonitored stream reaches would likely benefit from environmental flow standards. To begin the process of prioritizing environmental flow needs in the state, study sites included in this report are grouped as:

- High-Priority Sites for Environmental Flow Restoration (18 sites). This group includes sites where upstream human activities have likely driven streamflow change. Sites demonstrate hydrologic alteration in at least one flow metric that is consistent with flow alteration commonly associated with known upstream human impacts. These include reduced high and/or low flow magnitude, reduced high flow frequency or duration, increased low flow frequency and/or duration, and/or increased zero flow frequency for sites downstream of water diversions, groundwater wells, or a major dam. Additionally, low flow changes that are consistent with flow stabilization by a major dam and flow augmentation by a transbasin diversion are considered (increased magnitude, reduced frequency/duration);

- High-Priority Sites for Environmental Flow Protection (5 sites). This group includes sites that have a high degree of hydrologic health and minor upstream human influence. Sites demonstrate no change in any flow metric, a change in peak flow timing only, or an increase in low flow magnitude only;

- Sites Requiring Additional Analysis (9 sites). This group includes sites demonstrating change across multiple flow metrics that is inconsistent with the effects of known upstream human impacts or sites demonstrating minimal/no flow alteration despite known upstream drivers of hydrologic alteration. For sites demonstrating variable flow alteration, additional research into upstream impacts would reveal the cost-benefit potential for environmental flow restoration efforts. For sites demonstrating no flow alteration, additional hydrologic alteration analysis would confirm the need for environmental flow protection or identify opportunities for flow restoration.

Study sites are grouped according to environmental flow need in Table 7. These groupings are intended to highlight sites where environmental flow restoration can address flow alteration that has resulted from human activities, and where environmental flow protection can preserve streams in good hydrologic condition.

Prioritization of environmental flow activities within needs groups can be based on the vulnerability of aquatic and terrestrial ecosystems to degradation from flow alteration, and on vulnerability to future hydrologic alteration. Here, a preliminary review of the ecological vulnerability of each study site is provided according to four measures of watershed health that reflect current ecological stress: species of greatest conservation need, impaired stream reaches, riparian development, and saline soils. A preliminary review of the vulnerability of study sites to future hydrologic alteration is also provided, based on projected climate change and human development data, and current water use within study watersheds. Table 8 outlines ecological and hydrologic vulnerability scores within environmental flow needs groups[5].

[5] See comment 3 in Appendix A. Notes on Analysis Methods for a description of ecological and hydrologic vulnerability score calculations.

Table 7. Environmental flow needs for study sites included in this report. Note that sites within groups are listed in no particular order.

Environmental Flow Need	Site Name
High-Priority Restoration	
	Mora River at La Cueva
	Canadian River near Sanchez
	Red River near Questa
	Rio Grande at Embudo
	Rio Ojo Caliente at La Madera
	Santa Fe River near Santa Fe
	Rio Grande at Albuquerque
	Rio Puerco near Bernardo
	Gallinas River near Colonias
	Pecos River below Santa Rosa Dam
	Rio Hondo at Diamond A Ranch Near Roswell
	Rio Hondo below Diamond A Dam Near Roswell
	South Seven Rivers near Lakewood
	Black River above Malaga
	Pecos River at Red Bluff
	San Juan River at Farmington
	La Plata River near Farmington
	Rio Grande Below Caballo Dam
High-Priority Protection	
	Rio Hondo Near Valdez
	Santa Cruz River near Cundiyo
	Fourmile Draw near Lakewood
	Rio Mora near Terrero
	Mogollon Creek near Cliff
Additional Analysis Needed	
	Vermejo River Near Dawson
	Ponil Creek near Cimmaron
	Rayado Creek near Cimmaron
	Rio Chama near La Puente
	Jemez River near Jemez
	Gallinas Creek near Montezuma
	Pecos River above Santa Rosa Lake
	Rio Ruidoso at Hollywood
	Gila River near Gila

Table 8. Ecological and hydrologic vulnerability scores.

Ecological Vulnerability[a]			Hydrologic Vulnerability[b]		
High-Priority Restoration	*Score*	*Rank*	*High-Priority Restoration*	*Score*	*Rank*
Gallinas River near Colonias	2.18	1	La Plata River near Farmington	2.96	1
Pecos River at Red Bluff	2.16	2	Black River above Malaga	2.49	2
Canadian River near Sanchez	2.03	3	Rio Grande at Embudo	2.42	3
Mora River at La Cueva	1.91	4	San Juan River at Farmington	2.27	4
Rio Grande at Embudo	1.84	5	Rio Grande at Albuquerque	2.27	5
Rio Ojo Caliente at La Madera	1.81	6	Rio Grande Below Caballo Dam	2.26	6
La Plata River near Farmington	1.76	7	Pecos River at Red Bluff	2.19	7
Rio Grande at Albuquerque	1.57	8	Rio Puerco near Bernardo	2.07	8
Rio Grande Below Caballo Dam	1.51	9	Rio Hondo below Diamond A Dam Near Roswell	1.94	9
San Juan River at Farmington	1.44	10	Rio Hondo at Diamond A Ranch Near Roswell	1.93	10
Rio Hondo at Diamond A Ranch Near Roswell	1.40	11	Santa Fe River near Santa Fe	1.58	11
Rio Hondo below Diamond A Dam Near Roswell	1.37	12	Mora River at La Cueva	1.49	12
Pecos River below Santa Rosa Dam	1.37	13	Gallinas River near Colonias	1.49	13
Red River near Questa	1.12	14	Rio Ojo Caliente at La Madera	1.45	14
Black River above Malaga	1.07	15	Pecos River below Santa Rosa Dam	1.45	15
Rio Puerco near Bernardo	0.92	16	South Seven Rivers near Lakewood	1.38	16
South Seven Rivers near Lakewood	0.57	17	Red River near Questa	1.35	17
Santa Fe River near Santa Fe	0.05	18	Canadian River near Sanchez	1.27	18
High-Priority Protection	*Score*	*Rank*	*High-Priority Protection*	*Score*	*Rank*
Mogollon Creek near Cliff	2.00	1	Rio Hondo Near Valdez	2.28	1
Fourmile Draw near Lakewood	1.36	2	Fourmile Draw near Lakewood	2.00	2
Rio Mora near Terrero	1.00	3	Santa Cruz River near Cundiyo	1.52	3
Santa Cruz River near Cundiyo	0.67	4	Rio Mora near Terrero	0.70	4
Rio Hondo Near Valdez	0.17	5	Mogollon Creek near Cliff	0.33	5
Additional Analysis Needed	*Score*	*Rank*	*Additional Analysis Needed*	*Score*	*Rank*
Rio Ruidoso at Hollywood	2.82	1	Rio Chama near La Puente	2.80	1
Pecos River above Santa Rosa Lake	1.99	2	Jemez River near Jemez	2.52	2
Gila River near Gila	1.55	3	Gila River near Gila	1.87	3
Rayado Creek near Cimmaron	1.51	4	Rio Ruidoso at Hollywood	1.78	4
Jemez River near Jemez	1.21	5	Gallinas Creek near Montezuma	1.70	5
Ponil Creek near Cimmaron	1.20	6	Pecos River above Santa Rosa Lake	1.56	6
Vermejo River Near Dawson	1.09	7	Rayado Creek near Cimmaron	1.15	7
Rio Chama near La Puente	1.03	8	Vermejo River Near Dawson	1.05	8
Gallinas Creek near Montezuma	0.00	9	Ponil Creek near Cimmaron	0.92	9

[a] Ecological vulnerability is based on 4 watershed health measures that reflect current ecological stress upstream of study sites. Ecological vulnerability scores can range from 0 to 4.

[b] Hydrologic vulnerability is based on 4 watershed health measures that reflect projected climate and population changes, and current water use, upstream of study sites. Hydrologic vulnerability scores can range from 0 to 4.

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Appendix A. Notes on Analysis Methods

1. Criteria used for selection of study sites included:
   - Daily streamflow record spanning at least 20 years through 2008;
   - Less than 10% missing data over entire period of record;
   - Data quality generally identified as "good" or "fair" (poor records during extreme or estimated flows acceptable);
   - Data available for entire year (seasonal stations excluded); and
   - Located within Gila, Rio Grande, San Juan, Pecos, and Canadian watersheds.

   82 candidate stream gaging stations fit the above criteria, from which 32 were selected as study sites using the following methods:
   - A number of streams/rivers contained multiple candidate gaging stations. One study site location was selected based on length of data record, record completeness, and data quality. For large rivers with distinct upper/middle/lower reaches, one study site location was selected for each reach.
   - A number of candidate gaging stations were located downstream of a large dam. Candidate stations lacking at least 10 years of pre-dam flow data were not considered unless a reference candidate station was present immediately upstream of the dam. An exception was made for Lower Rio Grande and Lower Pecos River gaging stations to evaluate long-term flow change on two of the state's most significant rivers.
   - A large proportion of candidate gaging stations were in the Pecos and Rio Grande watersheds. For stations in these watersheds, the data record length criterion was changed to at least 55 years.

2. IHA uses linear regressions of annual flow metric values with time to compute trends. The presence/absence of a trend and rate of change is affected by the degree of human influence and climate conditions at the start and end of the data record. Most sites were not in a "pre-developed" state when streamflow monitoring commenced, however, trend analysis is useful in such situations to evaluate the cumulative effects of changes in water use, water management, and climate over time.

3. Ecological vulnerability scores were calculated using 4 watershed health metrics: 1) the number of SGCN upstream of study sites; 2) the ratio of impaired to assessed stream reaches upstream of study sites; 3) saline soil area within study watersheds; and 4) riparian development within study watersheds. For each environmental flow needs group (High-Priority Restoration, High-Priority Protection, Additional Analysis Required) values of these 4 watershed health measures were scaled so that they ranged from 0 (lowest value in group) to 1 (highest value in group). Scaled values were summed to generate ecological vulnerability scores.

   Hydrologic vulnerability scores were calculated using 4 watershed health metrics: 1) projected precipitation change through 2050 within study watersheds; 2) projected temperature change through 2050 within study watersheds; 3) projected levels of "high-priority development" within study watersheds; and 4) the ratio of water use to water availability within study watersheds. For each environmental flow needs group (High-Priority Restoration, High-Priority Protection, Additional Analysis Required), values of these 4 watershed health metrics were scaled so that they ranged from 0 (lowest value in group) to 1 (highest value in group). Scaled values were summed to quantify hydrologic vulnerability scores.

Appendix B. IHA Output

Table A-1. Median values of IHA parameter group 1 (magnitude of monthly water conditions) for each study site. Values are reported in cfs.

USGS Station #	Site Name	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
07203000	Vermejo River near Dawson	6.0	5.2	4.0	4.1	5.3	5.5	8.0	28.0	20.0	18.0	17.0	8.9
07207500	Ponil Creek near Cimarron	1.9	2.6	2.0	1.7	1.8	3.0	13.5	29.5	6.8	3.6	4.6	2.4
07208500	Rayado Creek near Cimarron	4.5	4.4	3.7	3.4	3.9	6.1	20.8	31.0	11.8	7.7	6.8	4.5
07215500	Mora River at La Cueva	12.0	6.0	4.6	6.6	5.3	6.9	11.0	42.0	38.0	19.0	26.0	18.5
07221500	Canadian River near Sanchez	24.0	27.5	33.0	40.0	46.0	25.5	15.5	42.0	44.5	64.0	125.5	50.3
08265000	Red River near Questa	22.0	18.0	15.0	15.0	15.8	17.0	32.0	106.5	120.5	47.0	36.5	26.8
08267500	Rio Hondo near Valdez	17.0	14.0	12.0	11.0	10.5	12.0	25.8	85.5	97.0	38.0	25.0	20.3
08279500	Rio Grande at Embudo	359.5	516.8	518.5	508.5	574.3	727.5	799.0	1,735.0	1,525.0	474.5	353.0	317.0
08284100	Rio Chama near La Puente	55.0	61.5	53.0	50.0	60.0	121.0	651.0	1,730.0	390.5	67.0	63.0	51.5
08289000	Rio Ojo Caliente at La Madera	11.0	15.0	16.0	17.5	20.3	36.5	187.3	232.5	16.0	6.0	8.0	7.3
08291000	Santa Cruz River near Cundiyo	12.5	11.0	9.8	9.0	9.3	15.5	43.5	87.5	57.8	22.0	18.0	14.0
08316000	Santa Fe River near Santa Fe	3.4	2.0	1.9	1.7	1.9	2.8	6.7	15.0	10.5	7.3	6.2	4.9
08324000	Jemez River near Jemez	26.0	28.0	27.0	26.0	31.0	58.0	190.0	164.0	36.5	24.0	31.0	23.5
08330000	Rio Grande at Albuquerque	298.0	752.5	739.0	691.5	785.8	814.5	1,353.0	2,620.0	1,218.0	535.5	474.5	356.8
08353000	Rio Puerco near Bernardo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	10.3	0.0
08362500	Rio Grande Below Caballo Dam	2.3	1.8	1.4	1.7	2.3	1,615.0	1,305.0	1,385.0	1,908.0	1,950.0	1,760.0	848.8
08377900	Rio Mora near Terrero	13.0	8.3	6.4	5.8	6.2	9.4	31.0	115.0	47.5	22.0	26.0	18.0
08380500	Gallinas Creek near Montezuma	6.7	6.2	5.4	5.0	5.0	8.6	22.5	33.5	10.8	8.8	15.0	8.1
08382500	Gallinas River near Colonia	0.6	3.1	2.2	1.9	2.0	1.2	0.0	0.0	0.0	3.8	11.0	2.9
08382650	Pecos River above Santa Rosa Lake	22.5	19.3	16.5	17.5	18.5	24.0	77.5	296.0	103.8	40.0	57.5	33.5
08382830	Pecos River below Santa Rosa Dam	0.2	0.1	0.1	0.1	0.1	0.1	0.1	1.0	2.8	0.5	0.4	0.4
08387000	Rio Ruidoso at Hollywood	9.7	8.3	8.1	8.1	9.7	15.0	24.0	17.0	8.3	8.5	14.0	13.0
08390500	Rio Hondo at Diamond A Ranch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08390800	Rio Hondo Below Diamond A Dam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08400000	Fourmile Draw near Lakewood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08401200	South Seven Rivers near Lakewood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08405500	Black River above Malaga	6.9	9.0	10.0	11.0	10.0	6.8	9.0	8.4	7.6	7.2	6.2	6.4
08407500	Pecos River at Red Bluff	71.0	79.0	73.0	71.0	63.0	52.0	40.0	38.0	34.0	36.0	41.0	50.5
09365000	San Juan River at Farmington	868.0	761.3	744.5	778.5	837.0	1,070.0	1,828.0	4,220.0	3,893.0	1,265.0	872.5	811.8
09367500	La Plata River near Farmington	1.7	4.0	8.0	12.0	16.0	15.0	8.1	3.8	2.0	0.3	0.5	0.7
09430500	Gila River near Gila	64.0	68.0	69.0	73.0	102.5	189.0	149.0	92.0	45.0	47.0	77.0	70.0
09430600	Mogollon Creek near Cliff	2.7	3.9	7.5	9.9	27.0	47.0	27.5	9.9	0.8	0.9	6.9	4.3

Table A-2. Median values of IHA parameter group 2 (magnitude and duration of annual extreme water conditions) for each study site.

USGS Station #	Site Name	Minimum Flow (cfs)					Maximum Flow (cfs)					No. Zero Days	Baseflow Index
		1-day	3-day	7-day	30-day	90-day	1-day	3-day	7-day	30-day	90-day		
07203000	Vermejo River near Dawson	1.0	1.1	1.3	2.7	3.7	203.0	141.7	95.0	58.7	37.4	0	0.09
07207500	Ponil Creek near Cimarron	0.1	0.1	0.2	0.6	1.4	97.5	71.5	63.1	45.4	26.5	0	0.02
07208500	Rayado Creek near Cimarron	1.8	2.0	2.3	2.8	3.4	89.0	81.3	70.1	45.8	28.0	0	0.20
07215500	Mora River at La Cueva	1.0	1.1	1.2	2.4	3.8	190.0	160.7	137.4	81.1	52.0	0	0.07
07221500	Canadian River near Sanchez	1.0	1.5	2.2	4.8	14.0	2,490.0	1,565.0	1,058.0	521.7	327.1	0	0.01
08265000	Red River near Questa	8.3	9.2	10.0	12.9	14.7	189.5	184.0	175.3	154.9	102.2	0	0.23
08267500	Rio Hondo near Valdez	8.0	8.5	8.8	10.0	10.8	135.0	133.7	126.1	110.5	73.2	0	0.28
08279500	Rio Grande at Embudo	237.0	238.2	243.6	271.5	374.9	3,220.0	3,110.0	2,882.0	2,325.0	1,598.0	0	0.31
08284100	Rio Chama near La Puente	19.0	20.0	24.3	32.7	46.3	3,020.0	2,910.0	2,711.0	1,944.0	1,106.0	0	0.08
08289000	Rio Ojo Caliente at La Madera	3.9	3.9	4.0	5.2	8.3	659.0	600.3	550.1	360.2	198.3	0	0.07
08291000	Santa Cruz River near Cundiyo	5.0	6.0	6.8	8.0	9.0	127.0	119.2	116.4	96.9	67.0	0	0.25
08316000	Santa Fe River near Santa Fe	0.9	0.9	0.9	1.1	1.7	39.0	34.7	30.9	22.1	14.8	0	0.13
08324000	Jemez River near Jemez	12.0	13.0	14.3	17.6	23.7	463.0	420.7	336.9	248.2	172.9	0	0.23
08330000	Rio Grande at Albuquerque	27.5	33.5	54.0	179.9	437.8	4,590.0	4,188.0	3,922.0	3,226.0	2,170.0	0	0.06
08353000	Rio Puerco near Bernardo	0.0	0.0	0.0	0.0	0.0	1,245.0	844.5	471.3	191.9	88.1	237	0.00
08362500	Rio Grande Below Caballo Dam	1.0	1.0	1.0	1.2	1.6	2,545.0	2,498.0	2,434.0	2,159.0	1,875.0	0	0.00
08377900	Rio Mora near Terrero	4.0	4.3	4.6	5.1	6.3	220.0	210.7	191.0	146.1	85.5	0	0.14
08380500	Gallinas Creek near Montezuma	2.2	2.4	2.6	3.5	4.6	137.0	114.7	105.7	60.7	38.4	0	0.16
08382500	Gallinas River near Colonia	0.0	0.0	0.0	0.0	0.2	579.0	287.7	173.1	74.8	38.3	118	0.00
08382650	Pecos River above Santa Rosa Lake	11.5	11.5	12.2	14.1	15.8	1,560.0	1,018.0	844.6	495.2	284.1	0	0.13
08382830	Pecos River below Santa Rosa Dam	0.0	0.0	0.0	0.0	0.1	1,235.0	1,187.0	1,167.0	571.2	273.7	9	0.00
08387000	Rio Ruidoso at Hollywood	4.0	4.6	4.7	5.8	7.2	109.0	91.7	73.3	45.5	28.3	0	0.26
08390500	Rio Hondo at Diamond A Ranch	0.0	0.0	0.0	0.0	0.0	414.0	229.0	163.4	77.3	36.6	264	0.00
08390800	Rio Hondo Below Diamond A Dam	0.0	0.0	0.0	0.0	0.0	213.0	141.7	104.4	51.2	25.2	297	0.00
08400000	Fourmile Draw near Lakewood	0.0	0.0	0.0	0.0	0.0	33.0	14.0	6.0	1.4	0.5	362	0.00
08401200	South Seven Rivers near Lakewood	0.0	0.0	0.0	0.0	0.0	51.5	20.0	8.6	2.3	1.1	359	0.00
08405500	Black River above Malaga	2.7	3.0	3.4	4.8	6.6	331.0	147.0	75.7	27.0	17.5	0	0.35
08407500	Pecos River at Red Bluff	18.0	18.7	22.0	25.7	34.6	974.0	719.7	573.6	268.1	165.7	0	0.23
09365000	San Juan River at Farmington	378.0	402.0	424.3	517.4	665.5	7,880.0	7,605.0	7,084.0	5,602.0	3,938.0	0	0.24
09367500	La Plata River near Farmington	0.0	0.0	0.0	0.1	1.1	264.0	179.7	128.7	56.2	29.3	10	0.00
09430500	Gila River near Gila	26.0	26.3	27.9	34.2	54.0	1,440.0	1,028.0	642.6	373.0	237.4	0	0.24
09430600	Mogollon Creek near Cliff	0.0	0.0	0.0	0.2	2.6	468.0	331.3	240.6	102.7	59.1	27	0.00

Table A-3. Median values of IHA parameter group 3 (timing of annual extreme water conditions; reported as Julian day of year), group 4 (frequency and duration of high and low pulses), and group 5 (rate and frequency of water condition changes) for each study site.

USGS Station #	Site Name	Date of min.	Date of max.	Low Pulse			High Pulse			Rise Rate (cfs/day)	Fall Rate (cfs/day)	No. Reversals
				Threshold (cfs)	Count	Duration (days)	Threshold (cfs)	Count	Duration (days)			
07203000	Vermejo River near Dawson	280	215	3.7	9	3	17.0	8	3	1.0	-1.0	124
07207500	Ponil Creek near Cimarron	201	150	1.3	5	5	8.2	6	3	0.5	-0.5	109
07208500	Rayado Creek near Cimarron	336	130	3.5	8	4	11.0	5	3	0.7	-0.6	115
07215500	Mora River at La Cueva	26	171	4.0	4	6	26.0	5	4	1.0	-1.9	120
07221500	Canadian River near Sanchez	183	216	13.0	4	6	102.0	9	4	4.2	-5.0	107
08265000	Red River near Questa	352	151	15.0	6	3	46.0	3	5	2.0	-2.0	106
08267500	Rio Hondo near Valdez	10	153	12.0	5	4	34.0	2	28	1.5	-1.0	87
08279500	Rio Grande at Embudo	262	146	371.0	4	6	813.3	4	11	21.8	-20.0	115
08284100	Rio Chama near La Puente	262	130	47.0	7	4	237.0	3	5	9.0	-9.0	112
08289000	Rio Ojo Caliente at La Madera	215	121	10.0	5	8	35.0	4	3	2.0	-2.0	118
08291000	Santa Cruz River near Cundiyo	326	144	9.6	10	3	32.0	4	3	2.0	-2.0	112
08316000	Santa Fe River near Santa Fe	322	150	1.7	2	21	8.9	3	18	0.3	-0.5	50
08324000	Jemez River near Jemez	244	113	23.0	12	3	60.0	6	3	3.0	-3.5	125
08330000	Rio Grande at Albuquerque	273	146	410.0	8	4	1,260.0	5	4	55.5	-50.0	136
08353000	Rio Puerco near Bernardo	275	227	0.0	0		4.8	10	6	15.5	-5.5	53
08362500	Rio Grande Below Caballo Dam	325	183	2.0	1	48	1,660.0	6	10	60.0	-50.1	72
08377900	Rio Mora near Terrero	10	143	7.4	5	5	32.0	4	7	1.2	-1.0	98
08380500	Gallinas Creek near Montezuma	226	210	4.4	6	5	18.0	6	4	1.0	-1.0	110
08382500	Gallinas River near Colonia	275	220	0.0	0		8.6	11	4	1.0	-1.0	77
08382650	Pecos River above Santa Rosa Lake	191	190	15.0	4	6	91.0	8	3	5.0	-8.5	107
08382830	Pecos River below Santa Rosa Dam	275	177	0.0	2	5	2.6	6	11	0.1	-0.1	80
08387000	Rio Ruidoso at Hollywood	195	227	6.2	5	4	21.0	6	6	1.0	-1.0	111
08390500	Rio Hondo at Diamond A Ranch	275	224	0.0	0		14.0	6	3	4.4	-4.0	43
08390800	Rio Hondo Below Diamond A Dam	275	229	0.0	0		3.1	6	4	4.5	-3.3	27
08400000	Fourmile Draw near Lakewood	275	242	0.0	0		0.0	2	2	9.5	-5.0	3
08401200	South Seven Rivers near Lakewood	275	242	0.0	0		0.0	3	2	5.1	-4.5	5
08405500	Black River above Malaga	214	236	5.7	7	8	11.0	9	3	0.6	-0.4	72
08407500	Pecos River at Red Bluff	173	258	31.0	7	6	95.0	7	3	3.0	-3.0	124
09365000	San Juan River at Farmington	238	155	671.0	6	6	2,270.0	4	5	64.0	-59.8	120
09367500	La Plata River near Farmington	256	191	0.5	6	6	19.0	7	2	2.0	-1.0	102
09430500	Gila River near Gila	188	226	57.0	6	7	135.0	5	5	5.0	-4.0	82
09430600	Mogollon Creek near Cliff	175	69	1.7	5	9	25.0	6	4	2.0	-1.0	85

Table A-4. Annual rate of change for significant trends (at $p \leq 0.1$) in IHA parameter group 1 (magnitude of monthly water conditions). Values reported in cfs per year.

USGS Station #	Site Name	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
07203000	Vermejo River near Dawson		0.04	0.07	0.05	0.03	0.06						
07207500	Ponil Creek near Cimarron		0.03	0.02	0.02	0.03	0.14	0.39					
07208500	Rayado Creek near Cimarron			0.01			0.06						0.04
07215500	Mora River at La Cueva		-0.09	-0.08									
07221500	Canadian River near Sanchez	-1.19									-1.85		
08265000	Red River near Questa	-0.08	-0.08	-0.12	-0.08	-0.08							
08267500	Rio Hondo near Valdez								-0.46				
08279500	Rio Grande at Embudo	-3.30							-15.29	-19.05			-2.38
08284100	Rio Chama near La Puente				0.27		2.11						
08289000	Rio Ojo Caliente at La Madera			0.05	0.04								
08291000	Santa Cruz River near Cundiyo		0.04			0.05	0.18						
08316000	Santa Fe River near Santa Fe		-0.01					-0.14	-0.13				0.03
08324000	Jemez River near Jemez						0.73						
08330000	Rio Grande at Albuquerque	5.88			3.79		7.94	14.89					6.60
08353000	Rio Puerco near Bernardo												
08362500	Rio Grande Below Caballo Dam	4.17											5.48
08377900	Rio Mora near Terrero				0.10	0.10	0.17	0.66	1.44				
08380500	Gallinas Creek near Montezuma				0.04	0.05	0.14						
08382500	Gallinas River near Colonia	0.13	0.16	0.15	0.14	0.16	0.12			0.17			
08382650	Pecos River above Santa Rosa Lake							3.86					
08382830	Pecos River below Santa Rosa Dam	-0.11			-0.32								
08387000	Rio Ruidoso at Hollywood			0.13		0.18					0.20	0.27	
08390500	Rio Hondo at Diamond A Ranch										-0.32		
08390800	Rio Hondo Below Diamond A Dam												
08400000	Fourmile Draw near Lakewood												
08401200	South Seven Rivers near Lakewood												
08405500	Black River above Malaga						0.06					0.04	
08407500	Pecos River at Red Bluff	-5.54			-1.95	-1.27	-0.85	-0.51	-6.08	-2.86	-1.18	-0.72	-2.65
09365000	San Juan River at Farmington		6.55	9.25	9.21	8.94		-35.12	-41.80	-42.37			
09367500	La Plata River near Farmington												
09430500	Gila River near Gila		0.42	0.62	1.30								
09430600	Mogollon Creek near Cliff												

Table A-5. Annual rate of change for significant trends (at p≤ 0.1) in IHA parameter group 2 (magnitude and duration of annual extreme water conditions).

USGS Station #	Site Name	Minimum Flow (cfs/year)					Maximum Flow (cfs/year)					No. Zero days	Baseflow Index
		1-day	3-day	7-day	30-day	90-day	1-day	3-day	7-day	30-day	90-day		
07203000	Vermejo River near Dawson	0.03	0.03	0.04	0.04	0.04						-0.05	0.002
07207500	Ponil Creek near Cimarron	0.01	0.01	0.02	0.02	0.03				0.82	0.42	-0.94	0.001
07208500	Rayado Creek near Cimarron	0.01	0.01	0.01	0.01	0.01							
07215500	Mora River at La Cueva	-0.03	-0.03	-0.04	-0.05	-0.04	-1.85					-0.01	-0.001
07221500	Canadian River near Sanchez						-146.50	-85.66	-46.35	-15.57	-6.75		0.0004
08265000	Red River near Questa	-0.07	-0.08	-0.08	-0.09	-0.09	-1.77	-1.60	-1.37				-0.001
08267500	Rio Hondo near Valdez												
08279500	Rio Grande at Embudo		-0.40	-0.46	-0.48		-34.63	-34.04	-32.86	-23.78	-12.77		0.001
08284100	Rio Chama near La Puente	0.23	0.24	0.25	0.35								
08289000	Rio Ojo Caliente at La Madera	0.04	0.04	0.03	0.02								0.001
08291000	Santa Cruz River near Cundiyo	0.03	0.02	0.02		0.03							
08316000	Santa Fe River near Santa Fe	0.00	0.00	-0.01	-0.01	-0.01	-0.42	-0.29	-0.22	-0.13	-0.10	0.03	-0.001
08324000	Jemez River near Jemez												
08330000	Rio Grande at Albuquerque	4.42	4.65	5.22	5.87	6.70						-0.13	0.005
08353000	Rio Puerco near Bernardo						-35.45	-20.25	-10.44	-4.62	-2.06	-2.35	
08362500	Rio Grande Below Caballo Dam												
08377900	Rio Mora near Terrero		0.03	0.04	0.05	0.06							
08380500	Gallinas Creek near Montezuma	0.02	0.02	0.02	0.02	0.03							0.001
08382500	Gallinas River near Colonia		0.01	0.01	0.06	0.10	-6.74					-5.38	
08382650	Pecos River above Santa Rosa Lake												
08382830	Pecos River below Santa Rosa Dam			-0.01	-0.03		14.41	14.79	15.99		-5.63	8.03	-0.0002
08387000	Rio Ruidoso at Hollywood	0.07	0.08	0.08	0.10	0.12				0.59	0.38		0.004
08390500	Rio Hondo at Diamond A Ranch							-6.91					
08390800	Rio Hondo Below Diamond A Dam						-3.11						
08400000	Fourmile Draw near Lakewood												
08401200	South Seven Rivers near Lakewood						-38.35	-17.22	-7.48	-1.74	-0.60		
08405500	Black River above Malaga						-17.87	-7.70	-3.33				0.002
08407500	Pecos River at Red Bluff		-0.21	-0.26	-0.43	-0.64		-55.99	-40.30	-14.70	-7.57		0.001
09365000	San Juan River at Farmington	6.32	6.38	6.79	6.99	7.38	-100.70	-87.88	-74.80	-56.82	-43.38		0.005
09367500	La Plata River near Farmington	0.003	0.004	0.005			-5.97	-4.21	-2.98			-2.00	0.0002
09430500	Gila River near Gila						41.64	25.52	13.87	5.75	2.82		-0.002
09430600	Mogollon Creek near Cliff												

Table A-6. Annual rate of change for significant trends (at $p \leq 0.1$) in IHA parameter group 3 (timing of annual extreme water conditions), group 4 (frequency and duration of high and low pulses), and group 5 (rate and frequency of water condition changes).

USGS Station #	Site Name	Date of min.	Date of max.	Low Pulse		High Pulse		Rise Rate	Fall Rate	No. Reversals
				Count	Duration	Count	Duration			
07203000	Vermejo River near Dawson	-1.11		-0.08					0.01	0.23
07207500	Ponil Creek near Cimarron		-0.63	-0.11						0.46
07208500	Rayado Creek near Cimarron	-1.11		-0.06					0.003	0.27
07215500	Mora River at La Cueva								0.01	0.16
07221500	Canadian River near Sanchez							-0.08	0.09	0.22
08265000	Red River near Questa	1.20	0.26					-0.01	0.01	0.30
08267500	Rio Hondo near Valdez		0.23					-0.01	0.01	0.26
08279500	Rio Grande at Embudo					-0.02		-0.14	0.15	0.33
08284100	Rio Chama near La Puente								0.06	0.60
08289000	Rio Ojo Caliente at La Madera			-0.06	0.33	-0.03		-0.02	0.02	0.16
08291000	Santa Cruz River near Cundiyo									0.24
08316000	Santa Fe River near Santa Fe				0.40			-0.005	0.005	
08324000	Jemez River near Jemez	1.05								
08330000	Rio Grande at Albuquerque			-0.14				-0.34	0.43	
08353000	Rio Puerco near Bernardo	-0.53			0.000000			-1.13	0.23	0.79
08362500	Rio Grande Below Caballo Dam					0.04	-0.28		-0.27	-0.21
08377900	Rio Mora near Terrero		-0.75							
08380500	Gallinas Creek near Montezuma			-0.04					0.01	0.17
08382500	Gallinas River near Colonia	-1.88	-0.91		0.000000	0.07		-1.10	0.25	1.59
08382650	Pecos River above Santa Rosa Lake	4.51								0.90
08382830	Pecos River below Santa Rosa Dam			0.14	1.20			4.32		-1.74
08387000	Rio Ruidoso at Hollywood							0.02		0.31
08390500	Rio Hondo at Diamond A Ranch				0.00000	-0.08				-0.35
08390800	Rio Hondo Below Diamond A Dam		-1.23		0.00000			-0.33	0.11	
08400000	Fourmile Draw near Lakewood				0.00000					
08401200	South Seven Rivers near Lakewood				0.00000			-8.88	4.07	
08405500	Black River above Malaga									0.47
08407500	Pecos River at Red Bluff		0.93				-0.35	-0.14	0.15	-0.53
09365000	San Juan River at Farmington			-0.07	-0.09	-0.03	0.23	-1.40	0.96	0.34
09367500	La Plata River near Farmington			-0.07	0.12			-0.05	0.05	0.77
09430500	Gila River near Gila	-0.29		-0.03	0.13		0.14			
09430600	Mogollon Creek near Cliff									

Table A-7. Study sites included in RVA analysis. For study sites with a pre- and post-impact data record, the first post-impact year is provided. For sites with upstream reference data, USGS monitoring station information is provided for the reference site.

USGS Station #	Site Name	Disturbance Type	Pre/Post	Upstream/Downstream
08265000	Red River near Questa	Mining Diversion	1966	-
08316000	Santa Fe River near Santa Fe	Major Dam	1926	-
08330000	Rio Grande at Albuquerque	Major Dam	1976	-
08382830	Pecos River below Santa Rosa Dam	Major Dam	-	Pecos River above Santa Rosa Lake (USGS Station # 08382650)
08390800	Rio Hondo below Diamond A Dam	Major Dam	-	Rio Hondo at Diamond a Ranch (USGS Station # 08390500)
09365000	San Juan River at Farmington	Major Dam	1962	-

Table A-8. Hydrologic Alteration Factors (HAFs) for IHA parameter group 1 (magnitude of monthly water conditions).

USGS Station #	Site Name	HAF Range	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
08265000	Red River near Questa	High HAF	-0.48	-0.40	-0.88	-0.76	-0.74	-0.40	-0.35	-0.28	-0.40	-0.16	-0.21	-0.16
		Middle HAF	-0.34	-0.76	-0.64	-0.76	-0.92	-0.90	-0.67	-0.16	0.33	0.11	0.22	-0.40
		Low HAF	0.80	1.16	1.52	1.52	3.53	2.04	1.04	0.44	0.05	0.05	-0.04	0.56
08316000	Santa Fe River near Santa Fe	High HAF	-0.05	-0.15	-0.01	-0.26	-0.44	-0.61	-0.86	-0.44	-0.61	-0.05	0.27	0.94
		Middle HAF	0.38	-0.36	-0.65	-0.54	-0.33	-0.61	-0.12	-0.52	-0.33	0.41	-0.18	-0.19
		Low HAF	-0.33	0.52	0.66	0.80	0.76	1.22	0.98	0.98	0.94	-0.62	-0.06	-0.75
08330000	Rio Grande at Albuquerque	High HAF	0.80	-0.31	0.37	0.89	0.46	0.80	0.63	0.29	0.46	1.66	0.63	1.40
		Middle HAF	-0.14	1.06	0.20	-0.40	-0.14	-0.23	0.03	0.20	0.37	-0.66	0.29	-0.57
		Low HAF	-0.66	-0.74	-0.57	-0.49	-0.31	-0.57	-0.66	-0.49	-0.83	-1.00	-0.91	-0.83
08382830	Pecos River below Santa Rosa Dam	High HAF	-1.00	-0.90	-0.80	-1.00	-0.67	-0.90	-0.60	-0.50	-0.10	-0.60	-0.60	-0.60
		Middle HAF	-1.00	-1.00	-1.00	-0.82	-1.00	-1.00	-1.00	-0.60	-0.70	-1.00	-0.82	-1.00
		Low HAF	2.00	1.90	1.80	2.11	1.70	1.90	1.60	1.10	0.80	1.60	1.67	1.60
08390800	Rio Hondo below Diamond A Dam	High HAF	-0.54	-0.54	-0.15	-0.15	-0.21	-0.18	-0.08	-0.04	-0.31	-0.52	-0.31	-0.15
		Middle HAF	0.26	0.26	0.07	0.07	0.10	0.08	0.04	0.02	0.06	0.19	0.14	0.07
		Low HAF												
09365000	San Juan River at Farmington	High HAF	0.77	1.59	1.91	1.78	1.72	0.27	-0.68	-0.81	-0.81	-0.11	0.20	0.64
		Middle HAF	-0.02	-0.65	-0.89	-0.83	-0.77	-0.14	-0.25	0.09	0.15	0.61	0.38	0.27
		Low HAF	-0.75	-0.87	-0.94	-0.87	-0.87	-0.11	0.96	0.71	0.64	-0.56	-0.62	-0.94

Table A-9. Hydrologic Alteration Factors (HAFs) for IHA parameter group 2 (magnitude and duration of annual extreme water conditions).

USGS Station #	Site Name	HAF Range	Minimum Flow (cfs/year)					Maximum Flow (cfs/year)					No. Zero days	Baseflow Index
			1-day	3-day	7-day	30-day	90-day	1-day	3-day	7-day	30-day	90-day		
08265000	Red River near Questa	High HAF	-0.86	-0.88	-0.87	-0.88	-0.76	-0.64	-0.64	-0.88	-0.64	-0.52		-1.00
		Middle HAF	-0.81	-0.76	-0.89	-0.64	-0.76	0.08	0.20	0.68	0.44	0.44	0.00	0.08
		Low HAF	1.88	1.64	1.76	1.52	1.52	0.56	0.44	0.20	0.20	0.08		0.92
08316000	Santa Fe River near Santa Fe	High HAF	0.08	0.22	-0.19	-0.29	-0.29	-0.54	-0.61	-0.65	-0.68	-0.79		0.38
		Middle HAF	-0.10	-0.18	0.09	0.13	-0.15	0.45	0.55	0.59	-0.12	-0.01	-0.04	-0.44
		Low HAF	0.06	0.06	0.09	0.16	0.45	0.09	0.06	0.06	0.80	0.80		0.06
08330000	Rio Grande at Albuquerque	High HAF	1.49	1.73	1.49	1.74	1.57	-0.31	-0.06	0.03	0.03	0.29	-0.91	1.57
		Middle HAF	-0.74	-0.75	-0.57	-0.74	-0.57	0.63	0.46	0.29	0.29	0.20	0.46	-0.66
		Low HAF			-0.91	-1.00	-1.00	-0.31	-0.40	-0.31	-0.31	-0.49		-0.91
08382830	Pecos River below Santa Rosa Dam	High HAF	-1.00	-1.00	-1.00	-1.00	-0.90	-0.90	-0.50	0.40	-0.30	-0.20		-1.00
		Middle HAF	-1.00	-1.00	-1.00	-1.00	-1.00	0.40	1.40	0.50	0.90	0.10	-0.73	-1.00
		Low HAF	2.33	2.00	2.00	2.00	1.90	0.50	-0.90	-0.90	-0.60	0.10		2.00
08390800	Rio Hondo below Diamond A Dam	High HAF			-1.00	-0.70	-0.41	-1.00	-1.00	-0.80	-0.41	-0.34	0.58	-1.00
		Middle HAF	0.00	0.00	0.01	0.05	0.20	-0.34	0.21	0.21	0.21	-0.09	-0.27	0.01
		Low HAF							1.36	0.77	0.58	0.18	0.45	-0.28
09365000	San Juan River at Farmington	High HAF	1.66	1.66	1.72	1.72	1.78	-1.00	-1.00	-1.00	-1.00	-0.94		1.97
		Middle HAF	-0.60	-0.65	-0.65	-0.71	-0.89	0.27	0.21	0.27	0.27	0.38	0.00	-0.89
		Low HAF	-1.00	-0.94	-1.00	-0.94	-0.81	0.71	0.77	0.71	0.71	0.52		-1.00

Table A-10. Hydrologic Alteration Factors (HAFs) for IHA parameter group 3 (timing of annual extreme water conditions), group 4 (frequency and duration of high and low pulses), and group 5 (rate and frequency of water condition changes).

USGS Station #	Site Name	HAF Range	Date of min.	Date of max.	Low Pulse		High Pulse		Rise Rate	Fall Rate	No. Reversals
					Count	Duration	Count	Duration			
08265000	Red River near Questa	High HAF	0.32	1.04	-0.61	0.70	0.80	0.05	-0.76	2.17	1.75
		Middle HAF	-0.40	-0.22	0.22	-0.32	-0.75	-0.52	-0.46	-0.31	-0.67
		Low HAF	0.08	-0.87	0.32	-0.14	0.57	0.60	2.60	-0.52	-0.88
08316000	Santa Fe River near Santa Fe	High HAF	0.34	0.48	-0.89	1.26	-0.29	0.32	-0.19	0.80	-0.36
		Middle HAF	-0.72	-0.19	0.24	-0.51	-0.10	-0.18	-0.41	-0.36	-0.75
		Low HAF	0.38	-0.29	0.66	-0.44	0.34	-0.15	0.93	-0.51	1.12
08330000	Rio Grande at Albuquerque	High HAF	0.41	-0.57	-0.83	0.04	-0.06	0.13	-0.49	0.20	-0.27
		Middle HAF	-0.14	1.06	-0.53	-0.76	0.20	0.23	0.29	0.20	0.23
		Low HAF	-0.23	-0.49	1.55	-0.06	-0.14	-0.43	0.20	-0.40	-0.06
08382830	Pecos River below Santa Rosa Dam	High HAF	0.80	0.00	-0.60	4.40	-0.86	1.89	-0.50	1.50	-0.80
		Middle HAF	0.00	0.10	1.60	-0.73	-0.67	-0.82	-1.00	-1.00	-0.73
		Low HAF	-0.80	-0.10	-1.00	-1.00	2.00	-0.80	1.78	-0.50	1.78
08390800	Rio Hondo below Diamond A Dam	High HAF	0.04	0.18			-0.52	-0.24	0.18	0.45	-0.21
		Middle HAF	0.16	0.03	0.00		-0.01	-0.01	-0.10	-0.09	-0.58
		Low HAF	-0.62	-0.21			0.69	0.51	-0.06	-0.34	0.84
09365000	San Juan River at Farmington	High HAF	0.14	0.52	-0.86	-0.30	0.34	0.20	-0.94	1.40	1.21
		Middle HAF	-0.19	-0.02	-0.81	-0.60	-0.61	-0.37	-0.42	-0.37	-0.31
		Low HAF	0.08	-0.49	2.02	0.27	0.52	0.45	1.40	-1.00	-0.87

Appendix C. Watershed Health Metrics

Parameter 1: Aquatic Species of Concern

Metric: Number of Species of Greatest Conservation Need (SGCN)

Source: [New Mexico Comprehensive Wildlife Conservation Strategy Geospatial Data]()

Description: The Comprehensive Wildlife Conservation Strategy (CWCS) for New Mexico designates 452 wildlife species as Species of Greatest Conservation Need (SGCN) according to their abundance, distribution, and recreational and economic value. Development of the CWCS included modeling analysis of known and potential habitat for each SCGN throughout the state. CWCS habitat geospatial data were used to calculate the total number of fish and amphibian SGCN with habitat in study watersheds using GIS software.

Parameter 2: Clean Water Act Impaired Waters

Metric: Impaired Waters Ratio

Source: [New Mexico 2010 305(b) Report Geospatial Data]()

Description: The New Mexico Environment Department (NMED) provides an assessment of the condition of New Mexico's streams and rivers in its biannual Clean Water Act 303(d) and 305(b) Integrated List & Report. Geospatial data related to the location of assessed waters and waters designated as impaired by the NMED in the 2010-2012 list and report were used to calculate the ratio of impaired stream/river miles to assessed stream/river miles in study watersheds using GIS software.

Parameter 3: Riparian Condition

Metric: Riparian Disturbance

Source: NMED/EPA EMAP Stream Survey Dataset

Description: Since 1999, NMED has collected data on stream and river condition according to the U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program (EMAP) protocol. The EMAP procedure includes an evaluation of riparian condition by noting the prevalence and distance of riparian disturbance by urban development, agriculture, mining, and forestry within EMAP reaches. These data are used to generate a proximity-weighted count of observed riparian disturbance, with high values associated with prevalent riparian disturbance near the stream channel. The riparian disturbance value reported for the EMAP reach in closest proximity to each study site's USGS stream gaging station was selected as the representative value of riparian disturbance.

Metric: Riparian Development

Source: SWReGAP Land Cover Geospatial Data

Description: Land cover data generated by the Southwest Regional Gap Analysis Project (SWReGAP) were used to calculate the ratio of developed riparian area to total riparian area in study watersheds using GIS software. Developed and agricultural land cover classes were included in developed area calculations. Riparian land cover was defined as all grid cells in the SWReGAP dataset containing a stream channel based on NHDPlus hydrography geospatial data.

Parameter 4: Watershed Condition

Metric: Watershed Development

Source: SWReGAP Land Cover Geospatial Data

Description: Land cover data generated by the SWReGAP project (USGS National Gap Analysis Program, 2004) was used to calculate the ratio of developed watershed area to total watershed area in study watersheds using GIS software. Developed and agricultural land cover classes were included in developed area calculations.

Metric: High-Priority Forest

Source: The Nature Conservancy's New Mexico Forest Health Model Geospatial Data

Description: The New Mexico Statewide Resources Assessment is an effort lead by the New Mexico State Forestry Division to evaluate the current and projected condition of natural resources throughout the state. As part of the assessment, the New Mexico Conservation Science Program of The Nature Conservancy has developed a forest health model that incorporates data related to forest stand density, recent drought stress, and observed and projected tree mortality following insect and disease outbreaks. The model classifies forest health by priority class, with high-priority forest associated with areas susceptible to die-off from insect and disease outbreaks. Forest health geospatial data were used to calculate the ratio of high-priority forest area to total forest area within study watersheds using GIS software.

Parameter 5: Geomorphic Condition

Metric: Relative Bed Stability

Source: NMED/USEPA EMAP Dataset

Description: Stream survey data collected by NMED using EPA's EMAP protocol includes relative bed stability (the ratio of mean bed material diameter to erodible bed material diameter) as a measure of geomorphic condition at each EMAP reach. Low relative bed stability values are associated with an unstable streambed, characterized by excessive deposition of fine particulate matter. The relative bed stability value reported for the EMAP reach in closest proximity to each study site's USGS stream gaging station was selected as the representative value.

Metric: Channel Sinuosity

Source: NHDPlus Hydrography Geospatial Data

Description: Channel sinuosity provides an estimate of the degree of channelization along a stream reach and was calculated for study sites as the ratio of channel length to straight-line distance between two channel points using GIS software. The downstream channel point was designated as the USGS stream gaging location. The straight-line upstream distance varied by site, and was calculated as 100 times channel bankfull width. The regional specific drainage area-bankfull width function provided in (Moody, Wirtanen, & Yard, 2003) was used for bankfull width calculations. Information related to channel length and location was determined from NHDPlus hydrography data.

Parameter 6: Groundwater-Surface Water Connection

Metric: Mean Baseflow Index

Source: USGS Baseflow Index Geospatial Data

Description: The baseflow index (the proportion of total streamflow attributed to groundwater discharge) provides an estimate of the connectivity of groundwater and surface water in a region. The USGS nationwide gridded baseflow index dataset was used to calculate the mean baseflow index within study watersheds using GIS software.

Parameter 7: Agro-Ecosystem Health

Metric: Saline Lands

Source: USDA NRCS STATSGO Geospatial Data

Description: STATSGO geospatial soil data provided by the USDA NRCS were used to estimate areas with high soil salinity. Saline soils were defined as those with a reported electrical conductivity value greater than or equal to 4 mmhos cm^{-1} (U.S. Department of Agriculture, Natural Resources Conservation Service). From this, the ratio of saline land area to total watershed area was calculated for each study watershed.

Parameter 8: Drought & Climate Change Vulnerability

Metric: Observed and Projected Change in Annual Precipitation and Temperature

Source: Climate Wizard Geospatial Data

Description: Historical and projected geospatial climate data provided by the Climate Wizard research group were used for evaluation of trends in annual precipitation and temperature. Gridded values of change in temperature and precipitation from 1951-2006 (PRISM Climate Group, Oregon State University, Created 4 Feb 2007) were used to estimate mean observed change in each study watershed. Gridded values of projected change in temperature and precipitation from 1991-2050 relative to 1960-1991 conditions (Maurer, Brekke, Pruitt, & Duffy, 2007) were used to estimate mean projected change in study watersheds. The low (B1) IPCC 4th Assessment emission scenario was used for analysis of projected conditions.

Metric: Water-Use Ratio

Source: USGS Water Use Data; USGS Average Annual Runoff Geospatial Data

Description: USGS estimates of water-use and availability throughout the United States were used to calculate the ratio of water-use to water availability in each study watershed using GIS software. County level water-use data for the year 2000 was spatially-weighted according to the location of water-rights claims within each county (obtained from the New Mexico Office of the State Engineer and Colorado Water Conservation Board). Water availability was estimated from USGS gridded values of long-term average annual runoff.

Metric: Development Potential

Source: The Nature Conservancy's New Mexico Development Potential Model Geospatial Data

Description: The Nature Conservancy's New Mexico Conservation Science Program created a development potential model as part of the New Mexico Statewide Resources Assessment to highlight areas where increased housing development is expected. The model classifies expected development by priority class, with high-priority development associated with extreme changes in population density. Modeled development potential data were used to calculate the ratio of high-priority development area to total predicted development area within study watershed using GIS software.

Table C-1. Values of watershed health metrics for parameters 1 through 6.

USGS Station #	Site Name	1) Aquatic Species Of Concern	2) CWA Impaired Waters	3) Riparian Condition		4) Watershed Condition		5) Geomorphic Condition		6) GW-SW Connection
		No. SGCN	Impaired Waters Ratio	Riparian Disturbance	Riparian Development	Watershed Development	High-Priority Forest	Relative Bed Stability	Channel Sinuosity	Mean Baseflow Index
07203000	Vermejo River near Dawson	8	87%	NA	0%	0%	6%	NA	1.66	55%
07207500	Ponil Creek near Cimarron	8	94%	1.3	0%	0%	20%	0.01	1.14	59%
07208500	Rayado Creek near Cimarron	8	76%	1.0	0%	0%	3%	0.23	1.07	56%
07215500	Mora River at La Cueva	8	73%	NA	10%	5%	20%	NA	1.21	59%
07221500	Canadian River near Sanchez	9	65%	2.1	2%	1%	14%	0.78	2.06	49%
08265000	Red River near Questa	8	54%	0.0	4%	1%	42%	0.23	1.03	72%
08267500	Rio Hondo near Valdez	5	0%	1.2	0%	0%	50%	0.81	1.02	73%
08279500	Rio Grande at Embudo	11	49%	NA	8%	11%	26%	NA	1.07	66%
08284100	Rio Chama near La Puente	9	60%	1.0	2%	1%	1%	0.64	1.14	53%
08289000	Rio Ojo Caliente at La Madera	10	84%	NA	5%	1%	20%	NA	1.09	59%
08291000	Santa Cruz River near Cundiyo	8	0%	3.0	0%	0%	49%	0.15	1.11	72%
08316000	Santa Fe River near Santa Fe	5	0%	3.1	0%	0%	66%	0.77	1.03	71%
08324000	Jemez River near Jemez	9	88%	NA	0%	0%	45%	NA	1.19	54%
08330000	Rio Grande at Albuquerque	11	55%	NA	5%	8%	23%	NA	1.15	59%
08353000	Rio Puerco near Bernardo	9	20%	NA	0%	0%	7%	NA	1.46	25%
08362500	Rio Grande Below Caballo Dam	16	51%	NA	2%	4%	17%	NA	1.07	45%
08377900	Rio Mora near Terrero	4	0%	NA	0%	0%	35%	NA	1.10	66%
08380500	Gallinas Creek near Montezuma	6	27%	0.7	0%	0%	59%	0.49	1.26	58%
08382500	Gallinas River near Colonia	7	74%	NA	3%	2%	22%	NA	1.27	43%
08382650	Pecos River above Santa Rosa Lake	8	72%	3.4	2%	1%	24%	3.4	1.51	47%
08382830	Pecos River below Santa Rosa Dam	8	73%	3.4	2%	1%	24%	3.4	1.45	45%
08387000	Rio Ruidoso at Hollywood	6	82%	NA	8%	3%	57%	NA	1.11	38%
08390500	Rio Hondo at Diamond A Ranch	9	82%	NA	3%	1%	33%	NA	1.30	33%
08390800	Rio Hondo Below Diamond A Dam	10	75%	NA	3%	1%	33%	NA	1.75	32%
08400000	Fourmile Draw near Lakewood	9	NA	NA	0%	0%	0%	NA	1.21	17%
08401200	South Seven Rivers near Lakewood	5	NA	NA	0%	0%	0%	NA	1.09	15%
08405500	Black River above Malaga	9	0%	2.2	0%	0%	0%	0.43	1.04	17%
08407500	Pecos River at Red Bluff	26	72%	0.2	1%	2%	29%	NA	1.16	23%
09365000	San Juan River at Farmington	6	72%	NA	6%	5%	1%	NA	1.17	58%
09367500	La Plata River near Farmington	4	100%	NA	5%	5%	0%	NA	1.12	55%
09430500	Gila River near Gila	16	60%	0.1	0%	0%	30%	0.1	1.87	54%
09430600	Mogollon Creek near Cliff	10	100%	NA	0%	0%	25%	NA	1.05	53%

Table C-2. Values of watershed health metrics for parameters 7 and 8.

USGS Station #	Site Name	7) Agro-Ecosystem Health	8) Drought/Climate Change Vulnerability					
		Saline Lands	Observed Change P (%/year)	Observed Change T (°F/year)	Projected Change P (%)	Projected Change T (°F)	Water Use Ratio	Development Potential
07203000	Vermejo River near Dawson	0%	0.4	0.03	-5.2	3.9	8%	13%
07207500	Ponil Creek near Cimarron	0%	0.6	0.03	-5.2	3.9	11%	0%
07208500	Rayado Creek near Cimarron	3%	0.5	0.04	-4.8	3.9	20%	0%
07215500	Mora River at La Cueva	0%	0.6	0.03	-4.3	3.8	15%	45%
07221500	Canadian River near Sanchez	18%	0.4	0.03	-4.6	3.8	24%	27%
08265000	Red River near Questa	0%	0.4	0.07	-3.8	3.9	9%	25%
08267500	Rio Hondo near Valdez	0%	0.4	0.06	-3.1	3.9	5%	61%
08279500	Rio Grande at Embudo	4%	0.3	0.02	-3.3	4.0	57%	27%
08284100	Rio Chama near La Puente	0%	0.3	0.03	-1.4	4.1	6%	57%
08289000	Rio Ojo Caliente at La Madera	4%	0.5	0.03	-3.7	4.0	2%	31%
08291000	Santa Cruz River near Cundiyo	0%	0.4	0.03	-2.5	3.8	0%	9%
08316000	Santa Fe River near Santa Fe	0%	0.1	0.05	-2.9	3.8	0%	43%
08324000	Jemez River near Jemez	0%	0.1	0.04	-3.2	3.9	45%	29%
08330000	Rio Grande at Albuquerque	4%	0.3	0.03	-3.3	4.0	51%	29%
08353000	Rio Puerco near Bernardo	10%	0.4	0.03	-3.3	3.9	50%	27%
08362500	Rio Grande Below Caballo Dam	5%	0.4	0.03	-2.7	3.9	54%	27%
08377900	Rio Mora near Terrero	1%	0.3	0.04	-3.3	3.8	1%	0%
08380500	Gallinas Creek near Montezuma	0%	0.5	0.04	-4.4	3.8	24%	46%
08382500	Gallinas River near Colonia	19%	0.5	0.05	-3.3	3.7	40%	14%
08382650	Pecos River above Santa Rosa Lake	5%	0.5	0.04	-3.1	3.8	19%	22%
08382830	Pecos River below Santa Rosa Dam	5%	0.5	0.04	-3.1	3.8	19%	21%
08387000	Rio Ruidoso at Hollywood	6%	0.3	0.04	-1.1	3.6	20%	26%
08390500	Rio Hondo at Diamond A Ranch	1%	0.3	0.03	-1.7	3.6	35%	32%
08390800	Rio Hondo Below Diamond A Dam	1%	0.3	0.03	-1.7	3.6	35%	32%
08400000	Fourmile Draw near Lakewood	0%	0.6	0.00	-2.0	3.6	36%	0%
08401200	South Seven Rivers near Lakewood	10%	0.6	-0.02	-1.7	3.6	37%	0%
08405500	Black River above Malaga	16%	0.6	-0.01	-2.2	3.5	58%	63%
08407500	Pecos River at Red Bluff	7%	0.6	0.01	-2.1	3.6	70%	21%
09365000	San Juan River at Farmington	0%	0.2	0.03	-2.0	4.1	19%	24%
09367500	La Plata River near Farmington	5%	0.2	0.04	-1.0	4.2	34%	29%
09430500	Gila River near Gila	0%	0.4	0.00	-1.8	3.6	1%	74%
09430600	Mogollon Creek near Cliff	0%	0.3	0.01	-3.1	3.6	0%	0%