Lower Rio Fernando de Taos Hydrogeological Study

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Biohabitats
SOUTHWEST BASIN & RANGE BIOREGION

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EXECUTIVE SUMMARY

The Rio Fernando de Taos and its watershed play a critical role in the Taos County region's water management, recreation, and natural habitat. This study looks closer at the hydrologic and geologic conditions and develops a preliminary concept of the hydrogeologic system to help inform future restoration actions and community understanding of this resource.

The Rio Fernando de Taos watershed is in the Sangre de Cristo Mountain range in north-central New Mexico. The watershed is approximately 71.7 square miles (45,888 acres). The Rio Fernando de Taos is approximately 21 miles long from its headwaters in La Jara Canyon to its confluence with the Rio Pueblo de Taos. The upper watershed extends from the headwaters in La Jara Canyon to the mouth of Taos Canyon. The lower part of the river begins at the mouth of the canyon and can be subdivided into an Intermittent Reach and Gaining Reach.

The Rio Fernando de Taos delivers to five acequias that were established approximately 200 to 230 years ago. Water is directly diverted from the Rio Fernando de Taos for the Acequia Madre del Sur del Cañon, Vigil y Romo Ditch, Jose Venito Martinez Acequia, and Alamitos Ditch.

The complex geology of the region—resulting from sedimentation, erosion, uplift, and faulting—is a significant factor in how water moves through the Rio Fernando de Taos watershed and the larger Taos Valley. The soils tend to be thin on gravelly slopes and transition to loamy range soils in the valleys.

WATER CYCLE

Surface Water

The volume of water in the study area is heavily influenced by the Rio Fernando de Taos flowing out of the upper watershed and by the diversion of water through the acequia system that was introduced earlier. In addition, seeps and springs contribute to flows.

Rio Fernando de Taos

Surface water in the Rio Fernando de Taos watershed is driven by precipitation, particularly by snow that falls on the upper watershed and then melts, causing higher spring flows. The adjacent watershed to the north is the upper Rio Pueblo de Taos. Due to their proximity and similar watershed size, soils, and geologic condition, the flows for each river might be expected to also be similar. However, comparison of discharges for an overlapping period of record shows that Rio Fernando flow was consistently lower than Rio Pueblo, with the most significant differences during higher flow events. Other reports have noted that the average monthly streamflow for Rio Fernando is lower than Rio Pueblo for all months. It appears that the combination of seemingly small differences in numerous watershed parameters has a cumulative effect causing the resulting volume generated from the Rio Fernando upper watershed to be much less than might be expected. The estimated median annual volume at the canyon mouth is 2,353 acre-feet.

Water is also diverted from the upper watershed of the Rio Fernando de Taos. Private ditches are permitted to take water from the Rio Fernando to irrigate about 282 acres. In addition, the Rio Fernando watershed has 857 wells distributed over the entire Rio Fernando watershed (with 173 wells in the headwaters).

Acequias and Irrigated Lands

The centuries-old system of diversion structures, ditches, and irrigated lands redistributes much of the Rio Fernando de Taos flow out into the lower watershed. Irrigation volumes are split between the Crop Irrigation and Farm Delivery Requirements with an estimated annual diverted volume of 3,195 acre-feet.

Groundwater

Groundwater is stored in multiple layers beneath the Taos valley, which are loosely grouped into the shallow, alluvial aquifer (unconfined) and the deep confined aquifer(s). These aquifers are recharged along the foothills of the Sangre de Cristo range as snowmelt infiltrates along the drainages and faults. Movement occurs through the pore spaces between the rocks and soil particles and through fractures and faults. On the eastern edge of the valley, the unconfined and confined systems are connected hydraulically.

Groundwater discharge to the surface occurs in springs, generally located at the interface between rock types, as observed in the canyon during a site visit, as well as downstream near Hatchery Road and Fred Baca Park.

HYDROGEOLOGIC CONCEPT

The preliminary conceptual model of the hydrogeologic system for the lower Rio Fernando de Taos represents above and below ground relationships and general water flow direction. Key flow paths include precipitation, infiltration, groundwater flow, and springs. The basalt geology appears to act as an impermeable layer that may force groundwater to the surface and appears to correspond with the beginning of the Gaining Reach.

Most years there is not enough water entering the lower watershed to meet the volume allocated to the acequias, resulting in river dry ups. For this study, we developed a simplified water balance that focuses on river flow through the Intermittent Reach:

Water for River = Flow at Canyon Mouth – (Loss to Groundwater + Evapotranspiration)

- The Flow at Canyon Mouth median annual volume is 2,353 acre-feet.
- Loss to Groundwater is not known. However, it appears to be a relatively significant part of the overall system.
- Evapotranspiration of the water used to irrigate land is estimated at 3,195 acre-feet. Some portion of this water may be lost to the ground and may eventually return to the river, but those values are not known.

Considering that the estimated median volume from the Rio Fernando is lower than the volume allocated for the acequias, the challenge of maintaining flow in the river while also providing the water needed for irrigation is very evident. Similarly, the Mayordomo of Acequia del Sur del Cañon stated that the acequias usually do not divert their entire allotted amount because there is not enough water in the river.

Further downstream, the flow of groundwater into the river becomes more dominant and return flows from irrigation may become more prevalent, which results in this part of the river becoming a gaining reach. The volume of groundwater inflow and return flows is unknown since it is not measured.

RECOMMENDATIONS

The following recommendations are to help improve both the natural and historical systems in the watershed:

Ecological Restoration

Upper Watershed

- Implement projects that promote water storage in the upper watershed, such as beaver-based restoration approaches, improve ecological health and increase wildfire resilience. Their location should be carefully considered to avoid areas that may have a more direct connection to the subsurface that would result in loss of the stored water.

Intermittent Reach along Los Pandos Road

- Restore this reach through the establishment of a greenway that provides more room for the river, allowing modification of the river's cross section to better accommodate the range of flows (particularly low flows) and promoting infiltration along the Intermittent Reach. Amigos Bravos is talking with Taos County to explore future improvement projects.
- Additional components of the revitalization of the Los Pandos Road corridor could include the use of easements on the opposite (north) side of the channel and establishment of an agreement for a minimum flow that would be allowed to remain in the Intermittent Reach. Even a very small flow would provide considerable benefits over no flow.

Water Conservation

- Complete a modernization assessment of the irrigation system that investigates where the water goes, where it is lost, the benefits that it provides, and the problems that it may cause. Develop improvements to the system that help make water use more efficient and management easier while, at the same time, preserving benefits that the water provides.

Wastewater Treatment

- Evaluate the decentralized wastewater treatment system and develop recommendations to improve water quality. E-Coli is a constituent of concern and has been found in all three segments of the river. Probable sources include cattle grazing and onsite wastewater septic systems. The following approaches should be studied:
  - Regular maintenance including pumping is important to maintain adequate treatment in the septic tank.
  - Small aerator units can be installed to new or existing septic tanks that add oxygen to help break down organic constituents and treat nutrients.
  - A separate secondary treatment unit can be added after primary treatment to further remove organics and nutrients in the wastewater.
  - Residential homes can be connected to a small community treatment system.

1. INTRODUCTION

The Rio Fernando de Taos (RFdT) and its watershed are important parts of Taos County, New Mexico, playing a role in the region's water management, recreation, and natural habitat. The river has been the subject of multiple past studies and a focus of Amigos Bravos and the associated Rio Fernando de Taos Revitalization Collaborative. With the mission to protect and restore the waters of New Mexico, Amigos Bravos obtained funding from the U.S. Bureau of Reclamation (Reclamation) for "*Improving the Ecological Function of the Rio Fernando through Hydrology and Streambank Restoration Planning*" and contracted with Biohabitats to complete this hydrogeologic assessment of the lower watershed. This study looks closer at the hydrologic conditions and develops a preliminary concept of the hydrogeologic system to help inform future actions and community understanding of this resource. The Reclamation grant is also funding two other related projects focused on community outreach and green infrastructure associated with improving the RFdT.

1.1. Related Past Studies

Several Taos area studies provided useful information on the RFdT to help inform the current analysis, including the documents listed below.

- Rio Fernando de Taos Watershed Based Plan (Draft) by Amigos Bravos, 2019
- Rio Fernando de Taos Revitalization Project and Work Plan (Draft) by the Rio Fernando de Taos Revitalization Collaborative, 2017
- Taos Regional Water Plan by State of New Mexico Interstate Stream Commission Office of the State Engineer, 2016

Additionally, several geologic maps and regional studies on hydrogeology were referenced as noted in Section 2.x and References.

1.2. Data and Analysis

At the outset of the study, Biohabitats reviewed available reports and publicly available data sources to compile geospatial data using ArcGIS Pro and ArcGIS Online software. Key inputs included watershed and surface water features, acequia locations, geologic units, and well locations, along with several other data sources such as land cover, elevation contours, and soils, described in **Appendix A**.

Some of the information required preprocessing and digitization prior to use in GIS. For example, when digital geospatial data were not publicly available, we georeferenced and digitized relevant information from existing maps such as those listed below.

- Groundwater contours and the losing and gaining reaches of the Rio Fernando de Taos were referenced from the "*Hydrologic Characteristics of Basin-Fill Aquifers*" map in a New Mexico Geological Society Guidebook (Drakos et al., 2004).
- The "*Geologic Map And Potentiometric Surface Map Of The Southern Taos Valley*" figure was used to digitize the basalt line, zone of permeability, and fault lines (Bauer, Johnson and Kelson, 1999).

Well data from the New Mexico Office of the State Engineer Water Rights Reporting System were downloaded for water use information. We used a 1000-foot buffer on either side of the Rio Fernando de Taos to clip the well data and select wells in the immediate project area.

Additionally, because the well information in the state database was often incomplete, we filled in data gaps for representative wells by interpreting ground elevations and depth to water based on nearest elevation contours and reviewing of well logs. These representative wells were used to confirm the general groundwater contours depicted in regional maps and in relation to the river.

The process of compiling the data for the Rio Fernando de Taos study area in GIS helped establish the framework for the conceptual hydrogeological model or diagram. To assist in developing the diagram, we used a three-dimensional map in ArcGIS Scene Viewer, hosted in ArcGIS Online. This allowed us to visualize our 2D datasets on 3D features like terrain and elevation at all angles and better understand relationships between features.

The data review and analysis help assemble these elements into one place to get a holistic picture of how the watershed pieces fit together (**Figure 1**). Some of these key elements are summarized below and provide the basis for the conceptual model and preliminary water budget in the following section.

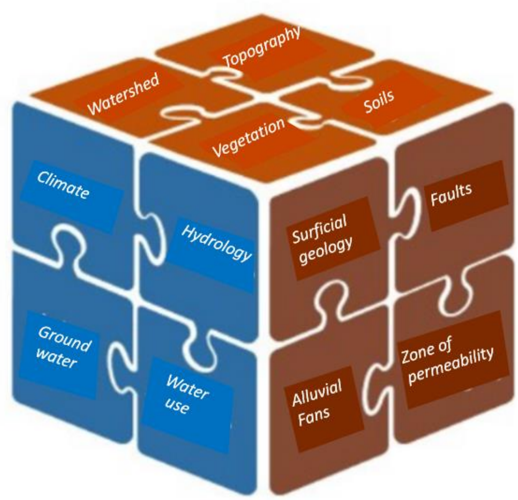

Figure 1. Example of elements that fit together to provide holistic picture of hydrogeologic system.

2. PROJECT AREA

Developing strategies for protecting and enhancing water resources requires understanding the factors that influence the natural hydrologic regime, including watershed context, channel characteristics, water management, and geologic and hydrologic setting.

2.1. Watershed Context

The Rio Fernando de Taos watershed is in the Sangre de Cristo Mountain range in north-central New Mexico. The watershed is approximately 71.7 square miles (45,888 acres) (Amigos Bravos, 2019, p.18) and contains Taos Canyon. (See **Figure 2**, attached; full-page figures are compiled at the end of this document.) Amigos Bravos conducted an extensive study on the Rio Fernando de Taos for its 2019 Rio Fernando de Taos Watershed Based Plan, which provided detailed descriptions of the watershed including the land cover, vegetation, wildlife, and water quality.

Rather than repeat that background information here, please refer to Section 3 Watershed Background in the Rio Fernando de Taos Watershed Based Plan.

2.2. Rio Fernando de Taos Overview

The Rio Fernando de Taos is approximately 21 miles long from its headwaters in La Jara Canyon to its confluence with the Rio Pueblo de Taos. The 2019 watershed plan divided the Rio Fernando into three (3) segments – upper, middle, and lower – following the State's organization for water quality sampling. This study, which mostly focuses on the lower segment, lumps together the middle and upper segments and refers to them collectively as the "upper watershed."

As shown in **Figure 3**, the current study is focused on the lower segment, which runs from the mouth of the canyon to the confluence with the Rio Pueblo and is approximately 5 miles long. We have further divided the lower segment into an intermittent reach and, at the downstream-most part of the river, a gaining reach (as described later in this section).

2.2.1. Upper Watershed

The upper watershed extends from the headwaters in La Jara Canyon to the mouth of the Taos Canyon (refer to Figure 2). An abandoned USGS gage site is located near the mouth of the canyon, which is also near the US Forest Service boundary for Carson National Forest. The length of the Rio Fernando through the upper watershed is approximately 16 miles and follows Highway 64 through Taos Canyon. Most of the upper watershed is comprised of National Forest with private land along the highway, including residential homes and a small town called Valle Escondido. There are several tributary drainages in the upper watershed including La Jara Canyon Creek and Tienditas Creek, as well as wetlands and springs.

This part of the Carson National Forest is heavily used by campers at designated campgrounds or dispersed sites, hikers, and mountain bikers. The area has seen an increase in recreation over the years and, unfortunately, dumped trash is an expanding problem. Management of this increased active recreation is challenging for the USFS.

2.2.2. Lower Segment

The lower part of the river begins at the mouth of the canyon and can be subdivided into two reaches based on observed and mapped flow patterns (refer to Figure 2).

> **Intermittent Reach.** The intermittent reach of the Rio Fernando is approximately 3 miles long and extends from the abandoned USGS gage location to the wetlands upstream of Fred Baca Park near La Posta Road. According to local observations, there are periods when this section of the channel is a "losing" river as water infiltrates into the ground and flows diminish. The rate of infiltration or loss can vary by location and timing. The frequency, duration, and extent of the losing periods is unknown but likely occurs during lower flows and when the surrounding subsoils are unsaturated. On USGS maps, most of this part of the Rio Fernando is shown with a dotted or dashed line, indicating intermittent, as opposed to perennial, flow. These maps show the river with a solid line, indicating perennial flow, at a spring near Hatchery Road or further downstream near Fred Baca Park (depending on the map date). Similarly, the draft Rio Fernando de Taos Revitalization Plan (2017) states how, during "the mid to late irrigation season, (July/August), there is often no flow in the river from the USFS boundary until La Posta Road." This section of the river is defined by urban development and some private agricultural land.

Gaining Reach. This downstream-most part of the Rio Fernando is approximately 2 miles long and extends from Fred Baca Park to the confluence of the Rio Pueblo de Taos. This section of the river is defined mostly by agricultural land and wetlands. Homes in this area mostly depend on onsite septic systems for wastewater management. Amigos Bravos conducted regular water quality sampling along the Rio Fernando de Taos and observed elevated E-coli and temperature in this portion of the reach. The water quality issues are likely attributed to old septic systems that may be contaminating the groundwater. Water quality and wastewater management is discussed further in Section 5.3, of this report.

2.3. Rio Fernando de Taos Acequias

The river has been important to the livelihood of many agricultural farmers in the area for generations; the Rio Fernando provides a surface water source for irrigation via acequias in the lower segment of the river. Acequias are unlined irrigation ditches that divert water from a river or stream to supply irrigation water via gravity for agriculture. It is estimated there are 1,000 to 1,200 working acequias throughout New Mexico, of which 54 acequias diverted from six rivers and streams are in the Taos Valley (Ernest Atencio, year unknown). These acequias are supported by the Taos Valley Acequia Association, a non-profit organization that protects these centuries-old traditions and ensures long-term sustainability of community agriculture. They are a community network that manages and takes care of the acequias throughout the Taos Valley. For more information, see their website (www.taosacequias.org/acequias) and the video available from the organization *Rivers & Birds* (www.riversandbirds.org/video).

The Rio Fernando de Taos delivers to five acequias that were established approximately 200 to 230 years ago. The location of the acequias along with their diversions and irrigated areas are in Figure 4and are listed below.

1. Acequia del Sur del Cañon – 383.21 acres *(includes Randall Reservoir Ditch)*
2. Acequia del Norte del Cañon – 138.8 acres
3. Vigil and Romo Ditch – 45.28 acres
4. Jose Venito Martinez Acequia – 79.2 acres
5. Alamitos Ditch – 134.47 acres

Surface water is diverted from the Rio Fernando and routed to the acequias through a series of headgates and pipes. Water is directly diverted from the Rio Fernando for the Acequia del Sur del Cañon, Vigil y Romo Ditch, Jose Venito Martinez Acequia, and Alamitos Ditch. The Acequia del Sur del Cañon is considered the Acequia Madre (or Mother Ditch) because it is the first headgate on the Rio Fernando and is the primary irrigation canal. It also supplies water to the Acequia del Norte del Cañon and the Randall Reservoir Ditch (**Figure 4**).

Every spring, the annual cleaning occurs. *Parciantes*, who are the members of an acequia, help clean the acequias that provide them with water. The *Mayordomo* manages the release of water into the acequia during spring runoff when snowmelt from the mountains increases the flow in the river. At the Acequia Madre headgate diversion, the Acequia del Sur receives 2/3 of the river flow and the Acequia del Norte receives 1/3 of the flow, which is based on gentlemen's agreement made in 1909 (V. Fernandez, personal communication, December 4, 2023). During times of drought, the acequias may share water equally.

Vicente Fernandez, the Mayordomo of the Acequia Madre de Sur de Cañon, shared his perspective in an interview on how climate change is impacting the timing of water. Spring snowmelt runoff varies year-to-year, but over the last few decades, it has appeared to be trending earlier in the year. He shared that, historically, the acequias would be cleaned and water released mid-April, but, more recently, cleaning occurs a month earlier, in early March. The earlier spring runoff does not coincide with the agricultural season that begins in May and June.

The acequias and their management are an important component of the overall water cycle for Rio Fernando. During drier years with lower flows, most or all the water from Rio Fernando is diverted to the acequias. While the Mayordomo noted that diverting water can dry out the river downstream, the diversions also distribute the water throughout the lower basin, supporting wetlands and meadows. The hydrologic influence of acequias is discussed further below in Section 3.1.

2.4. Geology & Soils

The complex geology of the region—resulting from sedimentation, erosion, uplift, and faulting—is a significant influencing factor of how water moves through the Rio Fernando watershed and the larger Taos Valley. The Taos Valley is a large depression that filled over millions of years with interbedded layers of sand, silt, clay, gravel, along with occasional lava flows. Major rock types and structural features found on the Rio Fernando watershed are summarized below based on mapping by the New Mexico Bureau of Geology and Mineral Resources (Bauer and Kelsen, 2001) at the 24,000 scale and additional descriptions of regional geology found in Hydrogeologic Investigation of the Southern Taos Valley (Johnson et al., 2016), as well as in several other water resource studies prepared over the last 20 years.

2.4.1 Structural Features

Approximately 35 million years ago, the earth's crust thinned and pulled apart forming the Rio Grande Rift, extending 600 miles from central Colorado southward to Mexico. The result of the Rift was the formation of a series of blocks (horsts) and long trenches (grabens), including the Taos Valley (**Figure 5**). More recently, within the last several million years of the Quaternary era, the Sangre de Cristo fault zone formed with several subsections extending south to near Taos. The location and types of faults were reviewed to understand the extent to which they could create preferred flow paths for water movement (**Figure 6**).

2.4.2 Stratigraphy

The stratigraphy of the Rio Fernando de Taos watershed consists of younger alluvial deposits in the valley, over older sedimentary rocks in the mountains and at depth, which in turn are underlain by volcanic and ancient rock types. Key geologic layers in the project area are described briefly below.

- **Paleozoic Sedimentary Rocks** (Pennsylvanian age, ~300 million years ago [mya]). These rocks are found in the Sangre de Cristo mountains east of Taos and are mapped as undifferentiated deposits, consisting of various layers of shale, sandstone, siltstone, limestone, and conglomerate. In places where the rocks outcrop, such as where streams have carved through the canyons, the exposed rocks are a variety of colors and types (i.e., "greenish, reddish, yellowish, buff, tan, black, and brown, sandy to clayey siltstone, mudstone, and shale interbedded with mostly greenish and brownish quartzose, feldspathic, and arkosic, silty to pebbly sandstone and sandy conglomerate, and rare dark limestone" Johnson et al., 2016).

- **Surficial Deposits.** Relatively recent deposits (from the Holocene in Quaternary age, 11 mya) occur as alluvium along the river corridors and colluvium on side slopes. These unconsolidated materials range from fine sand and silt to cobble size deposits but tend to be coarse sand and gravel closest to the mountains. Tectonic activity in the area along with the stream and mountain erosion processes have resulted in intersecting, heterogenous patterns of fans and stream deposits, which add complexity to the drainage patterns. Well log records suggest that the unconsolidated materials are anywhere from 30 to nearly 200 feet thick, depending on the location. They also indicate that a clay layer is sometimes encountered.

- **Servilleta Basalt.** Interlayed within the alluvial valley in the Western portion of the Rio Fernando de Taos is the Servilleta basalt formation, which was deposited as a lava flow in the Pliocene epoch (roughly 5 mya). The extent of this layer has been mapped as shown in **Figure 7**. Clay layers are sometimes found along with the basalt, and groundwater perching can occur above the clay.

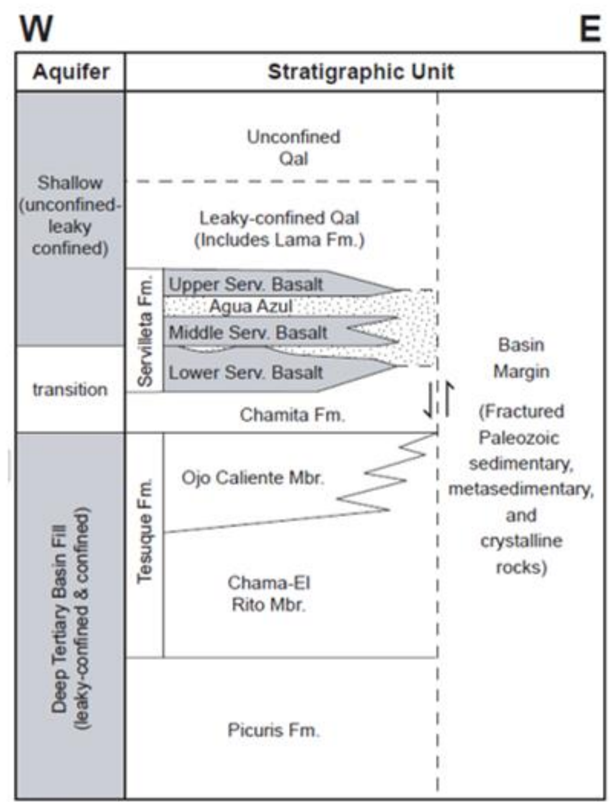

Figure 7. Profile view of stratigraphy in study area. Source: Drakos, et al., 2004.

Figure 8 provides a map of major rock types, and **Figure 9** is a cross-sectional view of the geologic profile in the vicinity of the Rio Fernando de Taos.

2.4.3 Soils

Mapping by the Natural Resource Conservation Service (NRCS) shows thin soils on gravelly slopes transitioning to loamy range soils in the valleys. Typical soils are a mix of loam, gravelly loam, loamy fine sand, fine sandy loam, sandy loam, silt loam or clay loam. The 2019 Watershed Plan provides more detailed descriptions of the soil characteristics that can be found on mountain slopes, valley floors, terraces, and alluvial fans. The Plan also notes that clay loam soils associated with the alluvial fans make up the bulk of the agricultural land in the watershed and are considered prime farmland when irrigated. (Refer to Section 3.3 of the Watershed Plan.)

The soil type provides an indicator of potential water storage in the study area. Most of the eastern portion of the watershed is dominated by steep areas of rock outcrop with little to no storage capacity. Areas that are less steep with some loam soils and the stream corridor bottomlands have the highest potential for water storage in the Rio Fernando watershed. Water storage potential increases in the soils of the foothills and valley floor.

3. WATER CYCLE

To help develop a conceptual hydrologic understanding of the lower river system, elements of the water cycle are characterized below, including inflows such as precipitation and outflows, including irrigated lands/evapotranspiration and well water use. Groundwater inflows and outflows are also generally described based on the available literature.

Climate is an important driver of the water cycle. Regional climate characteristics are summarized in Section 3.7 of the 2019 Watershed Plan. New Mexico, like elsewhere in the semi-arid west, is known for temporal and spatial variability in precipitation intensity, and some storm events may be localized or too small to produce runoff.

3.1. Surface Water

The volume of water in the study area is heavily influenced by the Rio Fernando de Taos flowing out of the upper watershed and by the diversion of water through the acequia system that was introduced earlier. In addition, seeps and springs contribute to flows.

3.1.1. Rio Fernando de Taos

The 2019 Watershed Plan provides a description of general hydrologic conditions, including the monthly variation in discharge that peaks in the spring. Surface water in the Rio Fernando de Taos watershed is driven by precipitation, particularly by snow that falls on the upper watershed and then melts, causing the higher spring flows. Please refer to the 2019 document for more information.

For this study, we evaluated the overall volume of water that flows into the lower segment and how that volume compares with the neighboring watershed (Rio Pueblo de Taos) to the north. Stream gages that measure discharge are useful in analyzing surface flow. There is an abandoned gage location on Rio Fernando de Taos at the mouth of the canyon that was active from January 1, 1963, to October 17, 1980. According to USGS, the watershed above this site (referred to as the "upper watershed" in this report) has an area of 60.5 acres. The adjacent watershed to the north, the upper Rio Pueblo de Taos, has an active stream gage at an equivalent location, with an area of 66.6 acres. Due to their proximity and similar watershed size, soils, and geologic condition, the flows for each river might be expected to also be similar. However, comparison of discharges for the period of record in the Rio Fernando that overlaps with the same period for the Rio Pueblo shows that Rio Fernando flow is consistently much less than the slightly smaller watershed area might indicate. For the period from January 1, 1963, to October 17, 1980, when both gages were in operation, the daily flows in the Rio Fernando were consistently lower than Rio Pueblo, with the most significant differences during higher flow events (**Figure 10**).

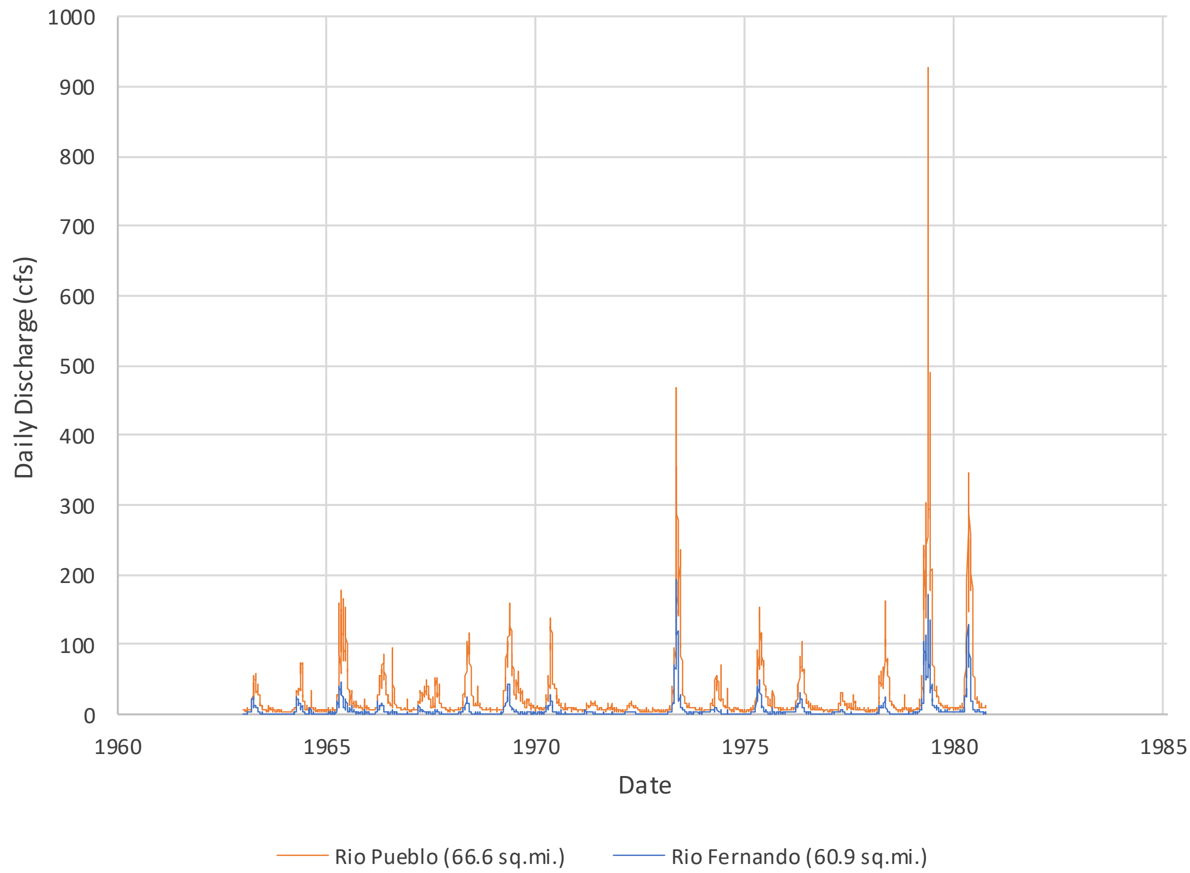

Figure 10. Comparison of Rio Fernando and Rio Pueblo de Taos Daily Discharge

This difference in volume is also evident in the Taos Regional Water Plan (2016) evaluation of regional stream gages. It provides annual statistics based on the entire record for each station; Rio Fernando de Taos and Rio Pueblo de Taos results are shown in **Table 1**.

Table 1. Annual Yield Comparison

Annual Yield (ac-ft)	Rio Fernando	Rio Pueblo
Minimum	760	3,526
Median	2,353	16,941
Maximum	14,769	52,850

In addition, the report shows that the average monthly streamflow for Rio Fernando is lower than Rio Pueblo for all months.

A parameter that directly relates to the amount of runoff that a drainage area generates from precipitation is the runoff coefficient. It is the ratio of runoff to precipitation and can range from 0.05 for flat sandy soils to 0.95 for impervious surfaces such as parking lots. To further illustrate the reduced flow from the upper watershed of the Rio Fernando de Taos, we looked closer at the daily flow data at both gage sites for the overlapping period of record. For Rio Fernando, the average annual flow was 4,141 acre-feet; the contributing watershed average annual precipitation is 18.9 inches or 61,400 acre-feet, resulting in an extremely low average runoff ratio of 0.067. For Rio Pueblo, the average annual volume for that same period was 17,915 acre-feet, and, with an average annual precipitation of 22.5 inches or 79,920 acre-feet, the resulting runoff ratio was much higher at 0.22.

It is not immediately clear why there is such a difference between the volume of water generated from the neighboring and similarly sized watersheds. It appears that the combination of seemingly small differences in numerous parameters (See **Table 2**, below) has a cumulative effect that is larger than expected. In particular, the difference in average aspect, with Rio Fernando de Taos watershed averaging a northerly aspect and the Rio Pueblo de Taos watershed due south, along with the difference in slope, would result in lower runoff, particularly from snow melt. Combined with the slightly smaller watershed size and precipitation amount, the resulting volume generated from the Rio Fernando upper watershed is much less than might be expected, which has consequences for the lower river.

Table 2. Comparison of Watershed Parameters

Parameter	Rio Fernando de Taos	Rio Pueblo de Taos
Size (square miles)	60.3	66.6
Latitude (degrees)	36.38	36.44
Mean Elevation (feet)	9070	9520
Mean Annual Precipitation (inches)	18.9	22.5
Average Aspect (degrees)	315	180
Mean Slope (percent)	31.2	40.2

Another difference between the watersheds is the amount of water that is diverted from the upper watershed of the Rio Fernando. The 2017 draft document states: “Also, thirty-two (32) “private ditches” are permitted to divert water from the Rio Fernando to irrigate about 282 acres in the watershed; all but 11.8 acres are in the upper watershed.” The amount of water diverted is not known, but, if the irrigation volume is assumed to be 2 to 4 acre-feet/year/acre, it would range between 564 to 1,128 acre-feet.

The Rio Fernando watershed also has more wells than the Rio Pueblo de Taos. Available GIS data show that there are 857 wells distributed over the entire Rio Fernando watershed (with 173 in the headwaters) compared to 372 wells for the Rio Pueblo de Taos (with none in the headwaters). Further analysis of the aquifer being used and of pumping volumes would be needed to better estimate the impact of wells on river flow.

Additional variables that may contribute to difference between river flow for the similarly sized watersheds include the following items:

- Vegetation cover – more trees can intercept a higher percentage of snowfall that is held longer and lost to evaporation.
- Soil type, including rock outcrops – a higher percentage of land cover that is rock can produce higher runoff volumes.

3.1.2. Acequias and Irrigated Lands

The centuries-old system of diversion structures, ditches, and irrigated lands redistributes much of the Rio Fernando flow out into the lower watershed. For each acre of land that is irrigated, there is an expected volume of water diverted that eventually leaves the system through transport losses as it travels to its destination or through plant uptake once it arrives. The 2017 draft of the Rio Fernando de Taos Revitalization Project and Work Plan provides the allowable irrigation volumes based on the 2016 Taos Pueblo Indian Water Rights (Abeyta) Settlement court orders. The volumes are split between the Crop Irrigation and Farm Delivery Requirements:

- Crop Irrigation Requirement - 1.38 acre-feet/year/acre
- Farm Delivery Requirement - 2.76 acre-feet/year/acre

Using these values with a total irrigated acreage of 771.8 acres (2016 court orders referenced in the draft 2017 document) results in an annual diverted volume of 3,195 acre-feet.

3.2. Groundwater

Groundwater is stored in multiple layers beneath the Taos valley, which are loosely grouped into the shallow, alluvial aquifer (unconfined) and the deep confined aquifer(s). These aquifers are recharged along the foothills of the Sangre de Cristo range as snowmelt infiltrates along the drainages and faults. Movement occurs through the pore spaces between the rocks and soil particles and through fractures and faults. On the eastern edge of the valley, the unconfined and confined systems are connected hydraulically (see **Figure 11**).

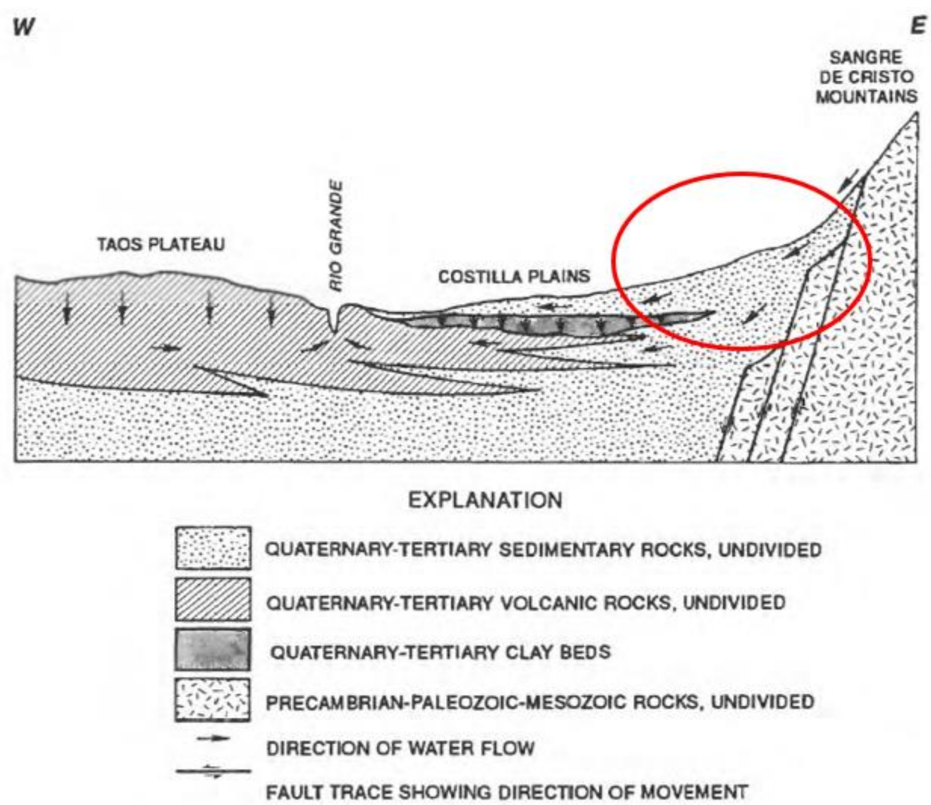

Figure 4.--Generalized west-to-east section across the Taos Plateau and the Costilla Plains in Taos County, New Mexico (from Hearne and Dewey, 1988).

Water Resources of Taos County, New Mexico, Lynn A. Garrabrant, 1993

Figure 11. Red circle shows where unconfined and confined systems are hydraulically connected. Adapted from Garrabrant, 1993.

While the predominant flow path is horizontal in this area, some downward movement also occurs in more permeable zones, likely along the fault zones. As the water flows downward, some of it flows under more confining clay layers into the lower, confined aquifer. Places of upward leakage from the lower aquifer also occur but are not well mapped. In addition to the downward groundwater movement in the mountains and edge of the valley, a zone of increased permeability is mapped near the middle of the lower reach as shown by the downward arrows.

The alluvial aquifer beneath Taos extends from the edge of the mountains westward into the valley, varying in depth and thickness depending on location. Well logs indicate groundwater in this alluvial aquifer was encountered at anywhere from 10 to 40 feet below ground surface. Regional groundwater contours for the valley show groundwater flows from east to west along the Rio Fernando de Taos (**Figure 12**). In the northern part of the Taos valley, there are areas where the tectonic structures (horst blocks) and faults alter and compartmentalize groundwater flow. Further south, in the shallow aquifer of the RFdT, groundwater flow is reported to be less compartmentalized (i.e., faults do not appear to be major boundaries).

There are also numerous deeper aquifers. These are described in more detail in Section 5.3.2 in the 2003 Taos Regional Water Plan.

Groundwater discharge to the surface occurs in springs, generally located at the interface between rock types, as observed in the canyon during a site visit, as well as downstream near Hatchery Road and Fred Baca Park.

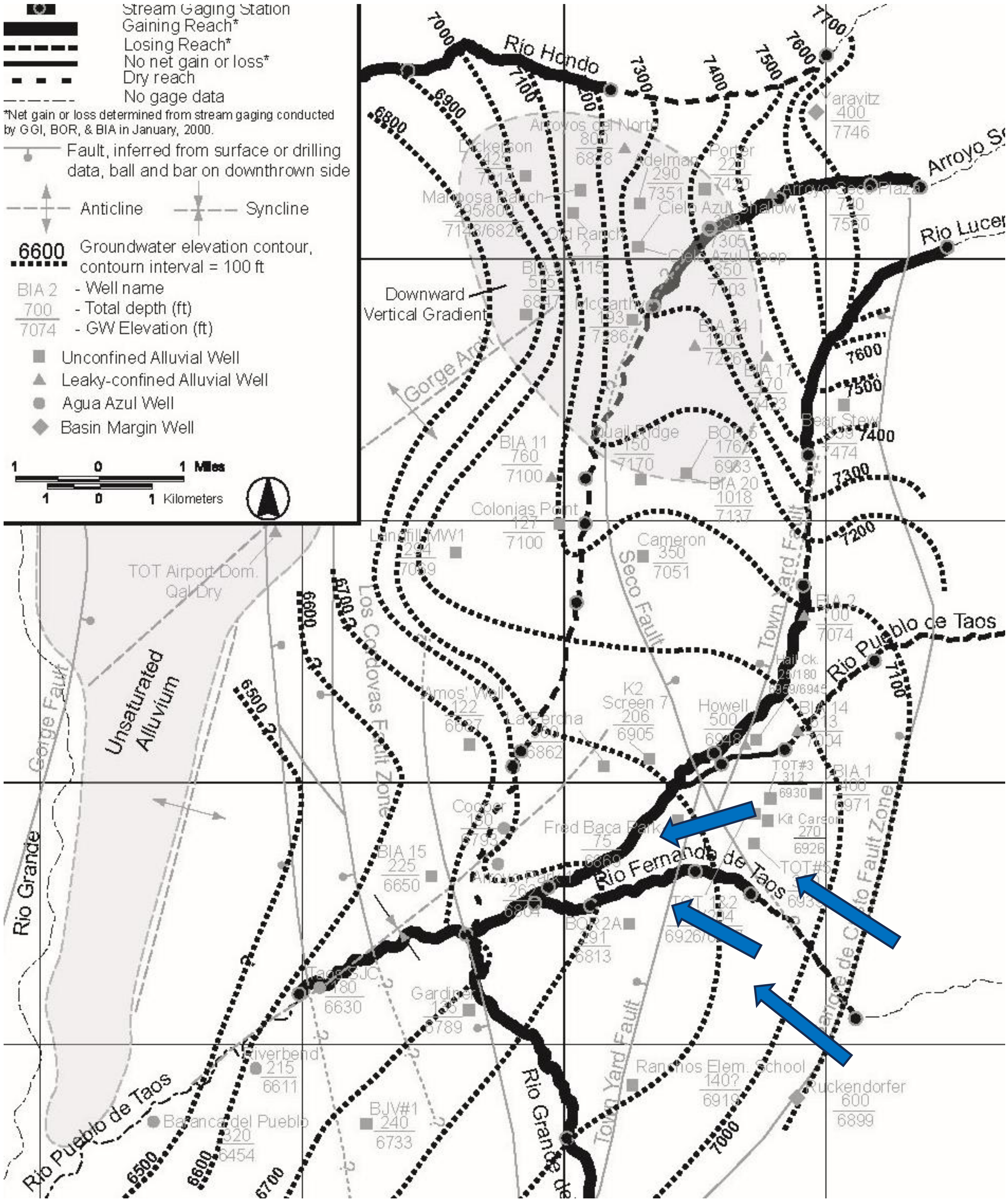

Figure 12. Alluvial groundwater contours. Blue arrows depict the general direction of groundwater flow. Contours that are perpendicular to the river indicate that the groundwater and surface water are at the same elevation, at least during some periods. Contours that bend and point up the channel indicate a gaining reach and those that point downstream indicate a losing reach. Also note in the legend identification of losing and gaining reaches.
Source: Drakos et al., 2004

4 HYDROGEOLOGIC CONCEPT

A conceptual hydrogeologic model is an illustration of the relationships between different elements including precipitation, surface water and groundwater flows, and water use. Based on these elements, we developed a preliminary conceptual model of the hydrogeologic system for the lower RFdT (**Figure 13**). It shows above and below ground relationships (in an isometric view) of a section of the study area as well as arrows indicating general water flow direction.

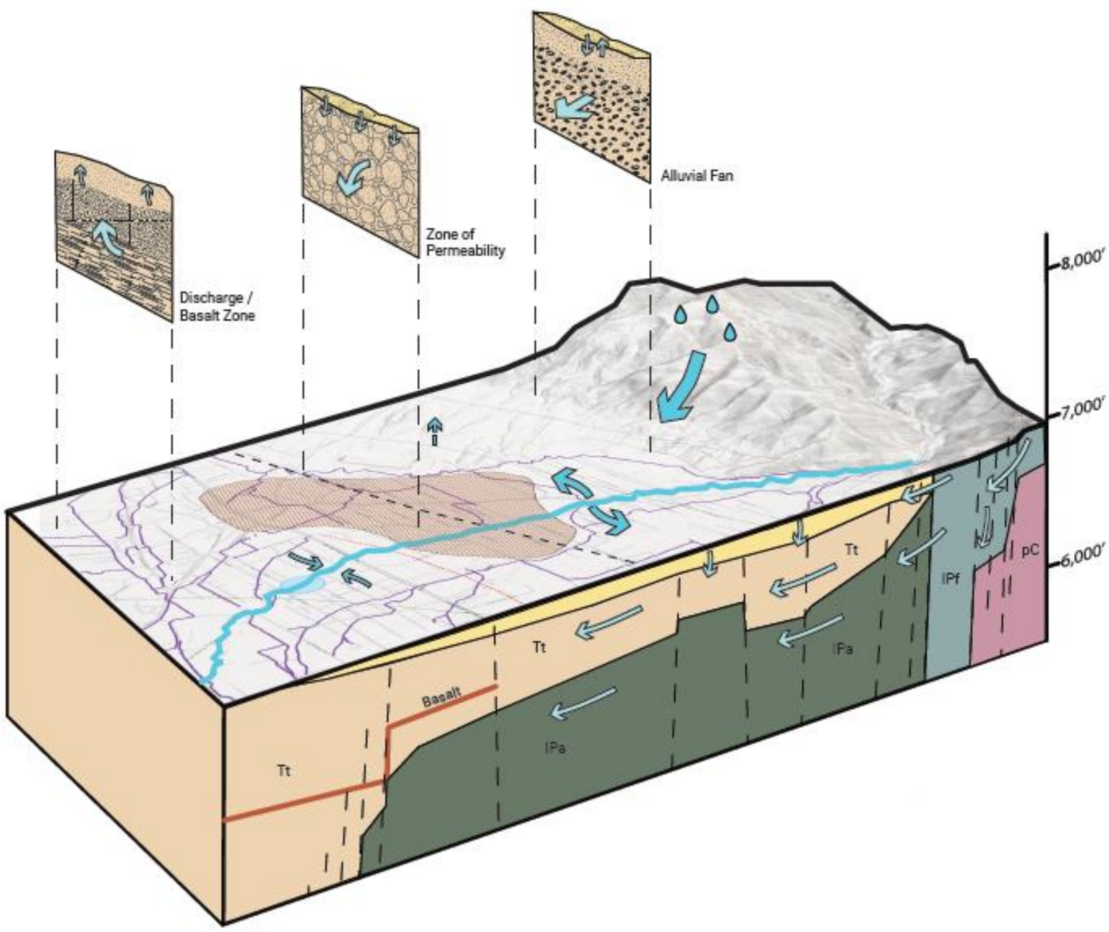

Figure 13. Conceptual diagram of Hydrogeologic System of Lower Rio Fernando de Taos

Key flow paths are summarized below and provide the basis for a preliminary water budget to understand the balance of inflows and outflows.

- Precipitation is the main input feeding the Rio Fernando de Taos as well as smaller creeks. Water enters the Intermittent Reach of the study area via the RFdT, where it is divided and routed into the complex geologic system below ground and into the acequia system above ground.
- Some of the precipitation in the mountains and foothills infiltrates into the ground, flowing through the pore spaces and fractures of the bedrock and recharging groundwater aquifers.
- The direction of groundwater flow generally follows the slope of the land; in this case, it moves in a westerly direction from the mountains and canyons into the valley.

- Some of the below-ground water ends up in deep aquifers while other parts of it resurface in the Gaining Reach further down gradient. The deeper water may come back to the surface via domestic wells.
- Depth to groundwater in relation to the river channel is not well documented, but it is expected to fluctuate with elevations highest in the spring when it may be in equilibrium with the channel and then falling to depths below the channel during summer and fall.
- Springs are fed by groundwater discharge from the aquifer, which appears at rock interfaces in the canyon and at springs at the start of the gaining reach in the lower segment.
- The basalt mentioned earlier appears to act as an impermeable layer that may force groundwater to the surface and appears to correspond with the beginning of the Gaining Reach.

As discussed earlier, most years there is not enough water entering the lower watershed to meet the volume allocated to the acequias, and it is even less likely for there to be enough to leave for the river.

With all the different components and complexity of the balance of water in such a large and diverse landscape, water budgets can become quite detailed. For this study, we developed a simplified water balance that focuses on river flow through the Intermittent Reach:

Water for River = Flow at Canyon Mouth – (Loss to Groundwater + Evapotranspiration)

- The Flow at Canyon Mouth can be approximated using the abandoned gage information that was discussed earlier. The median annual volume is 2,353 acre-feet.
- Loss to Groundwater is not known. However, it appears to be a relatively significant part of the overall system based on the geologic studies that have been completed.
- Evapotranspiration in the Lower Segment can be approximated by the water used to irrigate land. The volume of Rio Fernando water that is allocated to the acequias is 3,195 acre-feet. Some portion of this water may be lost to the ground and may eventually return to the river, but those values are not known.

Considering that the estimated median volume from the Rio Fernando is lower than the volume allocated for the acequias, the challenge of maintaining flow in the river while also providing the water needed for irrigation is very evident. Similarly, the Mayordomo of Acequia del Sur del Cañon stated that the acequias usually do not divert their entire allotted amount because there is not enough water in the river (V. Fernandez, personal communication, December 4, 2023).

Further downstream, the flow of groundwater into the river becomes more dominant and return flows from irrigation may become more prevalent, which results in this part of the river becoming a gaining reach. However, the volume of groundwater inflow and return flows is unknown since it is not measured.

A subcomponent of the water balance is the volume that is pumped from wells for domestic use. This study did not go into detail determining flow from the hundreds of wells that are in the lower segment. (As mentioned previously, there are also numerous wells in the upper watershed that may be a factor.) Many of these wells take water from deeper bedrock aquifers, so their impact on river flow may be minimal overall. However, the increased well use in the Valley due to continued development likely contributes to water table lowering.

5 DISCUSSION & NEXT STEPS

RFdT is an important water resource to Taos residents and to the aquatic ecosystem. The river's lower section typically loses flow and can go dry in the summer, which negatively impacts aquatic and terrestrial species and the ecosystem overall. The challenge of water availability is a growing problem, particularly throughout the Western U.S. and other semi-arid regions of the world. Addressing this challenge is difficult and requires collaboration. Fortunately for the Rio Fernando de Taos, several non-profit organizations have been working to address various issues to improve the health of the watershed. Building on these relationships, the following recommendations describe potential future projects that can help improve conditions for this community and that work with both the natural and historical systems in the watershed.

5.1. Ecological Restoration

The watershed and river channel has suffered from overgrazing, pressure from recreation, fire suppression, and road development. There has been an alliance of organizations to improve the rivers' water quantity and quality, and the Rio Fernando de Taos Revitalization Collaborative was formed to revitalize the Rio Fernando de Taos along with efforts from other organizations including the Taos Valley Watershed Coalition (TVWC), Amigos Bravos, and the Taos Valley Acequia Association (Hooks, 2019).

5.1.1. Upper Watershed

The La Jara Wetlands Restoration Project is a great project example that showcases the collaboration between multiple organizations including Amigos Bravos, the Rio Fernando de Taos Collaborative, NM Game and Fish, Carson USFS, as well as the local communities along the river and acequia communities in Taos. Restoration work was completed in 2022 that benefits the health of the environment and downstream communities. The acequia communities were particularly interested in improving the health of the river upstream of their diversions to store water and extend the duration of spring runoff. In addition to helping the acequias, this work also benefits the ecological system. The restoration project addressed overgrazing and restored wetlands. The water stored in the wetlands is slowly released during late spring and early summer, which can help the river flow longer (Plant, 2022).

Implementation of similar projects that promote water storage in the upper watershed, including beaver-based restoration approaches, improve ecological health and increase wildfire resilience. Based on the results of this study, these types of projects are recommended to continue. Their location should be carefully considered to avoid areas that may have a more direct connection to the subsurface that would result in loss of the stored water.

5.1.2. Intermittent Reach along Los Pandos Road

Raising groundwater and increasing flow in the part of RFdT is challenging. Three basic approaches to have more water in the stream are as follows:

- Ponding through methods such as creating beaver ponds or regenerative channel design
- Recharging groundwater near the river channel using reclaimed wastewater and stormwater
- Increasing flow by letting more water downstream or supplementing with other sources

While full implementation of all three approaches may not be feasible, restoration of this reach is highly recommended and can help improve local conditions. The focus of this restoration should be establishment of a greenway that provides more room for the river, allowing modification of the river's cross section to better accommodate the range of flows (particularly low flows) and promoting infiltration along the Intermittent Reach. As part of the same grant that is funding this study, Amigos Bravos is already looking at alternatives to improve the Intermittent Reach where it parallels Los Pandos Road. These alternatives seek to provide trail access, improved road conditions, and storm water quality treatment. As part of this effort, Amigos Bravos is talking with Taos County to explore future improvement projects.

There is an opportunity to locate storm water management immediately adjacent to the channel to create a contiguous area that both buffers the river while providing a larger riparian habitat corridor. **Figure 14** shows a conceptual section to help demonstrate the main components of this potential greenway.

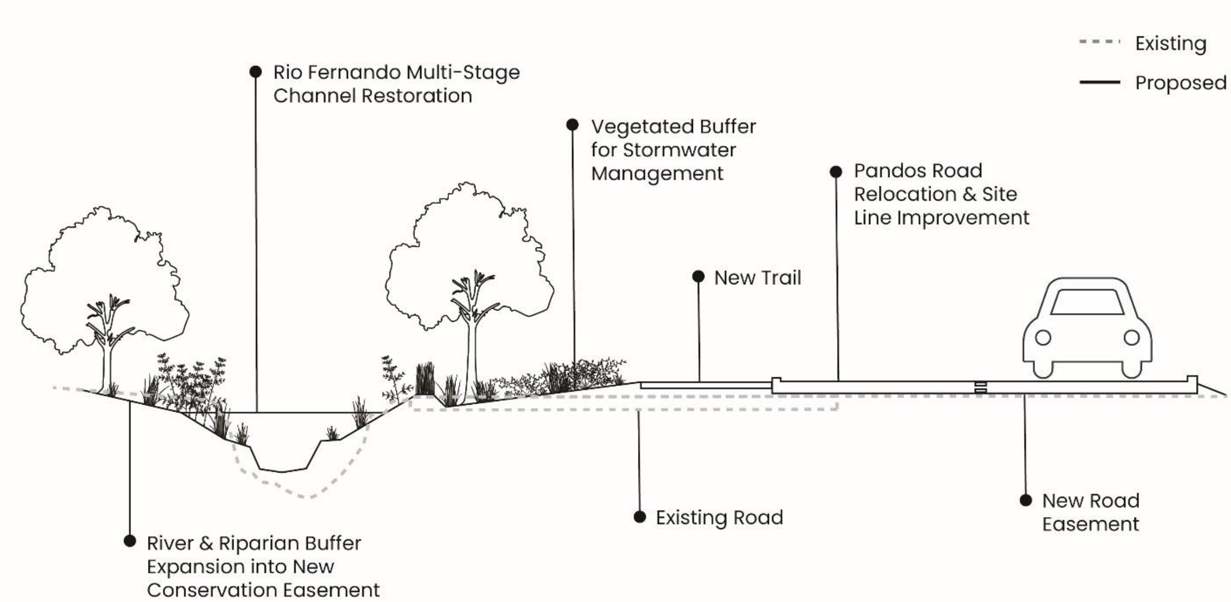

Figure 14. Conceptual alternatives for the Rio Fernando de Taos and Los Pandos Road greenway. Credit: Biohabitats

In conjunction with trail and road improvements, there is an opportunity to modify the cross section of the river channel to improve ecological conditions during lower flows. Due to the hydrologic impacts caused by the geologic conditions and the acequia diversions, the river is smaller through this section. Instead of the existing ditch-like trapezoidal shape, a multi-stage cross section that provides better low-flow habitat as well as conveyance of flood flows could be considered. This work would involve more detailed analysis of the range of flows that the channel needs to accommodate.

Additional components of the revitalization of the Los Pandos Road corridor could include the following items:

- The use of **easements** on the opposite (north) side of the channel. There are examples across the U.S. of conservation easements that can be used to expand the river buffer while paying landowners for the lost agricultural value.
- Establishment of an agreement for a **minimum flow** that would be allowed to remain in the Intermittent Reach. Even a very small flow would provide considerable benefits over no flow.

The next step to further explore this opportunity is to continue collaborating with Taos County and to complete a greenway assessment along this reach of the river. Cooperation with private landowners will be key to future success and should be a focus of these efforts.

5.2. Water Conservation

Past studies have mentioned improvements that could be made to the acequia system to better conserve water. They also recognize that seepage losses provide benefits, such as supporting riparian vegetation. Throughout the West, we have seen agricultural communities working to improve water conservation in their irrigation system through a modernization assessment and recommend that such an assessment be done for the Rio Fernando de Taos. It would entail investigating the movement of water through the system, including where it goes, where it is lost, the benefits that it provides, and the problems that it may cause. Based on this investigation, improvements to the system are developed and evaluated that can help make water management easier and more effective while, at the same time, preserving benefits that the water provides. Examples of the types of improvements that might be possible include a siphon pipe for Rio Pueblo water to cross the Rio Fernando, SCADA (Supervisory Control and Data Acquisition) technology with automation of gates, and other needed upgrades and longer-term maintenance issues for existing infrastructure.

5.3. Wastewater Treatment

The Rio Fernando has water quality impairment concerns that have been identified through frequent testing by Amigos Bravos. E-Coli is a constituent of concern and has been found in all three segments of the river (Amigos Bravos, 2019 p. 16). The source of E-coli has not been identified with precise confidence, but probable sources that have been recognized include cattle grazing and onsite wastewater septic systems. Other possible sources include wildlife and waste from pets. A comprehensive list of probable sources and the significance of E. coli on the impairment of the Rio Fernando is described in the 2019 Watershed Plan.

The residential water systems around the lower segment of the river are supported by decentralized onsite wastewater that are primarily comprised of septic tanks with leach fields. There are several factors that may contribute to E-coli entering groundwater and surface water from onsite septic systems. These systems require maintenance by the individual homeowner, and unmaintained systems can contribute to poor effluent quality. Additionally, onsite septic systems have a limited lifespan, and concrete tanks are vulnerable to leaks over time. However, there are various avenues to address the water quality concerns from onsite septic systems. Presented below are four general options for improving onsite septic system effluent water quality:

- **Regular maintenance** including pumping is important to maintain adequate treatment in the septic tank. This is a low-cost solution but may require homeowner education and incentives.
- **Small aerator units** can be installed to new or existing septic tanks that add oxygen to help break down organic constituents and treat nutrients. A product available on the market is called a SludgeHammer. This is an approved product by NMED and is a relatively cost-effective solution.
- A **separate secondary treatment unit** can be added after primary treatment to further remove organics and nutrients in the wastewater. Such systems are likely more costly, particularly for individual homeowners, but they can extend the lifespan of their leach field. Packaged units are available such as Orenco's Advantex system (textile filter), Delta's ECOPOD, as well as many others that have been approved by NMED.

- Residential homes can be connected to a **small community treatment system**. Each residential home would be equipped with a septic tank and the liquid portion (by either gravity or pump) is sent to a centralized facility for additional treatment. Small-diameter collection system or septic tank effluent pump (STEP) / septic tank effluent gravity (STAG) system are other names that refer to this type of approach. The wastewater undergoes further treatment at the centralized facility and is then discharged into the ground or to surface water. This option requires extensive engineering and would be the most expensive, requiring an external organization that funds and manages the system.

Further study is recommended to evaluate and recommend the most feasible solution. The Rio Fernando de Taos Revitalization Collaborative has identified this issue as a priority and expects to work with NMED to take an inventory of all the septic tanks along the river corridor and address the septic tanks that are out of compliance (such as tanks in the floodplain). Refer to Strategy 1.7 of the Rio Fernando de Taos Collaborative Plan on priority activities for this project.

5.4. Data Gaps

- Flow data for the river is a critical missing link to better understanding and managing the Rio Fernando de Taos. While continuous measurements of flow would be ideal, more simple periodic readings from staff gauges at key locations would be useful.
- Further analysis of the aquifer being used and of pumping volumes to better estimate the impact of wells on river flow.
- Groundwater monitoring to better understand fluctuations and levels over time.
- A better understanding of property boundaries, owners, and existing easements is necessary for carrying out a greenway assessment for the intermittent reach.

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FULL PAGE FIGURES

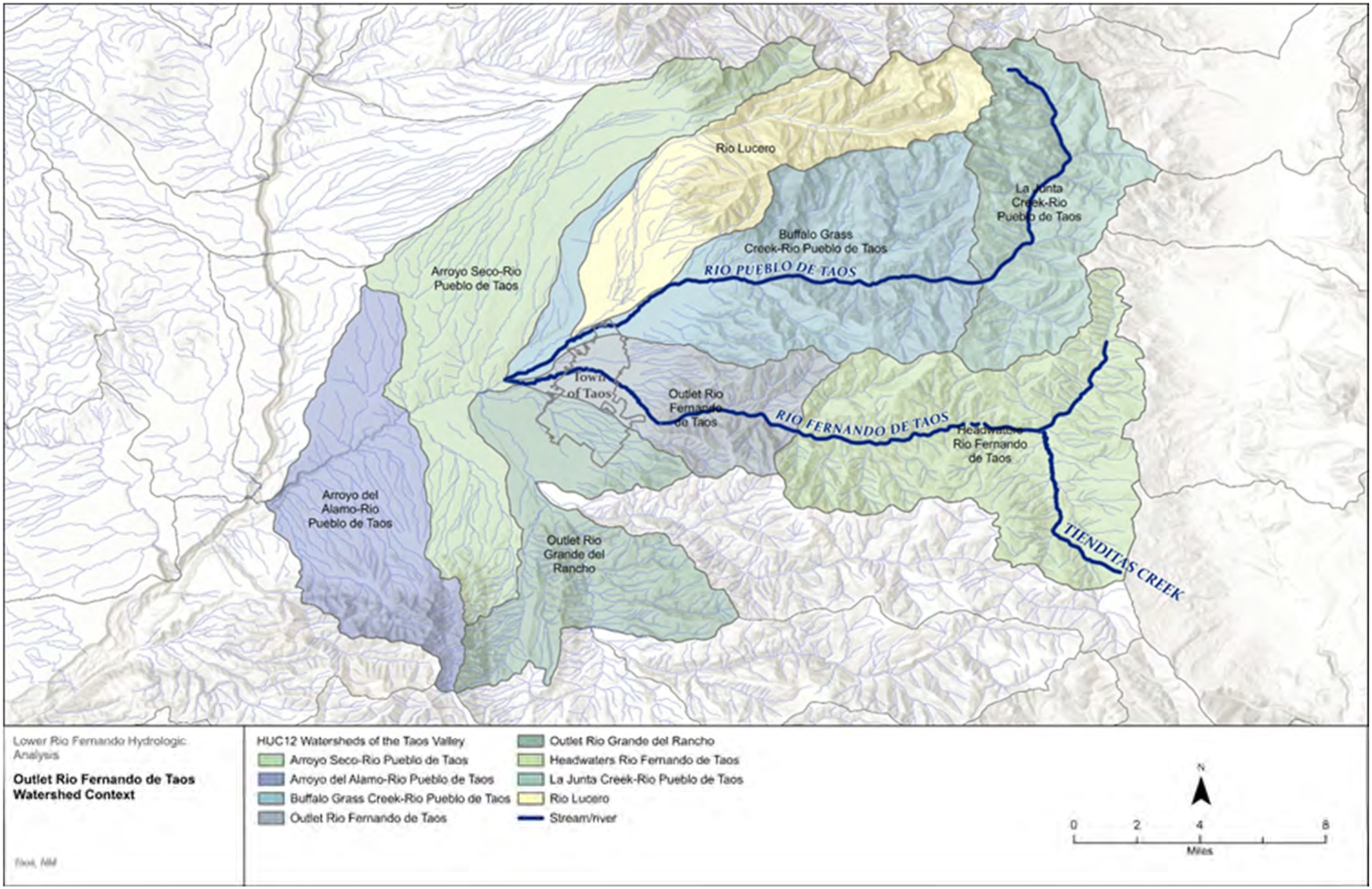

Figure 2. Watershed context of Rio Fernando de Taos and Rio Pueblo de Taos from headwaters to confluence

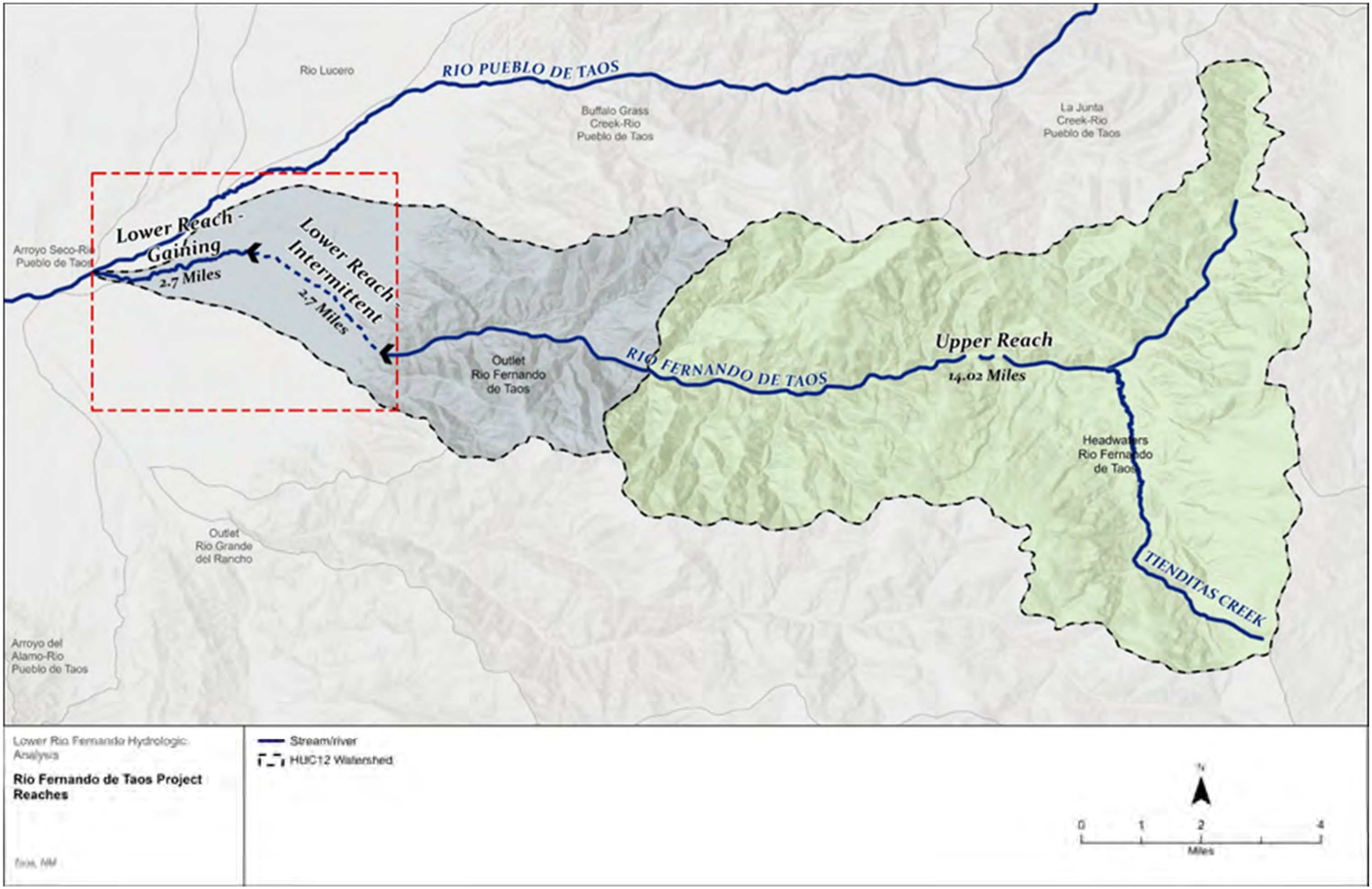

Figure 3. Extent of current study. Red dashed line indicates focus area in lower reach, which is subdivided into intermittent and gaining subreaches.

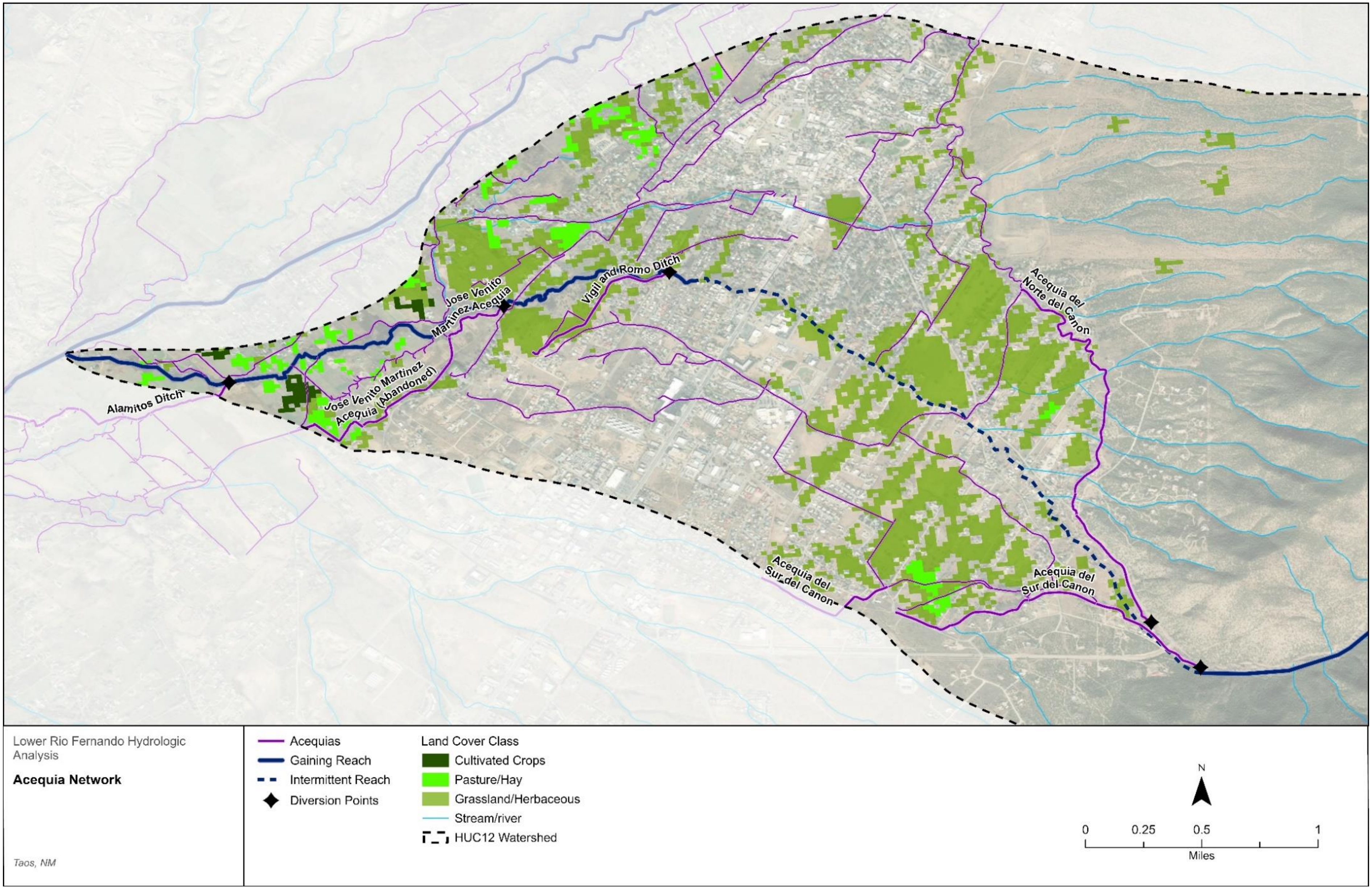

Figure 4. Acequia Network and Potentially Irrigated Lands.

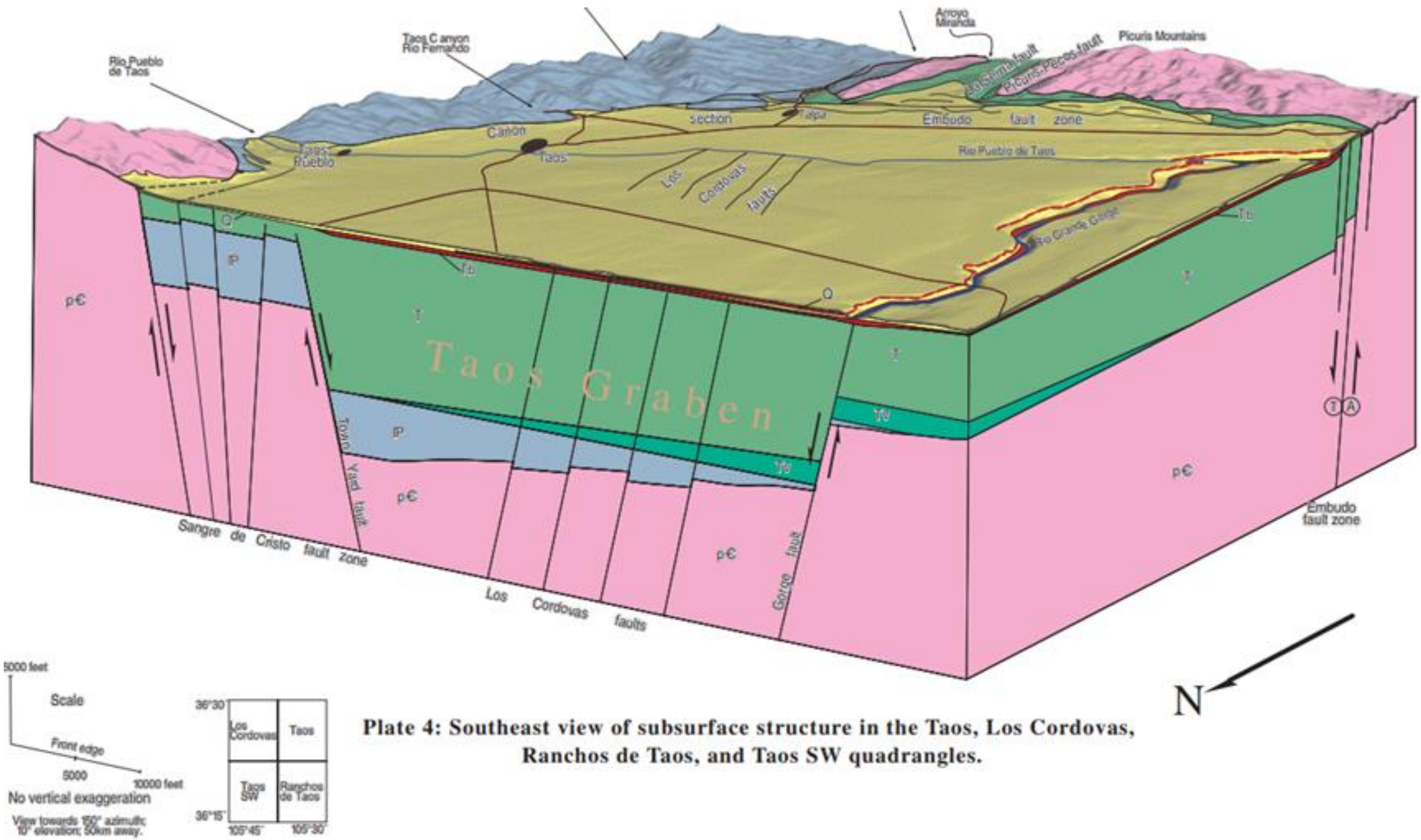

Figure 5. Taos graben. View is to the southeast. Source: Bauer and Johnson (1999)

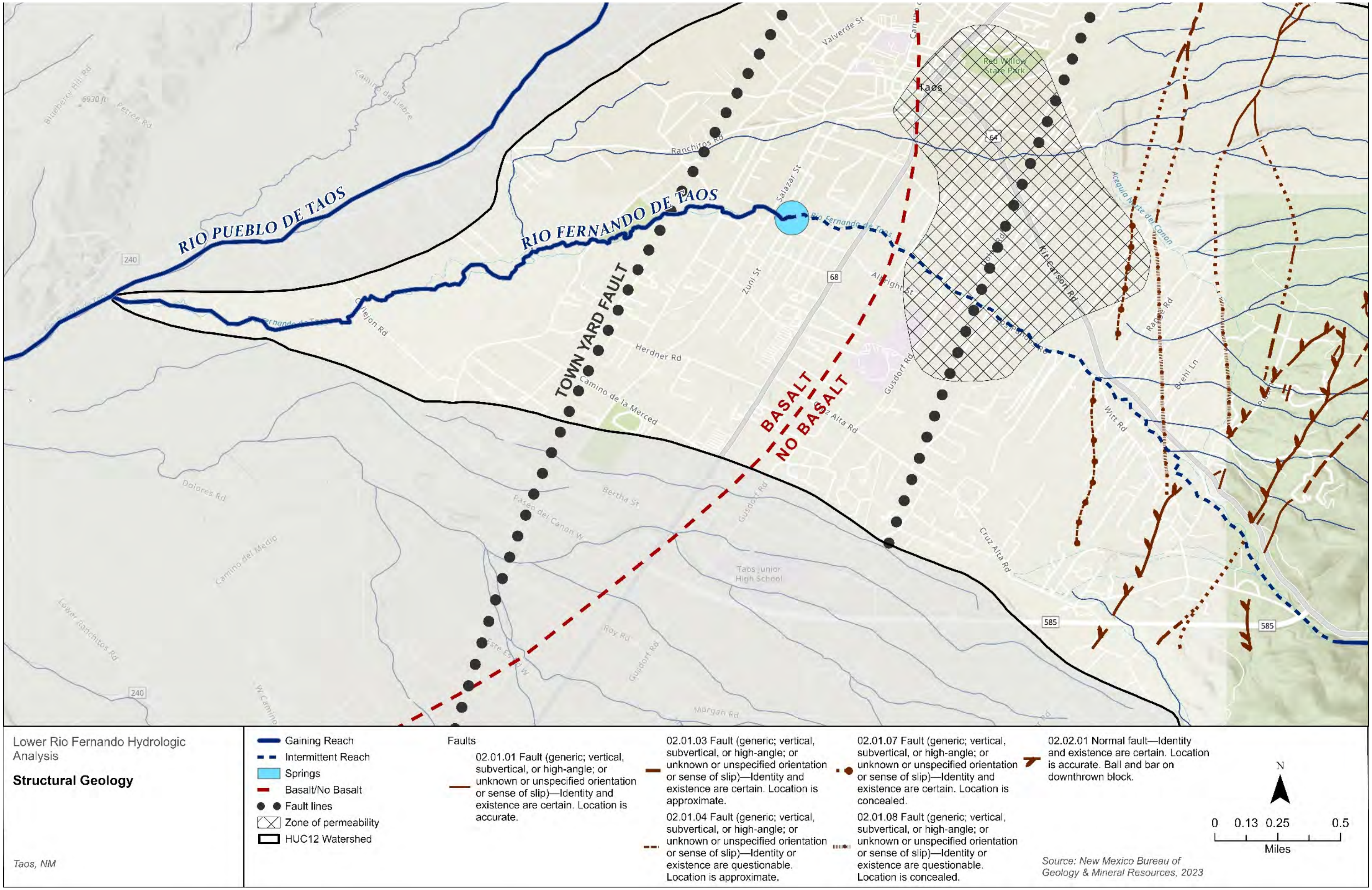

Figure 6. Structural Geology. No basalt is present east of the red line.

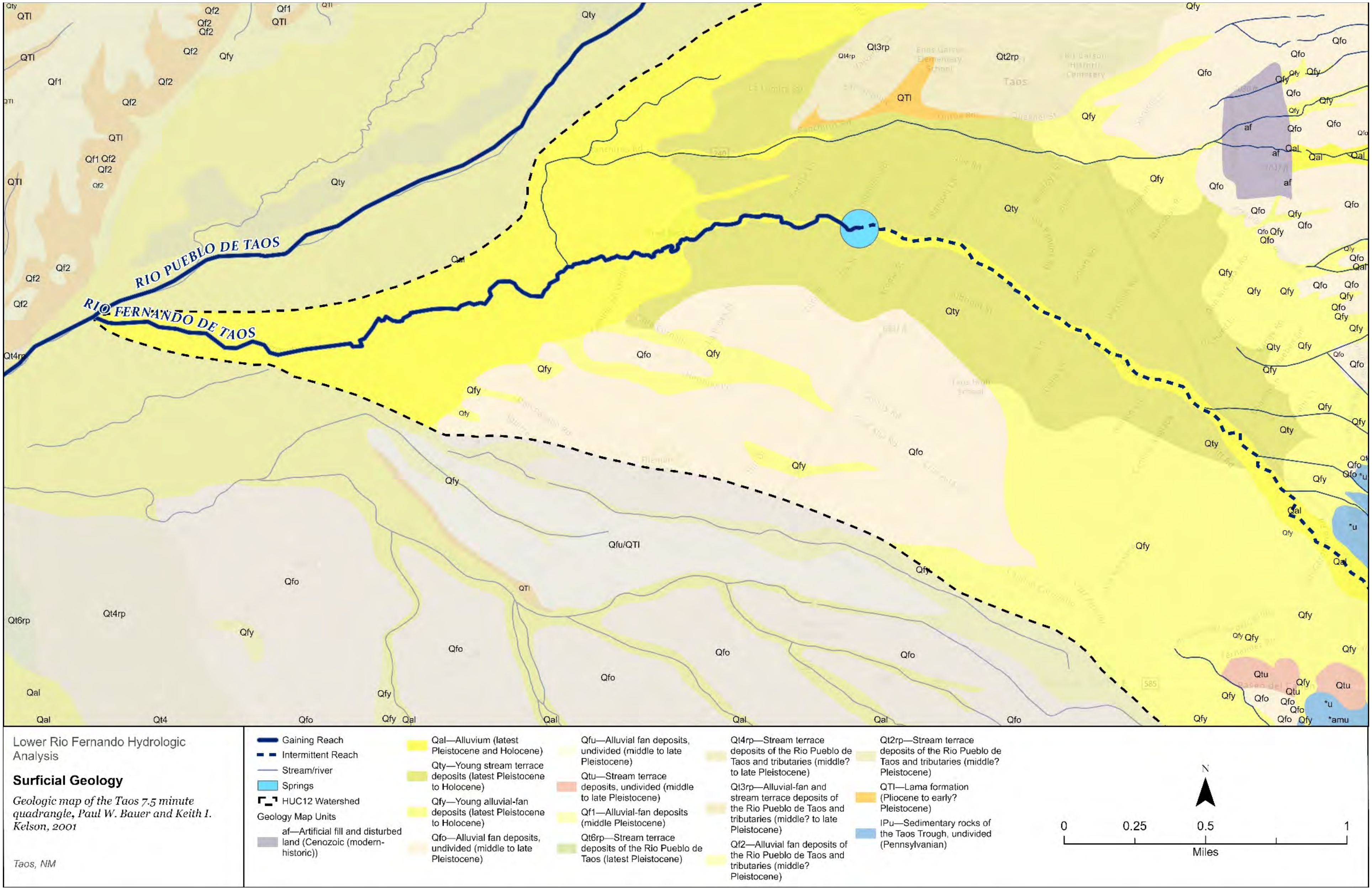

Figure 8. Geologic map of lower Rio Fernando de Taos watershed. Source: Bauer and Kelson 2001.

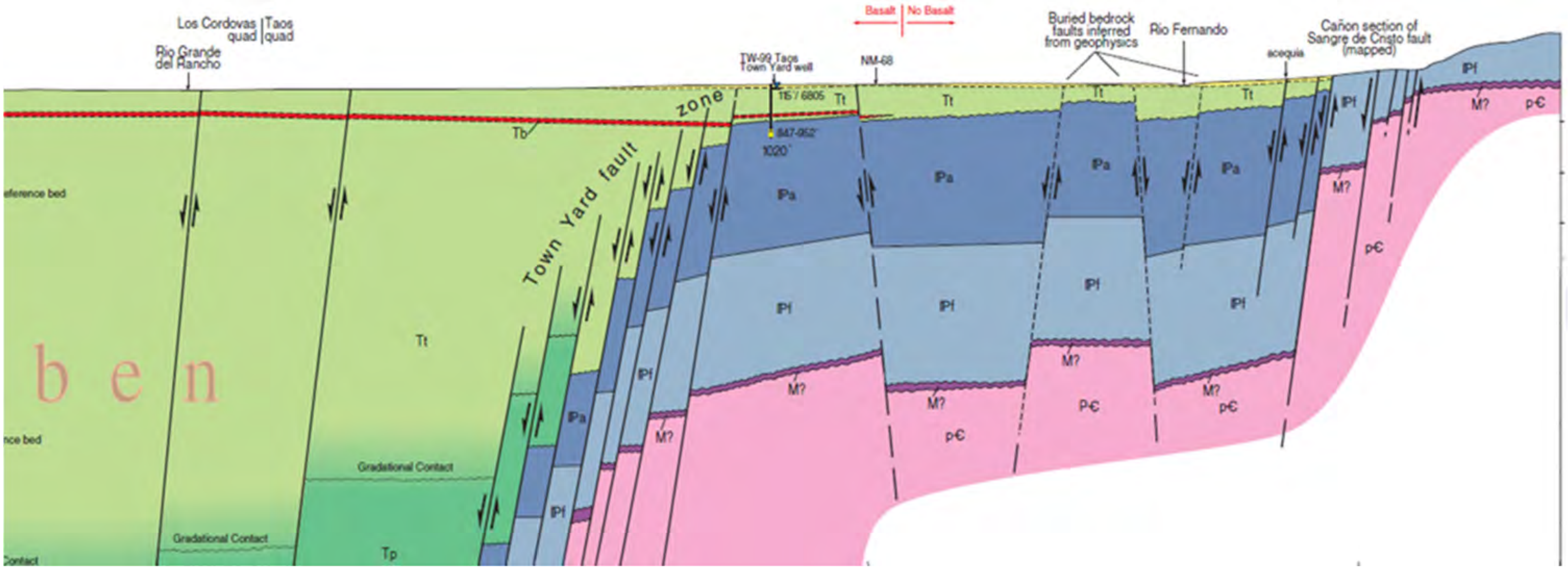

Figure 9. Cross-section of geology in vicinity of Rio Fernando de Taos. View is to the north. Note extent of basalt layer in red. Source: Paul W. Bauer and Peggy S. Johnson January 1999. Plate 1 Geologic cross section through Taos.

APPENDIX A DATA INVENTORY

DATA	DESCRIPTION	GEOMETRY	SOURCE	LOCATION	YEAR	NOTES
HUC12 Watersheds	HUC12 Watersheds surrounding the Rio Fernando De Taos and Rio Pueblo De Taos	Polygon	USGS National Hydrography Dataset (NHD)	New Mexico	20200615	
Rivers	River flowlines	Line	Rio Bravos	New Mexico	2023	Used for the Rio Fernando de Taos and Rio Pueblo de Taos centerlines
NHD Flowlines	Streams, rivers, and ditches	Line	USGS National Hydrography Dataset (NHD)	New Mexico	20200615	Used for all rivers and tributaries besides the Rio Fernando de Taos and Rio Pueblo de Taos centerlines
Level IV Ecoregions	Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources.	Polygon	Level III and IV Ecoregions of the Continental United States | US EPA	United States	20130416	
Terrain: Slope	Colorized representation of slope	Raster	Terrain: Slope Map - Overview (arcgis.com)	United States	2023	
NLCD Land Cover Classes	National Land Cover Databse	Raster	National Land Cover Database Class Legend and Description | Multi-Resolution Land Characteristics (MRLC) Consortium	United States	2021	
NWI Wetlands	National Wetlands Inventory	Polygon	USA Wetlands - Overview (arcgis.com)	United States	2023	
Diversion Points	River diversion points along the Rio Fernando De Taos	Point	Digitized based on intersections of major ditches along the Rio Fernando de Taos	New Mexico	2024	
Zone of Permeability	Zone of high transmissivity (from Spiegel and Couse, 1969)	Polygon	Digitized from "Geologic map and potentiometric surface map of the southern Taos Valley,"	New Mexico	1969	
Acequias	Acequias surrounding the Rio Fernando de Taos	Line	Taos	New Mexico	2023	
Surficial Geology	Geologic units and structural features in New Mexico	Polygon	https://maps.nmt.edu/ NMBGMR Interactive Resources Map	New Mexico	1997	
Wells	Wells within a 1000-ft buffer of the Rio Fernando de Taos centerline	Point	New Mexico Office of the State Engineer::Water Rights Reporting System	New Mexico	2022	
Basalt line	Subsurface limit of Servilleta Fm. Basalts inferred from boreholes	Line	Digitized from "Geologic map and potentiometric surface map of the southern Taos Valley,"	New Mexico	1999	
Gaining/Losing Reach	Gaining Reach and Losing Reach of the Rio Fernando de Taos main centerline	Line	Digitized from "Hydrologic Characteristics of Basin-Fill Aquifers" (Figure 5 of *HYDROLOGIC CHARACTERISTICS OF BASIN-FILL AQUIFERS IN THE SOUTHERN SAN LUIS BASIN, NEW MEXICO) https://uttoncenter.unm.edu/resources/ombudsman/pdfs/aquifer-description-summary.pdf*	New Mexico	2004	
Fault line	Fault inferred from air photography	Line	Digitized from "Geologic map and potentiometric surface map of the southern Taos Valley,"	New Mexico	1999	
Spring	Spring	Polygon	Digitized from "Geologic map and potentiometric surface map of the southern Taos Valley,"	New Mexico	1999	
Groundwater Contours	Groundwater elevation contours at 100ft interval	Line	Digitized from "Hydrologic Characteristics of Basin-Fill Aquifers" (Figure 5 of *HYDROLOGIC CHARACTERISTICS OF BASIN-FILL AQUIFERS IN THE SOUTHERN SAN LUIS BASIN, NEW MEXICO) https://uttoncenter.unm.edu/resources/ombudsman/pdfs/aquifer-description-summary.pdf*	New Mexico	2004	