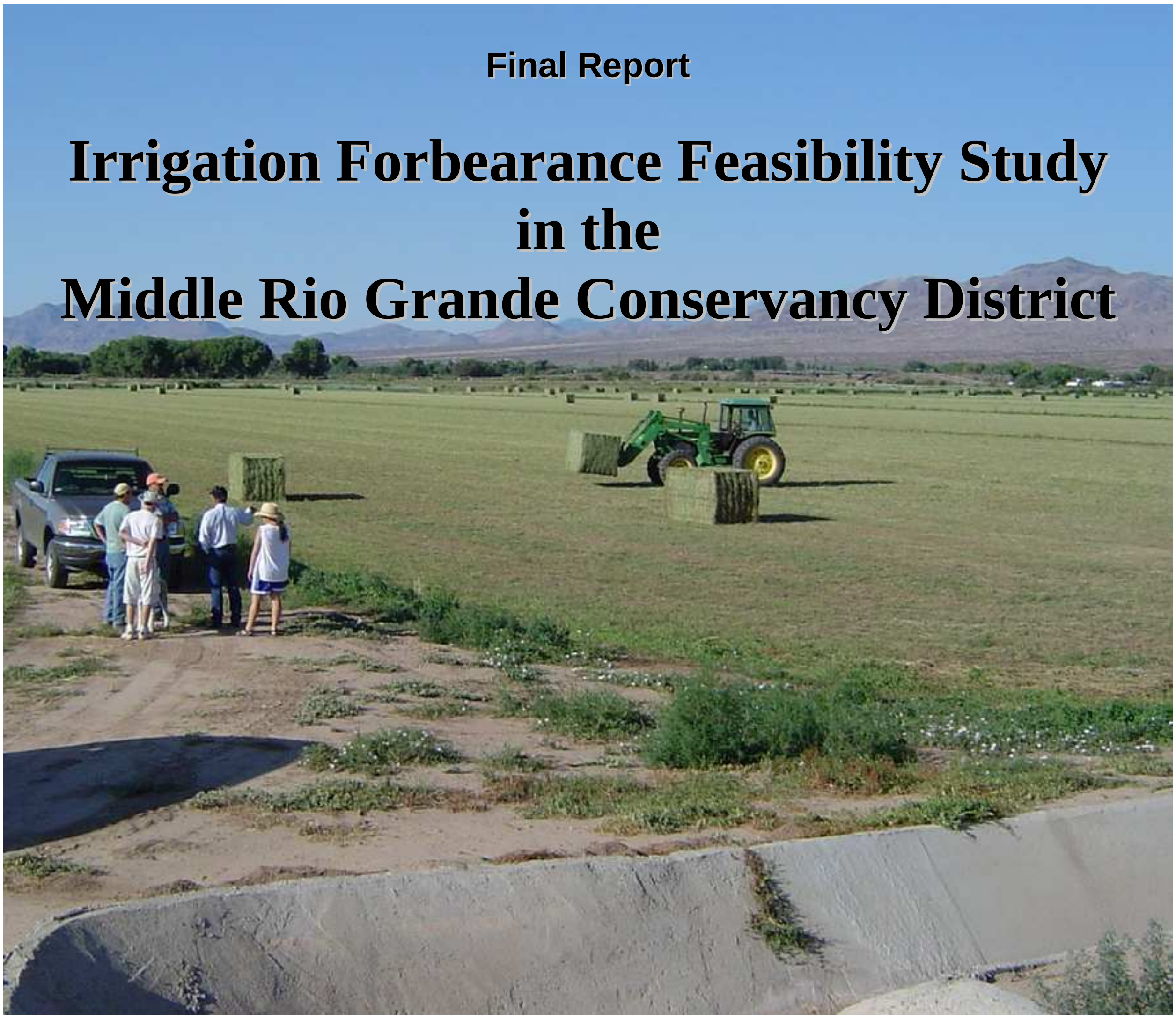
Final Report

Irrigation Forbearance Feasibility Study in the Middle Rio Grande Conservancy District



Prepared for MRGCD
by
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Executive Summary

This report, commissioned by the Middle Rio Grande Conservancy District (MRGCD), examines the hydrologic and practical aspects of implementing an irrigation forbearance program in the MRGCD to provide water for upstream storage. The objective of storing water upstream is to regulate it to maintain in-stream flow to support the recovery of the endangered Rio Grande Silvery Minnow.

Many practical obstacles exist to successful implementation of a forbearance program. Forbearance of canal water is especially complicated, compared to groundwater, since it can provide savings when a group of water users collectively forbear so that their lateral canal can be effectively closed and the associated losses reduced. As such, surface canal water forbearance programs will have elements of "management" as compared to complete voluntary programs. Ensuring or verifying that irrigators who agree to forbear actually do so is beyond the existing capabilities of the MRGCD and any other agency in the area. Irrigators may accept compensation for forbearance and continue to irrigate either from surface water or groundwater, and either will severely reduce the amount of water actually made available for upstream storage by forbearance.

Two major physical constraints on the storage of water made available for in-stream flow management through forbearance are the source and timing of irrigation water. The MRGCD's primary storage is El Vado Reservoir, located on the Rio Chama, a tributary of the Rio Grande. Only about one quarter of MRGCD's irrigation season flow comes from El Vado releases, and these releases are generally timed in the mid season. Flows from the main stem of the Rio Grande, or tributary flow from the Rio Chama below El Vado, cannot be captured in storage and regulated because there is no storage facility to catch them. The main stem Rio Grande water that is not diverted due to forbearance cannot be stored upstream if there is no simultaneous release from El Vado to reduce accordingly. This limited access to storage significantly reduces the quantity of water that can actually be stored upstream resulting from forbearance within MRGCD.

Upstream storage of forborne water has real institutional problems associated with it as well. The Rio Grande Compact restricts storage in post-Compact reservoirs, including El Vado, when the usable water downstream in the Rio Grande Project falls below 400,000 acre-feet. The usable storage has been below that level for most of the past two years or so, and continuing drought may limit the legal ability to store and regulate water in El Vado even if irrigation forbearance does make it available. Also, equivalent of all forborne water would need to come from San Juan-Chama water. But, in reality, irrigated lands in MRGCD receive only a portion of their water from Rio Chama (25-40%) This could adversely affect the non-forbearing water users, since there would be less stored water for critically short times.

The existing riparian ecosystem of the Middle Rio Grande extends far from the river due to the diversion, conveyance, farm application, and return flows associated with irrigation by MRGCD constituents. Large-scale or concentrated forbearance may have negative impacts on riparian habitat for avian, terrestrial, and aquatic species, including the Rio Grande Silvery Minnow that forbearance is intended to benefit.

From a purely hydrological analysis point of view, between 3.26 and 4.80 acre-feet of water per acre of forbearing land can be made available for storage upstream without adversely affecting other irrigators and deliveries to Texas downstream. Due to the impracticality of getting an entire division to forbear, we recommend that, if forbearance is pursued, the best approach is to try to get all irrigators on a lateral to forbear, thus closing that lateral for the season. The yield from such an approach will be about 4.36 acre-feet of water per acre of forbearing land (assuming 50 % return flow efficiency in the irrigation system). Access to and availability of storage capacity will further reduce this amount. About 14% of the cropped land in MRGCD service area would need to forebear to make available sufficient storage to release appropriate in-stream flow (100 cfs for six months).

I. Introduction, Problem Statement, Scope and Limitations

1. Problem Statement

The Middle Rio Grande Conservancy District (MRGCD), located along the Rio Grande in central New Mexico, commissioned this report to assess the potential for reducing diversions from the Rio Grande through irrigation forbearance. The ultimate objective of reducing irrigation diversions is to have more water available in upstream storage to manage and maintain in-stream flows in critical river reaches.

Water use and management are extremely contentious issues in New Mexico. The complex hydrology of highly interactive surface and ground water systems, years of tradition and cultural evolution, wild swings in water supply, and booming population growth make the Middle Rio Grande a fascinating, but baffling area for study. We hope in this report to, as Albert Einstein recommended, “make things as simple as possible, and not one bit simpler.”

The Endangered Species Collaborative Program (the Program) in the Middle Rio Grande is investigating options for maintaining adequate stream flows in the river for endangered fish species. One proposed option by the program is to ask the present irrigators to voluntary give up or ‘forbear’ their use of water. This forborne water could be held in an upstream reservoir and used to manage instream flows to assist in the recovery efforts for the endangered species.

The Rio Grande is the major river in the Chihuahuan Desert, and it supports a dynamic diverse ecologic system including fish and wildlife habitat. Agriculture, in general, diverts large quantities of river water, which is believed by some to leave insufficient water to sustain suitable fish habitats. In the case of the Middle Rio Grande, a large portion of the river diversion subsequently returns to the river. These ecological concerns are common to many major river basins in the western United States, including the Middle Rio Grande Basin, where competing water resources interests include irrigated agriculture, interstate and international compact delivery requirements, municipal and industrial growth, and environmentalists. Two wildlife species in the Middle Rio Grande valley, the Rio Grande Silvery Minnow and the Southwestern willow flycatcher are federally listed endangered species (Rinkevich and Leon, 2000).

Irrigation forbearance is one option for MRGCD to reduce its water diversions from the river. It involves voluntary reduction or giving up the use of water by some of the cultivators. A farmer could give up the use of water and fallow his/her land for one or more seasons or permanently, and reassign the allocated water to other in-stream uses. The "forborne" water secured through such a program can, if permitted and if storage space is available, be stored in an upstream reservoir and released to supplement the river flow during critical periods for the benefit of fish habitat. The forbearance concept appears somewhat similar to the Set-Aside program under the Federal Farm Bill. The set-aside program pays farmers not to cultivate part of their landholdings for the purpose of supporting commodity prices. There are important differences, however. The benefit of each land set-aside is cumulative irrespective of the location of the land parcel that is retired. For surface water forbearance to yield benefit, location of the landholdings that want to forbear is very important because of the hydrologic connectivity of a gravity riparian irrigation system

2. Scope and Limitations

To assess the amount of water made available for upstream storage by forbearance in riparian irrigation systems, the complex hydrology (e.g. diversions, transit loss, return flows, etc.) associated with the water flow must be considered. Therefore, the goal of evaluating irrigation forbearance and water transfer to in-stream flows, involves at least four major tasks:

- An assessment of habitat water requirements, including an estimation of how much additional water is required for maintaining desirable stream flow and suitable habitat. This feasibility study of irrigation forbearance does not include any assessment of the management or water requirements for endangered species recovery.
- A hydrologic assessment, including the basin wide effects of irrigation forbearance and its ability to yield an adequate amount of water for the river habitat needs. In this assessment, we quantify the amount of water saved for upstream storage and instream flow management if scattered individuals agree to forbear (the checkerboard scenario), if all irrigators on a lateral agree to forbear, and if all irrigators in an entire division agree to forbear.

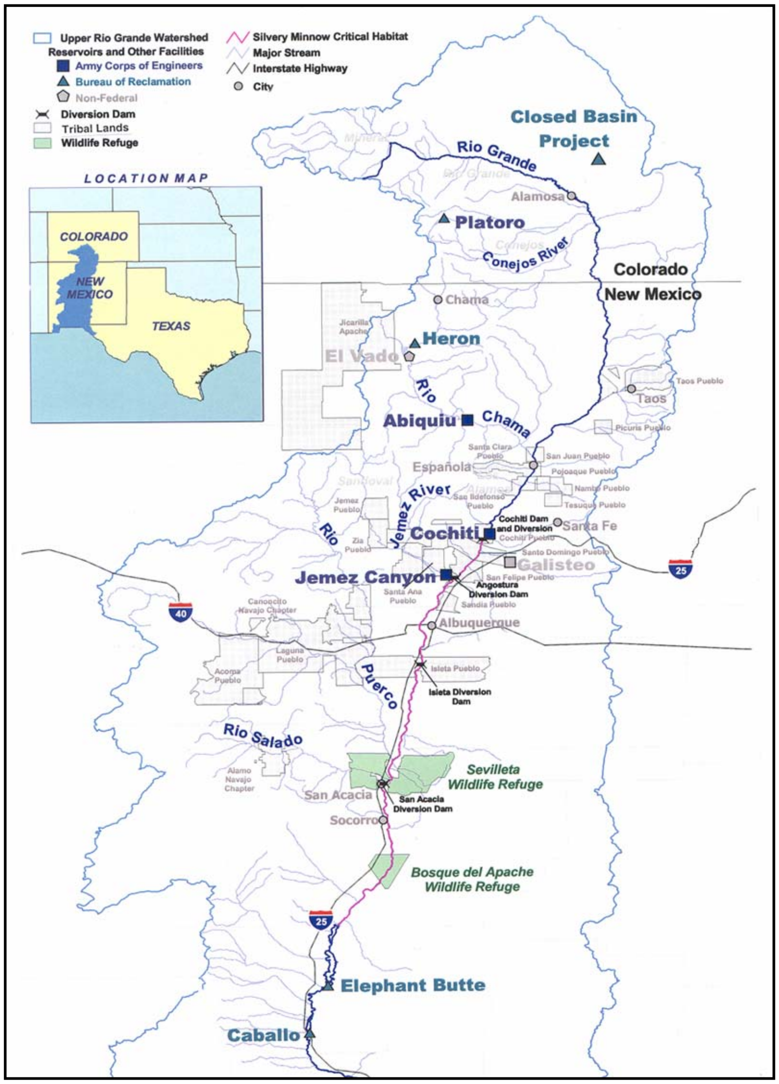
- A socio-economic assessment: The most important consideration here is to determine the fair compensation for the irrigators who choose to forbear irrigation. Also, what compensation would the Program provide to MRGCD for its increased management expenses in implementing the forbearance program? Identification of irrigators/water users who would like to participate in the program would be another important aspect of this assessment. We do not perform an in-depth economic analysis, though based on our experience in the MRGCD and discussions with irrigators; we do address some of their thoughts on the concept.
- Identify and address the operational level impediments to implementation of a successful forbearance program. We discuss these impediments in this report, though we do not have complete solutions for all of them.

This feasibility study is primarily focused on the hydrologic assessment. It will identify related institutional and organizational constraints, but the main scope is to investigate whether the forbearance program is feasible from a hydrological view point, and determine how much land must forbear to yield a target volume of water in upstream storage.

II. Description of the Middle Rio Grande Valley and the District

1. Middle Rio Grande Valley

The Middle Rio Grande (MRG) Valley runs north to south through central New Mexico from Cochiti Reservoir to the headwaters of Elephant Butte Reservoir, a distance of approximately 175 miles. The valley is narrow with major surface water features confined to within five miles on either side of the river (other than ephemeral arroyos). The *bosque* or riparian forest of native and exotic tree species is supported by waters of the Rio Grande and return flows from MRGCD. It is very different from the more desert-like conditions above the valley floor. Although the valley receives less than 10 inches of rainfall annually, the Rio Grande supports a rich and diverse ecosystem of fish and wildlife as well as a common property resource for communities in the region.



Water supply available for use in the MRG Valley includes native flow allocated according to the Rio Grande Compact of 1938, San Juan-Chama (SJC) trans-mountain diversion, tributary inflows and groundwater gains. Recent findings show that, on average, water supply in the region is barely adequate to meet present and future demands. Not only is the water supply fully appropriated in the region, but also priority of use has not been determined through the adjudication process (Hernandez, 1997).

Native flow: Water is fully appropriated in the MRG Valley and its utilization is limited by the Rio Grande Compact. The Compact sets forth a schedule of deliveries of native Rio Grande water to New Mexico from Colorado and to Texas from New Mexico. New Mexico's obligation to deliver water to Texas is determined using gauged flow on the Rio Grande at Otowi Bridge (near San Ildefonso Pueblo), is adjusted in accordance with Compact provisions and is delivered to Texas at San Marcial gauge as measured at Elephant Butte Reservoir. The water obligation to Texas is a percentage of the water flow passing Otowi Gage and is determined on a sliding scale. For example, in an average year when 1,100,000 acre-feet of water passes Otowi Gage, 707,000 acre-feet must be delivered at the Elephant Butte Reservoir (Rio Grande Compact Commission, 1997). According to the sliding scale, the maximum amount of native flow that is available for use in the MRG Valley is limited to 405,000 acre-feet/year (Rio Grande Compact Commission, 1997).

Groundwater: Groundwater supply in the region is currently derived primarily from stream-connected aquifers. In the vicinity of Albuquerque, the once stream-connected aquifer has been disconnected from the river as a result of pumping, estimated at 156,000 af/yr. Groundwater does not represent an additional source of supply, since the groundwater withdrawals ultimately result in river depletions and because river flows are considered fully appropriated.

Trans-mountain diversion: The U.S. Bureau of Reclamation (USBR) began diverting water from tributaries of the San Juan River in the Colorado River Basin in 1971, through the San Juan-

Chama Project (SJC). The SJC trans-mountain diversion provided an average of 75,844 ac-ft/yr from 1990 to 1998 to users in the MRG Valley, including the MRGCD and the City of Albuquerque.

Water demand in the MRG Valley includes the Rio Grande Compact delivery requirements for delivery to Texas and southern New Mexico, urban and industrial consumption, Endangered Species Act (ESA) requirements, and irrigated agriculture in the MRGCD including six Indian pueblos. In addition to these demands, there are significant consumptive uses associated with riparian vegetation, and wetland and reservoir evaporation (Action Committee of the MRG Water Assembly, 1999).

Sunday, June 29, 2003 Albuquerque Journal

Group Discusses Solutions to Water Shortage

By Dan McKay
Journal Staff Writer

On a recent Saturday, in a conference room at the Intel plant near Rio Rancho, 30 volunteers and experts pushed the Middle Rio Grande Valley a little closer to a sustainable water supply. The bottom line is figuring out how to balance the region's water use with the renewable supply. So far, the Middle Rio Grande Valley is "overspending" its water supply by 18 billion gallons a year, or about 55,000 acre-feet, according to the assembly. The conservation ideas are aimed at bridging the gap between the region's annual water use and its available supply. The planning effort — which roughly covers Bernalillo, Sandoval and Valencia counties — is required by the state Legislature. The draft being discussed includes:

- Turning the bosque into a mosaic of grasses and cottonwoods, with thirsty non-native underbrush removed.
- Importing and treating water from the salty aquifer in the Tularosa basin by 2020. The desalinated water could be piped to El Paso, with New Mexico getting credit for it under the Rio Grande Compact.
- Lining 150 miles of irrigation ditches with concrete, which reduces water lost to seepage.
- **Reducing land irrigated for agriculture by 25 percent to 30 percent by 2050. That's an estimate of what the groups expect to happen, not necessarily a recommendation**.
- Converting the lawns for 30 percent of existing homes and commercial properties to low-water-use xeriscapes.
- Storing more water in upstream reservoirs, where the evaporation rate isn't as high.

Rio Grande Compact: The annual yield from the Rio Grande is allocated among States according to an equitable apportionment for use described in the Rio Grande Compact and supporting documentation (National Resources Committee. 1938). Water depletions in the MRG Valley are limited by the State of New Mexico to ensure that Compact obligations to Texas are met. The Compact limits the amount of debit or under-delivery of water to downstream States. Colorado is prohibited from accruing a debit greater than 100,000 acre-feet to New Mexico, while New Mexico is limited to accruing a debit of 200,000 acre-feet to Texas. Drought conditions over the last several years, in combination with changes in river operations due to ESA requirements, have reduced the stored water supply available for irrigation and other uses in the valley. Under these conditions, Article VII of the Rio Grande Compact, which is presently in effect, prohibits water storage in reservoirs above Elephant Butte Reservoir that were constructed after 1929.

Article VII of the Rio Grande Compact states that:

> *Neither Colorado nor New Mexico shall increase the amount of water in storage in reservoirs constructed after 1929 whenever there is less than 400,000 acre feet of usable water in project storage; provided, that if the actual releases of usable water from the beginning of the calendar year following the effective date of this Compact, or from the beginning of the calendar year following actual spill, have aggregated more than an average of 790,000 acre feet per annum, the time at which such minimum stage is reached shall be adjusted to compensate for the difference between the total actual release and releases at such average rate; provided, further, that Colorado, or New Mexico, or both, may relinquish accrued credits at any time, and Texas may accept such relinquished water, and in such event the state, or states, so relinquishing shall be entitled to store water in the amount of the water so relinquished.*

In a general sense, Article VII, when in effect, prohibits storage of native Rio Grande water for use in the MRG Valley unless the amount of usable water available for users downstream of Elephant Butte Reservoir is above 400,000 acre-feet. ***Article VII requirements will therefore present a major institutional constraint for effective implementation of irrigation forbearance***. It will not allow storage of the forborne water and its subsequent use in the MRG valley unless New Mexico relinquishes a like amount of credit in Project Storage, or until enough water is available for the downstream users to deactivate Article VII.

Urban and Industrial: In 2000, there were approximately 690,000 inhabitants in the MRG Valley, about 38 percent of New Mexico’s entire population (USGS, 2002). Population has increased steadily since the 1950’s and has been supported through development of the SJC project and increased groundwater pumping in the vicinity of Albuquerque. A shift from rural to urban water use in municipalities and non-agricultural industries has increased groundwater demand in the region (Hansen and Gorbach, 1997). Although groundwater currently supports urban and industrial demands in the region, groundwater withdrawal is an unsustainable means of supporting future populations, as it borrows water from a fully appropriated river with downstream delivery obligations.

Endangered Species Act: The Rio Grande Silvery Minnow (RGSM, *Hybognathus amarus*) has been listed as a federally endangered fish species since 1994 (USFWS, 2002). It is believed that the RGSM existed on the Rio Grande upstream of Cochiti Reservoir, in the downstream reaches of the Chama and Jemez Rivers and throughout the Middle and Lower Rio Grande Valleys to the Gulf of Mexico (Wilber, 2001). Extirpated from over 95 percent of its historic range, wild populations of the RGSM are found only in the MRG Valley (USFWS, 2003c).

Adult RGSM are small, reaching no more than 4 inches in length. Spawning activities require relatively high flow conditions during spring runoff and adequate temperatures, as fertilized eggs are semi-buoyant and must drift for a significant time before larvae hatch (USFWS, 2002). Habitats utilized by adult RGSM are primarily low velocity areas such as eddies, pools, debris piles and backwaters. According to the USFWS, water management and use in the MRG Valley has resulted in a large reduction of suitable habitat for the RGSM (USFWS, 2003b; USFWS, 2003c). The USBR and the U.S. Army Corps of Engineers (ACOE), in consultation with the USFWS, have developed water operations and river maintenance procedures in various Biological Assessments and Opinions that are believed necessary for the recovery and survival of the RGSM (USFWS, 2003b; USFWS, 2003c). These procedures include: instream flow requirements at various river reaches, timing of instream flow requirements and habitat improvements necessary for the RGSM (USFWS, 2003b). The final designation of critical habitat for the RGSM was issued in March 2003. The significance of the final designation of critical habitat is that Federal agencies, the State of New Mexico and the MRGCD are expected to take actions that will assist in the survival and recovery of the species and the ecosystem upon which the species depends.

2. The Middle Rio Grande Conservancy District

Historical Background and Water Rights

The MRGCD was formed in 1925 in response to flooding and the deterioration of irrigation works (Shah, 2001; NRC 1938). Irrigation in the Middle Rio Grande Valley, however, is much older dating back to at least 1700s and perhaps earlier. Although MRGCD attempted to provide benefits of irrigation, drainage and flood control, by the 1940's the MRGCD was financially unstable and in need of further rehabilitation. In 1950, MRGCD entered into a 50-year contract with the USBR to provide financial assistance and system rehabilitation (Middle Rio Grande Project). System improvements occurred until 1975 when MRGCD resumed operation and maintenance of the system. In 1999, MRGCD completed repayment of loans to the USBR.

The MRGCD holds water permits with the New Mexico Office of the State Engineer for storage in El-Vado Reservoir and irrigation of 123,267 acres. Of this total, 53,926 acres predated the establishment of the MRGCD, 26,859 acres MRGCD claimed in its 1930 survey but did not irrigate due to high groundwater tables and 42,482 acres MRGCD intended to develop and render irrigable. The USBR Crop Production and Water Utilization Data (1991-1998) indicate that MRGCD irrigates about 54,500 acres, but MRGCD claims irrigation of approximately 63,000 acres including the Pueblo lands. Irrespective of the actual amount of irrigated land, MRGCD is taking a proactive approach in exploring whether voluntary forbearance can help reduce water diversions from the river and thereby allow better management of in-stream flow using reservoir storage and release.

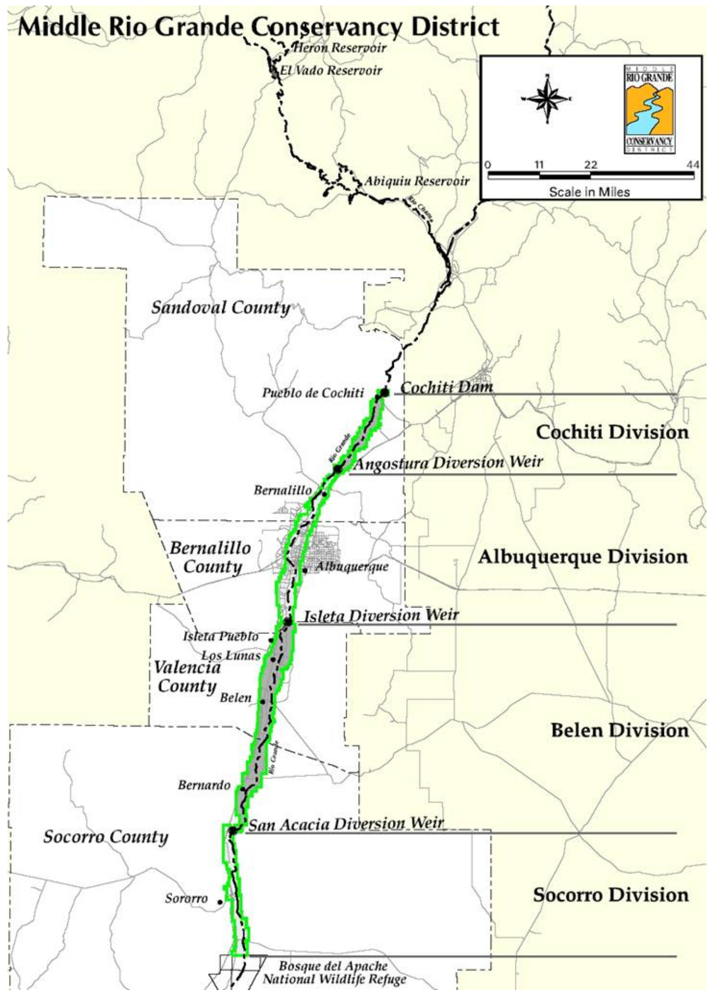
As mentioned, MRGCD holds two permits with the Office of the State Engineer – 0620 and 1690 – filed in 1930. These permits allow for storage of water in El Vado reservoir, release of the water to meet irrigation demand, and diversion from the Rio Grande river to irrigate the lands served by MRGCD. Water diverted by MRGCD originates as native flow of the Rio Grande and its tributaries, including the Rio Chama. It has a contracted right to about 20,900 acre-feet annually from the San Juan-Chama Project that diverts water from the Colorado River. MRGCD stores water upstream in El-Vado reservoir, which has a present storage capacity of about 180,000 acre-feet. This is the reservoir that would be potentially used to store the forborne water. Also, there is a recent agreement with the City of Albuquerque for MRGCD to store water in the Abiquiu reservoir.

Physical System

The MRGCD serves irrigators from Cochiti Reservoir to the Bosque del Apache National Wildlife Refuge. Irrigation facilities managed by MRGCD divert water from the river to service agricultural land. Irrigated lands include small scale urban landscapes as well as large scale production of alfalfa, pasture, corn and vegetable crops. The diversity of users includes six

Indian pueblos, community ditch associations, large scale farmers, independent *acequia* communities and urban landscape irrigators.

The MRGCD supplies water to its four divisions, Cochiti, Albuquerque, Belen and Socorro, through Cochiti, Angostura, Isleta and San Acacia diversion structures, respectively. In addition to direct diversions at these structures, all divisions except Cochiti receive return flow from divisions above. These return flows are conveyed through riverside drains and are eventually diverted into a main canal for reuse in the MRGCD or are returned to the river. Although drains were originally constructed for the purpose of collecting excess water from the agricultural lands, many now serve as interceptors of return flow and provide a source of interdivisional water supply.



The Cochiti division is primarily Pueblo lands, which are managed by the Pueblos' own ditch-riders. MRGCD has few ditch-riders in the Cochiti Division for managing the non-Pueblo lands. The Albuquerque division services primarily small-scale urban water users, but some large-scale and Pueblo water users irrigate in the northern and southern boundaries of the division. The Belen division is the largest division in terms of service area, and irrigates small-scale, large-scale, and Pueblo water users. The Socorro division is relatively small but serves entirely large-scale water users.

Water is delivered to users in a hierarchical manner; it is typically diverted from the river into a main canal, to secondary canal or lateral, and eventually to the farm. The conveyance system in

MRGCD is primarily earthen. Concrete lined canals and pipe networks exist in few areas where bank stabilization and water seepage problems are prevalent. After water is conveyed through laterals, it is delivered to the farm through a turnout structure, often with a check structure in the lateral canal. On-farm water management is entirely the responsibility of water users and the method of application is surface irrigation, either basin or furrow.

Organization and Water Delivery

The MRGCD delivers water to users through services and administration provided at a central office and four division offices. The central office provides many administrative services, including management of service charges to water users. Each division office includes administrative, field maintenance and water operation services. A division manager and several ditch-riders manage water delivery operations in each of the four divisions. Ditch-riders are responsible for the distribution of water to users in a particular service area. The ditch-rider controls check structures and head-gates, using local knowledge of the distribution system and irrigator needs to deliver water. Ditch-riders evaluate water delivery and water use conditions through physical monitoring or “riding” of ditches and laterals and through communication with water users.

Sunday, May 30, 2004 Albuquerque Journal

Water Spigot Tightens

By Tania Soussan
Journal Staff Writer
The Middle Rio Grande Conservancy District has been called one of the most wasteful irrigation districts in the West, vilified by environmentalists for how much water it takes from the river. But things have changed and the district deserves praise, said hydrologist David Gensler. Greater efficiency has come with the installation of dozens of gauges and automated dam gates, he said. "It's not business as usual. We've made changes," Gensler said. "I think we're on the way to becoming a very efficient irrigation system."

The bottom line is a roughly 40 percent decrease in total diversions from the Rio Grande. The drop is from around 600,000 acre-feet in the late 1990s to about 320,000 acre-feet last year. Others agree the conservancy district has made strides toward efficiency. "The steps that MRGCD have made are just stunning in terms of their willingness to move forward and implement the sort of tools that are called for in Water 2025," said Assistant Interior Secretary Bennett Raley, referring to the department's program to address water problems in the West.

Now, the district's 150 miles of river and 1,200 miles of canals boast 67 state-of-the art gauges. Another 11 are in the works. The new gauges are computerized and transmit data through a radio connection every 30 minutes to a computer in the district office. The information also is available on the Internet. Metering the water flows in and out of the Rio Grande has taught the district how to improve its operations so it can take less water out of the river yet still give farmers full supplies— a vital skill in times of drought and battles over water for endangered species, such as the Rio Grande silvery minnow. Water flowing into the Peralta Main Canal at Isleta, for example, was cut by about half after Gensler installed a gauge and tracked the new data. In the late 1990s, about 315 cubic feet per second of river water was flowing into the canal. Every night when the farmers stopped irrigating, the flows back into the river at the bottom of the canal would jump up to 150 cubic feet per second. That told Gensler way too much water was being pulled out of the river, so the district cut the diversion to 180 cubic feet per second or less and put farmers on a rotation schedule where some irrigate their fields at night. Making the district more efficient also allows it to have longer irrigation seasons when water supplies are short and help keep water in the river for the silvery minnow, added Rolf Schmidt-Petersen, Rio Grande basin manager for the New Mexico Interstate Stream Commission.

"I see it as a good thing," he said. "They've done quite a good job and I hope they continue."

The MRGCD does not meter individual farm turnouts, rather they estimate water delivery on the basis of time required for irrigation. In the past, MRGCD operated the main canals and laterals on a continuous basis. More recently (since 2001), MRGCD has adopted water-saving measures such as rotational water delivery, whereby it is able to meet the same user demand with reduced river water diversions. In addition to providing irrigation benefits, the MRGCD is also providing a common property resource in the MRG Valley by "keeping the bosqu*e* green." In addition to providing water for irrigation, the MRGCD inadvertently supports a riparian environment and way of life for people in the valley.

Past Recommendations for Improved Performance

Several studies in the past have recommended options for improving performance in MRGCD (Gould, 1996; Frizell et al., 1996; Hernandez, 1997; SSPA, 2002). These studies suggest structural and operational methods that could improve performance in the MRGCD. Gould (1996) and Frizell et al. (1996) suggest MRGCD: (1) automate measurement and control systems, and (2) inventory geospatial and relational data through information resources. Automation allows for efficient physical operation by increasing the reliability and flexibility of water delivery to users. Information resources manage data needed to inventory MRGCD facilities, monitor system operation, schedule maintenance, and plan, model and manage administrative operations. Gould (1996) recommends a framework be developed to implement programs that allow for better management decision-making in MRGCD.

Hernandez (1997) recommends a forbearance process for supplementing water supply in critical reaches of the Rio Grande. Under Hernandez's (1997) forbearance process, the USBR would make restitution to irrigators in the MRGCD based on their overt act to forego use of native Rio Grande water (Hernandez, 1997). Forbearance requires land be removed from production in return for financial compensation. Hernandez (1997) proposes several forbearance alternatives, all of which transfer water from irrigation to other uses in the MRG Valley. Oad and Barta (2004) recommend a change in operational procedures to reduce the river diversions. The primary recommendation is to deliver water to the users on a rotational basis as compared to the past practice of continuous flow delivery in all canals. MRGCD has adopted this recommendation, and combined with related structural improvements, and have in recent years reduced their river diversion substantially. A record of their river diversions, shown in Figure 1, clearly supports this observation.

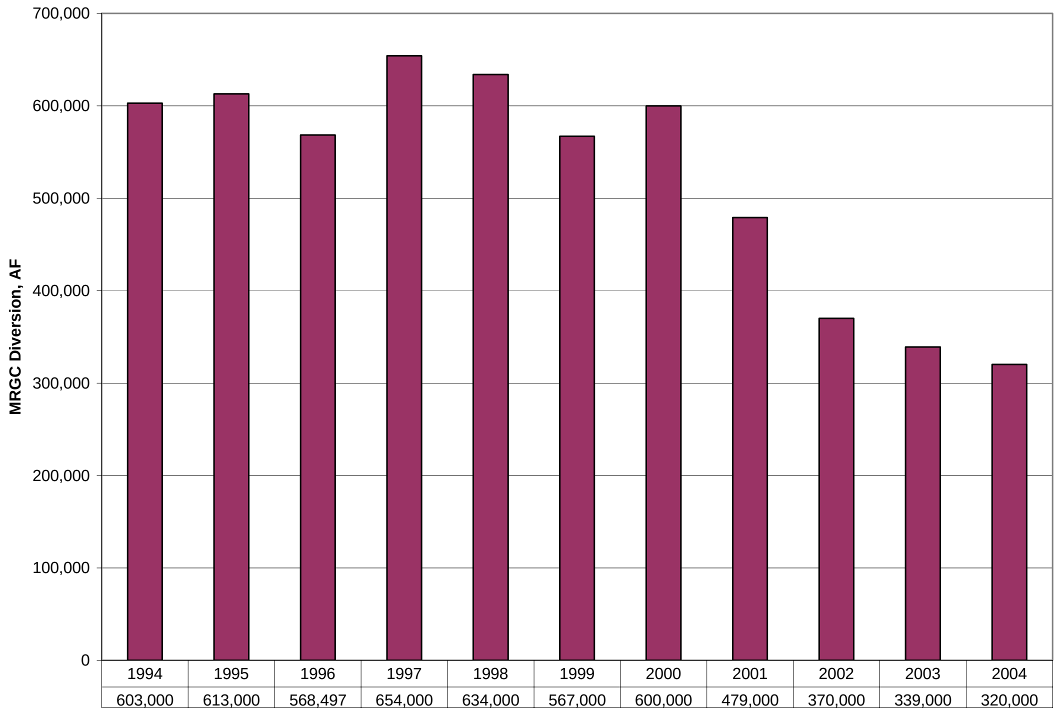


Figure 1: Diversion in MRGCD, 1994-2004. From MRGCD records.

Figure 1 shows the diversion for the past 11 years. The reduced diversions from 2001 through 2004 are indicative of both reduced water supply due to drought and efforts by MRGCD to reduce diversion and implement operational and physical improvements to the system.

III. Forbearance Case Studies

All major river basin systems in the West are faced with the challenges of integrating the water requirements of plant and animal species into their current water allocation schemes. Water transfers from agriculture have historically been analyzed as a solution to water shortages. Over 40 years ago, Hirshleifer et al. (1960) proposed transferring low-valued water from agriculture in California's Imperial Valley, as a cost-effective alternative to constructing the Northern California Feather River Project. Cummings (1974) analyzed inter-basin water transfers from a basin with plentiful supply to a basin where irrigation was depleting ground water supplies. In the framework of a regional trade model, Vaux and Howitt (1984) linked five demand and eight supply sectors in California and showed that over a forty-year planning period, reallocation of water from existing agricultural uses would cost less than development of new supplies.

1. The Upper Rio Grande in Colorado

Physical Description

Surface water: The Rio Grande system drains approximately 8,000 square miles in south central Colorado, where the Rio Grande and the Conejos River rise in the eastern San Juan Mountains and flow through the San Luis Valley. In the northern portion of the basin, streams flow into the "Closed Basin", an internal drainage encompassing approximately two-thirds of the San Luis Valley. There is no natural outlet from the closed basin to the Rio Grande. The Closed Basin Project is a system of 170 salvage wells that draw water from the shallow unconfined aquifer and thus salvage water that otherwise would be lost to evapotranspiration.

Irrigated agriculture is the largest water use in the basin, consuming an estimated 2 million acre-feet of water annually (about 85 percent of all water used in the valley). An estimated 600,000 acres of cropped land are under irrigation, which are supplied by conjunctive use of surface and groundwater. Irrigated agriculture in the San Luis Valley of Colorado is a major cultural and economic activity, contributing about $ 300 million a year. It supports cultivation of diverse food crops including wheat, barley, alfalfa, potato and vegetables on an estimated 400,000 acres of land.

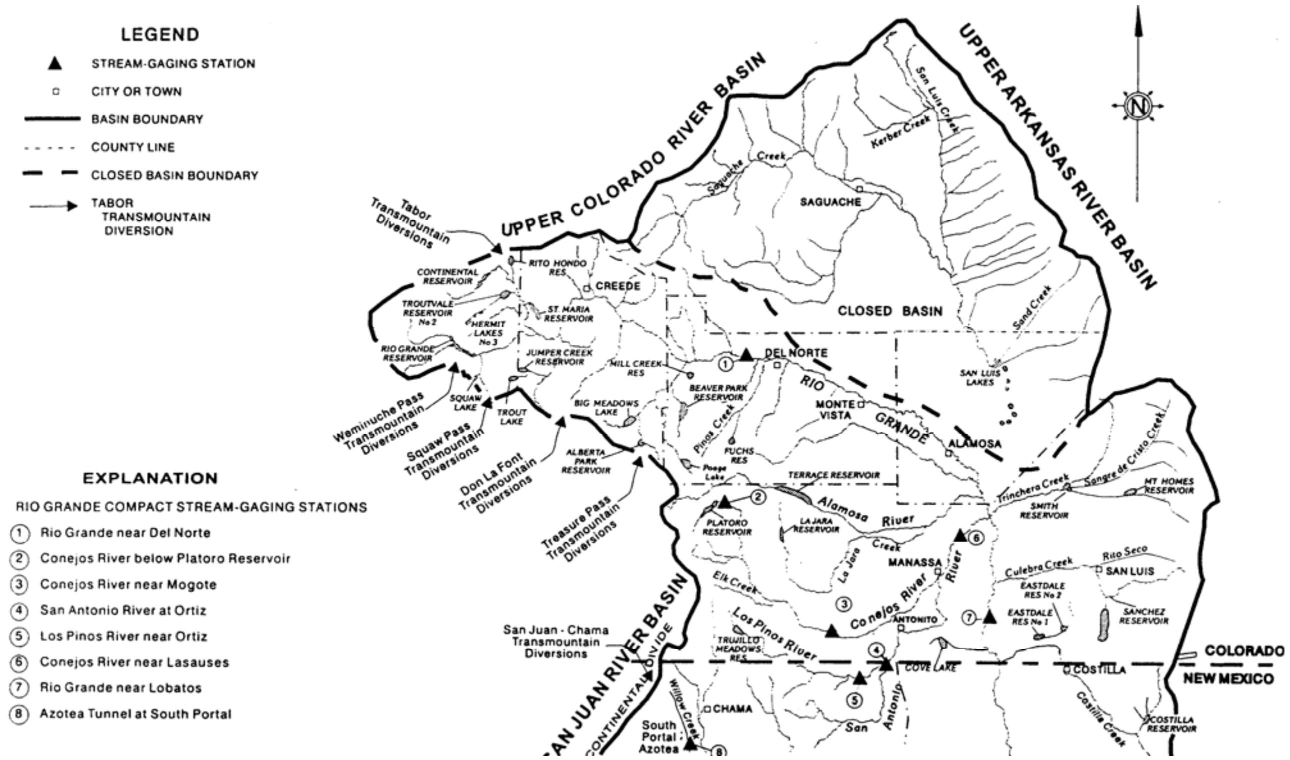


Figure 2: The Upper Rio Grande in Colorado (Rio Grande Compact Commission, 2002)

Groundwater: A large portion of the irrigation water supply comes from the Rio Grande surface water, but the farmers supplement it with pumping from the groundwater aquifers. Of the estimated 2 million acre-feet of total water used, approximately 800,000 acre-feet are from groundwater (40 percent). The problem is that the farmers are taking out water faster than the groundwater aquifer can recharge, especially during the current drought. The desaturation of the aquifer may induce subsidence, thereby reducing the pore space in the aquifer material and permanently reducing its storage capacity and productivity dramatically. Water users in the San Luis Valley risk ruining the aquifer that has made it one of the state's richest agricultural areas. The use of groundwater in the San Luis Valley dates from the late 1800s, when small-production wells were drilled into the upper few hundred feet of the confined aquifer. Since the 1970s, well pumping from the shallow (unconfined) aquifer has become the predominant method of irrigation water use, particularly north of the Rio Grande.

Another problem associated with unregulated pumping from the unconfined aquifer is that it is injuring the surface water rights, which are senior rights. This fact could provoke a lengthy and expensive water battle among the water users, which most farmers would like to avoid. All streams in the Rio Grande Basin are on call throughout any normal irrigation season. The Rio Grande and the Conejos River system are on call year-round from water right calls and/or the Rio Grande Compact.

Groundwater use in the San Luis Valley (Division 3 of Colorado) has never been regulated by the State Engineer's office. The State Engineer has had a moratorium on new appropriations from confined aquifer wells since 1972, and on unconfined aquifer wells since 1982. Agreements were reached with all major water user groups that have precluded the need for groundwater administration rules in the past. Most stakeholders agree that the unregulated use of groundwater, coupled with the drought, have resulted in precipitous declines in the groundwater reservoirs. The Rio Grande Water Conservancy District engineer Allen Davey estimates that the aquifer has lost more than 90,000 acre-feet of water since year 2001. The District maintains that even with normal weather, the aquifer might never recover if pumping continues at its current rate. The solution, therefore, lies in reducing the current pumping by decreasing the irrigated area.

Legal Options:

The Colorado Senate recently passed the Senate Bill 04-222 that could provide the legal basis for the State Engineer to regulate groundwater pumping in its Division 3. The valley water users are well aware of two past examples of state regulation of groundwater, and would certainly want to avoid that fate. In the Arkansas River Valley, the State Engineer was required to curtail well water pumping, especially under the threat of litigation from Kansas. The result has been very expensive efforts, on the part of well water users, to find augmentation water. In the South Platte River basin, the experience was worse. The Court in that case ruled that the State Engineer must shut down groundwater wells if a court approved augmentation plan is not in place. The groundwater pumping in the South Platte basin in Colorado was found to cause injury to senior surface water rights in the neighboring State of Nebraska.

The State Engineer, Hal Simpson, is urging farmers to voluntarily reduce cropping (estimated at 400,000 acres) by about 10 percent. ***Though the state law passed this year (04-222) gives him the authority to force farmers to cut acreage, he has urged voluntary efforts by the community***. Still, the State Engineer's Office is drafting a regulation that will require any additional water taken from the aquifer to be matched with water re-injected into it. Also, those who take water could offset the amount by buying up pumping rights elsewhere in the aquifer and setting them aside.

Voluntary Community Options:

The Valley water users are well informed of the above mentioned experiences in other parts of Colorado, and consider the threat of litigation from the State Engineer very real. They would surely want to avoid the legal course, and are working very hard in a number of ways to prevent litigation. First, the Senate Bill 222 provides the State Engineer with standards for how groundwater administration in the Valley might occur. Most importantly, it allows for locally based solutions, specifically in the form of groundwater management sub-districts.

The groundwater management sub-districts can be created under the Rio Grande Water Conservancy District or under one of the local conservancy districts. Their objective and approach would be to reduce water consumption by providing positive economic incentives to the water users instead of harsh legal actions. The sub-districts would raise funds by imposing a fee on groundwater use, and then use those funds to compensate farmers who agree to reduce their pumping. The farmers could agree: (a) not to plant for an agreed number of seasons, or (b) to permanently retire their lands. A permanent retirement of 10 percent of cropped land would be very desirable, for reducing aquifer pumping. These voluntary approaches will certainly not be easy since they require building consensus among various regions, irrigation ditch companies and diverse classes of water users.

Technical options:

Science and technology also provide some good tools to solve this problem. The State of Colorado has recently completed development of The Rio Grande Decision-Support System, which is a series of data-based computer models. It will be very effective in assessing the extent of the aquifer problem and analyzing options of rectifying the problem. The Rio Grande Water Conservancy District actively assisted in the formulation of the DSS models, and they are now using the models in their system operations.

Relevant Lessons Learned for the Middle Rio Grande Valley:

Will farmers really forbear voluntarily?

On-going experiences in the Upper Rio Grande seem to be positive. There are reports that farmers already are voluntarily reducing crop acreage to preserve the aquifer during the drought. ***Karla Shriver, coordinator of Citizens for Colorado Water, maintains that farmers have reduced cropping by more than 10 percent in year 2003***. Her family held back some 300 acres of the 900 they normally would have in potatoes and wheat on their Monte Vista farm. The education and outreach efforts in the Colorado case are undoubtedly key to this success.

What external factors would prompt water users to forbear?

The above mentioned mobilization of local efforts are heavily influenced by two recent occurrences. First, the court rulings in the Arkansas and the South Platte River Basins have clearly demonstrated that the groundwater pumping causes injury to the senior surface water rights. The court actually ordered the State Engineer to shut down the wells in the two river basins, since they were found to cause injury to the users in adjoining states of Kansas and Nebraska.

Second, the Colorado Senate Bill 222 now gives the State Engineer's Office the authority to regulate groundwater pumping in the region. ***The local water users***

> Thursday, November 6, 2003 Albuquerque Journal
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> **Water Controls Predicted**
>
> **By Leslie Linthicum**
> *Journal Staff Writer*
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> SANTA ANA PUEBLO— The forecast for New Mexico water users is big change. The State Water Plan, available to the public in its draft form this week, melds worries about a multiyear drought with the realities of population growth to come up with a blueprint for some new ways of doing business. The state engineer, who was responsible for the draft and its final version that will go the governor and the Legislature later this year, ***envisions water metering throughout the state, water masters sorting out who gets how much water and when, water banking programs that will lead to markets for water sales, limits on domestic wells and even a hint that Indian tribes should have to suffer water shortages when the rest of the state does.***
> The plan tries to balance long-established agricultural water uses with the demands of growing populations, especially in times of drought. It envisions a future when the state engineer will not just sort out pieces of paper that represent water rights, but will actively measure water use and dispatch water masters to dole out water. **The State Engineer *suggested that cooperative agreements, water banking and compensating for water that is voluntarily given up could accomplish that and avoid involuntary cutoffs.***

know that they will be forced to reduce pumping if they don't do so themselves. The Coordinator of Citizens for Colorado Water was quoted as saying, "Hal Simpson has given us a chance to solve our problems on our own, and hopefully we will. If not, he will be forced to come in and do the rules and regs." Ray Wright, president of the Rio Grande Water Conservation Board has echoed similar views, "Long term, we are going to see the amount of acreage decrease. Long term, we have to."

It will be helpful for the program in the Middle Rio Grande to investigate what similar external incentives could be used for encouraging forbearance, if the option is finally chosen for implementation. Considering the large of amount of public concerns indicated below, water users in the Middle Rio Grande must be aware of the need to explore all options for conserving water.

How will the forbearance program be administered?
The forbearance program in the San Luis Valley could be administered by federal, state or local agencies. The preference of the vast majority of stakeholders seems to be in favor of a local agency. ***The proposal is to create a sub-district within the Rio Grande Water Conservancy District, which will have the authority to tax farmers who pump water from the shallow aquifer and reimburse those who forbear groundwater pumping***. In the Middle Rio Grande, the

> Tuesday, August 17, 2004 Albuquerque Journal
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> **Domenici: Share Water Rights**
>
> **By Tania Soussan**
> *Journal Staff Writer*
> SANTA FE— Water rights settlements are vital to New Mexico's future but can't be a winner-takes-all proposition, Sen. Pete Domenici, R-N.M., said Monday. "You don't settle water rights any more where somebody gets everything," he said. Speaking to about 150 people at the 12th annual New Mexico Water Law conference in Santa Fe, Domenici said resolving questions of water rights is "absolutely important and paramount." "As soon as we establish the individual rights up and down a stream or in a basin, ... the better we put water in a position for it to be a marketable commodity," he said. Domenici, chairman of the Senate Energy and Natural Resources Committee, said markets would move water to its highest and best use".
> In a separate panel on the endangered Rio Grande silvery minnow, Jennifer L. Gimbel, Interior Secretary Gale Norton's personal representative on the middle Rio Grande, said efforts to reach a long-term solution are running into trouble. "The collaborative program is a cumbersome process," Gimbel said, after stating she was expressing her opinions and not those of the federal government. "There are meetings ad nauseum for hours and hours. ... We just don't seem to be able to get organized." ***She advocated a permanent pool of water stored upstream for minnows, a forbearance program that would pay farmers to temporarily fallow fields and leave water in the river and establishing populations of minnows outside the middle Rio Grande.***

MRGCD may be one obvious choice for reasons such as their knowledge of water users and the water delivery system. The MRGCD, with the consent of their water users, could increase their service fee for the farmers who do not want to forbear in order to reimburse the ones who do, but this would likely be an unpopular and ultimately unworkable solution. An external funding source, such as ESA funds, could also be used to reimburse the water users who participate in the forbearance program.

What are some important differences between the two cases?
First and foremost, the nature of water supply is very different. Forbearance in the case of groundwater provides real and immediate savings in each individual act of forbearing well pumping. Further, the amount of water made available by forbearance needs no storage since it is already stored in the groundwater aquifer. ***Forbearance of surface canal water is much more complicated, since it can provide significant savings when a group of water users collectively forbear so that the lateral canal feeding their lands can be effectively closed and the associated losses reduced.***

Second, in Colorado, the Court ordered the State Engineer to shut down wells in the Lower Arkansas and the South Platte River basins, to comply with interstate compacts with Kansas and Nebraska. Farmers in the Upper Rio Grande basin, who are pumping groundwater, know they are out of compliance. They know if they don't voluntarily reduce groundwater use, the State Engineer will force them to do so. ***Farmers in the Middle Rio Grande are not necessarily out of compliance, and therefore not under similar pressure to forbear their water use.***

2. Big Hole River Valley, Montana

A fairly routine forbearance program in the Big Hole River Valley in southwestern Montana paid ranchers irrigating pasture a total of $774,000 in 2004 to forgo the use of irrigation water in an effort to maintain instream flows for the Arctic Grayling (U.S. Water News Online, 2004). While the species was not listed as endangered, it was thought that the population in the Big Hole River was the last stronghold of the fish in the lower 48 states, and loss of that population

could result in the species being listed as protected. Fifteen ranchers participated in the program, and several others agreed not to use irrigation water, but said they did not expect payment.
In June, consistent rain began falling. The water supply was plentiful, and the forbearance was likely unnecessary, yet the participating ranchers received the forbearance payment. The Arctic Grayling population was never in danger during 2004. This created significant second-guessing and criticism of the program, as many people thought that the ranchers who accepted payment did not deserve what they got, since the forborne water was unnecessary.

Lessons for the Middle Rio Grande:

The political environment in the Middle Rio Grande is very volatile, and a program to forbear use of irrigation water must be very carefully designed. It will require a combination of positive incentives in the form of voluntary community efforts and financial compensation, and a corresponding legal and institutional framework. The later is especially difficult since farmers in the Middle Rio Grande are not necessarily at fault while using river water for irrigation. If a forbearance program is undertaken, the rules of the game should be made clear to all, including the general public. Should irrigators agree to forbear, and a plentiful water supply may make the forbearance unnecessary, it must be made absolutely clear to all concerned that irrigators who participate would be contracting to forbear, not to manage water for the ESA recovery effort. If irrigators fulfill their contractual obligations to forbear, they must be compensated as agreed, regardless of what the weather or countless other factors in the species' survival conspire to do.

Management of a surface canal water forbearance program would be much more complicated, compared to groundwater forbearance programs. Every individual voluntary pump closure would benefit groundwater conservation. But, in a surface canal water irrigation system, a completely "voluntary" forbearance will result in a "checker board" scenario with not much water savings. Forbearance of surface canal water can provide significant savings only when a group of farmers collectively forbear so that the lateral canal feeding their lands can be effectively closed and the associated losses reduced. Also, the forborne surface water must be stored in a reservoir so that it can be used in times of need to manage in-stream flows, which can be very difficult. Groundwater forbearance has no such considerations since it is already stored in the aquifer.

IV. Hydrologic Analysis of Irrigation Forbearance

The objective of this chapter is:

".. to quantify the amount of water that, if forborne, could be stored upstream for later release to augment Rio Grande flow for endangered species purpose." (MRGCD RFP)

This task relates to the primary concern whether the forbearance program can yield sufficient water quantity to benefit the river flow. Estimation of forborne water amount needs to be based on a complete analysis of complex hydrology as water flows from its storage to the river, through the delivery canal network and on the farm. Before doing that, it is useful to consider the upper and lower bounds on the potential water savings – from a low of crop consumptive use to a high of river diversion.

In this feasibility study we are particularly interested in understanding the interaction between irrigation system management and the hydrology of the Rio Grande. We are less interested in the specific quantities of water associated with a particular hydrologic component; rather, our interest is to estimate the difference in amount of water associated with a change in management, specifically forbearance. In developing the hydrologic budget for forbearance evaluation, we will begin our analysis at the farm level, as this is where the primary changes take place. We will then follow the water upstream to conveyance and diversion, and downstream as it returns to the river.

Our approach is to first determine the crop consumptive use, consumptive irrigation requirement, and associated losses at the farm. We will then compare the consumptive use to the main canal diversions to estimate conveyance losses in the irrigation delivery system. Having estimated these hydrological elements, we will then investigate the effect of various forbearance scenarios on these elements, to quantify the resulting amount of water. This analysis will be incomplete if we don't address the issue of return flow, since associated decreases in return flow will need to be compensated by increased water releases in the delivery system.

Finally, given the amount of water made available for upstream storage and release for instream management, we examine limitations the actual amount of water that can be stored due to the timing and source of flow.

1. Consumptive Use and Consumptive Irrigation Requirement

One of the most important components of the hydrologic budget of a flow-through system, one with downstream delivery obligations such as the Middle Rio Grande, is the depletion of water. There are many sources of depletion within MRGCD – crops, riparian vegetation, urban consumptive use, etc. – but the depletions of concern here are those associated with irrigation system management.

Consumptive Use (CU) is the depletion to the local hydrologic system by crop production. At the farm level, the CU is generally calculated as the evapotranspiration (ET) from the fields during the irrigation season, since ET comprises about 99.99 percent of the CU. We therefore use ET and CU interchangeably. ET varies with crop, soil type, management of water, and weather. The predominant crop in the MRGCD is hay, particularly alfalfa, which typically accounts for more than half of the irrigated acreage. Irrigated pasture is the second most common crop, covering about one quarter of the irrigated area. Other crops include corn, sorghum, wheat, barley, cotton, and vegetables, none of which constitute more than 10 percent of the irrigated area. In the analysis here, we base the estimate of CU on alfalfa for the following reasons:

- Alfalfa is by far the most common crop in MRGCD,
- Alfalfa has the best available CU estimation information available of the crops,
- Alfalfa is generally a fairly heavy water user; the CU from alfalfa represents the upper end of depletion that could be reduced through forbearance.
- Irrigated pasture has a lower potential CU, but considering the on-field operations for alfalfa harvesting, an alfalfa crop is typically more moisture stressed than pasture, and so the typical CU from the two crops is probably not very different.

While many methods may be applied to this calculation, data limitations constrain what is practical. We use the SCS Modified Blaney Criddle method using weather data and alfalfa crop coefficients developed from ET research data at the Los Lunas Agricultural Experiment Station, which is roughly in the middle of the MRGCD. The SCS Modified Blaney Criddle formula is appropriate for monthly CU estimates which can be aggregated into seasonal estimates.

The SCS Modified Blaney Criddle formula states that

$$ET_i = \frac{p_i T_i k_{T_i} k_{c_i}}{100},$$

where ET_i is the ET during month i of the growing season in inches, p_i is the percentage of daylight hours occurring during month i, T_i is the mean temperature for month i in °F, k_{Ti} is a temperature correction factor for month i calculated as $k_{Ti} = 0.0173\ T_i - 0.314$, and k_{ci} is the crop coefficient for the crop of interest during month i. The CU, or ET during the growing season is

$$ET = \sum_{i=1}^{n} ET_i,$$

where n is the number of months in the growing season.

Luo (1994) developed crop coefficients for alfalfa grown at the Agricultural Experiment Station, which is certainly more fully irrigated than most alfalfa grown in the MRGCD. The National Weather Service (2005) state that based on data from 1991-2001, the growing season at Los Lunas, and in the MRGCD in general, typically runs from May through October, inclusive. We used monthly average temperature data from the Los Lunas, derived from data for the period July 1923 through September 2004, as compiled by the Western Regional Climate Center (2005). Climate data, crop coefficients, and ET calculations using the SCS Modified Blaney Criddle formula are presented below in **Table 1**. (In all calculations, we carry full significant figures through the entire calculation, so some round-off operations in intermediate calculations displayed in the report may appear inconsistent in the last significant figure).

Month	Precip, in.	Avg Temp, °F	BC p, %	k_T	k_c^*	ET, in
Jan	0.35	34.6	7.06			
Feb	0.42	40.1	6.89			
March	0.53	46.9	8.36			
Apr	0.47	54.5	8.82			
May	0.47	63.1	9.76	0.78	1.74	8.33
Jun	0.63	71.9	9.75	0.93	1.73	11.27
Jul	1.25	76.5	9.92	1.01	1.64	12.55
Aug	1.73	74.5	9.36	0.97	1.48	10.06
Sep	1.18	67.1	8.36	0.85	1.27	6.03
Oct	1.07	55.7	7.88	0.65	1.02	2.91
Nov	0.50	43.4	6.98			
Dec	0.50	35.0	6.87			
Total	9.10		100.00			
Gr. Season	6.33				Total	51.2
% effective	75 %					
Eff. Prec. P_e	4.7					
*from Luo (1994), NMSU94.						

Table 1: Climate data and ET calculations using SCS Modified Blaney Criddle formula for Los Lunas, New Mexico.

The calculated seasonal ET of 51 inches is, of course, higher than one would expect in the MRGCD. As Luo (1994) states, this is a potential ET for alfalfa, not an actual ET. The operations and objectives associated with typical alfalfa production necessitate stressing the crop, and the actual ET can be estimated from the degree of stress or the resulting crop yield (water production functions). Sammis, et al (1982, cited in Luo, 1994) examined the response of alfalfa yield to ET. They produced a water production function, a linear model of yield at harvest moisture to seasonal ET. Converted to U.S. Customary units, the water production function for alfalfa in New Mexico is:

$$Y = -0.5904 + 0.1572\ ET,$$

where Y is the yield of alfalfa at 12 percent moisture in tons/acre, and ET is the seasonal evapotranspiration in inches. For an ET of 51.15 inches as calculated in **Table 1**, this water production function indicates a yield of 7.45 tons/acre, which is high for MRGCD service area, though it is about average for Elephant Butte Irrigation District 200 miles to the south. MRGCD has lower temperatures, a shorter growing season, and less solar radiation than EBID, so yields are expected to be lower. MRGCD records derived from the New Mexico Agricultural Statistics reports for the period 1986-1995 showed an average yield of alfalfa of 4.33 tons per acre. The New Mexico Agricultural Statistics reports are at best approximate for alfalfa yields, and 4.33

tons per acre is probably on the low side of average. In our judgment, based on five years of work in the MRGCD, an average yield of 5 tons per acre better represents alfalfa production in the MRGCD.

Inverting the water production function and solving for ET given a yield of 5.0 tons per acre, the actual ET estimate is $\frac{5.0 + 0.5904}{0.1572}$ = 35.6 inches, or about 3 feet. The Natural Resources Committee (1938) estimated the CU in the MRG to be 2.6 feet. Considering improvements in alfalfa yields since 1938, our finding is consistent with the NRC (1938).

Part of the consumptive use (CU) is supplied by rainfall. It is the primary function of irrigation to supply the rest. The amount of CU supplied by irrigation is the **consumptive irrigation requirement (CIR)**, and it is the CU minus effective precipitation. CIR is a very important concept in New Mexican water law, as it is the core component of the beneficial use that quantifies a water right. ***If a farmer forbears irrigating his land, evapotranspiration will still occur from the fallow field. Native desert vegetation, weeds, or even bare ground will still evapotranspire, so that the differential amount of CU reduction due to forbearance is not the total CU, but rather the CIR.***

Total average growing season precipitation at Los Lunas, shown in **Table 1**, is 6.33 inches. We assume that 75 percent of this will be effective precipitation (4.7 inches) regardless of land management. If a higher percentage is actually effective under cropping, the CIR will be reduced. If a higher percentage is actually effective under fallow conditions, less water will be made available for upstream storage than is calculated below. It is unlikely that the average effective precipitation would vary from our estimate of 4.7 inches by more than one inch.

Our estimates of 35.6 inches of CU and 4.7 inches of effective precipitation yield a CIR estimate of 30.8 inches, or 2.57 feet. Again, this is consistent with our experience. The New Mexico State Engineer's Office uses a working value of CIR as 2.1 feet in the MRGCD. This estimate would imply a higher level of water stress and lower crop yield. Taking CIR as 2.1 feet and 4.7 inches of effective precipitation, the water production function gives the crop yield as 4.1 tons/acre, lower than the reported average. We will carry though the calculations using the value of 2.57 feet, though we will examine the sensitivity of the results to this value relative to the OSE's value of 2.1 feet for CIR.

2. Application Efficiency and Farm Delivery

One of the most used (and abused) terms in irrigation management is efficiency. In all engineering fields, an efficiency is generally defined as the ratio of an output to an input. Irrigation systems have so many hydrologic input terms (release, diversion, farm delivery, etc.) and so many output terms (diversion, delivery, consumptive use, crop production, etc.) that the term "efficiency," unless specifically defined, is meaningless. We strive, therefore, to define all of our efficiency terms unambiguously. In the Standards of the ASAE (1990), application efficiency (e_A) is defined as the amount of irrigation water that is stored in the root zone (where the crop can extract it for consumptive use) divided by the amount of water applied to the field during an irrigation event. On a seasonal basis, our operating timeframe, the application efficiency can be expressed as the CIR divided by the total seasonal on-farm application of irrigation water. Conceptually, it is the percentage of applied irrigation water that is actually depleted by the crop, and it is dimensionless.

Recent research on application efficiency in the MRGCD (Moreno, 2004) indicates that for the well-managed farms that were evaluated, e_A was considerably higher than anecdotal evidence on the MRGCD would support – sometimes in excess of 80 percent. This is possible because of the typically short runs, low intake rate soils, the deep root zone (1.8 m, or 5.9 feet) of alfalfa, and high management allowable deficit (often greater than 50 percent), and conscientious and effective management by farmers. On sandier soils, e_A was much lower, closer to 50 percent. Undoubtedly, smaller farms managed by more casual irrigators will have lower efficiency. While a great many small farms will have e_A lower than 50 percent, a great deal of the acreage is in larger farms with higher e_A (Belen and Socorro Divisions). Considering the highly variable levels of management and soil types, we estimate that the area-weighted average or representative e_A for MRGCD is about 65 percent.

In order to supply the CIR to the crop, the amount of water that must be delivered to the farm turnout, termed **farm delivery requirement** (FDR), is calculated as $FDR = \frac{CIR}{e_A}$. With a CIR of 2.57 feet and e_A equal to 65 percent, this indicates an FDR of 3.95 feet.

This means that typically 35 percent of the irrigation water applied to the field, or 1.38 feet, is not depleted by crop. Applied water that is not depleted by the crop can run off the field or deep percolate. Evaporation from the water surface on the field during a flood irrigation event is, by definition, part of the seasonal ET. Farmers in MRGCD typically irrigate in closed basins or borders, so that tail water runoff is negligible. Therefore, the 35 percent of the applied water that is not depleted by the crop percolates through the crop's root zone to the groundwater. This is the potential return flow originating on farm and is shown in Table 2.

There is some confusion as to the actual irrigated area within MRGCD. USBR Crop Production and Water Utilization Data records indicate that about 54,500 acres of land are irrigated excluding Pueblo lands. Aerial photography studies have shown about 63,000 acres of land irrigated within the basin, but this includes irrigated land that is not a part of MRGCD. Because the diversion for MRGCD includes water for delivery to Pueblo lands, it is important to include the Pueblo lands in this hydrologic budget. We therefore conduct our analyses under the assumption of both 54,500 and 60,000 irrigated acres. The impact on the final outcome is minor, considering the lack of precision in other parameters. Our further discussion and recommendations cite the values generated by an irrigated acreage of 60,000 acres. Table 2 shows the volumetric CIR and FDR for the MRGCD under both assumptions of irrigated acreage.

Assumed Irrigated Acreage	54,500	60,000
CIR, f	2.57	2.57
CIR, AF	139,951	154,074
FDR, f	3.95	3.95
FDR, AF	215,309	237,037
Potential On-farm Return flow, f	1.38	1.38
Potential On-farm Return flow, AF	75,358	82,963

Table 2: Volumetric CIR and FDR in MRGCD.

3. Diversion and Conveyance

The term diversion is commonly used in two ways in the study area. When applied to surface water, it refers to the quantity of water removed from a river or stream, and directed through a heading into a main canal. Once water is in the canal conveyance system, it is under the control of MRGCD. The term is also commonly applied to groundwater withdrawal by pumping, but in this document, diversion is restricted to the former definition unless it is specified as a groundwater diversion.

The efficiency with which diverted water is transported though the canal and lateral system to the farm turnout is termed conveyance efficiency (e_c), and it is the ratio of total farm deliveries to total diversion. The difference in volume of water between diversion and farm delivery is comprised of seepage in the canal system, operational spills, where water is returned directly to the river, and evaporation from the surface of the water flowing in the canals. The largest loss component by far is the seepage. We consider the conveyance loss in terms of seepage, and implicitly include the evaporative loss as part of the consumptive term in seepage losses that will be introduced later. The operational spills are generally small compared to seepage losses, and they are entirely non-consumptive, as they are returned through surface channels directly to the river. We therefore do not consider operational spills in this analysis.

MRGCD maintains records of its diversions. Over the past five years (2000-2004), the average annual diversion for all four divisions was 421,600 acre-feet. This is a reduction over earlier years, when the annual diversion as typically on the order of 600,000 acre-feet (see Figure 1). The recent diversion reduction of roughly 30 percent results from both structural and operational system improvements implemented by MRGCD.

The term “conveyance loss” is somewhat misleading in this context. Because the surface water system is so closely connected to the groundwater system, water seeping from the unlined canals is not entirely lost. It returns to the shallow groundwater system where it may be collected by the drainage system and returned to the Rio Grande or conveyed directly into a downstream canal system. In either case, the conveyance “loss” is not lost to the system because some of it is recaptured and constitutes part of the downstream water supply. Of course, the vigorous bosque growing in the MRGCD lives largely on the shallow groundwater, and it will deplete some portion of the canal seepage. We use the term conveyance loss throughout this section and the rest of the document because it is commonly used in the study area, but we do not consider it to be a total loss to the local hydrologic system.

With measured diversions and farm deliveries as quantified in Table 2, the conveyance efficiency (e_c), which is the ratio of deliveries to diversion, is 56 percent. This estimate of e_c is within the typical values for a delivery system that consists primarily of unlined canals and laterals, and is consistent with our expectations of MRGCD.

Quantity	Value
FDR, AF	237,037
Diversion, AF	421,600
Diversion, f	7.03
Conveyance efficiency e_c	56%
Conveyance Loss, AF	184,563
Conveyance Loss, f	3.08
Main Canal Loss, AF	52,732
Main Canal Loss, f	0.88
Lateral Loss, AF	131,831
Lateral Loss, f	2.20

Table 3: Farm delivery, diversion, and conveyance analysis for MRGCD assuming a CIR of 2.57 feet and 60,000 irrigated acres.

To adequately evaluate the effect of various forbearance scenarios on the system's hydrology, the conveyance loss must be partitioned between the loss in the main canals and the loss in the laterals. Elephant Butte Irrigation District (EBID) is similar to MRGCD in that it is a largely earth-lined gravity irrigation conveyance system. EBID estimates that, in a full supply year, about 35 percent of its diversion is conveyance loss. Of this 35 percent conveyance loss, about 10 percent of the diversion (or 29 percent of the loss) occurs in the main canals, and the remaining 25 percent of the diversion (or 71 percent of loss) occurs in the laterals. These values are consistent with our expectations for MRGCD. Applying these percentages to the total conveyance loss yields the quantities stated in Table 3.

4. Water Use Reduction Associated with Various Forbearance Scenarios

Water use reduction associated with irrigation forbearance in the MRGCD can be evaluated based on three different scenarios described as follows:

A. **Checkerboard** forbearance: If the lands on which irrigators are willing to forbear are scattered throughout the service area with no particular consolidation, the District will still have to fill the main canals and laterals to maintain delivery to those constituents who choose to continue irrigating. Therefore the forbearance does not reduce the conveyance loss in either the main canals or laterals, and the change in hydrology is the elimination of farm delivery, crop depletion, and return flows from deep percolation associated with the forbearing acreage.

B. **Lateral** forbearance: If all of the water users on a lateral agree to forbear, the entire lateral can be shut off for the year. In this case, the seepage loss due to operation of the lateral is eliminated, as is the return flow associated with it. This pattern of forbearance will also eliminate the farm delivery, crop depletion, and return flow from deep percolation associated with the irrigation of the forbearing lands on the lateral. Lateral forbearance will make implementation much more manageable than checkerboard forbearance, as described in Chapter V.

C. **Main canal** forbearance: If the irrigators in an entire main canal command area agree to forbear, the entire main canal could be closed for the year, assuming the downstream division has adequate capacity to divert its required water at its own heading, and it does not does not depend on bypass flow from the forbearing division. All lateral conveyance losses and associated return flows, as well as farm deliveries, crop depletions, and return flows from deep percolation would also be eliminated. However, the practical feasibility of this option is very doubtful.

5. Accounting for Return Flow

While we have quantified diversion, conveyance losses farm deliveries, and CIR, the quantity of associated return flow, either returning to the river where it is available for downstream use or flowing directly into a downstream canal, is more problematic. It is a critical question because in looking at the water available for storage and in-stream flow management, we must consider that the portion of return flows that are reused must be made up with released water to maintain the water supply for downstream irrigators who choose not to forbear. Essentially, we must quantify the net effect of forbearance, and that requires quantification of the usable return flow reduction associated with each of the three forbearance scenarios.

We introduce and define the return flow efficiency e_R as the percentage of potential return flows from irrigation, including deep percolation and surface runoff from on-farm application, seepage from conveyance, and operational spills that are recaptured and reused within the system.

The savings resulting from irrigation forbearance can be bounded by making limiting assumptions about the reuse of return flows. First, if we assume that all of the return flow produced by current operations is available for downstream use (e_R = 100 percent), then in all three scenarios all of the conveyance loss and deep percolation from on-farm irrigation would be usable, and the only savings would be the CIR, estimated to be 2.57 acre-feet per acre. Clearly this is not representative of the MRGCD, as the riparian vegetation that comprises the bosque depletes a significant amount of the return flows from the shallow groundwater, and some return flows occur at a time or place where they are not usable.

At the other end of the spectrum, if we assume that none of the return flows are recaptured and reused (e_R = 0 percent), then all of the farm delivery from forbearing land could be held in upstream storage in all three scenarios, or 3.95 acre-feet per acre; all of the lateral seepage would be available for upstream storage in the lateral forbearance scenario for a total of 6.15 acre-feet per acre; and all of the conveyance loss would be available for upstream storage in the main canal forbearance scenario, for a total of 7.03 acre-feet per acre. This too is not representative of the MRGCD, as we see large quantities of return flows being returned to the Rio Grande or the District's conveyance system and being reused.

Reality lies somewhere between these two extremes. Available return flow data include large volumes of storm inflows and other discharges not associated with irrigation, so the data are not particularly useful for refining the estimate of e_R. We therefore present our quantification of the quantity of water that can be made available for upstream storage and in-stream flow management not as a point estimate but as a bounded range. The actual e_R varies temporally and spatially, but we assume that the District-wide effective e_R is on the order of 50 percent, and present the net savings of water for upstream storage and in-stream flow management below in Table 4. The dependence of these estimates on assumed return flow efficiency is presented graphically in Figure 3.

Forbearance Scenario	Water saving (ft.)
Checkerboard	3.26
Lateral	4.36
Main	4.80

Table 4: Estimates of water made available for upstream storage and in-stream flow management by irrigation forbearance under three scenarios (acre-feet per acre) for e_R = 50 %, CIR = 2.57 ft, and irrigated acreage of 60,000 acres.

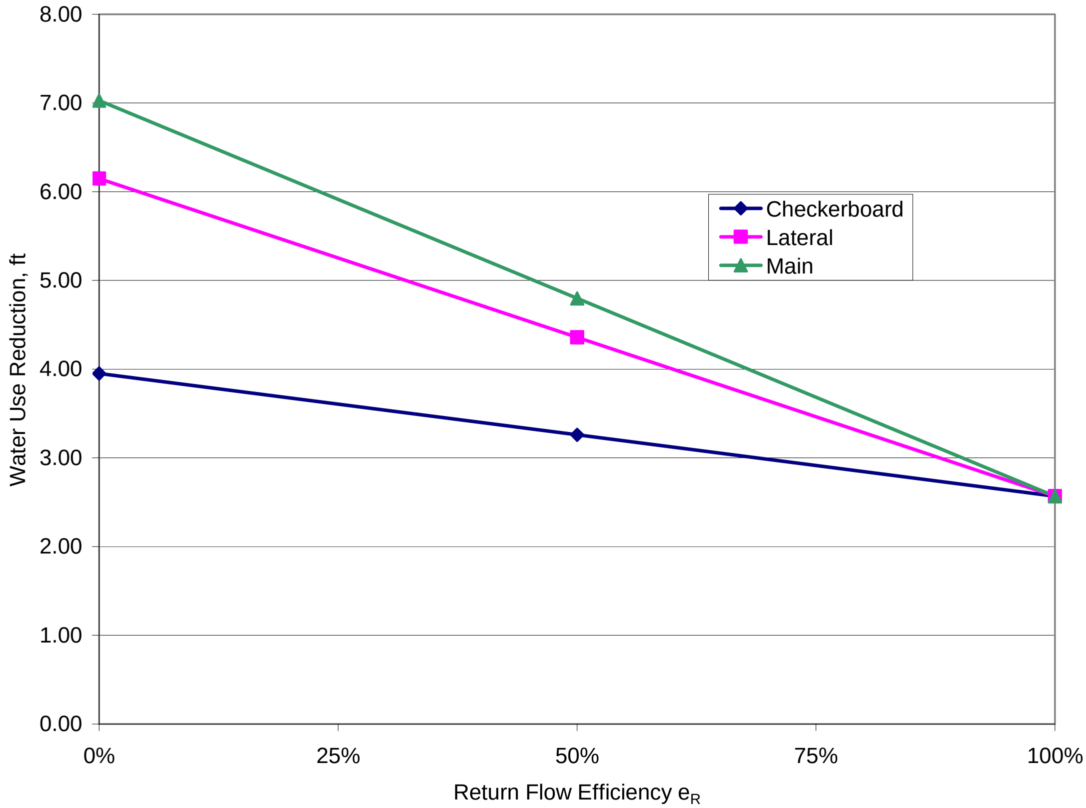

Figure 3: Water use reduction as a function of assumed e_R and forbearance scenario for CIR of 2.57 feet and 60,000 irrigated acres in MRGCD.

In summary, our estimate of water made available by irrigation forbearance for upstream storage and in-stream flow management is 3.26 acre-feet per acre forborne for the checkerboard scenario, 4.36 acre-feet per acre forborne if an entire lateral forbears, and 4.80 acre-feet per acre forborne if an entire main canal chooses to forbear. The practical aspects of implementation of forbearance are considered in the following chapter.

A simple sensitivity analysis is presented in Table 5, where the amount of water made available for upstream storage under assumptions of 54,000 and 60,000 irrigated acres, and CIR values of 2.1 and 2.57 f are expressed as a percentage of the values presented in Table 4. Note that the acreage has less effect than the CIR value.

CIR, f	2.10		2.57	
Irrigated Acreage	54,500	60,000	54,500	60,000
Checkerboard	2.67 (82%)	2.67 (82%)	3.26 (100%)	3.26 (100%)
Lateral	4.27 (98%)	4.02 (92%)	4.61 (106%)	4.36 (100%)
Main	4.92 (103%)	4.56 (95%)	5.15 (107%)	4.80 (100%)

Table 5: Water use reduction relative to that calculated for 60,000 irrigated acres and CIR of 2.57 feet, assuming e_R = 50 %.

6. Required Forbearance Acreage

One approach to examining the forbearance hydrology would be to base the estimation on the perceived need. That is, what is the amount of water required to maintain a certain target flow for the fish habitat, and what fraction of this amount should come from the forbearance program? In the most simple scenario, one could say that the forborne water would meet the total target flow. For a base "desirable or target flow" for good river habitat, we can refer to the U.S Fish and Wildlife Service Biological Opinion of March 17, 2003, which states the target flow to be 100 cfs:

"*Action agencies, in coordination with the parties to the consultation, shall provide year-round continuous river flow from Cochiti Dam to Isleta Diversion with a target flow of 100 cfs over the Isleta Diversion Dam.*"

The amount of forborne water needed to maintain 100 cfs in the critical reaches of the river is impossible to determine with certainty. In 2004, no forborne water would have been necessary due to the local precipitation. In 2005, no forborne water will likely be necessary because of the high snow pack and runoff forecasts, though if conditions deteriorate later in the year and the typical monsoons do not materialize, late 2005 could still be critical. We can, however, estimate the amount of water available to be released from storage given a forbearance scenario based on

Table 4. Since we are examining the amount of water made available for upstream storage by forbearance in a differential analysis, that is the difference in available storage with forbearing irrigators versus the amount available without, we can neglect the incremental losses associated with conveyance from release to diversion, as the flow that is there in any case will suffer roughly the same quantity of loss.

For each day that 100 cfs is released from storage, 198 acre-feet is released (1 cfs-day = 1.98 acre-feet). Therefore, based on the savings associated with return efficiency assumptions and forbearance scenarios presented in Table 4, the required acreage to be forborne for a single day of 100 cfs release from storage of forborne water is as shown in Table 6.

Forbearance scenario	Required forborne acreage
Checkerboard	61
Lateral	46
Main	41

Table 6: Required forborne acreage to yield 100 cfs for one day (irrigated acreage = 60,000, CIR = 2.57 ft, e_R = 50 %).

The results show that forbearance on entire laterals, which is possible, is more attractive than checkerboard forbearance, since the former option would need forbearance on 46 acres as compared to 61 acres to yield a one-day flow of 100 cfs. Forbearance of an entire division or main canal has higher yield still, but as discussed below, we do not consider it to be feasible on a voluntary basis.

Considering that lateral service area forbearance is a realistic and efficient option and assuming 50 % return flow efficiency, we need 46 acres to forbear for yielding a daily storage release of 100 cfs. In reality, a certain land area will forgo irrigation for the whole cropping or irrigation season. So, the land area necessary to yield a flow of 100 cfs over a period of 6 months (about 35,700 acre-feet) is about 8,193 acres, or 14 % of the total irrigated land in MRGCD. The acreage and percent of the MRGCD that would have to forbear to make available 100 cfs for 6 months (180 days) the three forbearance scenarios is shown below in Table 7. Note the significant reduction in necessary acreage going from checkerboard to lateral forbearance compared to the minor improvement going from lateral to main forbearance.

Scenario	AF/acre forborne	Acreage forborne	Percent of District acreage forborne
Checkerboard	3.26	10,954	18%
Lateral	4.36	8,193	14%
Main	4.80	7,442	12%

Table 7: Required forbearance acreage to yield a release for instream management of 100 cfs for six months.

7. Storage Limitations

The above analysis considers how much water can be made available for upstream storage and subsequent release for in-stream flow management. The other limiting constraint on the quantity that can be managed for in-stream flow is the ability to capture and store water. The location and operation of MRGCD's primary storage facility – El Vado Reservoir – complicates the proposition of storing all of the forborne water from a given acreage of land for use at critical times of the year.

El Vado is located on the Rio Chama, a tributary that meets the Rio Grande just above the Otowi river gauge. Heron and Abiquiu reservoirs are also on the Rio Chama, though El Vado is MRGCD's primary reservoir. Cochiti Reservoir is on the main stem of the Rio Grande downstream of Otowi; however, Cochiti is a flood control reservoir, and storage of large volumes of water there is problematic. Most of MRGCD's water supply originates from the main stem of the Rio Grande and never passes through El Vado. Therefore, the water supply from the main stem of the river that is made available through forbearance cannot be captured and stored for later release unless storage in Cochiti is allowed.

The limiting constraint imposed by storage can be seen by examining the timing and quantities of flow from El Vado and the main stem of the Rio Grande. Embudo is a USGS river gauge located on the Rio Grande just above its confluence with Rio Chama, and all of the flow passing this gauge originates on the main stem. The USGS also maintains a gauge in the Rio Chama below El Vado, measuring the releases from the reservoir. These two gauges illustrate the relative contribution of MRGCD's water supply from El Vado and from the main stem of the Rio Grande. While there is no such thing as a normal year for flow in the Rio Grande, data from 1997 and 2001 are shown in Figure 4 and Figure 5, respectively. Year 1997 was a reasonably full supply year, and 2001 was a drought year. Note that most of the irrigation season flow, about 75 percent of the total of the two gauges, comes from the main stem as indicated by the Embudo gauge. Furthermore, in 2001, El Vado did not begin releasing flow above the base flow until mid-May, and no releases above the base flow were made from mid-June through mid-July. Water forborne during periods that El Vado is not releasing cannot be stored, as it is main stem flow where no suitable storage facility exists. It would flow down the Rio Grande into Elephant Butte Reservoir, and while it would contribute to in-stream flow, the timing of the in-stream flow could not be controlled, and the Rio Grande would not likely be in a critical flow stage if El Vado is not releasing above the base flow.

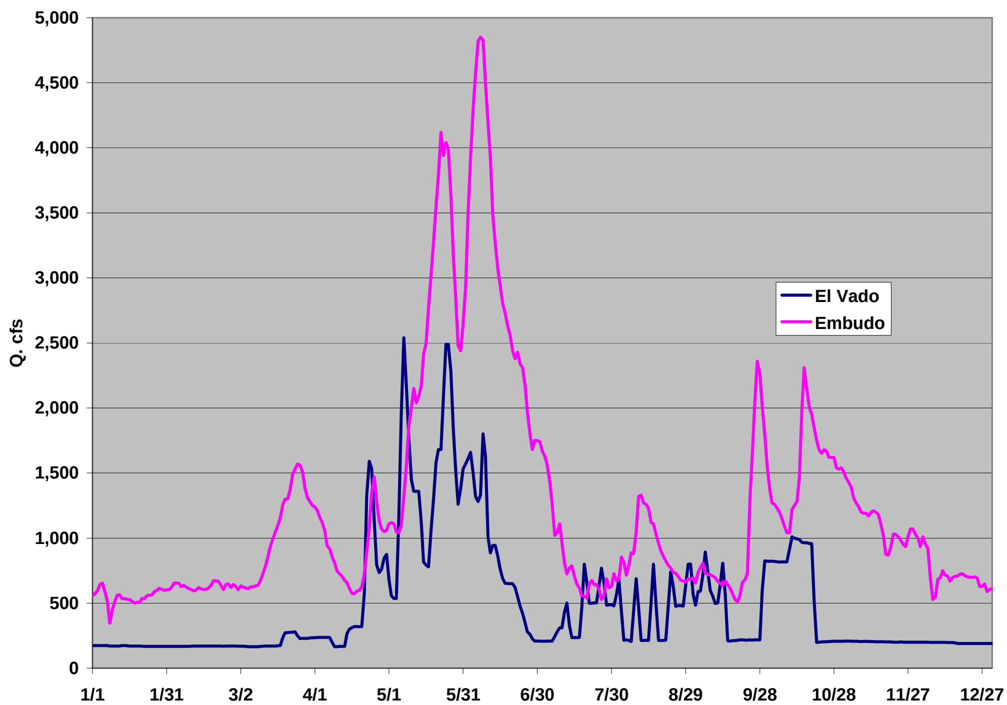

Figure 4: Flow below El Vado and at Embudo gauge, 1997 (USGS, 2005).

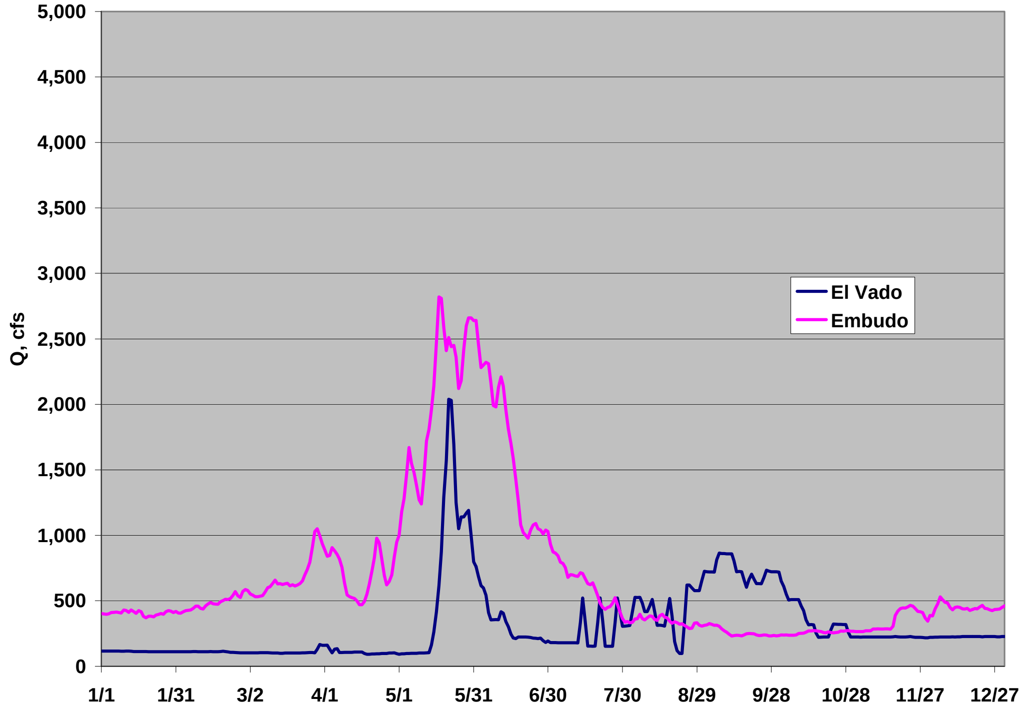

Figure 5: Flow below El Vado and at Embudo gauge, 2001 (USGS, 2005).

This constraint of physical access to storage is a serious limitation on the feasibility of a forbearance program. The amount of water made available for upstream storage discussed previously in this chapter represents the upper limit on actual water available for in-stream flow measurement. The lack of access to storage will significantly reduce the amount of water actually available unless the main stem flow can be regulated.

V. Practical Aspects of Implementing Forbearance

There are several technical, operational, legal, economic, and environmental concerns that will need to be studied in determining feasibility of irrigation forbearance. Some thoughts are listed below:

1. Administration and Monitoring

If a forbearance program is to be effective, it must be carefully monitored and enforced. Irrigators may accept payment to forbear irrigation, but if the water is flowing in their lateral, there is nothing in place in MRGCD's existing operations to prevent the irrigator from taking water anyway. Someone will have to assume a policing role, and MRGCD is the likely entity. They have the best knowledge of the system, operations, individual farmers, and what goes on in their system. This will be a substantial change in the relationship between the District personnel in general and their constituents, and in the District staff's obligations and duties.

The MRGCD has traditionally delivered water rather informally. The District had the luxury, in times of full supply, of keeping its canals and laterals filled the entire irrigation season. Since much of the seepage loss return to the river, the District did not consider it a harmful waste of water. Farmers did not have to irrigate in coordination with their neighbors, and the central control over the highly intricate system was limited. More recently, the District has taken a more active role, implementing a metering program and coordinating irrigation deliveries in a rotation strategy, as described previously.

Forbearance will require a quantum leap in District management and operations. Ditch riders will not only have to act as ditch tenders, they may also wind up enforcing forbearance agreements. This will require training, additional personnel, and additional administration and reporting. Just as the irrigators will be most receptive to a payment program that spreads the cost of the forbearance program over the tax-paying public that benefits from the recovery of the silvery minnow, the cost of additional capacity-building within MRGCD to implement the program should be paid by ESA funding.

One benefit of all irrigators on an entire lateral forbearing, in addition to the hydrologic benefit described in the previous chapter, is the ease of monitoring compliance. If all irrigators on a lateral enter into a forbearance agreement, their lateral headgate can be locked shut for the season and checked occasionally to ensure that no one tampers with it.

2. Groundwater Substitution

MRGCD delivers water to thousands of small irrigators who are authorized to irrigate less than two acres. A great many of these irrigators also have a domestic well, permitted by the State Engineer under New Mexico Sec. 72-12-1. While groundwater is the statutory jurisdiction of the State Engineer, these domestic wells are given a flat water right of three acre-feet, to be used "in relatively small amounts of water consumed in the watering of livestock, in irrigation of not to exceed one acre of noncommercial trees, lawn, or garden, in household or other domestic use …" (NM Statutes 1978). The wells are not required to be metered, and there is no reporting procedure for the State Engineer to monitor their use. It is quite conceivable, and even probable, that some irrigators will agree to forbear canal water, then irrigate from their domestic wells. They will not receive surface water, but they will still deplete groundwater, which will reduce the return flow from the rest of the system, and little is accomplished in terms of saving water for upstream storage.

Groundwater substitution is more problematic than irrigators using surface water in spite of a forbearance agreement because MRGCD does not have authority over groundwater use – the State Engineer does. However, the State Engineer does not monitor domestic well use. It is possible that contractual language could be developed whereby an irrigator receiving compensation for irrigation forbearance would not give up the domestic well water right, but agree not to use it for irrigation during the term of the agreement. This would likely generate additional work for MRGCD, since they would be the likely agency to monitor compliance. Unlike a lateral headgate, the groundwater cannot be shut off for a lateral.

3. Cooperation among Irrigators

The hydrology and administration of a forbearance program both favor forbearance on contiguous lands, particularly where entire laterals can be shut down. However, if even one irrigator on a lateral refuses to forbear, the lateral must still be operated, and the benefits of the lateral versus checkerboard forbearance are lost. The seepage from the lateral will still occur, and the lateral must be monitored for compliance. The oft-quotes statement by Mark Twain that "Whiskey is for drinking and water is for fighting over" reflects the mentality of many water users. Some individuals may hold out because they are opposed in principle to the forbearance program or the environmental goal that it supports, or to attempt to run up the price for their voluntary forbearance.

It will likely be difficult to identify entire laterals that are willing to forbear for manageable compensation, and we consider it virtually impossible to get an entire division to forbear. In the case of Cochiti and Albuquerque Divisions, the sheer number of constituents and the complicating issue of Pueblo irrigators make it extremely unlikely that all would agree to such a program. In the Belen and Socorro Divisions, commercial agricultural producers have large capital investments in equipment and land that require significant revenue to support.

Lateral level forbearance is likely the most attractive forbearance target. With all of the laterals in the District, some will be willing to participate. The hydrologic and administrative advantages over checkerboard forbearance are substantial, and it is much more feasible than main canal forbearance.

4. Environmental Effects

While the objective of forbearance is to provide water for environmental restoration, the environmental groups promoting forbearance should consider the environmental impacts. Currently, the vegetation in MRG's impressive riparian corridor, including native and non-native trees, grasses, and shrubs that support diverse avian and terrestrial wildlife, lives largely on the return flows from MRGCD's diversion, conveyance, and farm application. If irrigators forbear, the major source of water for the bosque will be reduced. One would expect that if all irrigators on a lateral agree to forbear, much of the associated bosque in the associated area may die because the forbearance has created a very localized but severe drought.

The return flows also create some of the best habitat for the very silvery minnow that the program is attempting to save. The low velocities, cover, and persistent nature of the drains make them suitable refuge for the species. As areas are identified as having irrigators interested in forbearance, the impact both on the bosque habitat for avian and terrestrial wildlife and the aquatic habitat of the drains should be evaluated, as it may be more valuable in the larger picture than the forborne water.

5. Storage

As stated in Chapter 2, the Rio Grande Compact prohibits New Mexico and Colorado from storing water in post-1929 reservoirs (including El Vado) when usable water in Rio Grande Project Storage is below 400,000 acre-feet unless they relinquish credit water in Project Storage. Usable Project storage exceeded 400,000 AF in early 2005, and New Mexico has some Article VII storage allowance from previous credit relinquishment. However, the current drought is far from over, and this storage limitation may become a Compact issue when usable Project storage again drops below 400,000 AF and if New Mexico runs out of accrued credit and relinquished credit storage allowance. Even if irrigators agree to forbear, if the flow from the spring runoff cannot be stored and released in the late summer and fall, critical conditions such as those that occurred in 2002 and 2003 will recur.

VI. Conclusions and Recommendations

The hydrology of forbearance is comparatively simple and straightforward in a groundwater system such as the San Luis Valley's groundwater-irrigated areas in southern Colorado. However, the close interaction between surface water and groundwater in the MRGCD makes the quantification of water that can be held upstream as a result of forbearance without impairing irrigators who continue to use water much more complex.

1. Quantification of Water Savings

The hydrology of a riparian irrigation system such as MRGCD is such that the return flows generated by canal and lateral seepage and deep percolation are partially recaptured and reused downstream. Therefore, if an irrigator agrees to forbear, the quantity of return flows that would have been generated by the irrigation of his/her land must be made up by release from storage and diversion to keep downstream irrigators and deliveries to Texas whole.

We have quantified the total diversion and diversion per acre based on MRGCD and Bureau of Reclamation records over the past five years. If none of the return flows were recaptured and reused downstream (return efficiency $e_R = 0$), this would be the amount of water available for storage upstream to manage in-stream flows, and it is the upper limit on water conserved by forbearance. We estimate this quantity to be 7.03 acre-feet per acre.

The lower end is determined assuming that all of the return flow is recaptured and reused downstream (return efficiency e_R = 100 percent). Under this assumption, the water made available for upstream storage by forbearance amounts to the consumptive irrigation requirement (CIR) of the crop, which we estimate to be 2.57 acre-feet per acre.

The actual net amount of water made available for upstream storage by forbearance lies between these two extremes. Canal seepage and deep percolation are the primary source of return flows resulting from irrigation, and we estimate that about 50 % of the seepage and deep percolation is the return flow is recaptured and reused downstream, and so would not be available for upstream storage.

Because of the interconnection of the irrigated lands provided by the canals, laterals, and groundwater system, the geographic pattern of forbearance is critical. We examine three scenarios: checkerboard forbearance, where randomly distributed parcels forbear, lateral forbearance, where all parcels on an entire lateral forbear, and main canal forbearance, where an entire division, or main canal agrees to forbear.

In all three scenarios, the CIR can be kept in storage upstream since this depletion is eliminated. From a hydrological view point, main canal forbearance would yield the most water per acre because the seepage in both the main canal and all laterals in the division would be eliminated. In the lateral forbearance case, the main canal would still need to be filled because other laterals and irrigators along the main would still be using it, but the seepage from the forbearing lateral would be eliminated. In the checkerboard forbearance case, no main canals or laterals can be shut off, so the seepage in the conveyance system is not reduced. For a return flow efficiency (e_R) of 50 %, the resulting quantities of water that can be saved for upstream storage and management of instream flows are shown below in Table 8.

Forbearance scenario	Water saving (ft)
Checkerboard	3.26
Lateral	4.36
Main	4.80

Table 8: Estimates of water saved for storage and in-stream flow management by irrigation forbearance under three scenarios (acre-feet per acre).

Based on the assumption that e_R = 50 %, the amount of land that would need to be forborne to make 100 cfs release from storage available for in-stream flow management in each of the three scenarios is as shown in Table 9:

Scenario	AF/acre forborne	Acreage forborne	Percent of District forborne
Checkerboard	3.26	10,954	18%
Lateral	4.36	8,193	14%
Main	4.80	7,442	12%

Table 9: Acreage and percent of District (based on 60,000 irrigated acres total and CIR of 2.57 ft) that would have to forbear to make available sufficient storage to release 100 cfs for six months (assuming e_R = 50 %).

2. Practical Considerations

The institutional, organizational, and administrative considerations of a forbearance program in MRGCD are far more complex than the district's hydrology. Some of the important considerations in implementing a forbearance program in MRGCD are:

1. Monitoring and administering the forbearance program is beyond existing organization capabilities. Particularly in the checkerboard forbearance scenario, confirming that forbearing irrigators do not use surface water flowing past them in the maze of laterals and small fields will be a major additional burden for the District, assuming they accept responsibility for the job. ***Additional administrative and operational burdens placed on the district should be supported with outside funding.***
2. The MRGCD has thousands of domestic wells that are not monitored for use. If an irrigator agrees to forebear surface water, but continues to irrigate with groundwater, the net savings to the system is drastically reduced. Groundwater is the jurisdiction of the State Engineer, so some interagency cooperation would be necessary to ensure that if an individual agrees to forbear, this includes both surface water and groundwater forbearance. ***Domestic wells are a politically charged issue in the state, and this will present a formidable problem.***
3. It is unlikely that any entire division will agree to forbear. Forbearing at the lateral level may be possible if all irrigators on a lateral will cooperate. Lateral forbearance offers both hydrologic and administrative advantages over checkerboard forbearance. The hydrologic advantage is the elimination of lateral seepage when an entire lateral is shut off. The administrative advantage is that if the lateral is shut off, forbearing irrigators on that lateral will not have water flowing past their turnout to tempt them. Groundwater substitution would continue to be a problem, but it would at least be consolidated into a manageable monitoring area. For these reasons, ***we recommend pursuing forbearance at the lateral level.***
4. The objective of the forbearance is to provide water for ESA compliance in the main stem of the Rio Grande. Ironically, forbearance could have significant effects on the environment of the entire riparian corridor of the middle Rio Grande. The shallow

groundwater and open drains returning canal seepage and deep percolation from irrigation to the Rio Grande provide a significant length and area of habitat.. Forbearance will reduce the recharge to shallow groundwater and may cause a drop in the groundwater level and reduction or even cessation of drain flows. This could cause die-off of riparian vegetation, thereby degrading the available avian and terrestrial wildlife habitat. ***Planning the forbearance distribution should consider this effect.***

5. Using water saved through forbearance is most effective for managing instream flows if it can be stored and released to supplement flows at critical times. There are serious institutional and equity issues associated with upstream water storage. The Rio Grande Compact's Article VII prohibits New Mexico from storing water in El Vado Reservoir when usable Project Storage in Elephant Butte and Caballo Reservoirs drops below 400,000 acre-feet, unless New Mexico relinquishes credit in those reservoirs. Water available for storage in El Vado will come from the SanJuan-Chama water, whereas the forborne water is both direct run-of-the-river and SanJuan-Chama water. ***We recommend that forbearance efforts be closely coordinated with the Interstate Stream Commission's management of Compact credits and deliveries to Texas.***

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