Rio Grande Water Fund Monitoring and Adaptive Management Plan

Final Report

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RIO GRANDE WATER FUND
A Wildfire and Water Source Protection Project

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Introduction

The Rio Grande and its tributaries supply water to Albuquerque, Santa Fe, Pueblos and other communities – water for more than half of New Mexico's population and an essential ingredient for economic growth. The security of water in the Middle Rio Grande and the Rio Chama is increasingly threatened by frequent high-severity wildfires and subsequent post-fire flooding, soil erosion and debris flows that degrade water quality and threaten critical water delivery infrastructure.

The Las Conchas Fire of 2011 exemplified the problem: approximately 45% of the 158,000-acre fire burned at moderate and high severity (USFS 2011). Average size thunderstorms in August, 2011, brought rain to the burned areas and created massive ash and debris flows in Peralta, Bland, Cochiti and Santa Clara canyons. River water turned black with sediment and ash and surface water withdrawals were halted for municipal use by Albuquerque and Santa Fe, while tons of debris was deposited in Cochiti Lake, closing the area to recreation and dumping excessive sediment in the reservoir. Floods, debris and sediments flows from these canyons are still a threat in Rio Grande.

Restoration of overgrown forests, which act as fuel for wildfires, is a proven strategy to reduce the risk of high-intensity wildfire, and such treatments are already underway at a small scale (Cram et al. 2006; Pollet and Omi 2002; Pritchard and Kennedy 2014; Waltz et al. 2014). However, the 2011 Las Conchas and subsequent large fires in New Mexico demonstrated that the pace and scale of these treatments are insufficient to prevent high-severity wildfire and the post-fire flooding and sediment flows that threaten water security for Albuquerque and surrounding New Mexico communities and Pueblos.

The Rio Grande Water Fund Advisory Board is poised to take proactive steps on a large scale to protect the Middle Rio Grande, Rio Chama, and their forested tributaries and headwaters – an area with roughly 1.4 million acres of fire-prone ponderosa pine and mixed conifer forest (Lowry et al. 2007) that needs approximately 600,000 acres of treatment over the next 20 years to reduce fire risks. **The goal of the Water Fund is to protect storage, delivery and quality of Rio Grande water through landscape-scale forest restoration treatments in tributary forested watersheds,** including the headwaters of the San Juan-Chama Project. This goal will be achieved through a variety of activities that:

- Reduce forest fuels, especially in areas identified as high-risk for wildfire and debris flow;
- Mitigate the downstream effects flooding and debris flows caused by wildfires;
- Improve the health and function of streams and riparian areas;
- Support a forest product industry; and
- Generate sustainable funding from water users, government, investors and donors for a 20-year program of large-scale forest and watershed restoration treatments.

The Rio Grande Water will include and pay for a monitoring program to: (1) track the environmental and economic effects of restoration activities; (2) ensure that investments are achieving their anticipated impacts; and (3) enable corrections to management strategies. The process of using monitoring information to make adjustments or corrections to management actions in order to achieve desired outcomes is called adaptive management.

The monitoring program is designed to provide accountability to donors, investors, agencies, external stakeholders, partners, participating communities, and land and water managers. To provide the best economy, the monitoring program will rely on historical and current studies as well as ongoing monitoring programs and protocols that yield relevant data and are being implemented by federal and state resource management agencies.

Progress to Date

The Water Fund's Monitoring Working Group completed a draft of the monitoring plan in March, 2014; the plan was briefly summarized in the Rio Grande Water Fund's Comprehensive Plan (TNC 2014). Since that time, we decided to re-visit and revise the plan for two reasons.

First, given the Water Fund's objective of protecting the *quality* of Rio Grande water, we wanted to expand monitoring of water quality directly or of indicators that indirectly relate to water quality. In the draft plan, there was only a single monitoring metric that addressed the question of whether large-scale restoration activities in the watershed were leading to an improvement in water quality. To this end, we received a contract from the Ciudad Soil & Water Conservation District to evaluate existing monitoring measures for water quality and modify the monitoring plan to incorporate these measures as needed. This iteration of the monitoring plan has six metrics that directly or indirectly relate to water quality.

Second, given the monitoring plan's objective of using monitoring data to enable corrections to management strategies, we revised the plan to create a framework that would facilitate adaptive management.

Adaptive Management

Resource managers are often forced to make land management decisions in the face of little to no information regarding the outcome of those decisions. Adaptive management is a systematic process designed to change this and views management actions as experiments rather than solutions (VCNP 2014). Collection of monitoring data assists in evaluating, and learning from, the effects of management actions and allows adjustments to future management to achieve improved ecological, social, and economic outcomes (Murray and Marmorek 2003; Gori and Schussman 2005). The approach is especially important in the context of anthropogenic climate change where physical and biological responses to management actions and environmental change are not readily predictable based on past experience.

The adaptive management process has five steps (Figure 1):

1) Identification of quantitative management objectives or desired conditions that include measurable triggers or thresholds to determine whether or not the objective is met;
2) Plan and implement management actions that will achieve management objectives or desired conditions (but recall this is an experiment and often the outcomes are not precisely known);
3) Monitor outcomes of the management actions; this involves: (a) selecting monitoring indicators or variables that explicitly relate to the management objectives or desired conditions; (b) identifying the data source and spatial scale of monitoring; and (c) specifying the measurement, analysis, and reporting frequency;
4) Review the monitoring results against the management objectives or desired conditions to determine whether or not the objectives have been met and, if not, review and modify management actions; and
5) Implementation of the needed management changes (and continued monitoring).

In the review phase (step #4 above), there is also an opportunity to revise management objectives and desired conditions based on new monitoring or research information.

The previous draft of the monitoring plan did not articulate quantitative management objectives or desired conditions and, therefore, does not lend itself to the practice of adaptive management.

Monitoring and Adaptive Management Plan

Details of the revised monitoring plan are summarized in Table 1. Each component of the plan begins with a monitoring question of interest to Water Fund donors and stakeholders, including public and private resource managers within the Water Fund area. For each monitoring question, we have identified a quantitative management objective or desired condition drawing from peer-reviewed publications, agency reports, other monitoring plans, and expert knowledge. Following this, the monitoring indicators or metrics that will measure whether the desired condition or management objective is met, the frequency of measurement and reporting, and the source and spatial scale of the monitoring data are described. Wherever feasible, monitoring is proposed at scales that are large enough to match the landscape approach of the Water Fund project. Each component of the monitoring plan (i.e. table row) is given a reference number to facilitate discussion in this report.

Not all monitoring questions have a *quantitative* management objective or desired condition either because the relevant information does not exist or we have not yet completed the necessary modeling or analysis of existing data. These components of the plan will be discussed later in this report, including our plan to address these information needs.

Forest Treatments: The Rio Grande Water Fund will track the number of acres treated in high-priority and lower priority watersheds by forest type and the treatment costs per acre across all treatment projects (Table 1, plan component 3, hereafter referred to as # 3). Project sites will require long-term maintenance to prevent a recurrence of overgrown forests and the associated risk to water supplies. Depending on the forest type and specific location, restored areas will need to be retreated within the life of the Water Fund every five to 20 years to maintain healthy conditions and reduced fire risk.

Forested Watershed Fuel Loads and Fire Behavior: Pre- and post-treatment measurements of fuel loads using Brown's transects, photopoints to document fuel models, and standard plot-based forest measurements, including basal area by tree species, crown base height, crown bulk density, canopy cover and canopy height, will be made in all treated stands (# 4,5). These data will be used to document changes in fuel loads and stand structure in treated areas compared to untreated ones and will be reported annually for treatments conducted in the Water Fund area. The US Forest Service, National Park Service, Bureau of Land Management and Valles Caldera National Preserve, routinely track this information as part of their work. Private landowners and their contractors will also be required to record and report this information as a condition for funding assistance to implement forest treatments on private land. Scientists from the Rocky Mountain Research Station will use FSIM, a sophisticated large fire simulation system, and the stand structure measurements collected in treated stands to quantitatively assess the extent to which Water Fund treatments reduce the potential for active and passive crownfire and reduce flame lengths in treated stands. In addition, FSIM can also predict how forest treatments reduce the probability of ignition and crownfire potential in areas adjacent to treated stands. Modeling will be conducted every 3-5 years and results will be reported at this frequency.

As another method to assess the effectiveness of forest treatments in reducing wildfire risk, when wildfires greater than 1,000 acres in size occur within the Water Fund area, we will summarize the number of acres and percent of treated and untreated stands that burned at high, moderate, low and very low severity as well as the distribution of patch sizes for these burn severity classes in treated vs. untreated stands (# 6). Publicly available, remotely-sensed data, Monitoring Trends in Burn Severity (MTBS) and Rapid Assessment of Vegetation Condition after Wildfire (RAVG), will be used for these analyses. These data are typically available 2 years after a wildfire so the results of the analysis will be reported within the following year.

Watershed Function and Water Quality: Although numerous factors directly and indirectly impact runoff and water quality in the Rio Grande, without extensive monitoring it is very difficult to quantify the effects of forest treatments and improvements in watershed health on water quantity and quality. Therefore, two approaches will be taken to monitoring water yield and water quality. The direct approach will assess the effect of forest treatments, including different thinning prescriptions, on water yield and water quality in a controlled setting using a paired basin study (# 7,8). The Valles Caldera National Preserve received funding through the Southern Rockies Landscape Conservation Cooperative to conduct such a study and is monitoring streamflow, precipitation, water temperature, turbidity, dissolved oxygen, electrical conductivity, and total suspended solids in response to different forest treatments in treated and control (untreated) catchments. Results from this study will be summarized annually and will address the question: what are the effects of forest treatments on water yield and water quality?

The second approach uses a variety of indirect monitoring measures to assess the effectiveness of forest and riparian restoration treatments in improving water quality. These will include tracking the following indicators:

- *Roads:* miles of new roads created to perform forest treatments; miles of roads decommissioned and rehabilitated consistent with design features, best management practices (BMPs), and mitigation measures to reduce soil erosion and minimize water quality impacts (# 9). The expectation is that there will be a net reduction in roads (miles) and rehabilitation of some existing roads, leading to improvements in water quality within the Water Fund area.
- *Forest Treatments:* acres of treatments by forest type implemented in accordance with design features, BMPs and mitigation measures designed to minimize water quality impacts (# 10). In addition, thinning and prescribed burning treatments typically result in an increase in herbaceous vegetation as a result of reduced canopy cover, greater light penetration, and increased soil moisture as the density of competing trees is reduced (Abella 2004; Covington and Moore 1994; Covington et al. 1997; Korb and Springer 2003). Following a wildfire, rapid regrowth of herbaceous vegetation in treated stands will catch soil and ash from burned areas resulting in improvements in water quality compared to untreated portions of the landscape. Within the Water Fund area, the Valles Caldera National Preserve and Bandelier National Monument measure the percent cover and height of native and non-native understory species in treated stands before and 3 to 5 years after treatment (# 11); the US Forest also makes these measurements in specific, but not all, treated stands. The Conservancy will augment these efforts with parallel monitoring on selected treatments that occur on private land. In addition to documenting the increase in herbaceous cover and reduction of exposed bare ground (e.g. soil erosion potential) following forest treatments, this indicator will provide information on the abundance of non-native grasses and herbs. If their cover exceeds the threshold or trigger value of 5% cover then treatment methods can be evaluated and potentially improved to reduce the spread of non-native species. The monitoring results for forest treatments will be reported annually.
- *Debris Flow Risk & Volume:* percent reduction in debris flow risk and volume, compared to the untreated landscape; output from the USGS debris flow model with burned area inputs calculated from FSim or FlamMap fire behavior models (Cannon et al. 2010; Tillery et al. 2014; Table 2).

Riparian Restoration Treatments and Water Quality: Riparian restoration can improve water quality by increasing herbaceous and woody riparian vegetation cover along stream banks and on the floodplain. The increased bankside and floodplain vegetation reduces flood velocities, “filters out” sediments, and reduces bank erosion leading to an overall improvement in water quality downstream. Increased floodplain (roughness) will also increase floodplain aquifer recharge and increase baseflows during the summer low-flow period. The Water Fund will track the miles of channel and acres of floodplain treated/restored and the miles/acres treated in accordance with design features, best management practices, and mitigation measures designed to reduce short-term impacts of treatments to water quality (# 12). In addition, the Rapid Stream-Riparian Assessment will be conducted prior to and 3-5 years after restoration treatments are applied to stream reaches (Stacy et al. 2006). This rapid assessment methodology measures a variety of indicators related to riparian condition and function including channel shading, vertical bank stability, cobble embeddedness, presence of large woody debris, fluvial habitat diversity, upper riparian zone plant community structure and cover, shrub, mid- and upper-canopy patch density (# 13). In addition, herbaceous, shrub and tree cover will be measured along cross channel transects and repeat photographs will be taken at permanent photopoints before and after treatments to document changes in these variables. The Rapid Stream-Riparian Assessment or similar methods are currently being employed by Valles Caldera National Preserve, Santa Fe National Forest, and within the Santa Fe Municipal Watershed.

Jobs and Economic Development: To assess the progress in developing New Mexico's forest industry and job creation, the Rio Grande Water Fund will track the following indicators on an annual basis, the number and type of jobs, duration of these jobs, number and percent of these jobs held by NM residents, tons of woody biomass being sold and utilized, types of wood products generated from woody biomass. This information will be provided by the contractors performing the forest treatments in the Water Fund area through an on-line tool circulated by the NM Forest Industry (# 14). Other possible data sources include the monetary value of service contracts, timber sales and stewardship contracts and agreements.

Networking for Greater Impact: The Rio Grande Water Fund has 30 signatories to its Charter as of April 15, 2015, and more than 45 organizations represented on the Advisory Board. These organizations are all contributing to the goal of the Water Fund (see page 1) in some way, and are benefiting from the collaborative effort to accelerate forest and watershed restoration. We will assess the health of the Rio Grande Water Fund collaborative through an annual survey of the signatory organizations, advisory board members, and other partners. This survey, or Water Fund Health Scorecard (#15), will seek to understand whether the Water Fund is meeting the participants needs and expectations, and the degree to which the members and participants are contributing to the design and implementation of larger-scale projects as a result of the collaboration (Plastrik et. al. 2014). The scorecard will be developed in summer 2015 and the first survey will be distributed to signatories and members in early fall 2015.

Rio Grande Water Fund Financing: Sustainable funding is necessary to ensure the Water Fund meets it goals and objectives within the timeframe agreed upon by stakeholders. While some of the work may be paid for through grants and donations, much of the long-term work could be paid for with recurring funding from the state legislature, state and federal agencies, and downstream water users such as municipalities, water utilities, agricultural districts and industry that benefit from the water source protection. The metrics for evaluating funding will consider two timescales: 1) short-term funding (0-20 years) that primarily finances treatment of the targeted 600,000 acres in high-priority watersheds; and 2) long-term funding (beyond 20 years) that finances maintenance of previously treated areas. In the short-term, the objective is that sufficient funds are available by 2017 to meet targeted treatment goals—30,000 acres of forest treated per year for the next 17 years. The Rio Grande Water Fund will track and provide annual reports on funds raised from different sources including government to government funding, private donors, municipalities, water utilities, agricultural districts and industry as well as the number and type of funders (# 1,2).

Additional Monitoring—Testing Assumptions

In addition to the monitoring summarized in Table 1, we will also collect information that can be used to test important assumptions of the Rio Grande Water Fund related to: (1) debris flow risk and volume; (2) the effect of forest treatments on runoff (water yield); and (3) the costs of forest treatments vs. the avoided cost of a large, high severity wildfire.

For the first, fire behavior output from FSim will be used to model debris flow risk and volume using the methods described in Cannon et al. (2010) and Tillery et al. (2014). This will be done using current forest stand conditions in the Water Fund area and, and again, for the target goal in 2034, 600,000 acres of fire-prone forest treated in high priority watersheds. Using FSim modelling results that will be repeated every 3-5 years with current treatment information, the estimated reduction in debris flow risk and volume from the 2015 values will be reported and progress toward the end-goal, the 2034 reductions, will be tracked.

In addition, we will use forest treatment information, specifically the basal area of trees in stands before and after treatment, to estimate (model) increases in water yield. The method uses regression equations derived from paired basin studies conducted in the Southwest during the 1960s to 1980s for thinning treatments in ponderosa pine and mixed conifer forests (Robles et al. 2014; F. O'Donnell, unpubl. data). The equations have several limitations that ongoing paired basin studies do not have. First, they are influenced by the type of forest thinning practices conducted in these watershed experiments, such as strip-thinning and patch clearing that had a similar range of basal area reductions but different spatial configurations compared to current thinning prescriptions. Second, the experiments were conducted on a limited set of soil types and soils can significantly affect runoff (Campbell et al. 1977; Ffolliott and Baker 1977). Finally, increased temperatures due to climate change in recent decades have resulted in a declining trend in snowpack throughout the West controlling for patterns of natural climate variability (Mote 2006; Pierce et al. 2008). Thus, these historic runoff models may overestimate water yield increases in response to thinning treatments due to changes in watershed hydrological processes caused by climate warming. Still, these estimates provide interesting information on the potential impacts of forest treatments on runoff within the Rio Grande Water Fund area and can supplement the results of the Valles Caldera paired basin study.

Finally, we recently completed an analysis of the estimated costs of a large, high severity wildfire occurring in the San Juan-Chama project drainages on both sides of the Continental Divide in New Mexico and Colorado; these estimated wildfire costs will be compared to forest treatment costs, to test our assumption that the treatment costs, spread across many years, are less than the avoided cost estimates of a wildfire. We will update the avoided cost analysis with current unit costs every 3-5 years and compare the avoided costs with actual treatment costs in the San Juan-Chama project drainages.

Next Steps—Revisions to the Monitoring and Adaptive Management Plan

The monitoring and adaptive management plan is a "living" document that will be updated as new research and monitoring information becomes available. Quantitative management objectives or desired conditions have not yet been identified for two components of the monitoring plan. The first relates to the effectiveness of treatments in reducing modeled fire behavior (# 4) and the associated management objective will identify the reduction in acres and percent reduction in active and passive crownfire and the percent reduction in flame lengths resulting from treatments in high priority watersheds after 20 years. In order to do this, and set the 20-year objective, we need to model wildfire behavior, that is, active and passive crownfire activity and flame lengths, under current forest conditions, using LANDFIRE current stand structure data for the Water Fund area, and again for 2034 after 600,000 acres of forest have been treated. We are now working with the Rocky Mountain Research Station to conduct this modeling and expect a result by early 2016.

Similarly, for stream restoration projects, we have specified that these treatments will *improve* water quality and *increase* herbaceous and woody riparian vegetation cover along banks and on the floodplain within 3-5 years after treatment, but have not specified a quantitative percentage increase or improvement in these indicators. As we learn more about the extent and time-course of riparian vegetation recovery and improvements in water quality from monitoring information collected in and out of the Water Fund area, we can improve our management objectives or desired conditions for these projects. In addition, the desired condition statements and quantitative triggers for other components of the monitoring plan may be revised as additional research and monitoring information becomes available (Table 1).

We also anticipate adding another component to the monitoring plan related to the effects of forest treatments on soil moisture; soil moisture is an important variable that impacts watershed hydrological processes, drought stress, tree vigor and survivorship, and the occurrence of insect outbreaks (Williams et al. 2012; Grant et al. 2013). Identifying a management objective for this will require a review of the literature to identify how different thinning prescriptions, reductions in tree density and basal area, and biomass removal techniques affect soil moisture following treatment; results from the Valles Caldera paired basin study will provide additional information. Soil moisture monitoring in treated areas will likely occur only in selected areas on the Valles Caldera National Preserve and on the Santa Fe National Forest.

Finally, Table 1 currently has no information on the costs of collecting and analyzing the monitoring data or conducting the modeling for specific components of the monitoring plan. These costs may be important for prioritizing which monitoring components should be implemented in the event that funds for monitoring are limited; in any case, an estimate of the total monitoring costs will be useful for planning purposes. We will complete this task over the next few months.

Adaptive Management Process

The Conservancy will coordinate the analysis and summary of the available monitoring data and modeling results on an annual basis, as specified in Table 1 (e.g. frequency of measurement/reporting). This information will be presented to the Monitoring Technical Team, a volunteer team comprised of scientists and resource managers with expertise in the analysis and interpretation of monitoring data and forest and riparian-aquatic habitat management. The Team will meet once a year in the winter, beginning in winter 2015, when monitoring data will be reviewed and compared to management objectives. If the quantitative triggers are not met, the Team will discuss changes in management that may be necessary to improve management outcomes; recommended changes may include modifications to treatment prescriptions and biomass removal methods, changes in the size or location of treatments, or revisions to management objectives or monitoring methods based on new information. A summary of monitoring results, along with any recommended changes by the Monitoring Technical Team, will be presented to the Charter Signatories for input in spring (spring 2016) and then forwarded to the Executive Board for final decision on any recommended changes. The monitoring data and results will also be posted on a website so that they are available to all Water Fund stakeholders and the public. This iterative process will provide peer review and allow different perspectives to be incorporated into future planning.

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Figure 1. A schematic diagram of the adaptive management process; see text for further explanation. The figure was adapted from VCNP (2014).

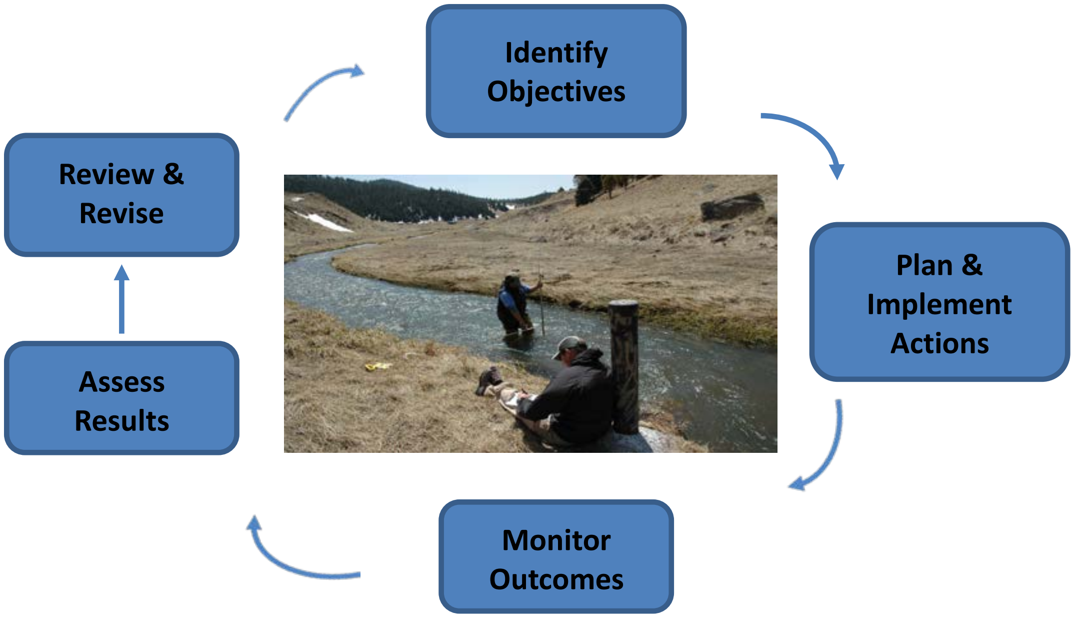

Table 1. Monitoring questions and their associated management objectives or desired conditions, monitoring indicators, frequency of measurement and reporting, and source, spatial scale and cost of collecting/analyzing the monitoring data. Reference numbers are given in parentheses for each component of the monitoring plan. Abbreviation: BMPs = Best management practices.

Monitoring Question & Reference Number	Management Objective/Desired Condition	Monitoring Indicator	Frequency of Measurement/ Reporting	Data Source/Spatial Scale/Cost
How many people are investing in and benefiting from the RGWF? **(1)**	A broad constituency of stakeholders are investing in and benefiting from the RGWF.	# and type of donors	Track annually	RGWF Executive Board & TNC
Is investment in the RGWF sufficient to meet goals? **(2)**	Funds available for treatment are sufficient to meet progress goals identified in #4.	Amount of money available: government to government funding, private donor funds incl. funds from utility rate-payers.	Track annually	RGWF Executive Board & TNC
What progress is being made in meeting our acreage goal for forest treatments? **(3)**	By year 3 (2017), 30,000 acres of forest are treated per year and $\geq$ 50% of these treatments are in priority areas; 600,000 acres of forest treated by 2034.	Total acres treated; acres treated in priority (high risk) areas; acres treated by forest type; treatment cost/acre	Track annually	Agencies, landowners conducting forest treatments
How effective have treatments been at reducing modeled fire behavior? **(4)**	Treatments reduce potential for active and passive crownfire and reduce flame lengths.	In each treated stand: crown base ht., canopy cover, canopy ht., crown bulk density and basal area; include Brown's transects and photopoints to measure fuel loading and document fuel model before and after treatment. FSIM modeling generates: acres w/ crownfire potential (active & passive); acres w/surface fire potential; and flame length. Also, need to track type of treatment and how fuels are removed from site (e.g., lop & scatter; lop, pile & burn, harvest and Rx fire).	Ground-based monitoring indicators measured annually on a in treated stands; FSIM fire modeling conducted every 3 to 5 years by RMRS and/or Region 3 USFS	Stand-level data collected by agencies & landowners receiving funding through RGWF; TNC modifies landscape input file for FSIM modeling
Do treatments in an area reduce ignition probability and crownfire potential fire in areas adjacent to forest treatments? **(5)**	Treatments reduce the probability of ignition and crownfire potential in untreated forest adjacent to treated areas; maximum patch size of forest expressing stand replacement fires (crownfire potential) adjacent to treated stands is 50 acres after 5 years and 10 acres after 10 years.	In each treated stand (and untreated forest): crown base height, canopy closure, canopy height., crown bulk density, and basal area; include Brown's transects and photopoints to measure fuel loads and document fuel models pre- and post-treatment. FSIM models pixel by pixel probability of ignition and probability of crownfire given an ignition; threshold for probability of crownfire needed to determine maximum patch size expressing crownfire (e.g. stand replacement fire) in adjacent stands.	Modeled every 3 to 5 years; in 2015 establish burn probability and acres with crownfire potential for Water Fund area and then model final burn probability after treatment of 600,000 acres (2034); in 2018, model actual treatments completed to date and repeat modelling at 3-5 years intervals after this.	Stand-level data collected by agencies & landowners receiving funding through RGWF; untreated stand information from agencies or LANDFIRE. TNC modifies landscape input file for FSIM modeling
How effective have treatments been in reducing observed burn severity during a wildfire? **(6)**	Wildfires that occur in treatment areas are predominantly low or very low severity. Less than 5% of treated areas in dry mixed conifer and less than 11% of treated areas in ponderosa pine burn at high severity; all high severity burn patches are < 20 acres in size.	Acres of treated and untreated forest that burn and experience high, moderate, low and very low severity burn	Two years after any wildfires greater than 1,000 acres in RGWF area	Monitoring Trends in Burn Severity (MTBS) data or Rapid Assessment of Vegetation condition (RAVG) data
What are the effects of forest treatments on water yield? **(7)**	Water yield in treated sub-basins is more than 10% greater than in untreated basins.	Measured runoff in treated vs. untreated sub-basins.	Annually	Paired basin study--Valles Caldera National Preserve
What are the impacts of forest treatments on water quality? Does water quality improve in treated areas compared to (continued)	Water quality recovers faster and is higher in treated vs. untreated basins following wildfires.Water quality improves or is similar 3 years post-treatment in treated basins	Temp, turbidity, dissolved O_2, electrical conductivity	Annually	Paired basin study--Valles Caldera National Preserve

Monitoring Question	Management Objective/Desired Condition	Monitoring Indicator	Frequency of Measurement/ Reporting	Data Source/Spatial Scale/Cost
untreated areas following mechanical thinning? Following a wildfire, is water quality higher in treated basins compared to untreated ones? **(8)**	compared to untreated ones.			
Have accelerated treatments increased the number (miles) of roads in the Water Fund area? Are treatment access and legacy roads decommissioned in accordance with design features, BMPs and mitigation measures to prevent or minimize water quality impacts? **(9)**	There is no net increase in roads (miles) within the RGWF project area. Impacts of access and legacy road on watershed condition are reduced due to decommissioning or rehabilitation in accordance with design features, BMPs and mitigation measures.	Miles of road created; miles of road decomissioned consistent with BMPs, design features & mitigation measures; miles of road rehabilitated consistent with BMPs, design features & mitigation measures to reduce soil erosion & water quality impacts; net road reduction (miles)	Annually	Agencies, landowners conducting treatments
Are mechanical treatments implemented in accordance with design features, BMP's and mitigation measures to minimize impacts on water quality? **(10)**	Mechanical treatments are implemented in accordance w/ design features, BMP's and mitigation measures to minimize impacts on water quality.	Acres of treatment by forest type implemented in accordance with design features, BMPs and mitigation measures.	Annually	Agencies, landowners conducting treatments
Does understory herbaceous vegetation increase after forest treatments? **(11)**	Within 5 years of treatment, cover of native understory vegetation increases to 20% (+/-5%) and percent bare soil decreases to < 30% in treatment areas, thereby reducing soil erosion and impacts to water quality. Non-native species increase by < 5%. Post-fire recovery of watershed condition is accelerated due to increased cover of native understory species.	Percent cover and height of native and non-native understory species.	Annually; report includes analysis of data for treatments implemented 5 years earlier	Field data collection along transects; monitoring conducted by Valles Caldera National Preserve, Bandelier National Monument (NPS) for treatments on their land; TNC collects these data for selected treatments within RGWF area
Are riparian restoration treatments occurring and being implemented consistent with design features, BMPs & mitigation measures? **(12)**	Riparian restoration treatments are occurring and implemented in accordance with design features, BMPs, and mitigation measures.	Miles of channel and acres of floodplain restored; miles/acres restored in accordance with design features, BMPs and mitigation measures.	Annually	
Do stream restoration treatments improve water quality and increase riparian vegetation cover along banks and within the floodplain? **(13)**	Stream restoration treatments improve water quality and increase herbaceous and/or woody riparian vegetation cover along banks and on the floodplain within 3-5 years of treatment.	Rapid Stream-Riparian Assessment (Stacy et al. 2006) including: algal growth; channel shading; floodplain connection & inundation; vertical bank stability; riparian area soil integrity; cobble embeddedness; large woody debris; overbank cover and terrestrial invertebrate habitat; lower and upper riparian zone plant community structure and cover; shrub-tree demography and recruitment; non-native herbaceous and woody plant species cover; mammal herbivory impacts on ground cover, shrubs, and trees; shrub patch density; mid-canopy patch density; upper-canopy patch density and connectivity; and fluvial habitat diversity. Includes cross-channel transects to measure ground cover, shrub & tree cover and photopoints to document changes.	Measured prior to treatment & repeat 3-5 years after treatment.	

Monitoring Question	Management Objective/Desired Condition	Monitoring Indicator	Frequency of Measurement/ Reporting	Data Source/Spatial Scale/Cost
How many direct jobs are provided by thinning projects supported by the Water Fund? Are those jobs held by NM residents or by people working for out-of-state companies? Is the wood generated by thinning projects supported by the Water Fund being utilized? What kinds of products are being made from wood generated by thinning projects supported by the Water Fund? **(14)**	Every 1,000 acres of thinning supported by the Water Fund will generate 22 total direct jobs, for example 4-10 jobs in mechanical or hand thinning; 8 jobs in product manufacturing and sales; 7 jobs in planning and transportation. Every 1,000 acres of thinning supported by the Water Fund will generate 6,000 tons of woody biomass for use in products from mulch to biofuel.	Number and type of jobs; percent of these jobs held by NM residents; tons of woody biomass being sold and utilized; types of wood products generated from the woody biomass.	Annually	Contractors working on thinning projects in RGWF focal areas with information provided through a Survey Monkey tool circulated by the NM Forest Industry Association.
What is the health of the Rio Grande Water Fund as a collaborative? How many signatories to the Charter and advisory board members? What is the diversity of signatories and members? What is the connectivity among signatories and members and what are the collaborative activities they are engaged in? **(15)**	The Rio Grande Water Fund has a diverse set of signatories who are actively engaged in the working groups and contributing resources and funding to large-scale restoration planning and implementation.	Number and diversity of signatories to the Charter and of advisory board members; Number of signatories and members serving on working groups and in positions of leadership; connectivity of signatories and members to one another in large-scale restoration projects; and type and status of restoration activities that signatories and members undertake together.	Annually	Develop a Water Fund Health Scorecard using guidance in Plastrik et. al. 2014

Table 2. Additional monitoring to test assumptions of the Rio Grande Water Fund; monitoring results from these components will likely not lead to a change in management strategies or adaptive management, but may be of interest to Water Fund stakeholders.

Monitoring Question	Management Objective/Desired Condition	Monitoring Indicator	Frequency of Measurement/ Reporting	Data Source/Spatial Scale/Cost
How effective have treatments been at reducing debris flow risk and volume?	Modeled debris flow risk and debris flow volume are reduced.	Percent reduction in debris flow risk and percent reduction in debris flow volume; modeled output from USGS debris flow model	Annually	FlamMap or FSIM output/USGS debris flow model output
Does water runoff (yield) increase as a result of forest treatments?	Modeled water yield increases in treated areas and watersheds.	Increase in water yield (acre-ft) in treated areas and watersheds using empirically-derived equations for ponderosa pine & mixed conifer; basal area (pre/post treatment), vegetation type, location	Annually	Regression equations developed for ponderosa pine (Robles et al. 2014) and mixed conifer (F. O'Donnell, unpubl. data)
What is the estimated cost of a 180,000-acre wildfire impacting San Juan-Chama project drainages on both sides of Continental Divide in Colorado and NM? How does this compare to actual forest treatment costs to reduce the risk of wildfire in approximately the same area (140,000 acres)?	Costs of treatment, spread across many years, are less than the avoided (or estimated) cost of wildfire. The total avoided cost is estimated to be from $104M to $1.3B, or $578 to $72,000/acre. This is compared to the total treatment cost estimate, from $72M to $174M, or $500 to $1,200/acre.	Actual treatment costs vs. avoided (or estimated) cost of a wildfire.	Update the avoided cost analysis with current unit costs approx. every 3-5 years. Other avoided cost analyses are also a source for unit costs used to generate estimates for both treatment and avoided costs.	Federal and state agencies, water utilities, land owners, and other stakeholders.