San Juan-Chama Headwaters Return on Investment Study for the Rio Grande Water Fund

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Special thanks to Steven Bassett of The Nature Conservancy whose fire modeling informed this study

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1. Introduction

The Rio Grande Water Fund ("RGWF" or "Water Fund") is an initiative of the Nature Conservancy ("TNC") and partners to "accelerate ecological restoration of forests throughout the upper Rio Grande watershed for communities, fish and wildlife, wildfire protection, and clean-water security" by proactively addressing the threat of high-severity fire, and the associated impacts on people and watersheds, through landscape-scale forest restoration treatments.

The goal of this study was to evaluate the return on investment (ROI) from the RGWF for the headwaters basins of the US Bureau of Reclamation's San Juan – Chama Project ("Project"). Results, therefore, only represent a portion of the benefits associated with all forest restoration treatments planned by RGWF across the larger Rio Grande watershed. We chose to focus on estimating the avoided costs of wildfire associated with market goods and services to best target values likely to represent potential motivation for RGWF funding. Avoided financial costs are generally the most germane to planning the public and private financial investments needed to support Water Fund treatments.

The Project diverts some 86,100 acre-feet (AF) of water per year from tributaries to the San Juan River in the Colorado River basin for delivery to the population centers of New Mexico's Middle Rio Grande basin via a tunnel under the continental divide. Project water originates in the headwaters of the Rio Blanco, Navajo and Little Navajo rivers in the southern San Juan Mountains just north of the Colorado state line from Chama, New Mexico. In the event of severe wildfire in these basins, there is concern that this critical water source for New Mexico could be placed at risk. Preventative forest treatments that seek to reduce the size and severity of wildfire in these basins has the potential to manage this risk, but questions remain about the benefits of this strategy relative to costs. This report estimates the return on investment of the RGWF forest treatments in this geography that is so critical to New Mexico's water supply.

This report outlines methods, data collection and analysis before presenting results for two "representative" fire scenarios in the Project headwaters in the Rio Blanco and Navajo River basins in Archuleta County, Colorado. For each fire, impacts were estimated for both "current" and "RGWF treated" scenarios. The difference in impacts allowed us to gauge the return on investment of the Water Fund's proposed treatments *in the event where the representative fire occurs.* Due to resource constraints, we did not undertake efforts to estimate the likelihood or timing of wildfires needed to calculate an expected value of the benefits from the RGWF. A full treatment and restoration plan for the RGWF is not currently defined, while the overall intention of the RGWF and effectiveness of full treatments in general are both well accepted. Consequently, while the simulation modeling results for the "current" scenario are relevant, and likely accurate, modeling results for the "RGWF treated" scenario are less so. We rely on a combination of simulation runs, experiences elsewhere, and generally accepted science and practice concerning fuel treatment effectiveness to identify and calculate wildfire effects under treatment scenarios. Accordingly, this study relies heavily on the assumption of a carefully designed and implemented treatment and restoration plan.

In addition, we discuss limitations of the study and opportunities for refinement of the study in the future.

2. Methods

The following sections provide an overview of the "representative fire" approach used as well as details of the study areas where treatment occurs, where and how the representative fires occur, and how related impacts are quantified and incorporated into return on investment analysis. Assumptions about post-fire downstream water resource impacts are described in greater depth in Section 3. In addition, we discuss potential benefits not included in the study and provide an explanation as to why they were not included.

2.1 Event-Based "Representative Fire" Approach

This study used an event-based "representative fire" approach to gain insight into the economics of RGWF treatments in the headwaters basins for the Project in Archuleta County, Colorado. Under this approach, we used fire-modeling software to develop two different representative fires, each of which was simulated under landscape conditions reflecting current conditions and improved post-RGWF treatment conditions. As expected, fires were substantially less damaging in the "RGWF treated" scenarios. We then estimated total costs of each fire in each case, and contrasted the "current" and "RGWF treated" scenarios to estimate the benefits from the RGWF treatments. Comparing these benefits with costs generated net present value and return on investment estimates of the Water Fund's treatments.[1]

The Project imports water from the Blanco, Navajo, and Little Navajo basins to the Rio Grande basin through a series of diversion dams and tunnels under the continental divide. Thirteen contractors, comprised of municipalities, irrigation districts, and Native American tribes, receive annual allotments to Project water, which is used for municipal and agricultural purposes primarily in the Middle Rio Grande Valley in Central New Mexico. Project water is an important supply component for these "downstream" water users. For this reason, there is particular interest in the costs and benefits of the RGWF in this geography.

Details about the location, size, and timing of the fire, as well as of the RGWF treatments, of course drive results. In the extreme, a large fire, occurring in an area with high value assets, and assumed to ignite in the near future will have larger economic impacts than a small blaze in an undeveloped area occurring some time from now. There are also assumptions to be made about the extent (and therefore cost) of RGWF treatments. On the one hand, it is unrealistic to associate only treatments that mitigate a specific representative fire with the benefits of preventing that fire, because the location and timing of the fire is unknown. "Cherry picking" the fire-treatment scenario yields little useful information – we all know that if you could buy insurance the day before being robbed the policy would pay off handsomely.[2] At the same time, associating the entire cost of an ambitious treatment effort like RGWF with the benefits of a single fire is overly conservative, because it counts costs of some treatment without acknowledging commensurate benefits over the full effective lifespan of those treatments.

The key to having this analysis deliver value is in ensuring that each fire is in fact realistic, or "representative". Described in greater detail below, two fires were modeled using simulation software under dry conditions with ignition points in areas of the Project headwaters where RGWF treatment projects are already underway or being planned in conjunction with the Chama Peak Land Alliance, Reclamation, and local stakeholders. One fire originates in the Blanco basin (the "Blanco" fire), while the other originates in the Navajo basin (the "Oso" fire named for the Project's Oso diversion from the Navajo River). The treatment acreage used includes areas both inside and outside of fire perimeters in the Blanco and Navajo River basins, and was chosen to reflect a realistic program of fuels reduction. The treatments also occur in the Little Navajo Basin, the third source watershed for the Project, although the modeled fires do not burn that watershed. Treatment acreage was held constant across both fires, reflecting the reality that the decision to treat is made prior to knowing where the fire will occur. The fires are in size ranges with precedent in Northern New Mexico and the Southern Rockies, and are certainly possible in a future of climate change. A conceptual model of post-fire water impacts completes the scenario used in analysis (see Section 3). The

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[1] Because the costs and benefits of RGWF treatments do not all occur at the same time, we use financial discounting to convert dollar-denominated valuation estimates to comparable figures, measured in 2015 dollars. This "present value" of costs and benefits can then be compared to yield a "net present value" of RGWF treatments.

[2] More so than other focal areas of the RGWF, the Project headwaters are conducive to targeted investment in treatment simply because the areas delivering Project water are discrete and known.

result is two scenarios that are realistic and informative indicators of the cost and benefits of the RGWF activities described, well-suited to informing stakeholder understanding of the Water Fund.

Importantly, this approach is "representative" but does not attempt to provide a probabilistic estimate of its likelihood. Recent years in the western US have seen variable fire seasons, with good years of limited activity interspersed with periods where multiple major blazes were burning simultaneously. The fire scenarios and associated return on investment described in this study are not assured. Fires could occur in larger or smaller sizes, in locations more perilous or relatively benign, and in greater or fewer numbers. Or, severe wildfire could occur without producing downstream water impacts, perhaps because of an auspicious lack of rain in the more unstable areas in the years immediately after fire. The economic case for the RGWF will vary accordingly, with our representative fire scenarios being one plausible outcome among many.

Despite this caveat, there is evidence from scientific literature that climate change in the Southwest will lead to increased frequency and magnitude of wildfire in the study area. While a complete review of this literature is beyond the scope of this report, frequency of large wildfires is projected to increase with continued climate warming and human activity leading to an increase in annual area burned by large wildfires (Westerling et al. 2011a, 2011b; Lutz et al. 2009; and Syphard et al. 2007). In addition, extreme wildfire weather becomes more common with continued increases in temperature (Collins 2014). Intensity of wildfire is also expected to increase; as area burned increases, area burned by high-severity fire is also likely to increase (Dillon et al. 2011; Miller et al. 2009; Miller and Safford 2012; Harris and Taylor 2015; van Mantgem et al. 2013). For the RGWF and its planned forest treatments in the Project headwaters, this means that the probability of a fire occurring is increasing, and with it the risk-weighted value of avoiding fire is also likely to increase. Climate chance makes an investment in RGWF treatments more likely to "pay off" in the future than historical trends would dictate.

Modeling the actual effectiveness of the RGWF treatment and restoration efforts is difficult at the time of this writing, both because the full treatment plan is not completely defined, and simulation modeling tools are too coarse to capture the full effectiveness of treatments to protect valuable assets and facilitate more successful protection and suppression efforts in the case of a fire. Where valuable and fire-sensitive assets occur, a treatment plan would provide targeted protections, and produce conditions that reduce the risk while increasing the effectiveness of efforts by fire crews. The benefits of such strategic fire suppression are not well-captured in the model, leading to potential understatement of benefits of the treatments.

2.2 Treatment Scenario

To measure the return on investment from treatments, assumptions about the type and extent of treatments had to be made. To approximate the extent of possible treatments, input was sought from scientists and land managers. Variables including distance from road, land owner, designated Roadless and Wilderness, Wildland Urban Interface ("WUI") context, and slope were identified as criteria for delineating potential treatment areas. Different treatment types are suitable in different areas; suitable treatments were defined by overlaying the variables used to determine treatable areas (see Table 1 and Figure 1).

FIGURE 1 TREATMENT SCENARIO

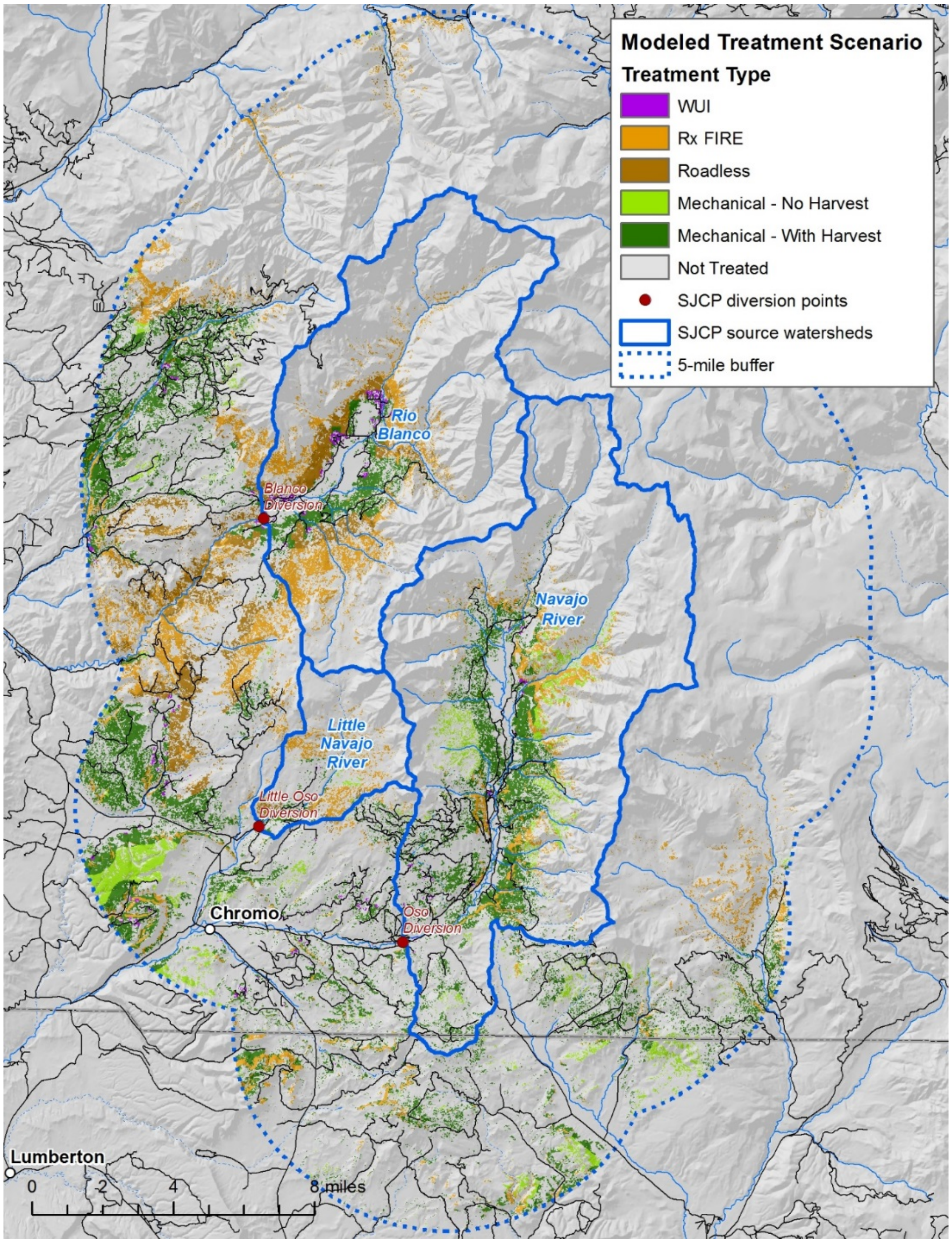


TABLE 1 TREATMENT CRITERIA

Treatment Type	Treatable Vegetation Type	Near Road (<1/2 mi)	WUI	Slope < 30%	Designated Roadless	Private	Wilderness
1. WUI	x	x	x	x	x	x	
2. Mechanical w/Harvest	x	x		x		x	
3. Mechanical w/o Harvest	x			x		x	
4. Roadless	x				x		
5. Rx Fire	x	x		x	x	x	x

Treatments were assigned in the order above with lower numbers taking precedence. Once treatment areas were identified, the fuelscape was modified using the transitions from the LANDFIRE Fuel Rulesets Database, used by the LANDFIRE program to account for fires, fuels reduction treatments and other disturbances (LANDFIRE 2015). Rules for determining conditions seven-years post-treatment were used to approximate the changes observed over the life of the treatments. In WUI and mechanically harvested areas, "high severity mechanical remove loading" rules were used. In the Roadless and Rx Fire treatment areas, "moderate severity fire" rules were used to modify the fuelscape. In areas where the existing fuel model was consistent with desired conditions, the pixel was not modified.

For this analysis, the model assumed 17,811 total acres would be treated. These acres were further broken out by assumed treatment type (see Table 2). Treatment acreage was held constant across both fire scenarios, reflecting the reality that the decision to treat is made prior to knowing where the fire will occur.

TABLE 2 TREATED ACRES BY TREATMENT TYPE

Treatment Type	Acres
Harvest	7,893
Mechanical	1,451
Roadless	1,851
Prescribed Burn	6,254
WUI	362
Total	17,811

A collaborative strategic plan for forest resilience and fuels reduction treatments is in development but was not ready in time for this return on investment analysis. Preliminary drafts of the plan indicate the area assumed to be treated in this analysis is smaller than the area that will be treated under the forthcoming collaborative landscape strategy. Without complete fire modeling results, it is not possible to forecast the impact of the larger treatment plan on the economics of the RGWF in the SJ-C headwaters.

2.3 Geographic Focus and Distribution of Benefits

This study focuses on the return on investment from RGWF activities, highlighting the distribution of Program benefits among stakeholders where possible. Impacts were explicitly assessed from the perspective of two stakeholder groups:

- The SJ-C Headwaters, more specifically Archuleta County, Colorado and Rio Arriba County, New Mexico; and
- Downstream stakeholders including Santa Fe, Albuquerque and the Middle Rio Grande Conservancy District, among others.

It is important to consider the geographic context and distribution of benefits and to understand that this study addresses only a minor portion of the larger RGWF effort.

2.4 Fire Scenario Modeling

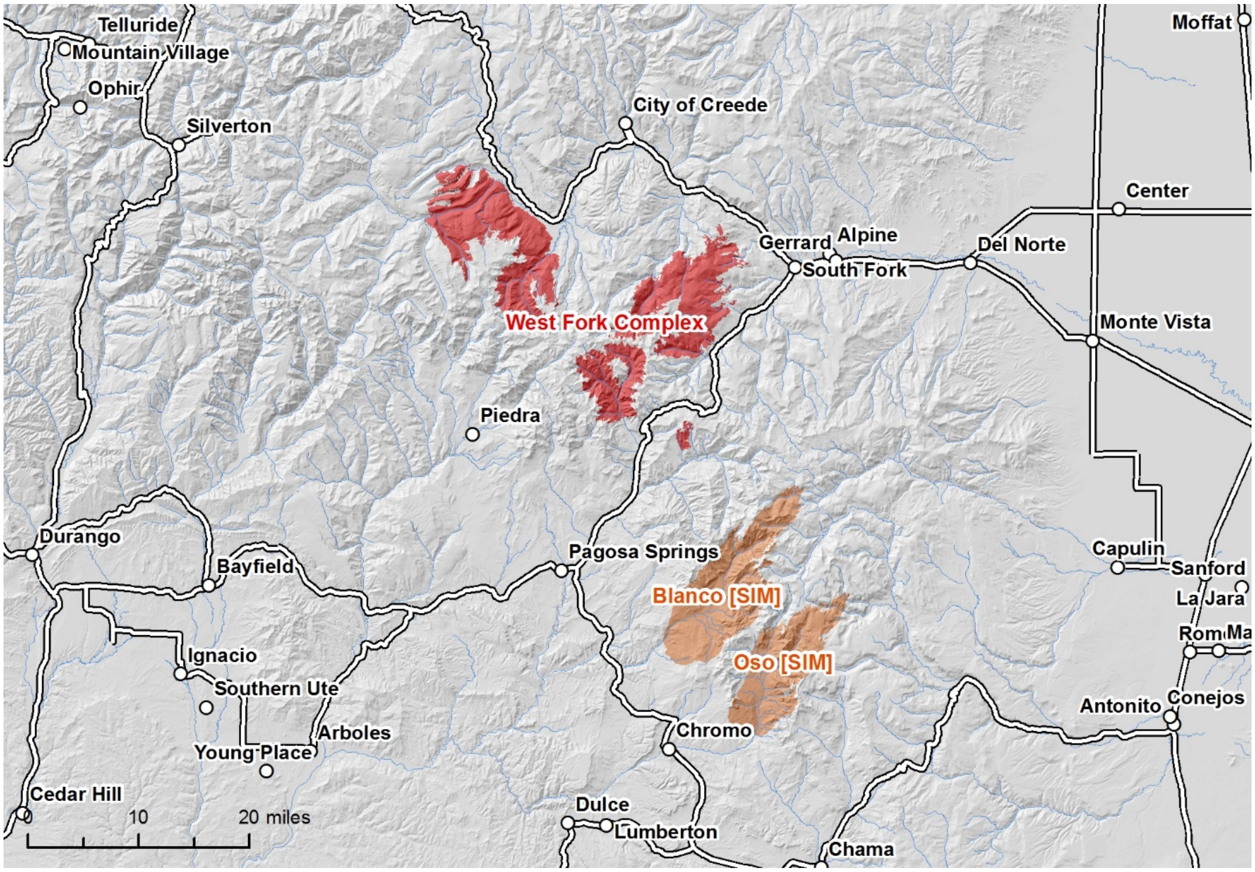
Modeled flame length is a measure of fire intensity and has been used to approximate the likely effects of a fire (e.g., Butler et al. 2014; Buckley et al. 2014; Roose et al. 2008). It is also used by Wildfire Incident Managers to understand potential fire behavior and the likely effectiveness of suppression and control efforts (NWCG 2013). In this analysis, values such as vegetation and infrastructure were overlaid with modeled flame lengths to calculate the area (or length) of each value impacted by high intensity fire.

Fires were simulated with the FlamMap 5 Minimum Travel Time tool (Finney 2006), under near-maximum fuel moisture conditions. Extreme winds outside of the historical period were used to drive rapid-fire growth and spot fire spread. Simulated fire size and behavior were compared to the fires in the West Fork Complex that burned over 100,000 acres in 2013, approximately 20 miles north of the study area (see Figure 2). Table 3 includes a complete list of modeled parameters used in the fire simulation.

TABLE 3 FIRE MODELING PARAMETERS

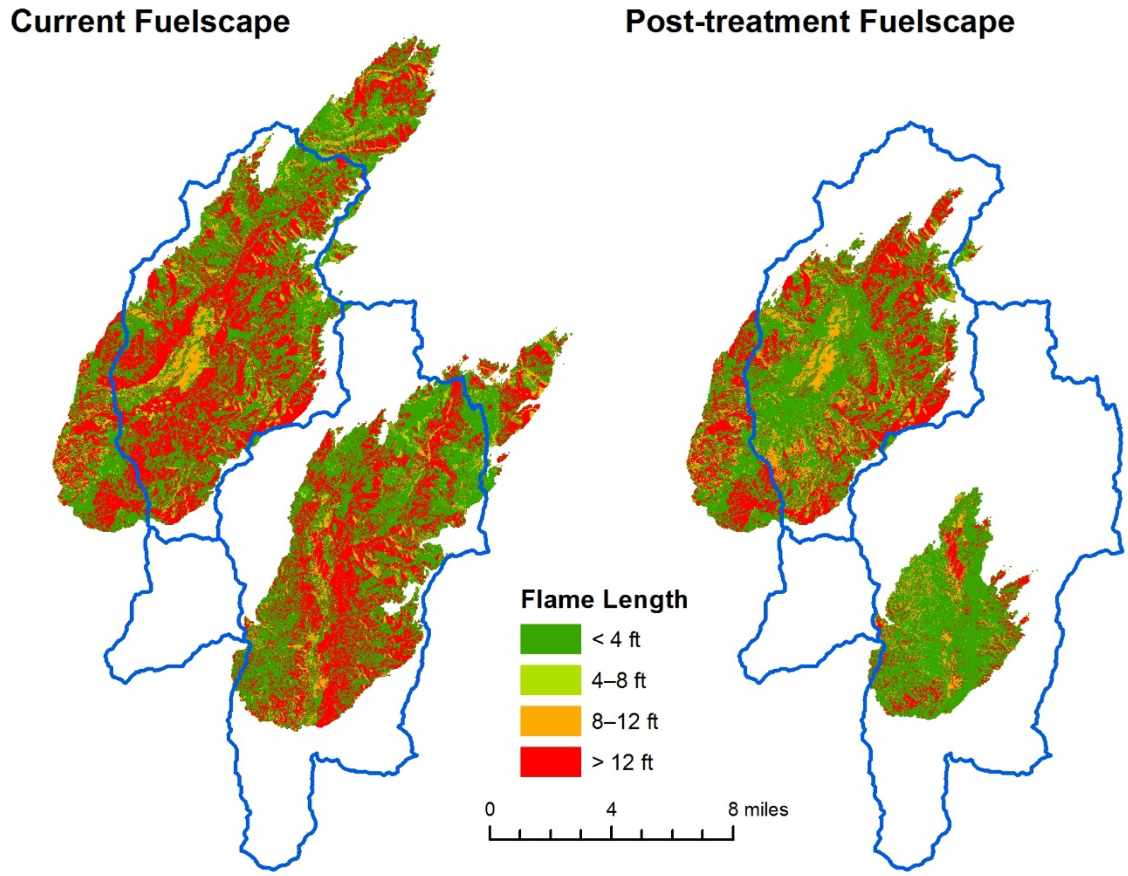
Model Parameter	Value
Wind Direction	225
1-hr Fuel Moisture (FM)	3
10-hr FM	4
100-hr FM	5
Herbaceous FM	60
Woody FM	90
Foliar Moisture	100
MTT Resolution	30
Simulation Time	4320 (minutes)
Interval	500
Spot Probability	0
Spot Delay	15 (minutes)
Lateral Search Depth	6
Vertical Search Depth	4

FIGURE 2 SIMULATED FIRE GEOGRAPHY



Fuelscapes reflecting two treatment scenarios were used while keeping all other parameters the same (Figure 3). Fire start points were placed in areas upwind from the source watersheds in areas with high fire probabilities. The "current" fuelscape was generated from LANDFIRE version 1.3.0, which represents fuels conditions in 2012. No large disturbances have occurred in the study area since then so it is assumed the 2012 fuelscape is still valid. A "RGWF treated" fuelscape was created by modifying LANDFIRE version 1.3.0 to reflect the treatment scenario identified in Section 2.2.

FIGURE 3 SIMULATED FIRE AREA AND INTENSITY UNDER CURRENT AND RGWF TREATED FUELSCAPE CONDITIONS



These fire simulations resulted in burned area of 52,202 and 38,597 acres respectively for the Blanco (north) and Oso (south) fires respectively under current, pre-treatment conditions. Following fuels treatments, the model simulated fires of 37,335 and 14,527 acres respectively for the two events. The program of RGWF fuels treatment therefore is modeled to reduce the areal extent of the fire by 28% and 62%, respectively, for Blanco and Oso fires.

After fire behavior was modeled, the flame length output was classified into four bins representing conditional fire intensity. The flame length classes used in this analysis were modeled on the recent avoided cost study in the Mokelumne watershed in the Sierra Nevada (Buckley et al. 2014). These bins were used to calculate the area impacted by high intensity fire. In addition, certain landscape areas that are valued by the community were overlaid with the modeled flame lengths to identify values that would be impacted by high severity fire.

- To evaluate the threat of fire to forestland in the burned area, vegetation types were overlaid with the flame length data. Generalized categories of forest type were derived from LANDFIRE v1.3.0 existing vegetation data (LANDFIRE 2014).
- The threat of high intensity fire to residential development was also analyzed. Structure data from Archuleta County, Colorado was augmented using additional structures digitized from aerial photographs taken in 2013 for the National Agricultural Imagery Program (NAIP).

- Fire intensity was also overlaid with land ownership data to evaluate which land owners would be most affected by high intensity fire. Land ownership data was aggregated into broad classes from nationwide data (USGS 2012).
- Road centerlines were digitized from the 2013 NAIP imagery.

2.5 Values Not Included

This study focused primarily on financial values substantiated in markets for property, goods, and services impacted. This approach was chosen for three primary reasons. First, using financial values and impacts is appropriate for stakeholders contemplating investing financially in RGWF alongside other potential uses of capital. Economic values that cannot be monetized are important but have less relevance to institutions managing public funding. Second, this approach is inherently conservative—if RGWF provides an attractive investment based solely on market values, then the broader societal economic case for the Water Fund is only bolstered. Finally, non-market valuation is inherently difficult and controversial, and avoiding questionable assumptions is desirable in gaining acceptance of the analysis.

In most cases, we did not explicitly include financial value estimates for "two-sided" benefits or impacts directly resulting from forest restoration treatments such as job creation and revenue from sale of wood products. To do so would require the inclusion of similar type benefits directly resulting from wildfire suppression and rehabilitation efforts and would have unnecessarily complicated the study. For example, while implementing Water Fund treatments would create employment, so would fire suppression, replanting and restoration work, and rebuilding following a major fire.

In general, wildfire also would create substantial impacts on a variety of non-market goods and services. These are important benefits and resources, some might argue of immeasurable value, both locally and more broadly. While literature exists on how wildfire might impact these categories (e.g., Bixby et al. 2015; Venn and Calkin 2011) and well-recognized methods, such as replacement cost valuation, are available, attempting to put a monetary value on some of these categories of impacts may not be appropriate.

The following are impact categories for which a monetary value was not calculated either because of insufficient data or because impacts include non-market values. It should be noted, however, that in all cases, the direction of impacts would be negative—meaning inclusion of some or all of these categories in the analysis would only strengthen the overall benefits resulting from the Water Fund.

- Lost infrastructure for campgrounds and cabins on National Forest land and elsewhere. Campgrounds and rental cabins operate in Archuleta County on both public and private lands, however, we were not able to determine the exact quantity, quality (e.g., furnished cabin vs. wilderness campsite) and location relative to the representative fires modeled. In addition, we were not able to identify reasonable replacement/rebuilding cost information.
- Multiplier effects: The direct impact on an industry is not the only impact wildfire could have on the local/regional economy—as additional multiplier effects may be seen across the broader economy in the form of employment, labor income and value added. When considering the broader effect of changes in economic activity, input-output analysis can be used to model the interrelationships of economic sectors and describe the multiplier effect of changes in one sector across a broader economy. While this methodology is commonly used to estimate the impact of a program or initiative that would result in new money entering an economy, it can also be used to understand how decreases in revenue and/or jobs in one industry sector might affect the larger economy. IMPLAN is perhaps the most commonly recognized input-output model; however, it is proprietary software whose purchase was outside the scope of this study.
- Consumer surplus: Consumer surplus is generally defined as the difference between the total amount a consumer is willing (and able) to pay and the total amount actually paid (i.e., the market price) for a

good or service. For example, our study can generally capture the market impacts of an individual canceling their trip to Pagosa Springs because of wildfire. What it cannot capture is the additional value of that trip to the individual associated with scenery/views unique to that area, the ability to view culturally and historically significant sites, etc..., nor can it capture how much the individual would have been "willing to pay" to ensure the trip was possible. This is a non-market value on which we did not attempt to place a monetary value.

- Cultural/traditional/ personal use: There are a variety of uses and values wildfire would impact that do not directly relate to market activities. In some cases, wildfire would impact individuals' abilities to grow, gather and/or harvest goods for personal use and/or for barter/trade. In other cases, wildfire could impact an area or prevent an activity with cultural, archeological and/or spiritual significance; however, we do not attempt to quantify such values as part of this analysis. While the Southern Ute Indian Tribe owns approximately 14% of Archuleta County, the representative fires do not occur in the general vicinity of these lands and, therefore, are not expected to result in quantifiable impacts to tribal lands or the use of these lands. That does not mean that loss of lands within the representative fires would have no cultural or spiritual impacts on local tribes and/or other individuals who use these areas for personal use, but these are values that we do not attempt to quantify as part of this analysis.
- Ecosystem services: There are numerous ecosystem services generated by forests and watersheds—many of which have the potential to be negatively impacted by wildfire. Examples include the ability to sustain habitat, purify air and water, mitigate floods, generate and preserve soil quality, cycle nutrients, control pests, sequester carbon and more. In addition to general habitat destruction and loss, there are several key species that could potentially be substantially impacted by a large wildfire including the Rio Grande Silvery Minnow, Rio Grande Cutthroat trout and Southwestern Willow Flycatcher, among others.[3] The value of these species and others in the study area, as well as the habitat on which they depend, would primarily be considered a non-market value. Aspects of forest and river ecology that could be valued through markets include values associated with fishing, bird watching, hunting, and wildlife viewing, among others. Impacts on these uses are included in the recreation and tourism valuation. Broader impacts likely do exist, but are difficult to estimate with precision, and were therefore not included in the study out of conservatism.

2.6 Impact Identification

Following fire modeling, we developed an initial inventory of the impacts from RGWF treatments that would be included as benefits in the return on investment analysis. As a first step, we created a matrix to categorize and describe the likely benefits (i.e., avoided costs) of forest restoration treatments (see Appendix A for the full matrix of initial impacts). For each category and/or sub-category, we included:

- A definition of the benefit;
- The beneficiary(s) (e.g., federal/state agencies, ratepayers, private landowners, etc.);
- The location (i.e., upstream, local, downstream); and
- The likely time frame (i.e., days, weeks, months, years).

The goal of this exercise was a first-cut assessment of the broad range of impacts associated with wildfire in the study area and the importance of each impact from an analytical perspective (not a societal perspective, necessarily). The initial matrix (in Appendix A) was a point of departure from which we refined estimates, combining and reassigning categories of impact as needed. This yielded final assumptions about impacts and values that are detailed in Section 4.

[3] Project water is used to sustain species in the Middle Rio Grande and other areas outside the immediate fire footprint.

2.7 Impact Quantification

Fire model outputs were used to quantify the estimated physical impacts of the fire for each impact category. Direct outputs from the fire model were available only for the suppression and property/ infrastructure categories including land, residences, roads and transmission lines. For these categories we directly input the fire model results (i.e., acres or miles impacted at each flame length) into the calculator.

For many of the other categories, impacts could not be linked to or are not as dependent on the relationship between the physical footprint of the fire and a specific location. For example, impacts on tourism are not directly related to a specific acre burning or not burning, but rather, to more general attributes like timing, magnitude and duration of the fire. As such, more generalized estimates based on evidence from past wildfires were used (e.g., number of visitor days lost after a fire, number of person days of smoke exposure).

The downstream water resource impacts of wildfire in the Project headwaters merit special attention and are described in detail in Section 3.

2.8 Impact Valuation

Methods for estimating the monetary value of each impact vary by impact type. Data sources, assumptions and final values selected for each category are included below in the data collection section of the report. The methods used for the overall impact valuation followed these general steps:

- Establish a baseline unit and value for each category based on best available data—update all values to constant 2015 dollars.[4]
  - Example 1: The baseline unit for wildfire suppression is an acre. The assumed average suppression cost per /acre is $808.
  - Example 2: The baseline unit for public health impacts is per individual per day. The assumed cost per individual per day is $10.
- Apply cost methodology to the estimated physical impact quantity/count.
  - Example 1: N acres burned multiplied by $808/acre in suppression costs.
  - Example 2: N individuals affected multiplied by the number of days affected (e.g., 7 days) multiplied by $10.
- Distribute the avoided costs and treatments over time in a financial model.
  - We assumed a time frame of 20 years, which is the number of years estimated to complete one round of forest thinning treatments (see below).
  - In all likelihood, forest restoration treatments would be done strategically—focusing on high risk areas first, resulting in diminishing marginal returns across time; however, as detailed information on this was not available, we used an even distribution of treatment costs and benefits to represent equal probability of a fire occurring in each of those 20 years.
  - We assumed only one fire would occur in those 20 years for each scenario.
- Calculate and sum the present value of avoided costs – We assumed a discount rate of 3%.
  - A discount rate is defined as the rate used to convert future economic value into present economic value. For example, one would not typically assume that a dollar would not have the same value today as it would five or ten years from now. The discount rate, therefore, is the annual rate at which future values (past the current year) are discounted. If we assume that a dollar has equal value this year and next year, then the total present value would be $2.00; however, if we assume a discount rate of 3%, then the value next year is discounted by 3% and the

[4] 2015 dollars are used to facilitate comparison with results of the companion study of the return on investment of the Rio Grande Water Fund in Taos County, New Mexico, which was completed in 2015.

total value would be $1.97 (i.e., $1.00 for the current year and $0.97 ($100 discounted by 3%) for the next year).

- Compare the total estimate of avoided costs to the cost of treatment.
- Calculate return on investment.

2.8.1 Distribution of Costs and Benefits Over Time

As described above, the financial model used in this report allocates all cost and benefits related to RGWF treatment and the modeled fire evenly over a 20-year time period and then discounts all dollar values to a present value at a three percent discount rate. For example, total treatment costs were estimated at $20,000, the model would assume that those costs were incurred at a rate of $1,000 per year for twenty years. Because of the time value of money, this series of equal payments over time would equate to a present value of $14,877.

Assumptions regarding when the costs and benefits of RGWF treatments occur directly impact the financial return on investment and are therefore critical to results (as does the choice of discount rate). All else equal, the ROI will be greater if costs can be deferred to later years and benefits can be captured sooner. The same modeled fire will have a greater ROI if it occurs (or is assumed to be mitigated) in Year 10 versus in Year 20. To have defensible results, it is therefore important not to artificially manipulate the timing of cash flows underlying the analysis.

The approach of distributing all costs and benefits over 20 years using the same methodology preserves this objectivity and is a reasonable basis for calculating a representative ROI. This assumption does have several implications worth noting:

- It assumes that notwithstanding the allocation of costs and benefits over time, the treatment Program is implemented prior to the fire event. Obviously if a fire occurs prior to treatment, it will not be mitigated and related benefits will not accrue. This assumption is offset by other conservative assumptions.
- It does not account for any strategic prioritization in implementation of the treatments. The model assumes that the final treatments will be as valuable as the first, whereas actual implementation would prioritize high value treatments (say around buildings or in the most at risk areas), thereby reducing risk more quickly than the approach assumes. This assumption makes the ROI calculation conservative.
- It accounts for no benefit from RGWF treatments after Year 20. In reality, maintenance treatments would continue beyond Year 20, as would the benefits of treated landscapes. Further, even if treatments were not maintained, some benefit of treatments would persist (because conditions would not immediately revert to pre-treatment conditions in Year 21). This out-year benefit is not included in the model, rendering the ROI calculation conservation.

3. Conceptual Model of Wildfire, Post-Wildfire Debris Flows and Quantification of Water Impacts

As mentioned in the introduction, a primary reason for the focus of this study on the SJ-C Headwaters area in the Blanco, Navajo, and Little Navajo River basins is their important role in provision of Project water to downstream contractors and the risk of wildfire-related disruption to deliveries. While catastrophic wildfire was a concern, little formal exploration of how wildfire and related events impact water deliveries had been made. Accordingly, we developed a conceptual model describing in detail the context in which our representative fires occur and linking them explicitly to water impacts. Based on this conceptual model, disruptions to Project water supply are quantified and allocated among contractors. This quantification of water "lost" in the representative fire scenario in turn drives financial analysis and estimation of the return on investment for Water Fund treatments in the area (in Sections 4.4 and 5).

3.1 Conceptual Model

The "conceptual model" is the series of linked events following the headwaters fires that ultimately impact downstream access to Project water. The representative fires described in Section 2 are only the first step in the story of downstream impacts; the conceptual model makes clear assumptions about context and other events that are assessed in the return on investment analysis. Simply put, the conceptual model is the extended scenario assessed, beginning with the representative severe wildfires but also including subsequent related impacts on watersheds and the Project. This section tells this story at a high level to underscore major assumptions. Appendix B presents the information gathered from stakeholder interviews and other sources that informs the model. It is included to provide context into the development of the key assumptions used in the analysis, all of which are detailed in Sections 3 and 4 of the main report.

3.1.1 Context

The conceptual model assumes that the wildfire occurs in a normal water year in which Project diversions would be sufficient to provide a full water allocation to contract holders if not disrupted. However, we assume that there is little to no carryover storage from unneeded past year supply in Heron Reservoir. This means that interrupted diversions will immediately result in a reduced allocation to Project contractors. We also assume that the Middle Rio Grande Conservancy District ("MRGCD") holds little to no stored water in El Vado Reservoir (whether from the Project or native flow), and that monsoon rains substantially fail in the Middle Rio Grande Valley during the year Project water deliveries are disrupted. This situation is not unlike current conditions, particularly if drought continues or worsens, and is certainly a very likely scenario in a future of climate change. As detailed in Section 4.4.3, this means that farmers will see their irrigation season cut short and will not be "saved" by fortuitous rains.[5] These hydrological conditions are also consistent with an active wildfire season; the same arid conditions that lead to severe wildfire drive water demand and stress stored water reserves. These conditions would also arguably be correlated with low municipal supplies of stored water in Abiquiu Reservoir (where both Albuquerque and Santa Fe have storage rights). Despite this and in light of the ability of cities to use other water sources, our analysis does not depend on assuming low municipal storage.

3.1.2 Wildfire, Debris, Sediment, and Project Operations

As described above, the two "representative fires" burn in the Blanco and Navajo basins supplying the bulk of Project water. This section discusses assumptions related to the water resource impacts of each of those fires in both the "current" and "RGWF treated" scenarios.[6] The conceptual model assumes post-fire rains consistent with local monsoonal precipitation events causes severe debris flows in the watershed and rivers at points upstream of the Project's Blanco and Oso diversions respectively.[7] Geophysical modeling of debris flows was beyond the scope of this study and there is no estimate of the probability or severity of these

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[5] As described in section 4.4.3, the assumption that monsoon rains fail is important to MRGCD having to implement Prior and Paramount ("P&P") operations in late summer, curtailing some agricultural production. This is certainly a plausible assumption but it is equally true that strong or even average late summer rains could allow MRGCD to avoid P&P operations, insulating farmers from the impact of a shortfall in stored water. The assumption was made to allow the analysis to explore the costs to irrigators of water lost due to severe wildfire (i.e. the value at risk). Because this value is only lost in the event of poor monsoonal rains, it is somewhat less likely than other water-related financial impacts of severe wildfire.

[6] As explained in Section 2, the representative fires burn in the RGWF treatments, albeit at smaller scale. Water resource impacts are also reduced but not completely eliminated in the "with treatment" case.

[7] Evidence from the Las Conchas fire suggests that even average rainfall has to potential to catalyze significant debris flows in burned landscapes. That is, it is not necessary to assume abnormal precipitation events are "needed" to trigger debris flows. Personal communication, D. Gori, November 8, 2016.

flows. However, experience in the Las Conchas and other fires, analysis of the volume of debris that could potentially be activated post-fire, and interviews with current and former Reclamation staff confirm that severe flows are possible.

Reclamation staff uniformly emphasized that the Blanco Diversion was more likely to be impacted by debris flow due to the local geography consisting of a steep and relatively incised canyon and the location of the diversion itself, while the Oso diversion in the Navajo basin is at less risk.[8] In the case of the Blanco, several potential mechanisms were cited through which project diversions could be prevented, including loss of access due to destruction of a bridge, complete burial of the diversion structure, and temporary clogging of diversion outfalls resulting in creation of a new channel bypassing the entire structure. Understandably, there was no estimate of the likelihood of these impacts, but there is general consensus that they are possible under certain conditions.[9] If any of these impacts were to materialize, repair could be difficult due to limited ability to work in the winter or during periods of high runoff. For this reason, if a debris flow occurred in late fall followed by a cold winter and early sustained spring runoff, repair could take a year or more. In the conceptual model, we assume that post-wildfire debris flows prevent use of the Blanco diversion for one year in the "current" case. Because fire modeling includes significant burned area around the Blanco diversion in the "RGWF treated" case, we assume that water diversions are lost for 10 days in the if a fire were to occur after RGWF treatments had been implemented.

In the Navajo basin, we assume in the "current" case that severe debris flows might temporarily stop diversions, but that service could be restored in a matter of several days.[10] The conceptual model assumes that the Oso diversion is lost for two five-day periods in the year following the fire in the "current" case. The conceptual model assumes no water resource impacts from fire in the Navajo basin in the "RGWF treated" case.

Reclamation staff also confirmed that acute debris flow post-wildfire is the outcome that poses risk to the Project. Elevated sediment, even at very high levels, was not anticipated to impact project operations or harm infrastructure. Further, diversions are independently operated such that losing one does not impact the others.

3.1.3 Tunnels, Heron Reservoir, and Rio Chama Impacts

Reclamation broadly confirmed that wildfire and subsequent watershed impacts pose little risk to Project infrastructure other than diversions. Trash racks at the diversions sites catch large debris, with any smaller material passing through tunnels without incident. There is also no risk of tunnels clogging due to elevated sediment transport; the project is designed to withstand significant sediment loads without damage. Similarly, discharge of sediment-laden water into Azotea and Willow Creeks for delivery into Heron Reservoir is not a concern. Heron Reservoir itself has 401,000 AF of storage capacity, and while sediment creates a delta area in the upstream/north end of the reservoir, this in no way materially threatens its use as a storage facility.[11] Reclamation would not anticipate needing to dredge the reservoir even after a severe wildfire.

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[8] The Oso Diversion is located in a wider valley to the side of the main river channel, reducing the possibility that debris flows would impact the structure itself. Personal communication V. Salazar, July 11, 2016, personal communication M. Hamman, July 12, 2016, personal communication C. Donnelly, Y. McKenna, K. Rice, R. Rust, July 13, 2016.

[9] It is important to note that the diversion has never been forced to close during its entire history, even in the event of a flash flood in 2015. At the same time, there has never been a severe wildfire in the basin.

[10] As in the Blanco basin, Navajo River diversions at the Oso diversion dam have never previously been interrupted.

[11] In July 2016, approximately 130,000 AF were stored in Heron Reservoir. Current excess capacity as well as additional storage capacity at Abiquiu, El Vado, and Elephant Butte reservoirs held by Project Contractors mean that reduction in storage capacity due to sediment inflow is not a concern, and that solutions like dredging that have been pursued in other basins are not relevant for the Project. For example, erosion after the 2002 Hayman fire in Colorado led to extensive (and expensive) dredging and rehabilitation

Heron Dam is a bottom-release facility so there is no issue with a minimum pool that could be undermined due to curtailment of diversions. Downstream of Heron, three other reservoirs on the Chama and Rio Grande (El Vado, Abiquiu, and Cochiti) would serve to capture any elevated post-fire sediment, and there is no concern that post-wildfire sedimentation would persist as a poor water quality issue by the time the water would be diverted in the Middle Rio Grande.

3.1.4 Summary

The conceptual model underlying this analysis assumes that monsoonal rains following severe wildfire leads to extreme debris flows that directly disrupt Project water diversions. The risk is concentrated in the Blanco basin, and is related to exposure to debris flows. Elevated sediment levels, though impactful, do not threaten to disrupt diversions or materially impact infrastructure. Implicitly, this analysis assumes that in the "RGWF treated" scenarios where fire size and intensity are reduced, the risk of debris flows severe enough to disrupt diversions is reduced (in the Blanco fire) or eliminated (in the Oso fire), and that avoiding this disruption is one of the main benefits of the RGWF treatments. The next section estimates the quantity of Project water that would be "lost" due to a debris flow event.

3.2 Quantification of Water Impacts[12]

The conceptual model assumes that there is little or no carryover water from the previous year in Heron Reservoir, meaning that Reclamation must rely on current-year diversions to serve Project contractors. In practice, this means the impact of any lost Project diversions are felt immediately by contract holders. Further, it assumes a normal water year in which SJ-C diversions would equal a full allocation of 86,210 AF, "but for" impacts from post-fire debris flows. The contribution of each of the three project diversion in this "but for" (i.e., no impact) case is assumed to match their historical levels of 48.2% of total water from Blanco, 48.8% from Oso, 3.0% from Little Oso. Table 4 illustrates the distribution of the SJ-C project allocations by source watershed and contractor.

in the Strontia Springs Reservoir. However, that reservoir has a total capacity of just under 8,000 AF, two orders of magnitude below that of Heron.

[12] This section adapted from Summit Conservation Strategies' document on Estimated Impact of Post-Severe Debris flow on SJ-C Project Water Diversions, completed and previously shared with TNC on August 12, 2016. "Diversion_Impacts.docx"

TABLE 4 PROJECT WATER ALLOCATION BY SOURCE AND CONTRACTOR

San Juan Chama Project
Total Project Allocation by Source Watershed and Contractor (acre-feet)
Historical Average (1986-2015 Water Years)

San Juan-Chama Contractor	Annual Full Allocation [1]	Average Allocation by Source Diversion [2]: Blanco (48.2%)	Oso (48.8%)	Little Oso (3.0%)
	(a) = (b) + (c) + (d)	(b)	(c)	(d)
City of Albuquerque	48,200	23,220	23,532	1,448
Jicarilla Apache	6,500	3,131	3,173	195
City and County of Santa Fe	5,605	2,700	2,736	168
County of Los Alamos	1,200	578	586	36
City of Espanola	1,000	482	488	30
Town of Belen	500	241	244	15
Village of Los Lunas	400	193	195	12
Village of Taos	400	193	195	12
Town of Bernalillo	400	193	195	12
Town of Red River	60	29	29	2
Twining Water & Sanitation District	15	7	7	0
Middle Rio Grande Conservancy District	20,900	10,068	10,204	628
Pojoaque Valley Irrigation District	1,030	496	503	31
Total	**86,210**	**41,531**	**42,089**	**2,590**

Note:
[1] Source: US Bureau of Reclamation
[2] Historical Distribution of Project Diversions by Source Watershed (Source: Colorado Division of Water Resources)

The conceptual model assumes the following impacts from post-fire severe debris flows based on fire and debris modeling and conversations with Reclamation staff:

- "Current" case:
  - Blanco Fire: The Blanco Diversion is lost for a period of one year.
  - Oso Fire: The Oso Diversion is lost for two five-day periods during the April 1–June 30 high flow period.
- "RGWF treated" case:
  - Blanco Fire: The Blanco Diversion is lost for a period of 10 days during the April 1–June 30 high flow period.
  - Oso Fire: There is no impact to the Oso diversion due to fire in the Navajo Basin in the with RGWF treatment case.

3.2.1 Blanco Basin: Loss of the Blanco Diversion

A severe fire in the Blanco basin under the "current" scenario could result in loss of the Blanco diversion for one year. The loss of the diversion could be driven by physical destruction of the diversion structure by debris, including in a scenario where debris clogs the tunnel and outfalls, backs up the river, and leads to a new channel bypassing the entire diversion. Repair following such an event would be difficult during winter or periods of high flows, resulting in the real possibility that a year's water would be lost. Note that due to the nature of the Basin's hydrology, a much shorter disruption could result in loss of nearly a full year's water, as is illustrated in the table below from the 2015 water year (in which ~95% of water was diverted between March and July).

TABLE 5 TOTAL PROJECT DIVERSIONS BY SOURCE, 2015 WATER YEAR

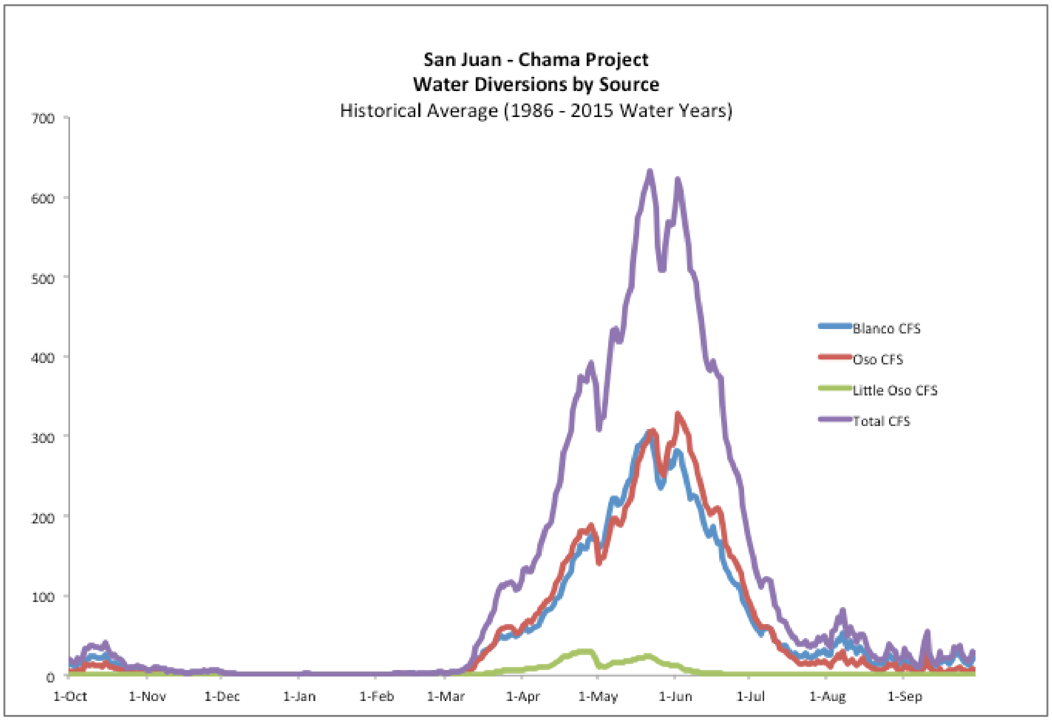
San Juan Chama Project
Total Project Diversions by Source (acre-feet)
October 2014 - September 2015

Month	Blanco	Oso	Little Oso	All Sources	Cumulative	Percent of Annual Total
October 2014	1,180	-	-	1,180	1,180	1.3%
November 2014	352	-	-	352	1,532	1.7%
December 2014	-	-	-	-	1,532	1.7%
January 2015	37	-	-	37	1,569	1.8%
February 2015	846	183	-	1,029	2,598	2.9%
March 2015	3,550	2,920	294	6,764	9,362	10.6%
April 2015	3,990	3,410	496	7,896	17,258	19.6%
May 2015	14,320	9,290	425	24,035	41,293	46.8%
June 2015	16,230	21,430	161	37,821	79,114	89.7%
July 2015	3,790	4,280	-	8,070	87,184	98.8%
August 2015	570	314	-	884	88,068	99.8%
September 2015	158	-	-	158	88,226	100.0%
Total	**45,023**	**41,827**	**1,376**	**88,226**	**88,226**	**100.0%**

Source: Colorado Division of Water Resources

The hydrograph in Figure 4 further illustrates the point that diversions are concentrated during the peak runoff period.

FIGURE 4 PROJECT DIVERSION HYDROGRAPH



Based on the above figure, it is plausible that if a post-fire debris flow event driven by a monsoonal storm in the late summer severely damaged the diversion and repair work was not possible during winter or spring runoff, an entire year's water could be lost.

Note that the conceptual model does not assess the likelihood of such an outcome, but is instead informed by Reclamation's assessment of what *could* happen in a severe case.

We assume that each contractor loses 48.2% of its annual SJ-C water allocation, which is equivalent to the average Blanco Diversion proportion over the last 31 water years.

In the case where RGWF forest treatments are implemented, the size of the Blanco fire is significantly reduced to approximately 37,000 acres compared to 52,000 in the "current" case, with the number of acres burned at flame lengths greater than 8' falling to approximately 16,000 acres from 25,000 acres. These reductions, though substantial, are not deemed sufficient to eliminate all risk of debris flow, and therefore we assume that the Blanco diversion is lost for 10 days during the April 1-June 30 period in the "RGWF treated" case.

3.2.2 Navajo Basin: Loss of the Oso Diversion for two 5-day periods between April 1-June 30

Reclamation staff were consistent in commenting that long term disruption of diversions at Oso was unlikely. We therefore assumed two five-day diversion disruptions from severe debris flow clogging the diversion structure during the period of high runoff between April 1 and June 30. Based on historical diversion rates for that period, we averaged the daily diversion during that period and calculated the lost diversion for 10 such "average high runoff days". Diversions average 380.8 AF per day at Oso during the April 1-June 30 period, implying lost diversion of 5 x 380.8 = 1,975 AF for each 5-day disruption, or 3,951 AF for both disruptions. This is equivalent to 4.6% of the Project's total allocation. There is no impact to the Oso diversion in the "RGWF treated" case.

3.2.3 Little Navajo Basin: No Modeled Impact

No fire was modeled in the Little Navajo Basin (see Section 2) and therefore there are no water resource impacts to the Little Oso diversion in our analysis. The Little Oso diversion only accounts for 3% of total Project diversions, on average.

3.2.4 Compensating Diversions

In the "current" Blanco scenario where the diversion is lost for one year, it is possible that Oso diversions could be increased to partially offset the lost diversions. This is possible because the combined capacity of the Blanco and Oso feeder tunnels exceeds that of the Azotea tunnel, implying that during periods of very high runoff one or both of the Oso and Blanco diversions may bypass some water to avoid overloading the Azotea tunnel. With the Blanco offline, some of the water that would have been bypassed could be diverted at Oso (and to a lesser extent Little Oso), partially offsetting any lost Blanco diversion.

To estimate the amount of these "compensating diversion", we analyzed daily diversions for the last six water years (beginning 10/1/10) to identify the numbers of days in which Azotea tunnel capacity constraints resulted in bypasses at the Oso and Little Oso diversions beyond those required by law. For those days, we then calculated the amount of additional water that could have been diverted had Blanco been offline, which was the lesser of: i) all of the water above the minimum bypass requirements; and ii) 650 cfs (the capacity of the Oso diversion).

There were only 15 days when flows were high enough to allow for "compensating diversions" in the last six years. Given the recent drought, we assumed that three days of "compensating diversions" would be available in a typical year, and calculated that, on average, 139 AF per day of additional water would be available for diversion on these days, for a total of 417 AF of "compensating diversions" over three days.

Although a similar dynamic theoretically exists in the cases of short duration disruptions to diversions (including the 10-day disruption of the Blanco diversion assumed in the "RGWF treated" scenario and the two 5-day disruptions to the Oso diversion in the Navajo "current" scenario), we did not include compensating diversions in those cases. This is justified by the very low probability that compensating diversion would be possible in a short disruption window and the small quantities of water involved.[13]

3.2.5 Water Yield

Although not included in this study's estimates of water lost due to wildfire, it bears note that there is some evidence that healthy watersheds yield greater quantities of water when compared to overgrown basins or severely burned areas. Thinning prescriptions (i.e., treatments) have been used in the Valles Caldera National Preserve to increase the amount of water available to the terrestrial hydrological cycle (Parmenter 2009). Studies have found 10% greater snowpack in intact forests as compared to burned areas of the Las Conchas fire (Harpold et al. 2013). While more research is needed, it is worth emphasizing that if treatments result in increased water yield, then the water resource benefits from the RGWF would scale commensurately.

3.2.6 Summary

Table 6 and

[13] Because only three days of compensating diversions are available in a given year, the odds of those days occurring during a short duration diversion disruption are small. As a result, though there may be on average some small quantity of compensating diversion to offset losses, the median amount available is likely to be zero.

Table 7 below summarize the water resource impacts of different fire scenarios described above, combining the effects of: i) loss of the Blanco diversion for one year (or 10 days in the "RGWF treated" case); ii) loss of the Oso diversion for two five-day periods (or not at all in the "RGWF treated" case); and iii) compensating diversions where applicable to calculate the estimated net impact of post-fire debris flow on SJ-C diversions. Data is presented by Project contract holder, and all impacts are distributed proportional to contractor water allocations. In the case of the modeled fire in the Blanco basin, the following impacts are estimated in the "current" scenario:

- Albuquerque loses 22,978 AF of SJ-C water;
- Santa Fe loses 2,672 AF of SJ-C water; and
- MRGCD loses 9,964 AF of SJ-C water.

This is equivalent to the loss of 47.7% of one year's full allocation for each contractor. Other contractors lose this proportionate amount of their full allocation.

TABLE 6 ESTIMATED IMPACT FROM POST-FIRE DEBRIS FLOWS ON PROJECT ALLOCATIONS: BLANCO BASIN FIRE UNDER "CURRENT" SCENARIO

San Juan Chama Project
Project Water Allocation and Estimated Impact from Post-Fire Debris Flows
Fire in the Blanco Basin: No RGWF Treatments

San Juan-Chama Contractor	Annual Full Allocation [1]	Debris-Flow Impacts on Project Diversions: One-Year Loss of Blanco Diversion [2]	5 Day Loss of Oso Diversion #1 [3]	5 Day Loss of Oso Diversion #2 [3]	Compensating Diversions [4]	Total Net Impact	Net Water Available
	(a)	(b)	(c)	(d)	(e)	(f) = (b) + (c) + (d)	(g) = (a) + (f)
City of Albuquerque	48,200	(23,220)			242	(22,978)	25,222
Jicarilla Apache	6,500	(3,131)			33	(3,099)	3,401
City and County of Santa Fe	5,605	(2,700)			28	(2,672)	2,933
County of Los Alamos	1,200	(578)			6	(572)	628
City of Espanola	1,000	(482)			5	(477)	523
Town of Belen	500	(241)			3	(238)	262
Village of Los Lunas	400	(193)			2	(191)	209
Village of Taos	400	(193)			2	(191)	209
Town of Bernalillo	400	(193)			2	(191)	209
Town of Red River	60	(29)			0	(29)	31
Twining Water & Sanitation District	15	(7)			0	(7)	8
Middle Rio Grande Conservancy District	20,900	(10,068)			105	(9,964)	10,936
Pojoaque Valley Irrigation District	1,030	(496)			5	(491)	539
Total	**86,210**	**(41,531)**			**432**	**(41,098)**	**45,112**

Note:
[1] Source: US Bureau of Reclamation
[2] The conceptual model assumes the loss of the Blanco diversion for one year, equivalent to 48.2% of total Project diversions. (Source: Colorado Divisionof Water Resources)
[3] There are no losses from the Oso diversion in the Blanco fire.
[4] In periods of acute high flows, it is possible to partially compensate for the loss of the Blanco diversion by increasing diversions at the Oso and Little Oso diversions. Based on daily diversion data from the last six water years, 432 acre-feet of compensating diversions are estimated to be available annually when the Blanco diversion is offline.

In the case of RGWF treatments, the impacts from the Blanco fire are reduced substantially to only 3,661 AF across all contractors, a loss of 4.2% of Project supply.

TABLE 7 ESTIMATED IMPACT FROM POST-FIRE DEBRIS FLOWS ON PROJECT ALLOCATIONS: BLANCO BASIN FIRE UNDER "RGWF TREATED" SCENARIO

San Juan Chama Project
Project Water Allocation and Estimated Impact from Post-Fire Debris Flows
Fire in the Blanco Basin: With RGWF Treatments

San Juan-Chama Contractor	Annual Full Allocation [1]	Debris-Flow Impacts on Project Diversions: 10 Day Loss of Blanco Diversion [2]	5 Day Loss of Oso Diversion #1 [3]	5 Day Loss of Oso Diversion #2 [3]	Compensating Diversions [4]	Total Net Impact	Net Water Available
	(a)	(b)	(c)	(d)	(e)	(f) = (b) + (c) + (d)	(g) = (a) + (f)
City of Albuquerque	48,200	(2,047)			-	(2,047)	46,153
Jicarilla Apache	6,500	(276)			-	(276)	6,224
City and County of Santa Fe	5,605	(238)			-	(238)	5,367
County of Los Alamos	1,200	(51)			-	(51)	1,149
City of Espanola	1,000	(42)			-	(42)	958
Town of Belen	500	(21)			-	(21)	479
Village of Los Lunas	400	(17)			-	(17)	383
Village of Taos	400	(17)			-	(17)	383
Town of Bernalillo	400	(17)			-	(17)	383
Town of Red River	60	(3)			-	(3)	57
Twining Water & Sanitation District	15	(1)			-	(1)	14
Middle Rio Grande Conservancy District	20,900	(888)			-	(888)	20,012
Pojoaque Valley Irrigation District	1,030	(44)			-	(44)	986
Total	**86,210**	**(3,661)**			**0**	**(3,661)**	**82,549**

Note:
[1] Source: US Bureau of Reclamation
[2] The conceptual model assumes the loss of the Blanco diversion for 10 days in the "with treatment" case.

[3] There are no losses from the Oso diversion in the Blanco fire.

[4] In periods of acute high flows, it is possible to partially compensate for the loss of the Blanco diversion by increasing diversions at the Oso and Little Oso diversions. No compensating diversions are assumed for short duration diversion disruptions.

The modeled fire in the Navajo Basin produces more modest impacts in the "current" case (see Table 8). These include:

- Albuquerque loses 2,209 AF of SJ-C water;
- Santa Fe loses 257 AF of SJ-C water; and
- MRGCD loses 958 AF of SJ-C water.

This is equivalent to the loss of 4.6% of one year's full allocation for each contractor. Other contractors lose this proportionate amount of their full allocation.

TABLE 8 ESTIMATED IMPACT FROM POST-FIRE DEBRIS FLOWS ON PROJECT ALLOCATIONS: NAVAJO BASIN FIRE UNDER "CURRENT" SCENARIO

San Juan Chama Project
Project Water Allocation and Estimated Impact from Post-Fire Debris Flows
Fire in the Navajo Basin: No RGWF Treatments

San Juan-Chama Contractor	Annual Full Allocation [1]	One-Year Loss of Blanco Diversion [2]	5 Day Loss of Oso Diversion #1 [3]	5 Day Loss of Oso Diversion #2 [3]	Compensating Diversions [4]	Total Net Impact	Net Water Available
		Debris-Flow Impacts on Project Diversions					
	(a)	(b)	(c)	(d)	(e)	(f) = (b) + (c) + (d)	(g) = (a) + (f)
City of Albuquerque	48,200		(1,104)	(1,104)		(2,209)	45,991
Jicarilla Apache	6,500		(149)	(149)		(298)	6,202
City and County of Santa Fe	5,605		(128)	(128)		(257)	5,348
County of Los Alamos	1,200		(27)	(27)		(55)	1,145
City of Espanola	1,000		(23)	(23)		(46)	954
Town of Belen	500		(11)	(11)		(23)	477
Village of Los Lunas	400		(9)	(9)		(18)	382
Village of Taos	400		(9)	(9)		(18)	382
Town of Bernalillo	400		(9)	(9)		(18)	382
Town of Red River	60		(1)	(1)		(3)	57
Twining Water & Sanitation District	15		(0)	(0)		(1)	14
Middle Rio Grande Conservancy District	20,900		(479)	(479)		(958)	19,942
Pojoaque Valley Irrigation District	1,030		(24)	(24)		(47)	983
Total	**86,210**		**(1,975)**	**(1,975)**		**(3,951)**	**82,259**

Note:
[1] Source: US Bureau of Reclamation
[2] The conceptual model assumes the loss of the Blanco diversion for one year, equivalent to 48.2% of total Project diversions. (Source: Colorado Divisionof Water Resources)
[3] The conceptual model assumes that the Oso diversion is disrupted for two five-day periods during the period between April 1 and June 30. Using average historical diversion rates for that time period, each five-day disruption is equivalent to 1,975 acre feet or 2.3% of the total annual allocation. (Source: Colorado Division of Water Resources)
[4] In periods of acute high flows, it is possible to partially compensate for the loss of the Blanco diversion by increasing diversions at the Oso and Little Oso diversions. Based on daily diversion data from the last six water years, 432 acre-feet of compensating diversions are estimated to be available annually when the Blanco diversion is offline.

There is no loss of water for the modeled Navajo Basin fire in the "with RGWF treatment" scenario. All contractors receive full allocations in this scenario.

In addition to examining the Blanco and Navajo Basin fires separately, we estimated the combined impact in the case where both fires occur. In this two-fire scenario without RGWF treatments, impacts are as follows:

- Albuquerque loses 25,187 AF of SJ-C water;
- Santa Fe loses 2,929 AF of SJ-C water; and
- MRGCD loses 10,921 AF of SJ-C water.

This is equivalent to the loss of 52.25% of one year's full allocation for each contractor. Other contractors lose this proportionate amount of their full allocation.

TABLE 9 ESTIMATED COMBINED IMPACTS FROM POST-FIRE DEBRIS FLOWS ON PROJECT ALLOCATIONS: TWO FIRES UNDER "CURRENT" SCENARIO

San Juan Chama Project
Project Water Allocation and Estimated Impact from Post-Fire Debris Flows
Fires in both the Blanco and Navajo Basins: No RGWF Treatments

San Juan-Chama Contractor	Annual Full Allocation [1]	Debris-Flow Impacts on Project Diversions: One-Year Loss of Blanco Diversion [2]	5 Day Loss of Oso Diversion #1 [3]	5 Day Loss of Oso Diversion #2 [3]	Compensating Diversions [4]	Total Net Impact	Net Water Available
	(a)	(b)	(c)	(d)	(e)	(f) = (b) + (c) + (d)	(g) = (a) + (f)
City of Albuquerque	48,200	(23,220)	(1,104)	(1,104)	242	(25,187)	23,013
Jicarilla Apache	6,500	(3,131)	(149)	(149)	33	(3,397)	3,103
City and County of Santa Fe	5,605	(2,700)	(128)	(128)	28	(2,929)	2,676
County of Los Alamos	1,200	(578)	(27)	(27)	6	(627)	573
City of Espanola	1,000	(482)	(23)	(23)	5	(523)	477
Town of Belen	500	(241)	(11)	(11)	3	(261)	239
Village of Los Lunas	400	(193)	(9)	(9)	2	(209)	191
Village of Taos	400	(193)	(9)	(9)	2	(209)	191
Town of Bernalillo	400	(193)	(9)	(9)	2	(209)	191
Town of Red River	60	(29)	(1)	(1)	0	(31)	29
Twining Water & Sanitation District	15	(7)	(0)	(0)	0	(8)	7
Middle Rio Grande Conservancy District	20,900	(10,068)	(479)	(479)	105	(10,921)	9,979
Pojoaque Valley Irrigation District	1,030	(496)	(24)	(24)	5	(538)	492
Total	**86,210**	**(41,531)**	**(1,975)**	**(1,975)**	**432**	**(45,049)**	**41,161**

Note:
[1] Source: US Bureau of Reclamation
[2] The conceptual model assumes the loss of the Blanco diversion for one year, equivalent to 48.2% of total Project diversions. (Source: Colorado Divisionof Water Resources)
[3] The conceptual model assumes that the Oso diversion is disrupted for two five-day periods during the period between April 1 and June 30. Using average historical diversion rates for that time period, each five-day disruption is equivalent to 1,975 acre feet or 2.3% of the total annual allocation. (Source: Colorado Division of Water Resources)
[4] In periods of acute high flows, it is possible to partially compensate for the loss of the Blanco diversion by increasing diversions at the Oso and Little Oso diversions. Based on daily diversion data from the last six water years, 432 acre-feet of compensating diversions are estimated to be available annually when the Blanco diversion is offline.

The two fire case with RGWF treatments results in the loss of 3,661 AF across all contractors; it is equivalent to the Blanco Fire "with treatment" case presented in Table 6.

These estimated losses of Project water from debris flows following a severe wildfire are an input into the economic analysis of RGWF return on investment detailed later in Section 4.4.

4. Data Collection

This section presents the data used quantify the magnitude and value of wildfire-related impacts. Data used to estimate the degree and value of impacts came from a variety of sources—in some cases, data were study-area specific, but in others, more generalized information was used. In this section, we document relevant studies and data sources for each impact area, and select a baseline value. It should be noted, as discussed later, that an additional component of this study was the development of a calculator, which allows the user to modify key parameters, adjust baseline values, and calculate results under differing assumptions.

4.1 Forest Treatment Costs

Treatment costs are affected by a number of variables including treatment type, stand age and species, topography and road access, among others.

Five categories of treatment type were used in this analysis (i.e., harvest, mechanical, roadless, prescription fire and WUI). Table 10 includes per acre cost estimates for each treatment type. These treatment costs, with the exception of WUI acres, were based on personal communications from forester Gary Harris who is working with RGWF on treatments in the area.

For private acres located within the wildland urban interface (WUI), we used a treatment cost estimate from a current pricing agreement for the study area (State of New Mexico 2014), which sets treatment costs at $2,150/acre for WUI acres on private land.

TABLE 10 TREATMENT COSTS BY TREATMENT TYPE

Treatment Type	$2015/acre
Harvest	$900
Mechanical	$950
Roadless	$500
Prescribed Burn	$300
WUI	$2,150

As points of comparison:

- In their comprehensive plan, the RGWF (2014) estimated average costs of $700/acre for thinning dense forest in Taos County;
- A 2010 report on treatments in the Santa Fe watershed estimated average costs of $920/acre (Stednick and Ice 2010); and
- A more recent article in the Santa Fe New Mexican (Matlock 2015) estimated treatment costs for Santa Fe National Forest at $400-950/acre with an average of $600/acre.

The assumed treatment costs are therefore both locally-informed and consistent with regional experience.

4.2 Wildfire Suppression

The costs of wildfire suppression (i.e., firefighting) can be affected by a number of variables including topography, accessibility, land cover, population density, etc., making it more difficult to predict costs for a specific area. As such, we relied on more general data from recent wildfires.

As part of their 2007 study, Gebert et al. estimated “wildland fire suppression expenditures per acre” for large woodland fires by National Forest System region. For Region 2, in which Colorado is located, average suppression costs per acre for fiscal years 1995-2004 was $808 in 2004 dollars.

As a point of comparison, we also calculated 5-year mean using the National Interagency Fire Center (NIFC) statistics on annual federal firefighting costs, which was an estimated $284/acre for the years 2011-15. These costs do not include risk of injury and death to fire crews, certainly an issue of high importance.

Lacking more detailed information, we chose to use the estimate from Gerbert et al. (2007) of $808, without updating it to constant 2015 dollars. The reason for this is that while inflation has occurred since 2004, it is not unreasonable to also assume that improvements in fire suppression tactics and equipment have also occurred and we assume these roughly balance out.

4.3 Wildfire Cleanup & Recovery

The US Forest Service Burned Area Emergency Rehabilitation (BAER) program supports basic rehabilitation and recovery efforts and could be viewed as emergency stabilization and treatment after a fire. It does not include replanting of commercial forests or grass for forage, replacement of habitat, etc… The BAER program estimates that, on average, rehabilitation costs are 5% of suppression costs (US Forest Service 2016). Given that some, and perhaps significant, additional cleanup and recovery would likely be required in addition to BAER efforts, we assumed rehabilitation costs were 10% of suppression costs (i.e., $81/acre).

4.4 Surface Water

This section picks up from the quantification of water impacts described in the conceptual model in Section 3 and focuses on financial impacts on uses of surface water by Project contractors downstream from the Navajo and Blanco Basins. The three largest active users of Project water are Albuquerque Bernalillo County Water Utility Authority ("ABCWUA"); City of Santa Fe Water Division; and irrigators served by MRGCD. Together, they hold contracts to some 74,705 AF of annual SJ-C water allotments, nearly 87% of Project supply. In addition to accounting for the vast supply of Project water, ABCWUA, Santa Fe, and MRGCD are the three contractors who currently divert and directly use their project water, and accordingly will be the focus of our valuation analysis.[14]

ABCWUA has a surface water diversion on the Rio Grande in Albuquerque that supplies a treatment plant and their distribution system. From a water rights perspective, the water used at the plant is imported from the Colorado River Basin through the San Juan Chama (SJ-C) project and is stored water. ABCWUA has contractual rights to 48,200 AF per year from the project. The SJ-C water is a complement to the Authority's groundwater use, providing 50% or more of production on an annual basis.[15] As described in the conceptual model, reduction in diversion of Project water due to catastrophic wildfire in the Blanco and Navajo Basins would directly reduce the amount of water available ABCWUA's surface water treatment plant. If available, previously stored water in Heron and Abiquiu reservoirs in the Upper Chama could delay the operational disruption from the loss of water, but the fire would still result in ABCWUA (eventually) having to find alternate supplies for water lost. Santa Fe is in a similar situation with their Buckman Direct Diversion.

Both Albuquerque and Santa Fe have other sources of water that allow them to maintain deliveries even without access to surface water from the Rio Grande, and it is important to emphasize that under no foreseeable circumstance does a wildfire-related reduction in availability of Project water leave the cities without access to water. ABCWUA has an extensive system of groundwater wells, while Santa Fe has both groundwater sources as well as surface water from the Santa Fe River. As a result, economic impacts are related primarily to the costs of substituting alternative existing sources of water rather than actual lack of water availability. For both cities, this means shifting back (at least temporarily) to greater reliance on finite groundwater resources that both cities have worked for decades to conserve. This section describes the estimated cost to the cities of this shift to alternative sources.

4.4.1 Albuquerque Bernalillo County Water Utility Authority (ABCWUA)

The cost to ABCWUA of losing an AF of Project water due to catastrophic fire in the Navajo and Blanco basins is the financial impact of replacing that water with an alternative source. Depending on the time

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[14] Other contractors typically use their water to offset current or future groundwater pumping consistent with their OSE permits, often marketing the water annually to other contractors or to Reclamation's Supplemental Water Program.
[15] Over 70% of 2016 ABCWUA water production through September was surface water (ABCWUA 2016).

horizon examined and assumptions about ABCWUA, there is wide range of legitimate estimates of the cost of lost Project water.

First, it is important to emphasize that ABCWUA is well-positioned to manage any operational disruption caused by losing Project water. The authority has the ability to store over 170,000 AF of water in Abiquiu Reservoir and through other arrangements, equivalent to over three years of a full Project allocation. It has developed and is expanding Aquifer Storage and Recovery (ASR) facilities that further bolster storage, and is similarly working to develop water reuse projects. Most importantly, the utility has extensive groundwater rights and production wells capable of meeting all demand without any contribution from the surface water treatment plant. Prior to completion of the surface water treatment plant in 2008, ABCWUA produced groundwater to meet all of its demand. In that sense, even a complete disruption of SJ-C water supply that required reliance on groundwater alone would operationally mirror standard practice from a decade ago.

At the same time, the central tenet of ABCWUA water policy and management is to use surface water and other renewable sources when available, saving groundwater to function as a reserve for times of drought or other supply interruption. This was the primary driver for construction of the $400 million surface water treatment plant and related infrastructure, and also underlies several planned projects under the recently adopted Water 2120 Water Resources Management Strategy adopted on September 21, 2016 by the Water Utility Board.[16]

This creates a paradox; on the one hand, years of effective planning and investment leaves ABCWUA well-positioned to handle a disruption in SJ-C supply, which might suggest that there is little if any cost to the disruption. At the same time, the utility is in this position only because of major investments in diversifying its water supply, which supports the idea that losing that supply is costly. To address this, we examined the cost of lost SJ-C water supply from catastrophic wildfire through several different approaches. Approaches include: (i) near-term financial impact; (ii) market value of lost water; and (iii) a revealed preference approach.

Near-term financial impact

Ironically, because ABCWUA's cost of surface water treatment exceeds that of groundwater production, the near-term financial impact of using groundwater in lieu of (disrupted) surface water is negative; the utility actually saves money by shifting to groundwater. The recent Water 2120 strategy states that while groundwater production costs $125/AF (primarily for pumping), surface water diversion and treatment costs are $237/AF.[17] This implies that substitution of groundwater for treated surface water would actually save ABCWUA $112 per AF. This near term negative financial cost is corroborated by a review of ABCWUA's audited financial statements from 2011 and 2012, which did not document any specific additional costs associated with impacts from the Las Conchas fire's disruption of surface water production for 40 days. Using near-term financial costs as the measure of the value of lost water does not account for the cost of depleting finite groundwater, and is therefore a poor measure of actual cost.

Market value of lost water

A market exists in which contractors and institutions buy and sell Project water, and the value of water in this market can be used as a measure of the cost of water lost due to wildfire-related supply disruptions. In simple terms, in the case where supply had not been disrupted, ABCWUA would have the option to sell its

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[16] http://www.abcwua.org/San_Juan_Chama_Project.aspx, ABCWUA 2016. Water 2120 Water Resources Management Strategy, Policies B and C.
[17] ABCWUA 2016. Water 2120 Strategy Chapter 5

water to others. The financial value of lost water can be estimated based on the foreclosure of this option. Viewed differently, ABCWUA could make up for water lost due to wildfire by purchasing supplies from others provided there was sufficient supply available, but would incur a cost in doing so; this cost could serve as an estimate of the cost of water lost due to wildfire.

The market for sale of SJ-C water is subject to institutional constraints and other major drivers that are worth noting. The Bureau of Reclamation's Supplemental Water Program purchases Project water annually to support the Rio Grande Silvery Minnow. This program expects to lease between 10,000 - 15,000 AF per year, though volumes leased could be as low as 5,000 AF in years of low supply. The Program has paid $48 per AF from non-tribal contractors and $100 per AF from Taos Pueblo and the Jicarilla Apache Nation.[18]

Reclamation policy influences the market for Project water even outside its role as a major buyer through the Supplemental Water Program. Specifically, Reclamation approval is required for all leases of contract water, leases to third parties are only allowed at cost, and Reclamation holds a right of first refusal on transactions.[19] The cost of project water is comprised of a capital construction component and annual operations and maintenance charge. The total cost varies but has averaged just under $50 per AF over the last several years.[20] These policies have interesting potential consequences for valuation of Project water in conditions of post-wildfire scarcity. First, it is possible the Reclamation would exercise its right of first refusal to what little Project water was available for the Supplemental Water Program; in this case, it would not be possible for ABCWUA or other contractors to simply "go to the market" to make up for lost supplies. Second, it implies that even if there were substantial scarcity-driven market demand, ABCWUA or other contractors would not be able to sell into the market at high (above cost) prices but would instead be limited to sale prices of approximately $50/AF. Valuation estimates based on this market value may be understated due to price controls.

ABCWUA estimates the market price of Project water at $100/AF.[21] This is broadly consistent with some Reclamation purchases as well as prices obtained in two auctions conducted by the Jicarilla Apache Nation in 2011 and 2012.[22] Absent policy constraints on prices, it is possible that market prices in the event of a post-wildfire supply shortage would increase significantly above this level, but there is no way to test this prospect. $100/AF is a reasonable estimate for the market value of SJ-C water, although it is unlikely that the utility would be able to purchase replacement supplies for Project water lost due to the impacts of catastrophic wildfire.

Revealed preference and implied willingness to pay

A final approach to understanding the value of Project water lost due to post-wildfire impacts derives a valuation estimate from policy and investment decisions made by ABCWUA in light of what they imply about the value the utility places on the water. These investment decisions "reveal" the value the utility

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[18] Reclamation 2016-2021 Supplement to the Rio Grande Supplemental Water Programmatic Environmental Assessment.

[19] Personal communication (to S. Wirth), Randy Rust, Water Contracts Group Supervisor, Bureau of Reclamation, 9/15/15

[20] Personal communication, Randy Rust, 7/13/16.

[21] ABCWUA 2016. Water 2120 Strategy Chapter 5

[22] The Jicarilla Apache Nation and Taos Pueblo are not subject to Reclamation "no profit" restrictions on the sales price of Project water. In 2011 and 2012, the tribe conducted auctions of 6,000 and 6,500 AF respectively, consistent with their right to market allotments when they were not using them pursuant to the tribal water rights settlement through which they originally acquired the allotments. The auctions produced lease prices of $75 per AF in 2011 and $82 per AF in 2012. Taos Pueblo was not an original project contractor but an allocation of 2,215 AF of Project water pursuant to the Taos Pueblo Indian Water Rights Settlement Act of 2010. Bossert and Bushnell 2013.

places on SJ-C water and therefore approximate what ABCWUA would be willing to pay to avoid losing the water given the opportunity.

The recently adopted Water 2120 strategy includes planned development of additional water supplies through additional aquifer storage and recovery (ASR) and water reuse projects. Additional ASR is planned beginning in 2020 with ongoing development of potable and non-potable reuse projects from 2035. Further stages of ASR and reuse projects are included in the portfolio further in the future.[23] The strategy estimates the cost of 'new' water supplies from ASR at $476 per AF. Cost estimates for water reuse projects are $1,465 per AF for the Eastside (Tijeras) project and $1,643 per AF for the Westside (Bosque) project.[24]

In light of the inclusion of these supply options in the recently adopted strategy, we conclude that they represent a reasonable indication of the utility's willingness to pay for water and offer a valid proxy for the cost to the utility of acquiring an additional incremental unit of water to offset supply disruptions to the Project. Using this method, we estimate a range of values for Project water used by ABCWUA between $476 and approximately $1,500 per AF in 2016 dollars. This cost assumption is applied to the Project water that ABCWUA, the Project's largest contractor, would lose due to post-wildfire impacts in our scenarios.

We assumed a range of cost between $476 and $1,500 per AF for the Project water lost by ABCWUA. The Utility Authority is estimated to lose 22,978 AF in the Blanco fire "without treatment" case, 2,047 AF in the Blanco fire "with treatment" case, and 2,209 AF in the Oso fire "without treatment" case (see section 3.2.5). This equates to total costs between $10,937,528 and $34,467,000 for the Blanco fire, and net costs of $9,963,156 and $31,396,500 compared to the with RGWF treatment scenarios. Out of conservatism, we used the lower end of this range in the calculation of ROI in the report, but it is worth noting that avoided financial impacts to ABCWUA are increased threefold if the higher unit cost estimate is used.

4.4.2 City of Santa Fe – Water Division

The City of Santa Fe faces similar dynamics as the ABCWUA with respect to the cost of lost Project water. As in Albuquerque, the utility has undertaken a deliberate strategy and made major infrastructure investments to reduce groundwater use and develop surface water as its primary supply. The Buckman Direct Diversion (BDD) provides 40-50% of the City's water supply using SJ-C water; it was built at a cost of $221 million.[25] The City produced some 8,167 AF in 2015 (exclusive of 'living river' flows). Of this, nearly 7,000 AF (over 80%) were from surface water between SJ-C water diverted at Buckman and Santa Fe River supplies.[26] This underscores the City's policy of using groundwater from its two wellfields only when needed due to surface water availability.

As in Albuquerque, Santa Fe has the capacity to produce groundwater sufficient to meet all demand for several years if necessary due to lack of surface water availability.[27] In the event of demand growth this may become difficult over the next 20 years, notwithstanding recent decreases in demand. Recognizing this, the City has been implementing contingency plans to increase the resilience of water supplies.[28] In the context of climate change, these investments are already being planned; a disruption in availability of project water conceptually equates to acceleration of this trend rather than a completely unforeseen development.

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[23] ABCWUA 2016. Water 2120: Securing our Water Future. Water Resources Management Strategy, September 2016, p. 3
[24] ABCWUA 2016. Water 2120 Strategy Chapter 5, p. 36.
[25] Personal communication Rick Carpenter (to M. Buckley), December 11, 2015.
[26] City of Santa Fe – Water Division. 2015. 2015 Annual Water Report
[27] Personal communication Rick Carpenter (to R. Hartwell), July 12, 2016.
[28] These investments include storage arrangements, pumping capacity, wells, and other infrastructure.

We estimate that Santa Fe would lose access to up to 2,929 AF of project water due to impacts from severe wildfire in the Navajo and Blanco basins, an amount roughly equal to one-third of the utility's annual demand.[29]

As in Albuquerque, Santa Fe faces high costs for diversion and treatment of SJ-C water through the Buckman Direct Diversion and would actually save money in the near term by shifting to alternative sources in event of a supply shortage. The city also has the same options to purchase or sell water by arrangement with other project contractors assuming it is available. As discussed above in Section 4.4.2, $100/AF is a reasonable estimate for this market value of project water, though this estimate is subject to limitations.

In light of the limitations on these other value estimates, developing an estimate of the City's marginal cost of developing new water supplies is an attractive proxy for the cost incurred by the City when it loses Project water. The City is currently making investments to rehabilitate the city well field to increase protection at an estimated cost of $532 per AF (converted to current dollars from a 2008 estimate of $484 per AF).[30] This figure serves as our lower bound estimate of the value of lost project water to Santa Fe. Other potential supply options are more costly (and more speculative), with coarse cost estimate as high as $3,772 in 2008 dollars. We conservatively assume a rough high-end estimate of $1,000 per AF for new supplies.

We assumed a range of cost between $532 and $1,000 per AF for the Project water lost by Santa Fe in the without-treatment scenario. This equates to total costs between $1,558,228 and $2,929,000 in the event of two fires, with most of this loss attributable to the Blanco basin (see section 3.2.5). Net cost estimates, accounting for the fact that some water would be lost even in the "with treatment" case, range from $1,431,612 to $2,691,000. Out of conservatism, we used the lower end of this range in the calculation of ROI in the report. Using the higher estimate roughly doubles the value at risk for the City of Santa Fe, a noteworthy consideration.

4.4.3 Middle Rio Grande Conservancy District

As described in the conceptual model in Section 3, we assumed that severe wildfire in the Navajo and Blanco Basins would reduce Middle Rio Grande Conservancy District's supply of Project water by 10,921 AF in the two fire scenario (with losses of 9,964 AF in the Blanco fire and 958 AF in the Navajo fire "current" cases). Historically, the District has used its SJ-C water supply to bolster supplies of irrigation water in the late summer and early fall when natural flow is at its lowest levels. MRGCD's full allocation of Project water is 20,900 AF annually, however they can store extra supply in El Vado reservoir along with stored "native" water originating in the Rio Grande Basin. According to District manager Mike Hamman, the most Project water they have ever banked at one time is 40,000 AF.

Operationally, the district uses this ability to store water to prepare for and mitigate the impact of dry years. A loss of Project water would directly hinder this ability, particularly in the likely scenario where there is little carryover storage from previous years. For purposes of this analysis, we assumed that the district is not able to store native water due to Section 7 restrictions under the Rio Grande Compact and that there is little available water from past year storage; both of these conditions have been common during recent drought years. In this situation, the direct result of the fire would be that the District was forced to operate with roughly 10,000 AF of stored water (in the case of the Blanco fire). Importantly, the District is not in a

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[29] This quantity would be lost in the case of fires both in the Blanco and Navajo Basins. A Blanco-only fire absent RGWF treatment is estimated to result in loss of 2,672 AF, while a Navajo-only event in an untreated forest would result in lost diversions of 257 AF for the City.

[30] City of Santa Fe – Water Division. 2015. City of Santa Fe Long Range Water Supply Plan, Appendix G, page. G-2. The cost of $484/AF in 2008 dollars is at the low end of supply options in the plan, which ranges as high as $3,772/AF.

financial position to acquire alternative water supply for its patrons and in contrast to major municipal utilities would simple "go without" lost water. In this situation, there would be several direct operational impacts to the District and its farmers.

First, the District would lack water to operate its water bank without injuring other water right holders and would therefore shut down the bank. This would result in fallowing of 3,500 acres and would impact District revenue. Water bank charges include three components:

- An administrative fee of $100 per year;
- A water service charge of $34 per acre; and
- A water lease rate of $50 per acre.

We conservatively assume that the administrative fee reflects actual program administration costs, which are also avoided, and therefore do not count this fee as lost revenue due to water bank closure. Instead, we assume that the water service charge and water lease rate are the direct costs to the District of not being able to lease water for 3,500 acres through the bank. This cost totals $294,000 in direct impact to District revenues.

Second, farming in the Middle Rio Grande would be reliant on monsoonal rainfall to a greater than normal extent, and farming productivity would be reduced barring exceptional precipitation.[31] For purposes of this analysis, we assume that in the case of a Blanco basin fire in the "without treatment" case, the District would required to enter into prior and paramount (P&P) operations to preferentially deliver water to Pueblo senior water right holders. We assume that this would result in the curtailing irrigation water to approximately 30,000 acres of irrigated land, effectively ending their irrigation season on August 1.[32] These 30,000 acres are roughly 50% of the total irrigated land in the District. For a Navajo basin fire that results in much less loss of Project water, the impacts would not push the District into P&P operations and would therefore not have a discrete impact on MRGCD irrigators; the impact of a Navajo Basin fire (958 AF lost) amounts to roughly a 5% reduction in stored Project water supply and would not materially change operations.[33] By the same token, the 888 AF lost in the Blanco Basin "RGWF treated" scenario would not trigger P&P operations in the District.

Analyses of the value of agricultural production in the Middle Rio Grande Valley estimated net returns from alfalfa farming of between $262 - $327 per AF per year for small bale hay production.[34] At the consumptive use of 2.1 AF per acre used in the Middle Rio Grande, this equates to $550 - $686 per acre of profit from farming.[35] Out of conservatism and noting USDA Agricultural Census statistics that report negative returns to agriculture in all MRG counties except Socorro, we reduced this estimate to $500 per acre per year and assumed a loss of 33% of this value due to curtailment, for a total financial impact of $166 per acre x 30,000 acres or $4.98 million due to curtailment of agriculture under P&P operations due to unavailability of SJ-C water. As shown in Table 11 below, that is roughly 13% of the $39 million in annual

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[31] The conceptual model assumes that monsoon rains "substantially fail", however it is likely that the District would enter into P&P operations even under average summer rains if they lost ~10,000 AF of Project water. (Personal communication, Mike Hamman, July 12, 2016). The actual decision to go into P&P operations is a function not only of quantity or precipitation, but also of the location and timing of precipitation, temperature, and availability of natural flow in the Rio Grande.

[32] P&P rights total only 8,847 acres as compared to an estimated 60,000 acres of total irrigation in MRGCD. While theoretically P&P operations protect only irrigation on the pueblo lands with P&P rights, in practice some other irrigators (both Pueblo and non-Pueblo) are able to irrigate using return flows and excess water in certain areas of the district even under P&P operation. For this reason, we assume 30,000 acres are actually curtailed (rather than 60,000 – 8,847 = 51,153 acres with junior water rights).

[33] Personal communication, D. Gensler, July 14, 2016.

[34] Confidential reports on water right value, Ecosystem Economics (2015) and WestWater Research (2016).

[35] This based on personal communications with farmers assuming 4-5 cuttings per year, 55 bales per cutting, and prices of $7.00 - $8.50 per bale.

gross crop sales in the Middle Rio Grande. In the event of such actual curtailment, reduced supply could create a secondary effect of raising hay prices in the local market; if this happened the impact could be greater still.

TABLE 11 CROP SALES FOR DOWNSTREAM COUNTIES

County	Crop Sales (2015$m)	% of market sales for 2012
Sandoval	$6	53%
Bernalillo	$8	42%
Valencia	$14	24%
Socorro	$12	15%
Total	**$39**	—

Based on the information available, we assumed MRGCD- related costs of: i) $294,000 in lost revenue due to water bank closure; and ii) $4.98 million in lost farm profits. These losses apply to the Blanco basin "current" scenario only.

4.4.4 Other San Juan – Chama Project Contractors

While Albuquerque, Santa Fe, and the MRGCD comprise both the vast majority of Project water and the entirety of current water diverted for actual use, ten other contractors are entitled to an annual allocation totaling 11,505 AF or 13% of total project volume. In the conceptual model, we assumed that these contractors would collectively lose up to 6,012 AF of water due to interrupted diversions following a post-wildfire debris flow (in the two fire scenario).

Unlike Albuquerque, Santa Fe, and MRGCD, the other contractors are not currently diverting this water supply for actual use. Instead, contractors are holding allotments for eventual sale or use to offset future groundwater pumping. At present, much of the water held by these contractors has been leased back to Reclamation's Supplemental Water Program. Because the bulk of this water is marketed rather than directly used, we assume that a market price estimate of $100 per AF is a reasonable estimate of the value of this water.

We assumed other contractors incur a cost of $100 per AF for Project water lost due to wildfire.

4.4.5 Reclamation Repair

In addition to the cost to downstream contractors of lost Project water, the Bureau of Reclamation would incur costs for cleanup and repair to Project infrastructure following catastrophic wildfire. As described in the conceptual model, we assumed that severe runoff post wildfire damages project infrastructure in the Blanco basin (at the Blanco diversion) and disrupts normal operations on the Navajo basin (at the Oso diversion). Pursuant to the contract between Reclamation and Project contractors, O&M costs related to infrastructure maintenance and repair are passed on to individual contractors. The avoided cost of this maintenance and repair is therefore a benefit from RGWF forest treatments that accrues to contractors.

Forecasting the specific nature and extent of downstream impacts from a post-wildfire debris flow is intrinsically uncertain, and this uncertainty also applies to estimation of the repair and maintenance cost related to any impacts. Despite that caveat, the baseline costs of project operation are well known and can form a point of departure for estimation of the repair and maintenance costs that would be incurred in a major debris flow as described in our conceptual model. Reclamation's May 8, 2015 Notice of Estimated Reimbursable Operation and Maintenance (O&M) Costs calculates $1,564,039 in projected O&M costs for the Project for FY 2016. Of this amount, $560,765 is related to diversion dam operation for the project, and $423,527 of this is for personnel costs related to field services monitoring and maintaining the diversions.

Based on conversations with Reclamation staff, the agency would use its existing crews and equipment, including potential out of area crews, to repair and restore infrastructure following a post-fire debris flow event.[36] In light of this and the considerable uncertainty about the extent and complexity of repair operations, we are conservatively estimating that field services related to diversion dam operations will double due to post-wildfire debris flows in the year following the event. That is, Reclamation will incur $560,765 in additional maintenance and repair cost due to severe wildfire and subsequent debris flows described in our conceptual model. These costs will be converted from 2015 dollars to account for inflation and distributed pro-rata to contractors in direct proportion to Project allocations (as Reclamation does with all Project costs). This is a conservative cost estimate in that it assumes a doubling the cost compared to routine maintenance even when the amount of debris removed could increase by as much as 100 fold.[37]

4.5 Archuleta County

This sections outlines the general categories of impacts to Archuleta County we would expect to see associated with the "representative" fires considered in this study.

4.5.1 Land Values

In order to estimate the potential impacts on land values, it was necessary to first identify land ownership, land type (e.g., forest, scrub, irrigated agriculture) and current per acre value by land type and/or ownership in Archuleta County.

As seen in Table 12, the federal government owns more than half of Archuleta County. An additional one-third of the county is privately owned, with the majority of private land being used as farmland.

[36] Personal communication, Randy Rust, July 13, 2016. Timeline constraints in the procurement process of hiring an external firm to repair infrastructure make outsourcing repairs impractical when repairs need to be accomplished quickly. For this reason, Reclamation anticipates that they would use their own crews to make repairs to the Project.

[37] This cost estimate is intentionally high level and conservative. Reclamation's actual budget estimate includes more granular detail by category including hours by employee position, travel and vehicle cost, utilities, supplies, and equipment. The category breakdown means that it would be possible to estimate costs as a function of more detailed assumptions about the level of effort needed to repair facilities. There is, however, pronounced uncertainty about the level of effort that will be needed to repair facilities and we therefore chose to use a less detailed conservative assumption to avoid false precision in the analysis.

TABLE 12 LAND OWNERSHIP IN ARCHULETA COUNTY

Land Ownership - Archuleta County	Acres	% of Total
Private	272,271	32%
Residential	33,340	4%
Farmland	210,194	25%
Cropland	13,211	2%
Woodland	31,242	4%
Farmsteads & Buildings	3,332	0%
Permanent Pasture/Rangeland	162,409	19%
Conservation Easement	28,737	3%
Federal	432,730	52%
Forest Service	421,200	50%
BLM	6,542	1%
Other	4,988	1%
State	2,373	0%
Tribal	131,388	16%
Total	838,774	—

With respect to current land values by type, a recent study by Larson (2015) estimated the value of federal, developed and agricultural lands by state. Table 13 includes estimates from the study in constant dollars (2015$) for Colorado lands. A review of recent land sales in Archuleta County (over the last year), however, suggest that values for this part of Colorado are substantially lower. The median per acre value of land sales in the general area of the representative fires was $32,300, which is the value we use.

TABLE 13 ESTIMATED COLORADO LAND VALUES (FROM LARSON 2015)

Land Type	$2015/acre
Federal	$5,690
Developed	$98,520
Agriculture	$1,150

For the Navajo basin, over 30,000 acres of private land are modeled as burning in the untreated scenario of the Oso fire. This figure is reduced to just above 12,000 acres due to RGWF treatments. The large reduction in burned area makes the return on investment for the Oso fire very sensitive to assumptions about value of private land. As described above, median values of observed private land sales were $32,300 in the area. The $32,300 per acre assumption of private land value is inappropriately high in the case of the large undeveloped parcels.

To avoid overestimation of land value and return on investment of the RGWF in the Navajo basin, we adjust the assumptions in two steps. First, we assume a "homestead" parcel size exists for each home in the Oso fire footprint based on the average parcel size in the Blanco. More specifically, for the Blanco fire, under both the "current" and "RGWF treated" scenarios, there are 287 homes within the burn area and just over 4,900 privately owned acres burn. This equates to approximately 17.1 acres of private land per home. In contrast, in the Oso fire, the "current" scenario burns 30,128 acres of private land and the "RGWF treated" scenarios burns 12,197 acres of private land, with 44 and 39 homes being affected, respectively. Under the "current" and "RGWF treated" scenarios, this equates to approximately 685 and 313 acres of private land per house, respectively. The $32,300 per acre assumption of private land value is inappropriately high in the case of the large undeveloped parcels seen in the Navajo basin, so we use the assumption of 17.1 acres of private land per home (fro the Blanco basin) for the Navajo basin as well.

These acres (i.e., 17.1 x 44 and 17.1 x 39) are assumed to command the full $32,300 per acre private land value. For the balance of undeveloped private range and forestland in the Oso (i.e., total acreage under each fire minus the assumed acreage associated with homes), we assume a value of $1,150—the agriculture land value from Larson (2015).

When considering the impact of wildfire on property values, it is important to note real financial impacts likely would be seen only 1) if a property were sold; or 2) if the property value was reassessed and property taxes adjusted accordingly. In the case of federal, state and tribal lands, the likelihood of land being sold is low.

In the case of agricultural land, an initial drop in value might be seen directly after the fire, but would likely recover as these lands could be reseeded/replanted the following year—resulting in the likelihood of minimal long-term impacts on agricultural land value. Also, note that impacts related to agricultural earnings and impacts directly on irrigation systems were accounted for elsewhere in the study.

The land type most likely to be impacted by wildfire is private developed land—primarily residential properties. Unfortunately, limited literature exists on the impact of wildfire on land values. A 2013 study on the impacts of wildfires on residential properties by Earth Economics cited three studies (i.e., Price-Waterhouse Coopers 2001; Loomis 2004 & Stetler et al. 2010) on the topic. All find that wildfires have a negative impact on residential property values ranging from 3% to 16% across the studies.

Based on this, we assumed that impacts to federal, state, tribal and agricultural lands were low (i.e., 2%), aside from small short-term impacts that are unlikely to be seen at the market level, while the impacts to private property values were higher (i.e., 15%).

4.5.2 Residential Homes

Due to the type and availability of data, impacts on residential home values were evaluated separately from the land, notwithstanding that homes and land are most commonly sold together. Developed land (not including structures) was accounted for in the previous section.

In 2015, the US Census estimated that there were 9,030 housing units in Archuleta County. The estimated median value for owner occupied housing units from 2010-2014 was $264,300. The Colorado Association of Realtors reported a median sales price for homes sold in Archuleta County in 2015 of $247,250.

It is also important to note that post-fire costs for homeowners often exceed the value of the house. In addition to rebuilding, demolition and removal of the destroyed structure may need to occur. In other cases, the insurance value of older homes may be insufficient to cover the costs of building a similar home under current regulations and codes. Out of conservatism, these considerations were not included in this study, and their inclusion would increase the benefit of avoided costs to homeowners over what is presented in the results.

Based on the information available, we assumed a home value of $215,040—calculated by subtracting the estimated value of 0.5 acres of private property (at $49,260) from the median home value (of $264,300). We assumed that homes located in areas with flame lengths greater than eight feet were completely destroyed, while home in areas with flame lengths less than eight feet saw a 15% decrease in home value.

4.5.3 Property Insurance

Any number of variables can affect property insurance rates—as such, we relied on an online site, valuepenguin.com, which collects sample insurance rates for a representative home from major insurance providers. The average homeowners insurance rate for Colorado (estimates were not available for Archuleta County or Pagosa Springs) was listed as $990 per year (valuepenguin.com 2016).

While the article focused on California, the Los Angeles Times recently reported that residents across the state in high-risk areas have seen homeowner (fire) insurance rates increase by 30% or more due in large part to a number of recent fires in the area (Masunaga 2015). Given that the Insurance Research Council recently reported that from 2009-13, Colorado ranked second out of the fifty states for homeowner catastrophe claims, many of which were fire-related, it does not seem unreasonable to use this California value (Sexton 2015).

We assumed an average annual premium of $1000/home. In the absence of data on individual home proximity to each fire scenario, we assumed an average increase in homeowners' insurance rates of 25% and 5% for all homes within Archuleta County for the "current" and "RGWF treated" scenarios, respectively.

4.5.4 Roads

With regards to road repair costs, the Colorado Department of Transportation (2011) provided two estimates for maintenance costs—one included chip sealing, sign repair, guardrail work and minor resurfacing/patching and the other included pavement repairs, minor resurfacing and sweeping. The estimated cost per mile per lane was $182,611 for the former and $8,916 for the latter.

Given that we include attribute costs to road miles in areas with flame lengths greater than eight feet, we chose to use an estimate of $182,611/mile or $192,200/mile in constant dollars ($2015). Roads in the area of the fire are predominantly single lane in width and include some gravel surface. This offsets added cost from areas where the roads may be two lanes. There are few roads in the area of the modeled fires, only 19 and 23 miles respectively for the Blanco and Oso fires in the "current" case.

4.5.5 Electric Transmission Lines

With regards to the cost to repair and/or replace damaged or destroyed lines after a wildfire, Black and Veatch (2014) prepared a report on capital costs for transmission and substations for the Western Electricity Coordinating Council. Table 14 summarizes the study's estimates of baseline capital costs for transmission lines by line type. Another recent study estimated repair costs of $150,000-$300,000/mile based on actual post-wildfire repair cost estimates from San Diego Gas and Electric Company (Johnson 2014).
We assumed a repair cost of $150,000 per mile for flame lengths greater than eight feet, the low end of the range estimated in the recent SDG&E study (Johnson 2014). It is worth noting, however, that no transmission lines were located in the fire perimeter of either scenario.

TABLE 14 BASELINE TRANSMISSION COSTS (FROM BLACK AND VEATCH 2014)

Line Description	$/Mile ($2015)
230 kV Single Circuit	$959,700
230 kV Double Circuit	$1,536,400
345 kV Single Circuit	$1,343,800
345 kV Double Circuit	$2,150,300
500 kV Single Circuit	$1,919,450
500 kV Double Circuit	$3,071,750
500 kV HVDC Bi-pole	$1,536,400
600 kV HVDC Bi-pole	$1,613,200

4.6 Industry

There are multiple ways the value of industry could be ranked and assessed—total gross income, total net income, number of employees, contribution to the community, etc. For the purposes of this study, we focus primarily on gross income and, more specifically, the potential impact of wildfire on county level gross income and the associated impact on county government tax revenue. In the following sections, we provide a brief overview of Archuleta County as a whole and then, as possible, discuss the industries most likely to be affected by wildfire: farm/forestry/mining, construction, real estate, tourism, and government (in the form of tax revenues).

Headwaters Economics maintains an online Economic Profile System that draws from a variety of federal data sources and provides county-level statistics for a variety of categories. We used this system to gather basic information on Archuleta County, including earnings by industry (see Table 15). In 2014, estimated total earnings by industries in the county totaled approximately $228 million.

TABLE 15 2014 EARNINGS BY INDUSTRY FOR ARCHULETA COUNTY (2015$M)

Industry Sector	2015$m	% of Total
Government	$42.9	18.5%
Construction	$26.5	11.4%
Retail trade	$24.4	10.5%
Accommodation and food services	$18.4	7.9%
Wholesale trade	$18.1	7.8%
Other services, except public admin.	$17.9	7.7%
Professional and technical services	$14.7	6.4%
Health care and social assistance	$14.4	6.2%
Real estate and rental and leasing	$10.5	4.5%
Finance and insurance	$7.7	3.3%
Farm	$5.7	2.5%
Administrative and waste services	$5.6	2.4%
Information	$5.0	2.1%
Educational services	$4.0	1.7%
Utilities	$3.4	1.5%
Manufacturing	$3.4	1.5%
Mining (including fossil fuels)	$2.8	1.2%
Transportation and warehousing	$2.0	0.9%
Arts, entertainment, and recreation	$2.0	0.9%
Forestry, fishing, & ag. services	$1.8	0.8%
Management of companies and enterprises	$0.7	0.3%
Total	$231.8	—

Table 16 shows industry earnings for key categories most likely to be affected by wildfire. Note that two of these are an aggregation of industries—those included in each are highlighted the same color in Table 15. More specifically, tourism includes retail trade; accommodation and food services; and arts, entertainment and recreation while outdoor industries include farm; mining; and forestry, fishing and agricultural services.

TABLE 16 SUMMARY OF GROSS INCOME FOR KEY INDUSTRY SECTORS (2015$M)

Industry Sector	2015$m	% of Total
Tourism	$44.8	19.6%
Construction	$26.5	11.6%
Real estate	$10.5	4.6%
Outdoor industries	$10.2	4.5%
All other industries	$135.9	59.6%

As mentioned previously, impacts on these industries are not directly related to a specific acre in the county burning or not burning, but rather, to more general attributes like timing, magnitude and duration of the fire.

Table 17 includes the model assumptions for the estimated percentage impact on annual gross revenue by industry under both the "current" and "RGWF treated" scenarios.

TABLE 17 ASSUMED % IMPACT ON ANNUAL GROSS REVENUE BY INDUSTRY

Industry	Current	Treated
Tourism	7.5%	3.8%
Construction	4.0%	2.0%
Real estate	4.0%	2.0%
Farm/forestry/fishing/ag services/mining	10.0%	5.0%
Other industry	2.0%	1.0%

In our review of the literature on wildfire cost studies, we did not find relevant estimates of indirect impacts to county economies from wildfire (most cost studies are focused on direct costs of fire suppression, property destruction, and rehabilitation). The assumptions above are developed using professional judgment and local knowledge of Archuleta County. For example, estimated impacts on tourism, construction, and real estate are all modest because the bulk of those industries occurs north of the Blanco and Navajo basins in the area around Pagosa Springs and the San Juan basin. While some "taint" effect would suppress economic activity, for example if tourists chose to travel elsewhere out of concern that viewsheds or recreational opportunities would be marred, these impacts would be minor because most actual tourism activity occurs away from the fires. Similar dynamics are in play for the other industries.

4.6.1 Government Tax Revenues

Like most local governments, Archuleta County and Pagosa Springs rely on a combination of state and local taxes to support their activities. The following sections describe the current tax rates as well as their contribution to local government revenues.

Property tax varies based on location of the property within the county, amenities provided at that location, etc… Based on the 2014 assessed value of properties in Archuleta County and the revenue received from property taxes, the estimated tax rate was approximately 0.44%. According to the county website (www.archuletacounty.org), Archuleta County sales tax rate is 4.0%, with proceeds being split 50/50 between the county and the Town of Pagosa Springs.

Estimated impacts to government tax revenues are calculated by multiplying the appropriate tax rate and the estimated impact to either property values or sales.

4.7 Rio Arriba County

Rio Arriba County is located directly downstream (through Project tunnels) of where the representative fires occur, making it exposed to potential debris flows, etc... associated with an upstream fire.

4.7.1 Industry – Tourism

Tourism is the primary industry likely to be affected in Rio Arriba County. In 2014, the tourism industry (i.e., retail trade; accommodation and food services; and arts, entertainment and recreation) generated approximately $60.6 million in gross revenue and accounted for just over 12% of total gross revenues for the county (Headwaters 2016). We assumed 2% and 1% impacts to the Rio Arriba tourism industry under the "current" and "RGWF treated" scenarios, respectively.

4.7.2 Government Tax Revenues

According to the 2015 gross receipts tax rate schedule for New Mexico, gross receipt taxes for Rio Arriba County range from 6.5% to 8.5625% based on the location of the business within the county (see http://www.tax.newmexico.gov/uploads/PressRelease/e19f5d4c8b014c6d870f8073d673341b/GRT_Rate_Schedule_July_2015_Revised_July_2_2015.pdf).

As in Archuleta County, estimated impacts to sales tax revenues are calculated by multiplying the appropriate tax rate and the estimated impact on sales.

4.8 Recreation

In addition to the impacts of lost tourism on the local economy, recreationalists would lose access to recreational opportunities in the area, including hiking, camping, climbing, fishing and elk hunting, among others. While real and important to consider, non-market values associated with recreating in the study area are outside the scope of this study.

4.9 Public Health

The primary impact of wildfires on public health is disease burden due to smoke-inhalation and poor air quality. A study by Richardson et al. (2012) estimated an average (private, not social) medical cost of $9.50 per exposed person per day for wildfire smoke. The same study also calculated willingness-to-pay (WTP) to avoid "a reduction in one wildfire smoke induced symptom day" of $84.42 per exposed person per day (Richardson et al. 2012).

These figures are subject to caveat. Private costs associated with seeking medical help, while based on market transactions, likely underestimate societal costs of smoke exposure (because some will experience disease but not seek medical attention). WTP, which is based on a hypothetical market, may or may not represent true costs.

The prevailing wind direction in Archuleta County is from the west-southwest. Given that the two representative fires occur in the eastern half of the county, the two counties most likely to be affected, in addition to Archuleta (estimated population 12,350), are Conejos and Rio Grande, with populations of approximately 8,300 and 11,800, respectively. Given the location of the representative fires, we assume half of Archuleta County's population and all of Conejos and Rio Grande are affected by smoke, which equates to approximately 26,000 individuals. We choose to use $10/person/day as a conservative estimate of the financial cost of health related impacts.

4.10 Carbon

This section addresses the value of carbon sequestration and avoided carbon release due to severe wildfire as another potential benefit of RGWF treatments.

Forests sequester carbon and can mitigate the harmful effects of climate change. By contrast, severe wildfire releases carbon into the atmosphere with attendant impact on total atmospheric carbon and climate change. Therefore, by reducing the scale and intensity of wildfire should it occur, RGWF treatments help avoid carbon release into the atmosphere. At the same time, treatments themselves release some amount of carbon, and this treatment release of carbon offsets the carbon benefits of avoided wildfire at least to some extent.

Recently, several studies have found that the net impact of forest treatments on atmospheric carbon is positive, particularly over time; that is the initial release of carbon from treatments are more than offset by: i) subsequent capture of carbon in the healthier forest; and ii) the reduction in carbon released in the event of a wildfire (because post-treatment fires burn smaller and less intensively, releasing less carbon).[38] These results depend in part on the specific type of forest, fuels treatment techniques, baseline conditions and assumptions, and time horizon. A central dynamic is the tradeoff between the total stock of carbon in the forest and the stability of that stock – overgrown forests may sequester more carbon but are at risk for massive release of that carbon in the event of huge fires.[39] This dynamic has led to proposal of risk-weighted carbon accounting for forest carbon to acknowledge the potential for release of carbon through wildfire. In a 2009 study, it was recommended that carbon trading mechanisms weight forest carbon in the Southern Rocky Mountains at 80-90% of the value of carbon in geographies that are less likely to burn.[40]

All of this points to the very real carbon sequestration value of RGWF treatments even when weighted for the risk of fire occurring. In our representative fire methodology, analyzing the return on investment in the RGWF in the case where a fire occurs, the net benefit is clear in the reduced scale and intensity of the two fires, and there is a strong economic argument for the economic value of carbon sequestration as a project benefit.

The arguments for inclusion of carbon value in a financial analysis of return on investment are fewer. First, there is no direct financial impact of carbon emissions from wildfire on the stakeholders considering funding RGWF treatments; for example, while downstream municipalities bear financial costs of Project water disruptions, they do not incur costs related to carbon emitted in a wildfire. Second, the process of establishing and selling carbon credits entails significant uncertainty – monetizing carbon sequestration is not straightforward and potentially not feasible, and conservatism requires exclusion of these values until they are more likely to materialize. This analysis has focused on financial rather than economic costs as the defensible drivers most germane to decisions to invest in the RGWF, with additional economic benefits mentioned separately as evidence that the total economic case for the project is better than our estimate. Were a nationwide regulatory or tax scheme for carbon to be implemented, the case for inclusion of carbon value would be bolstered, but at present it is excluded out of conservatism.

5. Results

The sizes of the two simulated fires resulted were 52,202 acres for Fire 1(Blanco) and 38,597 acres for Fire 2 (Oso) under the "current" scenario with no treatments. Under the "RGWF treated" scenarios, burned acres were 37,335 and 14,527 for Blanco and Oso, respectively. RGWF treatments are therefore estimated

[38] See Wiedinmyer and Hurteau (2010), Hurteau, Stoddard, and Fule (2012), and Hurteau and North (2010).
[39] See Hurteau and Brooks (2011).
[40] See Hurteau, Hungate, and Koch (2009).

to reduce the size of burned area by 28% and 62%, respectively, in the two scenarios. Figures 5 and 6 below present the simulated fires under both "current" and "RGWF treated" scenarios, illustrating the reduction in area and intensity of the two events.

FIGURE 5 SIMULATED FIRES UNDER "CURRENT" SCENARIO

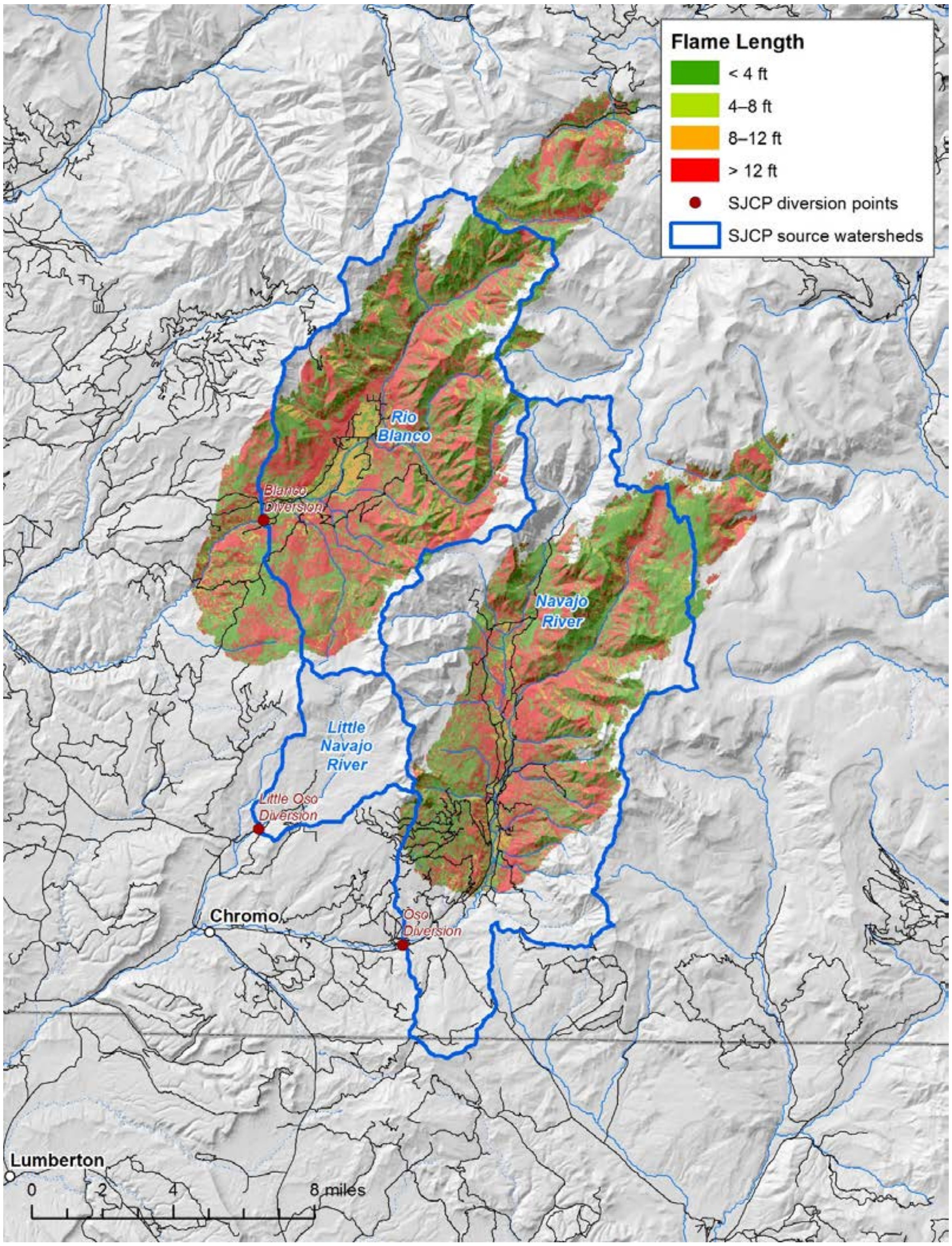
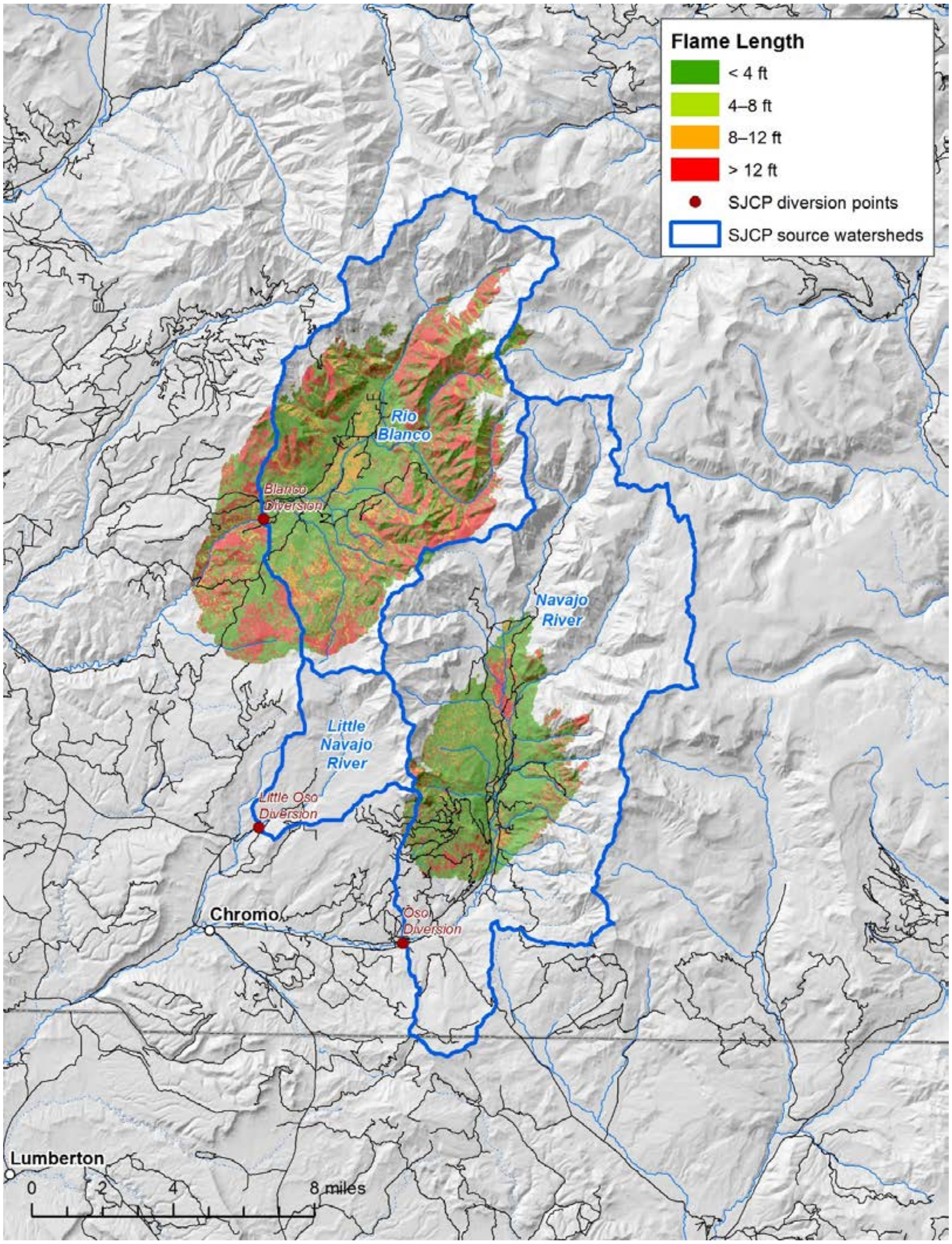


FIGURE 6 SIMULATED FIRES UNDER "RGWF TREATED" SCENARIO



This section presents the monetized benefits from this reduction in the scale and impact of fires, and then compares the benefits to cost to calculate the return on investment of the RGWF treatment program. These calculations only address the monetized benefits identified in the prior section of this report. Other unquantified benefits, such as recreation participation or existence value, increase the value of treatments. These results focus on the quantifiable and monetizable effects that can be attributed to the "current" scenario for each area fires, as compared to the costs of treatments. The values in these tables highlight the magnitude of value associated with benefits of treatments in study area for these representative fires. These values do not represent all assets at risk of wildfire over the lifespan of forest treatments, but rather two representative fires in high value areas.

Implementing treatments will take several years, and eventually maintenance treatments will be necessary to maintain treatment effectiveness in perpetuity. Treatment costs here represent the initial treatment costs for all areas to be treated in Archuleta County, spread over 20 years and discounted to present value at a rate of three percent. Similarly, benefit timing is uncertain, so benefits are similarly distributed uniformly across a 20-year timeframe, discounted to present value at three percent.

5.1 Fire 1 – Blanco

Fire 1 is the larger of the two fires modelled—with just over 52,000 acres inside the fire perimeter of the "current" scenario. Under the "RGWF treated" scenario, the estimated number of acres burned is just over 37,000. In addition to this reduced fire footprint, the number of acres burned at high intensity with flame lengths over 8' decreases from 25,552 to 16,348 acres. The water fund treatments therefore decrease both the size and intensity of the Blanco fire.

Quantifiable damages from this fire under the "current" scenario total approximately $136 million (See Table 18). Based on methods described in this report, damages under the "RGWF treated" scenarios were estimated to be $92.3 million. When combined with the estimated $9.2 million in treatment costs, the benefits still outweigh the costs by almost $35 million.

TABLE 18 ESTIMATED IMPACTS FOR FIRE 1 (BLANCO) IN CONSTANT 2015 DOLLARS

	Present Value (2015$m)		
Category	Current	Treated	Difference
Forest Treatment	$0	$9.2	-$9.2
Wildfire Suppression/Recovery	$35.6	$25.4	$10.1
Land Values/Residential Homes	$72.7	$59.9	$12.8
Roads & Transmission Lines	$2.7	$1.6	$1.1
Archuleta/Rio Arriba Economy	$8.1	$4.2	$4.0
SJ-C Surface Water	$13.9	$0.9	$13.0
Reclamation Project Repairs	$0.4	$0.0	$0.4
Public Health	$2.8	$0.4	$2.4
TOTAL	**$136.2**	**$101.6**	**$34.7**

5.2 Fire 2 – Oso

Fire 2 is smaller than Fire 1—with almost 39,000 acres inside the fire perimeter of the "current" scenario. Under the "treated" scenario, the estimated number of acres burned is reduced to approximately 14,500, a reduction of 62% in size. The Oso fire's intensity is also dramatically decreased in the "RGWF treated" case, where 3,617 acres are estimated to burn with flame lengths in excess of 8'. Without RGWF treatment, 17,571 acres were expected to burn at high intensity; the numbers of acres burned at these flame lengths is reduced by nearly 80% in the "RGWF treated" case.

Quantifiable damages from this fire under the current scenario total $52.9 million (See Table 19). Based on methods described in this report, damages under the "RGWF treated" scenarios were estimated to be $20.9 million. When combined with the estimated $9.2 million in treatment costs, the benefits still outweigh the costs by almost $23 million.

TABLE 19 ESTIMATED IMPACTS FOR FIRE 2 (OSO) IN CONSTANT 2015 DOLLARS

Category	Present Value (2015$m)		
	Current	Treated	Difference
Forest Treatment	$0	$9.2	-$9.2
Wildfire Suppression/ Recovery	$26.3	$9.9	$16.4
Land Values/Residential Homes	$11.7	$5.2	$6.5
Roads & Transmission Lines	$3.3	$1.5	$1.8
Archuleta/Rio Arriba Economy	$7.9	$3.9	$3.9
SJ-C Surface Water	$0.9	$0.0	$0.9
Reclamation Project Repairs	$0.0	$0.0	$0.0
Public Health	$2.8	$0.4	$2.4
TOTAL	$52.9	$30.2	$22.7

5.3 Comparative Analysis and Discussion

These results are based on our "representative fire" methodology grounded in the specific event where one of the two fires occurs. The actual realized value of RGWF implementation in the SJ-C Headwaters would depend on the number and distribution of future fires, which is, of course, unknown. Results can be scaled to provide some insight into the range of outcomes. For example, if both Fire 1 and Fire 2 were assumed to occur, then an estimated $76 million in combined damages would be avoided, but treatment costs would remain the same (i.e., $9.2 million), implying net benefits of almost $67 million (because RGWF implementation must only be funded once). If an even greater number of fires were to occur, benefits would increase further. These fires and the storm events generating major erosion would likely occur over time, and with discounting, the magnitude of these benefits would decline. Additionally, there would eventually be maintenance treatments necessary to continue effectiveness of initial treatments. These would occur at lower cost per acre than initial treatment per acre.

These specific benefits are not certain to accrue if RGWF treatments are implemented. Fires might be more intense but for treatments, and if treatments are effective, benefits could be greater than these estimates. If fires were to not occur during the treatment effectiveness timeframe, other benefits from risk reduction would still accrue. For example, reducing risk of wildfire could allow public and private investments, such as structures, roads, and water supply infrastructure, which might not make sense if wildfire threats are likely. Furthermore, treatments could have important ecological benefits regardless of whether or not fire would occur.

In addition to the aggregate costs and benefits of RGWF investments in the SJ-C Headwaters, our approach allows us to discuss the distribution of those costs and benefits by category and stakeholder. This analysis yields several insights (see Figures 7 and 8):

- Overall, benefits accrue to the local community more so than to downstream stakeholders (see Figure 7). Unsurprisingly, avoiding destruction of home and infrastructure is a major source of local benefit. In the case of the Blanco Fire, however, estimated benefits to downstream surface water users and the Bureau of Reclamation ($13.4 million) are almost as large as those accruing to the local community ($17.9 million). This is not the case in for the Oso Fire, where estimated local benefits are almost $12.2 million compared to less than $1 million for downstream users. This is consistent with the conceptual model in which most water resource impacts occurred in the Blanco basin.
- Avoided costs associated with fire suppression and rehabilitation costs also contribute substantially to the overall benefits, with estimated benefits of approximately $10.1 million and $16.4 million for the Blanco Fire and Oso Fire, respectively. This implies that the cost of RGWF treatments is more than offset by the savings on firefighting and recovery activities in the event of a fire, before accounting for other sources of value.

FIGURE 7 ESTIMATED BENEFITS BY AREA OF INTEREST IN CONSTANT 2015 DOLLARS

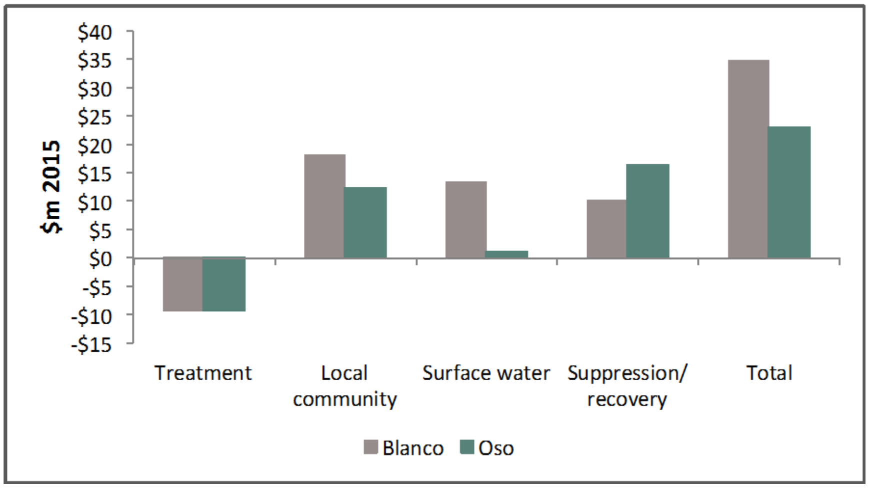
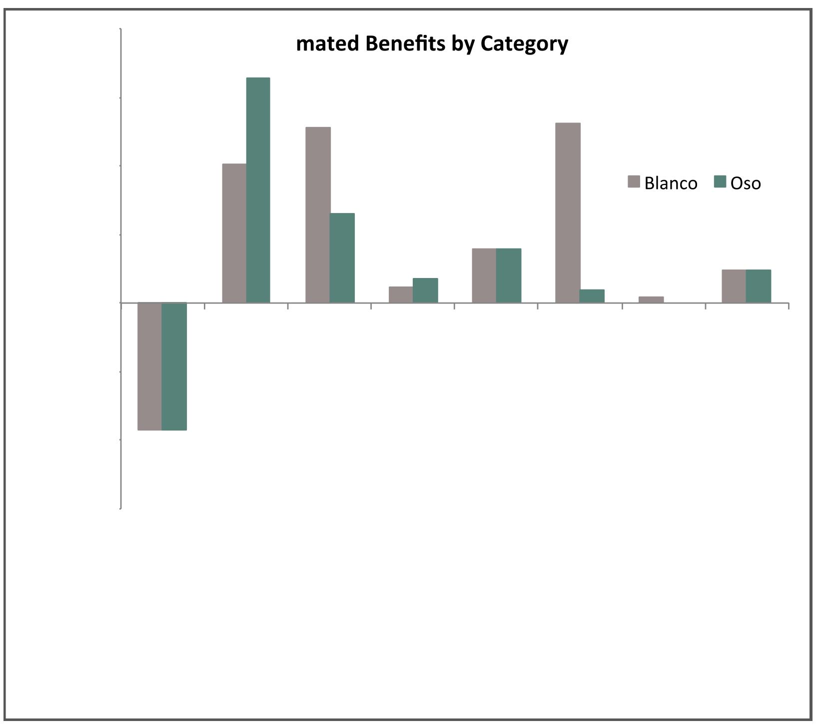


Figure 8 presents the results by major category of value, disaggregating the local community benefits into subcategories of land value/residential homes, power and transportation infrastructure, public health, and indirect local economic impacts. This disaggregation underscores that while the local community value from RGWF treatments is diversion, avoided damages to property are the largest driver for both fires. In fact, for the Blanco fire, the cost of RGWF treatments is more than offset by the avoided damage to land and homes in the event of a fire.

FIGURE 8 ESTIMATED BENEFITS BY CATEGORY IN CONSTANT 2015 DOLLARS



5.4 Return on Investment

Return on investment (ROI) is calculated as $\frac{Gain\ from\ investment - Cost\ of\ investment}{Cost\ of\ investment}$. In this case, the gains from investment are calculated as the difference in avoided costs between the "current" and "RGWF treated" scenarios. The estimated return on investment for the two representative fire scenarios modeled in this study were 375% and 246% for the Blanco and Oso fire scenarios, respectively. The difference between the two ROIs is due largely to the assumption that 17,811 acres were treated in each scenario; that is, the costs were constant across the fires, with the benefits (i.e. avoided costs) larger for the Blanco fire. In the case of the Blanco fire, a $9.2 million investment in the RGWF is estimated to avoid $43.9 million in aggregate cost. For the Oso fire, the same investment is estimated to avoid $32 million in cost. Benefit radically outweigh costs of RGWF treatments in the event that either of the fires occurs.

Compared to the Oso fire, the Blanco fire is seen as delivering greater financial benefits from RGWF treatments for two primary reasons. First, the Blanco basin is more heavily developed, with larger numbers of homes at risk due to wildfire. In our model, the number of homes destroyed declines by 45% from 161 to 89 due to water fund treatments – this alone is an avoided loss of $12.8 million that exceeds the cost of treatments. Second, the conceptual model assumes, based on Reclamation feedback, that the downstream water resource impacts from headwaters fire are concentrated in the Blanco basin. As a result, the vast majority of surface water benefits from the treatment program are attributed to the Blanco fire. The Oso fire still has an attractive benefit-cost ratio, though the drivers are savings on fire suppression and damage to private land in the basin.

This variation in both the composition and extent of benefits of RGWF treatments between the Blanco and Oso fires points to a potential opportunity for targeted investment. While it is impossible to know where and when a fire will occur, this analysis suggests that there is a concentration of fire risk in the Blanco basin, which may merit special attention. A first step in exploration of this targeted investment strategy would be to further investigate the physical risk of disruption of Blanco diversions to validate and confirm the emphasis of Reclamation staff that the bulk of risk was in the Blanco basin. At the same time, in light of the substantial modeling uncertainty intrinsic to this analysis, it is important to guard against a program strategy based in false precision.

The goal of this project was conduct a case study on one focal area, the SJ-C Headwaters, within the broader RGWF effort to evaluate the return on investment (ROI) from the RGWF. At the same time, we were restricted by the context and timing of the analysis to the use of currently available data. As a result, we were able to derive quantitative estimates of some impacts (e.g., property values, tourism) and only qualitative approximations of the direction of impact for others (e.g., river ecology, cultural values).

The refinement of current input values and the inclusion of values associated with impacts currently described only qualitatively would increase the robustness of the results. With respect to the latter, their inclusion would only bolster the benefits of the Water Fund. Another complicating factor of the analysis is the uncertainty associated with when, where and how often fires are assumed to occur across the time frame of the analysis.

That being said, the use of conservative estimates for impact categories included in the analysis and the known (negative) direction of omitted categories suggest that the Water Fund would provide robust benefits both locally and downstream with very high certainty. Additional research in other key focal areas within the watershed would improve understanding of the likely watershed-scale benefits of the RGWF effort, as well as the benefits that each stakeholder would expect to see at full-scale implementation.

6. Conclusion

This study analyzes two representative fire scenarios in the SJ-C Headwaters in an effort to gauge the return on investment of proactively addressing the threat of severe wildfire, and the associated impacts on people and watersheds, through landscape-scale forest restoration treatments. Fire 1 (Blanco), the larger event, resulted in approximately 52,000 and 37,000 burned acres in the “current” and “RGWF treated” scenarios, respectively. Fire 2 (Oso) is smaller, with almost 39,000 acres burned under the “current” scenario and approximately 14,500 burned under the “RGWF treated” scenario. Simulated fires were reduced in size and severity due to RGWF treatments.

Our analysis clearly demonstrates that investment in landscape resiliency through RGWF forest treatments dramatically reduces the potential financial impacts from severe wildfire when it occurs, and that the value of this reduction outweighs the cost of program implementation by $34.7 to $22.7 million for the Blanco and Oso fires, respectively. This study focused primarily on conservative estimation of financial benefits substantiated in market values for property, goods, and services with the potential to be impacted by wildfire in the study area. Using financial values is appropriate for stakeholders contemplating investing financially in RGWF alongside other potential uses of capital. This approach is inherently conservative—if RGWF provides an attractive investment based solely on market values, then the broader societal economic case for protecting and restoring environmental, cultural, and other resources only bolsters value of the Water Fund. In cases where fire is assumed to occur, Rio Grande Water Fund implementation in the headwater basins of the San Juan-Chama project has strong estimated return on investment ranging between 246% and 375% based on our modeling of two representative fires and their impacts to several important resources.

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Appendix A: Initial Matrix of Impacts

The table below presents the initial matrix of impacts (benefits table) used in development of the valuation methods underlying this report. It is interim work product that was submitted as a task 2 deliverable, serving primarily as an initial inventory of the significant sources of value included in the report. Value estimates were refined with stakeholder feedback and local data; the final assumptions used in the ROI analysis are described in detail in Section 4 of the report. The table below is included to provide context into the method used to identify and refine data inputs.

	Category	Description of Avoided Cost	Notes	Beneficiaries	Location of Impact	Likely Time Frame
Suppression & Recovery	Wildfire - Suppression	Costs of suppression (equipment, man-hours, etc.)	General treatment: $700/acre and WUI private: $2,150/acre (Taos numbers - adjust as needed)	Federal/state agencies, taxpayers	Local	Weeks - Months
	Wildfire - Cleanup & recovery	Costs of clean-up/recovery costs (equipment, materials, man-hours, etc.)	Suppression: $325/acre and Cleanup/recovery: $35/acre (Taos numbers - adjust as needed)	Similar to suppression	Local	Months - Years
Property & Infrastructure (Archuleta County)	Land - Federal/State	Cost associated with decrease in property value due to damage from and/or proximity to fire	52% of total (838,774) acres in Archuleta County	Federal & state agencies, insurance	Local	Years
	Land - Tribal		16% of total	Tribes	Local	Years
	Land - Private (Developed)		4% of total	Private owners, insurance	Local	Years
	Land - Private (Cropland - Irrigated)		2% of total	Private owners, insurance	Local	Months - Years
	Land - Private (Pasture/rangeland/woodland/easement)		26% of total	Private owners, insurance	Local	Years
	Residences - Destroyed	Cost of replacing residential infrastructure destroyed	9,030 units; Include streamside destruction below diversions	Private owners, insurance	Local	Months - Years
	Residences - Property value	Cost associated with decrease in property values due to proximity to fire, or partial damage, etc.	2010-14 median value: $264,300. Include streamside damages below diversion.	Private owners, insurance	Local	Months - Years
	Residences - Homeowner insurance	Cost of increased property insurance due to fire risk		Private owners	Local	Months - Years
	Roads - Primary	Costs of replacing/rebuilding roads damaged	222 miles of primary roads - 44 paved/chip-sealed	County	Local	Months - Years
	Roads - Secondary	Costs of replacing/rebuilding roads damaged	105 miles of secondary roads plus at least 172 miles of forest service roads	County, USFS	Local	Months - Years
	Transmission lines	Costs of replacing/reparing electrical lines damaged	From Steve	County	Local	Months - Years
Property & Infrastructure (Rio Arriba County)	Residences - Destroyed	Cost of replacing residential infrastructure destroyed	19,506 units	Private owners, insurance	Local	Months - Years
	Residences - Property value	Cost associated with decrease in property values due to proximity to fire, or partial damage, etc.	20102-14 median value: $140,900	Private owners, insurance	Local	Months - Years
	Residences - Homeowner insurance	Cost of increased property insurance due to fire risk		Private owners	Local	Months - Years
Water Supply	Surface water - San-Juan Chama project	Costs associated with immediate switch to alternative water supply source, increased construction and O&M costs from removal of accumulated sediment and debris at diversions and tunnel infrastructure, supply disruption and the incremental cost of new water sources that will produce the next 'sustainable' water unit in the supply curve	O&M cost ~$50/AF. JAN and Taos Pueblo market water at ~$100/AF. Construction cost was ~$35/AF w/ O&M ~$16.5/AF. Total lost diversions estimated at 45,049 acre-	Contract holders, federal gov't?	Downstream	Up to 1 Year
	Surface water - ABCWUA		25,187 acre-feet lost	ABCWUA, ratepayers	Downstream	Up to 1 Year
	Surface water - Santa Fe		2,929 acre-feet lost	City of SF, ratepayers	Downstream	Up to 1 Year
	Surface water - Downstream irrigation (MRGCD)		10,921 acre-feet lost	Irrigators	Downstream	Up to 1 Year
	Surface water - Other SJC contractors		6,012 acre-feet lost (of which 3,103 is JAN - is there reason for a separate valuation approach?)		Downstream	Up to 1 Year
	Reservoir storage & flood control			Storage right holders, reservoir owners (agencies), ISC	Downstream	Up to 1 Year

	Category	Description of Avoided Cost	Notes	Beneficiaries	Location of Impact	Likely Time Frame
Local Economy - Archuleta County	Farm, forestry, fishing, ag services, mining	Cost associated with loss of revenue (and possibly jobs) associated with these industries	2014 revenue: $10.2m (4.5% of total revenue)	County, Local residents	Local	Months - Years
	Construction		2014 revenue: $26.5m (11.6% of total revenue)	County, Local residents	Local	Months - Years
	Real estate		2014 revenue: $10.5m (4.6% of total revenue)	County, Local residents	Local	Months - Years
	Tourism		2014 revenue: $44.8m (19.6% of total revenue)	County, Local residents	Local	Months - Years
	Other industries		2014 revenue: $135.9m (59.6% of total revenue)	County, Local residents	Local	Months - Years
	Property tax revenues	Costs associated with loss of tax revenue due to impacts of wildfire on tax revenue sources	2014 assessed value of properties: $299,622,220. 2014 property tax: $5,270,145. Tax rate: ~1.759%	County	Local	Months - Years
	Sales tax revenues		Tax rate: 2% - split 50/50 between county and Pagosa Springs. 2014 revenue: $3,563,172 each.	County	Local	Months - Years
	Payment in lieu tax revenues		Received from Southern Ute Tribe and Federal gov't. Estimated 2015 revenue: $760k	County	Local	Months - Years
	Building permit revenues		2014 revenue: $185k.	County	Local	Months - Years
Local Economy - Rio Arriba County	Farm, forestry, fishing, ag services, mining	Cost associated with loss of revenue (and possibly jobs) associated with these industries	2014 revenue: $15.9m (3.2% of total revenue)	County, Local residents	Downstream	Months - Years
	Construction		2014 revenue: $25m (5.0% of total revenue)	County, Local residents	Downstream	Months - Years
	Real estate		2014 revenue: $2.9m (0.6% of total revenue)	County, Local residents	Downstream	Months - Years
	Tourism		2014 revenue: $60.6m (12.1% of total revenue)	County, Local residents	Downstream	Months - Years
	Other industries		2014 revenue: $394.9m (79.1% of total revenue)	County, Local residents	Downstream	Months - Years
	Property tax revenues	Costs associated with loss of tax revenue due to impacts of wildfire debris,etc. on tax revenue sources	2014 assessed value of properties: $1,434,904,540. Tax rate: ~0.44%	County	Downstream	Months - Years
	Sales tax revenues		Tax rate: 1.375%	County	Downstream	Months - Years
Other Considerations	Archuleta - National Forests	Costs associated with loss of trails, camptrounds, cabins and other NF infrastructure		National Forest	Local	Months - Years
	Archuleta - Southern Ute Indian Reservation	Costs to reservation residents		Tribe	Local	
	Rio Arriba - Below tunnel upstream impacts	Primarily recreation - see below			Downstream	
	Rio Arriba - Heron Reservoir	Costs associated with loss of recreational opportunities at the reservoir and associated impact on local businesses, etc.		County, Reservoir related businesses, Recreators	Downstream	
Health	Smoke exposure	Costs of health problems (& treatment) related to smoke/ decreased air quality	$10/person day (same as estimate used in Taos study)	Downwind population	Local	Days - Weeks

Appendix B: Conceptual Model of "Representative Fire" Impacts

The table below presents assumptions, additional information, and notes on valuation by location (and stakeholder) moving downstream from the SJ-C headwaters rivers through Project infrastructure to the Middle Rio Grande basin and its water uses. Together, the assumptions constitute a scenario or "conceptual model" of the water-related consequences of a "representative fire" in the headwaters used in our return on investment analysis. This table is interim work product and was submitted as a task 2 deliverable to document the results of stakeholder interviews, and is included here to provide context into the methods used in refining the analysis. It has been refined and is described in full detail in Section 3 of the report.

1. Context

Model Assumptions	Other Information	Analysis and Valuation
• Little to no carryover storage from previous year in Heron. • Little to no MRGCD storage in El Vado. • Little to no ABCWUA/Santa Fe Storage in Abiquiu (does not drive results due to municipal groundwater "cushion"). • Monsoon rains substantially fail in Middle Rio Grande Valley. • Normal water year otherwise.	• Implies that SJ-C allocation will be immediately impacted by fire year disruption. • MRGCD lacks any stored water to augment late season deliveries. • ABCWUA/Santa Fe are forced to cut back on SJ-C surface water use (vs. relying on stored water). • Rains do not support late season irrigation. • Water year impacts the amount of water lost due to fire-related disruption of diversions.	Qualify that this is a difficult context but not particularly extreme, especially in light of climate change.

2. Debris, Sediment, SJ-C Operations

Model Assumptions

Component 1

- Blanco diversion is substantially disrupted such that a full season's water is lost in the "current" scenario. In the "treatment" scenario, 10 days of diversions are lost.
- Mechanism 1: Extreme debris flows block diversion trash racks completely, then logs block outfalls completely, leading the river to cut a new channel bypassing the entire diversion structure. Repair requires 1 year.
- Mechanism 2: Shorter-term extreme debris flows clogs/buries the trash racks and tunnel entry. It can be removed during the same season, but most of the year's water is lost due to coincidence of the blockage with spring runoff.

Component 2

- Navajo diversion is disrupted for one or more short-term intervals (i.e. for several days) due to debris flows blocking trash racks.

Component 3

- Elevated sediment is in water for 4 years.
- In year 2, we could assume a few lost days of diversion in the Blanco (?)

Other

- Reclamation would not shut down diversions preventatively, even during or immediately after a large fire.
- Reclamation would not stop diversion due to sedimentation, even at very high levels.

Other Information

- Together, Components 1 and 2 are expected to result in missed diversion of over 50% of total available water during the year of the event.
- Loss of access (due to a bridge being destroyed) is another factor in the Blanco.
- The Project has never previously had to cease diversion, though they have come close during a flash flood driven debris event in 2015 (at Blanco).
- There are several ways that a debris flow event could result in no substantial impact, including i) debris begin trapped in a canyon upstream of the diversion (protecting the diversion), ii) debris being trapped at a bridge upstream of the diversion (protecting the diversion), iii) remote "cleaning" of the trash racks by short-duration closure of the gates, allowing high flows to push trapped debris downstream.
- Diversions are independent such that losing one does not impact the others.
- Debris removal is a problem and likely cost driver.

Analysis and Valuation

Need to develop quantitative estimated of lost diversions based on

- Timing of the disruption;
- Assumptions about water availability; and
- Partial substitutability between diversions.

Reclamation's work plan is a good source for costs.

3. Tunnels

Model Assumptions

- There is no risk of tunnels being blocked or clogged due to sedimentation – trash racks keep large material out of the tunnels.
- There may be some minor increase in wear and tear, which could entail a maintenance cost.

Other Information

- Multiple Reclamation staff consistently confirmed that there was really no risk to the tunnels themselves.

Analysis and Valuation

- Possible development of cost estimate for tunnel maintenance, if appropriate (need to confirm with Reclamation).

4. Heron Reservoir (and Azotea/Willow Creeks)

Model Assumptions

- Heron Reservoir's storage and water level would be lowered by the amount of water not diverted.
- There would be no issue with release of water from the reservoir – the dam is bottom-release.
- Sediment would accumulate on the creeks downstream of the tunnel outfall, requiring a greater than normal level of channel maintenance.
- Sediment would accumulate in the upstream portion of the reservoir; dredging is not anticipated given the large capacity of the reservoir.
- Fire in the watershed of Heron Reservoir itself is similarly not expected to create problematic sedimentation requiring dredging.

Other Information

- Recreation would be impacted both from lower water levels and from dirty water.
- While creek channel maintenance is a routine activity, the need would be increased during the 4-year period of increased sedimentation.
- Reservoir capacity is sufficient that no dredging is anticipated in the relevant time period.

Analysis and Valuation

- Development of estimates for recreation impacts.
- Development of estimate for increased channel maintenance.

5. Below Heron Reservoir

Model Assumptions

- No substantial impacts are anticipated to the Rio Chama below Heron Reservoir.
- Sediment should settle by the time water arrives in the Middle Rio Grande Valley (and likely long before).
- Localized sediment from downstream fire events not anticipated to create problematic sedimentation requiring dredging.

6. Downstream Use

Model Assumptions

MRGCD

- District would simply do without stored SJ-C water and would not seek to purchase additional water to mitigate lost supply.
- In the Blanco fire "current" scenario, 3,500 acres irrigated through the "water bank" would be fallowed, likely from early season (with commensurate impact on District water bank revenue).
- Per acre water deliver fees would be unaffected.
- In the Blanco fire "current" scenario, District would go to Prior and Paramount operations in mid-July, curtailing production at ~60% of lands.
- 5,000 acres have backup groundwater and would have the option to continue farming (with pumping costs).

Other Information

MRGCD

- Localized non-pueblo irrigation is possible during P&P operations (from return flows, local precip.) - adjust acreage estimates accordingly.
- District responsible for pro-rata share of Reclamation cost.

Analysis and Valuation

MRGCD

- Estimate of crop yields and revenue by season length.
- BBER study possible source, as is previous farming income analysis.

ABCWUA

- Utility would meet all demand from groundwater, and could do so for an extended period ("at least a decade").
- Financial cost of groundwater production is less than SJ-C surface water (hence no apparent financial impact from Las Conchas).
- Utility investing in system resiliency, including ASR and other high cost additional resources.
- Opportunity cost of using a finite groundwater resource is the real cost.

City of Santa Fe

- Near-term would provide all water from alternative sources (Buckman wells, City wells, SF watershed).
- Financial cost of other water sources is less than BDD surface water diversions – it saves money.
- Opportunity cost of using a finite groundwater resource is the real cost.
- SF is investing in system resiliency to ensure the ability to meet demand, even with SJ-C supply disruptions, into the future as demand grows.

ABCWUA

- Water 2120 draft strategy documents have a wealth of information on vast extent to groundwater supply cushion.
- Lee Brown (previously of UNM) has done work on opportunity cost of using groundwater – some will be included in strategy documents.
- Financial cost estimates of supply options to be releases September 21st.
- Utility responsible for a pro-rata share of Reclamation cost.

City of Santa Fe

- City has multiple options to store SJ-C water and manage a supply disruption.
- Declining per capita water use and population ease pressure on the system.
- Total annual production is ~9,500 AF.
- SF exited a long-term lease of SJ-C contract water from the Jicarilla Apache Nation at $500/AF.
- City responsible for pro-rata share of Reclamation cost.

ABCWUA

- Cost of pre-1907 water rights annualized.
- Incremental cost per unit of water from new supplies.
- Market value of SJ-C water (adjusted to reflect supply).
- Cost of SJ-C water.

City of Santa Fe

- SF purchases pre-1907 water rights at $15,000/AF (could annualize).
- SF has NTP groundwater offset obligations, purchases water rights at $30,000-$50,000/AF.
- Incremental $/unit water from investments in resiliency is another reference point for WTP for water – but these costs are born in advance of an actual fire event.
- Market value of SJ-C water (adjusted to reflect supply).
- Cost of SJ-C water.