Flagstaff Watershed Protection Project
Monitoring Plan
April 2018

OVERVIEW:

Background/Purpose: The Flagstaff Watershed Protection Project (FWPP), funded by a $10 million municipal bond, was overwhelmingly approved by voters (74%) in the November 2012 election. Because of the unique funding source and multiple-agency partnership, there is an obligation to assure voters their money is being spent in a manner that will effectively and efficiently achieve the stated goals of the project, which is to reduce severe wildfire risk and post-fire flooding.

During the campaign preceding the election, voters identified several issues that warranted benchmarks and follow-on reporting. In early 2013, we held two overarching workshops to further identity and refine these topics. These initial workshops developed three main areas of focus: 1) fire behavior, 2) hydrologic response, and 3) socioeconomic issues. Within each of these areas, working groups at these workshops developed six primary voter-based questions (see Figure A).

Figure A. Focus Areas - Voters Questions:

Fire Behavior:
- Did the investment effectively reduce the risk of catastrophic fire?

Hydrologic Response:
- How much did FWPP maintain/enhance water quality and quantity of Lake Mary?
- How much did the FWPP reduce the risk of fire-induced impacts of flooding and sediment transport?

Socioeconomic:
- How was the money invested?
- Was the investment effective in reducing post-fire/flood risk and associated costs?
- To what degree are voters aware and supportive of FWPP?

Once these three areas were clarified and the related monitoring questions determined, we hosted an additional six topic-focused monitoring workshops in the fall of 2013 (two in each focus area). During each workshop, entities that were involved with current or potential monitoring projects were invited to present and discuss how these studies would assist in answering the voters' questions. In addition, follow-on workshops were held in August 2015 and February 2018.

Capacity Monitoring Frameworks: As a result of these workshops and multiple follow-up one-on-one meetings with various entitles, we developed four capacity monitoring frameworks. The first three frameworks were focused around the previously identified voter questions; the fourth was developed as a new area outside of direct voter questions but will influence the other focus areas and addresses important issues that are important to many stakeholder groups.

These four frameworks, listed below and found in Appendix A1-A4, were designed to assess capacity - what is currently being addressed, identify gaps where studies initiated by FWPP may be necessary and the respective cost, and list other potential/future studies (to include outside funding opportunities):

1) Fire Behavior
2) Hydrologic Response
3) Socioeconomic and
4) Other Ongoing/Potential Monitoring Projects

Each of the four frameworks is organized into three main sections:

1) Studies that are planned/underway/complete
2) Studies that are needed to address knowledge gaps in order to answer voters' questions
3) Potential and future studies and funding opportunities

Each section is displayed as a table that provides: 1) the name and description of the studies that answer the respective monitoring questions, 2) the responsible entity, 3) the estimated timeline, and 4) the cost to FWPP.

Of primary interest is that the frameworks reveal that a great deal of work is already underway by others at no cost to FWPP. For those areas where FWPP financial assistance is required – limited in number (see Table I on the following page for a summary) – the frameworks provide those estimated costs and who will conduct the work. Lastly, these frameworks will be used as living documents and will be updated as new information, such as progress of ongoing/future projects, actual costs, and emerging opportunities becomes available.

Table 1. Framework Funding Summary

Focus Area	# Studies Planned, Underway, or Complete	Cost to FWPP	# Studies Needed to Address Gaps	Cost to FWPP	# Potential Future Studies	Cost to FWPP
Fire Behavior	5	None	1	None	1	None
			1	$25,000		
			1	$5,000		
Subtotal				**$30,000**		
Hydrologic Response	9	None	3	None	4	None
	1	$25,000			1	TBD
	1	$20,000				
	1	$18,270				
	1	$17,276				
	1	TBD*				
Subtotal		**$80,546**				
Socioeconomic	8	None	1	None	1	TBD
			1	TBD	2	None
			1	$3,000		
Subtotal				**$3,000**		
Other Studies	13	None	N/A	N/A	8	None
	1	$25,000				
	1	$3,000				
Subtotal		**$28,000**				
TOTAL FWPP $						
			Planned	**Needed**	**Potential**	
Total			**$108,546**	**$33,000**	**n/a**	

- TBD expense: installation fees for one hydrologic station in the DLHs.

I. Fire Behavior – Studies Planned/Underway/Complete				
Monitoring Question	**Name of Study/Description**	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
Did the investment effectively reduce the risk of catastrophic fire?	***Final Environmental Impact Statement (FEIS) Chapter 3: Affected environment and Environmental Consequences, Fire and Fuels –*** Analyzed for fire regimes and fire regime condition classes within the project. Crown fire potential (pre- and post-treatment): assessed using FlamMap 5.0 modeling, including LANDFIRE data GIS. The objectives were to: 1) Clarify potential effects of a wildfire burning under conditions similar to the Schultz fire and 97th percentile weather conditions; 2) Identify areas where fire behavior may be problematic from the perspectives of both fire effects and control issues and; 3) Analyzed and evaluated the effects of the four alternatives.	US Forest Service (USFS), Erin Phelps, Project Manager	Complete June 2015[1]	None
	Post-treatment effectiveness monitoring for prescribed fire (Rx) treatments – Provides effectiveness of Rx burns (i.e., changes in tree mortality, down woody debris, grasses, forbs, noxious weeds, crown base height, # of snags, etc.)	USFS, Beal Monday	Completed as treatments are implemented	None
	Pre-treatment Data/Stand Surveys – Completed in 2012 and 2013 on 6,621 acres within the project area. At least 71 percent of the surveyed area had a fire hazard rating of extreme.	USFS	Complete	None

[1] "USFS Final Environmental Impact Statement for the Flagstaff Watershed Protection Project" (see pg. 133) http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/92331_FSPLT3_2538953.pdf

Did the investment effectively reduce the risk of catastrophic fire?	***Vegetation monitoring to inform hazardous fuels reduction treatments in Mexican spotted owl (MSO) Protected Activity Centers (PACs) –*** Pre-treatment data collected to calibrate/verify pre-fire behavior modeling in mixed conifer MSO habitat (24% of project area).	Ecological Restoration Institute (ERI), Dave Huffman	Complete; Pre-treatment data collection in Dry Lake Hills (DLH) and on Mormon Mountain (MM) Reports available[2]	Costs included in the "Other Studies" Framework
	Drones as a Tool for Modeling Wildfire Risk: Measuring the effectiveness of forest fuel reduction treatment In Flagstaff, AZ – Remote sensing techniques (unmanned aerial vehicles (UAVs)) will be used to measure changes in forest structure from forest fuel reduction treatments. Pre- and post-treatment crown fire potential will be modelled to determine the effect these treatments have on fire behavior.	Patrick Shinn, Masters student, NAU Environmental Science & Policy	Introductory poster available[3] Fire modeling TBD at later date	None
	Case Studies/Reports: 1) *Severity of an uncharacteristically large wildfire, the Rim Fire, in forests with relatively restored frequent fire regimes*[i] 2) *The Two Wildfires Everyone Should Be Talking About (Op-Ed)*[ii] 3) *Restoring Surface Fire Stabilizes Forest Carbon Under Extreme Fire Weather in the Sierra Nevada*[iii]	See endnotes for study descriptions and links	Complete	None

[2] For 2015/16 progress reports, see: http://www.flagstaffwatershedprotection.org/wp-content/uploads/2016/07/FWPP_2015_ERI_ProgressReport.pdf and http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/FWPP-2015-ERI-MSO-Report.pdf

[3] http://www.flagstaffwatershedprotection.org/wp-content/uploads/2017/05/P_Shinn_thesis_poster.pdf

II. Fire Behavior – Studies Needed to Address Gaps				
Monitoring Question	**Name of Study/Description**	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
Fire Behavior Modeling – *(long-term monitoring). Combination of monitoring data will demonstrate effectiveness (results will validate USFS parameters in the FEIS).* Use pre- and post-treatment data to inform FlamMap modeling (add confidence, calibrate and verify the model) * Modeling for the FEIS is based on FVS modeled data inputs, not actual post-treatment data.				
Did the investment effectively reduce the risk of catastrophic fire?	***Post-treatment data collection in DLHs*** *(76% of project area).*	ERI, Dave Huffman	One-year post-prescribed fire treatments	$25k
Did the investment effectively reduce the risk of catastrophic fire?	***Fire Behavior Modeling DLH based on pre- and post-treatment data –*** *(76% of project area).* Calibrate/verify pre- post-fire behavior modeling in ponderosa pine.	ERI, Dave Huffman	Once post-treatment data collection is complete	$5k
	Vegetation monitoring to inform hazardous fuels reduction treatments in Mexican spotted owl (MSO) Protected Activity Centers (PACs) – Calibrate/verify post-fire behavior modeling in mixed conifer MSO habitat (Dry Lake Hills (DLH): 24% of project area; Mormon Mountain (MM) 33% of project area).	ERI, Dave Huffman	**DLH:** Post-treatment: summer 1 year and 5 years following implementation **MM:** Post-treatment: summer 1	None[4]

[4] ERI is seeking funding. For **DLH:** Post-year one $30k; Post-year five $30k. For **MM:** Post-year one $30k; Post-year five $30k.

			year and 5 years following implementation	

III. Fire Behavior – Potential Future Studies			
Name of Study/Description	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
***LIDAR*[5] –** Digital Elevation Models derive surface topography for storm flows/flooding, ground cover and canopy cover. The City has Lidar data (+ or – 6 inches) for all of the Rio de Flag watershed. Lidar data has not been collected in the Upper Lake Mary Watershed. Lidar data can potentially be used for fire modeling to determine changes in predicted fire behavior pre- to post-treatment.	City of Flagstaff, Debra Vian Brown, GIS Team Administrator	TBD	None

[i] "The 2013 Rim Fire, originating on Forest Service land, burned into old-growth forests within Yosemite National Park with relatively restored frequent-fire regimes. Forest structure and fuels data were collected in the field 3–4 years before the fire, providing a rare chance to use pre-existing plot data to analyze fire effects. Our results suggest that wildfire burning under extreme weather conditions, as is often the case with fires that escape initial attack, can produce large areas of high-severity fire even in fuels-reduced forests with restored fire regimes. Plots located at higher elevations (1700–2000 m) and those that had burned more recently burned predominantly at low severity despite recent drought conditions, suggesting that forests with restored frequent-fire regimes are resilient to wildfire under less-than-extreme fire weather conditions. To effectively influence fire behavior, agencies should coordinate fuel reduction and wildfire policies across large landscapes if both jurisdictions are within the same potential 'fireshed." https://www.fs.fed.us/psw/publications/lydersen/psw_2014_lydersen001.pdf

[5] "LIDAR is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target." USGS, *FEMA Standards for LiDAR and Other High Quality Digital Topography*. https://www.fema.gov/media-library-data/1469794589266-f404b39e73fa7a1c5ffe4447636634d4/Elevation_Guidance_May_2016.pdf

[ii] "…this year, since the arrival of monsoon rains in July, the height of Arizona's fire season has seemingly come to a close. As anyone in the West knows, the weather can change on a dime, and there is plenty of fuel in the forests left to burn. But two fires had the conditions, and the chance, to burn hundreds of houses and destroy some of the state's most coveted recreational tourist attractions, and they didn't. They are the fires that didn't make the headlines." https://www.livescience.com/47510-wildfire-prevention-is-science-not-art.html

[iii] "Our goal was to compare the impacts of extreme wildfire events on carbon stocks and fluxes in a watershed in the Sierra National Forest. We ran simulations to model wildfire under contemporary and extreme fire weather conditions, and test how three management scenarios (no-management, thin-only, thin and maintenance burning) influence fire severity, forest C stocks and fluxes, and wildfire C emissions. We found that the effects of treatment under contemporary fire weather were minimal, and management conferred neither significant reduction in fire severity nor increases in C stocks. However, under extreme fire weather, the thin and maintenance burning scenario decreased mean fire severity by 25%, showed significantly greater C stability, and unlike the no- management and thin-only management options, the thin and maintenance burning scenario showed no decrease in NEE relative to the contemporary fire weather scenarios. Further, under extreme fire weather conditions, wildfire C emissions were lowest in the thin and maintenance burning scenario, (reduction of 13.7 Mg C/ha over the simulation period) even when taking into account the C costs associated with prescribed burning. Including prescribed burning in thinning operations may be critical to maintaining C stocks and reducing C emissions in the future where extreme fire weather events are more frequent."
https://www.srs.fs.usda.gov/pubs/ja/2017/ja_2017_loudermilk_001.pdf

I. Hydrologic Response – Studies Planned/Underway/Complete				
Monitoring Question	**Name of Study/Description**	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
How much did the FWPP reduce the risk of fire-induced impacts of flooding and sediment transport?	***Schultz Emergency Watershed Protection (EWP) Project*** Natural Channel Design determined sediment yield (quantities/sources) and how this affects flood mitigation. Conducted pre- post-hydrologic modeling and monitored channel stability, damage, etc. "As of summer 2014, monsoon rain events were significant, but runoff never entered into the neighborhood from restored watersheds; flows spread across rehabilitated fans on-forest as intended."	Coconino County Public Works, Engineering Division Manager, Christopher Tressler	Complete; Project update available[1]	None
	Hydrologic Modeling (WILDCAT5) Using Forest Service Simulated Soil Burn Severity Maps – Model changes in watershed runoff as a result of wildfire. Demonstrates predicted peak discharge for: 1) No Action (current conditions), No Wildfire; 2) No Action, Simulated Wildfire; 3) Alternative 2, Simulated Wildfire; and 4) Alternative 4, Simulated Wildfire. The USFS Erosion Risk Management Tool (ERMiT) calculates that sediment yield from burned watersheds during flood events will increase as forest burn severity increases. **Results**: No Action (current conditions) coupled with Simulated Wildfire has the largest peak discharge followed by Alt. 4 (minimal treatment approach) with Simulated Wildfire.	US Forest Service (USFS) Coconino NF, Tom Runyon, Hydrologist	Complete; Report available[2]	None

[1] Four watersheds are complete that describes an assessment of impacts. http://naturalchanneldesign.com/projects/
[2] "USFS Final Environmental Impact Statement for the Flagstaff Watershed Protection Project" (see pg. 266) http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/92331_FSPLT3_2538953.pdf

How much did the FWPP reduce the risk of fire-induced impacts of flooding and sediment transport?	***Evaluating Erosion Risk Mitigation due to Forest Restoration Treatments Using Alluvial Chronology and Hydraulic Modeling –*** This analysis was conducted in the FWPP Dry Lake Hills area. Hydraulic modeling using HEC-RAS 4.1 indicates that forest treatments reduce the magnitude of post-fire flow at the confluence of the watershed by up to 55%.	Victoria A. Stempniewicz's thesis work Northern Arizona University (NAU)	Complete; Report available[3]	None
	City of Flagstaff MIKE SHE Modeling Project – MIKE SHE is a two-dimensional overland flow model coupled with a one-dimensional channel hydraulics model that can approximate flood flows from changes in watershed characteristics. The modeling results conclude that catastrophic flood flows from burned watersheds can be reduced with forest treatments.	City of Flagstaff, Water Services Division; Jim Janacek, Storm Water Section	Complete; Report not released	None
How much did FWPP maintain/enhance water quality and quantity of Lake Mary?	***Lake Mary-Walnut Creek Technical Advisory Committee (TAC) –*** TAC funded hydrology data collection equipment in the Four Forest Restoration Initiative (4FRI) Upper Lake Mary paired watersheds. The TAC's objective is to identify best management practices and to evaluate projects or methods that may increase the likelihood of runoff and improve the inner-canyon environment in Walnut Canyon National Monument. *See two funded (April '14) projects below (Flowtography and Newman Canyon).*	TAC members: Paul Whitefield, National Park Service (NPS); Garrett Port (USFS); Erin Young, Brad Hill (City Water Services)	Ongoing	None
	Streamflow and Precipitation Gauges:	City of Flagstaff, Water Services	**ULMW:** All equipment installed and	$5,000 in FY16 for NC equipment/

[3] http://www.flagstaffwatershedprotection.org/wp-content/uploads/2014/12/Fullthesisdec10.pdf

	(8) Flowtography® Stations[4], (6) Pressure Transducers, (3) Precipitation Gauge Stations[5] – **(**7) flowtography® stations, (6) transducers and (3) precipitation gauges in the Four Forest Restoration Initiative (4FRI) Upper Lake Mary Watershed (ULMW); (1) flowtography station at Newman Canyon (NC). **ULMW:** Flowtography, in combination with transducers and precipitation gauges, will provide stream channel flow data in relation to precipitation[6]. **NC:** Flowtography will be used for approximately two years to verify the gauge at NC with photo documentation of flows (see Newman Canyon Gauge below). Note: 1) City water level data is being used to assess Upper Lake Mary inflow volume; 2) City staff will validate data set provided by Salt River Project (SRP) as part of data Quality Assurance/Quality Control (QA/QC).	Division; Erin Young	operating as of Sept. 2016 with some data collection beginning in 2014[7] **NC:** Equipment installed 2016. Fact Sheet available[8]	O&M $5,000 per year for four years (FY17-20) **Total $25k**

[4] April '14: Lake Mary TAC funded $14,840 to purchase equipment.
[5] Flagstaff City Council approved three-year agreement with Salt River Project (FY18-FY20) to operate and maintain equipment. Data are available upon request. Water Services has an annual budget of $110,000 for O&M.
[6] Post forest treatment data collection needed to determine effects of forest treatments.
[7] City of Flagstaff Upper Lake Mary Watershed Monitoring Project http://www.flagstaff.az.gov/3467/Upper-Lake-Mary-Watershed-Monitoring-Pro
[8] http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/FWPP-Upper-Lake-Mary-Monitoring.pdf

How much did FWPP maintain/enhance water quality and quantity of Lake Mary?	***USGS Newman Canyon Gauge***[9] **–** With a combined rainfall, sediment, and stream flow gauge on Newman Canyon Wash, the largest tributary of the lake, the City intends to monitor and understand the volume, timing and quality of surface water recharge into the lake from the surrounding forested areas. The gauge collects rainfall and stream flow data in real-time and stores it in a database for future analysis. These data are available on the Internet, which will allow water managers to know when and at what level the wash is flowing and when water quality and sediment sampling is possible. These data might also be useful in evaluating water quality and quantity impacts associated with forest thinning projects that will be occurring within the watershed.[10]	City of Flagstaff, Water Services Division; Erin Young	USGS gauge installed 2014. Flowtography equipment installed 2016. USGS data available[11]	$5k annually for 4 years[12] **Total $20k**
How much did the FWPP reduce the risk of fire-induced impacts of flooding and sediment transport?	***Dry Lake Hills Data Logger Precipitation Alert***[13] ***Gauges and Pressure Transducers*** (2 each) **–** Collect precipitation and stream flow measurements during flood events so that these measurements can be compared to what hydrologic and hydraulic models predict for Dry Lake Hills.	City of Flagstaff, Water Services Division; Jim Janacek, Storm Water Section	Instrumentation installation complete on City land (Spruce Ave Wash) and ADOT right-of-way (Schultz Creek).	$9,135 each station (equipment and installation); **Total $18,270**[14]

[9] Lake Mary TAC funded $23k (April '14) for equipment.
[10] Post forest treatment data collection is needed to determine effects of forest treatments.
[11] https://waterdata.usgs.gov/usa/nwis/uv?09400815
[12] Council approved agreement with USGS for five fiscal years on 7/15/14 (effective July 1, 2014 – September 30, 2018).
O&M: total = $12,200/yr. paid by: 1) FWPP: $5k annually for 4 years (FY15 - FY18); 2) Water Services: $5k annually for 4 years (FY15 - FY18) and $3,050 in FY19; 3) TAC: $2,200 annually for 4 years (FY15 - FY18). Total 5-year match: $74,300 City and $66,200 USGS.
[13] Residence can sign-up for the alert system by sending an e-mail address or cell phone number to JJanecek@flagstaffaz.gov
Hydrographs available at: Azwatergage.com
[14] O&M: $500/station annually – paid for by City of Flagstaff Water Services Division, Storm Water Section.

How much did the FWPP reduce the risk of fire-induced impacts of flooding and sediment transport?	***Dry Lake Hills Data Logger Precipitation Alert Gauges and Pressure Transducers*** (2 each) **–** Collect precipitation and stream flow measurements during flood events so that these measurements can be compared to what hydrologic and hydraulic models predict for Dry Lake Hills.	City of Flagstaff, Water Services Division; Jim Janecek, Storm Water Section	Instrumentation installed on USFS land (Schultz Creek Station)[15]	Equipment purchased for two stations + installation fees for one station **$17,276**[16]
	Post-Wildfire Debris-Flow & Flooding Assessment: Coconino County, Arizona (2017) – This study comprised a countywide evaluation to identify areas that are at risk for flooding and debris flows in the aftermath of a wildfire like the Schultz Fire. It includes a detailed planning-level evaluation of post-fire flood and debris flow hazards for two pilot study areas in Fort Valley and the City of Williams.	AZ Geological Survey; J.B. Loverich, A.M. Youberg, M.J. Kellogg and J.E. Fuller	Complete; Report available[17] *AZ Daily Sun* article, "Study: without forest treatment, wildfire above Ft. Valley means inundation"[18]	None

[15] For rainfall and stream gauge data, see: http://www.jefullerdata.com/ADWR/Flagstaff/mapfs.html.
One additional gauge on Spruce Ave Wash on USFS land in the higher elevation of DLH is expected for installation Spring '18.
[16] Labor fees for the Spruce Ave Gauge installation will be added to this figure once installed.
[17] http://repository.azgs.az.gov/uri_gin/azgs/dlio/1727
[18] http://azdailysun.com/news/local/study-without-forest-treatment-wildfire-above-fort-valley-means-inundation/article_4b4a034d-a322-57da-8523-6061d6f7ed50.html?utm_medium=social&utm_source=email&utm_campaign=user-share

How much did FWPP maintain/enhance water quality and quantity of Lake Mary?	***Hydrologic Monitoring in Walnut Canyon National Monument –*** The National Park Service (NPS) is conducting long-term hydrology monitoring at three locations in the Walnut Creek watershed below Lower Lake Mary. Two continuous stage recording stations are operated and maintained on Walnut Creek and a third station is on the tributary of Cherry Creek.	Hydrologist; Southern Colorado Plateau Network (SCPN) Inventory & Monitoring Program; NPS; Flagstaff, Arizona	Ongoing, long-term monitoring. Results from 2010-2014 are available in two summary reports (2012 & 2015)[19]	None
What are the impacts of thinning operations on sediment transport (erosion) and water flows?	***Best Management Practices (BMP) Minimize Impacts to Soils, Water Resources and Trails –*** Public document developed from FWPP's Final Record of Decision (Appendix B: Design Features) that describes plans to use BMPs that mitigate on-the-ground disturbance to soil, water resources and trails[20]	FWPP Project Team	Complete; Public document available[21]	None
	LIDAR[22] – LiDAR surveys can be used to create surface topography through digital elevation models (DEM's). Imagery associated with the LiDAR provides additional information on ground cover, vegetation and canopy cover. These watershed characteristics are useful for increasing the accuracy of hydrologic and hydraulic modeling predictions for storm flood flows and sedimentation.	City of Flagstaff, Debra Vian Brown, GIS Team Administrator	The City has Lidar data (+ or - 6 inches) for all of the Rio de Flag watershed. Lidar data has not been collected in the upper Lake Mary watershed.	None

[19] https://irma.nps.gov/DataStore/DownloadFile/454663 and https://irma.nps.gov/DataStore/DownloadFile/545590

[20] Record of Decision for the Flagstaff Watershed Protection Project, Coconino National Forest, http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/92331_FSPLT3_2578859.pdf

[21] http://www.flagstaffwatershedprotection.org/wp-content/uploads/2016/05/Best-Management-Practices_Final.pdf

[22] "LIDAR is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target." USGS, *FEMA Standards for LiDAR and Other High Quality Digital Topography*. https://www.fema.gov/media-library-data/1469794589266-f404b39e73fa7a1c5ffe4447636634d4/Elevation_Guidance_May_2016.pdf

	Case Studies/Reports: 1) *Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation* [i] 2) *Wildfire Effects on Source Water Quality - Lessons from Fourmile Canyon Fire, Colorado, and Implications for Drinking-Water Treatment* [ii] 3) *Wildfire Impacts on Water Quality* [iii] 4) *Wildfires and the Impact on Water Quality* [iv] 5) *Wildfire Impacts on Surface Water Quality* [v] 6) *Wildfires may double erosion across a quarter of western US watersheds by 2050* [vi] 7) *Western Water Threatened by Wildfire* [vii] 8) *Effects of Climate Variability and Accelerated Forest Thinning on Watershed-Scale Runoff in Southwestern USA Ponderosa Pine Forests* [viii] 9) *Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation* [ix] 10) *The Influence of Restoration Treatments on Hydrologic Output in Fire Adapted Forests of the Southwest* [x] 11) *Climate, wildfire, and erosion ensemble foretells more sediment in western USA watersheds* [xi] 12) *Increases in wildfire-caused erosion could impact water supply and quality in the West* [xii] 13) *Groundwater, Surface-Water, and Water-Chemistry Data from the C-Aquifer Monitoring Program, Northeastern Arizona, 2005–11* [xiii] 14) *Managing for Future Risk of Fire, Extreme Precipitation, and Post-Fire Flooding* [xiv] 15) *Effect of forest management on water yields and other ecosystem services in Sierra Nevada forests* [xv] 16) *Wildfire Impacts on Water Supplies and the Potential for Mitigation: Workshop Report* [xvi]	See endnotes for study descriptions and links.	Complete	None

II. Hydrologic Response – Studies Needed to Address Gaps				
Monitoring Question	**Name of Study/Description**	**Entity Responsible/Contact**	**Timeline**	**$ From FWPP**
How much did FWPP maintain/enhance water quality and quantity of Lake Mary?	Post implementation data is needed to address this question. In order to understand the effects of forest treatments equally within paired watersheds, 7-9 years of baseline data is required, coupled with specifically timed forest treatments. This would assist in validating model predictions (assess how the model results compare with real events/data).	TBD	TBD	None
What are the impacts of thinning operations on sediment transport (erosion) and water flows?	See Fire Behavior Framework for vegetation monitoring metrics	TBD	TBD	None
What are the impacts of thinning operations on sediment transport (erosion) and water flows?	USFS' Best Management Practices post-implementation monitoring results	USFS, Tom Runyon	Monitoring results after forest treatments are implemented	None

III. Hydrologic Response – Potential Future Studies			
Description	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
Inform future treatment maintenance decisions	Paul Summerfelt, City FWPP Project Manager; Brad Hill, City of Flagstaff Water Services Director	TBD	TBD
Paired Watershed Study	Abe Springer, NAU School of Earth Sciences and Environmental Sustainability	TBD	None
Relocate Rain Gauge/Transducer – Move rain gauge/transducer from Lake Mary to Fanning Drive Wash (City land) (1 of 4 tributaries in the DLHs/FWPP project area). Collect precipitation and stream flow measurements during flood events so that these measurements can be compared to what hydrologic and hydraulic models predict for DLHs.	City of Flagstaff, Water Services Division, Jim Janecek, Storm Water Section	Expected completion FY '18	None
Observatory Mesa – Visual Inspection for Sedimentation and Erosion	City of Flagstaff, Water Services Division, Jim Janecek, Storm Water Section	Conduct annually after monsoon season or formidable precipitation events (mid-Sept.)	None
4FRI Springs Monitoring – Implemented a citizen science-based springs survey and inventory application for smartphones and tablets for 4FRI. This is expected to provide baseline	Springs Stewardship Institute, Wildlands	Ongoing	None

information about spring health.[23] Potential to inventory springs in the FWPP project areas.	Network and Northern Arizona University		

[i] "Although wildfire is an integral part of a healthy environment, it can have significant impacts on the drinking water industry due to its widespread effects on source water quality and associated treatment needs. In an effort to promote a more complete understanding of these effects and the steps drinking water utilities can take to mitigate wildfire risk and damage to their infrastructure and watershed, The Cadmus Group, Inc. (Cadmus), with funding from the Water Research Foundation (Foundation) and the U.S. Environmental Protection Agency (USEPA) Source Water Protection Program and Urban Waters Federal Partnership, developed this report, which presents 1) current information on the impacts from wildfires on drinking water utilities and 2) lessons learned and recommendations for future research that were discussed during the Wildfire Readiness and Response Workshop held in Denver, Colo. April 4-5, 2013." (Water Research Foundation (WRF). 2013; http://www.waterrf.org/Pages/Projects.aspx?PID=4482)

[ii] "In order to evaluate the effects of wildfire on water quality and downstream ecosystems in the Colorado Front Range, the U.S. Geological Survey initiated a study after the 2010 Fourmile Canyon fire near Boulder, Colorado. Hydrologists frequently sampled Fourmile Creek at monitoring sites upstream and downstream of the burned area to study water-quality changes during hydrologic conditions such as base flow, spring snowmelt, and summer thunderstorms. This fact sheet summarizes principal findings from the first year of research. Stream discharge and nitrate concentrations increased downstream of the burned area during snowmelt runoff, but increases were probably within the treatment capacity of most drinking-water plants, and limited changes were observed in downstream ecosystems. During and after high-intensity thunderstorms, however, turbidity, dissolved organic carbon, nitrate, and some metals increased by 1 to 4 orders of magnitude within and downstream of the burned area. Increases of such magnitude can pose problems for water-supply reservoirs, drinking-water treatment plants, and downstream aquatic ecosystems." (USGS. July 2012; http://pubs.usgs.gov/fs/2012/3095/FS12-3095.pdf)

[iii] "The results of the San Dimas Experimental Forest (SDEF) drinking water quality research suggest that wildfires may have a greater impact on water quality than prescribed fire; other studies have demonstrated the relatively benign effects of prescribed fire on water quality (Stephens et al., 2004; Richter et al., 1982). Taken together, these findings indicate that more frequent use of prescribed fire may have a beneficial impact on long-term water quality management in the western United States." (*Southwest Hydrology.* Sept/Oct 2004; http://cierzo.sahra.arizona.edu/swhydro/archive/V3_N5/SWHVol3Issue5.pdf)

[iv] Review of USGS 2012 study (above), Burn Area Emergency Response (BEAR) rehabilitation measures and others. Suggests a proactive means of reducing impacts from wildfires (use of thinning and prescribed fire); in areas that were treated with prescribed fire, levels of sediment runoff and nitrate concentrations were substantially lower. (University of Denver Water Law Review. A. Brunskill. Feb 2013; http://duwaterlawreview.com/2013/02/page/2/)

[v] The primary impact on surface water quality after a wildfire are: 1) introduction of debris and sediment, including black ash from burned vegetation, 2) increases in nitrates and other plant nutrients, 3) introduction of radionuclide and heavy metals, and 4) introduction of fire retardant chemicals into water bodies that can be toxic to aquatic organisms. The magnitude of these effects is dependent on fire severity (how much of the fuel is consumed) and fire intensity (how

[23] SSI website: http://springstewardshipinstitute.org and *AZ Daily Sun* article: "Stewards of springs get new app" http://azdailysun.com/news/local/stewards-of-springs-get-new-app/article_cb5493d7-3e49-5e8a-ac17-5a3813ef91bd.html

hot the fire burned) coupled with seasonal weather events, such as monsoonal rains. Therefore, the more severe the wildfire, the more susceptible the watershed is to erosion and increased nutrients, which could negatively impacts water quality. If the fire is severe enough, it can also affect the formation of hydrophobic soils, which repel water and increase the probability of storm run-off. If slopes are steep, this further compounds fire effects, whereas, steep slopes cause greater runoff and increased transport of chemicals and sediment in the waterways. (New Mexico Environment Department. 2013; http://www.nmenv.state.nm.us/swqb/Wildfire/)

[vi] "The scientists used computer models to simulate future wildfire activity across the West between now and 2050. The models incorporated how climate change may alter the number and size of wildfires. Then, the scientists used a second set of models to estimate the amount of erosion that would result within a year of these wildfires." They concluded, wildfires may double erosion across a quarter of western US watersheds by 2050. (USGS. 2015; https://phys.org/news/2015-11-wildfires-erosion-quarter-western-watersheds.html)

[vii] Key Findings: "1) Across the West, private and family-owned lands with high wildfire risk cover an area the size of Kansas. More than one-third, or 52 million acres, of the high wildfire risk falls on private and family-owned lands, not public land; 2) Nearly 40% of the land that keeps water clean in important watersheds that are at a high risk of wildfire, are private and family-owned. This is three times the size of New Jersey; 3) Western family forest owners offer an opportunity to protect public water supply by addressing wildfire risk now. Family forest owners want to do the right thing and they are motivated to take action on their land. The majority cite the high cost of implementing management as a barrier." "The clear conclusion is fire in the West is not exclusively a public lands problem. Understanding the distribution of risk can and should inform the strategies and approaches to mitigating that risk, particularly in areas where a critical public good such as water is implicated." (American Forest Foundation, Washington, D.C. 2015; https://www.forestfoundation.org/western-water-forests-report)

[viii] "The recent mortality of up to 20% of forests and woodlands in the southwestern United States, along with declining stream flows and projected future water shortages, heightens the need to understand how management practices can enhance forest resilience and functioning under unprecedented scales of drought and wildfire. We found that runoff on thinned forests was about 20% greater than unthinned forests, regardless of whether treatments occurred in a drought or pluvial period. The magnitude of this increase is similar to observed declines in snowpack for the region, suggesting that accelerated thinning may lessen runoff losses due to warming effects. Gains in runoff were temporary (six years after treatment) and modest when compared to mean annual runoff from the study watersheds (0–3%). Nonetheless gains observed during drought periods could play a role in augmenting river flows on a seasonal basis, improving conditions for water-dependent natural resources, as well as benefit water supplies for downstream communities. Results of this study and others suggest that accelerated forest thinning at large scales could improve the water balance and resilience of forests and sustain the ecosystem services they provide." (Robles MD, Marshall RM, O'Donnell F, Smith EB, Haney JA, Gori DF (2014) Effects of Climate Variability and Accelerated Forest Thinning on Watershed-Scale Runoff in Southwestern USA Ponderosa Pine Forests. PLoS ONE 9(10): e111092. doi:10.1371/journal.pone.0111092; http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0111092).

[ix] "Steps to prepare for wildfires can include assessment of the vulnerability of the watershed to wildfire, assessment of the vulnerability of the drinking water system, and development of emergency response plans. More information is needed on appropriate post-fire monitoring strategies for drinking water utilities because they may need water quality information on a more frequent basis than is typically acquired when a watershed is studied. Drinking water utility staff indicated that they were better able to identify serious wildfire risks and develop mitigation plans once they were informed about the risks within their watershed.

Survey participants reported that collaboration with other drinking water systems, landowners, non-profit organizations, and local, state, and federal government agencies was a critical aspect of wildfire mitigation." (Water Research Foundation. 2013; http://www.waterrf.org/publicreportlibrary/4482.pdf).

[x] "A number of forest restoration projects to protect municipal water supplies are planned or underway in fire-adapted forests in the Southwest, including the Flagstaff Watershed Protection Project, the Upper South Platte Watershed Protection and Restoration Project near Denver, and the Santa Fe Municipal Watershed Project. Forest restoration in the Southwest will expand to the landscape scale in the coming decades. The Four Forest Restoration Initiative (4FRI) plans to conduct thinning and prescribed burning on 2.4 million acres of forest in Arizona (USDA 2013). Large-scale restoration is also being planned in New Mexico through the Rio Grande Water Fund (RGWF 2014). With the increase in scale of forest restoration, it is possible that restoration treatments will affect major river basins and regional aquifers. This working paper summarizes research relevant to understanding the effect of restoration treatments on the hydrologic cycle of southwestern forests. An overview of forest hydrology in the Southwest is presented, followed by discussions of forest restoration and wildfire effects on water quantity, water quality, and hydrologic function." (Ecological Restoration Institute. 2016; https://cdm17192.contentdm.oclc.org/digital/collection/p17192coll1/id/662/rec/1)

[xi] "The area burned annually by wildfires is expected to increase worldwide due to climate change. Burned areas increase soil erosion rates within watersheds, which can increase sedimentation in downstream rivers and reservoirs. However, which watersheds will be impacted by future wildfires is largely unknown. Using an ensemble of climate, fire, and erosion models, we show that postfire sedimentation is projected to increase for nearly nine tenths of watersheds by >10% and for more than one third of watersheds by >100% by the 2041 to 2050 decade in the western USA. The projected increases are statistically significant for more than eight tenths of the watersheds. In the western USA, many human communities rely on water from rivers and reservoirs that originates in watersheds where sedimentation is projected to increase. Increased sedimentation could negatively impact water supply and quality for some communities, in addition to affecting stream channel stability and aquatic ecosystems." (AGU Publications. Geophysical Research Letters. 2017; https://www.fs.fed.us/pnw/pubs/journals/pnw_2017_sankey001.pdf)

[xii] "USGS scientists analyzed a collection of climate, fire and erosion models for 471 large watersheds throughout the western U.S. They found that by 2050, the amount of sediment in more than one-third of watersheds could at least double. In nearly nine-tenths of the watersheds, sedimentation is projected to increase by more than 10 percent." (USGS. 2017; https://www.usgs.gov/news/increases-wildfire-caused-erosion-could-impact-water-supply-and-quality-west-2)

[xiii] "The C aquifer is a regionally extensive aquifer supplying water for municipal, agricultural, and industrial use in northeastern Arizona, northwestern New Mexico, and southeastern Utah. This report presents data from an ongoing study by the U.S. Geological Survey (USGS) in cooperation with the Bureau of Indian Affairs to monitor water quality and quantity within the C aquifer along Interstate 40 (I-40) corridor from near Holbrook to Flagstaff." (USGS. 2012; https://pubs.usgs.gov/of/2012/1196/)

[xiv] "Resource managers, and urban planners convened in Las Vegas, Nevada [2014], to discuss research and management needs related to severe fires and post-fire flooding in the Intermountain West. The workshop was motivated by the concerns of water management agencies about the potential for a changing climate to exacerbate re impacts through: 1) projected increases in acres burned; 2) potential changes in the intensity of future extreme precipitation; and 3) the frequency of extreme events, which the National Climate Assessment projects to at least double across the region. The main purpose of this workshop was to further the understanding of the scientific and management decision-making research needs and gaps at the confluence of wildfire, post-fire floods, and extreme

precipitation. Participants accomplished this by sharing lessons learned and best practices from case studies, through group discussions identifying research and management needs, and through the suggestions of participants to inform the development of a toolkit of processes and products to inform water and floodplain managers. Research, data, and management needs identified by workshop participants focused on the topics of extreme precipitation, fire ecology, flooding and sediment transport, water supply and reservoir infrastructure, and water quality." FWPP is included as one of the case studies in the report. (Institute of the Environment. 2016; https://www.snre.arizona.edu/sites/snre.arizona.edu/files/Managing_for_%20Future_Fire_Risks_FinalReport.pdf)

[xv] "…a three - part, multi-year and multi-disciplinary research and assessment project that addresses issues related to climate warming, vegetation manipulation, and the forest water cycle. The three components are: i) measurements at sites of opportunity where fire or thinning treatments have taken place or are taking place, ii) meta - analysis and modeling using available data to interpret these results, and iii) evaluation of multiple ecosystem services and how multiple service providers (land and resource owners/managers) can effectively interact with service consumers (downstream and downhill residents)." (University of California. 2015; http://ciwr.ucanr.edu/files/272758.pdf)

[xvi] "Canadian Water Network (CWN) convened a two-day experts' workshop in Kananaskis, Alberta, to assess the state of knowledge with respect to wildfires, water supplies, and the potential for mitigation of the impacts of wildfire on the provision of safe drinking water. From September 18 to 19, 2013, thirty leading scientists and practitioners from Canada, the United States, and abroad discussed what leading-edge science exists to explain trends in wildfire occurrence and risks, the impacts of wildfires on water supply and treatment, and the evidence supporting the effectiveness of forest and water management techniques to mitigate the impacts of wildfires on drinking water supplies and treatment. The following report captures the high-level messages that emerged through the workshop discussions and the relative state of the confidence in current abilities to address the questions considered." (Water Research Foundation. 2014; http://www.waterrf.org/PublicReportLibrary/4529.pdf)

I. Social/Economic Studies Planned/Underway/Complete				
Monitoring Question	**Name of Study/Description**	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
How was the money *invested?*	***FWPP Project Update –*** The update highlights work completed since the project began in Nov. 2012. The update includes how much work has occurred and the location, how much of the voter approved bond funding has been used to support the ongoing project, and how much outside leverage funding has been brought into the project with the help of all partners.	Flagstaff Fire Dept.	Complete (2018); Report available[1]	None
Was the *investment* effective in reducing post-fire/flood risk and associated costs?	***Extrapolate "A Full Cost Accounting of the 2010 Schultz Fire" to the FWPP –*** Illustrates economic impact to the community if treatment is not implemented and the area experienced uncharacteristic wildfire and flooding.	Arizona Rural Policy Institute (NAU)	Complete (2013); Report available[2]	None
	Post-Wildfire Sediment Reduction and Flood Mitigation "Schultz Emergency Watershed Protection (EWP) Project" – Coconino County is tracking costs associated with the Schultz Fire – this will further contribute to this study.	Coconino County Public Works, Christopher Tressler, Engineering Division Manager	Complete; Report available[3]	None
	Flagstaff Watershed Protection Project Cost Avoidance Study –	Arizona Rural Policy Institute (NAU)	Complete (2014);	None

[1] http://flagstaffwatershedprotection.org/2018-fwpp-project-update/
[2] https://cdm17192.contentdm.oclc.org/digital/collection/p17192coll1/id/276/rec/3
[3] Four watersheds are complete that describes an assessment of impacts, see: http://naturalchanneldesign.com/projects/

	Estimates the potential financial damages mitigated by the implementation of FWPP.		Report available[4]	
To what degree are voters aware and supportive of FWPP?	***Results from the Four Forest Restoration Initiative Socioeconomic Monitoring Report as Recommendations for the Flagstaff Watershed Protection Project –*** Extract pertinent results from the *Four Forest Restoration Initiative Socioeconomic Monitoring Report* as recommendations for development of the Draft Environmental Impact Statement and for public outreach and education.	Mottek Consulting, Anne Mottek Lucas,	Complete; Report available[5]	None
	***Flagstaff Watershed Protection Project Equestrian Project Survey* (2014) –** Survey results revealed positive feedback was received from the first mechanical treatment in the FWPP project area.	Flagstaff Fire Dept.	Complete; Results available[6]	None
	Flagstaff Watershed Protection Project: Public Perceptions – Surveys were conducted as recreationists visited the FWPP project area to assess awareness, knowledge and support of forest restoration and the FWPP. The surveys explored various social factors and documented public feedback related to FWPP.	Meredith Prentice, ERI Undergraduate Senior Research Project	Complete; Report available[7]	None

[4] http://www.flagstaffwatershedprotection.org/wp-content/uploads/2014/10/Final-FWPP-Cost-Avoidance-October-27.pdf
[5] http://www.4fri.org/pdfs/documents/collaboration/4FRI_SE_Monitoring_Report_7_26_13.pdf
[6] http://flagstaffwatershedprotection.org/monitoring/socioeconomic-monitoring/
[7] http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/FWPP-Public-Perceptions.pdf Additional surveys are being collected and a second and final report is expected Jan '18

To what degree are voters aware and supportive of FWPP?	***FWPP communication tools and activities*** – This includes tools and activities like the project's website, Biannual Reports, project area signage, ranger walks, participating in Earth Day and Festival of Science, and *Cityscape* (City of Flagstaff) and *Report to Citizens* (Coconino County) articles.	FWPP Communications Team	Ongoing	None
	Case Studies/Reports: 1) *Monitoring Socioeconomics within Collaborative Forestry Projects: Trends in Practices and Challenges*[i] 2) *The Economic Impact of the 2013 Rim Fire on Natural Lands*[ii] 3) *City of Flagstaff Multi-Hazard Mitigation Plan*[iii] 4) *Return on investment from fuel treatments to reduce severe wildfire and erosion in a watershed investment program in Colorado*[iv] 5) *Northern Arizona Water Fund – SRP & National Forest Foundation*[v] 6) Rio Grande Water Fund[vi]	See endnotes for study description and links	Complete	None

II. Social/Economic – Studies Needed to Address Gaps				
Monitoring Question	**Name of Study/Description**	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
How was the money *invested?*	Continue annual "Flagstaff Watershed Protection Project Update" (initiated in Feb '18).	Flagstaff Fire Dept.	Annual	None
Was the *investment* effective in reducing post-fire/flood risk and associated costs?	Update as fire and flood modeling results become available (see Fire Behavior and Hydrologic Response Frameworks.	TBD	TBD	TBD

To what degree are voters aware and supportive of FWPP?	City of Flagstaff's Citizen Survey – Explore support for alternative funding mechanisms to sustain and continue forest treatments and compare results with prior surveys.	City of Flagstaff, Jessica Drum, Communications Manager	Next survey est. 2019	**$3K**[8]

III. Social/Economic - Potential Future Studies			
Name of Study/Description	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
Funding maintenance of forest treatments – initialize with reference to the Mueller study[9]	FWPP Project Team	2018 initiate discussion	TBD
Conduct an exit poll during the Nov. 2018 General Election to gauge current citizen awareness and support of future funding mechanisms.	Northern Arizona University (NAU), Erik Nielsen, Fred Solop	Nov. 2018	None[10]
Consider opportunities to link monitoring studies (e.g., National Park Service model, wildlife, invasive plants) using citizen scientists/volunteers that will increase citizen involvement and investment.	TBD	TBD	None

[i] "This study seeks to understand how [Collaborative Forest Landscape Restoration Program] (CFLRs) are navigating the largely uncharted waters of CFLR socioeconomic monitoring. We examined individual CFLR's socioeconomic monitoring strategies to identify each program's 1) overall status and progress; (2) primary party responsible for conducting monitoring; (3) indicators and measures used; (4) assessment methodology; (5) unit of analysis; and (6) challenges." https://www.nationalforests.org/assets/pdfs/Monitoring-Socioeconomics-within-Collaborative-Forestry-Projects_-Swezy-et-al.pdf

[8] Submit 2-3 questions max. $800-$1000/question (rough estimate)

[9] Mueller, J.M. "Estimating willingness to pay for watershed restoration in Flagstaff, Arizona using dichotomous-choice contingent valuation." *Forestry* 2013; 0, 1–7, doi:10.1093/forestry/cpt035

[10] $10,000 based on 2012 exit poll cost

[ii] "Environmental benefits are the benefits humans receive from nature. In the first year after the Rim Fire, environmental benefit losses are estimated to range from $100 million to $736 million." David Batker, et al, Earth Economics, 2013, http://www.eartheconomics.org/FileLibrary/file/Reports/Earth%20Economics%20Rim%20Fire%20Report%2011.27.2013.pdf

[iii] "A county-wide vulnerability analysis was performed [in 2005} to assess and evaluate the city's and county's population and critical facility exposure risk to the identified hazards. The risk was tabulated in terms of economic loss estimates and human population exposure. Economic losses include estimates of damage to critical, residential, industrial, and commercial facilities." For collective community- or county-wide wide exposure to wildfire, potential economic loss of $896.7 million was predicted. http://www.flagstaff.az.gov/DocumentCenter/Home/View/1078

[iv] "A small but growing number of watershed investment programs in the western United States focus on wildfire risk reduction to municipal water supplies. This paper used return on investment (ROI) analysis to quantify how the amounts and placement of fuel treatment interventions would reduce sediment loading to the Strontia Springs Reservoir in the Upper South Platte River watershed southwest of Denver, Colorado following an extreme fire event. We simulated various extents of fuel mitigation activities under two placement strategies: (a) a strategic treatment prioritization map and (b) accessibility. Potential fire behavior was modeled under each extent and scenario to determine the impact on fire severity, and this was used to estimate expected change in post-fire erosion due to treatments. We found a positive ROI after large storm events when fire mitigation treatments were placed in priority areas with diminishing marginal returns after treating >50e80% of the forested area. While our ROI results should not be used prescriptively they do show that, conditional on severe fire occurrence and precipitation, investments in the Upper South Platte could feasibly lead to positive financial returns based on the reduced costs of dredging sediment from the reservoir. While our analysis showed positive ROI focusing only on post-fire erosion mitigation, it is important to consider multiple benefits in future ROI calculations and increase monitoring and evaluation of these benefits of wildfire fuel reduction investments for different site conditions and climates." https://www.sciencedirect.com/science/article/pii/S0301479717304711

[v] "The Northern Arizona Forest Fund (NAFF) was established in partnership between the Salt River Project (SRP) and the NFF to address these declining forest health concerns in the Salt and Verde River watersheds which are the sources of irrigation, commercial, and municipal water supplies for millions of Arizonans in the Greater Phoenix Metropolitan area. The NAFF provides an easy way for businesses and residents of Arizona to invest in the lands and watersheds they depend on. These are the special places that are the source of our drinking water, the places we go to in the hot summer months, and the home to many valuable species of fish and wildlife." https://www.nationalforests.org/who-we-are/regional-offices/southernrockies/azforestfund

[vi] "Established in 2014, The Nature Conservancy-led Rio Grande Water Fund is a ground-breaking project that is **protecting vital forests in northern New Mexico—and the water they provide.** With 60 charter signatories, we are working to generate sustainable funding for a 20-year program to restore 600,000 acres north of Albuquerque by thinning overgrown forests, managing fire, restoring wetlands and streams, educating youth, providing research to policy makers, and creating forestry and wood products jobs. Restoring overgrown forests is a proven solution to make forests safer and healthier. And research shows that fighting catastrophic mega-fires and rehabilitating damaged areas afterward can cost tens of millions of dollars. The bottom line is simple: **Restoring forests now is a smarter investment.**" https://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newmexico/new-mexico-rio-grande-water-fund.xml

I. Other - Studies Planned/Underway/Complete			
Name of Study/Description	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
Wildlife			
Mexican Spotted Owl (MSO) Response to Fuel Reduction/Restoration – Developed for the Final Environmental Impact Statement (FEIS) for FWPP. MSOs are a Threatened and Endangered Species (TES). Determine MSO Protected Activity Centers (PAC) effects (habitat/population) in treated vs. untreated sites.	US Forest Service (USFS), Cary Thompson, Wildlife Biologist; US Fish & Wildlife Service (USFWS), Shaula Hedwall	Complete (2015-2017); Reports available[1]	None
Vegetation monitoring to inform hazardous fuels reduction treatments in Mexican spotted owl (MSO) Protected Activity Centers (PACs) – Monitor changes in habitat characteristics and MSO population responses (monitored by USFWS and USFS) to FWPP treatments. Will serve as a benchmark for MSO conservation and public interest. This initial funding will cover plot installation and pre-treatment data collection related to forest structure and hazardous fuel loading in Dry Lake Hills (DLH) and Mormon Mountain (MM).	Ecological Restoration Institute (ERI), Dave Huffman	Complete; Progress reports available DLH (2015) and MM (2016)[2]	$25k[3]
Red Squirrel Monitoring – (Developed for the FEIS – NEPA planning). Red squirrels are a Management Indicator Species (MIS) and are primarily associated with mixed conifer forest. The purpose of this study is to establish long-term trends in	USFS, Cary Thompson; AZ Game and Fish (AZGF), Hannah Griscom	Pre-data collection complete summer 2014	$3k

[1] Included in these reports are the results of the Flagstaff Ranger District 2015-2017 MSO monitoring and inventory for the FWPP project area. http://www.flagstaffwatershedprotection.org/wp-content/uploads/2016/02/2015-FWPP-MSO-Monitoring-Report_Final.pdf http://www.flagstaffwatershedprotection.org/wp-content/uploads/2016/12/2016_Final_FWPP-MSO-Monitoring-Report.pdf and http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/2017-_FWPP_MSO_Monitoring_Report.pdf

[2] http://www.flagstaffwatershedprotection.org/wp-content/uploads/2016/07/FWPP_2015_ERI_ProgressReport.pdf and http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/FWPP-2015-ERI-MSO-Report.pdf

[3] Matched by USFS: $25k

populations and habitat use and the effects of forest restoration on red squirrels. This has the potential for a community-based data collection effort.			
Bird Conservancy of the Rockies – Changes in songbird occupancy will be monitored via point-transects surveys across the project area. This will document project area changes in MIS (pygmy nuthatch).	USFS, Cary Thompson	Pre-treatment surveys complete summer 2014	None
Bat species composition and activity in varying tree densities on Observatory Mesa – Monitor the effects of forest restoration on bat activity.	NAU School of Forestry, Clarissa A. Starbuck	Complete; Report available[4]	None
Habitat Use by Abert's Squirrels in Managed Forests – Determine cha*nges* in home range sizes as a result of restoration treatments.	Washington Dept. of Fish and Wildlife; AZ Game & Fish Dept.: R. Fenner Yarborough, Jessica Gist, Chad Loberger, Steven Rosenstock	Complete; Report available[5]	None
Case Studies/Reports – *1) Giant forest fires exterminate spotted owls, long-term study finds*[i]	See endnotes for study descriptions and links.	Complete	None

[4] http://www.flagstaffwatershedprotection.org/wp-content/uploads/2017/08/Starbuck_Bat_Project_OM_Final.docx
[5] http://flagstaffwatershedprotection.org/wp-content/uploads/2016/07/Yarborough-et-al.pdf

Planning/Administration			
Flagstaff Watershed Protection Project: Creating Solutions through Community Partnerships – This case study spans the first two years of the Flagstaff Watershed Protection Project and intends to convey to other communities, municipalities, and/or government agencies the administrative functions and mechanisms used by the City of Flagstaff and the U.S. Forest Service to develop and implement FWPP. This was designed as a case study for others considering a similar initiative.	Mottek Consulting, Anne Mottek Lucas, ERI White paper	Complete (2015); Report available[6]	None
Linking Payments for Watershed Services and Wildfire Risk Mitigation: Institutional Design and Governance of the Flagstaff Watershed Protection Project (FWPP) – Explores the gap between theory and practice by investigating: 1) FWPP institutional design and its applications to the national forest management community; and 2) stakeholder perceptions of the following institutional performance outcomes - efficacy/effectiveness, efficiency, and accountability.	NAU School of Earth Sciences and Environmental Sustainability, Roy Miller, M.S.	Complete; Thesis available[7]	None
Ecosystem Service Valuation through Wildfire Risk Mitigation: Design, Governance, and Outcomes of the Flagstaff Watershed Protection Project – Describes the novel FWPP governance structure to understand the potential benefits to communities and federal land management agencies for protecting watershed services.	NAU; Roy Miller, Erik Nielsen and Ching-Hsun Huang	Complete; Publication available[8]	None

[6] http://www.flagstaffwatershedprotection.org/wp-content/uploads/2015/11/FWPP-Creating-Solutions-Through-Community-Partnerships.pdf
[7] http://flagstaffwatershedprotection.org/wp-content/uploads/2018/04/Miller_Roy_Thesis.pdf
[8] http://flagstaffwatershedprotection.org/wp-content/uploads/2016/07/Miller_forests-Ecosystem-Service-Valuation.pdf

The Role of Science and Policy in the Flagstaff Watershed Protection Project – Focused on the role of science in the policy development of FWPP.	Environmental Science (555 class) and Policy Interface Laura Brown, Megan Deane-McKenna, Miranda Perrone, Patrick Shin, Cole Webster	Complete; Report available[9]	None
Other Biophysical Monitoring			
Stand Attributes and Site Index on Observatory Mesa – Provides estimates of cubic foot volume per acre, basal area per acre and tree density (both pre- and post-treatment), as well as site index and an associated diameter distribution.	NAU School of Forestry, Andrew Sanchez-Meador	Complete; Report available[10]	None
Bundles & Beetles Project – Included three local sites with downed bundles of trees and downed individual trees. Monitored for: 1) wood desiccation (drying) process; 2) presence of bark beetle, wood borers and Ambrosia beetles; and 3) insect emergence (60 and 120 days).	NAU graduate student, Marcos Riquelme; Project completed in collaboration with: USFS, Four Forest Restoration Initiative (4FRI), Campbell Global, The Nature Conservancy and FWPP	Complete; Summary Report available[11]	None

[9] http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/FWPP-ENV-555-Final-Paper.pdf
[10] http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/NAU-Inventory-Observatory-Mesa-Summary.pdf
[11] http://flagstaffwatershedprotection.org/wp-content/uploads/2018/02/Bundles-Beetles-All-sites-complete-report-for-Spring-Summer-and-Fall-2017.pdf

United States Geological Survey (USGS) – Quantitative data for smoke conditions based on 3-band HDR images. ***"***Changing sky conditions and smoke from the Slide fire, a major wildfire near Flagstaff, Arizona, are apparent in this sequence of natural-color, hemispheric images acquired on May 21, 2014. Individual images are collected at 10-minute intervals at the USGS Flagstaff Science Campus by the High Dynamic Range All-Sky Imaging System (HDR-ASIS). The instrument is used in USGS research to study the effects of atmospheric conditions and clouds on photosynthesis and the uptake of atmospheric carbon dioxide by land vegetation."	USGS, Dennis Dye	Complete; You Tube video available[12]	None
Case Studies/Reports: 1) *Assessment of Climate Change in the Southwest United States, Summary for Decision Makers (adapted from the book)*[ii]	See endnotes for study descriptions and links.	Complete	None

II. Other – Potential Future Studies			
Name of Study/Description	**Entity Responsible/ Contact**	**Timeline**	**$ From FWPP**
Wood Quality Models for Southwestern Ponderosa Pine – Measure wood properties, develop models and integrate data that will ultimately support value added ponderosa pine products.	NAU School of Forestry Ph.D. Candidate, Damon Vaughan	TBD	None
Distributed Field Trial Network for Dryland Restoration – Developing a network of field sites distributed in the Southwest to systematically test dry restoration techniques. Facing climate change and disturbance regimes, this will assist managers with effectively reestablishing native perennial vegetation and stabilize soils. Locally, wood chips from	USGS, Molly McCormick	USGS overview[13]	None

[12] https://www.youtube.com/watch?v=wPRFT8XYkpM

[13] https://www.usgs.gov/centers/sbsc/science/distributed-field-trial-network-dryland-restoration?qt-science_center_objects=0#qt-science_center_objects

Observatory Mesa (part of FWPP) were used by the US Geological Survey (USGS) for restoration research on Babbitt Ranch.			
Vegetation monitoring to inform hazardous fuels reduction treatments in Mexican spotted owl (MSO) Protected Activity Centers (PACs) – Post-treatment in DLH and MM – Monitor changes in habitat characteristics and MSO population responses (monitored by USFWS) to FWPP treatments. Will serve as a benchmark for MSO conservation and public interest.	ERI, Dave Huffman	**DLH:** Post-treatment: summer 1 year and 5 years following implementation. **MM:** Post-treatment: summer 1 year and 5 years following implementation.	None[14]
Mexican Spotted Owl (MSO) Response to Fuel Reduction/Restoration – Long-term study Determine MSO Protected Activity Centers (PAC) long-term occupancy and reproduction effects in treated vs. untreated sites.	USFS, Cary Thompson	Post-treatment: 10, 15 and 20 years following implementation.	None
Vegetation monitoring to inform hazardous fuels reduction treatments in Mexican spotted owl (MSO) Protected Activity Centers (PACs) – Post-treatment in DLH and MM – Long-term study Monitor long-term changes of MSO habitat characteristics to FWPP treatments.	USFS, Cary Thompson	Post-treatment: 10, 15 and 20 years following implementation.	None
Bird Conservancy of the Rockies – Monitor long-term changes in songbird and red squirrel occupancy via point-transects surveys across the project area. This will document long-term project area changes in MIS (pygmy nuthatch).	USFS, Cary Thompson	Post-treatment 10, 15 and 20 years following implementation	None

[14] ERI is seeking funding for: **DLH:** Post-year one $30k; Post-year five $30k. For **MM:** Post-year one $30k; Post-year five $30k.

Small mammal (owl prey) and bat studies – Determine how different treatment types affect bat and small mammal population size, species richness, and species diversity and evaluate survival or reproduction of individual species in the project area.	USFS, Cary Thompson	Pre-treatment surveys: 1-2 years prior to implementation; Post-treatment: 1, 5, 10, and 15 years following implementation	None
Citizen Science for long-term monitoring – General Technical Report (GTR)[15] describes a pilot project to evaluate the feasibility of using citizen observers for a long-term monitoring program. The GTR outlines lessons learned to assist in guiding a potential FWPP citizen science program.	USFS Rocky Mountain Research Station, Jamie Sanderlin, Quantitative Vertebrate Ecologist	TBD	None

[15] https://www.treesearch.fs.fed.us/pubs/54536

[i] "We had this long-term demographic study, we knew all the owls in the 137-square mile study area," says Peery. "The fire burned almost half the study area. On one side was the treatment, a large, high severity fire, and on the other side was the control, with little or no fire. Almost all the owl territories within the megafire went from occupied to unoccupied. We can now say that megafires have a significant impact on the spotted owl, and so we think that forest restoration through fuel reduction benefits both the forest ecosystem and the spotted owl." https://news.wisc.edu/giant-forest-fires-exterminate-spotted-owls-long-term-study-finds/

[ii] "…the Southwest can be considered to be one of the most "climate-challenged" regions of North America. This document summarizes current understanding of climate variability, climate change, climate impacts, and possible solution choices for the climate challenge…" http://www.swcarr.arizona.edu