

1. TITLE: Impacts and management implications of multiple extreme disturbance events to formerly diverse, canyon riparian ecosystems within Bandelier National Monument, New Mexico.

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5. PARTNERSHIPS AND ROLES:

* Dr. Jonathan Friedman, Research Hydrologist, USGS Fort Collins Science Center, 2150 Centre Ave., Bldg. C, Fort Collins, CO 80526. Ph: (303) 541-3017; E-mail: friedmanj@usgs.gov Role: assessment of fluvial geomorphic conditions and dynamics.

* Dr. Tim Assal, Post-doctoral Research Ecologist, USGS Fort Collins Science Center, 2150 Centre Ave., Bldg. C, Fort Collins, CO 80526. Ph: (970) 226-9134; E-mail: assalt@usgs.gov Role: assistance with geospatial analysis (aerial imagery time series; LiDAR; canyon mapping).

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* Scott McFarland, Natural Resource Program Manager, Bandelier National Monument, 15 Entrance Road, Los Alamos, NM 87544; (505) 672-3861 ext. 706; scott_mcfarland@nps.gov. Role: In-kind onsite support, coordination with partners, issuing permits, assisting with environmental compliance.

* Stacy Stumpf, Ecologist, NPS Southern Colorado Plateau Inventory and Monitoring Network (SCPN), PO Box 5663, Flagstaff, AZ, 86011. stacy_stumpf@nps.gov. Role: In-kind linkage to extensive SCPN experience, knowledge, and riparian/aquatic monitoring data for Bandelier, including water quality, stream habitat, and FY18 trend analyses of aquatic macroinvertebrates and riparian vegetation.

* Dr. Esteban Muldavin, Division Leader, Natural Heritage New Mexico, MSC03 2020, Univ. of New Mexico, Albuquerque, NM 8713; (505) 277-3822. muldavin@unm.edu. In-kind riparian vegetation expertise, including mapping pre-fire BAND vegetation, & pre-fire riparian plot data.

* Collin Haffey, Conservation Coordinator, The Nature Conservancy, 212 E Marcy St., Santa Fe, NM 87501; 505-988-3867. chaffey@tnc.org Role: In-kind technical assistance & coordination as a lead partner in the East Jemez Landscape Futures project (described below) and ecologist studying high-severity fire impacts and vegetation type conversion, including 8 years at BAND.

* Other in-kind contributors, all with extensive field experience in BAND's canyon ecosystems: Dr. Michael L. Scott, Emeritus USGS, riparian ecologist; Dr. Brian Jacobs, retired NPS botanist (>20 years at BAND); Dr. Nicole Vieira, Colorado State Univ., aquatic macroinvertebrates of BAND; Steve Monroe, retired NPS-SCPN, hydrologist; Dr. Anne Tillery, USGS hydrologist, New Mexico Water Science Center.

6. PARK STATEMENT OF NEED ADDRESSED: Impacts and management implications of multiple extreme disturbance events to formerly diverse, canyon riparian ecosystems within Bandelier National Monument (BAND).

7. PROBLEM STATEMENT AND IMPLICATIONS: Globally and regionally, extreme disturbance events have become increasingly common with hotter drought in recent decades, a trend projected to continue this century (Williams et al. 2013). Severe wildfires, droughts, and associated land cover change contribute to increased sediment yields and peak runoff rates in stream corridors throughout western North America (Dahm et al. 2015, Moody & Martin 2009, Sankey et al. 2017). Combinations of high-severity fire, debris flows, large-magnitude floods, and high sediment fluxes drive a range of disturbance intensities to riparian and aquatic environments (e.g., Parsons et al. 2005). The recent emergence and growing trends of historically-unprecedented extreme fires and post-fire disturbances cause uncertainty about Western riparian and freshwater ecosystem resiliency, and pose challenges for resource managers. NPS and other regional resource managers need better information regarding recovery trajectories of these disturbed canyon systems both in the absence of active management and in the context of planning potential restoration treatments that might facilitate recovery to desired conditions and functions (Jacobs et al. 2015, NPS 2015, O'Brien et al. 2017).

Our proposal is focused on two streams and their watersheds (Capulin and Frijoles creeks) in the eastern Jemez Mountains, New Mexico, where a series of severe fires, post-fire floods and debris flows, and hotter droughts have impacted an area of over 300,000 acres since 1996 (Allen 2016), including most of BAND (Fig. 1 and 2). In particular the Dome (1996), Cerro Grande (2000), and Las Conchas (2011) fires were all far outside the historical range of variability for fire severity (Swetnam et al. 2016), with effects likely unprecedented for at least a thousand years (Allen 2016). The nearly complete burning of living and dead plant biomass from much of these watersheds (including riparian gallery forests) contributed to dramatically increased post-fire runoff, stormflow discharges, and sediment transport (Fig. 3-7). Flood peaks in Capulin (USGS gaging station 083133655) and Frijoles (USGS gaging station 08313350) increased up to 160 times the pre-fire peak flows following the Dome and La Mesa (1977) fires, respectively (Veenhuis 2002). Flood magnitudes in 2011-2013 following the Las Conchas fire were >450 times larger than typical pre-fire peak flows in Frijoles, and likely in Capulin also based on heights of high-flood debris lines. Extensive vegetation removal, and sediment erosion and deposition, dramatically cut, filled, widened, & straightened channels in many canyon reaches, and numerous log jams and woody debris piles were left behind. While fires and floods occur naturally in these systems, the cumulative severity of these events is historically unprecedented and related to human activities (e.g., grazing, fire suppression & associated fuel buildups, hotter droughts), creating uncertainty regarding natural ecosystem responses (Johnstone et al. 2016) and appropriate NPS resource management response (Hobbs 2016).

Capulin and Frijoles canyons were severely impacted by extreme fire, debris flows, and flooding from 2011-2013, although many of the recent impacts and trends have not been documented (but see Stumpf 2016). Located largely within the Bandelier Wilderness, these canyons once supported much of BAND's biodiversity, including diverse riparian forests, wetlands, and critical habitat for a number of threatened and endangered species, including Mexican spotted owls and Jemez Mountains salamanders (Allen 1989, Jacobs et al. 2015). While riparian organisms are commonly disturbance-adapted and thus able to recover relatively rapidly following floods (Bornette et al. 2008), anecdotal observations of Frijoles and Capulin canyons suggest that plant cover and associated habitats have been slow or unable to reestablish in many places to date. Examples include the apparent extirpation of riparian alder (*Alnus*) and birch (*Betula*) populations from Capulin, and the loss of locally-rare populations of yellow ladyslipper (*Cypripedium*) and grape fern (*Botrychium*) from Frijoles. The diverse vegetation in these riparian canyon bottoms also provided important ethnobotanical resources (Stoffle et al. 2007), and some of these plants are now rare or apparently have been locally extirpated (Stortz et al. 2017). Further, in part because disturbance is

common along rivers, riparian systems are particularly susceptible to invasions of non-native plants (Richardson et al. 2007), and there is significant potential for new plant invasions in these severely-disturbed canyons.

Dramatic changes to riparian vegetation and fluvial geomorphology also affect aquatic organisms (Ziegler et al., in revision). For example, the loss of riparian tree canopy can have important functional ramifications (Kominoski et al. 2013), including increased water temperatures due to reduced shading that likely now exceed the standard for high-quality coldwater aquatic life in much of Capulin and Frijoles canyons. Further, extreme post-fire floods, sediment pulses, and geomorphic instability have scoured away much of the habitat required by both aquatic macroinvertebrates and fish (Dyer et al. 2016; Stumpf 2016). The result has been the near-elimination of aquatic macroinvertebrates (including some unique species recorded only from BAND) for several years during the unstable, post-fire, high-flood period in both canyons, and the extirpation of all fish species from both watersheds, including reintroduced Rio Grande cutthroat trout from Capulin.

Canyon bottom ecosystems and the associated services (e.g., wilderness recreation and traditional cultural associations) are fundamental resources identified in BAND's foundation document, and their loss prevents the park from carrying out its legal responsibilities (NPS 2015). There are also numerous archeological sites and other cultural resources located in canyon bottoms within BAND that are threatened by increased erosion and changes in geomorphology (NPS 2015). Changes associated with severe fire and drought have also impacted canyon resources and values protected under the Wilderness Act (16 U.S.C. 1131-1136), including outstanding opportunities for visitors to enjoy solitude, primitive recreation and unique ecological settings such as cool, shaded riparian forests and wetlands that are rare in this part of the southwestern US. Further, historical recreational opportunities such as sport fishing are no longer possible, and rapid ecosystem changes have impacted people's emotional connections to BAND's resources (Stortz et al. 2017).

In response to these issues, BAND, in partnership with the co-located USGS New Mexico Landscapes Field Station, and the Landscape Conservation Initiative at Northern Arizona University, launched a project in 2016 called the East Jemez Landscape Futures (EJLF, www.eastjemez.org), which seeks to facilitate landscape-scale, interagency planning; create watershed-level work groups focused on restoration and management options; identify research needs; and provide opportunities for public engagement through art and storytelling. EJLF partners include: the pueblos of Cochiti, San Ildefonso and Santa Clara, BAND, Santa Fe Nat'l Forest, Los Alamos Nat'l Laboratory, and Los Alamos County. Canyon bottom ecosystems were identified through the EJLF needs assessment process as high priority focal areas for future management, research, and stakeholder engagement (Stortz et al. 2017); actions identified by the assessment included protecting and restoring riparian areas to enhance biodiversity, restoring native fish habitat and fisheries, documenting geomorphological changes, and collecting baseline status and trend data for riparian vegetation (Stortz et al. 2017). A working group has been established recently for Frijoles and already includes representatives from NPS, USGS, U.S. Forest Service, New Mexico State University, New Mexico Highlands University, Trout Unlimited, Pajarito Environmental Education Center, and The Nature Conservancy. This proposed NRPP project would provide key information and support for the EJLF and Frijoles watershed group members as they work to determine canyon ecosystem conditions and trends, develop restoration plans, and determine future adaptive management needs. Note that the EJLF project is linked to The Nature Conservancy's national Fire Learning Network, which will foster wide distribution of our proposed research findings.

In addition to the EJLF Needs Assessment, the objectives of this proposal also address data gaps identified in several other NPS planning documents including the 2015 Bandelier National Monument Foundation Document, and 2015 BAND Natural Resource Condition Assessment. These documents

identified BAND's diverse vegetation, watersheds, wildlife and biotic communities as fundamental values essential to achieving the park's purpose and maintaining its significance (NPS 2015) and included a number of areas where more information or data is necessary to support park decision-making, including aerial and remote-sensing data to track erosion and vegetation changes; creating updated vegetation cover mapping, and resampling of vegetation plots in areas impacted by extreme fires, floods and drought; and post-disturbance ecosystem monitoring (Jacobs et al. 2015, NPS 2015). The apparent persistence of highly-altered post-disturbance conditions in these canyon riparian ecosystems has continued to elevate the importance of these issues at BAND. As a result, the NPS SCPN inventory and monitoring program has made BAND its top priority for trend analysis work, meshing perfectly with this proposal. BAND is also in line to receive funding for a Resource Stewardship Strategy (RSS) in the next few years. The information gained from this project would provide vital information about current and desired future resource conditions for the RSS.

Overall, this proposal represents a unique applied research opportunity, given: a) the availability of diverse, long-term, pre-disturbance baseline datasets; b) the occurrence of multiple combinations of well-documented extreme fire and flood disturbances; c) a strong, interdisciplinary research team with decades of experience working on BAND watershed issues; d) the long-term place-based USGS field station at BAND (since 1993), with strong science-management partnerships to ensure research findings will be directly applied to management needs at BAND, and beyond (through publication); e) applicability to other Southwest NPS units that have been subject to similar high-severity fire-flood disturbance combinations (MEVE, ZION, GRCA); and f) applicability West-wide as the recent extreme impacts to BAND canyons are likely a preview of more-severe future riparian ecosystem disturbances regionally.

8. OBJECTIVES: The overarching goal of our proposed research is to provide information to resource managers at BAND to inform decision-making regarding appropriate management of canyon ecosystems impacted by compounded severe disturbances. The approaches we take will be general enough that they can be applied by land and water managers across the nation and even globally faced with similar situations. Specific objectives include:

Objective 1: Understand the current status and dynamics of hydrology and fluvial geomorphology, native and exotic riparian vegetation, water quality, and macroinvertebrates along two high-priority, fire- and flood-affected canyons in BAND (Frijoles, Capulin). Use repeat measurements of diverse, pre-Las Conchas fire baseline datasets (Fig. 2) to compare these current conditions and dynamics to those that prevailed prior to the onset of multiple high-severity fires (1996 & 2011 for Capulin, 2011 for Frijoles) and associated debris flows and floods. Establish a network of channel cross-sections and vegetation transects to serve as a basis for future monitoring of recovery.

Objective 2: Estimate reasonable targets for future canyon ecosystem attributes, functions, and dynamics, based on likely trajectories of hydrology and fluvial geomorphology, riparian vegetation, water quality, species persistence probabilities and BAND management priorities.

Objective 3: Describe and evaluate management actions that might facilitate recovery of desired ecosystem attributes and functions, and estimate the relative likelihood of success of implementing such actions in different canyon segments. Further, describe key resource variables (hydrology/geomorphology; vegetation; water quality) and articulate methods for assessing these variables in the context of evaluating: a) ongoing and future environmental change dynamics; and b) the need for, and effectiveness of, management treatments on resource conditions.

9. METHODS AND STUDY AREA: Study area: BAND is located on the eastern flank of the Jemez Mountains, a large volcanic landmass at the southern edge of the Rocky Mountains in north-central New

Mexico (Allen 1989). The study area focuses on two BAND riparian canyon ecosystems, in the Frijoles and Capulin watersheds (12,530 acres and 12,880 acres, respectively); from their headwaters at up to 10,199 feet in the southeastern Jemez Mountains, both streams flow generally southeast through deep (up to 900'), steep-walled canyons into the Rio Grande at 5300-5400 feet (Fig. 1, 2). The study area includes both canyons from their headwaters to the confluence with the Rio Grande (12 miles for Frijoles, 13 miles for Capulin), including smaller tributary canyons and side drainages that are part of each watershed.

Objective 1 methods: We will take three approaches to address Objective 1: a) compile, review, and analyze diverse existing information to inform our understanding of the dynamics of hydrology, fluvial geomorphology, riparian vegetation, water quality and aquatic macroinvertebrate communities in recent decades (Tables 1 & 2); b) conduct an inter-disciplinary field survey that will emphasize rapid assessment and mapping of priority resource attributes as well as canyon bottom features that are likely to best inform our estimates of future dynamics and restoration potential; and c) conduct detailed field assessments, including repeat measurements of a set of key pre-disturbance historical baseline and ongoing monitoring datasets, at sites selected to represent a range of disturbance intensities, as well as reference sites. Site selection for these more detailed assessments will be based on a) & b), above.

Objective 1-a) Compile, review and analyze existing information (Table 1 & 2, Fig. 1 & 2).

i) review and interpretation of historical documentation. We will review, interpret, and summarize the wealth of information described in Tables 1 & 2, which includes aerial and oblique photos, published and unpublished reports on a range of topics, vegetation surveys, fish and wildlife surveys, fire histories, channel cross-sections. Although we have done considerable work to identify these items (Table 1), we have not thoroughly reviewed all of this material, and we anticipate that additional items will be revealed in the course of a funded effort. Some key data sources (e.g., aerial imagery, past SPCN monitoring) provide the basis for proposed work described below.

ii) interpretation and analysis of remotely-sensed data (aerial photos/imagery; LiDAR). We will quantify the area of several cover types on three or four sets of orthorectified imagery. Time period 1, 1992, which pre-dates the Dome fire (1996); time period 2, 2008, between the Cerro Grande and Las Conchas fires; and time period 3, 2014, which immediately post-dates extreme fire and flooding disturbance. The fourth time period would be contemporaneous to our proposed work (i.e., 2018-2020) and would allow for an interpretation of changes since 2014. At this time, however, we are not certain what imagery will be available. We will delineate polygons that identify areas containing relatively homogeneous coverage of: wetted channel; dry channels or bare floodplain sediment; alluvial fans; herbaceous riparian vegetation; shrub-dominated riparian vegetation; coniferous tree-dominated riparian vegetation; and deciduous tree-dominated riparian vegetation. Polygon layers will be produced using geospatial software and made available as shapefiles. Results will include the amount and juxtaposition of each cover type. We will calculate the amount and location of change between each time period.

LiDAR data from 2000, 2010, 2011 (post-fire), 2013, and 2014 will be analyzed to map changing geomorphic conditions (Wheaton et al. 2015) and assess topographic changes in the canyon bottoms.

Objective 1-b) Conduct rapid longitudinal assessment of key resource attributes.

We will assess and map key resource elements or indicators of change along the Capulin and Frijoles canyon bottoms in summer 2018. We will record data on iPads with pre-loaded data forms (generated in GIS Pro or similar application), a tested approach that we have used in multiple other studies. Resource elements to be measured will include: presence/absence of flowing surface water; number and sizes of channels; locations and sizes of alluvial fans from tributaries or debris flows; locations and sizes of vertical cut banks; locations and sizes of other fluvial geomorphic features; locations and sizes of log or debris jams; locations and descriptions of other disturbance indicators such as flood-scarred trees;

locations and descriptions of patches of intact woody riparian vegetation; locations and abundance of priority invasive plants; location and abundance of sensitive plant species. We will use these results to generate maps, spatial analyses, and data summaries associated with the resource attributes, as well as to help identify sites for more detailed measurements (see below). For example, we will combine multiple geomorphic and vegetation attributes to classify and map stream reaches with different combinations of geomorphic and vegetation disturbance (Meitzen et al. 2017, O'Brien et al. 2017).

Objective 1-c) Conduct detailed field assessments, including repeat measurements of pre-disturbance data.

i) detailed assessments of hydrology, geomorphology, and riparian vegetation: We will select 3 to 5, ~500m long stream reaches in each canyon for more detailed field measurements, to be conducted in summer 2019. Some of the specific reach locations and attributes measured will be based on the availability of pre-fire and flood disturbance data and potential for re-sampling (Fig. 1, Table 1). We will select additional stream reaches to represent common geomorphic and vegetation disturbance classes (determined from aerial image analysis and rapid longitudinal assessment, above), and we will assess suitability using NPS protocols described in Scott & Reynolds (2007).

The layout of each detailed study reach will generally follow Scott & Reynolds (2007) and include at least 11 monumented transects/cross-sections, oriented orthogonally to the riparian zone. We will survey the topography along each transect using either a total station or an RTK-GPS system, and we will describe geomorphic surfaces along each transect (Scott & Reynolds 2007; Wheaton et al. 2015). We will conduct multiple pebble counts per reach to quantify sediment grain-size distribution (Wolman 1954). We will measure the composition and abundance of all vascular plants along each transect using multiple methods, including nested plots (1m² and 10m²), line-intercept, belt transects, and population census of legacy riparian trees (Scott & Reynolds 2007). One of these detailed study reaches was established in Capulin Canyon in 2006, and will be resampled by SCPN and BAND staff in 2019 (in-kind contribution). We will establish permanent ground photo points within each study reach.

ii) detailed assessments of water quality and aquatic macroinvertebrates: Since 2007 SCPN and BAND have collected annual aquatic macroinvertebrate data from two sites in Capulin Canyon. In 2009 an additional two aquatic macroinvertebrate sites were established in Frijoles Canyon, also annually collected (Table 1). Since 2009 SCPN and BAND have collected quarterly water quality data from two sites in both Frijoles and Capulin canyons. In-kind contributions in FY18 and FY19 will include completion and publication of a detailed trend analysis of all monitoring data on aquatic macroinvertebrates and stream physical habitat collected from 2007-2017 in Capulin and from 2009-2017 in Frijoles, to quantify changes due to the Las Conchas Fire and associated floods. Additional in-kind contributions will include annual collection of aquatic macroinvertebrate and water quality data.

New data collection proposed here includes measurements of stream temperature and flow intermittency along the study canyons. Stream temperature information is of great interest in the context of the potential for reintroducing Rio Grande cutthroat trout to these streams. Changes to the spatial and temporal distribution of dry reaches is a potentially significant indicator of system change with implications for riparian vegetation and aquatic organisms. Measurements will be obtained by deploying approximately 10 temperature underwater data loggers (Hobo Pendant) in each canyon (5 locations with 2 loggers/location) within the detailed riparian vegetation study reaches. The loggers will be modified to record when surface water is absent (Chapin et al. 2014), along with monthly field GPS documentation of dry reach extent.

Objective 2 methods: We will draw on information derived from all aspects of Objective 1 (above) to describe and illustrate the predominant hydrologic and geomorphic features, riparian plant communities, and water quality conditions present; their abundance and spatial distribution; evidence of their recent

dynamics, descriptions of possible future dynamics; and an evaluation of their functional value for different priority park resources. For Rio Grande cutthroat trout, we will model persistence probability for these two streams in 2040 and 2080 based on water temperature, stream length, and debris flow risk.

Objective 3 methods: We will review various actions that could be implemented in these canyons to achieve particular management goals, and estimate the likelihood of success of implementing these actions in different canyon reaches. Management goals include accelerating the re-establishment of woody species in the riparian corridor through restoration of both conifers and deciduous trees, reintroduction of Rio Grande cutthroat trout and other native fish species; and stabilizing geomorphic surfaces and channel sediments. For each of these goals, we will review the literature on different approaches and discuss their applicability in different canyon reaches. In the case of re-establishing riparian vegetation, for example, we will review and summarize the literature on different seeding methods (e.g., hydroseeding), and other planting approaches (bare-root staking; rooted cuttings; pole planting). Another example management goal is to stabilize sediment to facilitate deposition of finer sediments and promote persistence and growth of riparian vegetation. We will discuss the likely effects of management actions in the context of possible future dynamics without management (Obj. 2).

10. PROJECT DURATION/SCHEDULE:

- Start date: Spring, 2018; End date: December 30, 2020.
- FY 2018: Review of existing documentation; interpretation of aerial photo time series; longitudinal field survey and mapping.
- FY 2019: Analysis of aerial photo time series. Detailed field surveys.
- FY 2020: Describe likely trajectories of change and evaluate possible management actions. Complete final write-ups of all components of the work.

11. DELIVERABLES:

December, 2018: **Progress report** of FY18 activities and results, in the form of a technical briefing to BAND staff.

December, 2019: **Progress report** of FY19 activities and results, in the form of a technical briefing to BAND staff.

December 30, 2020: The final products will include a **final report** (as .docx file) and spatial data that, together, would be used to support park management decisions. The final report will include written summaries of resource conditions and dynamics; analyses of historical data; data, analyses, and associated interpretations of detailed studies at 3-5 sites along both canyons; illustrated descriptions of possible management actions associated with different resource objectives; an evaluation of where applications of different methods are more or less likely to succeed; a list of key resource variables for ongoing and future assessments; and a summary of associated methodologies and data analyses. **Spatial data products** will include maps (as .shp files) and spatial analyses of current riparian vegetation and fluvial geomorphology along the full length of both canyons.

January-June 2021: Submission of 1 or 2 **manuscripts to scientific journals** for further dissemination of this research (with understanding that timing of article publication can be variable).

LITERATURE CITED: (proposal participant names **bolded**)

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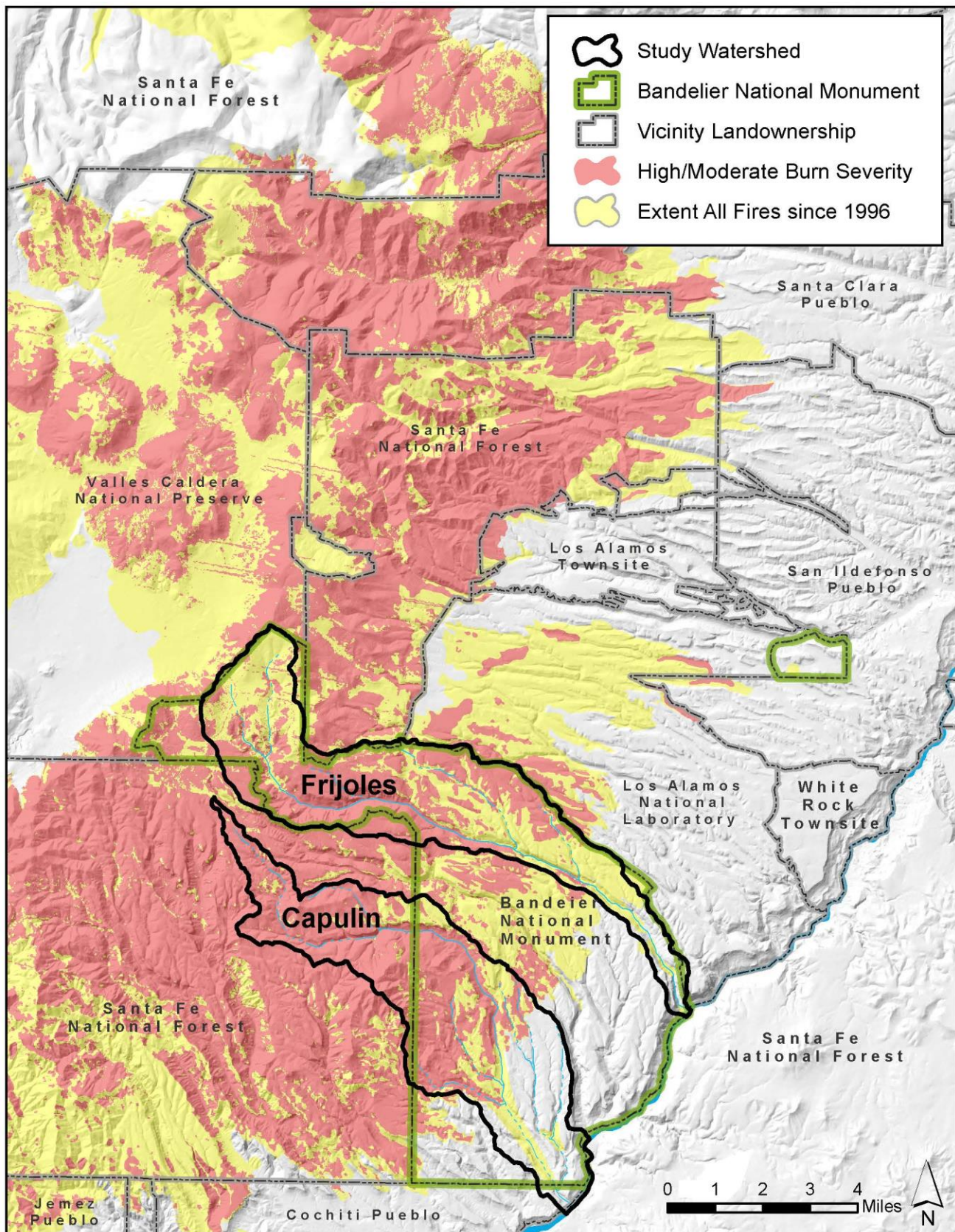


Figure 1. Map showing areas of the eastern Jemez Mountains, New Mexico, affected by severe fires, post-fire floods and debris flows, and hotter droughts since 1996. High-to-moderate burn severity patches (red) indicate areas of tree-killing fire.

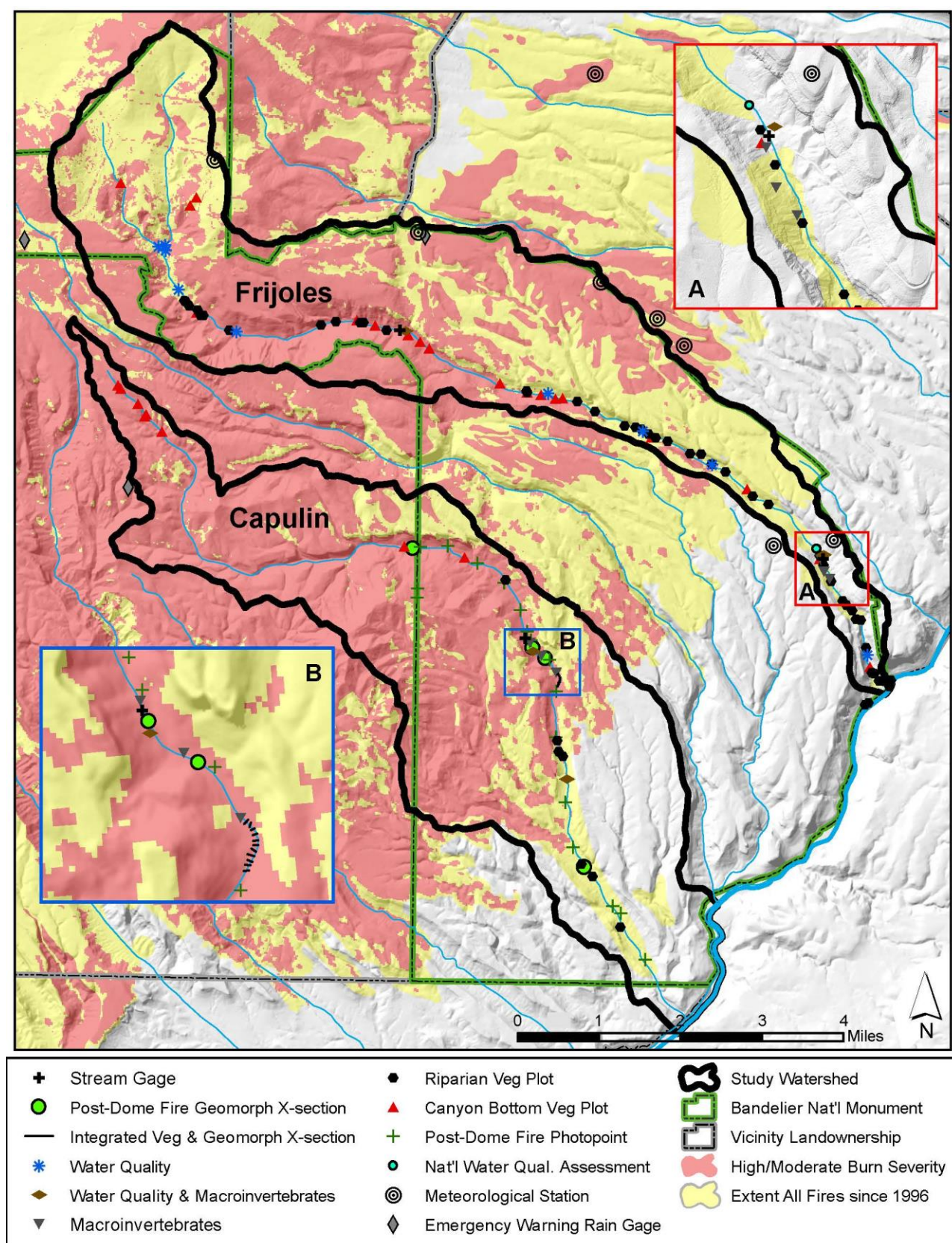


Figure 2. Map showing the locations of historic and ongoing diverse field studies and monitoring data collection sites in riparian zones and canyon bottoms of Frijoles and Capulin canyons in BAND, with fire severity also displayed. See Table 1 for more detailed info on these field datasets.



Figure 3. Upper Frijoles Canyon watershed, facing east, July 22, 1977 (prior to impacts of high severity fire), NPS photo.



Figure 4. Upper Frijoles Canyon watershed, facing east, August 18, 2011 (post-Las Conchas Fire), USGS photo.



Figure 5. Upper Frijoles Canyon SCPN water sampling location, October 28, 2010 (pre-Las Conchas Fire), NPS photo.



Figure 6. Upper Frijoles Canyon, 50 meters upstream of SCPN water sampling location in Fig. 5, showing impacts of high severity fire in the riparian corridor, July 22, 2011 (3 weeks post-Las Conchas Fire), NPS photo. Figs. 7 & 8 repeat Fig. 5 photo.



Figure 7. Upper Frijoles Canyon SCPN water sampling location, October 18, 2011 (post-Las Conchas Fire), NPS photo.



Figure 8. Upper Frijoles Canyon SCPN water sampling location, July 24, 2014 (after second major 2013 flood), NPS Photo.

CATEGORY	Canyon, F = Frijoles, C =Capulin	Data Type	Data Acquisition, Years	# Plots/Transects	Comment	Reference
Hydrology						
	F	HQ lower stream gage	1963-1969, 1977-2016	1 flume gage	USGS, others	Veenhuis, J.E. 2002.
	F	upper stream gage, Emergency	seasonally 2012-2016	1	USGS	Tillery et al., USGS ms. in preparation
	C	Capulin stream gage	1985-1996	1 flume gage	NPS, USGS	Veenhuis, J.E. 2002.
	F	Crest-stage gage	2000-2003	multiple	USGS	Veenhuis, J.E. 2002.
	C	Crest-stage gage	1996-1998	multiple	USGS	Veenhuis, J.E. 2002.
Fluvial Geomorphology						
	C	channel cross-sections, USGS	1996-1998	4 x-sections, high/mid/low in watershed	USGS; permanently monumented, read every 6	Veenhuis, J.E. 2002.
	C	channel cross-sections, NPS-SCPN	2006	11 x-sections in one 800-m reach	USGS, NPS-SCPN; permanently monumented,	Scott, M.L., and E.W. Reynolds. 2007.
	C	paleo-flood X-sections	1996	several x-sections	USGS, unpublished field notes	Veenhuis, J.E. 2002.
	F	channel incision & fluvial geomorph	1990s - multiple years	diverse, extensive field mapping	Los Alamos Nat'l Laboratory	Reneau 2000.
Vegetation						
	C	Integrated veg-geomorph transects	2006	11 transects	USGS, NPS-SCPN; permanently monumented,	Scott, M.L., and E.W. Reynolds. 2007.
	F, C	upland PJ woodland plots		21 plots	NPS-SCPN	
	F	upland mixed-conifer forest plots		23 plots	NPS-SCPN, NPS-BAND	
	F, C	riparian veg plots		52 plots	New Mexico Natural Heritage Program	Muldavin E and Others. 2011.
	F, C	canyon bottom (non-rip) veg plots		26 plots	New Mexico Natural Heritage Program	Muldavin E and Others. 2011.
	F, C	upland veg plots		508 plots	New Mexico Natural Heritage Program	Muldavin E and Others. 2011.
	F, C	LTER woodland veg transects	1991-2017	6 transects, 1800 of line transect	NPS, USGS	
	C	post-Dome transects (Foxx)		3 plots	LANL	
	C	post-Dome transects (Barclay)	1997, 1998, 2008, 2013,	32 transects	NPS, USGS, Univ. of AZ	Barclay, A.D., J.L. Betancourt, and C.D. Allen. 2004.
	F, C	NPS fire effects monitoring plots	installed 1993-1999	141 plots (only 4 in Capulin)	NPS-BAND fire monitoring program	
Water Quality						
	F, C	water quality, diverse, miscellaneous	1957-1999	34 historic locations, diverse data	NPS, LANL, USGS	Mott, D. 1999.
	F	NAWQA	1993-1995	1	USGS	
	F, C	water quality, current I&M	2009-2017	13	NPS-SCPN	Stumpf, S.E. 2016.
	C	aquatic macroinvertebrates &	1994-1996		M.S. thesis work	Stevens, L. 1996.
	F, C	aquatic macroinvertebrates &				Vieira, N. K. M., W. H. Clements, L. S. Guevara, and B. F. Jacobs. 2004.
	F, C	physical habitat structure	1994-2001	6	Ph.D. dissertation work.	Vieira, N. K. M and W. H. Clements. 2008
	F, C	aquatic macroinvertebrates &	2007-2017	4	NPS-SCPN	Stumpf, S.E. 2016. Aquatic macroinvertebrate and physical habitat monitoring
Misc						
	C	post-Dome Fire riparian repeat	1998-2001, 2003, 2006	17 photos/point	NPS, fire monitoring	
	F	Cerro Grande upland repeat	2000, 2001, 2003,	13 points/60 photos	NPS	

Table 1. Selected list of field studies conducted in Frijoles and Capulin canyons, mostly mapped in Figure 2.

Imagery Source	Dates	Scale/Resolution	Comment
Aerial Photos - LANL	1991	1:24k/2 ft pixels	Hard & digital copies at BAND; stereo is available
Aerial Photos - LANL	1991	1:7k	Hard copies at BAND; Los Alamos County only, neither watershed captured
Aerial Photos - USFS	1992 & 1994	1:15,840	These have been scanned by USFS; waiting to be rectified at UNM
Aerial Photos - LANL	2000	2 ft	Digital copies available at FORT and at BAND; parkwide coverage
Aerial Photos - LANL	2008	0.15 m	Digital copies available at BAND; coverage of middle Frijoles/Capulin and
Aerial Photos - LANL	2011	0.15 m	Digital copies available at BAND; taken in Spring; coverage of middle Frijoles/Capulin and north
Aerial Photos - USFS	2011	1 ft	Fire footprint
Aerial Photos - USFS	2011	1 ft	Digital copies available at BAND; taken in October; coverage of Las Conchas
Aerial Photos - NPS	2011	0.15 m	Fire footprint
Aerial Photos - LANL	2014	0.25 ft	Digital copies available at BAND; taken in September; parkwide coverage
Aerial Photos - NAIP	2004	0.5 m	Digital copies available at BAND; coverage of middle Frijoles/Capulin and
Aerial Photos - Statewide Collection	2005	1 m	3 band, digital photos
Aerial Photos - NAIP	2008	1 m	3 band, digital photos
Aerial Photos - NAIP	2011	1 m	3 band, digital photos; flown approx. early August
Aerial Photos - NAIP	2014	1 m	4 band, digital photos; flown approx. late May (pre-Las Conchas)
Aerial Photos - NAIP	2016	1 m	4 band, digital photos; flown approx. late June
LiDAR - LANL	2000	1 ft	4 band, digital photos; flown approx. late June
LiDAR - LANL	2000	4 ft	Digital copies at BAND; coverage of Frijoles Canyon north
LiDAR - VCNP	2010	1 ft	Digital copies at BAND; parkwide
LiDAR - USACE	2011	3 ft	Digital copies at BAND; coverage of Frijoles watershed only; need world files from VALL
LiDAR - VCNP	2012	3 ft	Digital copies at BAND; coverage of headquarters area of Frijoles Canyon
LiDAR - NPS	2013	0.5 m	Digital copies at BAND; coverage of Frijoles Canyon only
LiDAR - LANL	2014	1 ft	Not sure of the details of LiDAR acquired by NPS
Satellite - Landsat	1984-present	30 m	1 ft DEM-derived, park-wide
Satellite - SPOT5	2012	10 m	Coverage every 16 days; however, the east side of the Jemez are covered by alternating path/rows, so potential coverage every 9 days
Satellite - SPOT5	2013	10 m	late 2011, 2012 was a thin year. However, due to this we have access to SPOT data in 2012
Satellite - MODIS	2000-present	250 m	Acquired in June
Satellite - Quickbird	2011	0.6 - 1 m	Probably not helpful for this project; near daily coverage, reliable composites every 7 days
Satellite - WorldView2	2016	0.5 m	Acquired over BAND between March and April (?)
Satellite - Sentinel2	2015-present	10 - 60 m	8 band multispectral imagery; covers all of BAND; acquired in mid July 2016; we should have access to this data
National Agriculture Imagery Program (NAIP)			
Los Alamos National Laboratory (LANL)			
U.S. Forest Service (USFS)			
National Park Service (NPS)			
U.S. Army Corps of Engineers (USACE)			
Valles Caldera National Preserve (VCNP)			

Figure 2. Available remote-sensing and aerial imagery datasets covering Frijoles and Capulin canyons.