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Title: EFFECTS OF LANDSCAPE DISTURBANCE ON ECOHYDROLOGIC SYSTEMS

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Los Alamos
NATIONAL LABORATORY

Effects of Landscape Disturbance on Ecohydrologic Systems

Field Trip for
Chapman Conference
Eco-hydrology of Semiarid Landscapes: Interactions and Processes

On the Pajarito Plateau
near Los Alamos, New Mexico

September 11, 2002

Organized by:
Brent D. Newman
Craig D. Allen
David D.Breshears
Cathy J. Wilson

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Effects of Landscape Disturbance on Ecohydrologic Systems
Bus 1 Itinerary

Drought		
7:30 - 9:15	Bus loads, travel to Bandelier Natl. Monument ***- Restroom available on Bus***	
9:15 - 9:45	*Ecohydrologic Pattern and Functioning in Semiarid Woodlands*	Dave Breshears / Craig Allen
9:45 -10:00	Bus down to Visitor Center ***- Restrooms outside of the Visitor Center on the streamside***	
10:00 - 11:00	Hike to Frijolito Watershed Study Site with stop: *Landscape History of the Pajarito Plateau* **(Note: Strenuous hike)**	Craig Allen
11:00 - 11:30	*Ecohydrologic Responses to Drought*	Craig Allen / Dave Breshears
11:30 - 11:45	Hike to Frijolito Restoration Study Site	
11:45 - 12:15	*Restoration of an Ecohydrologic System*	Brian Jacobs / Brian Hastings
12:15 - 12:45	Hike back to Bandelier Visitor Center	
12:45 - 1:30	Lunch at Bandelier Visitor Center	
Fire		
1:30 - 2:00	Bus to Low Head Weir - ***Portable restrooms available***	
2:10 - 2:15	*Overview of Cerro Grande Fire: General Consequences and Research Efforts*	Cathy Wilson
2:15 - 2:30	*Post-fire ash and Contaminant Transport and Redistribution; Risk Analysis Process*	Danny Katzman
2:30 - 2:45	*Post-fire Hydrology and Chemistry of Surface Waters*	Bruce Gallaher
2:45 - 3:00	*Conceptual Model of Mineralogical and Hydrochemical Impacts of the Cerro Grande Fire*	Pat Longmire
3:00 - 3:15	*Impact of the Fire and the Low-head Weir on Shallow Groundwater Quality*	Bill Stone
3:25 - 4:00	Bus to Mitchell Trail	
4:00 - 4:20	Hike Mitchell Trail to presentation area	
4:20 - 4:35	*Rehabilitation Efforts – The Biggest Rehab Effort in History*	Alison Dean / Greg Kuyumjian
4:35 - 4:50	*Post fire Runoff, Erosion and Channel Processes and Observations*	Sue Cannon / John Moody / Deborah Martin
4:50 - 5:05	*Post-fire Flood, Erosion and Sediment Transport Predictions*	Cathy Wilson
5:05- 5:20	Return hike to Bus	
5:30 - 6:45	Return to Taos	

**** A minute of silence will be observed for September 11, 2001 events during the tour.***

Effects of Landscape Disturbance on Ecohydrologic Systems
Bus 2 Itinerary

Fire		
7:30 - 9:30	Bus loads, travel to Low-head Wier - ***Restroom available on Bus***	
9:30 - 9:35	*Overview of Cerro Grande Fire: General Consequences and Research Efforts*	Cathy Wilson
9:35 - 9:50	*Post-fire ash and Contaminant Transport and Redistribution; Risk Analysis Process*	Danny Katzman
9:50 - 10:05	*Post-fire Hydrology and Chemistry of Surface Waters*	Bruce Gallaher
10:05 - 10:20	*Conceptual Model of Mineralogical and Hydrochemical Impacts of the Cerro Grande Fire*	Pat Longmire
10:20 - 10:35	*Impact of the Fire and the Low-head Weir on Shallow Groundwater Quality*	Bill Stone
10:35 - 11:15	Bus to Mitchell Trail	
11:15 - 11:35	Hike Mitchell Trail to presentation area	
11:35 - 11:50	*Rehabilitation Efforts – The Biggest Rehab Effort in History*	Alison Dean / Greg Kuyumjian
11:50 - 12:05	*Post-fire Runoff, Erosion and Channel Processes and Observations*	Sue Cannon / John Moody / Deborah Martin
12:05 - 12:20	*Post-fire Flood, Erosion and Sediment Transport Predictions*	Cathy Wilson
12:20- 12:30	Return hike to Bus	
12:30 - 1:30	Lunch at base of Mitchell Trail	
Drought		
1:30 - 2:00	Bus to Bandelier Natl. Monument	
2:00 - 2:30	*Ecohydrologic Pattern and Functioning in Semiarid Woodlands*	Dave Breshears / Craig Allen
2:30 - 2:45	Bus down to Visitor Center - ***Restrooms outside of the Visitor Center on the streamside***	
2:45 - 3:45	Hike to Frijolito Watershed Study Site with stop: *Landscape History of the Pajarito Plateau* **(Note: Strenuous hike)**	Craig Allen
3:45 - 4:15	*Ecohydrologic Responses to Drought*	Craig Allen / Dave Breshears
4:15 - 4:30	Hike to Frijolito Restoration Study Site	
4:30 - 5:00	*Restoration of an Ecohydrologic System*	Brian Jacobs / Brian Hastings
5:00 - 5:30	Hike back to Bandelier Visitor Center	
5:30 - 6:45	Bus back to Taos	

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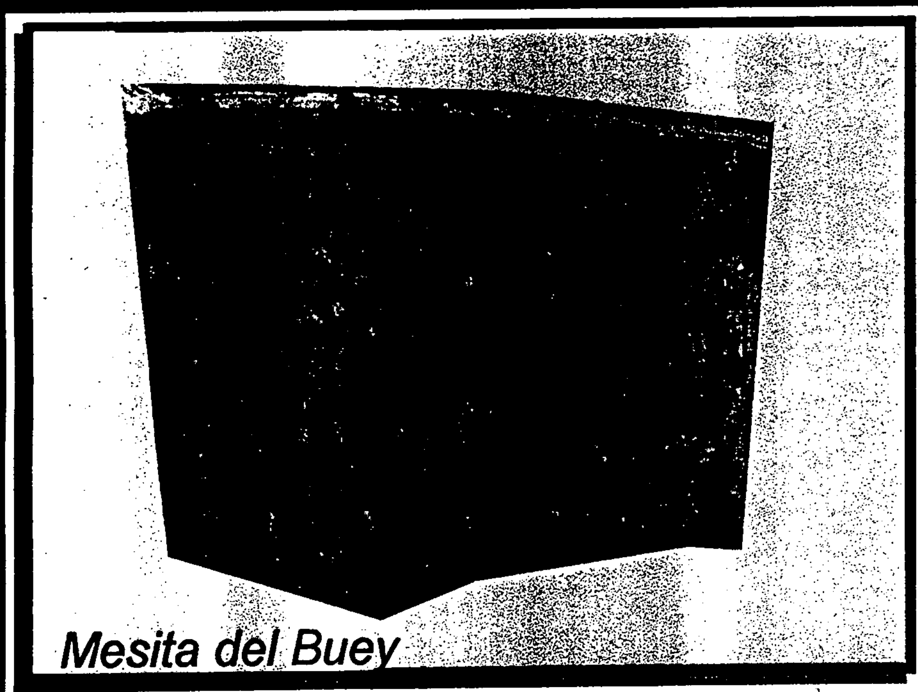
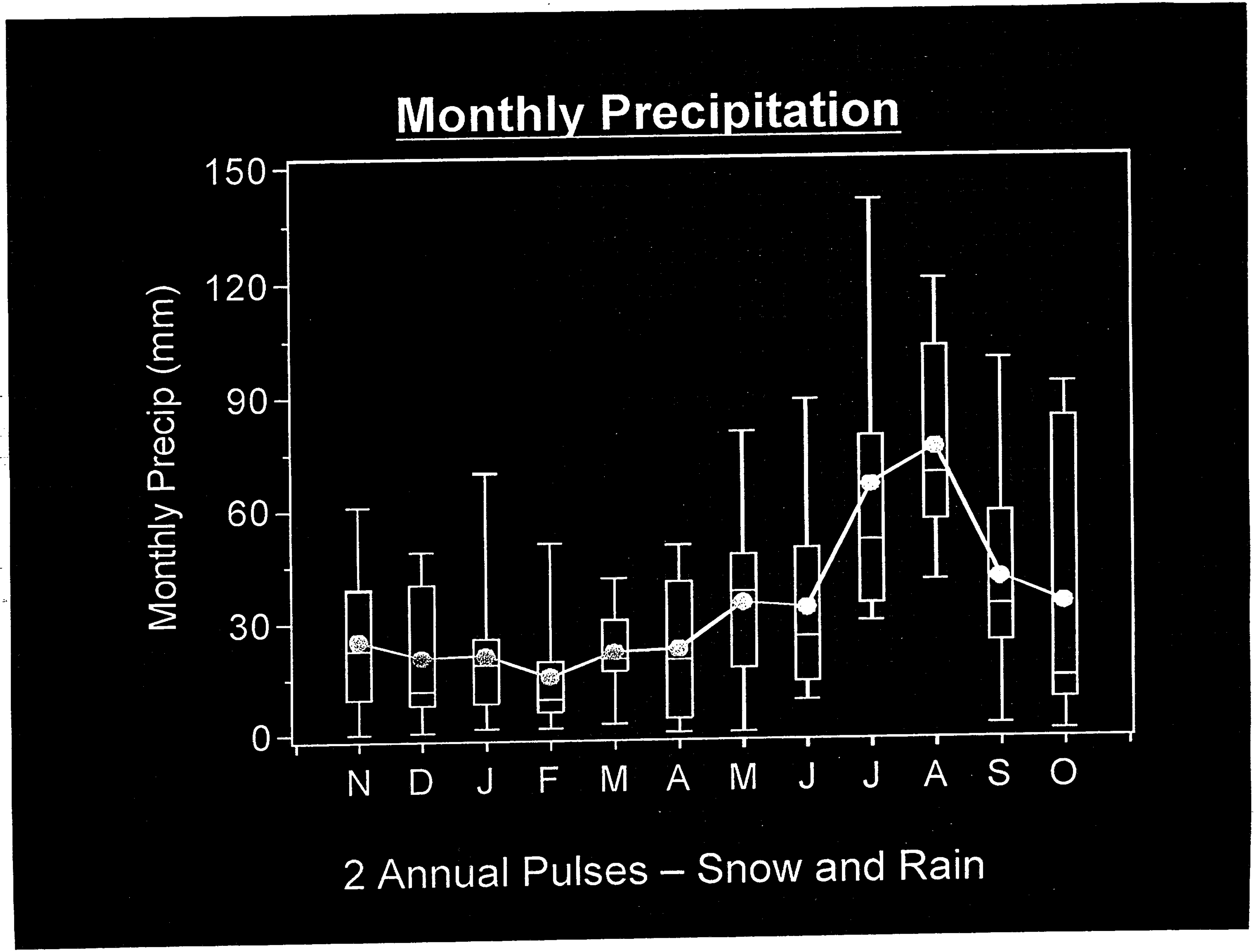
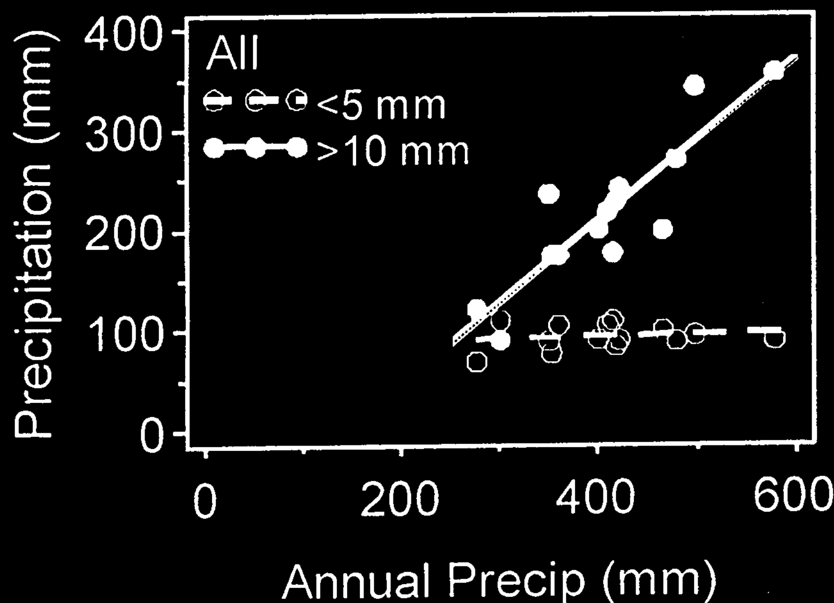
Mesita del Buey

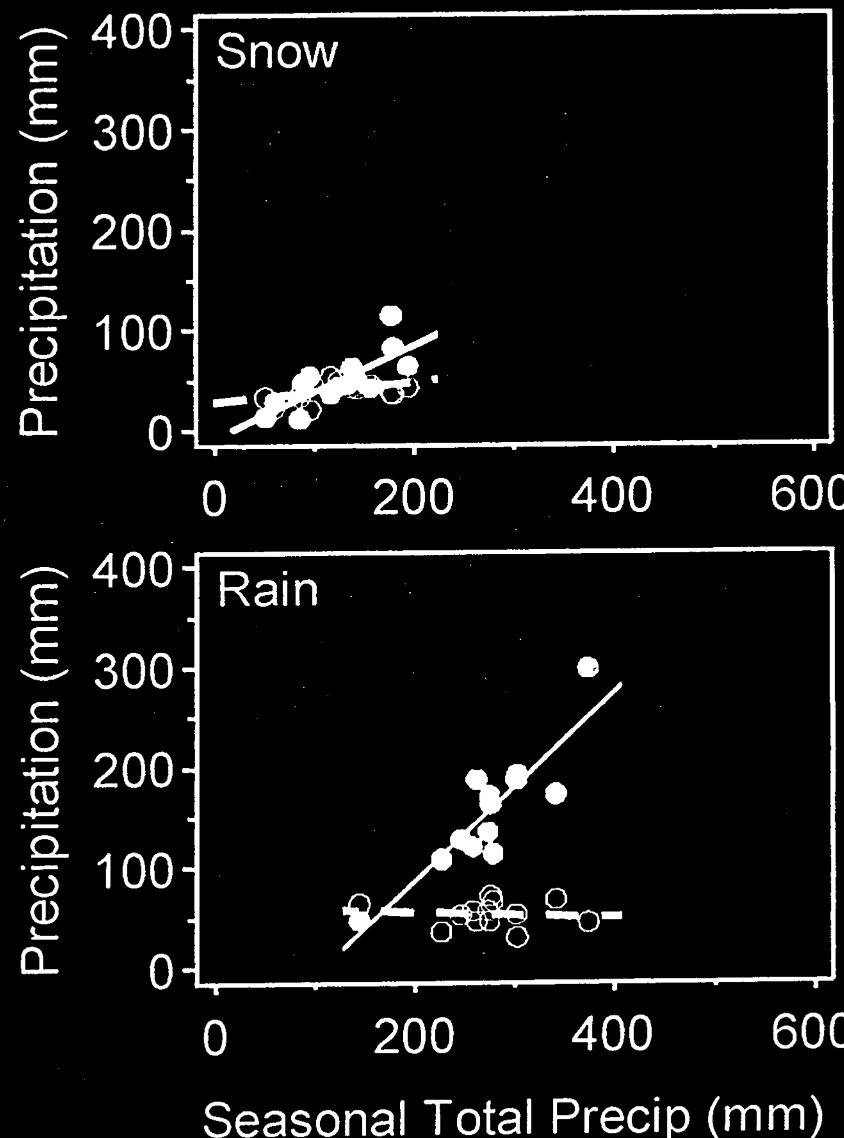


Studies include:
Soil morphology
Soil C and N
Soil water
Soil temperature
Soil evaporation
Near ground solar radiation
Tree patterns
Plant water stress
Transpiration & photosynthesis
Tree growth
Runoff and erosion


Monthly Precipitation
Monthly Precip (mm)
150
120
90
60
30
0
N D J F M A M J J A S O
2 Annual Pulses – Snow and Rain

Precipitation by Event Size

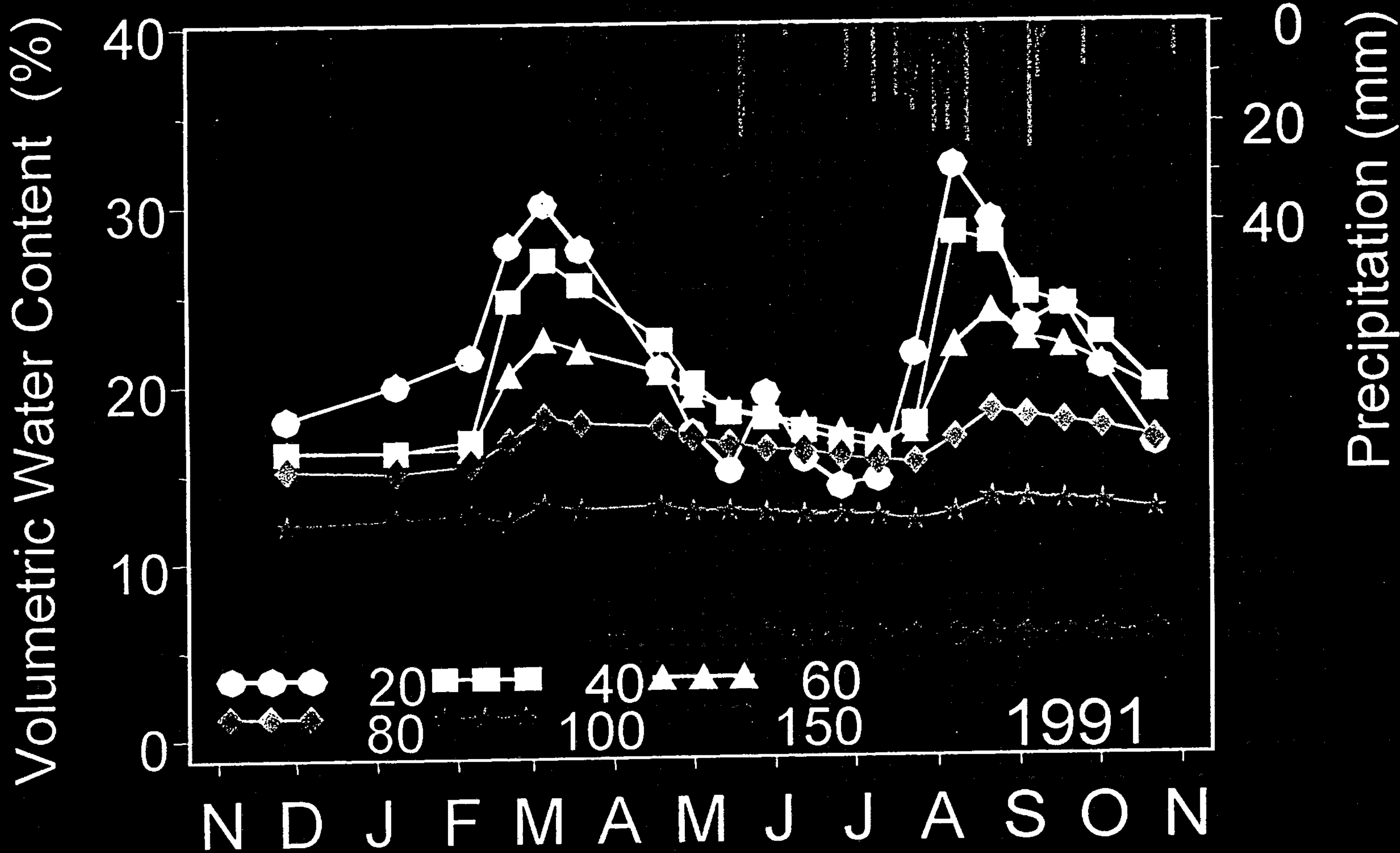




Breshears, Myers, and Barnes - unpublished

Wet vs. dry periods differ in large precipitation events - not small ones

Example Year of Soil Moisture



2 Annual Pulses – Snow and Rain

8

Heterogeneity in Plant Available Water

Intercanopy Patch | Canopy Patch

Upper layer

Lower layer

Breshears and Barnes 1999

Plant Available Water Heterogeneity

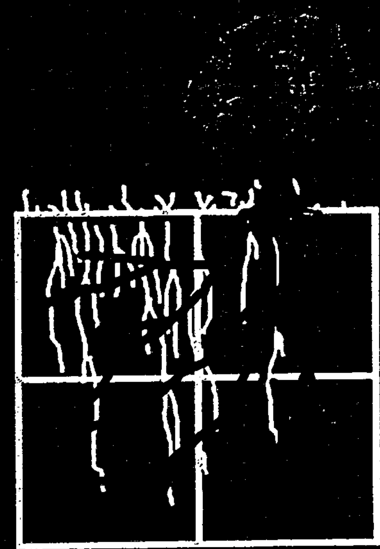
Annual Variation

Dry

	I	C
U	41	40
L	49	89

Wet

	I	C
U	57	63
L	54	90



Overall

	Inter-canopy	Canopy
Upper	41	44
Lower	49	89

Seasonal Variation

Snow

	I	C
U	58	54
L	52	89

Rain

	I	C
U	30	39
L	47	89

Breshears, Myers, and Barnes - unpublished

Causes of Horizontal Heterogeneity

Interception

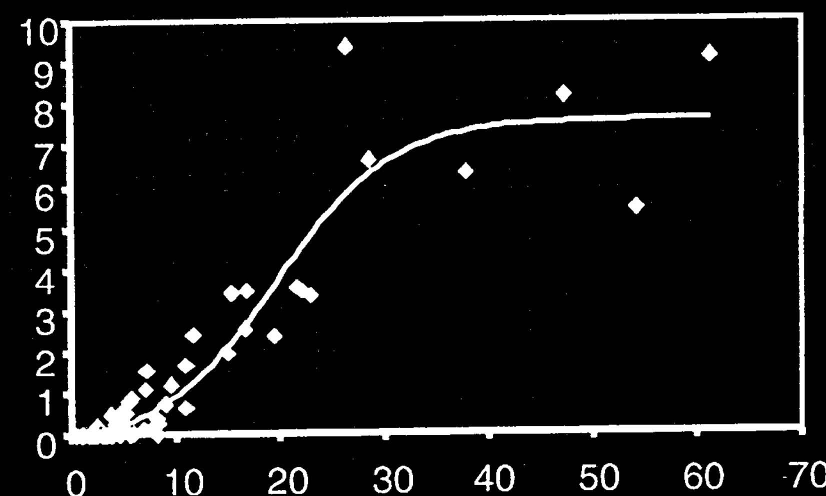
Interception = 17-25 % of Water Budget in Piñon-Juniper Woodlands

Canopy < Intercanopy

Causes of Horizontal Heterogeneity

Infiltration, Runoff and Runon

Runoff from bare patches becomes runon to herbaceous patches



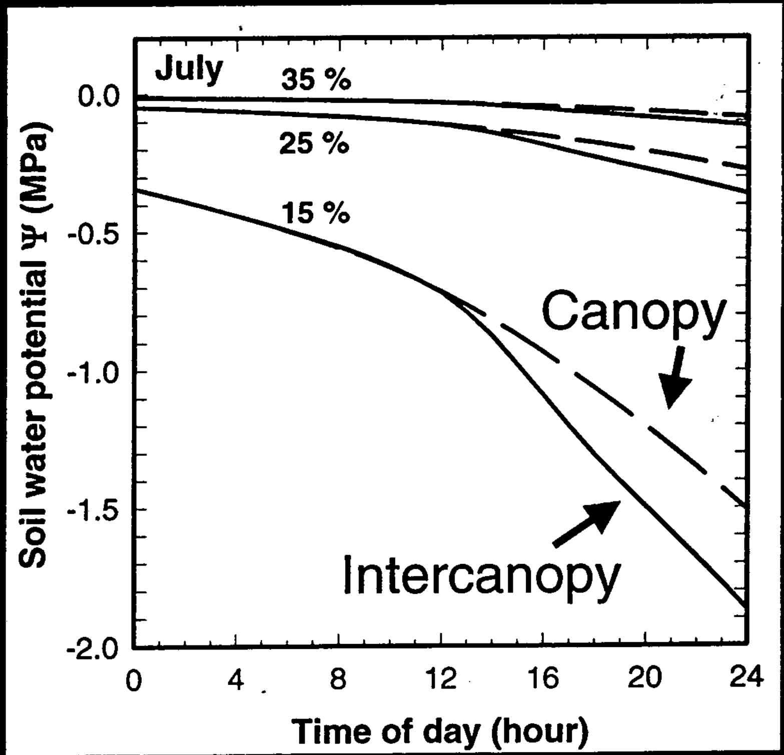
Reid et al. 1999

Causes of Horizontal Heterogeneity

Soil Evaporation

Near ground differences in incoming solar radiation produce greater soil evaporation rates in intercanopy

Martens et al. 2001

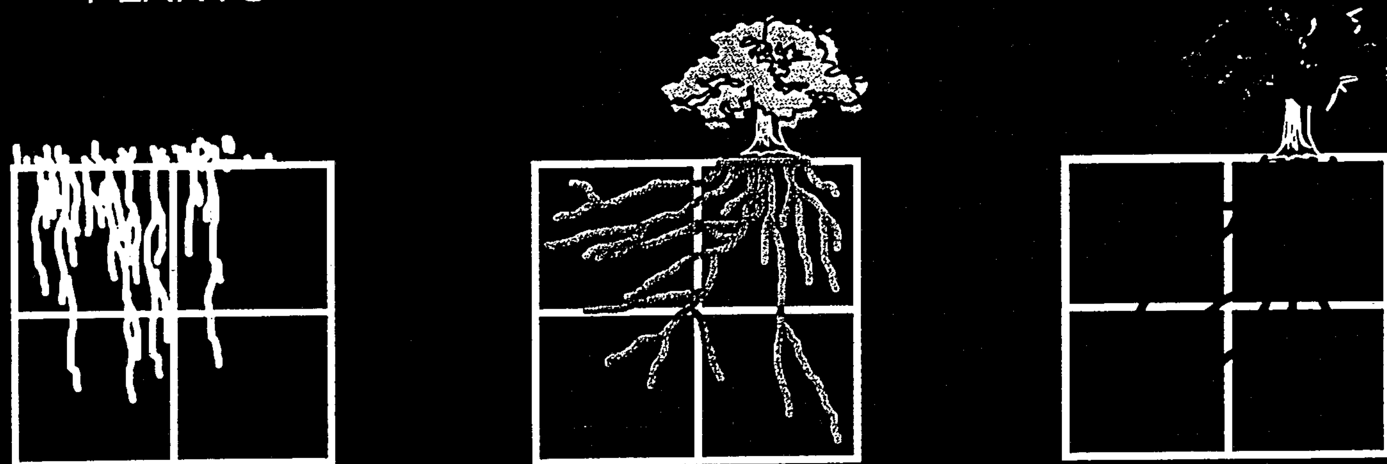


Breshears et al. 1998

Causes of Horizontal Heterogeneity

Plant Uptake, Redistribution, and Transpiration

HERBACEOUS PLANTS | SHALLOW ROOTED WOODY PLANTS | DEEPER ROOTED WOODY PLANTS



Dependent of Root Morphology
and Plant Phenology and Physiology

Breshears and Barnes 1999

Runoff, Erosion, and Restoration Studies in Piñon-Juniper Woodlands of the Pajarito Plateau

by *Craig D. Allen*, U.S. Geological Survey, Jemez Mountains Field Station, Midcontinent Ecological Science Center, Los Alamos

Piñon-juniper woodlands are one of the most extensive vegetation types in New Mexico, including large portions of the Pajarito Plateau. The woodland soils on local mesas largely formed under different vegetation during cooler, moister conditions of the late Pleistocene; in other words, they are over 10,000 years old, and many are over 100,000 years old (McFadden et al., 1996). Changes in climate and vegetation in the early Holocene (8,500–6,000 years ago) led to at least localized episodes of soil erosion on adjoining uplands (Reneau and McDonald, 1996; Reneau et al., 1996). During this time, the dominant climatic and associated vegetation patterns of the modern southwestern United States developed, including grasslands, piñon-juniper woodlands, and ponderosa pine savannas (Allen et al., 1998). On the basis of local fire history, the young ages of most piñon-juniper trees here, and soils data, we believe that many upland mesa areas now occupied by dense piñon-juniper woodlands were formerly more open, with fewer trees and well-developed herbaceous understories that: (1) protected the soil from excessive erosion during intense summer thunderstorm events, and (2) provided a largely continuous fuel matrix, which allowed surface fires to spread and maintain these vegetation types (Fig. 1). In contrast, rocky canyon walls have probably changed relatively little through the centuries, as grazing and fire suppression had fewer effects on such sites.

Native American effects on local woodlands are thought to have been insignificant or highly localized until the late 12th century, when the Ancestral Puebloan population began to intensively occupy and utilize the Bandelier area (Powers and Orcutt, 1999). Piñon-juniper woodlands were the core area of occupation by these prehistoric agriculturalists—most of the more than 2,500 archaeological sites recorded in the part (~50%) of the park surveyed to date are found in piñon-juniper woodland settings. Cutting and burning of piñon-juniper trees for cooking, heating, building, and agricultural activities likely led to significant deforestation of upland mesas from about 1150 to 1550 A.D. Thus, Ancestral Puebloan land use practices favored herbaceous vegetation. Intensive soil disturbance certainly occurred in farmed areas and around habitations, but there was probably little net change in landscape-wide erosion rates due to the small size and dispersed locations of fields and villages.

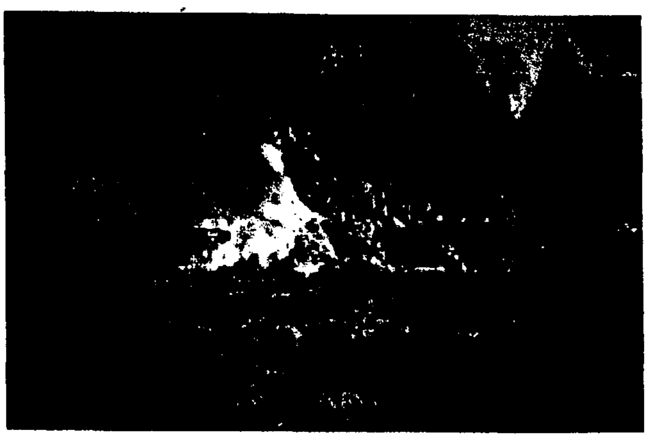


FIGURE 1—Grassy ground cover and surface fires once maintained more open conditions in many piñon-juniper woodland settings.

Euro-American settlement of the adjoining Rio Grande valley and the introduction of domestic livestock grazing began in 1598. It is unlikely, however, that significant livestock grazing (that is, with substantial widespread effects on the herbaceous understory, fire regime, or erosion rates) took place in much of Bandelier until railroads linked the Southwest to commercial markets in the 1880s. Millions of sheep and cattle were placed in the New Mexico landscape at that time, with unrestricted grazing on public lands. Livestock grazing continued in Bandelier until 1932, and feral burros were similarly allowed to cause grazing impacts until about 1980 (Allen, 1989). Sharp reductions in the herbaceous ground cover and associated organic litter resulted (Fig. 2), effectively suppressing previously widespread surface fires (in concert with institutionalized fire suppression initiated by the federal government after 1910). Severe drought during the 1950s contributed to declines in ground cover (Allen and Breshears, 1998). Fire-sensitive piñon and juniper trees became established in densities unprecedented for at least the past 800 years. As these trees grew, they became increasingly effective competitors for water and nutrients. Thus, a positive feedback cycle was initiated that favors tree invasion and decreased herbaceous ground cover on mesa top.

This land use history has caused the degraded and unsustainable ecosystem conditions observed in many piñon-juniper woodlands today. Intensive watershed research over the past decade, involving collaborations among Los Alamos National Laboratory, U.S. Geological Survey, Colorado State University, U.S. Forest Service, and Bandelier National Monument, shows that the intercanopy soils of Bandelier's woodlands are apparently eroding at net rates of about one centimeter per decade (Wilcox et al., 1996a,b; Davenport et al., 1998; unpublished data). Given soil depths averaging only 1–2 ft in many areas, entire soil bodies across extensive areas will soon be lost (Fig. 3). Also, this accelerated runoff and erosion is damaging thousands of archaeological sites at Bandelier; over 90% of inventoried archaeological sites are being damaged by soil erosion (Powers and Orcutt, 1999; unpublished data). For example, we have found as many as 1,040 cultural artifacts (mostly potsherds) moved by a single thunderstorm into a sediment trap draining only ¼ acre of gentle hillslope (Fig. 4). To a significant degree, the park's biological productivity and cultural resources are literally washing away, posing major management challenges (Sydoriak et al., 2000). Similar histories and high erosion rates likely characterize many piñon-juniper woodlands in New Mexico (Gottfried et al., 1995; Bogan et al., 1998), resulting in considerable transport of sediment through watersheds, with associated impacts on water quality.

Ecological thresholds have apparently been crossed (Fig. 2) such that harsh physical processes are now dominant across Bandelier's degraded piñon-juniper woodlands (Gottfried et al., 1995; Davenport et al., 1998). The loss of organic-rich topsoils, impeded plant-available water (Breshears and Barnes, 1999), extreme soil surface temperatures, and freeze-thaw activity severely impede herbaceous vegetation establishment and productivity (Davenport et al., 1998). Reductions in ground cover cause increased runoff from summer thunderstorms (Reid et al., 1999), with associated increases in erosion (Wilcox et al., 1996a,b). Re-establishment of herbaceous ground cover under today's desertified mesa-top conditions may also be difficult due to depleted soil seed banks, highly efficient seed predators (particularly harvester ants; Snyderman and Jacobs, 1995), and an unnaturally large elk

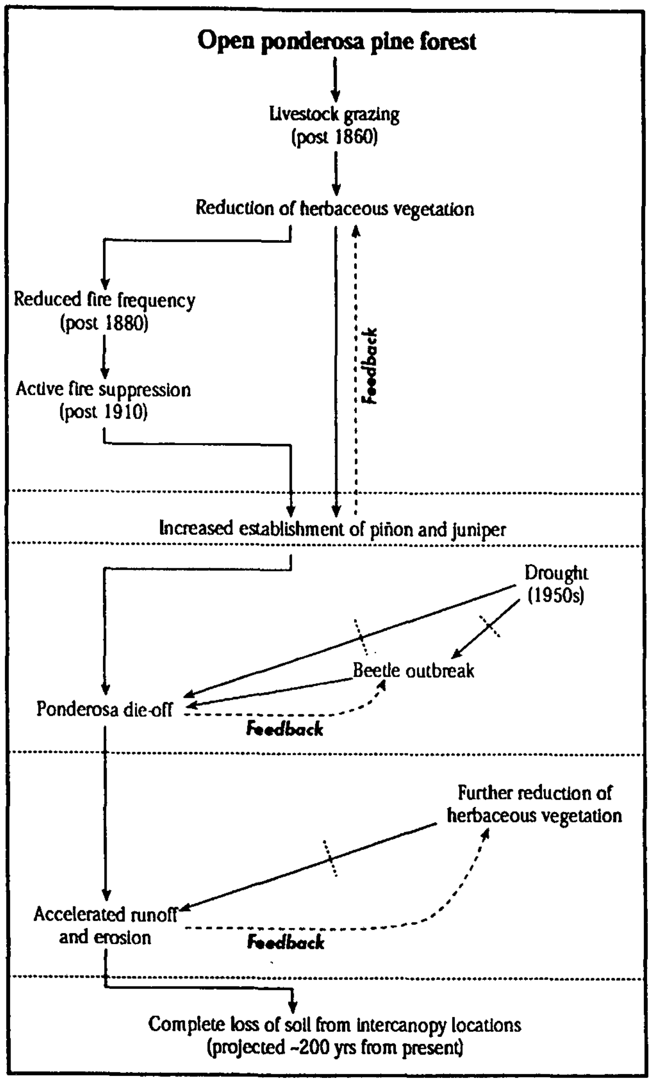


FIGURE 2—Historic changes in forest/woodland border (ecotone) areas on Frijolito Mesa, Bandelier National Monument (Davenport et al., 1998; Allen and Breshears, 1998). Short-dotted lines represent ecological thresholds.

population. Herbivore exclosures established in 1975 show that protection from grazing, by itself, fails to promote vegetative recovery in Bandelier's piñon-juniper ecosystems (Chong, 1992; Potter, 1985). Without management intervention, this human-induced episode of accelerated soil erosion appears to be highly persistent and irreversible (Davenport et al., 1998).

Happily, experimentation over the past decade shows that a simple, though labor-intensive, treatment can restore more stable ecological conditions (Chong, 1994; Jacobs and Gatewood, 1999; Loftin, 1999; Jacobs et al., 2000). By cutting many smaller piñon-juniper trees, and lopping and scattering the branches across the barren interspaces between trees, herbaceous ground cover and soil stability increase markedly (Figs. 5 and 6). It is likely that application of similar methods would restore more sustainable conditions to degraded piñon-juniper woodlands throughout the Southwest.

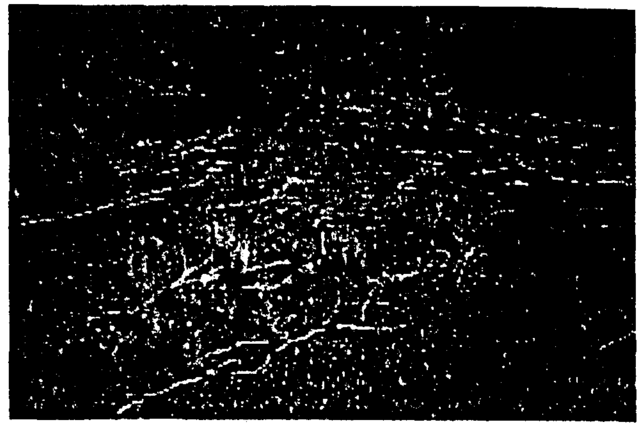


FIGURE 3—Bare soil and high erosion rates characterize the desertified interspaces between piñon-juniper trees across large areas of the Pajarito Plateau. Note the exposed roots.

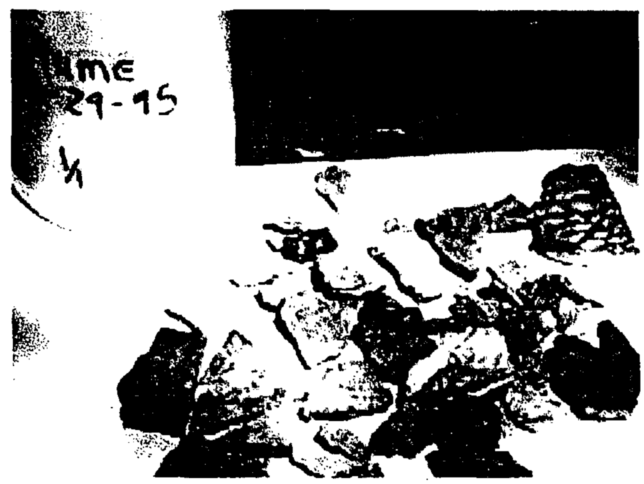


FIGURE 4—Immense numbers of ceramic and lithic artifacts are being transported by accelerated runoff and erosion at Bandelier, degrading the cultural resources for which the park was established. These artifacts were collected from a sediment trap after a single storm.

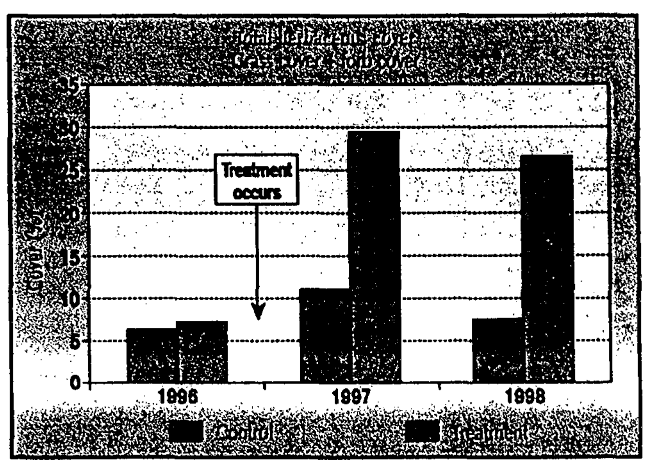


FIGURE 5—Herbaceous cover response to restoration treatment on Frijolito Mesa (Jacobs et al., 2000).

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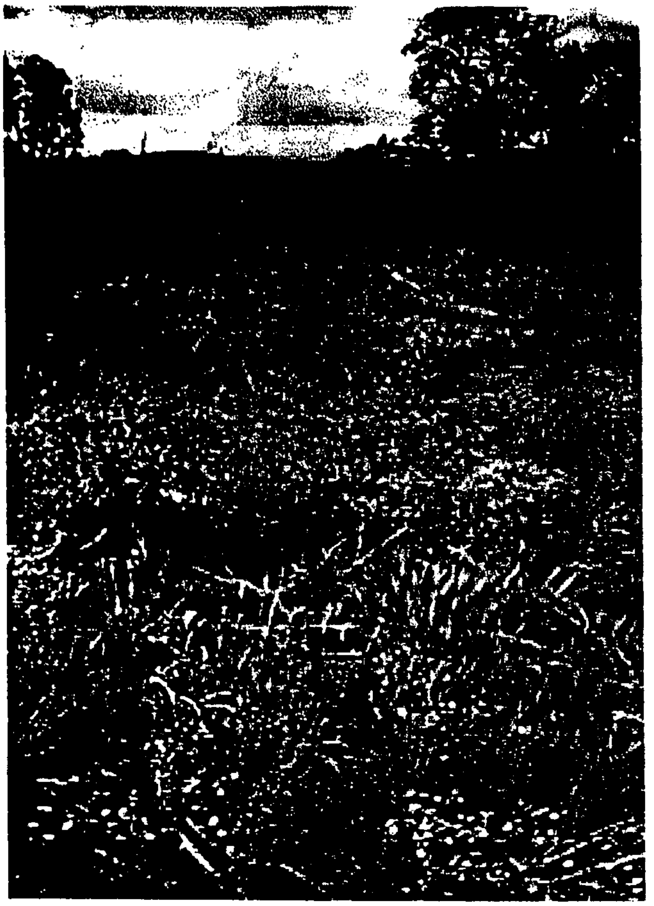

FIGURE 6—View of herbaceous cover response to restoration treatment after first growing season.

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Education: BS and MS, University of Wisconsin at Madison; PhD, University of California at Berkeley

Craig Allen is a research ecologist with the U.S. Geological Survey. He received degrees in geography from the University of Wisconsin (Madison), and a PhD focused on forest and landscape ecology from the University of California (Berkeley). He has worked as an ecologist with the Department of Interior since 1989, beginning with the National Park Service through his current post with USGS. Allen conducts research on the ecology and environmental history of southwestern landscapes, oversees the USGS Jemez Mountains Field Station at Bandelier National Monument (New Mexico), and provides technical support to land management agencies in the region. Ongoing research activities with multiple collaborators include: development of vegetation and fire histories in the Southwest; fire effects on Mexican spotted owls, Jemez Mountains salamanders, and nitrogen cycling; responses of semiarid forests and woodlands to drought (and links to global change issues); development of long-term ecological monitoring networks across landscape gradients at Bandelier; dynamics of runoff, erosion, and restoration of piñon-juniper watersheds; and determining elk movements and habitat effects in the Jemez Mountains. Allen lives with his wife, Sharon, and children Kiyana, Benjamin, and Nikolas in Los Alamos.

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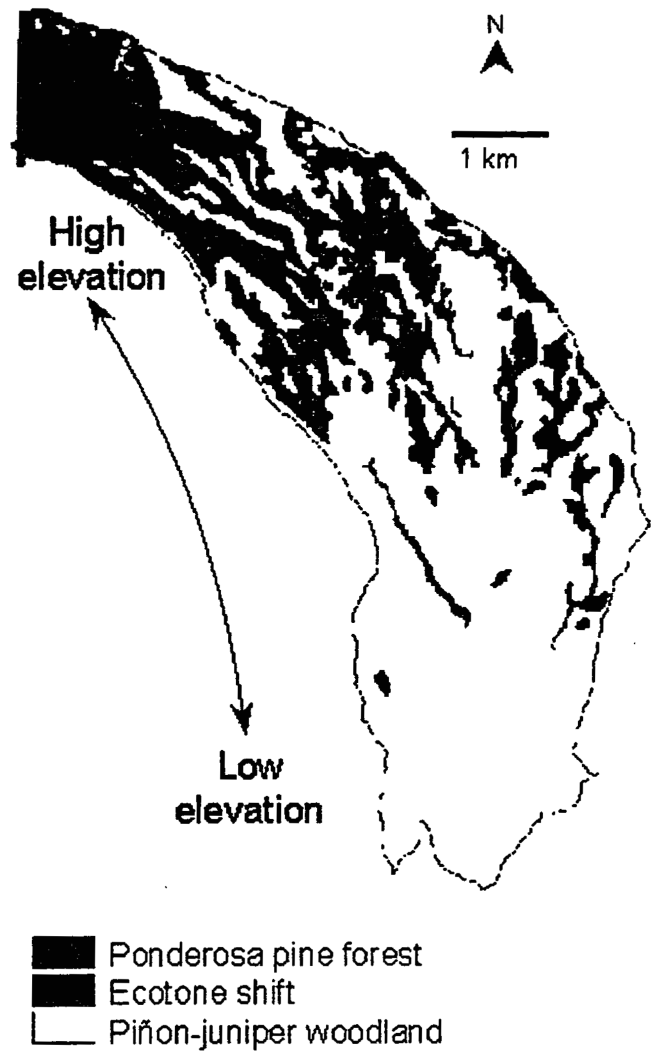
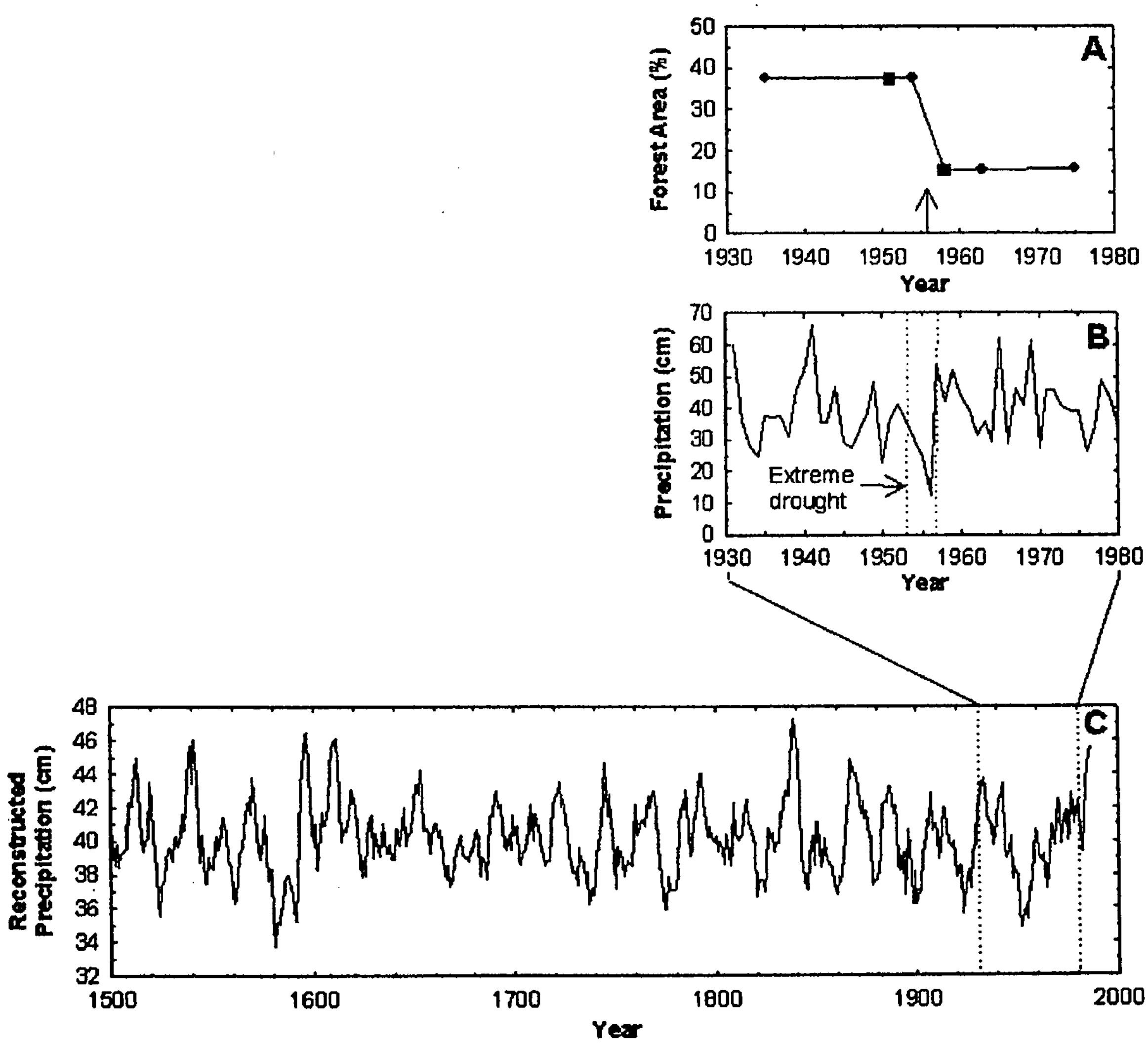
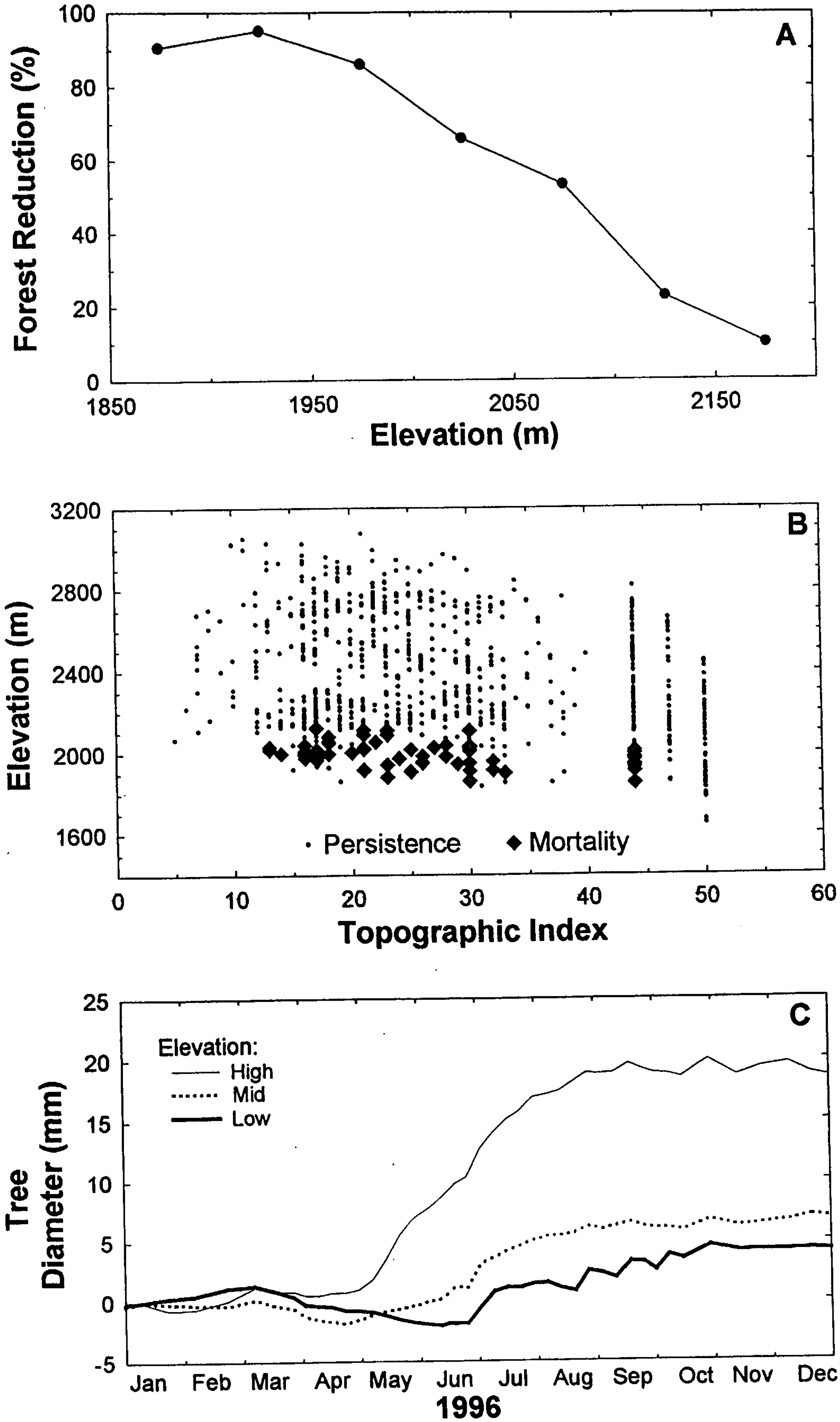


Allen & Breshears 1998

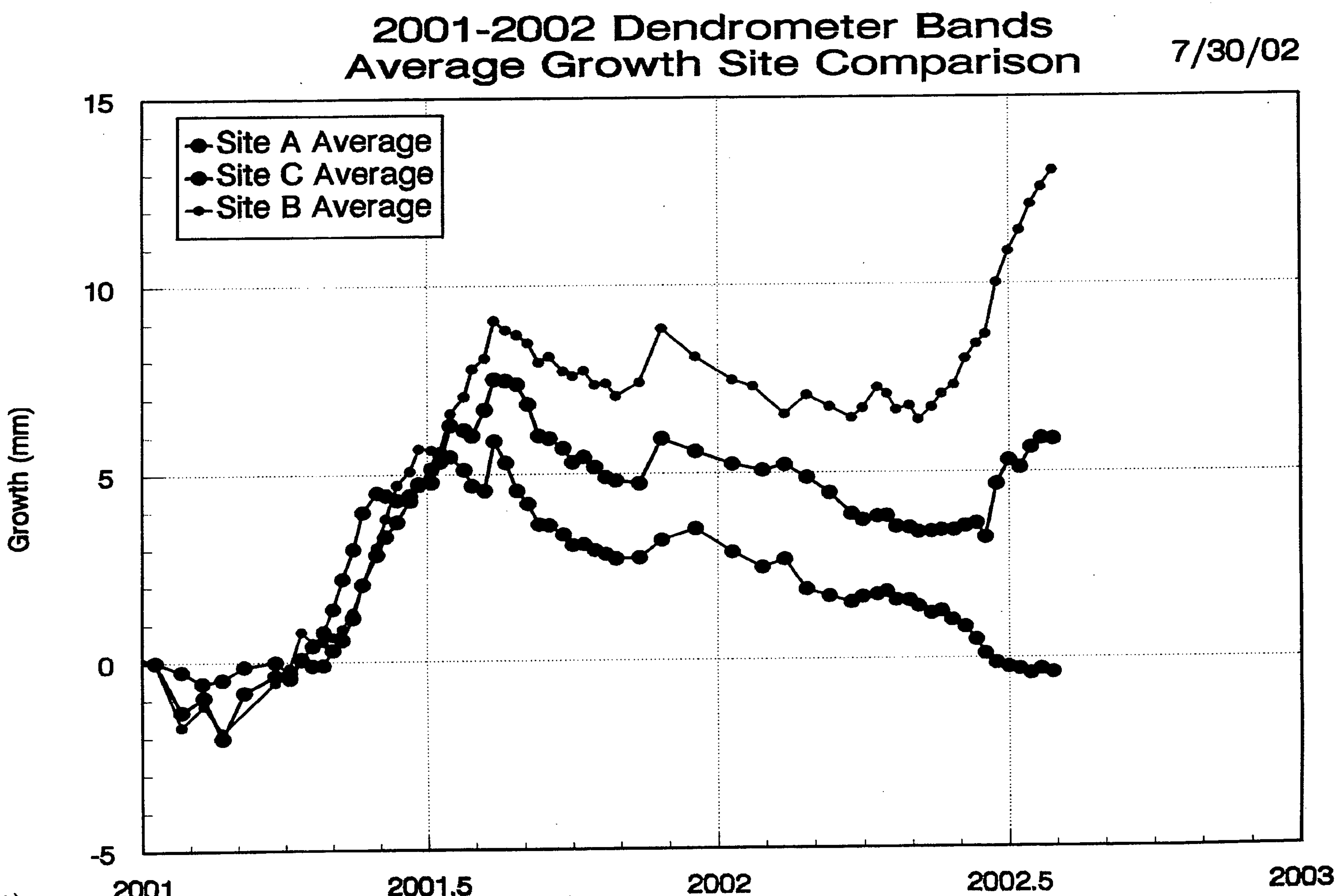
18

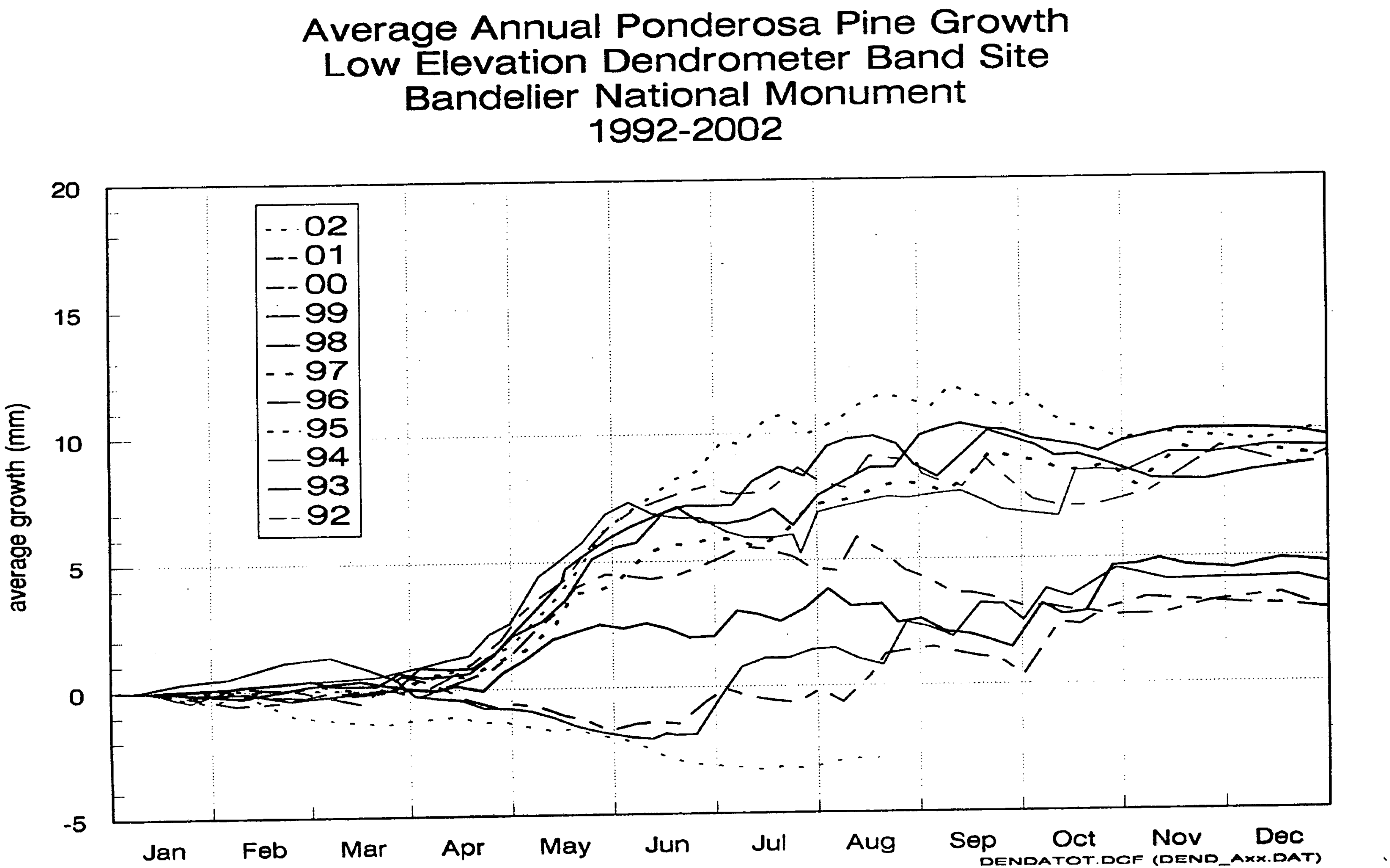


Allen + Breshears 1998

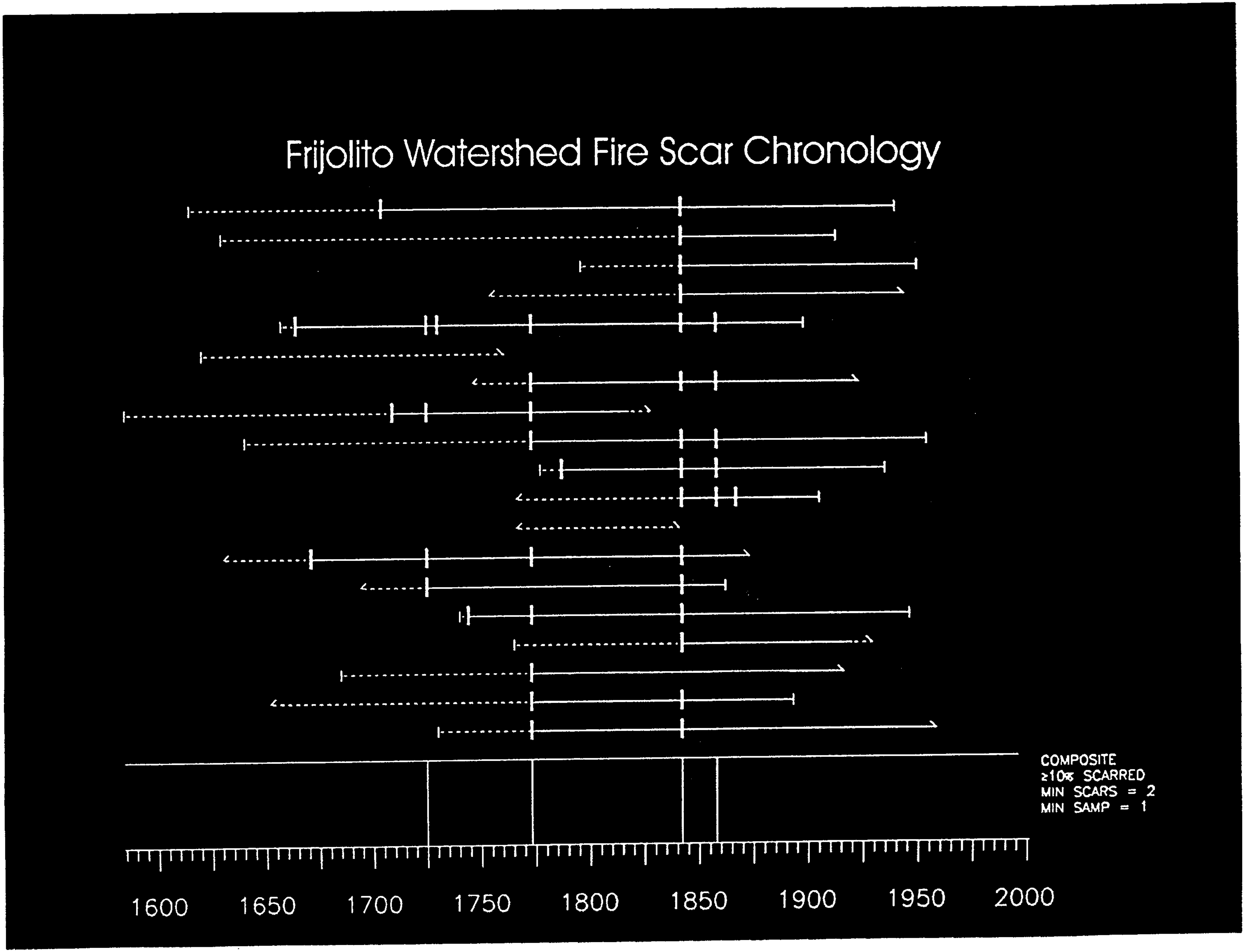


Allen + Breshears 1998


2001-2002 Dendrometer Bands
Average Growth Site Comparison
7/30/02
Site A Average
Site C Average
Site B Average
Growth (mm)
15
10
5
0
-5
2001
2001.5
2002
2002.5
2003



Average Annual Ponderosa Pine Growth
Low Elevation Dendrometer Band Site
Bandelier National Monument
1992-2002
02
01
00
99
98
97
96
95
94
93
92
average growth (mm)
20
15
10
5
0
-5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DENDATOT.DGF (DEND_Axx.DAT)

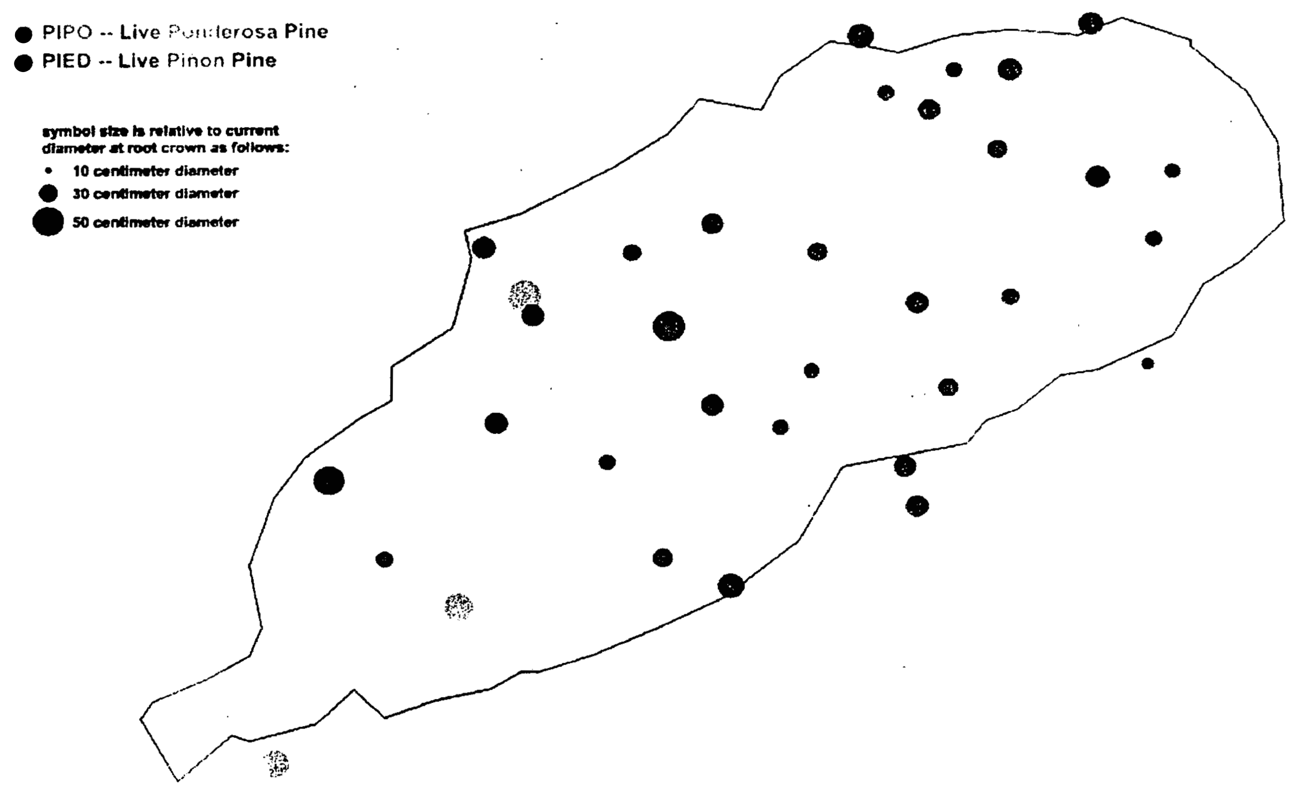


Frijolito Watershed Fire Scar Chronology
COMPOSITE
≥10% SCARRED
MIN SCARS = 2
MIN SAMP = 1
1600
1650
1700
1750
1800
1850
1900
1950
2000

23

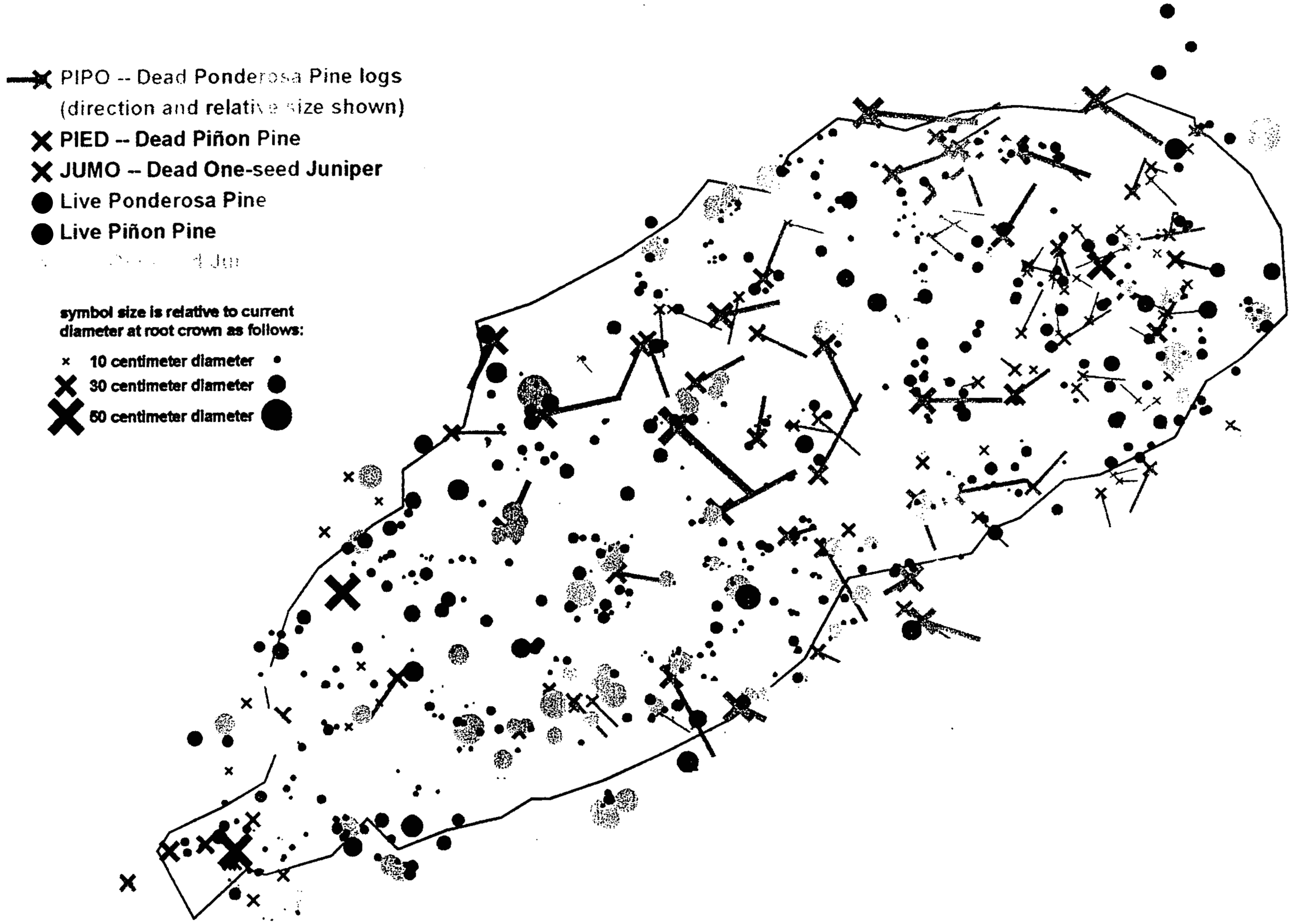
Circa 1800
Tree Distribution in the Frijolito Intensive Study Watershed

- ***Open ponderosa pine-dominated forest.***

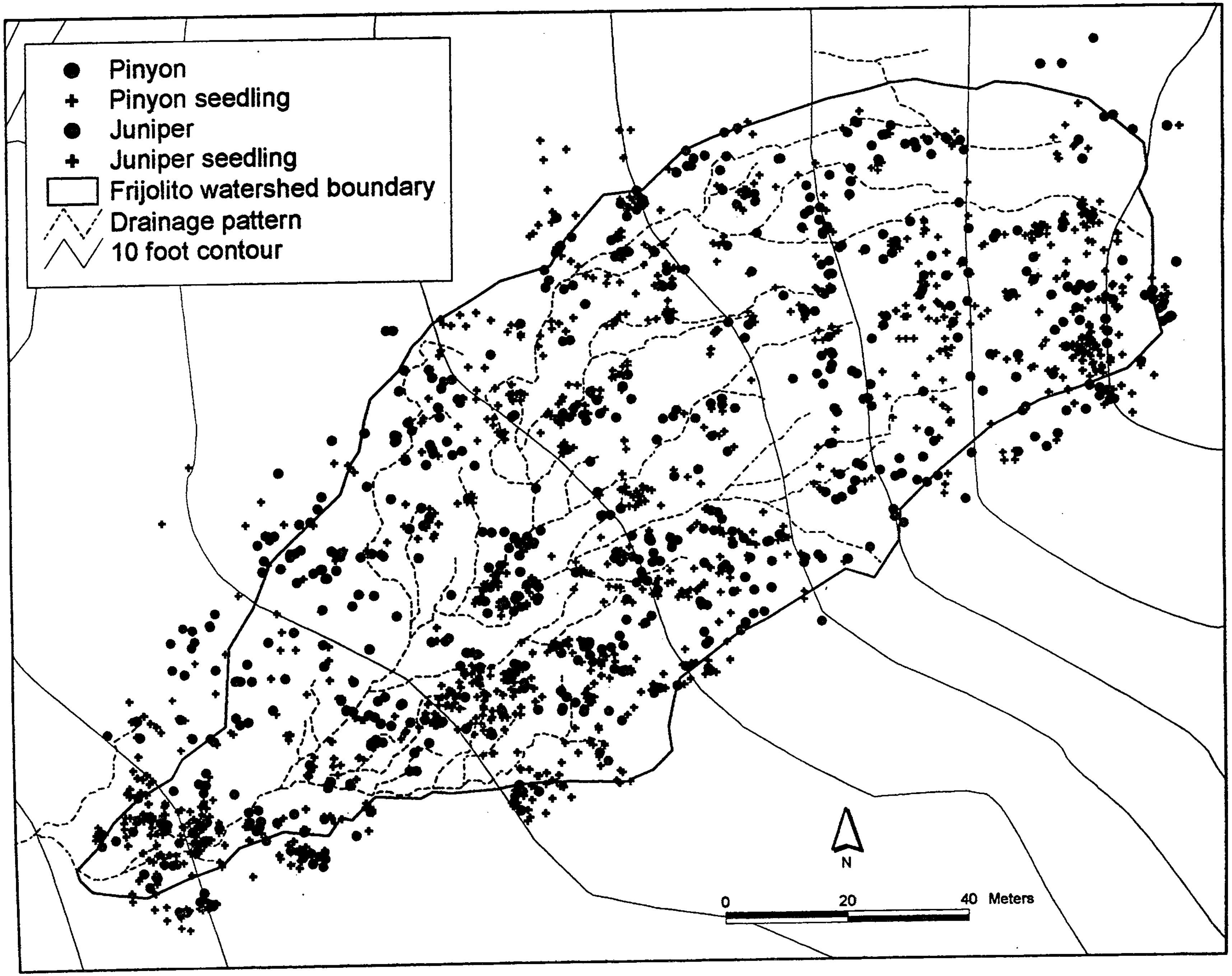


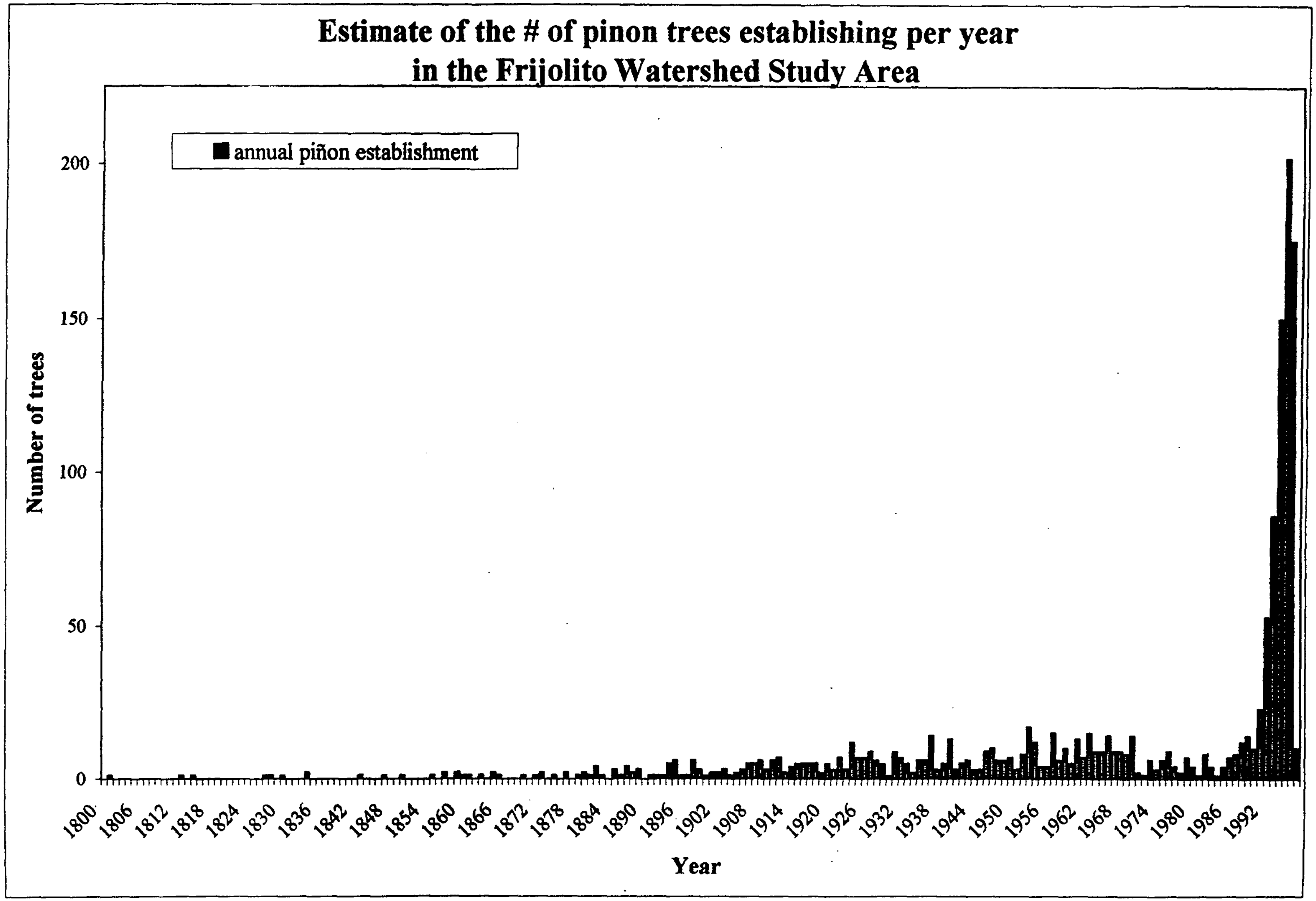
1996
Tree Distribution in the Frijolito Watershed

• After the 1950s drought all ponderosa were dead, leaving piñon and juniper as dominants.



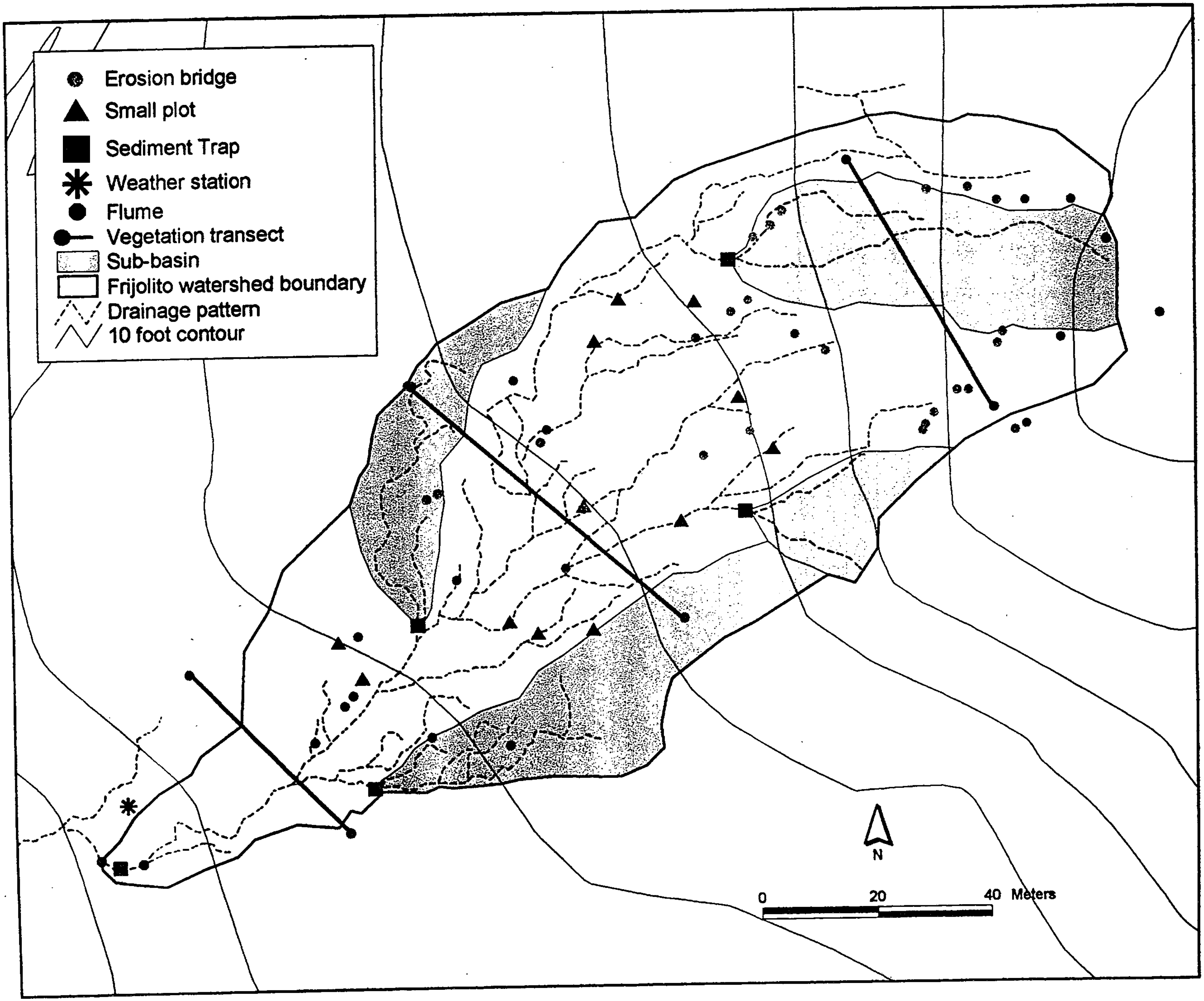
*only largest 81 juniper individuals and piñon >1.5 cm DRC are shown


Pinyon
Pinyon seedling
Juniper
Juniper seedling
Frijolito watershed boundary
Drainage pattern
10 foot contour
N
0
20
40 Meters

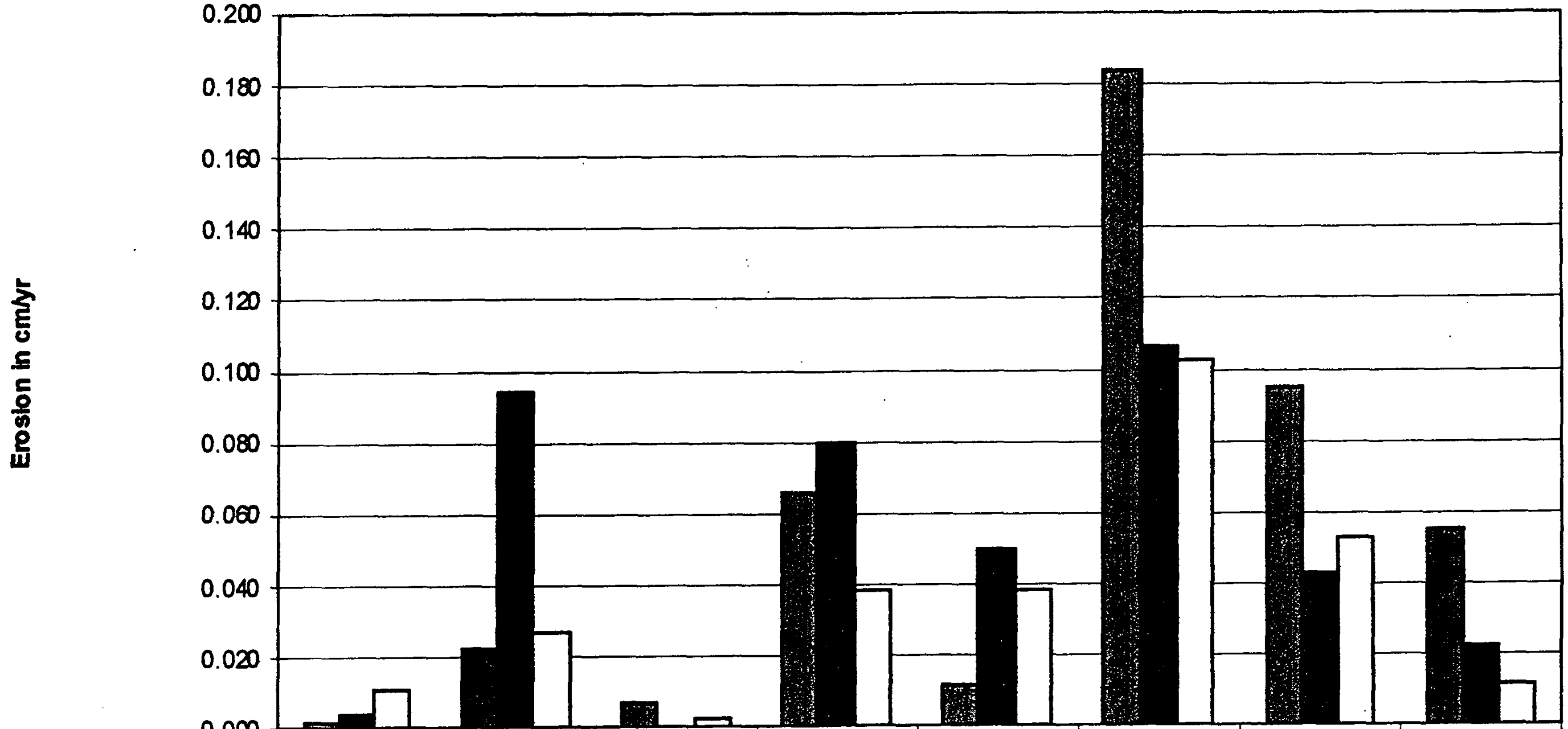


file located on HP Kayak XU
d:\david\fwhs\pinon.xls
8/29/2002

* sample includes all pinon trees in the FWHS area. Total = 1336. Total pinon trees cored and cross-dated to establish dia. at base to age relationship = 38 large trees and 9 seedlings.

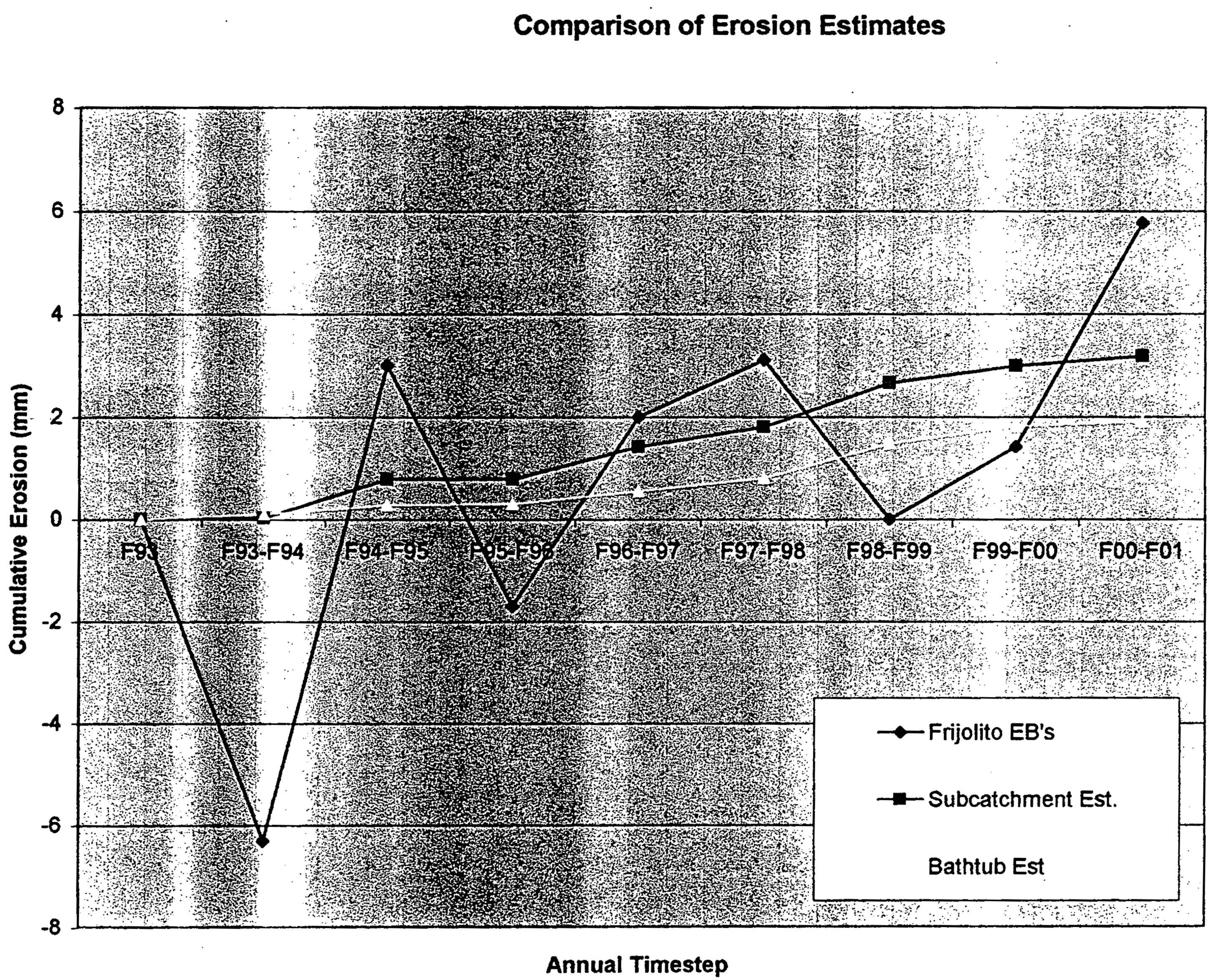

Erosion bridge
Small plot
Sediment Trap
Weather station
Flume
Vegetation transect
Sub-basin
Frijolito watershed boundary
Drainage pattern
10 foot contour
N
0
20
40 Meters

Comparison of Frijolito Erosion Estimates
Small Plots, Subcatchments, Bathtub & Lower Flume



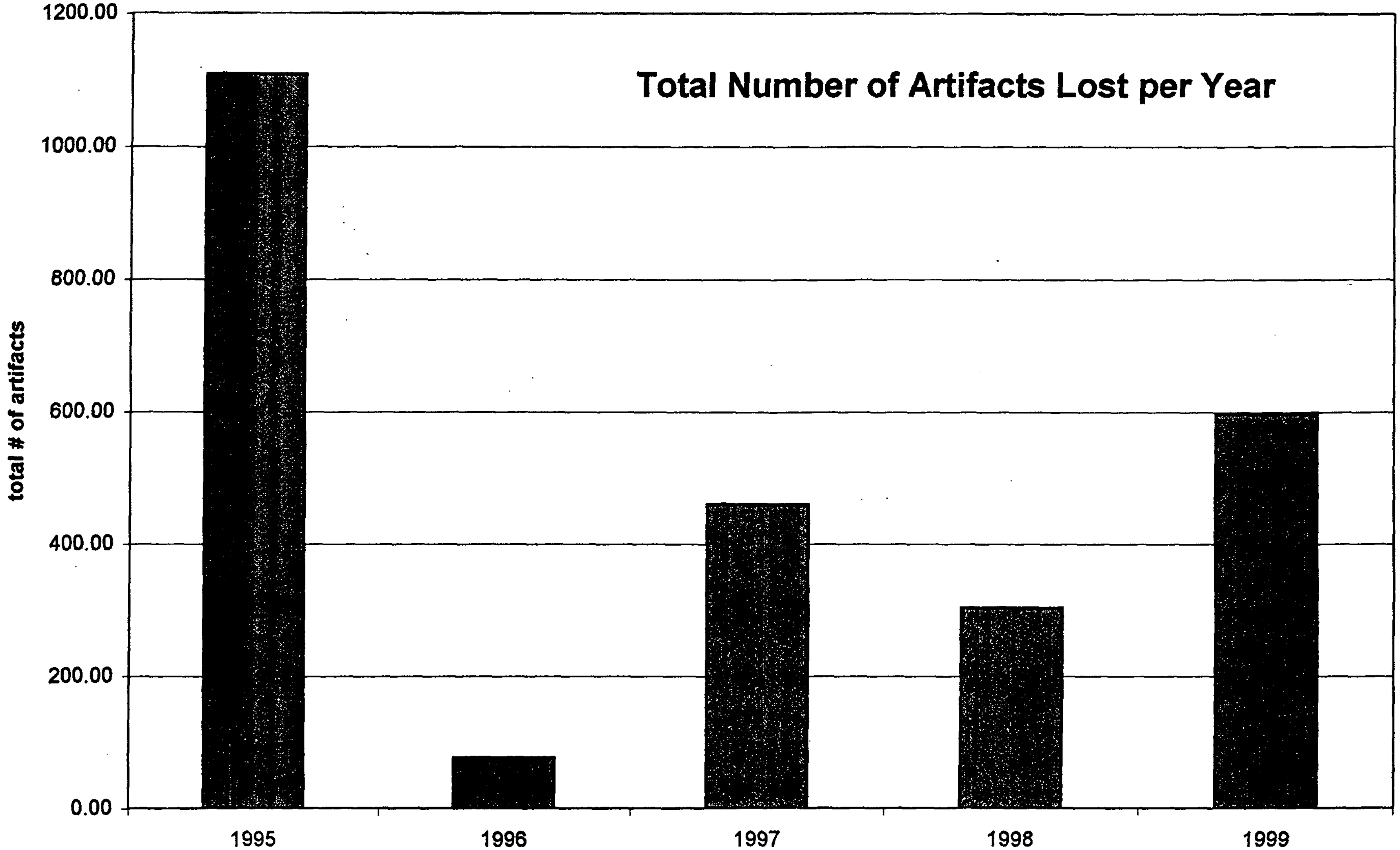
	1994	1995	1996	1997	1998	1999	2000	2001
All SP's included	0.002	0.022	0.007	0.066	0.011	0.184	0.095	0.055
Subcatchment Avg	0.004	0.094	0.000	0.080	0.050	0.107	0.043	0.022
BATH plus LF	0.011	0.027	0.003	0.039	0.038	0.103	0.053	0.012

Year



Comparison of Erosion Estimates
Cumulative Erosion (mm)
8
6
4
2
0
-2
-4
-6
-8
F93
F93-F94
F94-F95
F95-F96
F96-F97
F97-F98
F98-F99
F99-F00
F00-F01
Annual Timestep
Frijolito EB's
Subcatchment Est.
Bathtub Est

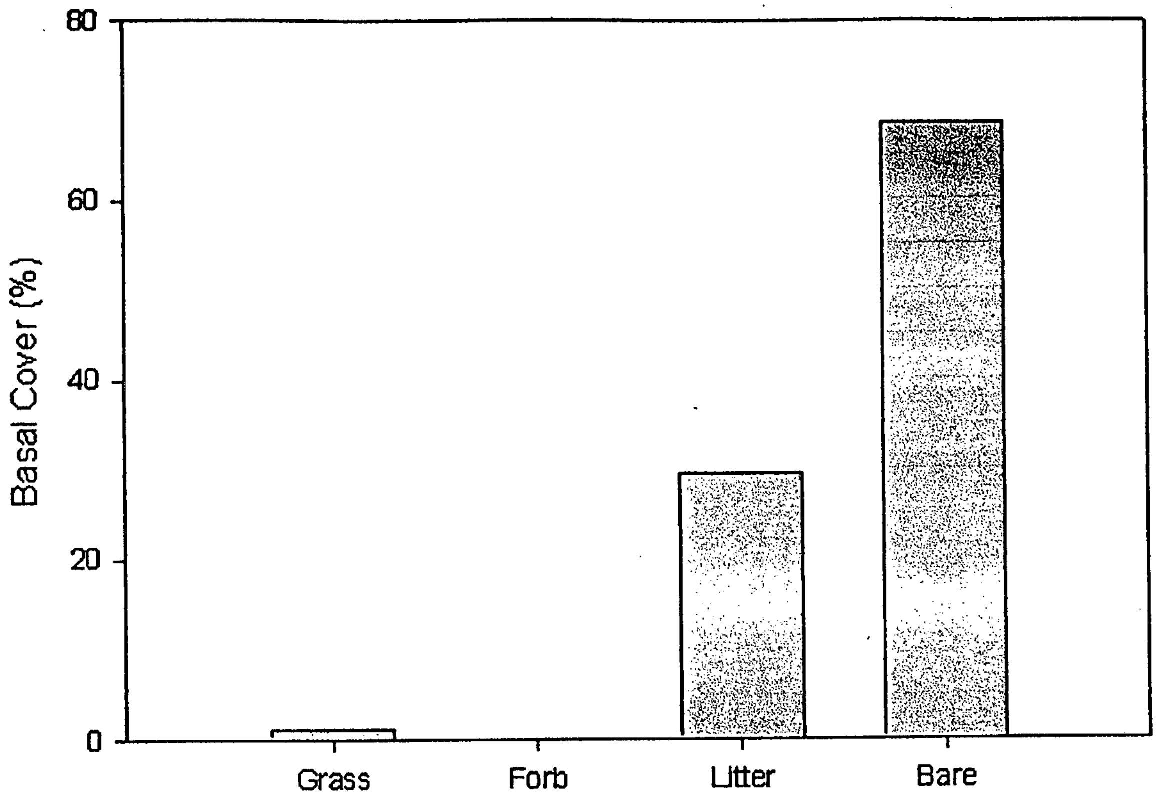
30



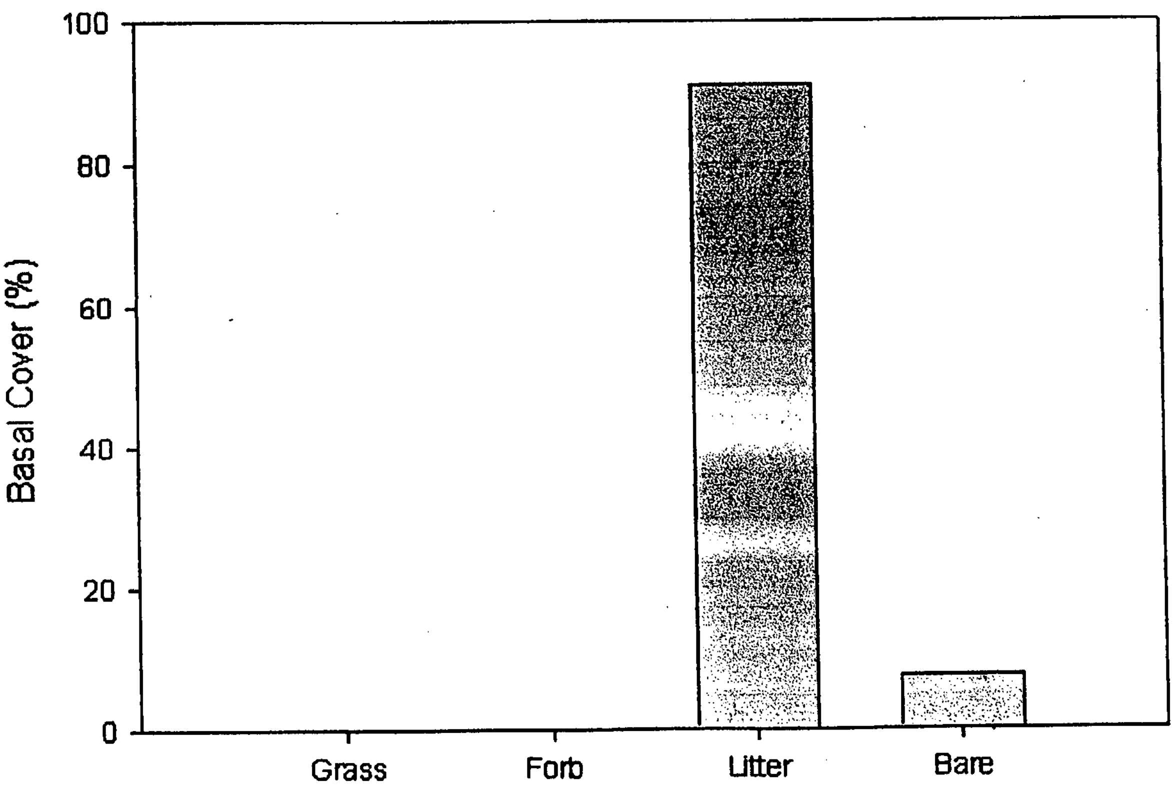
Total Number of Artifacts Lost per Year
total # of artifacts
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1995
1996
1997
1998
1999

31

2001 Intercanopy

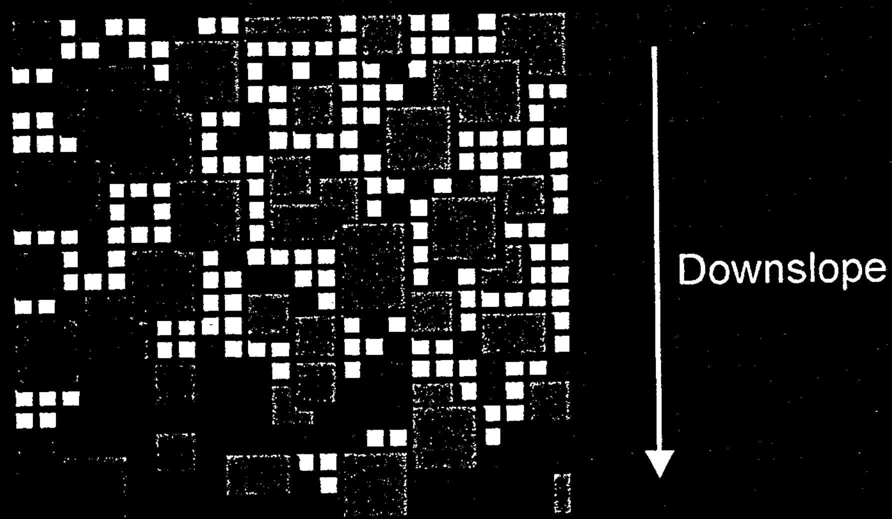


2001 Under Canopy




Canopy patch with storage.
Intercanopy patch with storage.
Intercanopy patch with no storage.

Low connectivity

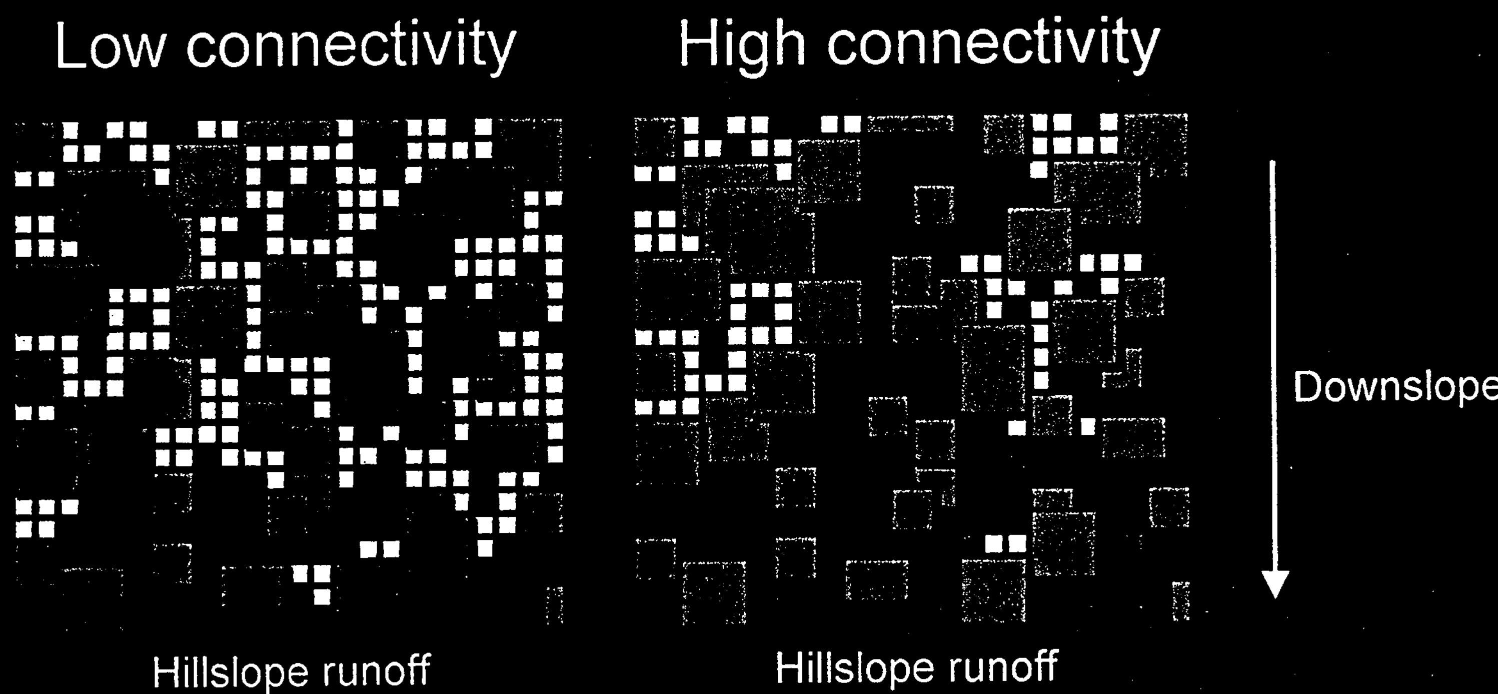


Canopy patch with storage.

Intercanopy patch with storage.

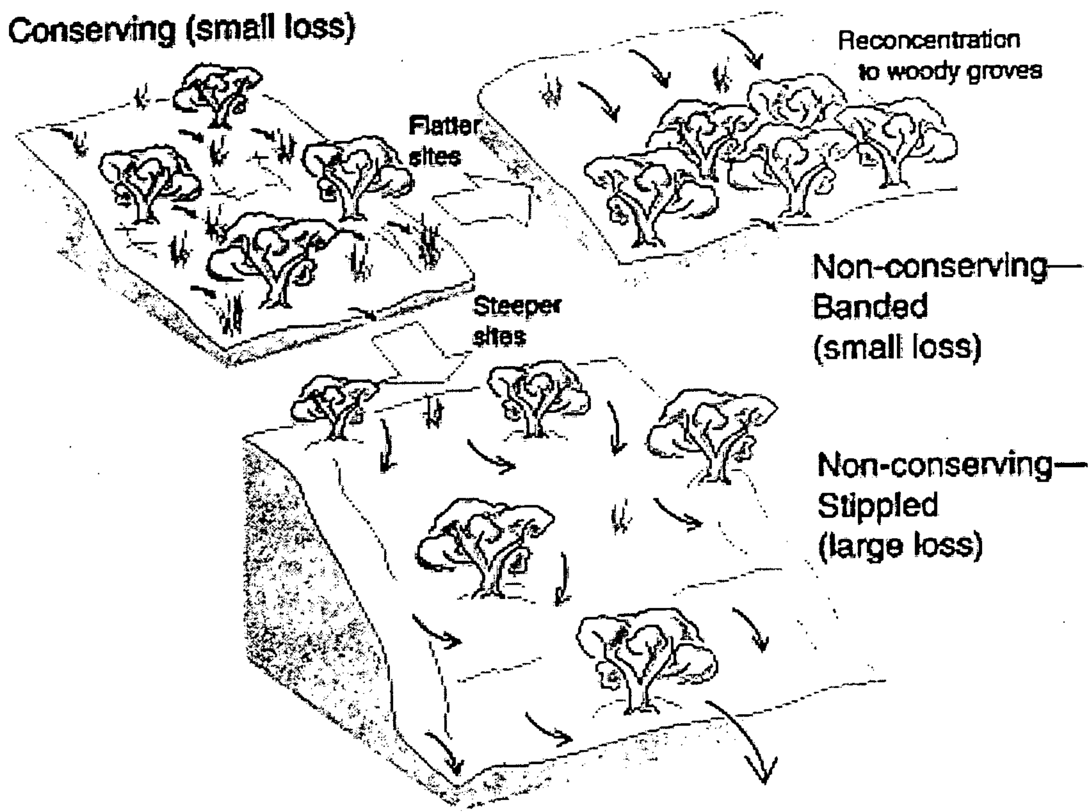
- Intercanopy patch with no storage: no contribution to hillslope runoff.

Intercanopy patch with no storage: contributes to hillslope runoff.

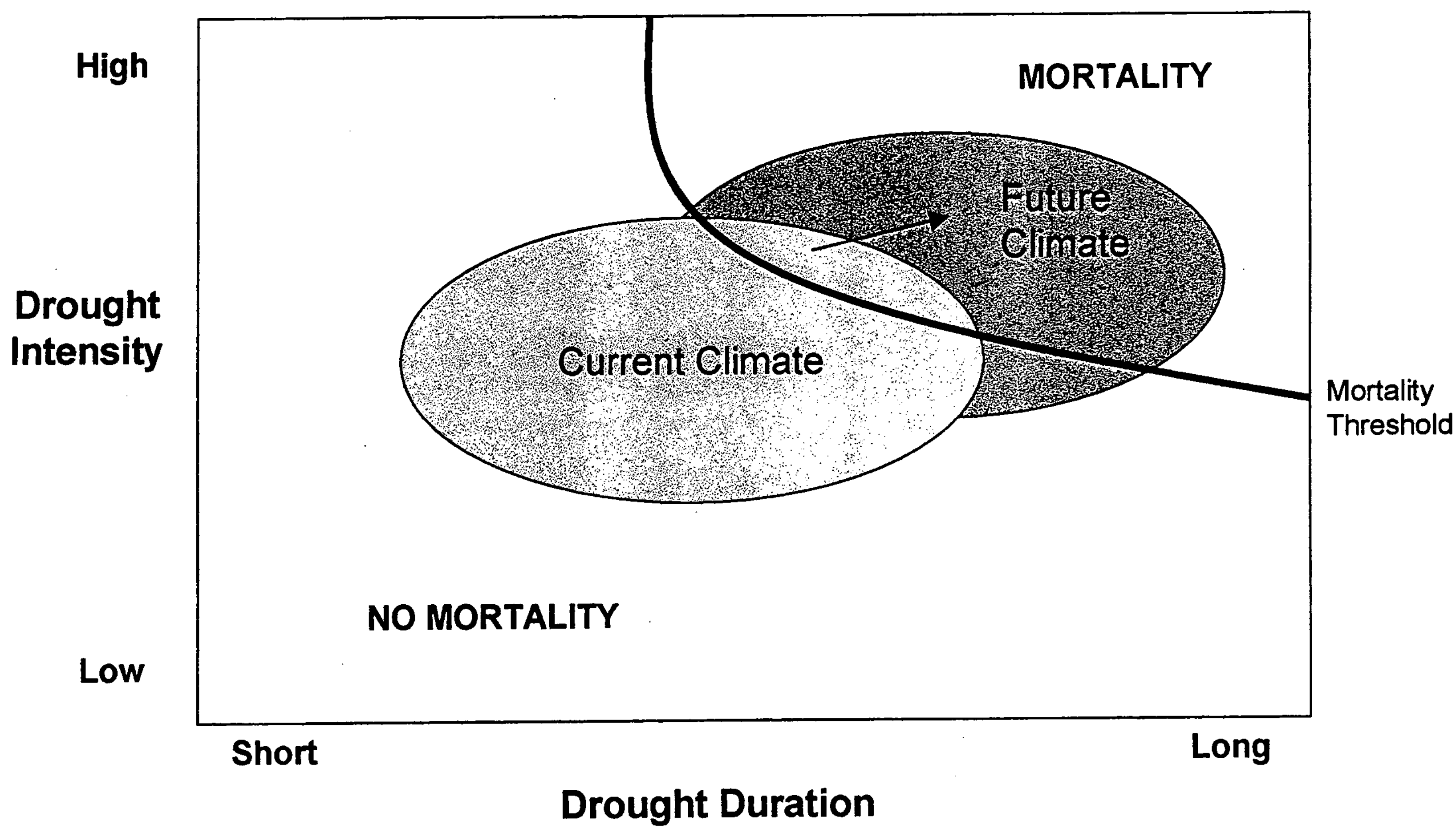


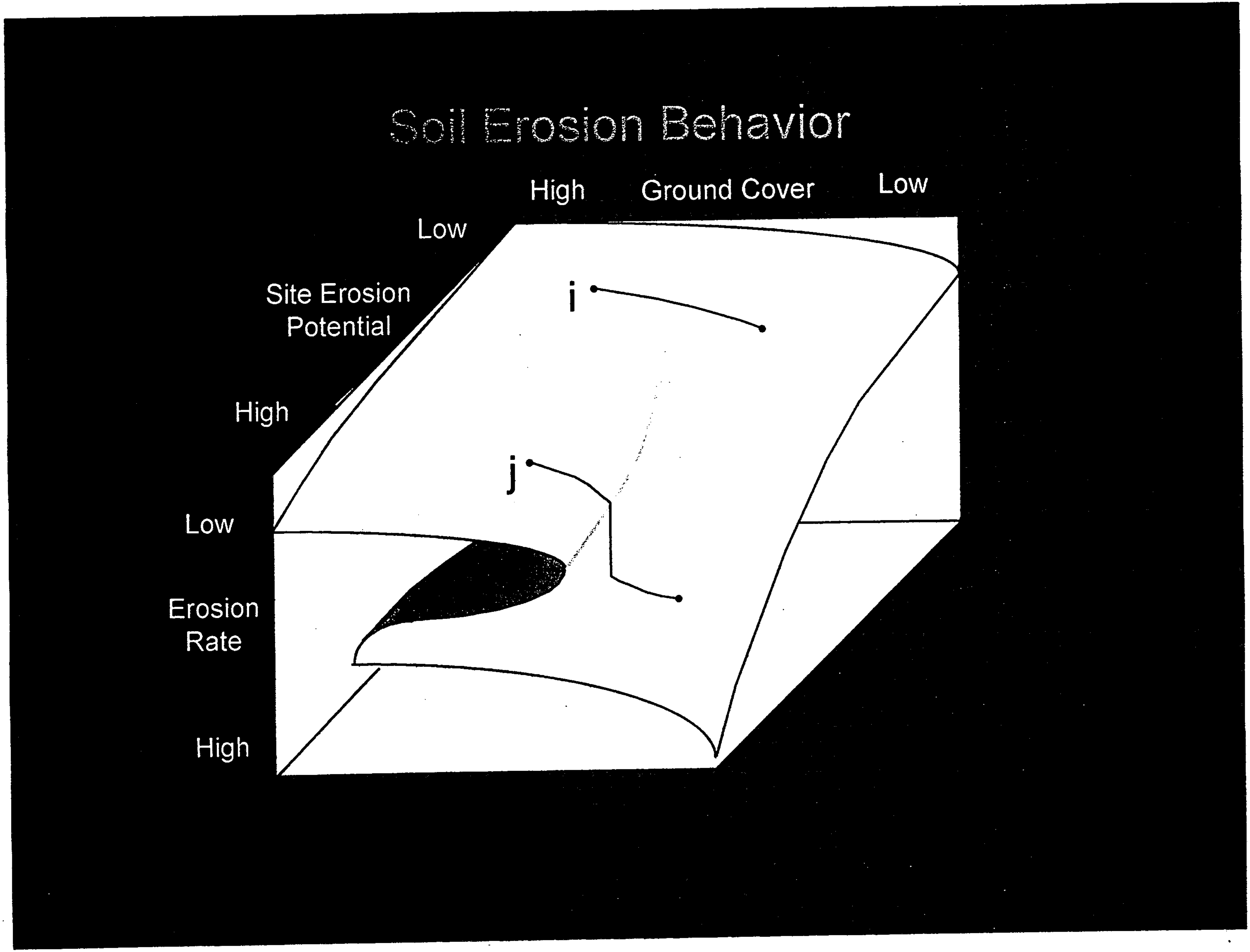
	A	B
Canopy patch with storage.	47%	47%
Intercanopy patch with storage.	11%	9%
Intercanopy patch with no storage: no contribution to hillslope runoff.	31%	12%
Intercanopy patch with no storage: contributes to hillslope runoff.	11%	32%

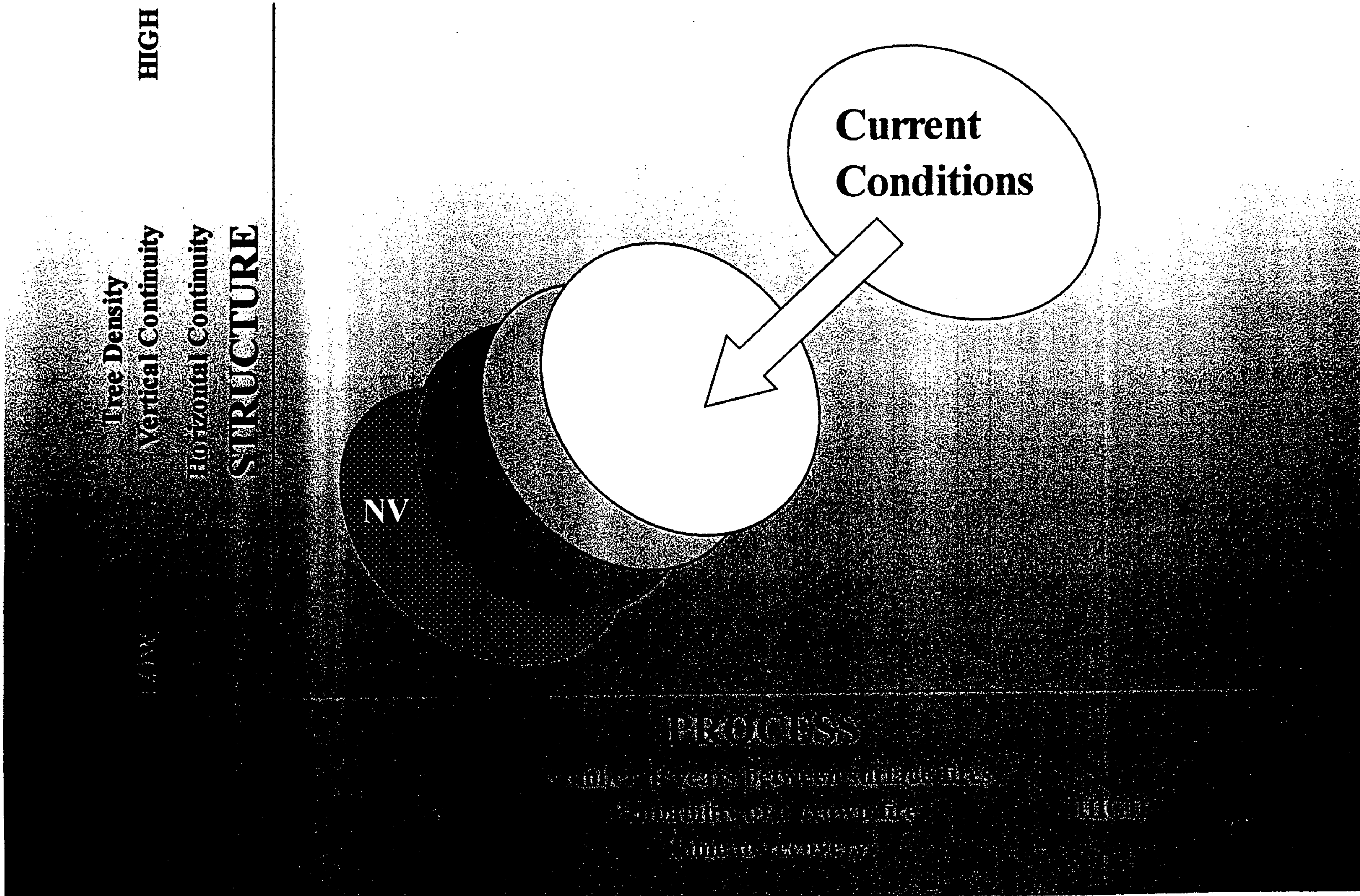
Davenport et al. 1998



Wilcox et al. 2003


High
Drought Intensity
Low
Short
Long
Drought Duration
MORTALITY
NO MORTALITY
Future Climate
Current Climate
Mortality Threshold


Soil Erosion Behavior
High
Ground Cover
Low
Low
Site Erosion
Potential
High
i
j
Low
Erosion
Rate
High


HIGH
Tree Density
Vertical Continuity
Horizontal Continuity
STRUCTURE
Current
Conditions
NV
PROCESS

**Pinyon-juniper woodland restoration studies:
a watershed scale, multi-disciplinary approach
Bandelier National Monument, New Mexico**

Brian F. Jacobs[1+], Richard G. Gatewood[2], Brian K. Hastings[3], Christian Julius[4], Paula K. Kleintjes[5], Stephen M. Fettig[1], and Craig D. Allen[6]*

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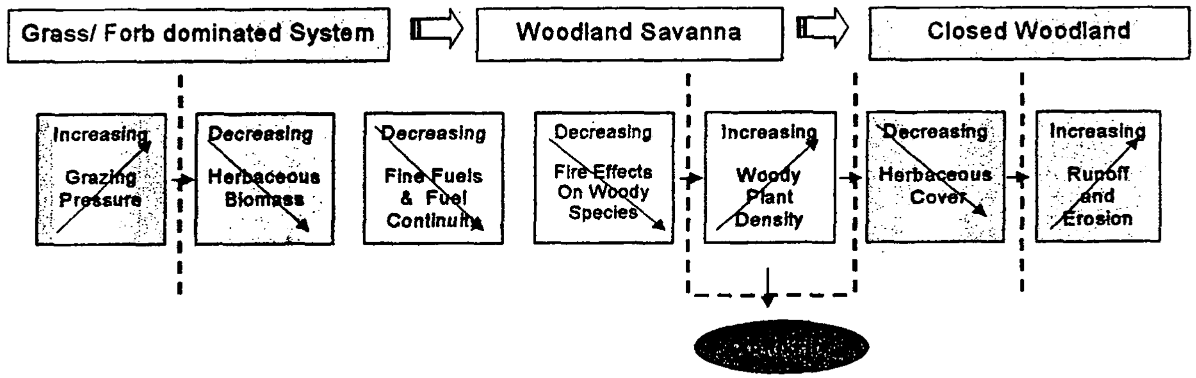
[3] *Earth Resources Department, Colorado State University, Fort Collins, CO 80523*
[4] *Rheinischen Friedrich-Wilhelms University, Bonn, Germany*
[5] *Biology Department, University of Wisconsin, Eau Claire, WI 54702*
[6] *USGS-BRD, Bandelier National Monument, Los Alamos, NM 87544*
[*] *Presenting Author*
[+] *Corresponding Author (brian_jacobs@nps.gov)*

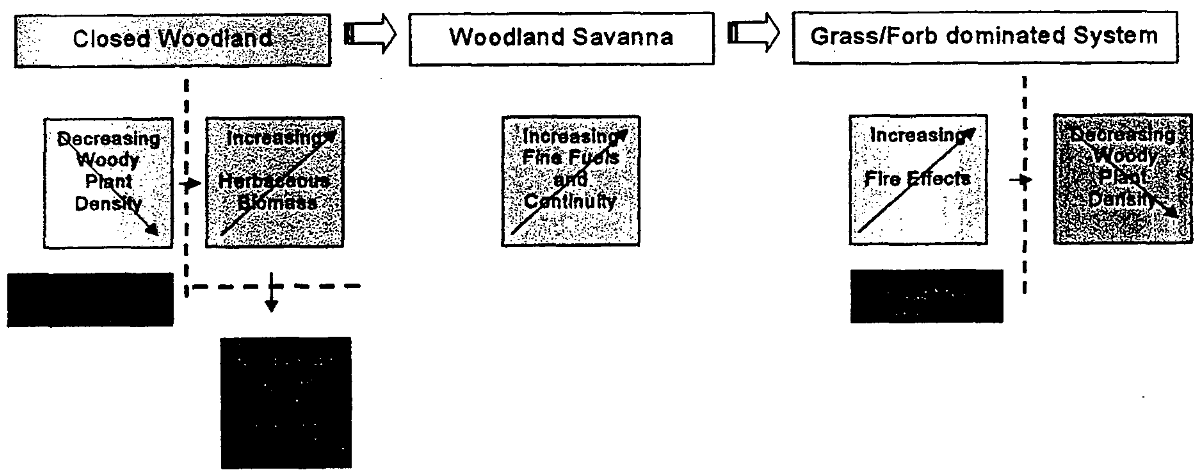
Restoration studies in *Pinus edulis* and *Juniperus monosperma* woodlands at Bandelier National Monument were conducted in semi-closed stands (~35-40% canopy cover) of high density (>1000 stems/ha), young aged (~75% <150 years) trees. Suppressed understory vegetation (<10% total cover), combined with fire history, age-class, and historical evidence, suggest pinyon-juniper woodland effectively displaced Ponderosa Pine savanna, coincident with historic grazing, loss of fire regime, and drought induced mortality of the pine component. In degraded woodlands, exposed soils predominate (>50% cover between trees) and summer monsoons generate unsustainable sediment loss (>2,000 kg/ha/season) which threatens embedded cultural resources. In 1997, mechanical thinning and slash mulching treatments (reducing tree cover to ~10%) were applied at a functional ecosystem scale of paired, 40 ha watersheds. Response to treatment was quantified using both biotic (i.e. plant cover, diversity, and biomass; richness and abundance of arthropods, birds, and butterflies; and ungulate utilization) and abiotic measures (i.e. exposed soil cover; sediment production; soil moisture; and soil micro-topography). At five years post-treatment, understory plant cover increased to >30% with associated decreases in sediment production (<100kg/ha/season) relative to control. Butterfly abundance and richness increased significantly in treated areas, while bird populations remained stable. Prescribed fire treatment is also being evaluated for long term maintenance of mechanically restored savanna structure and function. While response to mechanical restoration treatment is promising, practical management issues persist including implementation at scale (i.e. thousands of hectares) and on lands designated as both wilderness and cultural landscape.

Conceptual Relationships

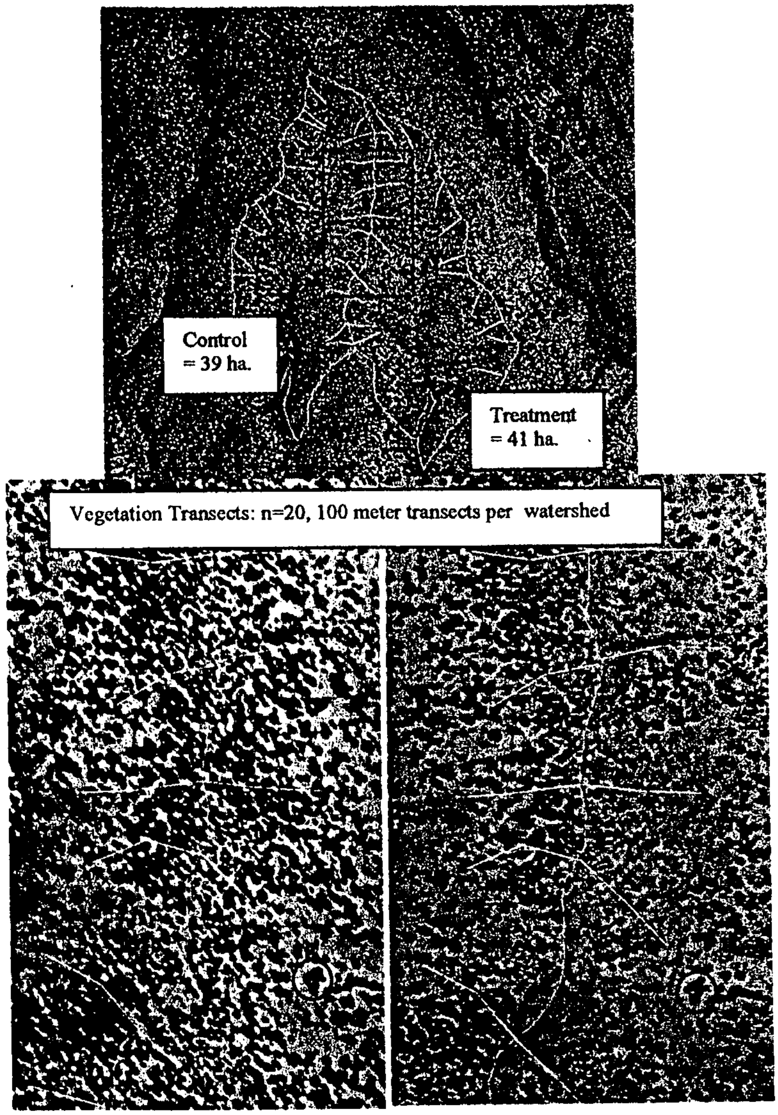
DEGRADATION



RESTORATION



Aerial View of Watershed Restoration Study Area:
Pre- and Post- Treatment Tree Density

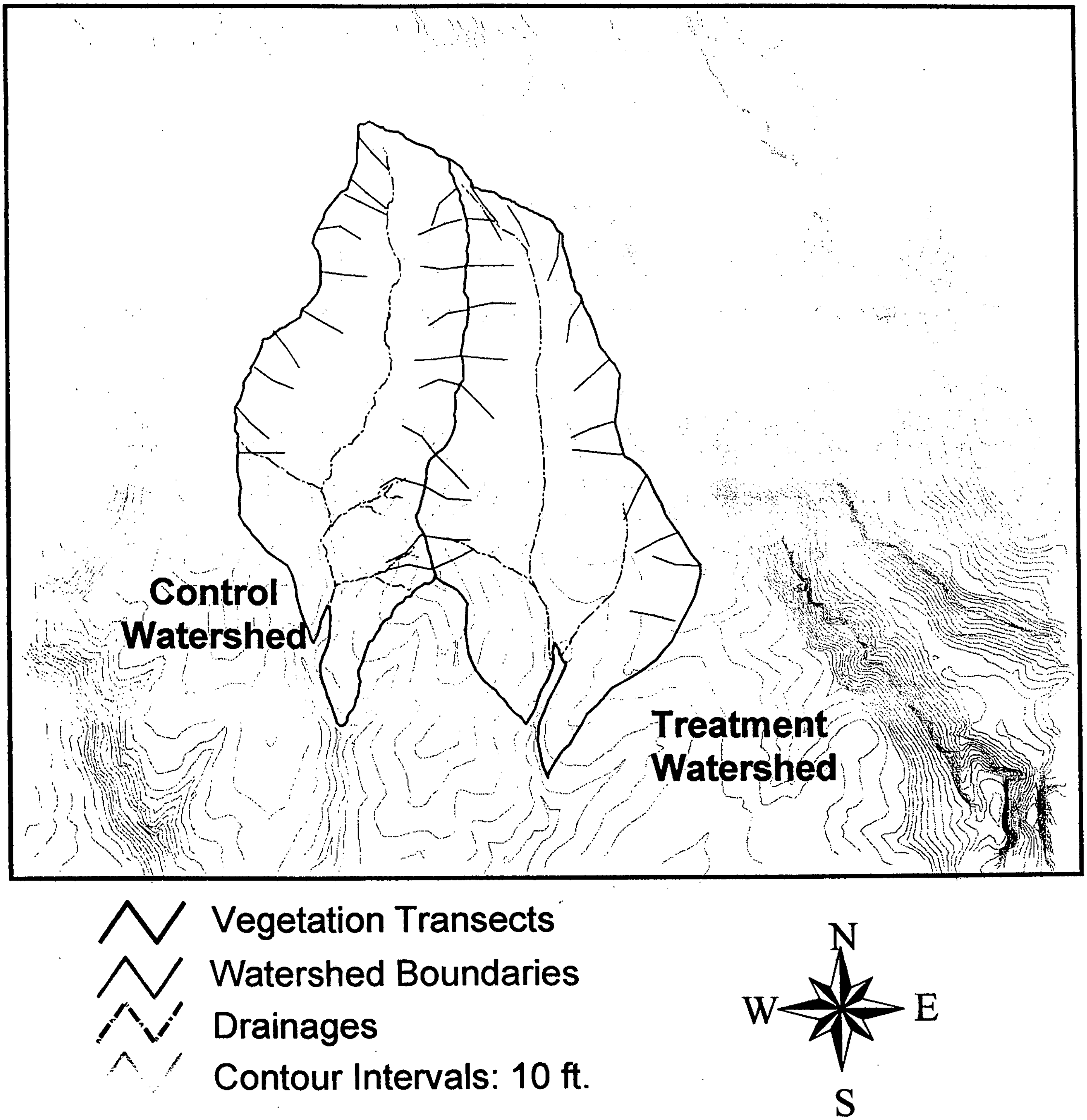


Pre-Treatment (Fall 1991)

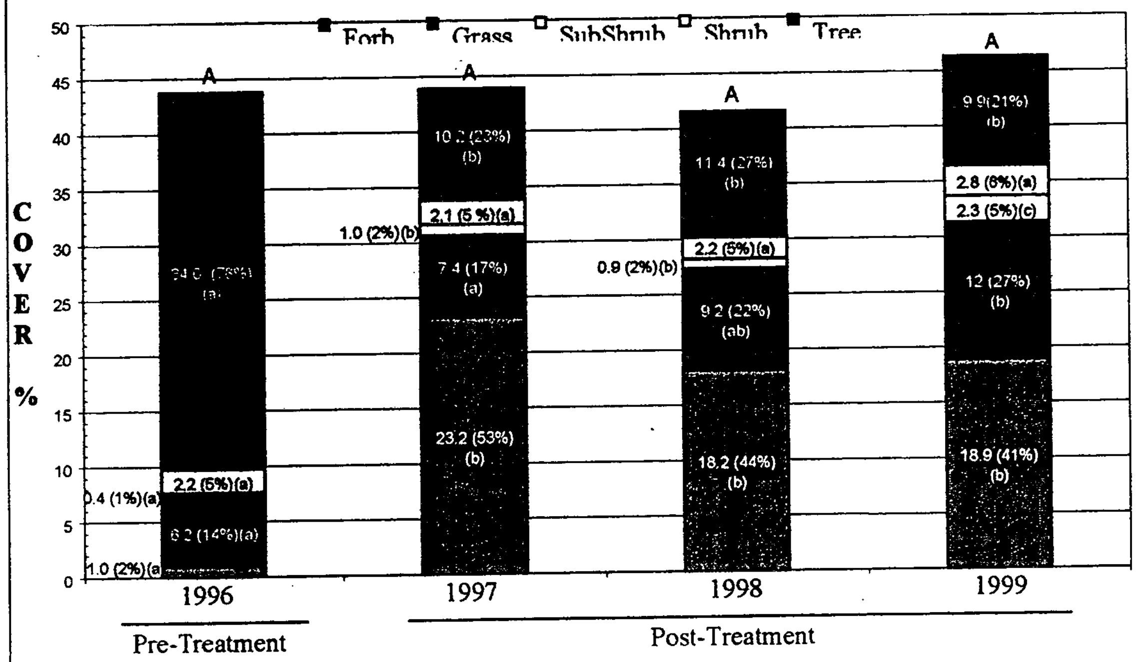
Post-Treatment (Summer 2000)

Color aerial view of the treatment and control watershed areas delineating perimeter (pink) and showing vegetation transects (blue). Tree densities were reduced by 75% using selective cutting of smaller diameter individuals (<6-8"dbh).

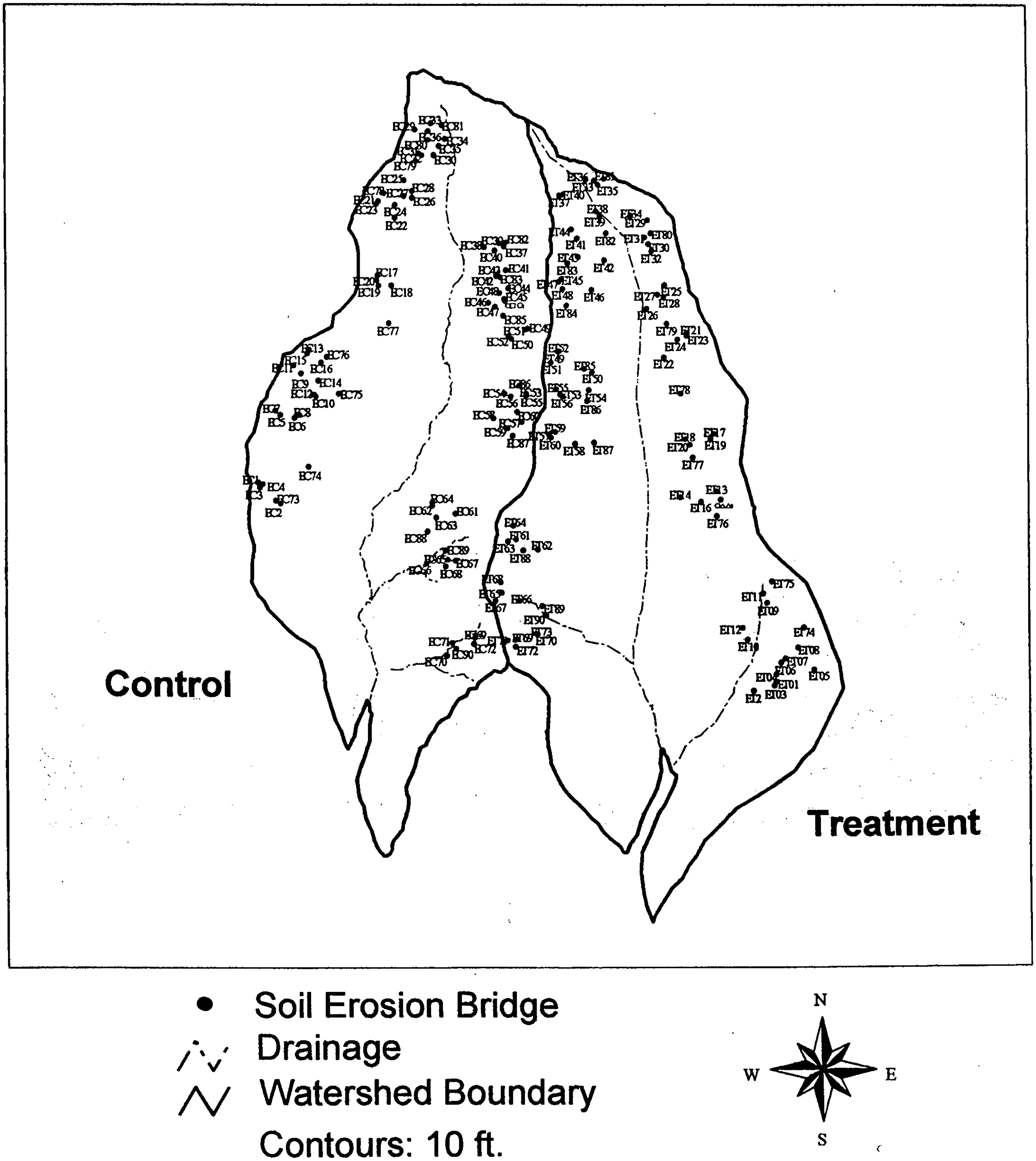
GPS Locations of 100-m Vegetation Transects

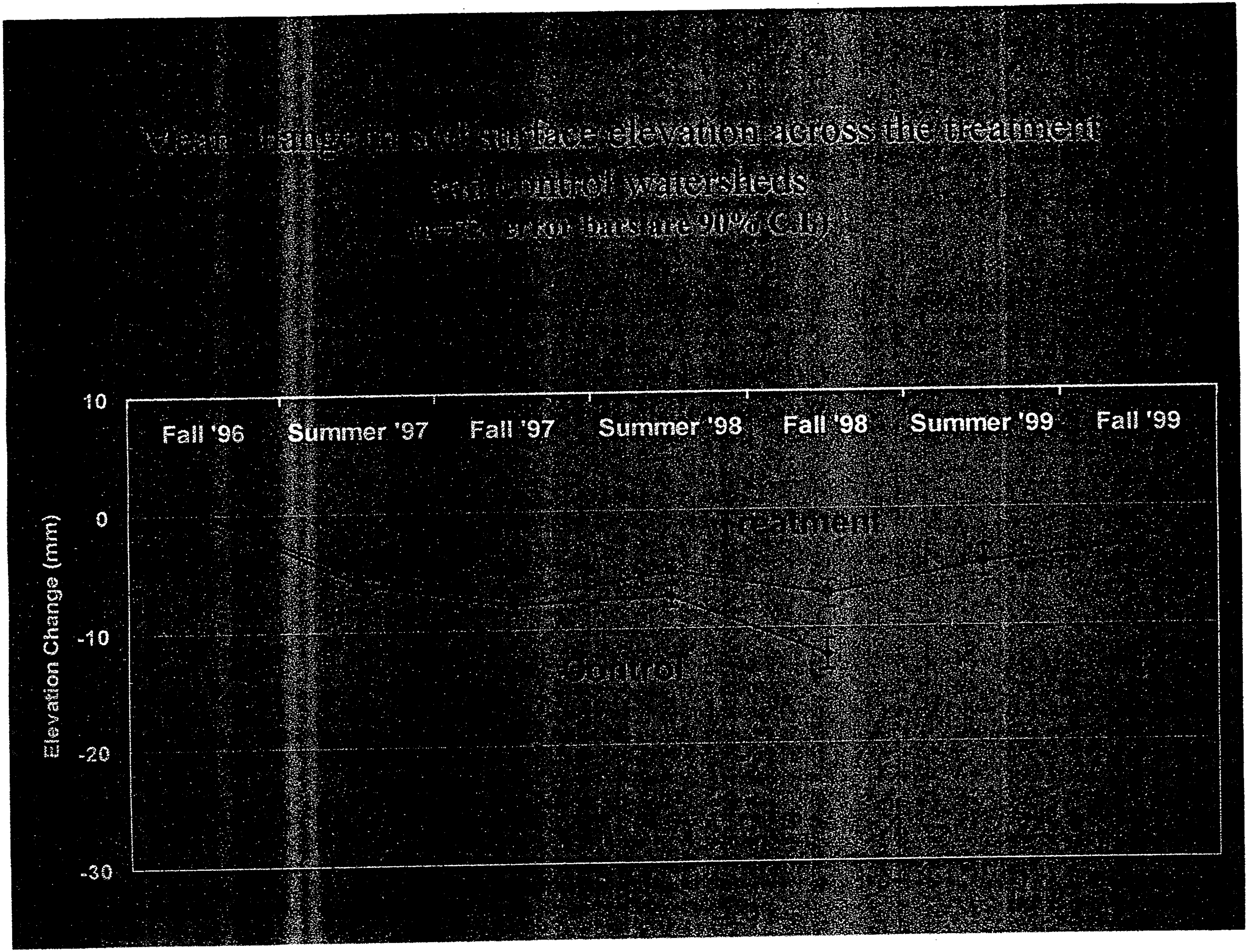


Cumulative Plant Canopy Cover within the Treatment Watershed

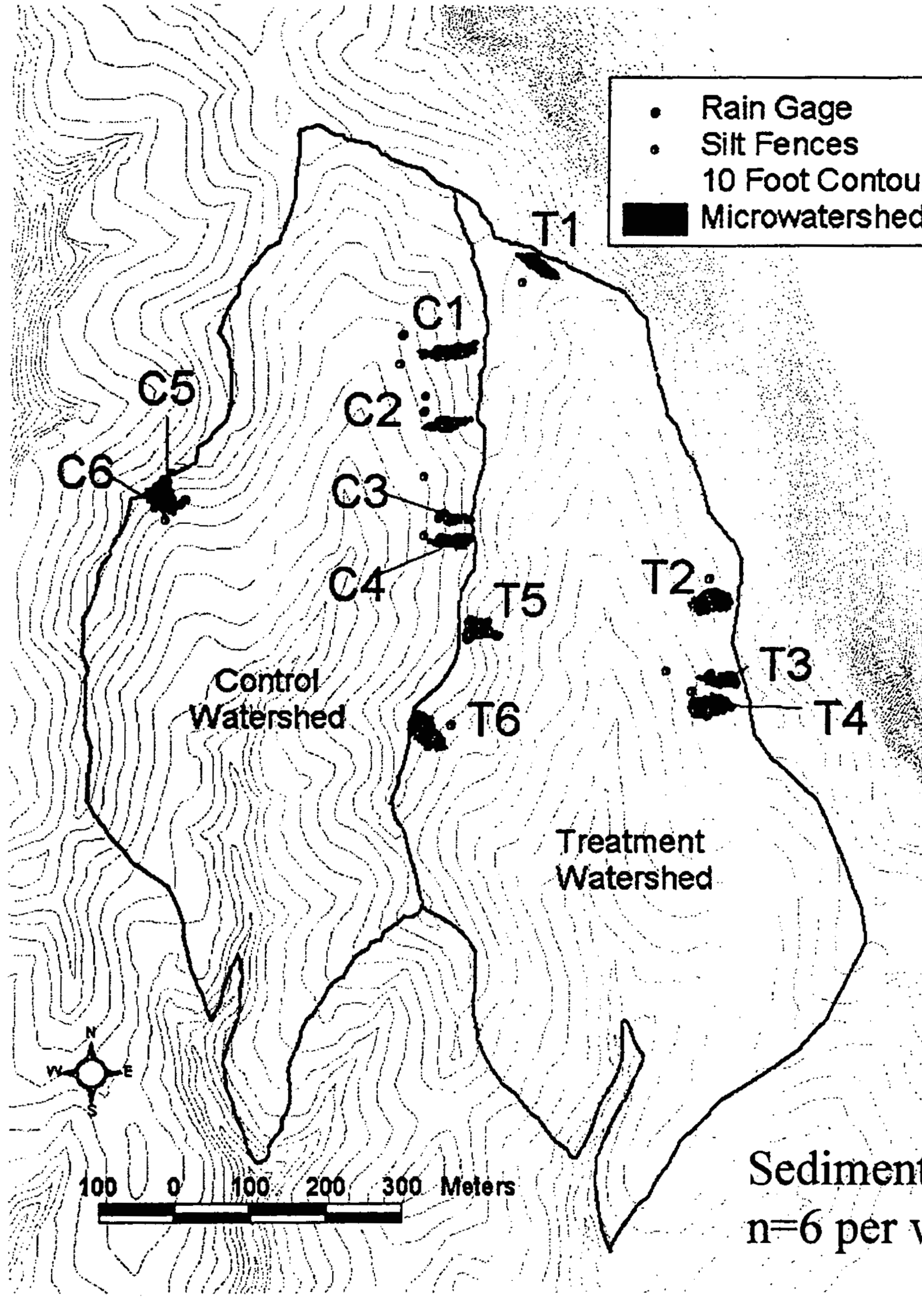


GPS Soil Erosion Bridge Locations in the Control and Treatment Watersheds



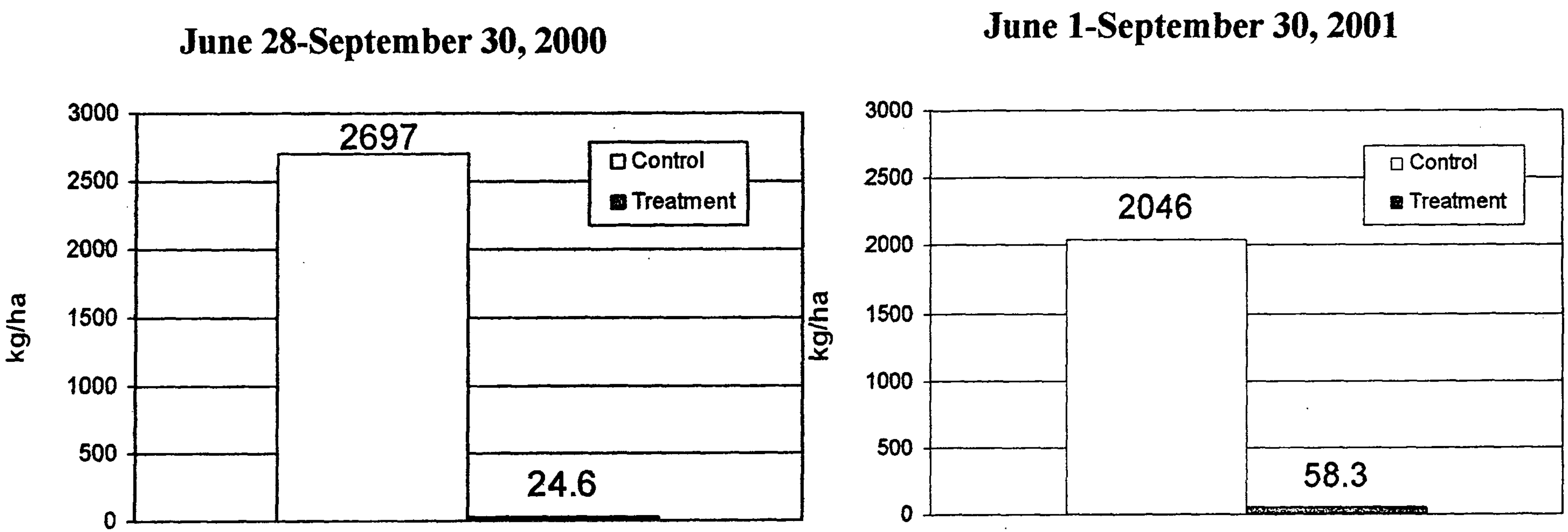

surface elevation across the treament
watersheds
bars are 90% C.I.)
10
0
-10
-20
-30
Elevation Change (mm)
Fall '96
Summer '97
Fall '97
Summer '98
Fall '98
Summer '99
Fall '99
Treatment
Control

Location of (0.1 ha.) Sediment Dam Microwatersheds



Sediment Dams;
n=6 per watershed

Sediment Production in Treatment and Control Watershed Restoration Areas



Sediment production calculated per event for n=6, 0.1 ha. sediment dams per watershed

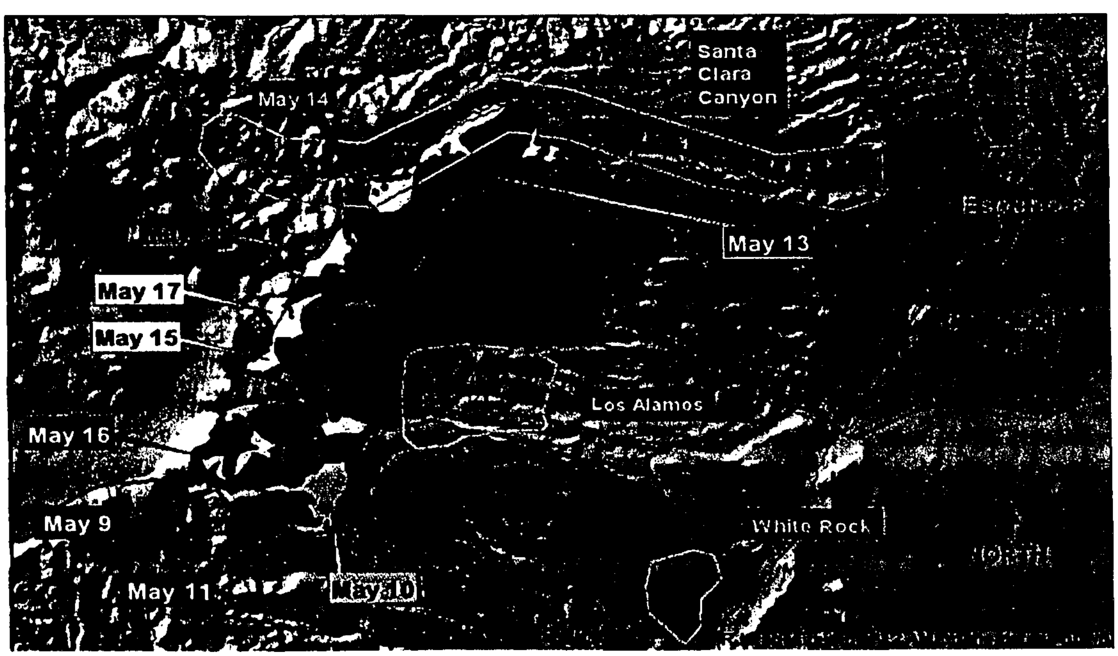
Cerro Grande Fire Overview Cathy Wilson, LANL, cjw@lanl.gov

Fire Update
June 8, 2000
8:00 AM

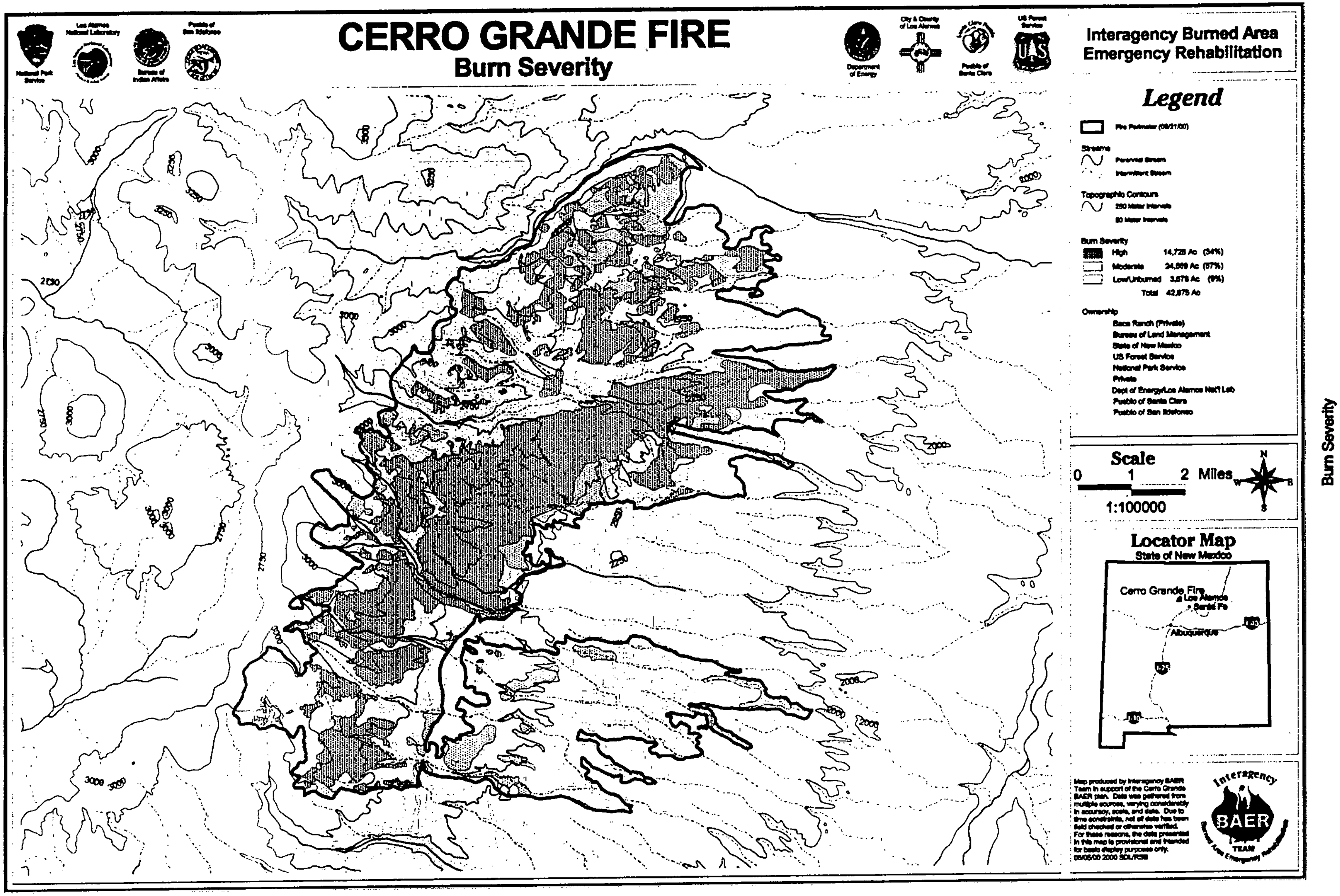
Website: www.fs.fed.us/r3/sfe/fire/cerrogrande

Size:	**Total fire area estimated at 47,650**
Started:	**Declared a wildfire at 1:00 p.m. on May 5, 2000**
Cause:	**Escaped prescribed burn from Bandelier National Monument**
Location:	**Approximately 8 miles southwest of Espanola, NM**
Containment:	**100% As of 1800 HRS on 6/6/00**
Fire Personnel:	**40 crews, 3 helicopters, 7 engines, 1 dozers, 4 water tender, 1213 total personnel**

Pinyon/Juniper stands at 6500' on east side running up to Ponderosa pines at 7500-8000'. The topography of the fire area is primarily mesas bisected by steep, rugged canyons.



Burn progression map EES GIS lab


CERRO GRANDE FIRE
Burn Severity
Interagency Burned Area Emergency Rehabilitation
Legend
Fire Perimeter
Streams
Perennial Stream
Intermittent Stream
Topographic Contours
250 Meter Intervals
50 Meter Intervals
Burn Severity
High 14,728 Ac (34%)
Moderate 24,569 Ac (57%)
Low/Unburned 3,578 Ac (9%)
Total 42,875 Ac
Ownership
Baca Ranch (Private)
Bureau of Land Management
State of New Mexico
US Forest Service
National Park Service
Private
Dept of Energy/Los Alamos Nat'l Lab
Pueblo of Santa Clara
Pueblo of San Ildefonso
Scale
0 1 2 Miles
1:100000
Locator Map
State of New Mexico
Cerro Grande Fire
Los Alamos
Santa Fe
Albuquerque
Map produced by Interagency BAER Team in support of the Cerro Grande BAER plan. Data was gathered from multiple sources, varying considerably in accuracy, scale, and date. Due to time constraints, not all data has been field checked or otherwise verified. For these reasons, the data presented in this map is provisional and intended for basic display purposes only.
Interagency BAER Team
Burn Severity

52

Bandelier National Monument
Cerro Grande Prescribed Fire Investigation Report

The Cerro Grande Prescribed Fire Investigation Report was delivered to the Secretary of Interior, Bruce Babbitt on May 18, 2000.*

EXECUTIVE SUMMARY

On May 4, 2000, in the late evening, fire personnel at Bandelier National Monument, National Park Service, ignited a prescribed fire with an approved plan. Firing and line control occurred during the early morning of May 5. Sporadic wind changes caused some spotting within the unit and a slopover on the upper east fireline. Because of the slopover the prescribed fire was declared a wildfire at 1300 hours on May 5. The fire was contained on May 6 and early on May 7; however, at approximately 1100 hours on May 7 winds increased significantly from the west and resulted in major fire activity and ultimately caused the fire to move out of control to the east on the Santa Fe National Forest. The fire was taken over by a Type 1 team on May 8.

In its most extreme state on May 10, the Cerro Grande Prescribed Fire was carried by very high winds, with embers blowing a mile or more across the fire lines to the north, south, and east, entering Los Alamos Canyon towards Los Alamos, New Mexico. The towns of Los Alamos and White Rock were in the fire's path and more than 18,000 residents were evacuated. By the end of the day on May 10, the fire had burned 18,000 acres, destroying 235 homes, and damaging many other structures. The fire also spread towards the Los Alamos National Laboratory, and although fires spotted onto the facility's lands, all major structures were secured and no releases of radiation occurred. The fire also burned other private lands and portions of San Ildefonso Pueblo and Santa Clara Pueblo. As of May 17 the fire was uncontrolled and approaching over 45,000 acres.

Secretary of the Interior Bruce Babbitt formed an interagency Fire Investigation Team on May 11 to examine events and circumstances from the beginning of planning the prescribed fire until the fire was turned over to a Type 1 Incident Management Team on May 8. Furthermore, Secretary Babbitt and Secretary of Agriculture Dan Glickman suspended all federal prescribed burning for 30 days, or longer, west of the 100^{th} meridian.

The team based its findings and recommendations on interviews with key personnel and other people who witnessed the fire; documents associated with approval and implementation of the prescribed fire; on-site observations; and technical analyses of factors including weather, climate, and fire behavior.

The Fire Investigation Team concludes that federal personnel failed to properly plan and implement the Upper Frijoles Prescribed Fire, which became known as the Cerro Grande Prescribed Fire. Throughout the planning and implementation, critical mistakes were made. Government officials failed:

- To utilize the correct National Park Service complexity analysis process.
- To provide substantive review of the prescribed fire plan before it was approved.
- To evaluate conditions adjacent to the prescribed fire boundary with regards to fire behavior, fuel conditions, and public safety in the event the fire crossed the planning boundaries.
- To complete and document the onsite review of critical conditions identified in the prescribed fire plan prior to ignition.
- To provide adequate contingency resources to successfully suppress the fire.
- To provide any wind predictions in the 3-5 day forecast for the periods of May 7 to May 9.
- To follow safety policies for firefighters and the public.

The investigation team believes that the Federal Wildland Fire Policy is sound; however, the success of the policy depends upon strict adherence to the implementation actions throughout every agency and at every level for it to be effective.

The Cerro Grande Prescribed Fire Investigation Report will be provided to an Independent Review Board, which will review the team's findings and recommendations.

LANL Fire Impacts

Cerro Grande Rehabilitation Project – Fire mitigation erosion control & Decontamination Decommissioning

Protect Laboratory facilities and infrastructure

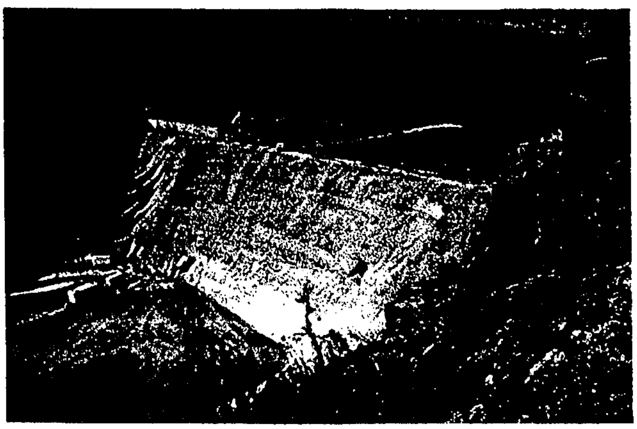
- Based on recommendations by the U.S. Army Corps of Engineers, Laboratory crews are preparing to dig weirs (large, relatively shallow basins that will serve as sediment retention structures) in lower Pajarito and lower Los Alamos Canyons. It is also likely that weirs will be placed in lower Pueblo and lower Mortandad Canyons. The purpose of the weirs is to trap sediment that may move down the canyons in the event of a flood.
- Crews worked Saturday and Sunday to disassemble the cooling tower at the Omega West Reactor at Technical Area 2 in Los Alamos Canyon. The tower is fully disassembled and the tower materials are being removed from the site today.
- Johnson Controls Northern New Mexico crews completed the placement of jersey bouncer concrete barriers and sandbags alongside the channel at TA-41.
- Today, the crew of approximately 100 voluntary Laboratory workers is conducting burned area rehabilitation, primarily raking and mulching, in Two Mile Canyon.

Minimize movement of contamination off Laboratory property

- Crews continued today to remove contaminated sediment from Los Alamos Canyon. The sediment is being removed to help minimize the overall potential for movement of contamination off Laboratory property in the event of a severe flood. The project started on Friday and continued over the weekend. Sediment is being removed from three separate sections of the stream bank in the canyon. Crews finished removing the sediment from the first section this morning. Lab officials expect the entire removal to be complete on Wednesday or Thursday. The removed sediment is being taken to the Laboratory's waste disposal area located at TA-54.
- Laboratory officials have established a schedule (see below) for the placement of erosion control efforts, called Best Management Practices, around known contamination sites, called potential release sites. BMPs include the placing of protective jute matting, rock gabions, log-silt barriers and straw wattles, cylindrical nylon mesh tubes filled with straw.
- Joint teams from the New Mexico Environment Department and the Laboratory have completed assessments in the field of which PRSs need BMPs and they agree that 91 sites need BMPs.
- To date, 14 of the 91 PRSs have received BMPs.

Projected BMP Implementation Schedule
The following table shows the number of PRSs, their locations by technical area, start and completion dates for the implementation of BMPs and the number completed:

Flooding



Flood control structure above TA-18.

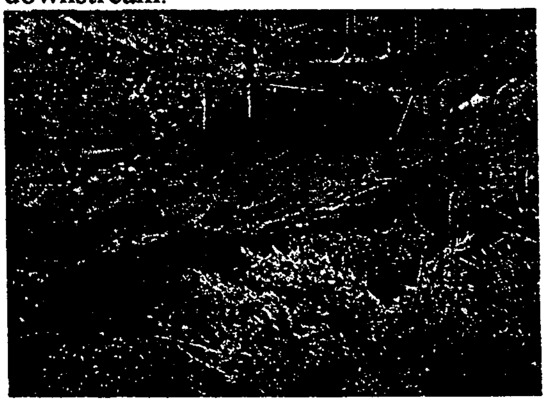
Erosion, sedimentation.

Los Alamos Reservoir filled with 25 acre-ft of sediment in 2 year period after fire.

Contaminant migration.

Field investigations and predictive modeling are being undertaken to understand potential migration of contaminants by surface and subsurface pathways.

Post-fire flood in upper Pajarito Canyon transporting ash, sediment and debris downstream.



HEC-6 cross sections overlain on LIDAR topographic data to predict post fire transport.

Emergency Rehabilitation Team (ERT)

A program to address potential impacts of increased runoff resulting from the Cerro Grande fire and look at potential long-term issues arising from the fire.

ERT Actions:

Sampling/Monitoring

- Preliminary results from June 2 rainfall (7/21 press release)
- Table of June 2 preliminary data
- Map of automated sampling stations
- Institutional Sampling and Monitoring Plan (as of 10/19, pdf 253 Kb)

- Plan/Summary (as of 6/30, MSW DOC 35 Kb)
- ERT Project Plan (7/7)
- Schematic of ongoing actions (coming soon)
- Orientation: Photo of area canyons (7/14)
- Notice of Emergency Action (PDF 140Kb)

The U.S. Department of Energy (DOE) is issuing this notice of emergency activities conducted at Los Alamos National Laboratory (LANL), Los Alamos County, New Mexico, in response to the recent Cerro Grande Fire.

ERT Updates:

- 9/15/00 ERT public meeting scheduled for today
- 8/31/00 UPDATE NO. 36
- 8/11/00 ERT public meeting scheduled for Friday morning
- 8/4/00 ERT public meeting today at LAAO
- 8/3/00 ERT public meeting scheduled for Friday morning
- 7/31/00 Weekend rains created insignificant runoff
- 7/27/00 Emergency Rehabilitation Team update
- 7/26/00 ERT public meeting scheduled for Friday morning
- 7/25/00 Construction continues in Los Alamos Canyon
- 7/21/00 ERT public meeting scheduled this morning
- 7/20/00 ERT public meeting scheduled for tomorrow morning
- 7/19/00 Tuesday storm produces no flows off Laboratory property
- 7/17/00 **Public Advisory Group Meeting**
- 7/14/00 ERT provides safety reminders
- 7/13/00 Wednesday rainfall in Los Alamos Canyon
- 7/11/00 ERT Update no. 23
- 7/12/00 Construction continues in lower Los Alamos Canyon
- 7/11/00 Weekend rains produce limited runoff
- 7/7/00 Emergency Rehabilitation Team public meeting is today
- 7/6/00 ERT hosts second public meeting tomorrow
- 6/30/00 ERT meeting to be open to the public

Photos of Flood Retention Structure Pajarito Canyon

Rainfall Gauges in Area Canyons (RAWS)

Learn more about the team:

Org Chart

Statement from John Browne on ERT

We will regularly post updates from the team, providing the latest information on what the Laboratory is doing to prepare for possible runoff and flooding.

Contaminant Redistribution in Pueblo Canyon Following the Cerro Grande Fire Los Alamos, New Mexico

Danny Katzman, Steven Reneau, Jared Lyman, Randall Ryti

(katzman@lanl.gov, 505-667-0599))

PROBLEM

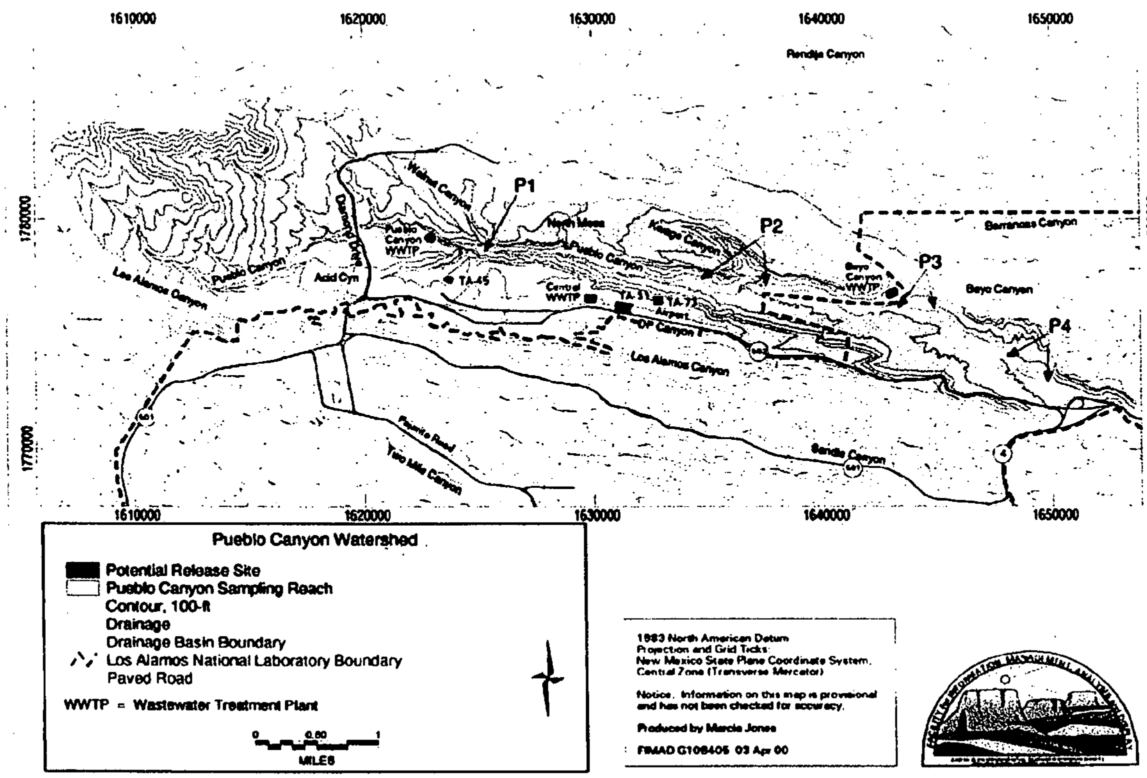
Erosive floods could cause accelerated downstream transport of legacy contaminants contained within valley-floor sediments

Floods transporting and depositing elevated constituents contained in ash could overprint characterized canyons media

CONCEPTUAL MODEL

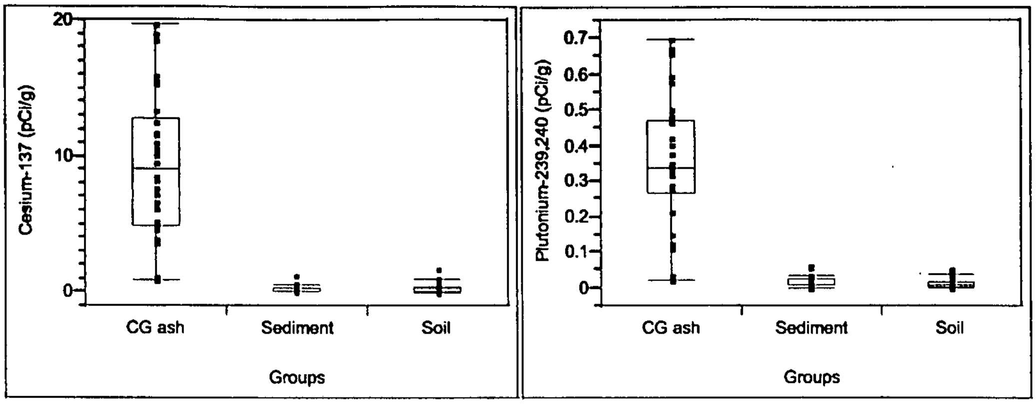
Constituents (especially fallout radionuclides) exist in ash at elevated concentrations. Floods were likely to mobilize and deposit ash onto floodplains containing contaminated sediment. These signatures could be difficult to distinguish.

Valley-floor erosion during floods could result in accelerated downstream (offsite) transport of contaminated sediments, although contaminant concentrations in flood deposits will be lower due to mixing with non-contaminated sediment during transport.

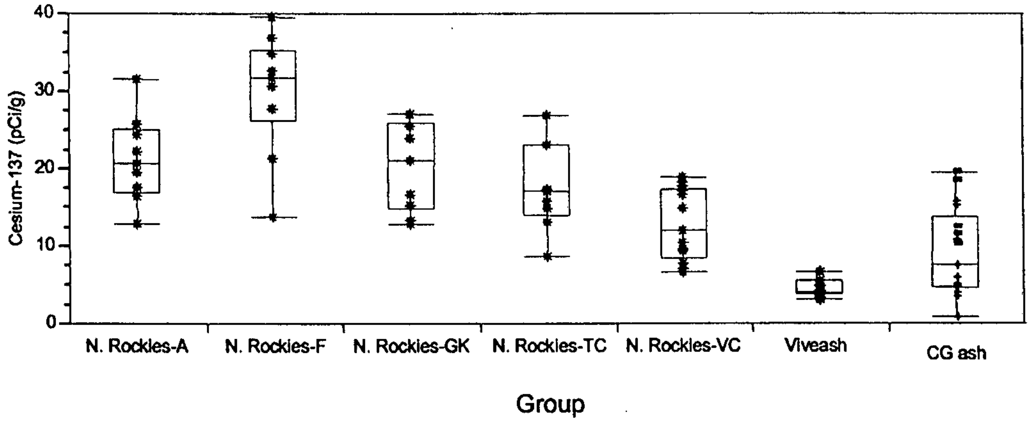


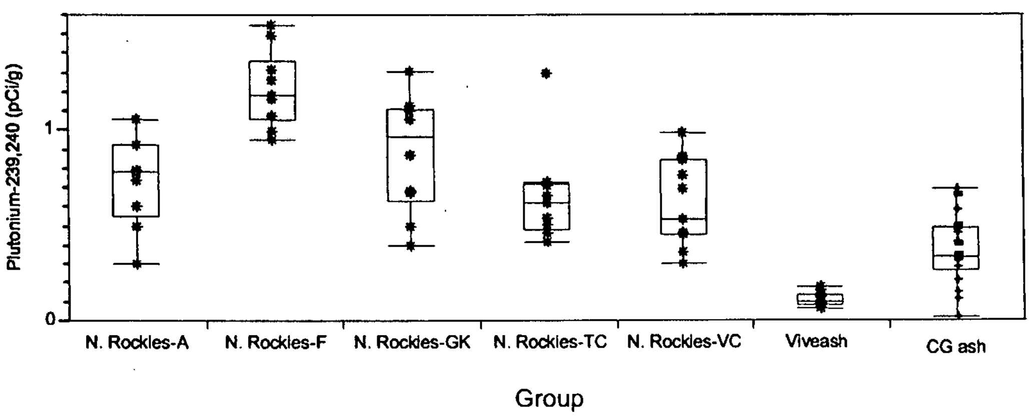
Map delineates Pueblo Canyon within context of entire Los Alamos Canyon watershed. Rendija and Guaje Canyons in the north also drain into Los Alamos Creek prior to its confluence with the Rio Grande. The upland area of each of these watersheds was nearly completely burned in the Cerro Grande fire. Representative ash samples were collected from these upland areas for characterization.

ASH DATA



Box plots show comparison of concentrations of representative constituents in Cerro Grande (CG) ash to background soil and sediment concentrations. Ash is not directly comparable to soil or sediment; the significantly elevated concentrations are important because the ash was a major component of sediment in floods.

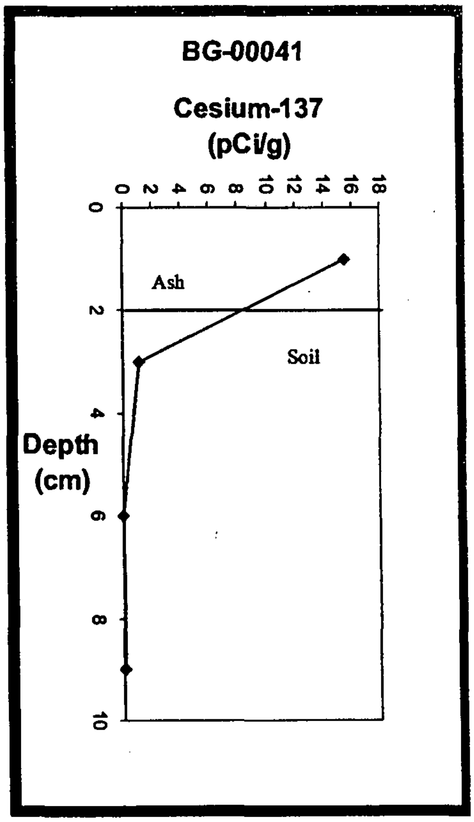




These box plots show variations in plutonium-239 and cesium-137 concentrations in ash from Rocky Mountain fires. Higher concentrations in northern burn areas are likely due a combination of factors including location relative to dispersion pathway from the Nevada Test Site, predominant jet-stream patterns, and precipitation gradients.

Fire	Ave. cs-137 (pCi/g)	Ave. pu-239,240 (pCi/g)	pu-239,240/cs-137
Fridley (Livingston, MT)	30.2	1.22	0.04
Green Knoll (Jackson, WY)	20.5	0.88	0.04
Trail Creek (south central ID)	17.9	0.67	0.04
Valley Complex (Darby, MT)	12.9	0.63	0.05
Arthur (Eastern Yellowstone)	21.3	0.74	0.03
Viveash (Near Pecos, NM)	5.1	0.13	0.03
Cerro Grande (Los Alamos, NM)	13.0	0.43	0.03

Concentrations in ash and ratio by burn area.

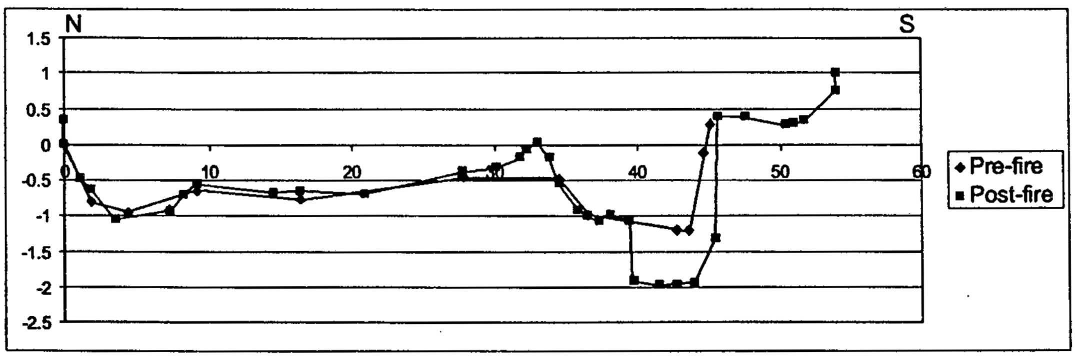


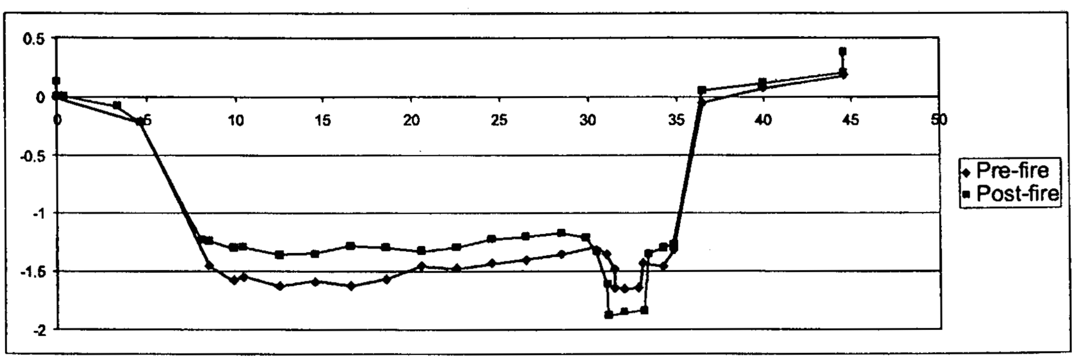
Plot shows a representative vertical distribution of fallout cesium-137 in mountain-front hillslope soils in Cerro Grande burn area. The inventory of cesium-137 was contained entirely (?) within the ash (burned duff >50-yr old). Indications are that fallout rads were deposited directly onto forest floor and onto foliage which was subsequently deposited onto the forest floor. Apparently root uptake and deposition of foliage onto forest floor was not an important process.

CONTAMINANT CONCENTRATIONS IN FLOOD DEPOSITS

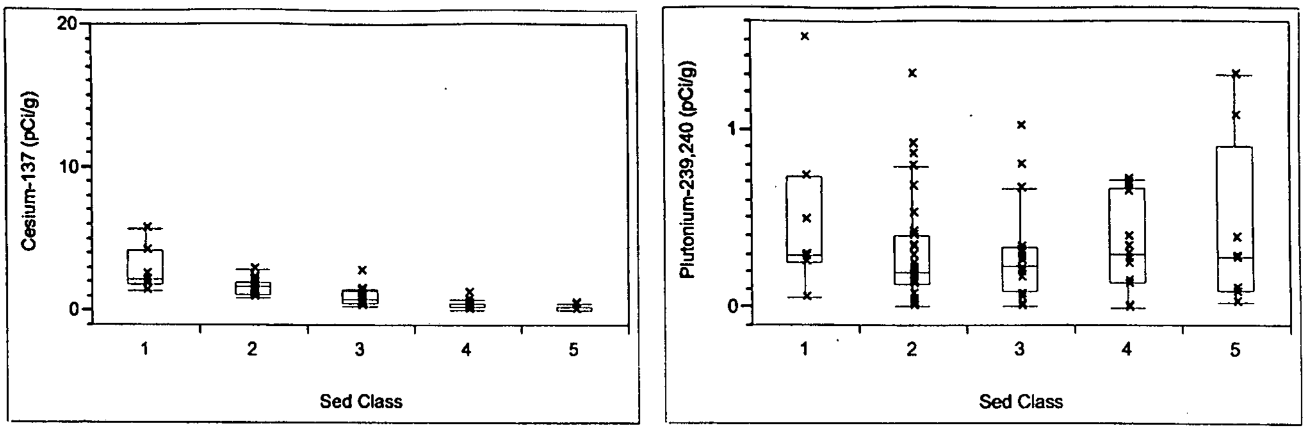
Upper watershed channel incision.

Typical flood stratigraphy. Note ash-rich layers.

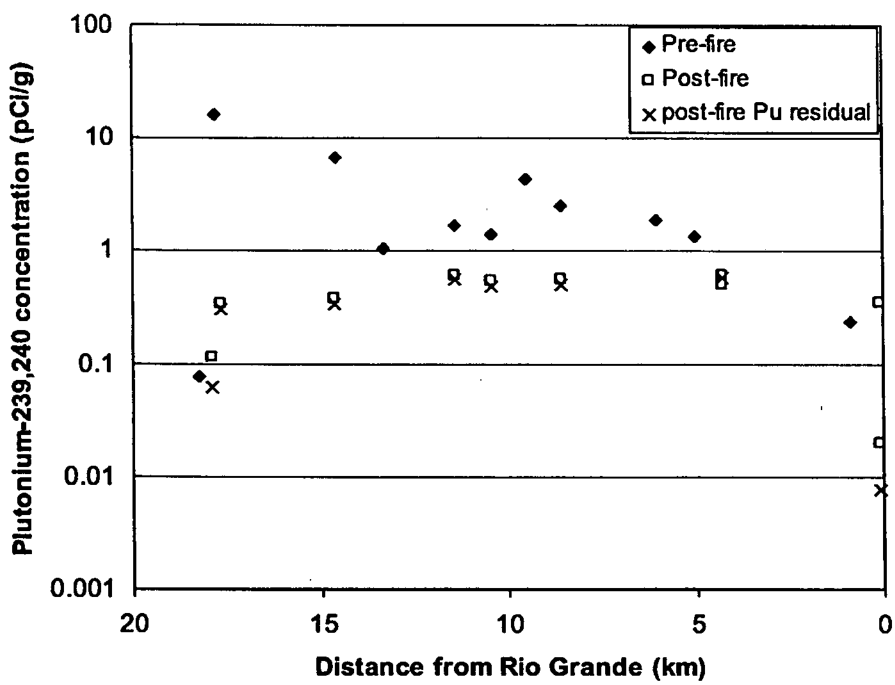




Plots show representative changes in channel and floodplain settings in Pueblo Canyon due to post-Cerro Grande flooding. Incision in these reaches mobilized legacy plutonium contamination sorbed to sediment. Thus, flood deposits contain both legacy plutonium and fallout plutonium.



These plots show variations in the concentration of cesium-137 (left) and plutonium-239,240 (right) as a function of particle size and organic content. Sediment class 1 = silty ash; sediment class 2 = ashy silt-vf sand, sediment class 3 = slightly ashy fine-med sand; sediment class 4 = coarse sand; sediment class 5 = vc sand and gravel. The trend in cesium concentrations reflects an ash source, whereas the trend in plutonium concentrations reflects a legacy source that includes plutonium associated (locally?) with coarser-grained deposits.



Plot shows trends of plutonium concentration along Pueblo Canyon and lower Los Alamos Canyon. Diamond patterns represent plutonium-239 concentrations in pre-fire sediments. Trend is a function of flood reworking of highest sediment concentrations near source at head of canyon. Open boxes show downstream trend in pu-239 concentrations in sediment deposited during the July 2, 2001 flood (approx max discharge of 1400 cfs). Plutonium concentrations result from a mix of plutonium in ash and legacy plutonium. The "X" pattern shows the *residual* plutonium concentrations for sampled reaches. The *residual* described how much of the plutonium in flood deposits is due to remobilization of legacy plutonium vs. plutonium in ash. Most of the plutonium in the sampled deposits is from remobilization of legacy plutonium.

Hydrologic and Water Quality Responses Measured after the Cerro Grande Fire

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The Cerro Grande fire burned major portions of watersheds draining onto LANL from adjacent Santa Fe National Forest Lands. On these hillslopes, from 20 to 90 percent of the acreage was considered "high severity burn" (Figure 1). In Pueblo Canyon, 96 percent was considered "high severity". Increases in runoff and sediment yield after the fire were anticipated to be severe due to the steepness of the terrain and high severity of the burn, creating water-shedding hydrophobic soils.

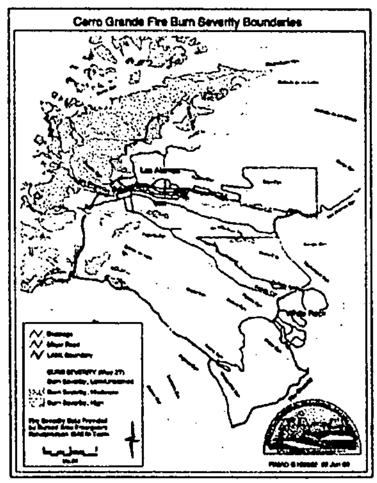


Figure 1. Cerro Grande Fire Burned Severity Map. The darkest shading shows the "high severity burn" area. The LANL boundary is also highlighted.

Monitoring Network

We operate a network of approximately 80 stream gages on drainages within the Laboratory and on adjacent lands. The station locations are shown in Figure 2. The gages are equipped with automated (stage-activated) water quality sampling devices. Water quality samples are commonly analyzed for metals, radionuclides, major ions, nutrients, cyanide, volatile and semi-volatile organic compounds, and high explosives.

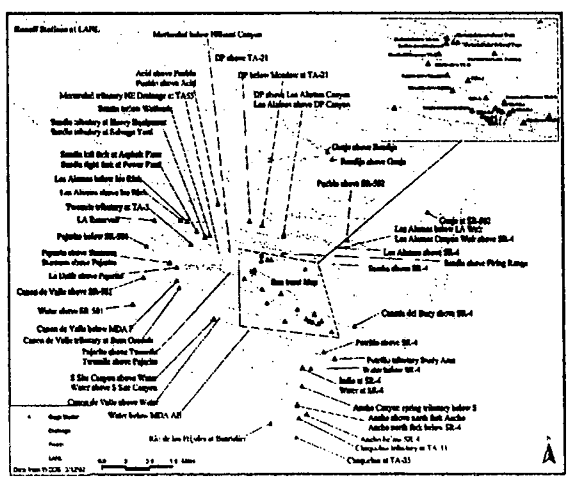


Figure 2. Flow Gaging and Water Quality Monitoring Stations near LANL.

Changes in Streamflow after the Fire

Watersheds undergo significant responses to wildfire in southwest ecosystems. The burning of the understory and forest litter triggers many of the changes. Under pre-fire conditions, the grasses and brush within a forest canopy serve to slow and capture precipitation, nutrients, and sediments. For the 5 years before the fire, the maximum peak discharge recorded at LANL's most upstream gages was 0.3 cfs. Following the Cerro Grande fire, peak flows often exceeded 600 cfs (Figure 3).

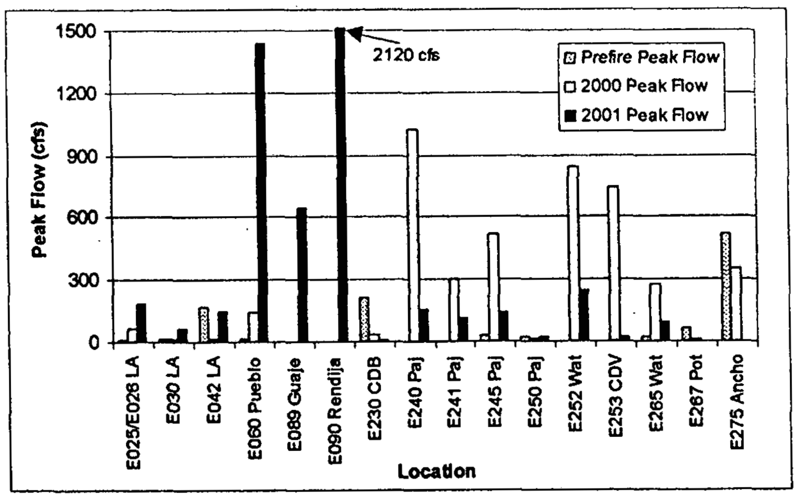


Figure 3. Peak runoff recorded in 2000 and 2001 compared with historical peak flows. To date, the largest peak flows are associated with severely burned watersheds. The 2001 peak flow in Pueblo Canyon resulted from a 60-minute thunderstorm.

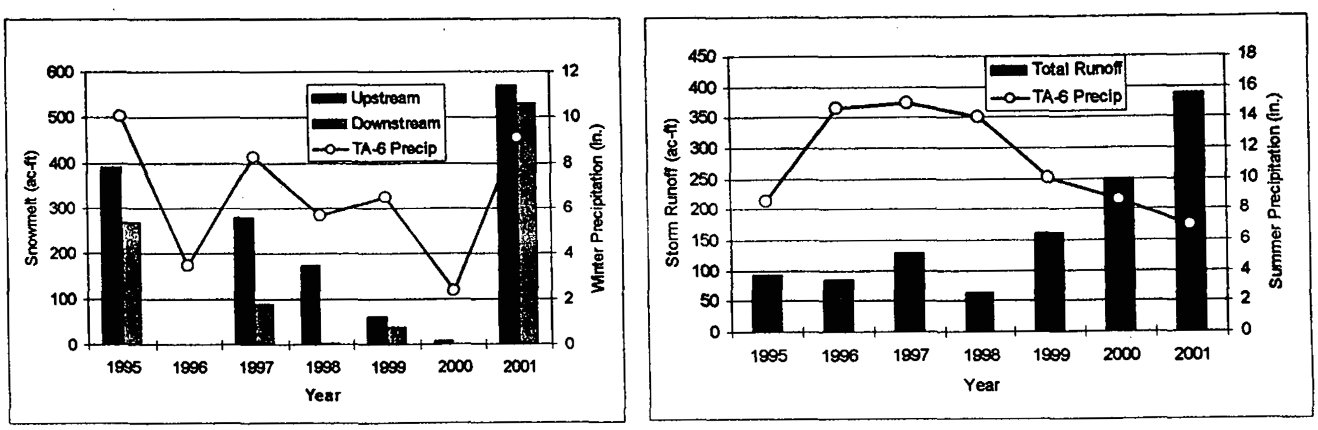


Figure 4. Runoff volumes for winter (left) and summer precipitation (right) in 2000 and 2001 compared with historical pre-fire flows.

Water Quality Changes

The recorded water quality responses to the Cerro Grande fire largely mirror those described in the literature for fires elsewhere. Once the runoff begins, loose soils and ash are quickly removed from the steeper hillslopes. Fire-associated debris can be suddenly delivered directly to streams in large quantities. Wildfires interrupt the uptake of anions and cations by vegetation and speed mineral weathering. Moreover, the ash is enriched in minerals and fallout radionuclides that had been incorporated within or attached to the vegetation.

After the Cerro Grande fire and other earlier crown fires in the Los Alamos area, runoff samples showed increases in concentrations of suspended sediment, ammonium, barium, bicarbonate, calcium, iron, bicarbonate, manganese, lead, strontium-90, and uranium. The sudden addition of substantial quantities of carbon and minerals (like calcite) to the watershed initiates geochemical and pH changes. Our data indicate, however, that major increases in alkalinity and dissolved concentrations lasted only for a few months. The most long-lasting change is in the suspended sediment load carried by the runoff (Figure 5).

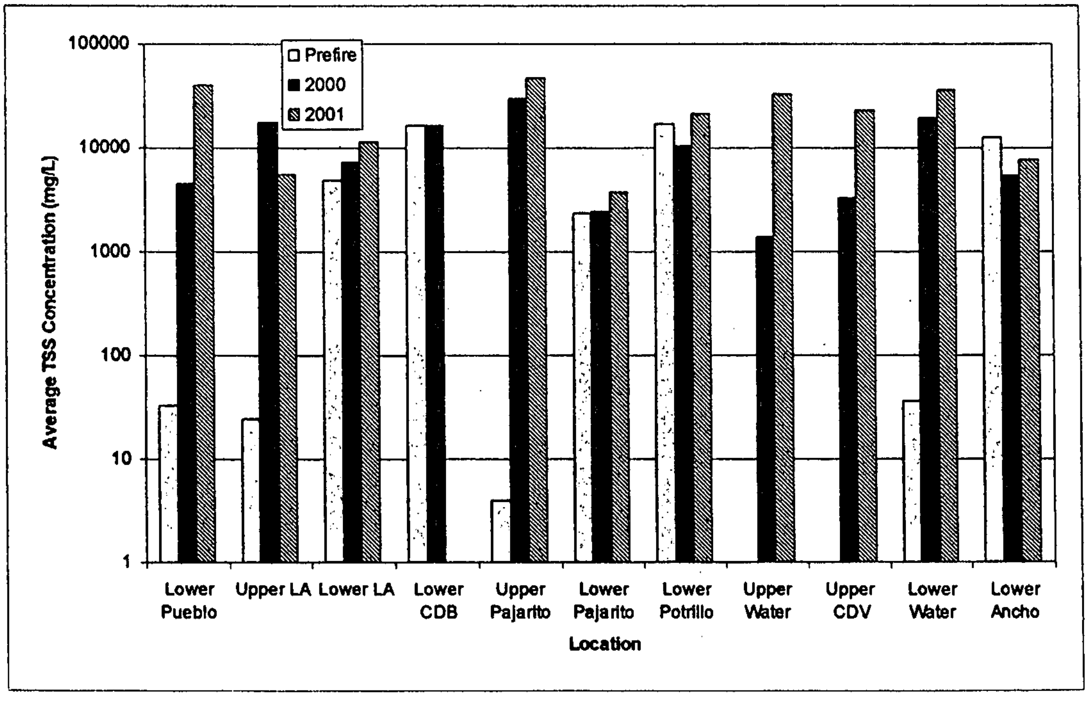


Figure 5. Volume-weighted average Total Suspended Solids (TSS) concentrations in 2000 and 2001 compared to pre-fire levels. The "Upper" stations are closest to the burned hillslopes and show increases of TSS of 100 to 1000 times.

Conceptual Model of Mineralogical and Hydrochemical Impacts From the Cerro Grande Fire, Los Alamos, New Mexico

Patrick Longmire, (plongmire@lanl.gov)[1], Dale Counce[1], Michael Dale[2], Steve Chipera[1], and Marjorie Snow[1]

[1]EES-6, LANL MS D469
[2]DOE Oversight, NMED

The Cerro Grande fire significantly impacted several major watersheds that drain into Los Alamos National Laboratory. These include Pueblo Canyon, Los Alamos Canyon, Sandia Canyon, Mortandad Canyon, Pajarito Canyon, and Water Canyon. Ash produced from the fire consists of a complex mixture of inorganic and organic compounds. Calcium, magnesium, silica, potassium, sodium, and carbonate are concentrated in the ash, producing alkaline pH values typically ranging from 9 to 10.5. During storm events, the ash is washed into canyons and is carried down stream. Alkaline pH values may persist in runoff water because rain water at Los Alamos is characterized by pH values ranging from 5.5-6.5. Rain water has a limited buffering capacity because it is depleted in base cations and anions including calcium, magnesium, potassium, sodium, and bicarbonate. During storm events, surface water typically recharges alluvial groundwater, which in turn, recharges deeper perched groundwater. Changes in pH and major ion water chemistry induced by the ash-rich runoff and surface water may influence the distribution and mobility of contaminants including strontium-90, uranium, plutonium, and americium. Strontium-90 is the contaminant of concern in upper Los Alamos Canyon, whereas the other contaminants are found in Mortandad Canyon. Calcium competes with strontium-90 through cation exchange and adsorption reactions, in which calcium displaces strontium-90 to solution. Under alkaline pH values, strontium complexes with bicarbonate forming $^{90}SrHCO_3^{1+}$, which does not adsorb as strongly as $^{90}Sr^{2+}$. This cation is stable under near neutral pH conditions typical of surface water prior to the Cerro Grande fire. Elevated activities of strontium-90 and other contaminants could be observed in surface water and alluvial groundwater samples collected during storm events, especially in June and July 2000. Geochemical reactions controlling the fate and transport of strontium-90 and other contaminants can be quantified through use of geochemical computer codes including MINTEQA2 and PHREEQC2.2. Predicted future trends in water chemistry can also be evaluated through the use of these computer codes.

IMPACT OF THE CERRO GRANDE FIRE AND THE LOW-HEAD WEIR ON INTERMEDIATE-DEPTH PERCHED-WATER QUALITY

William Stone (wstone@lanl.gov)

Field Trip Stop, 2002 Chapman Conference

Following the Cerro Grande fire, a low-head weir was constructed by the U.S. Army Corps of Engineers in Los Alamos Canyon to mitigate offsite transport of contaminant-laden sediments. However, temporary ponding of water behind the rock and mesh gabion enhances the potential for downward migration of both fire products and contaminants to perched saturation in fractured basalt lying at or near the surface. Thus, a monitoring site, consisting of three boreholes (see figures on following pages), was installed at the weir to address four issues: surface water/ground water connection, the impact of the fire and the weir on ground-water quality, and the hydraulic properties of the underlying basalt.

A conventional PVC well targets three perched saturated zones in the basalt. A Water FLUTe™ system provides for both isolation and sampling of the screens. Two angled boreholes drilled at 43° and 34° from horizontal target the unsaturated zone beneath the pond area. Sampling is by absorbent liners, deployed through scalloped or perforated PVC shields because the basalt is unstable.

Analysis of a ground-water sample from 162 ft bgs in the well in December 01 showed an elevated concentration of total organic carbon: 330 mg/L (background is ~ 3 mg/L), confirming that 1) there is good communication between the stream in Los Alamos Canyon and intermediate-depth perched water in the basalt and 2) a fire product has already percolated into the subsurface along the canyon.

A tracer test was initiated by applying a potassium-bromide solution to the dry pond area before the 2002 summer monsoons. A 21 June storm produced a peak discharge of 160 cfs and a maximum pond depth of 3 ft. Water level rose in the vertical well 2 days after ponding: 6 ft in screen 2 (162 ft bgs) and 1 ft in screen 3 (193 ft bgs). Bromide was detected in the vertical well at 162 ft by 1 July (movement of at least 18 ft/d) and at 193 ft by 5 July. Electrical-wire pairs with the liner in the 43° borehole showed an increase in moisture content 2 days after ponding. Interestingly, the shallowest wire pair experienced wetting last (9 days after ponding). Preliminary analysis of the liner showed bromide ranged from 1.9 mg/kg (103 ft along the liner) to 0.8 (136 ft along the liner). However, this profile should not be interpreted without the wire-pair data (the shallowest pair was wetted last).

The site is yielding data on surface/ground water connection as well as the impact of both the fire and the weir on perched-water quality. Modeling will better quantify hydraulic properties of the basalt underlying the area. Although such weirs resolve surface-water problems, they may create ground-water problems.

Cerro Grande Watershed Treatments

Alison Dean and Greg Kuyumjian USFS, Santa Fe National Forest
adean@fs.fed.us, (505) 638-5526

Goals

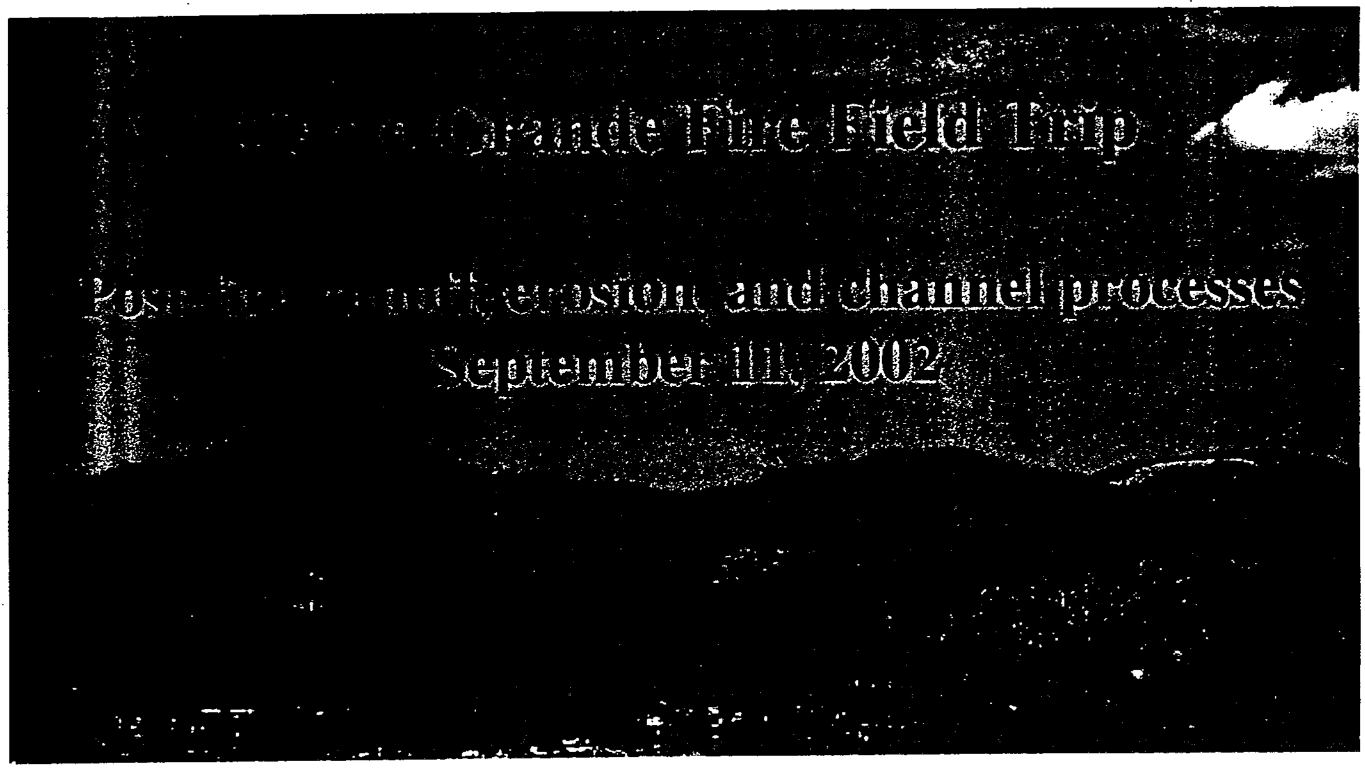
- Minimize threats to human life and property from flooding and debris flows: apply erosion control treatments to high severity burn areas.
- Reduce the risk of breaching embankments and dams: clean and/or re-size culverts, build trash racks in appropriate drainages.
- Increase the rate of forest recovery: stabilize soil by seeding rapid-growing grasses and by mulching to hold moisture, ash, and nutrients on the surface.
- Mitigate damage to cultural sites and stabilize surfaces to minimize erosion.
- Repair bulldozer lines and other damage incurred during fire suppression.

Treatments

- Contour Raking: breaks up hydrophobic layer at soil surface, promoting faster water infiltration and less runoff.
- Straw Mulching: holds moisture and ash on surface for seed germination, and prevents raindrop impact from eroding soil down slope.
- Aerial Seeding: rapid-growing grasses provide vegetative cover that holds soil and ash on slopes. seeds are sterile so they will be replaced by native species.
- Log Erosion Barriers: micro-terraces to catch sediment, provide roughness on slopes to slow runoff, reduce erosive energy, and trap small debris.
- Straw Wattles: functionally the same as log erosion barriers, but their flexibility allows them to be placed surfaces with microtopography.
- Grade Control Structures: rock or log checkdams in small channels to slow water flow and trap sediment.
- Floatable Debris Removal: manual or mechanical removal of wood that is apt to be carried by in-channel flow, to prevent debris jams and clogged culverts.
- Trash Racks: strainers in channel bottoms to catch debris before it reaches culverts.
- Rock, or Sandbag Armor: protects road crossings, well heads, and power lines in the path of projected floods.
- Retention Basins: (e.g. Los Alamos Reservoir, stock tanks) are drained and reinforced to capture flood flows for gradual release.
- Jersey Barriers: divert flood water away from buildings, and vulnerable infrastructure.

Burn severity refers to the degree of burn damage and the corresponding potential for revegetation following a wildfire. A low severity burn removes underbrush but leaves living trees, a moderate severity burn scorches trees but leaves needles to fall and provide mulch, and a high severity burn leaves only ash and blackened trunks with no ground cover at all. Because a high severity burn destroys both the tree canopy and needle or leaf litter that ordinarily protect soil from the erosive force of rainfall, severely burned hillslopes have a strong potential for increased storm runoff, contributing to flooding and debris flows

Chapman Conference on Eco-hydrology of Semiarid Landscapes: Interactions and Processes



Trip organizers:

John Moody, jamoody@usgs.gov, 303-541-3011

Deborah Martin, damartin@usgs.gov, 303-541-3024

Sue Cannon, cannon@usgs.gov, 303-273-8604

USGS
science for a changing world

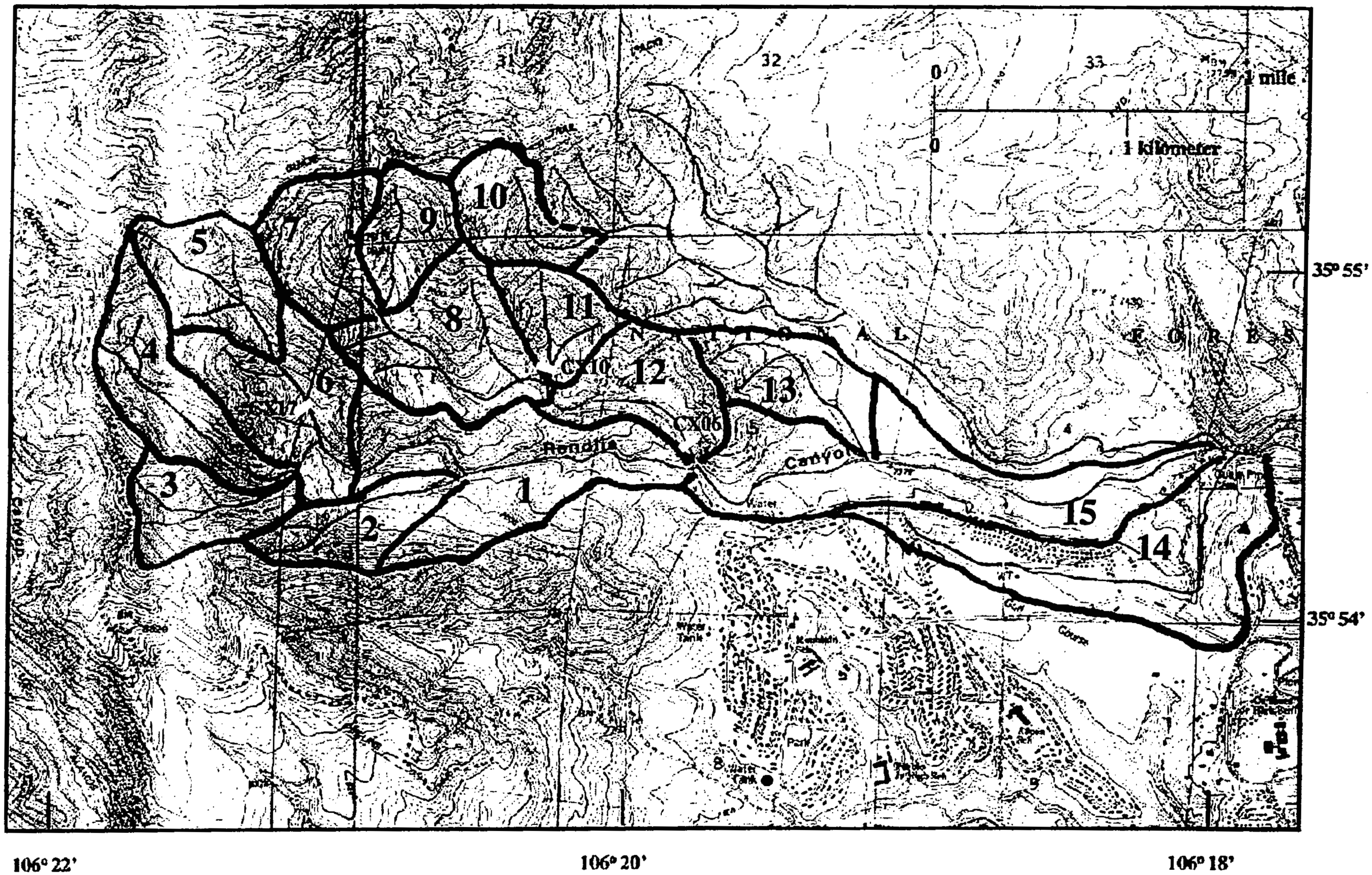
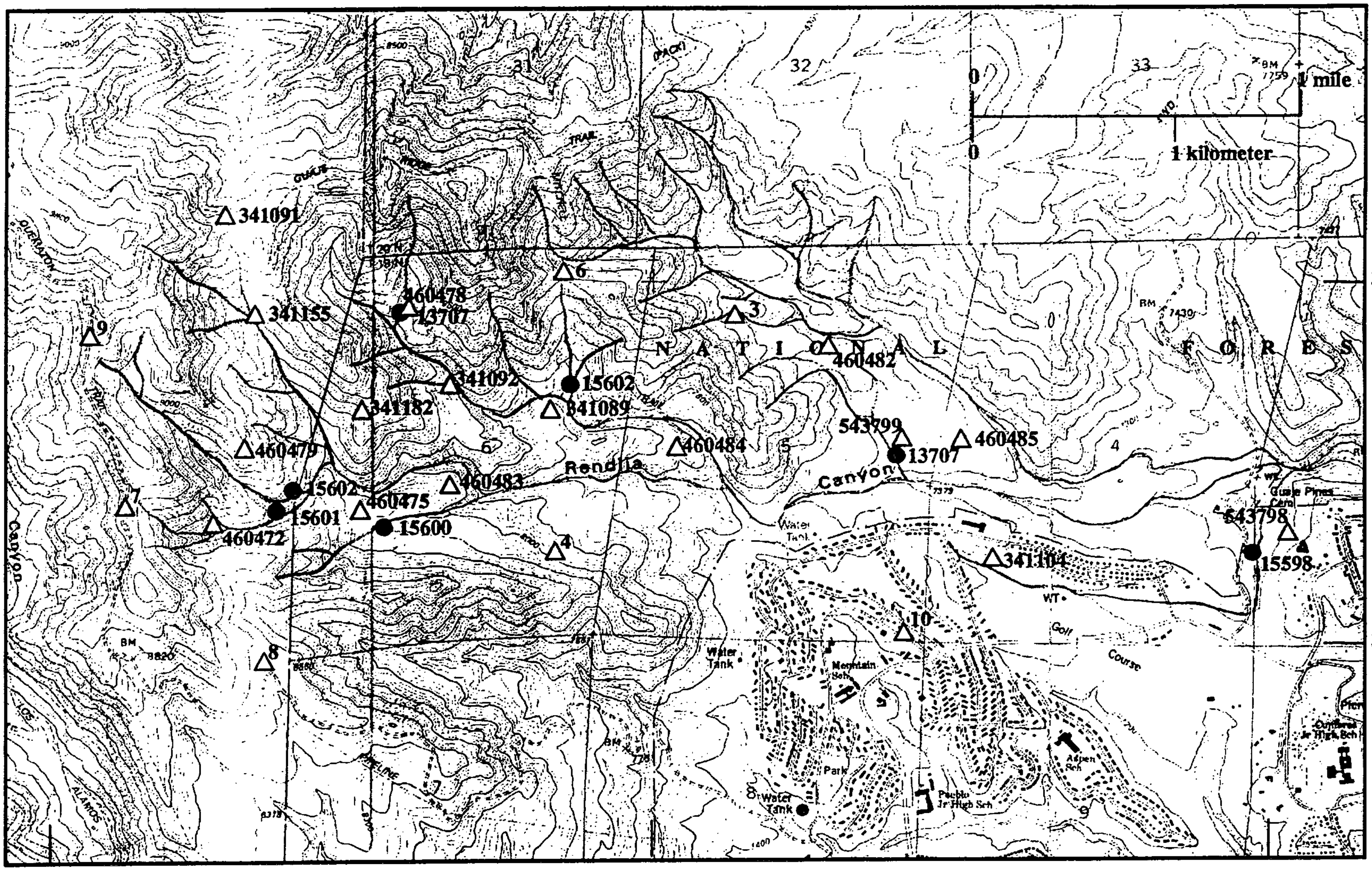


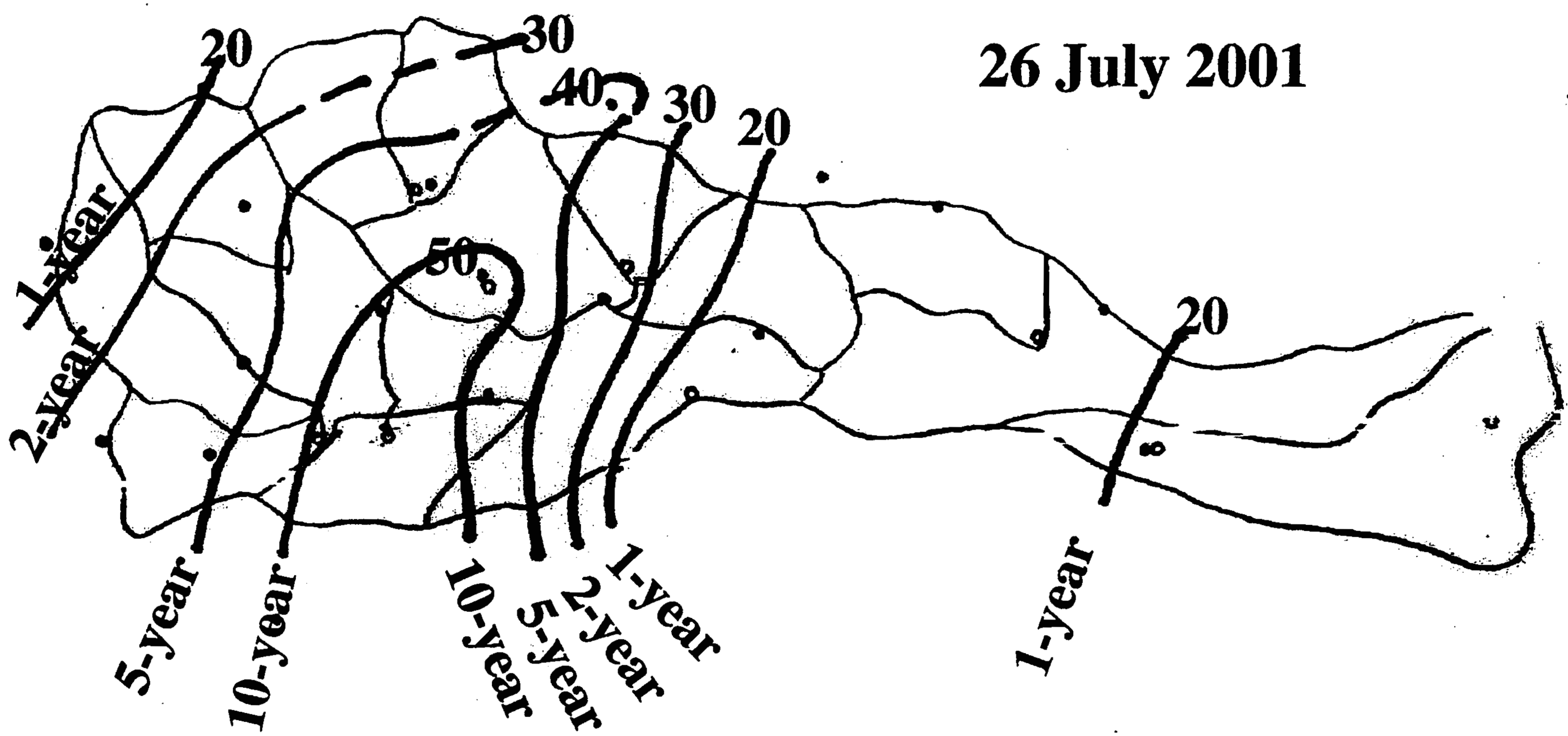
Figure 1. Location of subwatersheds in Upper Rendija Canyon



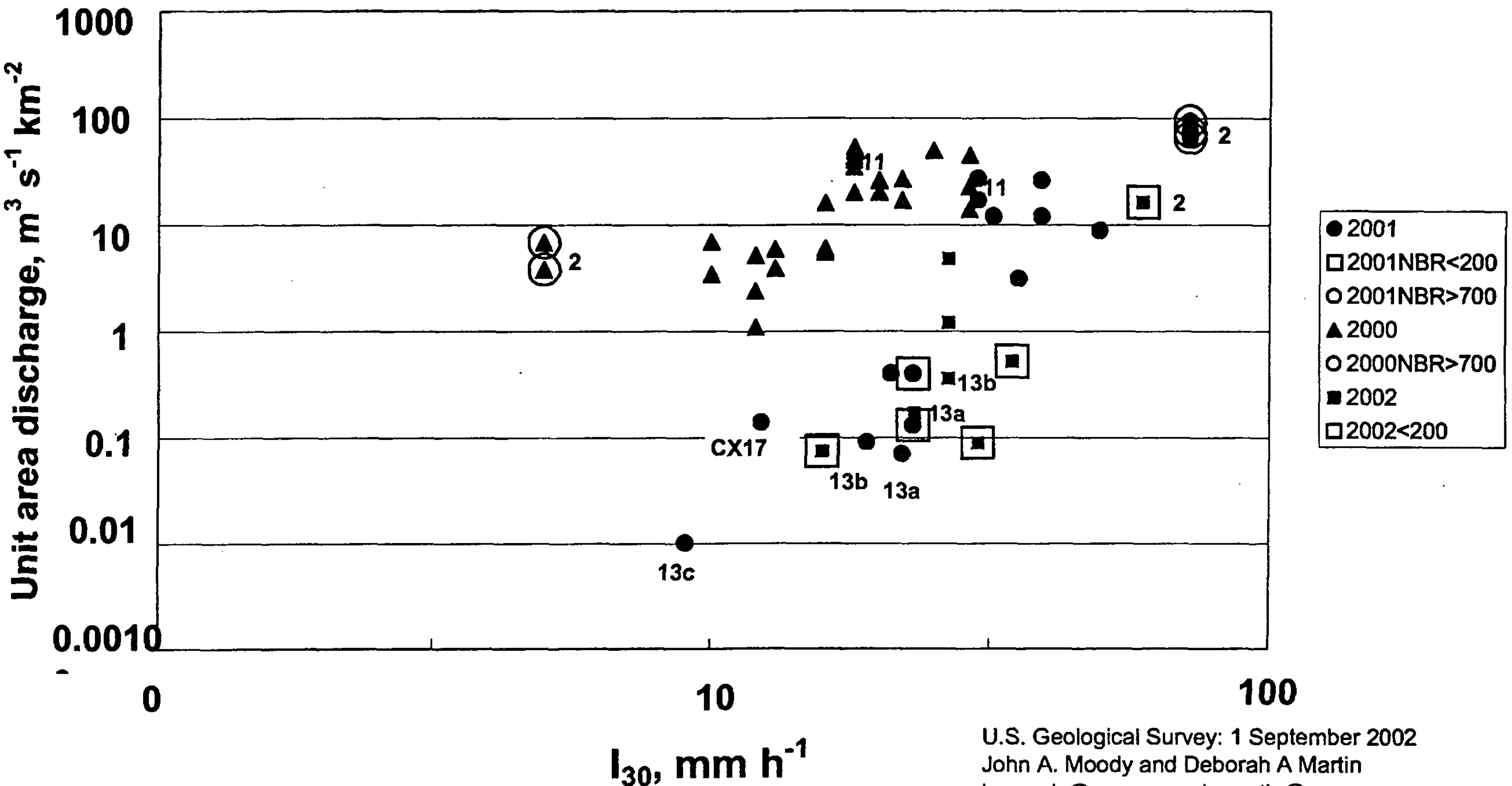
2002. Location of recording rain (yellow triangles) and stream (red circles) gages.

Maximum 30-Minute Intensity (mm h^{-1})

in Rendija Canyon



Rainfall-Runoff Relation
Upper Rendija Canyon



U.S. Geological Survey: 1 September 2002
John A. Moody and Deborah A Martin
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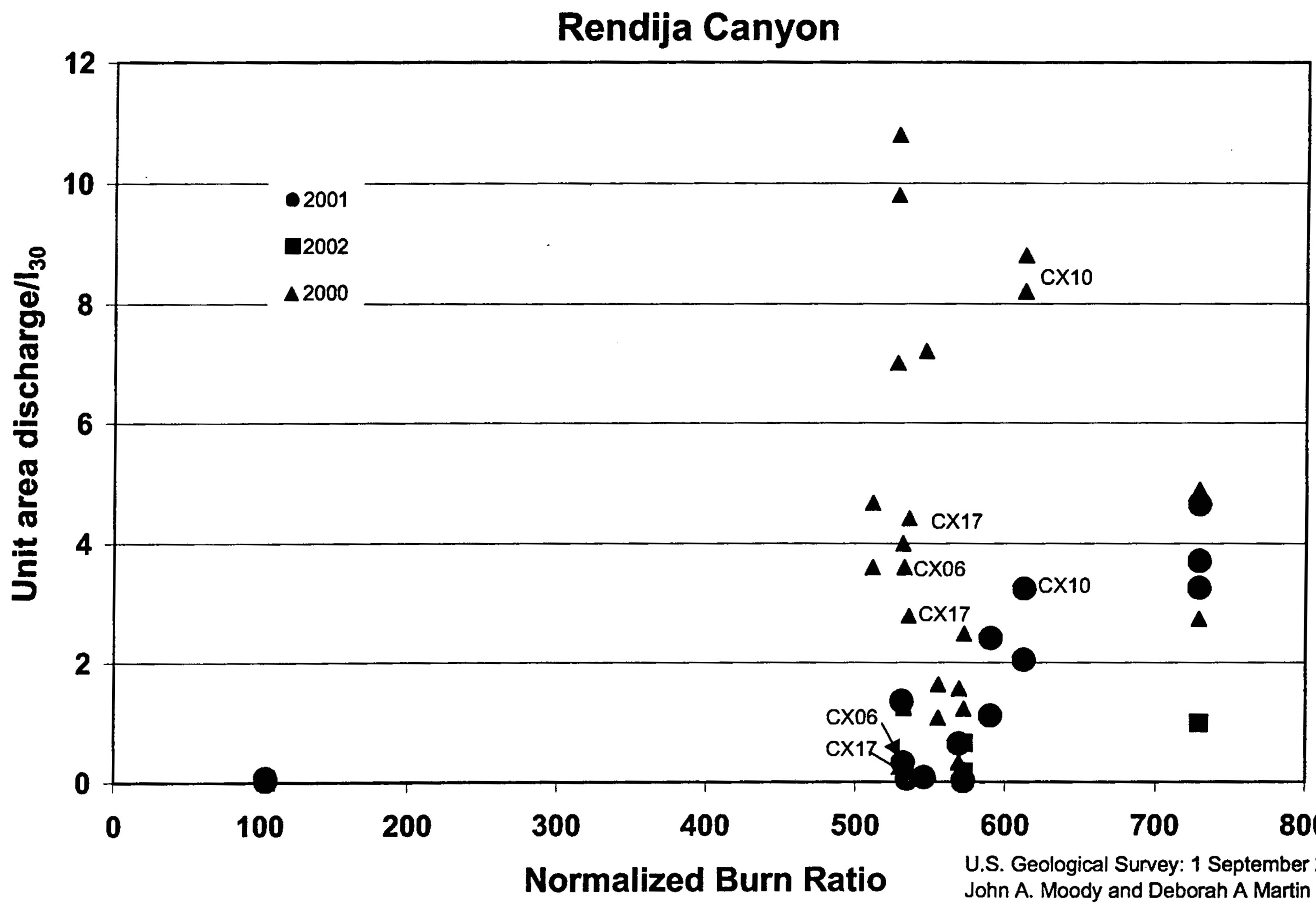

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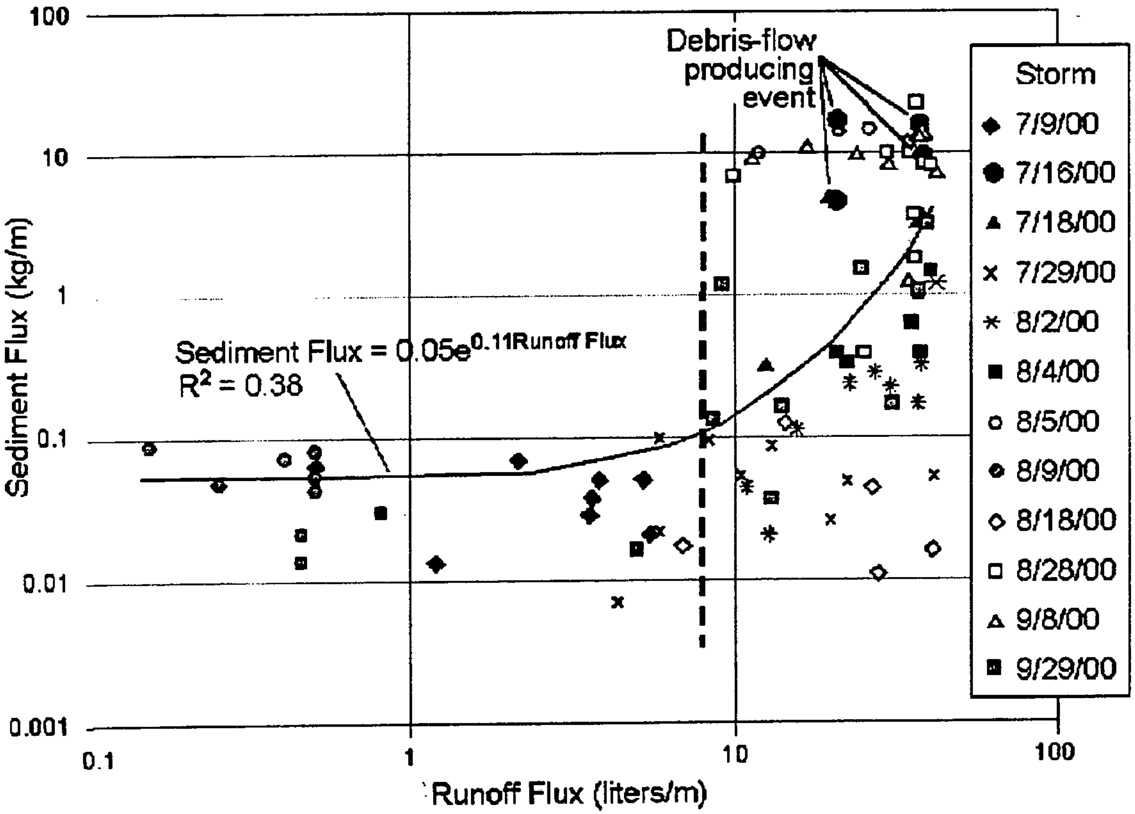
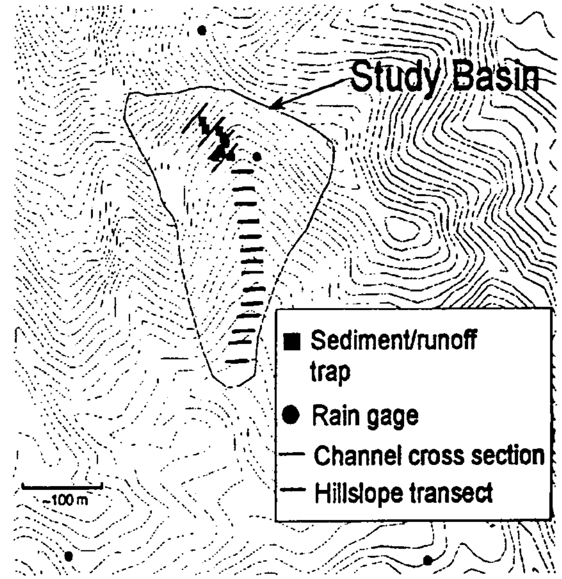
Post-Wildfire Hillslope Sediment/Runoff Fluxes and Debris-Flow Generation

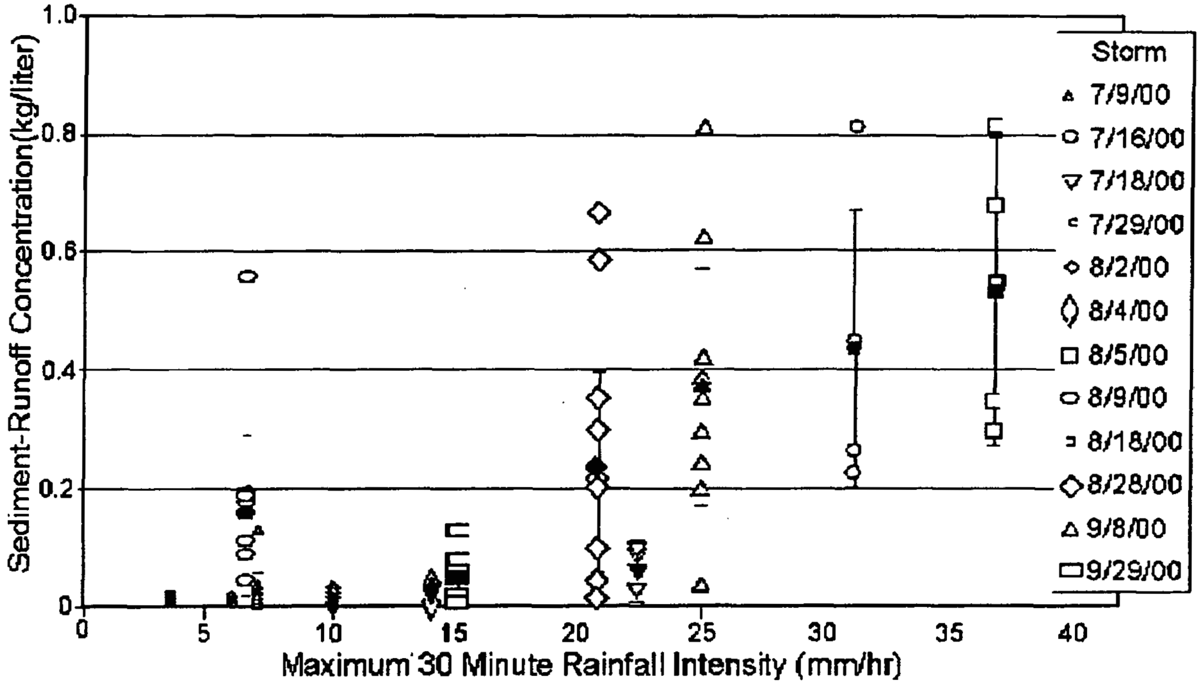
Sue Cannon, USGS



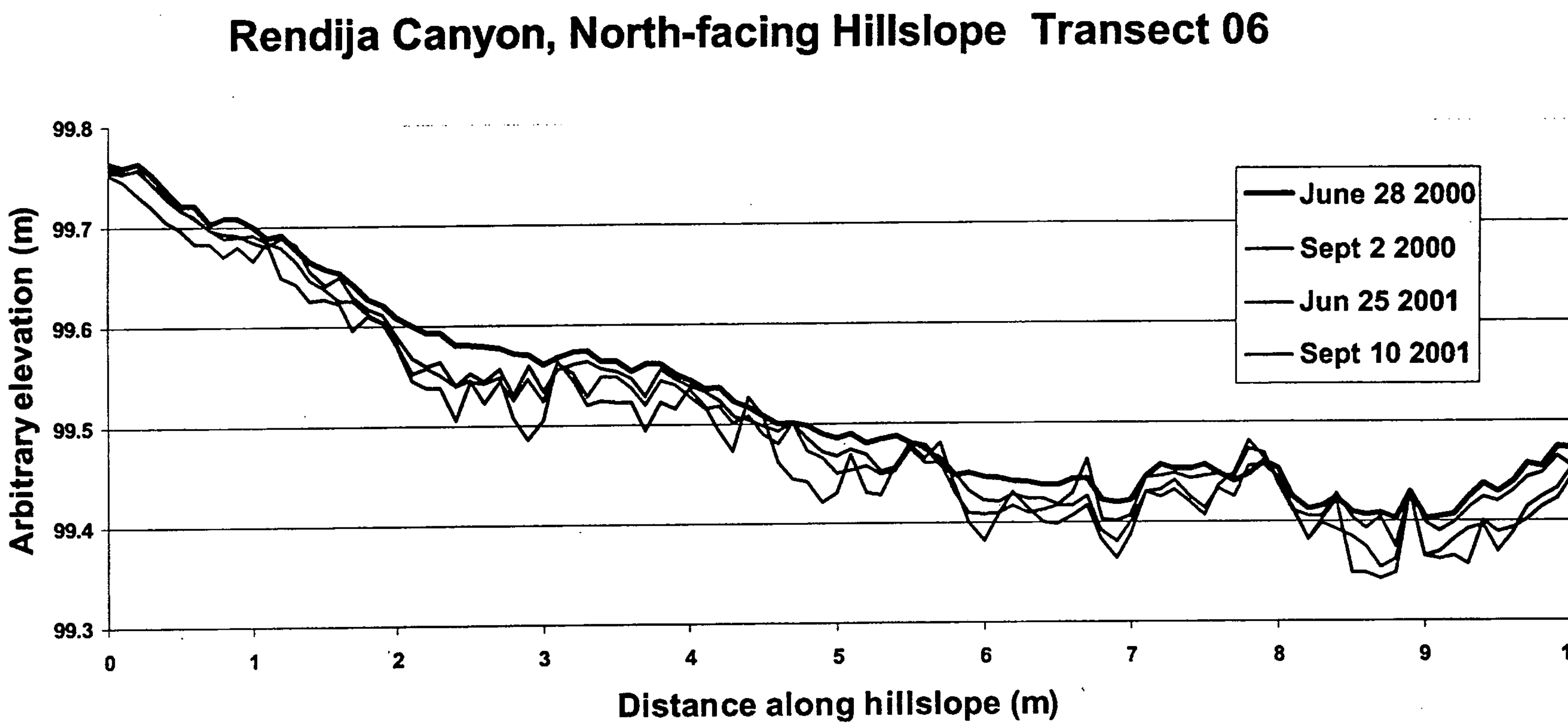


Sediment and runoff flux measurements for all hillslope traps. The solid lines shows a general exponential increase in sediment flux with increasing runoff flux. The dashed vertical line delineates a threshold value of runoff flux above which a wide range of sediment fluxes are produced. Note that although the sediment and runoff yields for the July 16 debris-flow producing storm are among the highest measured, storms on Aug. 5, Aug. 28 and Sept. 8 that did not produce debris flows yielded similar sediment and runoff fluxes.

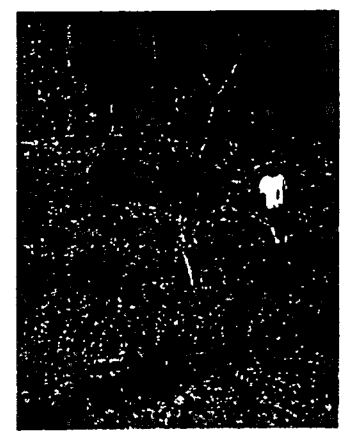
Post-Wildfire Hillslope
Sediment/Runoff Fluxes and
Debris-Flow Generation
Sue Cannon, USGS



Sediment-runoff concentrations for all traps (open symbol), and the means (corresponding solid symbol), for each storm. Confidence intervals (95%) for the means are calculated based on the data range and factors for small sample sizes 9Skeeog and West, 1976). Dashed vertical line delineates an approximate threshold value of maximum 30 minute intensities above which large sediment-runoff concentrations are produced.



JUNE 2000



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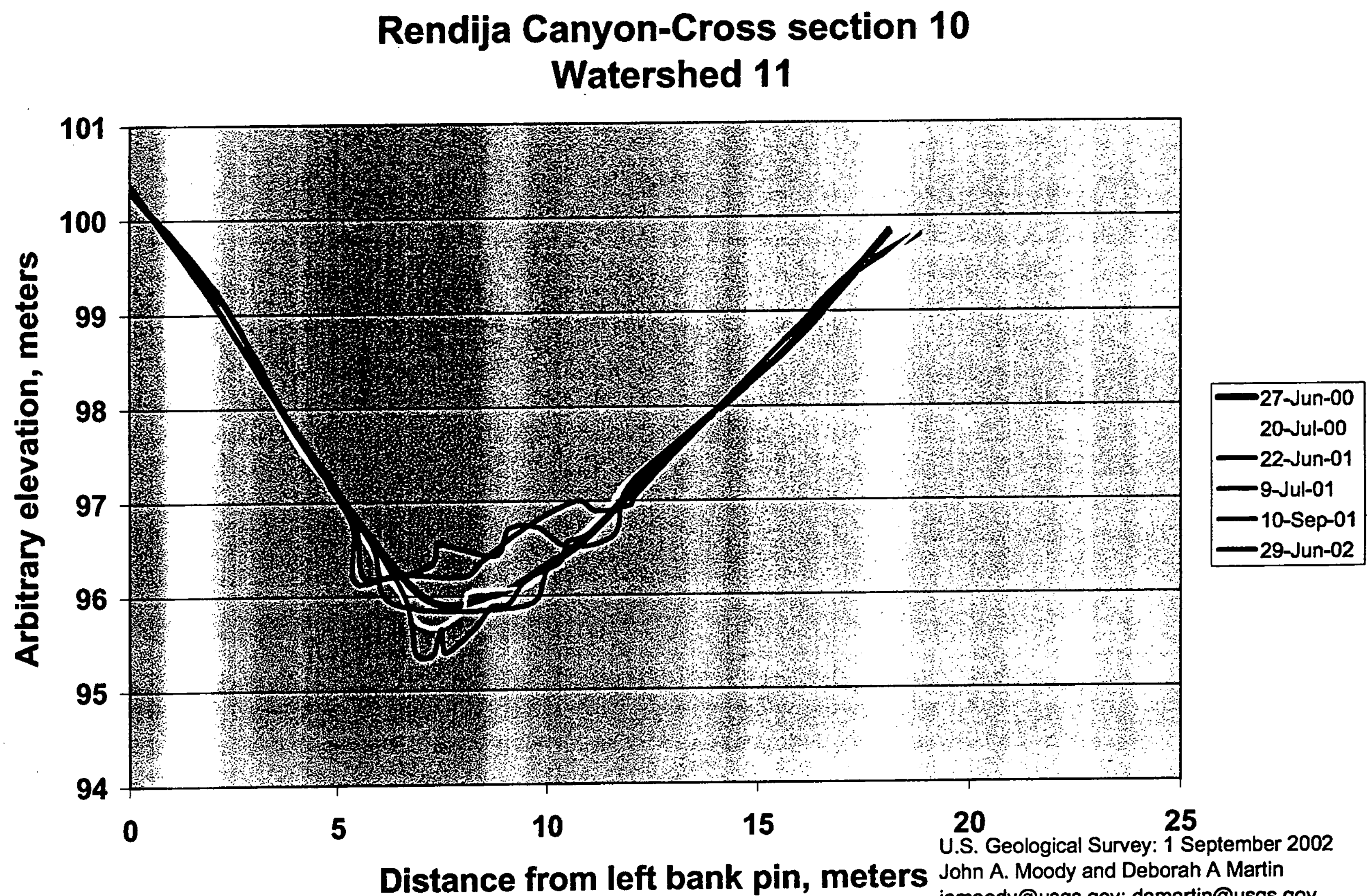
Rendija Canyon-Cross section 10
Watershed 11
Arbitrary elevation, meters
101
100
99
98
97
96
95
94
0
5
10
15
20
25
Distance from left bank pin, meters
27-Jun-00
20-Jul-00
22-Jun-01
9-Jul-01
10-Sep-01
29-Jun-02
U.S. Geological Survey: 1 September 2002
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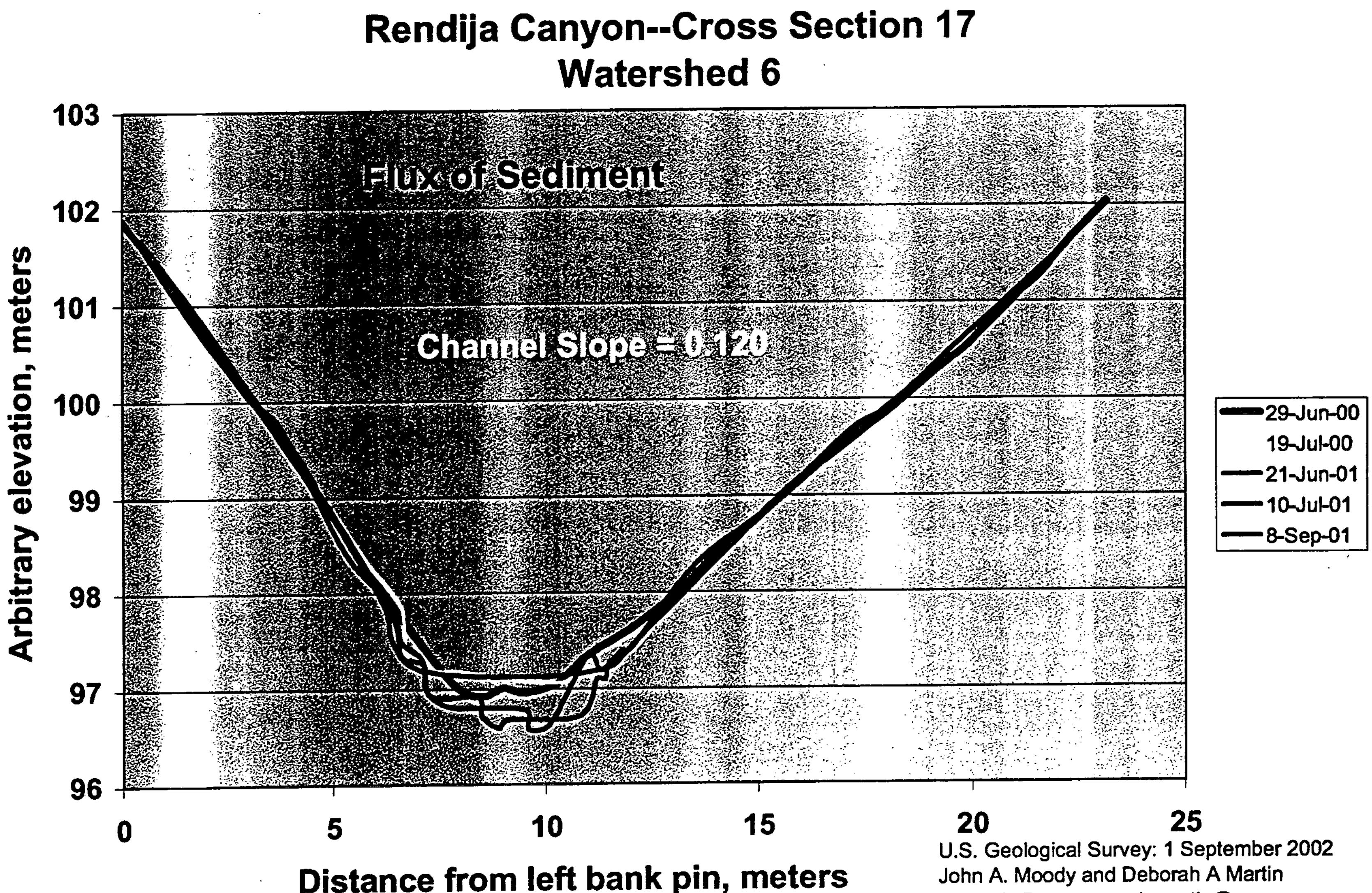

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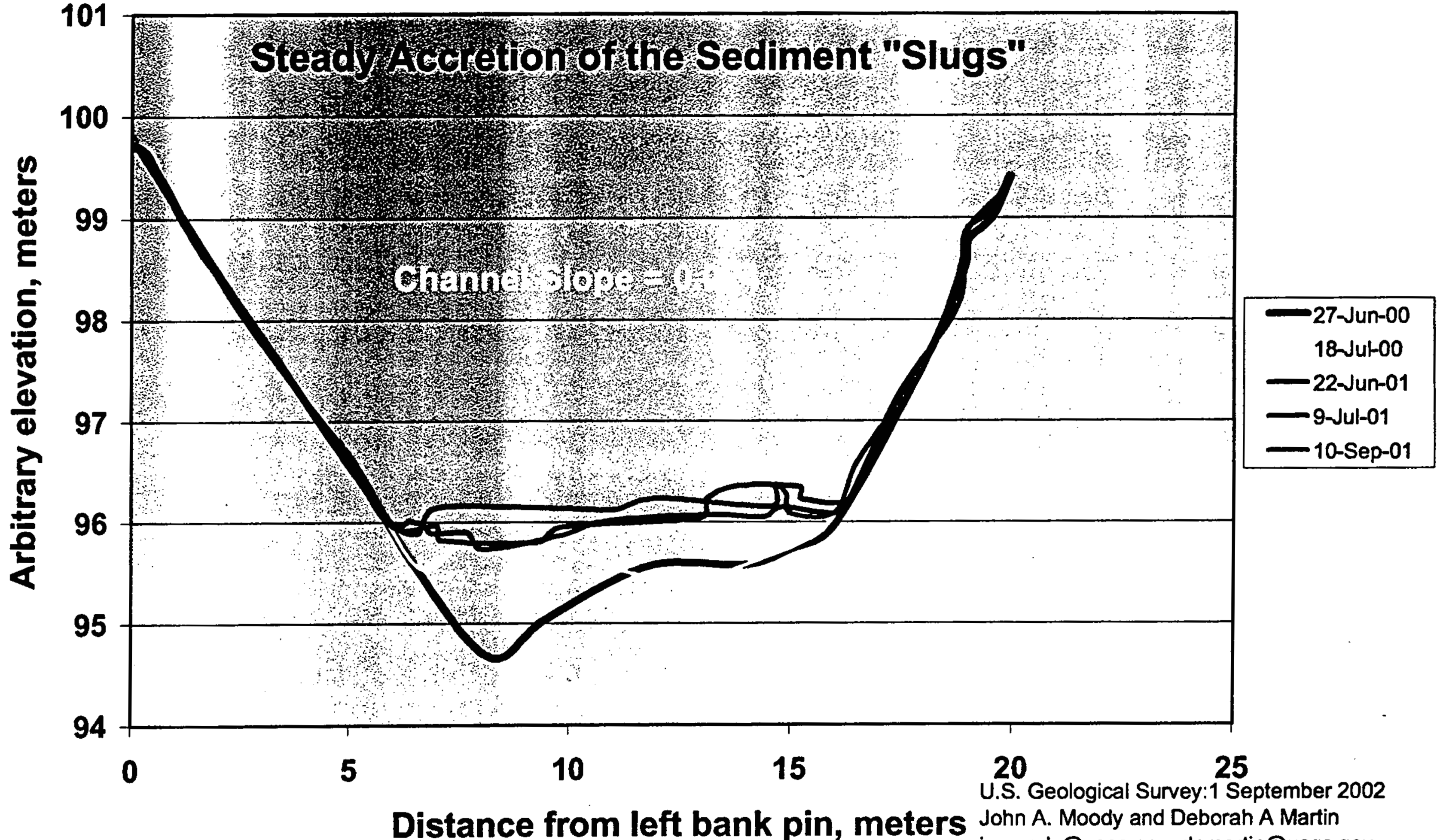
Rendija Canyon-Cross Section 06
Watershed 12



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FLOOD FLOW AND SEDIMENT TRANSPORT MODELING

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July 2, 2001 flood Pueblo Canyon Photo: Mark Van Eeckhout

Modeling Goals

- To assess impact of fire on increased risk to personnel, facilities and infrastructure due to flooding.
  - Flood flow modeling uses HEC-1 and HEC-RAS software
- To predict impacts of upland erosion and sediment transport on facilities and infrastructure and to assess contaminant transport
  - Hillslope Erosion Model in GIS framework developed to predict upland erosion
  - Channel sediment modeling uses HEC-6T (modified version of HEC-6)

The May 2000 Cerro Grande Fire severely burned the headwaters of many of the canyon streams draining through the Los Alamos National Laboratory (LANL), Los Alamos County and Pueblos in Northern New Mexico. The fire increased observed flood magnitudes and hillslope erosion rates by one to two orders of magnitude above pre-fire conditions (Figure 1). Flooding increased scour and deposition in canyon channels that had been relatively stable over the past 50 years (Figure 2).

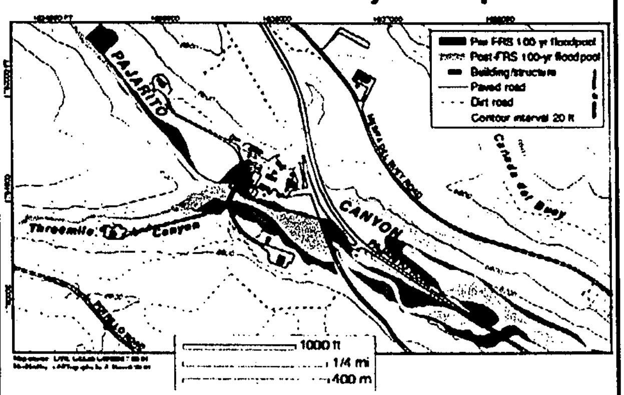
A set of modeling activities are being undertaken to predict the potential impacts of large and small rain events on human health, offsite contaminant transport, LANL facilities and infra-structure. A GIS-based hillslope erosion model was developed and applied to determine sediment inputs from burned uplands into the stream network. The US Army Corps of Engineers HEC models were used to predict flood magnitudes, durations and inundation areas. HEC6T, a one-dimensional sediment transport model, is being coupled to a contaminant transport model to predict potential redistribution and offsite transport of contaminated hillslope and floodplain sediments.

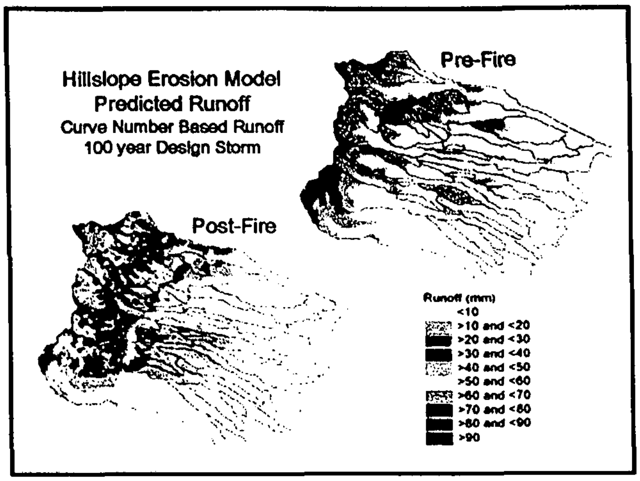
Model predictions are being tested against observed events. In particular, the canyon sediment/contaminant transport model is being tested against high-resolution Airborne Laser Scanning (ALS) topographic data. The ALS data were collected before and after a large flash flood that occurred in Pueblo Canyon. These data form the backbone of our model testing process, along with sediment and contaminant concentration data from flood events.

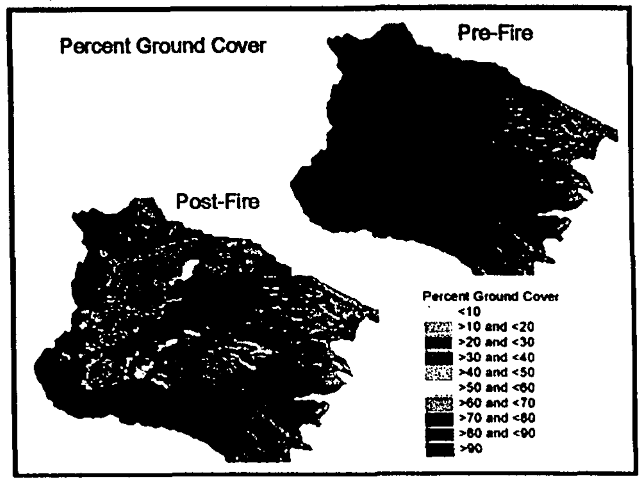
These modeling efforts will help LANL assess where to direct remediation efforts to best protect people and the environment.

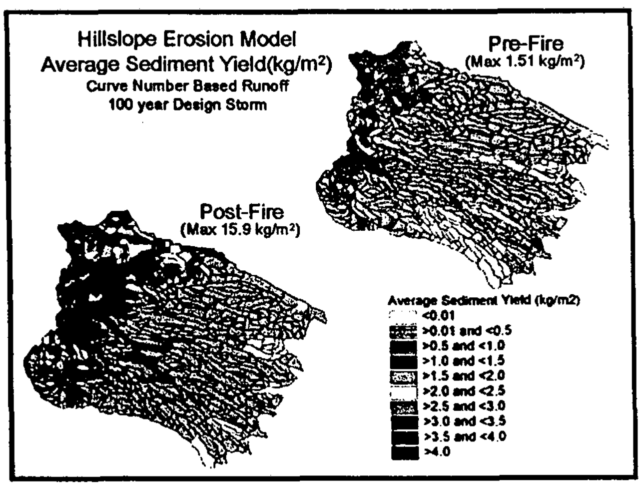
This work is funded by the Cerro Grande Rehabilitation Project, FWO, LANL.

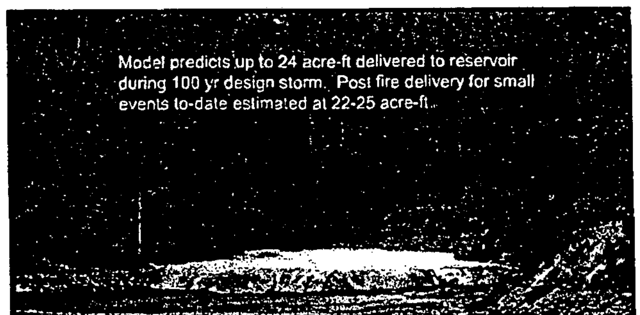
Post-Cerro Grande 100-yr Floodpools





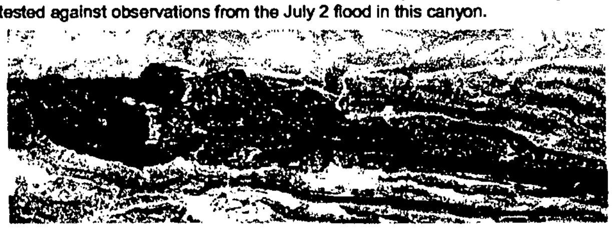




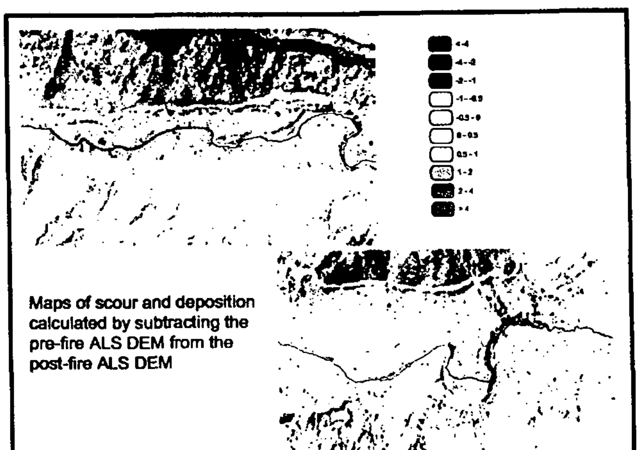


	Sediment (tons)			Runoff (m^3)		
	post-fire	pre-fire	x increase	post-fire	pre-fire	x increase
Pueblo Canyon	34983	1287	27	353470	63083	6
Los Alamos Canyon	64453	7352	9	791501	248356	3
Pajarito Canyon	30435	1734	18	342185	67856	5
Canyon De Valle	15971	3517	5	271273	86815	3
Water Canyon	33935	2809	12	506646	105501	5

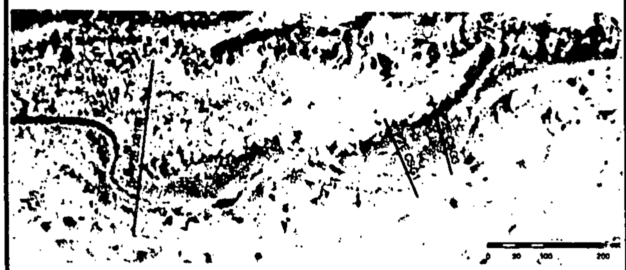
On July 2, 2001, a 1440 cfs flood occurred in Pueblo Canyon. This is the flood of record for the canyon. The headwaters of Pueblo Canyon were severely burned. Runoff from this area has produced several large floods in the Canyon since the Cerro Grande Fire. These floods have damaged roads and infrastructure as well as scoured and redistributed sediments contaminated with low levels of legacy radionuclides. The digital air photo was taken in July 2000 and shows the blackened burn area, as well as straw mulch (pale yellow) where intensive rehabilitation work was undertaken. Model predictions are being tested against observations from the July 2 flood in this canyon.



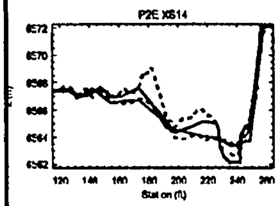
The Pueblo Canyon Watershed is being used as a test site for Post-Fire sediment transport modeling

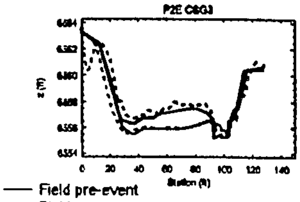


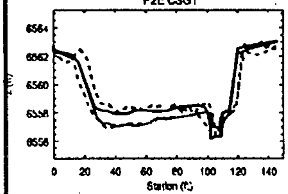
Maps of scour and deposition calculated by subtracting the pre-fire ALS DEM from the post-fire ALS DEM



Three of the surveyed cross-sections are shown on a close-up view of the difference map for Pueblo Canyon. This map shows a pattern of channel scour (red) and out-of bank deposition (green) on the floodplain.



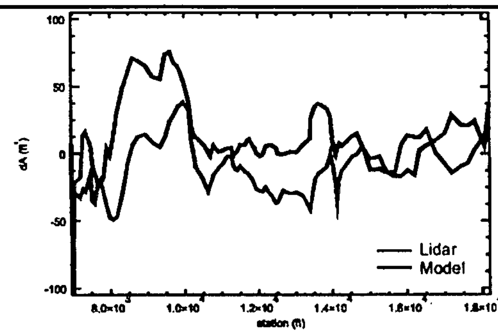




— Field pre-event
— Field post-event
······ Lidar pre-event
······ Lidar post-event

Elevation data extracted from the pre- and post-flood ALS DEM's (dashed lines) correspond well with surveyed cross-section data (solid lines). Red lines show pre-flood cross-section geometry and blue lines show post-flood geometry.

This shaded Digital Elevation Model (DEM) of the Pueblo Canyon model test reach shows the position of HEC6T cross-sections where sediment transport is computed. The photos show zones of scour, no change and deposition following the July 2 flood.



The change in cross-section area of the channel (x-axis) resulting from scour and deposition during the July 2 flood varies with position along the test reach (y-axis). Although the uncalibrated model (red line) predicts more scour than is shown in the ALS difference maps (blue line) at cross-sections, the pattern of modeled scour and deposition resembles the ALS data. Upstream is to the right of the figure and downstream is to the left.

Fire and Vegetation History of the Jemez Mountains

by *Craig D. Allen*, U.S. Geological Survey, Jemez Mountains Field Station,
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Historic patterns of fire occurrence and vegetation change in the Jemez Mountains of northern New Mexico have been described in detail by using multiple lines of evidence. Data sources include old aerial and ground-based photographs, historic records, charcoal deposits from bogs, fire-scarred trees (Fig. 1), tree-ring reconstructions of precipitation, and field sampling of vegetation and soils. The forests and woodlands that cloak the southwestern uplands provide the most extensive and detailed regional-scale network of fire history data available in the world (Swetnam and Baisan, 1996; Swetnam et al., 1999; Allen, in press).

Modern climate/vegetation patterns basically developed in the Southwest about 11,000–8,000 years before present. Substantial fire activity apparently emerged in the Southwest during that time, as evidenced by the contemporaneous and rapid spread of fire-adapted ponderosa pine forests across the region (Anderson, 1989), and by the abundant charcoal deposits found in lake and bog sediments (Brunner-Jass, 1999; Weng and Jackson, 1999). Charcoal sediments from Alamo Bog in the central Jemez Mountains indicate essentially continuous fire activity extending back almost 9,000 years (Brunner-Jass, 1999).

About 5,200 historic fires have been mapped in the Jemez Mountains for the period 1909–1996 from administrative records of local land-management agencies (Fig. 2). Lightning caused fully 75% of the recorded fires, with acreage burned

FIGURE 1—Map of fire scar sample site locations in the Jemez Mountains.

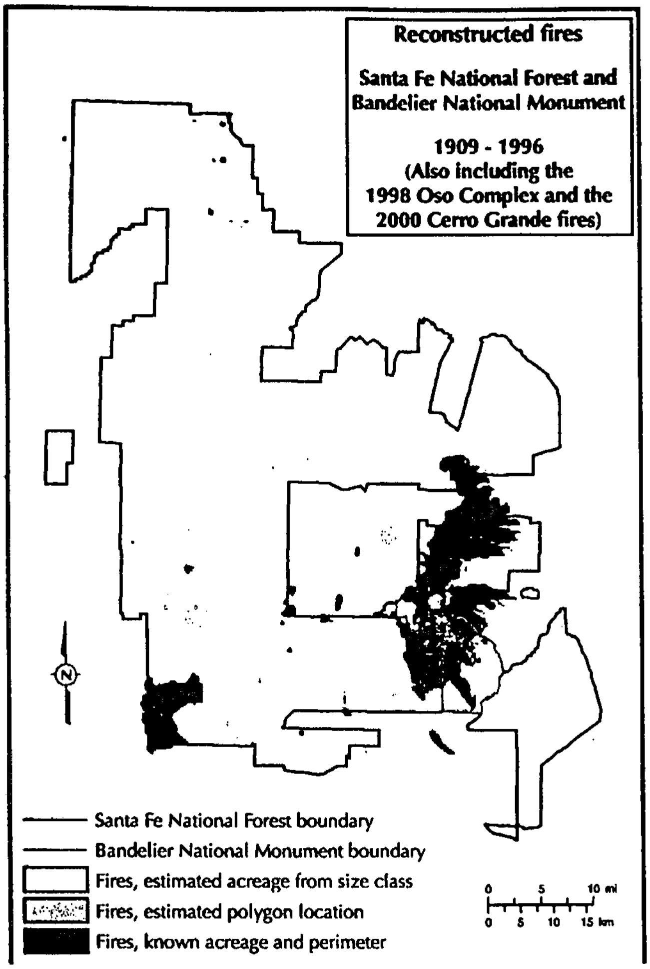

FIGURE 2—Point locations of more than 5,000 historic wildfires in the Jemez Mountains, 1909–1996, compiled from the administrative records of land-management agencies (Snyderman and Allen, 1997). Person-caused fires cluster near major roadways, campgrounds, habitations, and other human use areas.

peaking in the dry months of May and June before the onset of summer monsoon rains. High levels of lightning activity naturally foster fire ignitions here. For example, 62 thunderstorm-days/year are observed at Los Alamos, generating large numbers of lightning strikes. An automated lightning detection system recorded 165,117 cloud-to-ground lightning strikes over a 2,994 mi² area centered on the Jemez Mountains during the period 1985–1994 (Fig. 3). The annual number of recorded lightning strikes varied between 9,410 and 23,317. Particularly important for fire ignitions is the substantial lightning activity during the warm, dry, foresummer months of April through June. Lightning strikes during this period are the most significant sources of fire ignition because lightning is much more likely to start a spreading fire if it strikes dry fuels. Because lightning ignitions are so frequent and ubiquitous in the Southwest, climate and fuel conditions are the main drivers of fire regime dynamics in this region.

Fire scars were sampled from over 600 trees, snags, and logs at 42 sites around the Jemez Mountains in northern New Mexico (Fig. 1), resulting in over 4,000 dendrochronologically dated fire scars. Fire scar dates extend back to 1422 A.D. These data have been used to develop fire histories at multiple spatial scales, from individual trees to watersheds and finally the entire mountain range. Fire histories were reconstructed for vegetation types ranging from piñon-juniper woodlands up through ponderosa pine forests and mixed conifer forests into high-elevation spruce-fir forests (Touchan et al., 1996; Allen et al., 1996). These fire histories show that frequent, low-intensity surface fires naturally characterized most southwestern forests. These fires spread widely through grassy understory fuels, maintaining relatively open forest conditions (Fig. 4).

Pre-1900 mean fire intervals ranged from 5 to 25 years across the Jemez Mountains (Fig. 5). Significant spatial variation in past fire regimes is evident, depending upon such local factors as vegetation/fuel type, topography, and land-use history. Fire frequencies and area burned have been greatest in mid-elevation ponderosa pine forests. Fire activity commonly occurred over extensive areas (Allen et al., 1998); for example, watershed-wide fires occurred about every 16 years across the 9-mi-long Frijoles watershed in Bandelier before 1900 (Allen, 1989). In some years fires apparently burned across most of the Jemez Mountains (Allen et al., 1998), and indeed even across the Southwest (Swetnam et al., 1999; see graphics at: http://biology.usgs.gov/luhna/chap9.html).

Climate variability acted to regionally synchronize prehistoric fire activity, as major fire years were clearly associated with drought conditions, while wet periods recorded little fire activity (Touchan et al., 1996; Swetnam and Baisan, 1996; Swetnam and Betancourt, 1998). The most extensive fire activity in ponderosa pine forests occurred in dry years that followed within 1–3 years of wet conditions. This pattern of major fire years suggests the importance of both fuel production and fuel moisture in these fire regimes, with antecedent wet conditions stimulating the buildup of continuous fuels and subsequent drought conditions enabling the fuels to burn widely (Swetnam and Baisan, 1996). The common occurrence of persistent drought conditions in the Southwest likely allowed some fires to burn for months.

In most cases the seasonality of fire occurrence can be inferred by the relative position of a fire scar within the annual growth rings. The patterns of fire seasonality developed from prehistoric fire scars and modern fire records are generally

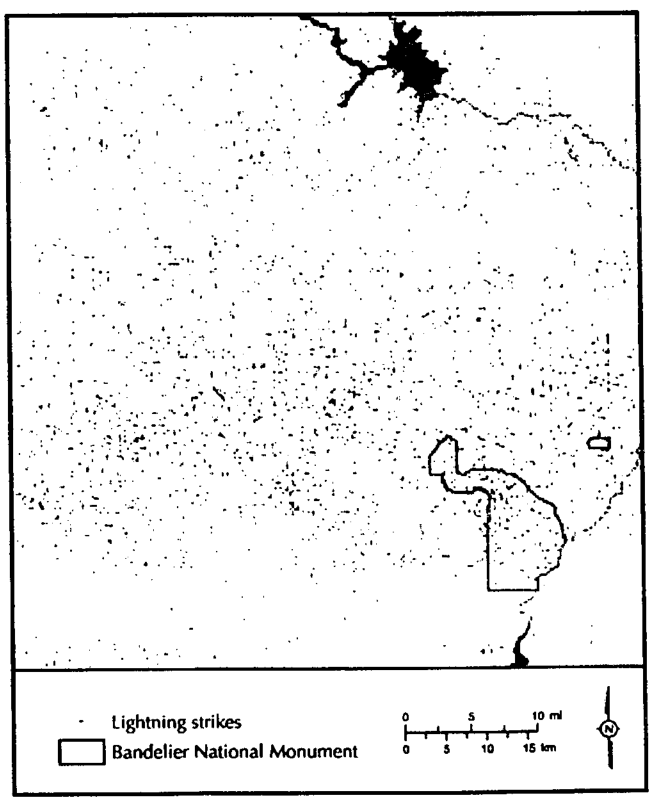

FIGURE 3—Map of 23,317 lightning strikes recorded across 2,994 mi² in the Jemez Mountains area during 1986 by the national automated lightning detection system. The nominal resolution of the locational data is ~± 2 km.

FIGURE 4—Open ponderosa pine forest representing "typical" pre-1900 conditions, with grassy understory and surface fire activity.

indistinguishable, indicating that prehistoric fires occurred during the same seasons as modern lightning-ignited fires—predominantly in the spring and summer. Fall fires were rare.

Spatial patterns of consecutive-year fire events indicate the importance of herbaceous fuels in supporting fire spread in pre-settlement forests. Railroads linked northern New Mexico to external markets by about 1880, leading to a local boom in livestock numbers. Abrupt declines in fire frequency throughout the Jemez Mountains in the late 1800s (Fig. 5), decades before active fire suppression, support the hypothesis that overgrazing induced suppression of surface fires as livestock (particularly sheep in mountain forests) literally ate the grassy fuels through which fires previously had spread. Fires would have repeatedly burned across widespread parts of the Southwest during the 20th century if the many natural and human-caused fires had not been vigorously suppressed after 1910 (Swetnam et al., 1999).

This history of livestock grazing and fire suppression in the Jemez Mountains has driven such landscape-wide vegetation changes as: increased density of woody species and accelerated erosion rates in piñon-juniper woodlands; conversion of ponderosa pine forests into thickets (or crown-fire-created grasslands and shrublands); changes in species composition and structure in mixed conifer forests (Fig. 6); and invasion of grasslands and meadows by trees and shrubs (Allen, 1989). Similar changes have occurred throughout the Southwest (Bogan et al., 1998; see graphics at http://biology.usgs.gov/s+t/SNT/noframe/sw152.htm). The increased densities of forests over the past century (often 10-fold increases) have markedly changed many ecosystem processes, including patterns of runoff and water yield from regional watersheds. For example, increased forest densities lead to decreases in total streamflow, peak flow, and base flow (Ffolliott et al., 1989), important concerns in the water-limited Southwest.

Fire behavior has also greatly changed due to the landscape-wide build ups of woody fuels associated with a century of fire suppression. As a result the frequency and severity of wildfire activity (including lightning-ignited fires) has been escalating despite increasing human suppression efforts, as the mean number of lightning fires/year in the Southwest grew by over 50% from 1940 to 1975 (Barrows, 1978) and the mean annual acreage burned has increased continuously since about 1960 (Swetnam and Betancourt, 1998). Unnatural stand-replacing conflagrations like the 1977 La Mesa fire (Allen, 1996), the 1996 Dome fire (Fig. 7), and the 2000 Cerro Grande fire are occurring more often in over-dense ponderosa pine forests

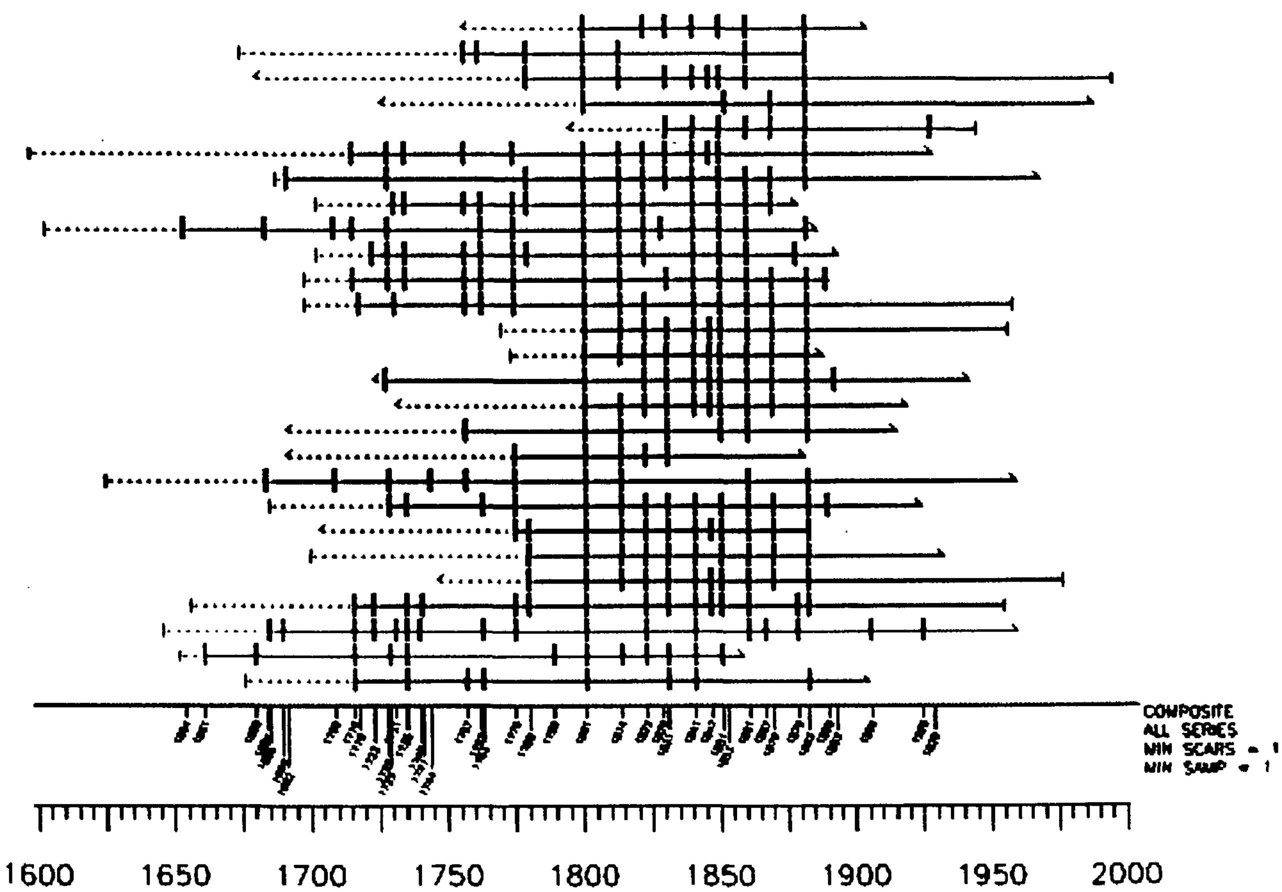

FIGURE 5—Fire scar chronology for Quemazon locality, western edge of Los Alamos townsite. Horizontal lines represent the life spans of individual trees, while fire scar events are shown by short vertical bars. Fire years are listed along the lower axis.

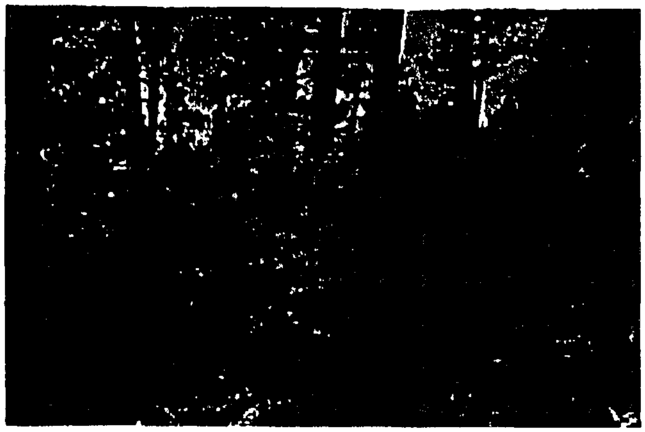

FIGURE 6—Altered ponderosa pine stand in need of restoration, showing changes in both stand structure and species composition. The dense midstory of mixed conifer trees provides ladder fuels that favor crown-fire development.

FIGURE 7—Dome fire, Day 2, April 26, 1996, near headwaters of Capulin Canyon.

(Covington and Moore, 1994). Extensive (>0.5 mi^2) stand-replacing fires rarely (if ever) occurred in pure, southwestern ponderosa pine forests before the middle of the 20th century. Severe crown fires typically cause major watershed impacts, including accelerated flooding and erosion. Twentieth century landscape scars created by stand-replacing fires in ponderosa pine and lower elevation mixed conifer are long-lasting lega-

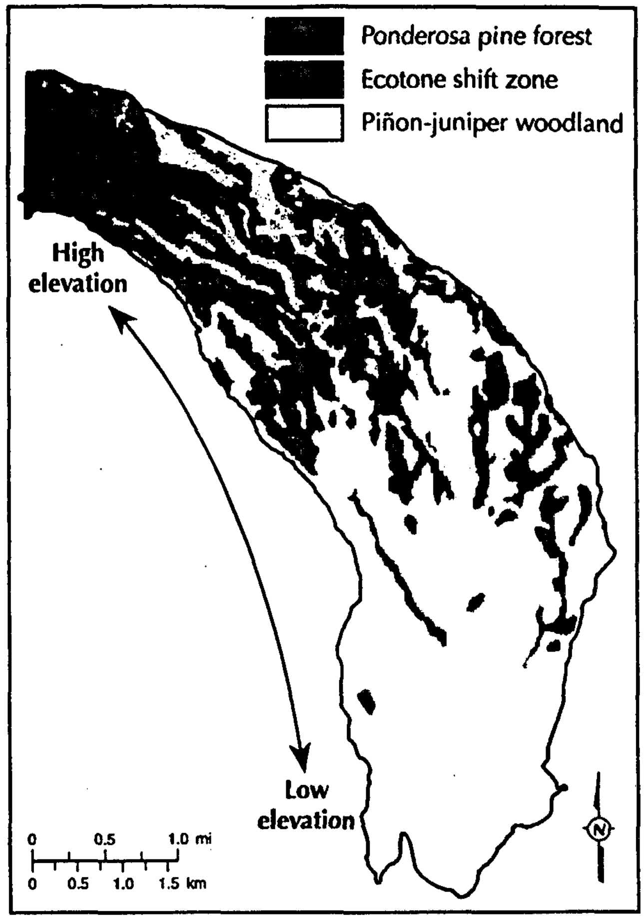

FIGURE 8—Changes in vegetation cover between 1954 and 1963 on Frijolito Mesa in Bandelier National Monument, showing persistent ponderosa pine forest (1.4 mi^2), persistent piñon-juniper woodland (5.9 mi^2), and the ecotone shift zone (1.9 mi^2) where forest changed to woodland due to the death of the overstory ponderosa pine trees.

cies of human error in managing these ecosystems. Recovery of forest communities within such burned and eroded landscapes may not occur for centuries. Fire history data and evidence of extreme geomorphic responses following extensive crown fires provide strong justification for management programs aimed at preventing the future occurrence of these ecological and societal disasters (Covington et al., 1997; Allen et al., in revision).

It is interesting to note that droughts can also cause extensive ecosystem changes by rapidly killing vegetation. For example, a severe, regional drought occurred during the 1950s in the Southwest. Associated tree mortality in the Jemez Mountains caused the ecotone between ponderosa pine forests and piñon-juniper woodlands to shift upslope by as much as 1.2 mi in less than 5 years (Fig. 8), while mixed piñon-juniper woodlands were converted to overstories of only juniper at many sites (Allen and Breshears, 1998). The 1950s drought may have also reduced herbaceous ground cover in these ecotone zones, contributing to current high erosion rates (discussed in a separate minipaper). Projected global climate changes may render over-dense southwestern forests increasingly susceptible to rapid decline through drought-induced mortality, associated insect outbreaks, and crown fires (Swetnam and Betancourt, 1998).

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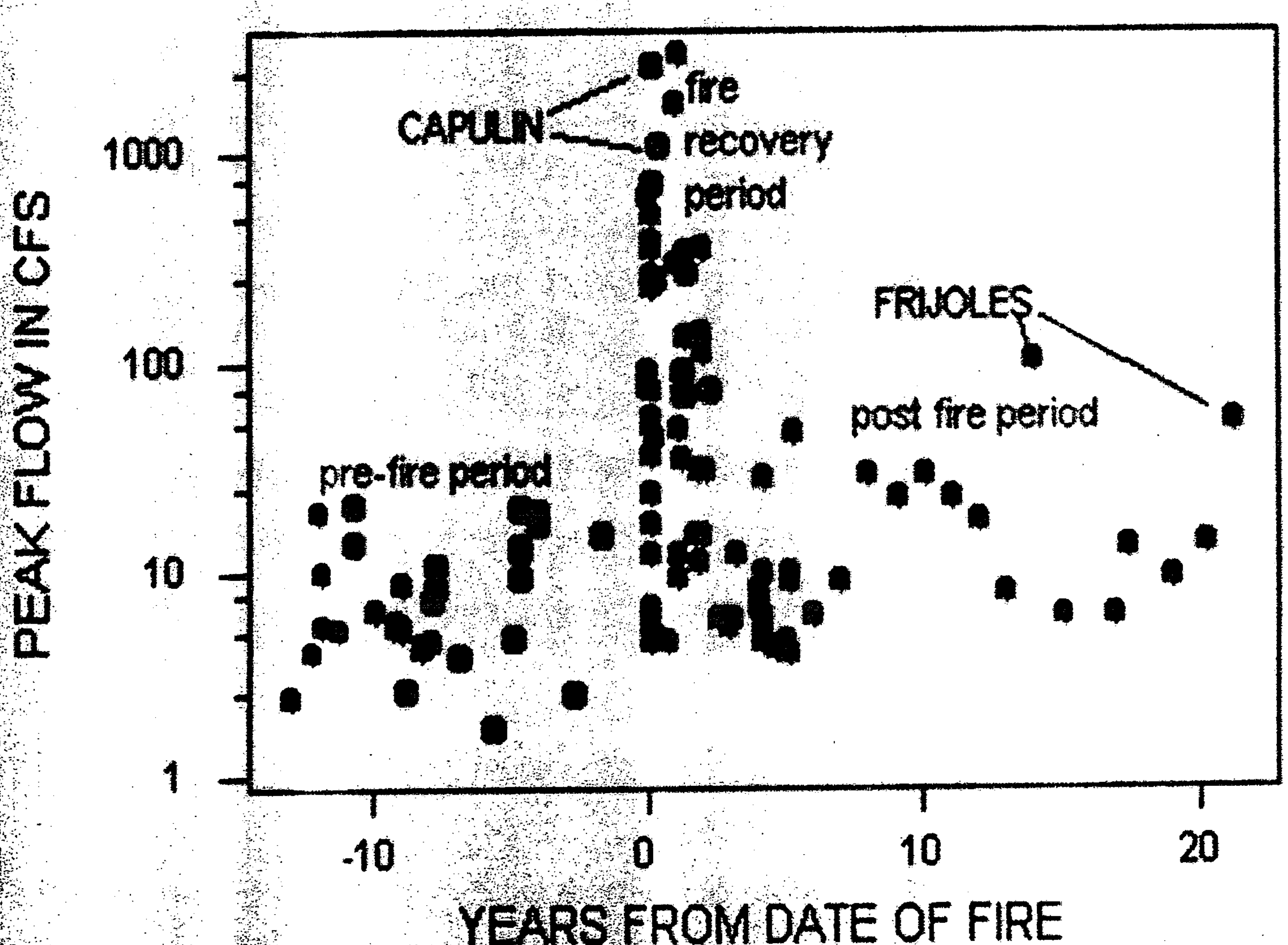
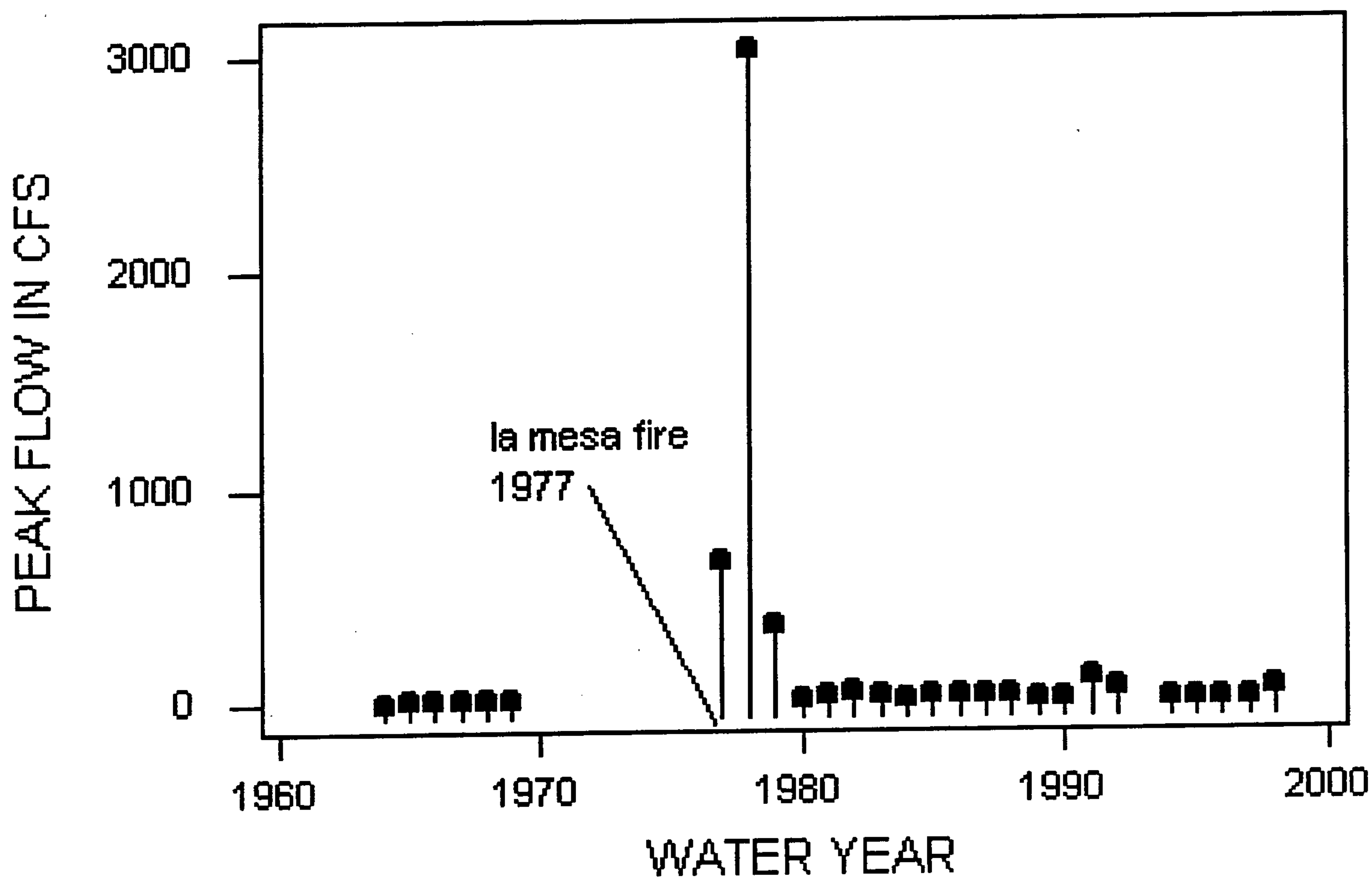
BANDELIER NATIONAL MONUMENT
PEAK FLOW IN TWO CANYONS BEFORE & AFTER A WILDFIRE



BANDELIER NATIONAL MONUMENT-RITO DE FRIJOLES CANYON
ANNUAL PEAK FLOW



An Annotated List of Ecohydrological Studies of the Pajarito Plateau

Reprints can be obtained by contacting
authors directly or Dave Breshears (daveb@lanl.gov).

Peer-Reviewed Journal Articles

Albrecht, A., G. F. Herzog, J. Klein, B. Dezfoulyaromandy, and F. Goff. 1993. **Quaternary erosion and cosmic-ray-exposue history derived from Be-10 and Al-26 produced insitu: an example from Pajarito Plateau, Valles Caldera Region.** *Geology* 21: 551-554.

- *Modeled erosion rates determined for different stratigraphic units within the Tshirege member, upper Bandelier Tuff, varied from 0.1 cm/ka for the resistant unit to 1.1 cm/ka for the softer unit.*

Allen, C. D., and D. D. Breshears. 1998. **Drought-induced shift of a forest-woodland ecotone: rapid landscape response to climate variation.** *Proceedings of the National Academy of Sciences of the United States of America* 95:14839-14842.

- *The most rapid shift of a woody ecotone to date, in which a severe drought the 1950s caused a rapid landscape scale ecotone shift due to ponderosa pine mortality and triggered high erosion rates.*

Allen, C.D., M. Savage, D.A. Falk, K.F. Suckling, T.W. Swetnam, T. Schulke, P.B. Stacey, P. Morgan, M. Hoffman, and J.Klingel. 2002. **Ecological restoration of Southwestern ponderosa pine ecosystems: A broad perspective.** *Ecological Applications* 12(5):(in press).

- *Overview of issues and principles associated with ecological restoration of forests in the Southwest, including the Jemez Mountains.*

Bowen, B.M. 1996. **Rainfall and climate variation over a sloping New Mexico plateau during the North American monsoon.** *Journal of Climate* 9 : 3432-3442.

- *Summary of spatial and temporal variation in precipitation on the Pajarito Plateau.*

Beeson, P. C., S. N. Martens, and D. D. Breshears. 2001. **Simulating overland flow following wildfire: mapping vulnerability to landscape disturbance.** Special issue: Wildfire and surficial processes. *Hydrological Processes* 15: 2917-2930.

- *Spatially-explicit modeling of pre- and post-fire runoff across a landscape highlights the importance of considering transfer of runoff from one cell to another for some locations.*

Brandes, D. and B. P. Wilcox. 2000. **Evapotranspiration and soil moisture dynamics on a semiarid ponderosa pine hillslope.** *Journal of the American Water Resources Association* 36: 965-974.

- *Soil moisture and water balance components from a ponderosa pine hillslope had a distinctly bimodal annual pattern (peaks occurring after spring snowmelt and during the late summer monsoon season) with weekly growing season ET rates invariably below calculated potential rates.*

Breshears, D. D., and C. D. Allen. 2002. **The importance of rapid, disturbance-induced losses in carbon management and sequestration.** Ecological Sounding. *Global Ecology and Biogeography* 11: 1-5.

- *Rapid landscape changes associated with fire and drought need to be better quantified and included in assessments for carbon management and sequestration.*

Breshears, D. D., and F. J. Barnes. 1999. **Interrelationships between plant functional types and soil moisture heterogeneity for semiarid landscapes within the grassland/forest continuum: a unified conceptual model.** *Landscape Ecology* 14: 465-478.

- *Accounting for both horizontal and vertical components of soil water unifies some concepts about woody-herbaceous plant ratios and land degradation.*

Breshears, D. D., O. B. Myers, S. R. Johnson, C. W. Meyer, and S. N. Martens. 1997. **Differential use of spatially heterogeneous soil moisture by two semiarid woody species: *Pinus edulis* and *Juniperus monosperma*.** *Journal of Ecology* 85: 289-299.

- *Both piñon and especially juniper are able to use shallow, intercanopy water, thereby somewhat overlapping in resource use with intercanopy herbaceous plants.*

Breshears, D. D., J. W. Nyhan, C. E. Heil, and B. P. Wilcox. 1998. **Effects of woody plants on microclimate in a semiarid woodland: soil temperature and evaporation in canopy and intercanopy patches.** *International Journal of Plant Sciences* 159: 1010-1017.

- *Differences in soil temperature under tree canopies vs. in intercanopy patches are sufficiently large to result in differential soil evaporation rates.*

Breshears, D. D., P. M. Rich, F. J. Barnes, and K. Campbell. 1997. **Overstory-imposed heterogeneity in solar radiation and soil moisture in a semiarid woodland.** *Ecological Applications* 7: 1201-1215.

- *Near-ground solar radiation and soil moisture differ between canopy and intercanopy patches and between north, center, south locations within a patch in a piñon-juniper woodland.*

Cannon, S. H., and S. L. Reneau, S.L., 2000, **Conditions for generation of fire-related debris flows, Capulin Canyon, New Mexico**. *Earth Surface Processes and Landforms* 25: 1103-1121.

- *Comparison of the response of three basins burned by the Dome fire of 1996 in New Mexico is used to identify the hillslope, channel and fire characteristics that indicate a susceptibility specifically to wildfire-related debris flow.*

Cannon, S. H., E. R. Bigio, and E. Mine. 2001. **A process for fire-related debris-flow initiation, Cerro Grande Fire, New Mexico**. *Hydrological Processes* 15: 3011-3023.

- *Storm-specific measurements of rates of hillslope sediment and runoff production, channel erosion, and storm rainfall accumulations from a steep, 0.15 km^2 basin burned during the May 2000 Cerro Grande fire are used to evaluate a processes for fire-related debris-flow initiation.*

Cannon, S. H., 2001. **Debris-flow generation from recently burned watersheds.** *Environmental and Engineering Geoscience* 7: 321-341.

- *Evaluation of the erosional response of 95 recently burned drainage basins is Colorado, New Mexico and southern California to storm rainfall provides information on the conditions that result in fire-related debris flows.*

Davenport, D. W., D. D. Breshears, B. P. Wilcox, and C. D. Allen. 1998. **Sustainability of piñon-juniper woodlands—a unifying perspective of soil erosion thresholds.** Viewpoint. *Journal of Range Management* 51: 231-240.

- *Thresholds between low and high erosion rates can be explained in terms of changing the amount and structure of vegetation patches, particularly by removing herbaceous patches and connecting bare patches.*

Davenport, D. W., B. P. Wilcox, and B. L. Allen. 1995. **Micromorphology of pedogenically derived fracture fills in Bandelier-tuff, New Mexico.** *Soil Science Society of America Journal* 59: 1672-1683.

- *Fills in fractures may be derived from older soils that have been stripped by erosion, with the presence of live roots throughout the fracture fills indicating the presence of water, but the smectitic clay and massive carbonate make it unlikely that significant water movement is now taking place through the fractures.*

Davenport, D. W., B. P. Wilcox, and D. D. Breshears. 1996. **Soil morphology of canopy and intercanopy sites in a piñon-juniper woodland.** *Soil Science Society of America Journal* 60: 1881-1887.

- *Canopy and intercanopy patches were similar in most soil physical properties, suggesting that if encroachment by piñon and juniper increases erosion risk, it is not due to changes in soil morphology.*

Dethier, D.P., and S. L. Reneau. 1996. **Lacustrine chronology links late pleistocene climate change and mass movements in northern New Mexico.** *Geology* 24: 539-542.

- *Well-dated lacustrine deposits in northern White Rock Canyon, New Mexico, record damming of the Rio Grande by at least four separate failures of a slump complex between about 17.5 and 12.4 ka (C-14), linking mass movements to a period of rapid climate change in the western United States.*

Hastings, B. K., F. M. Smith, and B. F. Jacobs. 2002. **Rapidly eroding piñon-juniper woodlands in New Mexico: response to slash treatment.** *Journal of Environmental Quality*: in press.

- *Tree thinning with application of the slash to a rapidly eroding woodland site effectively reduced erosion rates by more than two orders of magnitude.*

Johansen, M. P., T. E. Hakonson, and D. D. Breshears. 2001. **Post-fire runoff and erosion following rainfall simulation: contrasting forests with shrublands and grasslands.** Special issue: Wildfire and surficial processes. *Hydrological Processes* 15: 2953-2965.

- *Post-fire runoff from severely burned forests is greater than reported for other ecosystems, with forests being more vulnerable to rapid changes from low to high erosion rates.*

Kovacic, D. A. , D. M. Swift, J. E. Ellis, and T. E. Hakonson. 1986. **Immediate effects of prescribed burning on mineral soil-nitrogen in ponderosa pine of New Mexico.** *Soil Science* 141: 71-76.

- *Changes in soil-nitrogen following prescribed burning.*

Lajtha, K., and F. J. Barnes. 1991. **Carbon gain and water-use in pinyon pine-juniper woodlands of northern New Mexico: filed versus phytotron *chamber measurements.*** *Tree Physiology 9: 59-67.*

- *Based on phytotron chamber- and field-obtained gas exchange studies, piñon showed a greater response to increases in xylem pressure potential than juniper, and there were significant interactions between N and water use efficiency.*

Lajtha, K., and J. Getz. 1993. **Photosynthesis and water-use efficiency in pinyon-juniper woodland communities along an elevation gradient in northern New Mexico.** *Oecologia* 94: 95-101.

- *Piñon and juniper along a gradient both had higher water-use efficiency (WUE) at the lowest (driest) sites, but it appeared that changes in stand density compensated for changes in water availability, with water use efficiency related to foliar N for piñon but juniper.*

Malman, D. V., T. Dunne, and S. L. Reneau. 2002. **Predicting the fate of sediment and pollutants in river floodplains.** *Environmental Science and Technology* 36: 2026-2032.

- *A stochastic theory of sediment redistribution in alluvial valley floors that tracks particle-bound pollutants and explicitly considers sediment storage within floodplains indicates floodplain storage significantly reduces the rate of sediment delivery from upper Los Alamos Canyon.*

Martens, S. N., D. D. Breshears, and F. J. Barnes. 2001. **Development of species dominance along an elevational gradient: population dynamics of *Pinus edulis* and *Juniperus monosperma*.** *International Journal of Plant Sciences* 162: 777-783.

- *Piñons and junipers show increasing divergence with age when related to elevation, indicating mortality rather than establishment drives elevational patterns.*

Martens, S. N., D. D. Breshears, and C. W. Meyer. 2000. **Spatial distributions of understory light along the grassland/forest continuum: effects of cover, height, and spatial pattern of tree canopies.** *Ecological Modelling* 126: 79-93.

- *Estimates of general solar radiation patterns for plots and for canopy and intercanopy patches as a function of tree height, cover, and spatial pattern.*

Martens, S. N., D. D. Breshears, C. W. Meyer, and F. J. Barnes. 1997. **Scales of above-ground and below-ground competition in a semiarid woodland as detected from spatial pattern.** *Journal of Vegetation Science* 8: 655-664.

- *Spatial pattern of piñons and junipers suggest that both above- and below-ground competition are structuring the woodland, which is intermediate along a grassland-forest continuum.*

Martin, D. A., and J. A. Moody. 2001. **Comparison of soil infiltration rates in burned and unburned mountainous watersheds.** *Hydrological Processes* 15: 2893-2903.

- *The ratio of steady-state infiltration rate in burned sites to unburned sites was 0.15 in ponderosa forests on volcanic soils, 0.38 in mixed conifer forests on volcanic soils, and 0.38 for ponderosa pine forests on granitic soils.*

Moody, J. A., and D. A. Martin. 2001, **Post-fire, rainfall intensity-peak discharge relations for three mountainous watersheds in the western United States.** *Hydrological Processes* 15: 2981-2993.

- *A possible threshold of maximum 30-minute rainfall intensity was identified above which unit area peak discharges increase with increase in intensity more rapidly and reach a maximum of about 50* $m^3\ s^{-1}\ km^{-2}$.

McLin, S.G., E. P. Springer, and L. J. Lane. 2001. **Predicting floodplain boundary changes following the Cerro Grande Wildfire.** *Hydrological Processes* 15: 2967-2980.

- *A combined ArcView GIS-HEC modelling application for floodplain analysis of pre- and post-burned watersheds was applied in assessing flooding issues after the Cerro Grande fire.*

Newman BD, A. R. Campbell, and B. P. Wilcox. 1998. **Lateral subsurface flow pathways in a semiarid ponderosa pine.** *Water Resources Research* 34: 3485-3496.

- *Natural chloride, dissolved organic carbon, and stable isotope (delta D and delta(18)O) tracers were used to investigate the lateral subsurface flow process and the chemical changes that occur as a result of lateral subsurface flow, indicative of a two-domain flow system in which macropores conduct lateral subsurface flow that is not in chemical or hydrological equilibrium with the soil matrix.*

Newman B. D., A. R. Campbell, and B. P. Wilcox. 1997. **Tracer-based studies of soil water movement in semi-arid forests of New Mexico.** *Journal of Hydrology* 196:251-270.

- *Stable-isotope data indicate a similarity between pinyon-juniper and ponderosa communities with respect to evaporation (restricted mainly to the upper 10 cm of soil), whereas chloride profiles show a distinct difference between the two with respect to downward fluxes, with those for ponderosa pine forest being an order of magnitude lower than those in the piñon-juniper woodland.*

Padien, D. J., and K. Lajtha. 1992. **Plant spatial pattern and nutrient distribution in pinyon-juniper woodlands along anelevational gradient in northern New Mexico.** *International Journal of Plant Sciences* 153: 425-433.

- *Along an elevational gradient where the ratio piñon to juniper increases, seedling establishment patterns could result from nutrient-availability differences, shade protection, or seed-dispersal and germination patterns, but probably not from microsite water differences.*

Reid, K. D., B. P. Wilcox, D. D. Breshears, and L. MacDonald. 1999. **Runoff and erosion for vegetation patch types in a piñon-juniper woodland.** *Soil Science Society of America Journal* 63:1869-1879.

- *Runoff and erosion vary among tree canopy patches, intercanopy herbaceous patches, and intercanopy bare patches, with runoff being redistributed from bare to herbaceous patches for most storms.*

Reneau S.L., and D. P. Dethier. 1996. **Late Pleistocene landslide-dammed lakes along the Rio Grande, White Rock canyon, New Mexico.** *Geological Society of America Bulletin* 108: 1492-1507.

- *Massive slump complexes composed of Pliocene basaltic rocks and underlying Miocene and Pliocene sediments that indicate that three separate lakes formed between 13.7 and 12.4(14)C ka, with some of the landslide dams apparently stable.*

Reneau, S.L. 2000. **Stream incision and terrace development in Frijoles Canyon, Bandelier National Monument, New Mexico, and the influence of lithology and climate.** *Geomorphology* 32: 171-193.

- *Climatic influences on sediment supply and flood characteristics, mediated by lithologic variations in the canyon bottom, have controlled Late Quaternary stream profile evolution.*

Swetnam, T.W., C. D. Allen, and J. L. Betancourt. 1999. **Applied historical ecology: Using the past to manage for the future.** *Ecological Applications* 9:1189-1206.

- *Use of historical ecology to support land management, using examples from the Southwest, including the Jemez Mountains.*

Wilcox, B.P. 1994. **Runoff and erosion in intercanopy zones of a piñon-juniper woodland.** *Journal of Range Management* 47: 285-295.

- *Runoff and erosion in intercanopy zones varied between summer and winter, leading to hypotheses about how runoff amounts vary with scale, the infiltration capacity of soils is dynamic, and an annual cycle of soil erodibility.*

Wilcox, B. P., D. D. Breshears, and C. D. Allen. 2003. **Ecohydrology of resource-conserving semiarid woodland: temporal and spatial relationships and the role of disturbance.** *Ecological Monographs:* in press.

- *Long-term runoff and erosion data indicate a lack of relationship between precipitation amount and runoff, vegetation-influenced scale-dependent relationships in runoff and erosion, and persistence in elevated erosion rates following disturbance.*

Wilcox, B. P., and D. D. Breshears. 1997. **Interflow in semiarid environments: an overlooked process in risk assessment.** *Human and Ecological Risk Assessment* 3: 187-203.

- *Shallow, subsurface lateral flow documented in ponderosa pine forest has important implications for assessing contaminant transport issues.*

Wilcox B.P., B. D. Newman, D. Brandes, D. W. Davenport, and K. Reid. 1997. **Runoff from a semiarid ponderosa pine hillslope in New Mexico** *Water Resources Research* 33:2301-2314.

- *Measurements of components of the water budget for a ponderosa pine ecosystem, documenting that runoff accounts for between 3 and 11% of the annual water budget and that lateral subsurface flow is a major mechanism of runoff generation, especially following periods of above-average fall and winter precipitation.*

Wilson C.J., J. W. Carey, P. C. Beeson, M. O. Gard, L. J. Lane. 2001. **A GIS-based hillslope erosion and sediment delivery model and its application in the Cerro Grande burn area.** *Hydrological Processes* 15:2995-3010.

- *A profile-based, analytical model predicts rill and interrill erosion and sediment delivery to channels along flow pathways within a GIS framework to assess the impact of the Cerro Grande Fire across an 800 km2 area of the Jemez Mountains and Pajarito Plateau in NM.*

An Annotated List of Ecohydrological Studies of the Pajarito Plateau

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Book Chapters and Proceedings

Allen, C.D. 2002. **Lots of lightning and plenty of people: An ecological history of fire in the upland Southwest.** Pp. 143-193 in: T.R. Vale (ed.), *Fire, Native Peoples, and the Natural Landscape.* Island Press, Covelo, CA.

- *Most current and comprehensive review of fire history in the Southwest in general, and the Jemez Mts. in particular.*

Allen, C.D., J.L. Betancourt, and T.W. Swetnam. 1998. **Landscape changes in the southwestern United States: Techniques, long-term datasets, and trends.** Pages 71-84 In: T.D. Sisk (ed.), *Perspectives on the Land Use History of North America: A Context for Understanding our Changing Environment.* U.S. Geological Survey, Biological Science Report USGS/BRD/BSR-1998-0003. 104 p. Available online at *http://biology.usgs.gov/luhna/chap9.html*

- *Graphic illustration of methods for determining patterns of landscape change in the Southwest, including the Jemez Mountains.*

Allen, C.D. (tech. ed.). 1996. **Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium**; 1994 March 29-31; Los Alamos, New Mexico. USDA Forest Service Gen. Tech. Rep. RM-GTR-286. Fort Collins, CO. 216 p.

- *Proceedings volume covering fire effects on vegetation, erosion, birds, nitrogen cycling, elk, arthropods, and cultural resources.*

Bogan, M.A., C.D. Allen, E.H. Muldavin, S.P. Platania, J.N. Stuart, G.H. Farley, P. Melhop, and J. Belnap. 1998. **Southwest.** Pages 543-592 In: Mac, M.J., P.A. Opler, and P.D. Doran (eds.). *National Status and Trends Report*, U.S. Geological Survey, Washington, D.C. 964 p. Available online at *http://biology.usgs.gov/s+t/SNT/noframe/sw152.htm*

- *Review of the history, current status, and trends of biological resources in the Southwest, prominently featuring the Jemez Mountains.*

Gottfried, G., T. W. Swetnam, C. D. Allen, J. L. Betancourt, and A. Chung-MagCoubrey. 1995. Chapter 6: **Pinyon-juniper woodlands.** Pages 95-132 in D. M. Finch, and J. A. Tainter, (tech. eds.). *Ecology, Diversity, and Sustainability of the Middle Rio Grande Basin.* USDA Forest Service Gen. Tech. Rep. RM-GTR-268. Fort Collins, CO. 195 p.

- *Summary of piñon-juniper woodland ecology for this area.*

Jacobs, B. F., and R. G. Gatewood. 1999. **Restoration studies in degraded piñon-juniper woodlands of north-central New Mexico.** In S.B. Monsen, R. Stevens, R.J. Tausch, R. Miller and S. Goodrich (eds.), Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West. USDA Forest Service Proc. RMRS-P-9. Ogden, UT. pp. 294–298.

- *Summarizes initial vegetation responses to restoration treatments in piñon-juniper woodlands at Bandelier National Monument.*

Loftin, S.R. 1999. **Initial response of soil and understory vegetation to a simulated fuelwood cut of a pinyon-juniper woodland in the Santa Fe National Forest.** In S.B. Monsen, R. Stevens, R.J. Tausch, R. Miller and S. Goodrich (eds.), Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West. USDA Forest Service Proc. RMRS-P-9. Ogden, UT. pp. 311–314.

- *Summarizes initial soil and vegetation responses to restoration treatments in piñon-juniper woodlands at just north of Los Alamos.*

Sydoriak, C.A., C.D. Allen, and B.F. Jacobs. 2000. **Would ecological landscape restoration make the Bandelier Wilderness more or less of a wilderness?** Pp. 209-215 In: D.N. Cole, S.F. McCool, W.T. Borrie, and F. O'Loughlin (comps.). *Proceedings: Wilderness Science in a Time of Change Conference—Volume 5: Wilderness Ecosystems, Threats, and Management*; 1999 May 23-27; Missoula, MT. USDA Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-15-VOL-5. Ogden, UT.

- *Reviews the erosion issue at Bandelier, and discusses the practical and philosophical implications of practicing ecological restoration in designated wilderness areas.*

Touchan, R., C.D. Allen, and T.W. Swetnam. 1996. **Fire History and Climatic Patterns in Ponderosa Pine and Mixed-Conifer Forests of the Jemez Mountains, Northern New Mexico.** Pp. 33-46 In: C.D. Allen (tech. ed.), Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium. USDA Forest Service Gen. Tech. Rep. RM-GTR-286. Fort Collins, CO. 216 p.

- *A detailed overview of Jemez Mountains fire scar chronologies.*

Veenhuis, J. 2002. **Effects of wildfire on the hydrology of Capulin and Rito de los Frijoles Canyons, Bandelier National Monument, New Mexico.** USDI, U.S. Geological Survey, Water-Resources Investigations Report 02-4152. USDI, US Geological Survey, WRD, 5338 Montgomery Blvd NE, Suite 400, Albuquerque, NM 87109-1311. 39 p.

- *Detailed hydrological investigations into the effects of 2 major wildfires on 2 local watersheds.*

White, W. D. 1996. **Geomorphic responses of six headwater basins fifteen years after the La Mesa Fire.** Pages 95-113 in C. D. Allen, technical editor. Fire effects in Southwestern forests: Proceedings of the Second La Mesa Fire Symposium. USDA Forest Service General Technical Report RM-GTR-286. Fort Collins, Colorado.

- *Detailed, long-term study of upland geomorphic responses to a major fire at Bandelier National Monument.*

Wilcox, B. P., and D. D. Breshears. 1995. **Hydrology and ecology of pinyon-juniper woodlands: conceptual framework and field studies.** Pages 109-119 *in* Desired Furture Conditions for Pinyon-Juniper Ecosystems. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff Arizona.

- *Hypotheses about spatial scale and runoff and erosion.*

Wilcox, B. P., B. D. Newman, C. D. Allen, K. D. Reid, D. Brandes, J. Pitlick, and D. W. Davenport. 1996. **Runoff and erosion on the Pajarito Plateau: observations from the field.** Pages 433-439 *in* Geology of the Los Alamos-Jemez Mountains Region.

- *Summary of runoff and erosion studies in ponderosa pine forest and piñon-juniper woodland.*

Wilcox, B. P., J. Pitlick, C. D. Allen, and D. W. Davenport. 1996. **Runoff and erosion from a rapidly eroding pinyon-juniper hillslope.** Pages 61-71 *in* M. G. Anderson and S. M. Brooks, editors. Advances in Hillslope Processes. John Wiley & Sons, New York.

- *Documentation of high erosion at a site where vegetation died in response to a drought in the 1950s.*