Prepared in cooperation with the U.S. Department of the Army

Temporal and Spatial Variations in Precipitation, Streamflow, Suspended-Sediment Loads and Yields, and Land-Condition Trend Analysis at the U.S. Army Piñon Canyon Maneuver Site, Las Animas County, Colorado, 1983 Through 2007

Scientific Investigations Report 2008–5111

U.S. Department of the Interior
U.S. Geological Survey

FRONT COVER

Welsh Canyon, Piñon Canyon Maneuver Site, southeast Colorado. Photograph courtesy of John Kuzmiak, U.S. Geological Survey, October 2005.

BACK COVER

Background

Sunset, Piñon Canyon Maneuver Site. Photograph courtesy of John Kuzmiak, U.S. Geological Survey, 2006.

Top to Bottom

Van Bremer Arroyo at U.S. Geological Survey gaging station, Piñon Canyon Maneuver Site. Photograph courtesy of John Kuzmiak, U.S. Geological Survey, 1999.

Concealed tank. Photograph courtesy of U.S. Department of the Army.

U.S. Geological Survey gaging station, Red Rock Canyon, Piñon Canyon Maneuver Site. Photograph courtesy of John Kuzmiak, U.S. Geological Survey, 2001.

Taylor Arroyo at U.S. Geological Survey gaging station, Piñon Canyon Maneuver Site. Photograph courtesy of John Kuzmiak, U.S. Geological Survey, 1999.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
meter (m)	3.281	foot (ft)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton per day (ton/d)	0.9072	metric ton per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

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By M.R. Stevens, J. Dupree, and J.M. Kuzmiak

Abstract

In 2007, the U.S. Geological Survey, in cooperation with the U.S. Department of the Army, began an assessment of the spatial and temporal variations in precipitation, streamflow, suspended-sediment loads and yields, changes in land condition, effects of the tributaries on the Purgatoire River and the possible relation of effects from military training to hydrology and land conditions that have occurred at Piñon Canyon Maneuver Site (PCMS) from 1983 through 2007. Data were collected for precipitation (19 stations) and streamflow and sediment load (5 tributary and 2 main-stem Purgatoire River stations) during 1983 through 2007 for various time periods. The five tributary stations were Van Bremer Arroyo near Model, Taylor Arroyo below Rock Crossing, Lockwood Canyon Creek near Thatcher, Red Rock Canyon Creek at the mouth, and Bent Canyon Creek at the mouth. In addition, data were collected at two Purgatoire River stations: Purgatoire River near Thatcher and Purgatoire River at Rock Crossing.

Streamflow and sediment transport at PCMS were dependent upon precipitation. Ground-water and irrigation return-flow contributions to streamflow were present only at Van Bremer and Lockwood streamflow-monitoring stations. A probability plot indicates that precipitation of less than 0.01 inch generally occurs about 80 percent of the days of the 214-day period from April through October. While most of the storms are small, the larger storms produce most of the precipitation that falls on PCMS given that about 45 percent of runoff-producing storms were larger than 1 inch.

Storms larger than 1.0 inch of precipitation were associated with about 78 percent of total runoff during the period 1983 through 2007 at the Taylor monitoring station. Small storms, less than 0.5-inch total precipitation, were associated with only 2.6 percent of the total runoff in the same period. This indicates that larger storms are generally more important to streamflow-runoff generation, despite occurring less frequently. Statistical trend tests indicated that there were no statistically significant temporal trends in streamflow at the tributary streamflow stations at PCMS for the 1983 through 1990, 2000 through 2007, or 1983 through 2007 periods.

To assess spatial differences, storm-total streamflow yields were normalized to drainage area and precipitation for the 2000 through 2007 period and tested using the Mann-Whitney rank-sum test. Storm-total streamflow yields from 2000 through 2007 at Van Bremer were not significantly different from Taylor but were significantly different from Lockwood, Red Rock, and Bent. The storm-total streamflow yields at Taylor were significantly different from Lockwood, Red Rock, and Bent for the 2000 through 2007 period. The southernmost two tributary stations (Van Bremer and Taylor) were statistically similar, and the northern three stations (Lockwood, Red Rock, and Bent) were statistically similar, but the two groups (southern and northern) were significantly different. The reason for the spatial variations among watersheds may be associated with the following: differences in precipitation intensity among the watersheds, watershed morphology, topography, or geology, or differences in land condition, military training, and the intensity of pre-maneuver grazing and rates of post-grazing vegetation recovery.

Streamflow from tributary watersheds to larger streams and rivers as a result of storm runoff can be an issue if the flow is excessive when compared to the flow in the receiving stream or river. During the April through October period the cumulative daily tributary streamflow was greater than 5 percent of the daily streamflow at the Purgatoire Rock Crossing station only 3 percent of the time, indicating that the flow contribution from the PCMS generally was small.

During the 1983 through 2006 period, storm-total precipitation values larger than 1.5 inch at the Colorado Interstate Gas (CIG) precipitation-monitoring station were associated with about 73 percent of the storm-total sediment load at Taylor. Smaller storms less than 0.5-inch total precipitation were associated with only about 3 percent of the sediment load, despite accounting for 79 percent of the number of storms for the same period. This indicates that larger, less frequent storms generally are more of a factor in sediment transport than smaller, more frequent storms.

Sediment transport from the PCMS tributaries to the Purgatoire River is an important issue because excess suspended sediment may affect aquatic habitat or cause infilling of downstream reservoirs. During the April through October 2000 through 2006 period, 2 percent of the time the daily tributary load was greater than 20 percent of the daily load in the estimated sediment-load time-series at the Purgatoire Rock Crossing station. The tributary watersheds at PCMS are 13.9 percent of the drainage area of the Purgatoire Rock Crossing station. The stormflow suspended-sediment load contribution of the tributaries to stormflow loads at the Purgatoire Rock Crossing station was about 3.5 percent during the 2000 through 2006 period, indicating that the suspended-sediment load contribution from the PCMS generally was small.

Seasonal Kendall test for temporal trends in monthly flow-adjusted sediment loads for the 1983 through 2006, 1983 through 1990, and 2000 through 2006 periods indicated no significant or moderately significant monotonic temporal trends. A comparison of temporal differences between the 1983 through 1990 and 2000 through 2006 periods using the Mann-Whitney test indicated that median storm-total sediment yields (normalized to streamflow) were larger at both Taylor and Bent during the 1983 through 1990 period. For streamflow, there was a lack of statistically significant, substantial monthly or storm-total streamflow temporal trends for the 1983 through 2006 period at Taylor. But, changes in land-cover conditions and possibly precipitation may be responsible for some of the changes in storm-total sediment load rather than changes in streamflow, which showed no temporal trends. However, precipitation does not seem to be related to long-term changes in streamflow, and thus the relation between precipitation and sediment load is unclear.

The relative lack of 1983 through 1990 or 2000 through 2006 temporal trends in sediment load and yield was consistent with no temporal trends in streamflow for the same periods, but was not consistent with the finding of significant downward trends in precipitation at Van Bremer and Taylor during the 2000 through 2006 period, indicating that the processes of precipitation, runoff, and sediment erosion are complex, especially on short time scales.

Graphical distributions among tributary monitoring stations of suspended-sediment load normalized to storm-total streamflow and drainage area indicated an upward trend northward from Van Bremer to Bent during the 2000 through 2006 period. Mann-Whitney rank-sum test results supported the north to south differences by indicating differences between Van Bremer and the three northern tributaries of Lockwood, Red Rock, and Bent. However, no significant spatial differences between Taylor and the northern tributaries were indicated. Variations in geology and the differences in soil types or depths derived from the rocks in each of the watersheds, the topography and relief developed from that geology, the rainfall intensity, and the number of erosion-control ponds all might contribute to the spatial differences in suspended-sediment transport.

General sitewide Land-Condition Trend Analysis (LCTA) spatial patterns indicated larger and more variable disturbance and bare ground, and a tendency for less ground cover in the area between the Van Bremer and Lockwood streams. Because the Soil Protection Area along the western boundary of PCMS (SPA) and the eastern one-half of the area between Red Rock and Bent had areas that were off-limits to vehicular mechanized training, these plots indicated that areas with less mechanized training generally had less disturbance and bare ground and, in the Red Rock-Bent area, also relatively more ground cover. However, individual years of increased land disturbance, decreased ground cover, and increased bare-ground percentages did not correlate well with individual years of large streamflow yields or suspended-sediment yield. Most of the years with relatively increased disturbance, decreased ground cover, and increased bare-ground percentages do not seem to correlate well with the years of large streamflow yield or with suspended-sediment yield. The lack of correlation might be related to the missing years of LCTA information during the period. Another explanation could be that sediment delivery to the station locations in the watersheds requires a longer period than the assumed same-year response.

Because hydrologic data were available at Taylor and precipitation data were available at CIG during the 1983 through 2007 period, which includes the 1989 through 1999 LCTA period, the LCTA transects located within the Taylor drainage area were evaluated as a subset of all PCMS LCTA transects. Sediment and streamflow yields at Taylor showed some similarity in pattern with both ground cover and bare ground changes from 1989 through 1994. The disturbance metric showed patterns that were more similar to streamflow yield than to sediment yield. The analysis of LCTA metrics, streamflow, and sediment transport indicated that only a small similarity exists in the temporal patterns at Taylor during the 1989 through 1999 period.

Introduction

The Piñon Canyon Maneuver Site (PCMS) is composed of 381 square miles of rangeland and canyons in a semiarid part of southeastern Colorado located in Las Animas County, about 25 miles northeast of Trinidad, Colorado. Tributaries that drain the PCMS are intermittent or ephemeral (von Guerard and others, 1987) and primarily drain to the Purgatoire River, which flows northeastward from Trinidad and along the southeastern boundary of PCMS (fig. 1 and pl. 1). The site was acquired by the U.S. Department of the Army (Army) for mechanized and nonmechanized training in 1983, and military maneuvers began in July 1985 (von Guerard and others, 1987). Types of training activities have included the use of wheeled and track vehicles, mine plowing, trenching, defensive positions, bivouac areas, roads, and trails (Jeff Linn, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written commun., March 2008).

In 2007, the U.S. Geological Survey, in cooperation with the U.S. Department of the Army, began an assessment of the spatial and temporal variations in precipitation, streamflow,

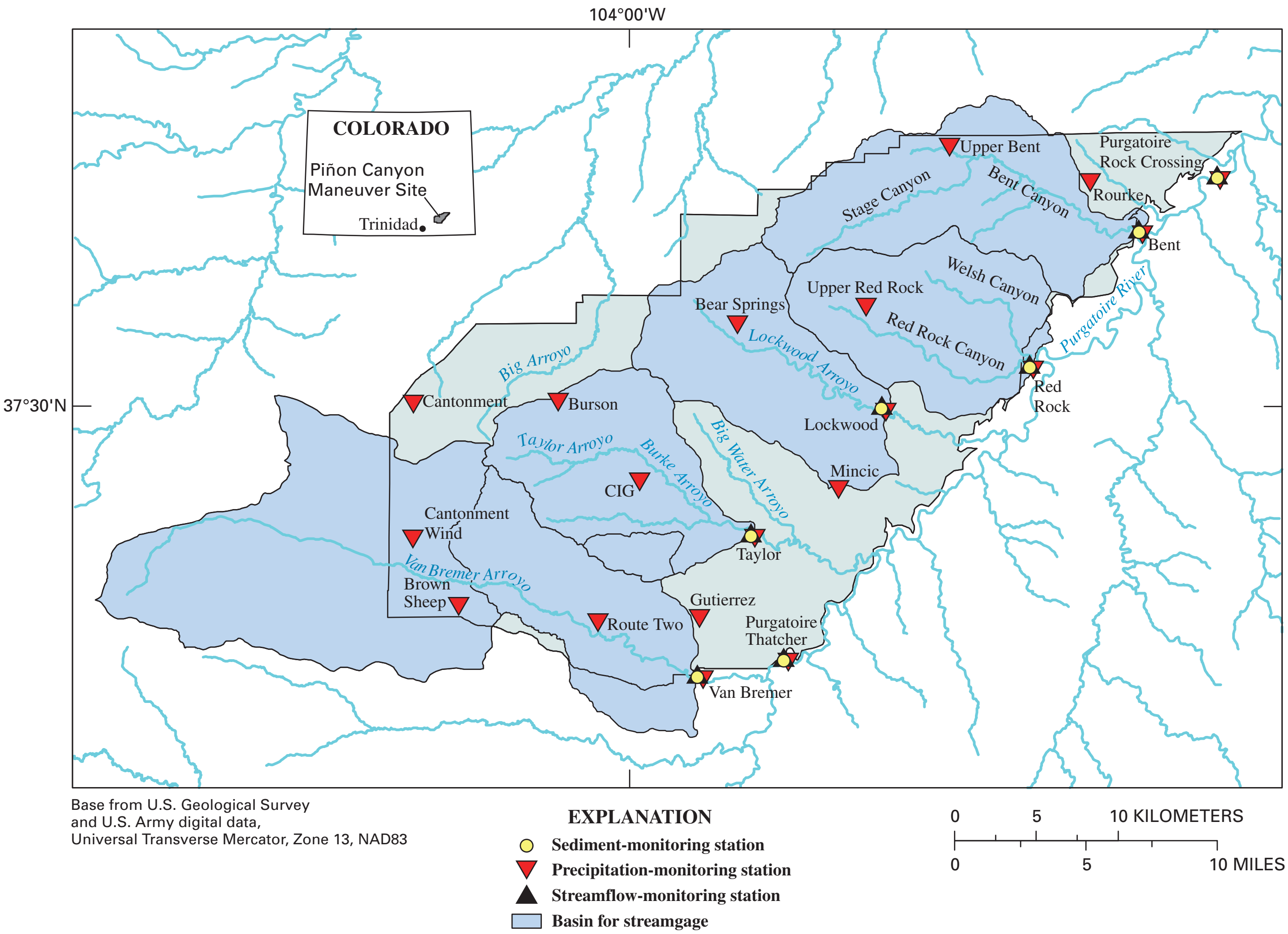

Figure 1. Location map of Piñon Canyon Maneuver Site showing U.S. Geological Survey streamflow, precipitation, and sediment monitoring stations. Station names in table 1.

suspended-sediment loads and yields, changes in land condition, effects of the tributaries on the Purgatoire River and the possible relation of effects from military training to hydrology and land conditions at the PCMS from 1983 through 2007.

Purpose and Scope

The purpose of this report is to describe the temporal and spatial variations of precipitation, streamflow, and suspended-sediment loads and yields. Also described are the relative contribution of streamflow and suspended-sediment yields from PCMS to the Purgatoire River downstream from PCMS, and changes in land condition that have occurred at PCMS from 1983 through 2007.

The scope of this report is limited to analysis of existing USGS data collected from 1983 through 2007 (table 1) and Land-Condition Trend Analysis (LCTA) data provided by the Army from 1989 through 1999. The analysis in this report covers the April through October seasonal period for each year. As shown in table 1, data collected by the USGS have varied substantially over time at various locations. As a result, data generally are presented for two time periods—from 1983 through 1990 and from 2000 through 2007, and, for some analyses, 1983 through 2007 (2006 for sediment). Precipitation and streamflow data were available from April 1983 through September 2007, and suspended-sediment data generally were available from April 1983 through September 2006.

Description of Study Area and Military Training Activities

The Piñon Canyon maneuver site is bounded generally on the west and north by uplands, by the Big Arroyo Hills on the west, and by the Bear Springs Hills on the north (pl. 1). A hogback lies along the southern boundary, and the eastern boundary is defined by the canyon of the Purgatoire River (pl. 1). The uplands and hills are forested with piñon pine and juniper trees. Rolling short-grass prairie lies between the uplands and the canyons. Livestock grazing, which was the primary land

Table 1. Summary of available precipitation, streamflow, and suspended-sediment data collected at Piñon Canyon Maneuver Site from 1983 through 2007.

[Contributing drainage area, mi^2; n/a, not applicable; short names shown in figure 1 and on plate 1; P, April through October; S, storms only; *, no break in operation, just a change from12-month to April through October operation; drainage areas are somewhat different than those reported in von Guerard and others (1993) because of revisions to contributing drainage area; CIG, Colorado Interstate Gas]

U.S. Geological Survey station number	Station name	Short name	Period of record	Contributing drainage area
		Precipitation-monitoring stations		
07126200	Van Bremer Arroyo near Model	Van Bremer	1999 through 2007 P	n/a
07126325	Taylor Arroyo below Rock Crossing	Taylor	1999 through 2007 P	n/a
07126390	Lockwood Canyon Creek near Thatcher	Lockwood	1999 through 2007 P	n/a
07126415	Red Rock Canyon Creek at the mouth	Red Rock	1999 through 2007 P	n/a
07126480	Bent Canyon Creek at the mouth	Bent	1999 through 2007 P	n/a
07126300	Purgatoire River near Thatcher	Purgatoire Thatcher	1999 through 2007 P	n/a
07126485	Purgatoire River at Rock Crossing	Purgatoire Rock Crossing	1999 through 2007 P	n/a
373232103555201	Bear Springs Hills	Bear Springs[1]	1983 through 2007	n/a
372319104073301	Brown Sheep Camp	Brown Sheep	1999 through 2007	n/a
373003104032001	Burson Well	Burson	1999 through 2007	n/a
372959104092201	Cantonment	Cantonment	1993 through 2007	n/a
372532104093001	Cantonment Windmill	Cantonment Wind	1999 through 2007	n/a
372721103595601	CIG Pipeline South	CIG[2]	1983 through 2007	n/a
372249103573302	Gutierrez Windmill	Gutierrez	1999 through 2007	n/a
372701103514501	Mincic	Mincic	1999 through 2007	n/a
373706103410701	Rourke	Rourke	1999 through 2007	n/a
372329104020501	Route Two Windmill	Route Two	1999 through 2007	n/a
373823103465601	Upper Bent Canyon	Upper Bent[3]	1983 through 2007	n/a
373315103493101	Upper Red Rock Canyon	Upper Red Rock[4]	1983 through 2007	n/a
		Streamflow-monitoring stations		
07126200	Van Bremer Arroyo near Model	Van Bremer	1983 through 1998, 1999 through 2007 P,*	163.2
07126325	Taylor Arroyo below Rock Crossing	Taylor	1983 through 1998, 1999 through 2007 P,*	48.4
07126390	Lockwood Canyon Creek near Thatcher	Lockwood	1983 through 1993, 1999 through 2007 P	48.8
07126415	Red Rock Canyon Creek at the mouth	Red Rock	1983 through 1990, 2000 through 2007 P	48.9
07126480	Bent Canyon Creek at the mouth	Bent	1984, 1986 through 1990, 2000 through 2007 P,*	56.2
07126300	Purgatoire River near Thatcher	Purgatoire Thatcher	1983 through 2007	1,779
07126485	Purgatoire River at Rock Crossing	Purgatoire Rock Crossing	1983 through 2007	2,623
		Suspended-sediment-monitoring stations		
07126200	Van Bremer Arroyo near Model	Van Bremer	1999 through 2006 P,S	163.2
07126325	Taylor Arroyo below Rock Crossing	Taylor	1983 through 1998, 1999 through 2006 P,S,*	48.4
07126390	Lockwood Canyon Creek near Thatcher	Lockwood	1999 through 2006 P,S	48.8
07126415	Red Rock Canyon Creek at the mouth	Red Rock	2000 through 2006 P,S	48.9
07126480	Bent Canyon Creek at the mouth	Bent	1984, 1986 through 1990, 2000 through 2006 P,S,*	56.2
07126300	Purgatoire River near Thatcher	Purgatoire Thatcher	1983 through 1992	1,779
07126485	Purgatoire River at Rock Crossing	Purgatoire Rock Crossing	1983 through 1992, 1997 through 2004 P,S	2,623

[1]Station known as "Lockwood precipitation gage" in von Guerard and others (1993).

[2]Station known as "Taylor precipitation gage" in von Guerard and others (1993).

[3]Station known as "Bent Canyon precipitation gage" in von Guerard and others (1993).

[4]Station known as "Red Rock precipitation gage" in von Guerard and others (1993).

use prior to land acquisition by the Army, was eliminated after 1983. Rock and cliffs are exposed along the 400- to 500-ft-deep Purgatoire River canyon, and riparian vegetation grows along the bottom of incised reaches of the major tributaries near their confluence with the Purgatoire River (von Guerard and others, 1987). About 96 percent of the PCMS drains eastward to the Purgatoire River; the remaining 4 percent drains north and east into the Timpas Creek watershed (von Guerard and others, 1993).

The Army initially purchased 244,000 acres in 1982. Some of those lands were found to be unsuitable for training needs in the 1980s. Eight hundred acres were sold back to a former landowner in 1989. An additional 17,708 acres was legislatively transferred to the U.S. Department of Agriculture Forest Service in 1991. Approximately 10,000 of those acres were in an area known as Picket Wire, and 7,700 acres were included as part of the Comanche National Grasslands. Small and isolated acreage transfers also took place on parcels adjacent to Welsh Canyon, Minnie Canyon, Lockwood Canyon, Spring Canyon, and Taylor Arroyo (pl. 1) (U.S. Department of the Army, Directorate of Environmental Compliance and Management, written commun., 2008).

Sedimentary geology has produced fine-grained soils, sandy to silty loams from the sandstone, shale, and limestone (von Guerard and others, 1993). The elevation of the land surface at PCMS ranges from 5,905 ft in the Big Arroyo Hills at the northwest edge of the site to 4,350 ft at the Purgatoire River at the northeast edge of PCMS (von Guerard and others, 1987). The climate is semiarid with approximately 12 inches of precipitation per year (Western Regional Climate Center, 2007); 80 percent of the precipitation occurs as rain during March through October from convective storms (von Guerard and others, 1987).

Some ponds in small watersheds existed before the Army acquired the PCMS that were used either for stock watering or erosion control, or both. In this report they are called erosion-control ponds because they now serve erosion-control purposes. The Army has built additional erosion-control ponds since 1983 at PCMS (pl. 1). The erosion-control ponds intercept an unknown amount of runoff and sediment, thus complicating characterization of the amount of stormflow and suspended-sediment transport that occurs at PCMS. Information regarding the status of a selected group of erosion-control ponds consisted of observations of the presence of stored water and whether the erosion-control ponds had spilled (table 2).

Monitoring of erosion-control ponds began in 1999 at selected stations, and additional sites were added until all stations in the network were monitored by 2003. Available data for the 1999 through 2007 period (all annual periods are calendar years for this report) indicate that fewer erosion-control ponds stored and spilled water during the 2002 through 2003 period. During the 2002 through 2003 period, 34 percent of the 61 total erosion-control ponds (2002) and 41 percent of the 71 total erosion-control ponds (2003) contained water. More erosion-control ponds contained water during the 2004 through 2005 wet period (70 percent [2004] and 85 percent [2005]) (table 2). Limited data documenting the sediment contents of erosion-control ponds were available, but because there were uncertainties about the accuracy of recovered datums during resurveys, changes in sediment contents were determined to be unreliable. In a previous study, sediment yields computed at 22 erosion-control ponds determined by a transit survey and probing of sediment depths ranged from 9.5 to 1,700 tons/mi^2 annually (von Guerard and others, 1987). Watersheds underlain by shale had the largest sediment yields (annual mean of 588 tons/mi^2), whereas watersheds underlain by sandstone or limestone had the smallest sediment yields (annual mean of 186 and 68 tons/mi^2, respectively) (von Guerard and others, 1987).

Multiple training areas have been designated for various types of maneuvers. Areas have been identified for mechanized training, and other areas have been identified for nonmechanized use. Additionally, sensitive areas have been determined to be off limits to training (U.S. Army Corps of Engineers, 2007). After-action reports compiled after completion of training exercises indicate that large-scale training exercises at the PCMS occurred an average of about once per year, and about 30 large-scale training exercises have occurred since 1985 (*http://cbs4denver.com/local/pueblo.colorado.pinon.2.562757.htm*, posted October 17, 200l). The Army indicated training generally occurred in the Taylor and Lockwood watersheds (Jeff Linn, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written commun., March 2008).

Prior to 1997, the Army practiced rest-and-rotation land management at PCMS, when for 2 years approximately one-half of the training lands were rested while other areas were used for training exercises (Jeff Linn, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written commun., March 2008). Also, prior to 1997, training was not allowed between April and June. In 1997, the PCMS was opened to year-round training use, although training activities are not continuous throughout a year.

Training at the PCMS began July 29, 1985 (von Guerard and others, 1987). Six major training exercises were reported from July 1985 through November 1987 and consisted of about 2 weeks of onsite maneuvers per exercise, and involved approximately 3,200 personnel and 1,160 vehicles (about 450 tracked vehicles). Most exercises during the 1985 through 1987 period involved training at the Van Bremer, Taylor, and Lockwood watersheds (fig. 1, pl. 1). Areas in Red Rock and Bent were only utilized in 1987 (von Guerard and others, 1987). Additional historical data indicate ground cover increased in drainage basins above 21 stock-watering reservoirs in the PCMS during the 1985 through 1987 period (von Guerard and others, 1993) despite the start of military training in July 1985 (bare ground: 64 percent in 1985, 55 percent in 1986, and 53 percent in 1987; litter cover: 13 percent in 1985, 32 percent in 1986, and 38 percent in 1987). Improvements were thought to be a result of less grazing pressure and sufficient precipitation that increased vegetation growth, which may have offset any adverse impacts from military training (von Guerard and others, 1993).

Table 2. Erosion-control pond fill and spill observations for monitored stations.

[nd shaded cell, pond not monitored in indicated year; X, pond held water during April through October of the indicated year; S, pond held water and spilled in the indicated year; Purgatoire River, any pond in a watershed not named in this study that drains to the Purgatoire River; Timpas watershed is north of PCMS; --, no water]

Station number (plate 1)	Watershed	Physiography	Year (April through October)								
			1999	2000	2001	2002	2003	2004	2005	2006	2007
223	Taylor	uplands	X	X	--	--	X	X	S	X	X
224	Taylor	uplands	nd	nd	nd	--	X	--	--	--	X
233	Taylor	uplands	nd	nd	--	--	--	S	S	--	X
236	Taylor	uplands	nd	nd	--	X	X	X	X	--	--
241	Taylor	plains	nd	nd	--	--	X	X	X	X	X
244	Taylor	plains	nd	nd	nd	X	X	S	S	--	X
253	Van Bremer	plains	nd	nd	nd	nd	X	X	X	--	--
256	Van Bremer	plains	nd	nd	nd	nd	X	X	X	--	--
261	Van Bremer	plains	nd	nd	X	X	X	X	S	X	X
262	Van Bremer	plains	nd	nd	nd	nd	X	S	X	X	X
263	Van Bremer	plains	nd	nd	nd	nd	X	X	X	--	X
267	Bent	plains	nd	--	--	--	--	--	X	--	X
268	Bent	uplands	--	X	X	X	X	X	X	X	X
274	Bent	plains	nd	--	--	--	--	--	X	--	--
276	Bent	plains	nd	X	--	--	--	--	--	--	--
283	Bent	plains	--	--	--	X	--	--	--	--	--
284	Bent	plains	nd	--	--	S	X	X	X	--	X
286	Bent	plains	--	--	--	--	X	--	X	--	X
300	Red Rock	plains	nd	--	--	X	--	--	X	--	
305	Lockwood	uplands	nd	--	--	--	--	--	S	--	X
310	Lockwood	plains	nd	--	--	--	--	--	X	--	--
313	Lockwood	plains	nd	--	--	--	--	X	X	--	--
316	Lockwood	uplands	nd	--	--	--	--	S	S	--	--
317	Taylor	uplands	nd	--	--	--	--	X	S	--	X
318	Taylor	uplands	X	--	--	--	--	--	S	--	X
351	Timpas	uplands	nd	X	X	X	--	--	X	--	--
355	Lockwood	plains	--	--	--	--	--	--	X	--	--
358	Lockwood	plains	--	--	--	X	--	--	X	X	--
360	Lockwood	plains	--	--	--	X	--	--	X	X	X
364	Lockwood	plains	nd	nd	nd	nd	--	--	--	S	X
372	Purgatoire	plains	--	--	--	X	--	X	X	--	--
373	Purgatoire	plains	X	--	--	S	X	S	X	S	X
382	Taylor	plains	nd	nd	--	--	--	X	X	--	--
386	Taylor	plains	nd	nd	nd	--	--	X	X	X	--
388	Lockwood	plains	nd	--	--	--	--	S	S	X	X
398	Taylor	plains	nd	--	--	--	--	S	--	--	--
401	Taylor	plains	nd	nd	nd	--	--	S	--	--	--
402	Taylor	plains	nd	nd	nd	--	--	S	S	X	--
408	Taylor	plains	nd	nd	--	--	--	X	X	X	X
410	Taylor	plains	nd	nd	nd	--	--	--	X	--	--
412	Taylor	plains	X	--	X	S	X	S	S	X	X
414	Taylor	plains	nd	X	--	S	--	S	S	--	X
415	Taylor	plains	S	--	X	X	--	X	X	X	X
416	Taylor	plains	nd	nd	S	--	X	S	S		X
418	Taylor	plains	--	X	--	--	--	X	X	X	X
419	Taylor	plains	nd	nd	--	--	X	X	X	X	--
420	Purgatoire	plains	nd	nd	nd	nd	--	--	--	--	--
423	Taylor	plains	nd	nd	nd	--	--	X	X	--	--
429	Van Bremer	plains	nd	nd	nd	nd	--	--	--	--	--
430	Van Bremer	plains	nd	nd	--	--	X	--	X	--	--
432	Taylor	plains	nd	nd	nd	--	--	X	S	--	X
433	Taylor	uplands	X	--	--	--	--	--	X	--	X

Table 2. Erosion-control pond fill and spill observations for monitored stations.—Continued

[nd shaded cell, pond not monitored in indicated year; X, pond held water during April through October of the indicated year; S, pond held water and spilled in the indicated year; Purgatoire River, any pond in a watershed not named in this study that drains to the Purgatoire River; Timpas watershed is north of PCMS; --, no water]

Station number (plate 1)	Watershed	Physiography	Year (April through October)								
			1999	2000	2001	2002	2003	2004	2005	2006	2007
441	Taylor	plains	nd	--	--	--	--	X	X	S	X
444	Taylor	uplands	nd	nd	nd	--	S	X	X	X	--
448	Taylor	uplands	X	X	--	X	--	X	S	X	--
452	Van Bremer	uplands	nd	--	X	X	X	X	X	--	--
455	Van Bremer	plains	nd	nd	nd	nd	S	S	S	X	X
457	Taylor	plains	nd	--	--	X	X	X	X	X	--
463	Taylor	uplands	S	S	--	--	--	S	S	--	X
473	Taylor	plains	nd	nd	nd	X	X	S	S	--	X
477	Van Bremer	plains	X	X	--	X	--	X	X	--	X
480	Van Bremer	plains	nd	nd	nd	nd	--	X	X	--	--
489	Van Bremer	uplands	X	X	--	--	X	X	X	X	X
493	Van Bremer	uplands	nd	X	--	--	X	X	X	--	--
497	Van Bremer	plains	nd	--	--	--	X	X	--	--	--
501	Van Bremer	plains	nd	--	--	--	S	X	X	--	--
155580	Bent	canyon	--	--	--	X	X	X	--	--	--
770461	Van Bremer	plains	--	--	--	--	--	X	--	X	--
924419	Taylor	plains	nd	nd	nd	--	X	S	S	X	X
943343	Van Bremer	plains	nd	nd	nd	nd	--	--	X	--	--
991439	Taylor	plains	nd	nd	nd	--	--	S	X	X	--

Between July 1989 and January 1993, training was reported in Taylor, Lockwood, and Bent. Although a total of 10 acres or less among the three watersheds was reported to have required restoration following each training exercise, larger acreages were used for training (Jeff Linn, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written commun., March 2008). In the summer of 1994, 5,900 total acres were reported by Army personnel as being disturbed in Big Arroyo, Lockwood, Red Rock, Bent, and Iron Canyon. It is important to note that disturbed acres prior to 1994 reflected only acreage that required repair. During this period, disturbed areas did not include "fair-wear-and-tear" type training. "Fair-wear-and-tear" is described as typical disturbance and vegetation or ground-cover damage that is a result of tracked-vehicle usage. Adverse impacts that are not considered to be "fair-wear-and-tear" include damage to wetlands, unusual degree of tree damage, or tracked-vehicle ruts greater than about 3 inches in depth (typically produced when soils are wet) (Bruce Miller, U.S. Department of the Army, Directorate of Environmental Compliance and Management, oral commun., May 2008). After 1994, field approximations were made by Army personnel of the total acres disturbed (Jeff Linn, Directorate of Environmental Compliance and Management, written commun., March 2008).

During 1996 two different maneuvers in Van Bremer, Taylor, Big Arroyo, and Red Rock indicated that 310 acres in all four watersheds were disturbed from January through February, and 230 acres in all four watersheds were disturbed from July through August (Jeff Linn, Directorate of Environmental Compliance and Management, written commun., March 2008). In 1997 a total of 14,100 acres were disturbed in Lockwood and Red Rock. In 1998, a total of 1,700 acres were disturbed within Lockwood and Taylor. In 1999, a total of 2,000 acres were disturbed within Lockwood, and a total of 2,550 acres were disturbed in Van Bremer, Taylor, Lockwood, and Red Rock. In 2000, a total of 8,200 acres were disturbed in Van Bremer, Taylor, Lockwood, and Red Rock (Jeff Linn, Directorate of Environmental Compliance and Management, written commun., March 2008). Since 2001, armored tracked-vehicle training has been limited because many troops have been deployed overseas.

Methods

This section of the report describes how data and samples were collected at the PCMS and how data were analyzed for hydrologic and LCTA interpretation. Data were collected from 1983 through 2007 at 19 precipitation stations; streamflow and suspended-sediment data were collected at 5 tributary and 2 main-stem Purgatoire River stations. In this report, for the purpose of consistency and brevity, the short names for precipitation, streamflow, and suspended-sediment stations will be used (table 1). An LCTA data-collection program was done by Army personnel in 1989, 1991, 1992, 1994, 1998, and 1999 using disturbance, ground cover, and bare-ground conditions recorded every meter along 100-meter transect centerlines at 206 locations. Units in meters are used in the LCTA analysis because observations in meters were used during the collection of the data. Aerial measurements of overhead canopy and juniper trees also were made at these locations.

Data Collection

From 1983 through 2007, the USGS collected hydrologic data including precipitation, streamflow, and suspended-sediment data (table 1). However, data collection at many stations was intermittent from 1983 through 2007 (table 1). Precipitation data were available at 4 precipitation-monitoring stations from 1983 through 2007, and at 19 precipitation-monitoring stations from 2000 through 2007 (table 1, fig. 1, and pl. 1). Annual precipitation was measured from 1983 through 2007 at four precipitation-monitoring stations: Colorado Interstate Gas (CIG), Bear Springs, Upper Red Rock, and Upper Bent) (table 1, fig. 2). These four precipitation-monitoring stations were named Taylor, Lockwood, Red Rock, and Bent stations, respectively, in von Guerard and others (1993). New precipitation-monitoring stations were installed at Taylor, Lockwood, Red Rock, and Bent in 1999 at the streamflow-monitoring stations. The new precipitation-monitoring stations installed in 1999 have the same names as those applied in von Guerard and others (1993). The stations in von Guerard and others were renamed in 1999 and are now called CIG, Bear Springs, Upper Red Rock, and Upper Bent. Prior to 1999, precipitation at the CIG precipitation-monitoring station was used in the analysis of streamflow at Taylor. In 1999, an additional precipitation-monitoring station (Taylor) was added at the Taylor streamflow-monitoring station. From 1999 through 2007, storm-total precipitation data at Taylor were used to analyze Taylor storm runoff instead of CIG. The Taylor streamflow-monitoring station is located about 5 miles to the southeast of the CIG precipitation-monitoring station. All precipitation-monitoring stations were 8- to 12-inch tipping-bucket gages and were regularly visited and maintained. During each warm-weather visit, calibration checks were made that cover the range of historical precipitation intensities. Because the tipping-bucket gages at some stations (those not co-located with streamgages) were operated throughout the year without heaters, the winter (November through March) precipitation data are considered less accurate than data for the remaining part of the year.

Streamflow data were collected continuously or intermittently at seven stations during the 1983 through 2007 period (table 1). Streamflow data have been collected continuously at Purgatoire Thatcher (1983 through 2007), located upstream from PCMS, and at Purgatoire Rock Crossing (1983 through 2007), located downstream from PCMS (fig. 1, pl. 1). In addition, streamflow from five tributary watersheds that account for more than 65 percent of the PCMS (von Guerard and others, 1987) was monitored for much of 1983 through 2007. Streamflow data were collected year-round at tributary streamflow-monitoring stations through the early 1990s. In the early 1990s, streamflow-data collection was discontinued at the Lockwood, Red Rock, and Bent stations. In 1999, streamflow-data collection at Lockwood was reestablished, and in 2000, streamflow-data collection at Red Rock and Bent was reestablished. Streamflow-data collection at Van Bremer and Taylor has occurred continuously from 1983 through 2007. For the months April through October during the 1999 through 2007 period (calendar years, began in 2000 at Red Rock and Bent), streamflow-monitoring stations were operated seasonally at all five tributary streamflow-monitoring stations. Discharge measurements were made approximately monthly at all streamflow-monitoring stations during the period of seasonal operation. When possible, measurements of streamflow were made with a current meter according to procedures described in Buchanan and Somers (1969). These measurements were used to compute and analyze the continuous streamflow data from the monitoring stations according to procedures described in Rantz and others (1982a and b) and Kennedy (1983). All data are stored in the USGS National Water Information System (NWIS) and are available on the Internet at the NWIS-Web Web site (*http://waterdata.usgs.gov/co/nwis/inventory*, accessed December 2007).

Suspended-sediment samples were collected at the five tributary streamflow-monitoring stations at PCMS and at two stations on the Purgatoire River—one upstream and one downstream from the PCMS (pl. 1, fig. 1, table 1). Each station was equipped with satellite data-collection recorders to transmit near real-time data. Suspended-sediment data were collected at Taylor from 1983 through 2006, whereas daily suspended-sediment data at Bent were collected during 1984 and from 1986 through 1990. From 1999 through 2006, suspended-sediment data were collected at Van Bremer, Taylor, and Lockwood tributary streamflow-monitoring stations from April through October. Sediment-data collection began at Red Rock and Bent in 2000. Beginning in 1999, suspended-sediment data were collected from all streamflow-monitoring stations only during storms from April through October. Suspended-sediment data were collected at the Purgatoire Thatcher streamflow-monitoring station from 1983 through 1992, and at the Purgatoire Rock Crossing streamflow-monitoring station from 1983 through 1992, and from 1997 through 2004 (calendar year, storms only beginning in 1999).

Suspended-sediment data were collected during storm runoff by using pumping-sediment samplers. In general, the satellite data-collection recorder actuated the pumping-sediment sampler when a predetermined rate of stage change was exceeded or when a predetermined time interval was exceeded. When possible, depth- and width-integrated suspended-sediment samples (Edwards and Glysson, 1988) were collected at streamflow-monitoring stations to define temporal or flow-related coefficients (or adjustments) between the depth- and width-integrated concentration and the pumped sediment-sample concentration. The depth- and width-integrated sample was considered representative of all suspended sediment in the channel. Pumping-sediment samplers were installed with a single-point intake to collect sediment from the suspended fraction of the water column. The pumping-sediment sample, which represents the concentration at the sampler intake point, can be adjusted with a coefficient that is expressed as a percentage of the depth- and width-integrated concentration. Because of the remoteness of the PCMS stations and the resulting inability to take frequent depth- and width-integrated samples and to determine a long-term temporal or flow-related relation, the depth- and width-integrated and point-sample relations were not used in sediment-discharge computations. Rather, those relations were used in assessing possible error in defining the cross-sectional sediment concentrations with the pumped samples. Few suspended-sediment samples were analyzed for size fractions. At Taylor, however, most of the suspended-sediment samples were more than 90 percent finer than 0.063 mm, which defines the separation between sand and silt grain size. The high percentage of silt and finer grain sizes indicates that most of the suspended sediment should be well mixed and uniformly distributed during turbulent streamflow associated with most storm events. Suspended-sediment samples were analyzed at the USGS Iowa Sediment Laboratory in Iowa City, Iowa, by gravimetric methods (Guy, 1969). All data were stored in the USGS National Water Information System (NWIS).

Army personnel implemented an LCTA program from 1989 through 1999 (Bruce Miller, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written commun., 2007) The key element of the LCTA program was a vegetation survey, which was made along 100-m by 6-m transects. Permanent transects were established to provide a statistical and spatial representation of the main soil types and vegetative cover. LCTA data were collected at 206 permanent transects starting in 1989, and collection occurred during 1989, 1990, 1991, 1992, 1994, 1998, and 1999. After 1989, one of the transects was discontinued. In addition, partial LCTA data collection occurred during 2001 at 52 of the permanent PCMS transects, but these data are not analyzed in this report.

Data were collected at each 100-m by 6-m transect. The 6-m width (or belt) of each transect was delineated as a 3-m-wide area on each side of the 100-m transect line. Each transect was measured for line, aerial, and belt-transect information. The line-transect data included ground-condition measurements of disturbance, ground cover, and bare ground recorded every meter along the transect centerline. Complementing the ground-condition information were aerial measurements, which included overhead canopy data collected by recording plant species up to 1 m vertically above the transect line. Belt-transect data recorded woody species within the 100-m by 6-m area, either as locations and heights of species or as species counts.

Measurements along each transect were made in a given year according to one of two protocols: a more comprehensive, long-term (detailed) monitoring method or a short-term (quick) method. If the long-term method was used, plant species were recorded along the line transects; if short-term monitoring was performed, plants were distinguished only as annual or perennial, and plant cover was differentiated from bare ground, rock, or gravel. Canopy information, disturbance data, and measurements of woody species were included for both types of monitoring methods, but the level of detail measured was much less for the short-term methods. Most LCTA parameters were calculated as a count, which can be expressed as a percentage, because transect measurements were made at every meter along the transect line.

Quality assurance procedures were implemented for precipitation, streamflow, and sediment data collection. Precipitation data-collection methods were well within procedures that were issued in 2006 by the Office of Surface Water (U.S. Geological Survey Technical Memorandum No. 2006.01; *http://water.usgs.gov/admin/memo/SW/sw06.01.pdf*, accessed March 2008). Quality assurance for streamflow data-collection methods were based on procedures outlined in Rantz and others (1982a and 1982b). The sediment data-collection program utilized replicate cross-sectional or pumped sampling to assess field data-collection methods; all indicated the acceptable reproducibility of variability within 10 percent in field data-collection methods. Daily precipitation, streamflow, and sediment data met acceptable protocol for publication in the annual USGS Water-Data Reports (*http://wdr.water.usgs.gov/*).

Data Analysis

Hydrologic data were analyzed using annual sums from time-series plots; plots of monthly means; probability plots that presented information about frequency of occurrence; and box plots that showed percentile, extreme, and mean statistics. The purpose was to discuss general characteristics, describe variations, and characterize patterns. Data analysis that included both parametric and nonparametric statistics was used in this report. Parametric statistics were used to analyze data typical of a standard normal distribution (Helsel and Hirsch, 1992). Because hydrologic data often were not normally distributed, caution should be used when using parametric statistics. The mean, or average of data, is a parametric statistic used to indicate the central tendency of a dataset but can be misleading when the data contain extreme values or outliers (Helsel and Hirsch, 1992). Despite these drawbacks, the mean was applied to the monthly hydrologic data because the low probability of occurrence of precipitation, streamflow, and sediment-transport events that characterize the PCMS would have resulted in median (50th percentile) values of zero. Probability plots indicate the probability of exceedance, or the likelihood that a number will be met or exceeded during a period of time, expressed in this report as a percentage. Another parametric statistic, the coefficient of variation, was used to characterize spatial variation among storm-total precipitation at different long-term streamflow-monitoring stations. The coefficient of variation is computed as the standard deviation divided by the mean (Helsel and Hirsch, 1992). Nonparametric statistics are preferred with hydrologic data because they are rank-based and are resistant to extreme values or outliers (Helsel and Hirsch, 1992). Median and other percentile statistics are nonparametric and provide a more robust indication of the distribution of the data (Helsel and Hirsch, 1992). Boxplots use nonparametric statistics such as median, 25th, and 75th percentiles.

Several scales of time-series hydrologic data are used in this report. Annual, monthly, and daily sums or means of the data are important for temporal trends because they preserve the frequency characteristics of the data and include zero data values of precipitation, streamflow, and suspended sediment. Monthly data are useful because they can be adjusted for seasonal effects. Storm totals of precipitation, streamflow, and suspended sediment do not effectively preserve the time distribution or frequency of hydrologic data but are useful for analyzing trends in magnitude of the storm totals. Storm totals are used in this report because (1) they are better suited than annual, monthly, or daily hydrologic data to characterize the relations among precipitation, streamflow, and suspended sediment; (2) they allow comparisons between precipitation, streamflow, and suspended sediment that have dissimilar timing or duration but are part of a common storm event; and (3) they can be normalized and adjusted for streamflow (for sediment data).

Temporal trends in annual and storm-total data were tested using the Mann-Kendall correlation test that assesses the statistical significance of any monotonic trend (Helsel and Hirsch, 1992). The term monotonic describes data values that are generally increasing or decreasing (often nonlinear), with gradual and continuing changes over time (Helsel and Hirsch, 1992). The Mann-Kendall test generally determines median changes over time by testing the monotonic dependence of the dependent variable on the independent variable by computing the Kendall “S” statistic, which uses rank-based comparisons of the data (Helsel and Hirsch, 1992). The application of the Mann-Kendall test to annual data indicates whether temporal changes have occurred at the scale of an annual time-step or whether temporal changes in magnitude have occurred, when applied to storm-total data. The computation of a trend slope, referred to as the “Theil” slope, allows the interpretation of the relative importance of the trend in terms of the rate of change and is computed as the median of all pairwise slopes for all possible pairings of the data (Helsel and Hirsch, 1992).

Temporal trend analysis for monthly precipitation, streamflow, and suspended-sediment data was done using the seasonal Kendall test to assess monotonic trends (Helsel and Hirsch, 1992). The seasonal Kendall test is a nonparametric trend test that computes the Mann-Kendall test on data only from similar seasons, thus reducing the effects that seasonal patterns may have on trend detection (Helsel and Hirsch, 1992). The 7 months from April through October were each defined as a season. Monthly data were used to reduce variability and serial correlation.

Trend tests were evaluated with two-tailed statistical procedures. The probability of error (p-value) was used in this report to determine the significance of statistical tests for all statistical methods. Statistical significance levels for p-values less than 0.05 were defined in this report as significant. The p-values between 0.05 and 0.10 were referred to as moderately significant, and p-values larger than 0.10 were not considered significant. The use of the word “significant” only applies to the p-value of the statistical test to reduce any confusion of descriptive terms. If the change was at least 5 percent of the median value of the hydrologic data for the period of the temporal test, the result was described as “substantial” in this report. If the change was less than 5 percent of the median value for the period of the temporal test, the result was described as “not substantial” in this report.

Adjustments of sediment load for the effects of streamflow were used in temporal trend tests in this report. Adjustment methods to improve the power of statistical trend tests involve testing residuals from a log-linear regression of the trend variable of interest and another variable that has a strong relation to the trend variable, rather than using the data values of the trend variable in the statistical test (Helsel and Hirsch, 1992). This method is commonly used to remove the effects of streamflow from suspended-sediment load data. For example, in a suspended-sediment load time-series dataset it may be misleading to assess the trend in suspended-sediment load that is not adjusted for streamflow, if suspended-sediment load generally changes proportionally with streamflow. If changes in sediment supply need to be assessed, then knowing whether any trends detected are the result of changes in sediment sources to a stream or whether trends detected are the result of changes in streamflow is important for the interpretation of the trend.

Yield computations were used to remove the effects (normalize) of the differences in watershed area and spatial differences in precipitation. Normalizing to watershed area allowed comparison of storm-total streamflow yields among streamflow-monitoring stations with dissimilar watershed areas. Normalizing to storm-total precipitation allowed comparison of streamflow yields when precipitation varies from watershed to watershed. From 2000 through 2007, streamflow was normalized using storm-total precipitation at each streamflow-monitoring station. Prior to 2000, streamflow was not normalized to storm-total precipitation because precipitation data were not available at the streamflow-monitoring stations. Storm-total precipitation at CIG could have been used to normalize streamflow at Taylor; however, the results would have been inconclusive because of the absence of suitable alternate precipitation-monitoring station data within the other watersheds.

The Mann-Whitney rank-sum test (Iman and Conover, 1983) was used to test for statistically significant temporal or spatial differences in monthly precipitation, streamflow, and suspended-sediment data between monitoring stations or different periods at the same monitoring station. The Mann-Whitney rank-sum test is a nonparametric procedure in which data for the two populations (data for both monitoring stations or both periods) are ranked; a two-sample t-test then is performed on the ranks of the data. The advantages of the Mann-Whitney rank-sum test over a simple two-sample t-test (Iman and Conover, 1983) are that (1) the data do not need to be normally distributed (and hydrologic data often are not normally distributed), and (2) the Mann-Whitney rank-sum test is less sensitive to the assumption of equal variances. The null hypothesis states that samples from both stations are from the same population; for example, the samples are not statistically different (Helsel and Hirsch, 1992). The Mann-Whitney rank-sum tests used in this report were two-tailed tests and have significance levels similar to the seasonal Kendall trend test.

The LCTA analysis evaluated six variables that are summarized in this report: disturbance, ground cover, bare ground lacking canopy cover, aerial cover, erodibility status, and juniper counts. The graphs and maps used in this report omit the partial data collected during 2001. Maps showing plots of categories of percentages for the various variables are plotted for each of the years of disturbance, ground cover, and bare ground lacking canopy cover data. Bar graphs summarizing the data for all six variables are included in the analysis.

Precipitation

Precipitation is an important driver of hydrologic processes in many environmental settings. Storm runoff and suspended-sediment transport at PCMS are dependent upon precipitation because ground-water contributions to surface streamflow are absent at the tributaries flowing from PCMS except at Van Bremer and Lockwood, where ground-water contribution has been minor. von Guerard and others (1987) noted that 80 percent of precipitation occurs as rain from March through October, and precipitation generally occurs in the form of low-intensity rainfall or snow the remainder of the year.

Definition of Terms

For purposes of this report, the term “annual precipitation” is defined as the sum of the precipitation recorded at a precipitation-monitoring station during the months of April through October. The term “monthly precipitation” is defined as the sum of the precipitation recorded at a precipitation-monitoring station during a particular month. Daily precipitation is defined as the sum of the precipitation recorded at a precipitation-monitoring station during a single day. Storm-total precipitation is defined for the report as the sum of the precipitation for a particular precipitation event as determined by examination of the precipitation record. The term “magnitude” when describing precipitation is used to denote the size of a storm-total precipitation in terms of precipitation volume rather than areal coverage. The term “runoff-producing storms” represents only storms that were associated with runoff at the streamflow-monitoring station in the same watershed. The term “all storms” represents runoff-producing and nonrunoff-producing storms. Data showing multiple pulses of precipitation commonly were separated into multiple storms on the basis of daily precipitation or the shape of the streamflow hydrograph.

The storm-total precipitation associated with streamflow for a given storm event was determined. Storm-total precipitation commonly included precipitation from the day previous to the first rise of the streamflow hydrograph through the end of the storm (most tributaries in this study area go dry between storms except Van Bremer and occasionally Lockwood). For example, if precipitation occurs in the upper watershed shortly before midnight, storm runoff (streamflow associated with a given storm) may not appear at the streamflow gage until the next day. The storm runoff may continue for days following the precipitation event, but the storm-total precipitation and the storm runoff are analyzed together.

Variations in Annual and Monthly Precipitation

The mean annual precipitation from April through October at the four long-term record stations (CIG, Bear Springs, Upper Red Rock, and Upper Bent) during the 1983 through 2007 period ranged from 10 to 11 inches. However, the minimum and maximum annual precipitation among the four stations occurred at the Upper Bent precipitation-monitoring station and ranged from a minimum of 4.6 inches in 2002 to a maximum of 20.5 inches in 2004 (fig. 2). Drought conditions during 2002 were some of the most extreme in Colorado since streamflow records have been kept (Kuhn, 2005). No PCMS tributary streams were analyzed by Kuhn (2005), but an analysis of the streamflow record for the October 2002 through March 2003 period at Purgatoire Thatcher determined that the 30-day winter streamflow was the second lowest for the period of record (1967 through 2002). However, the 30- and 180-day streamflows for the April through September 2002 period were not ranked in the five lowest for the period of record (1967 through 2002) (Kuhn, 2005). Because the Purgatoire Thatcher streamflow was affected by diversions and reservoir releases, the drought conditions in the Purgatoire River may not reflect conditions for the PCMS tributaries.

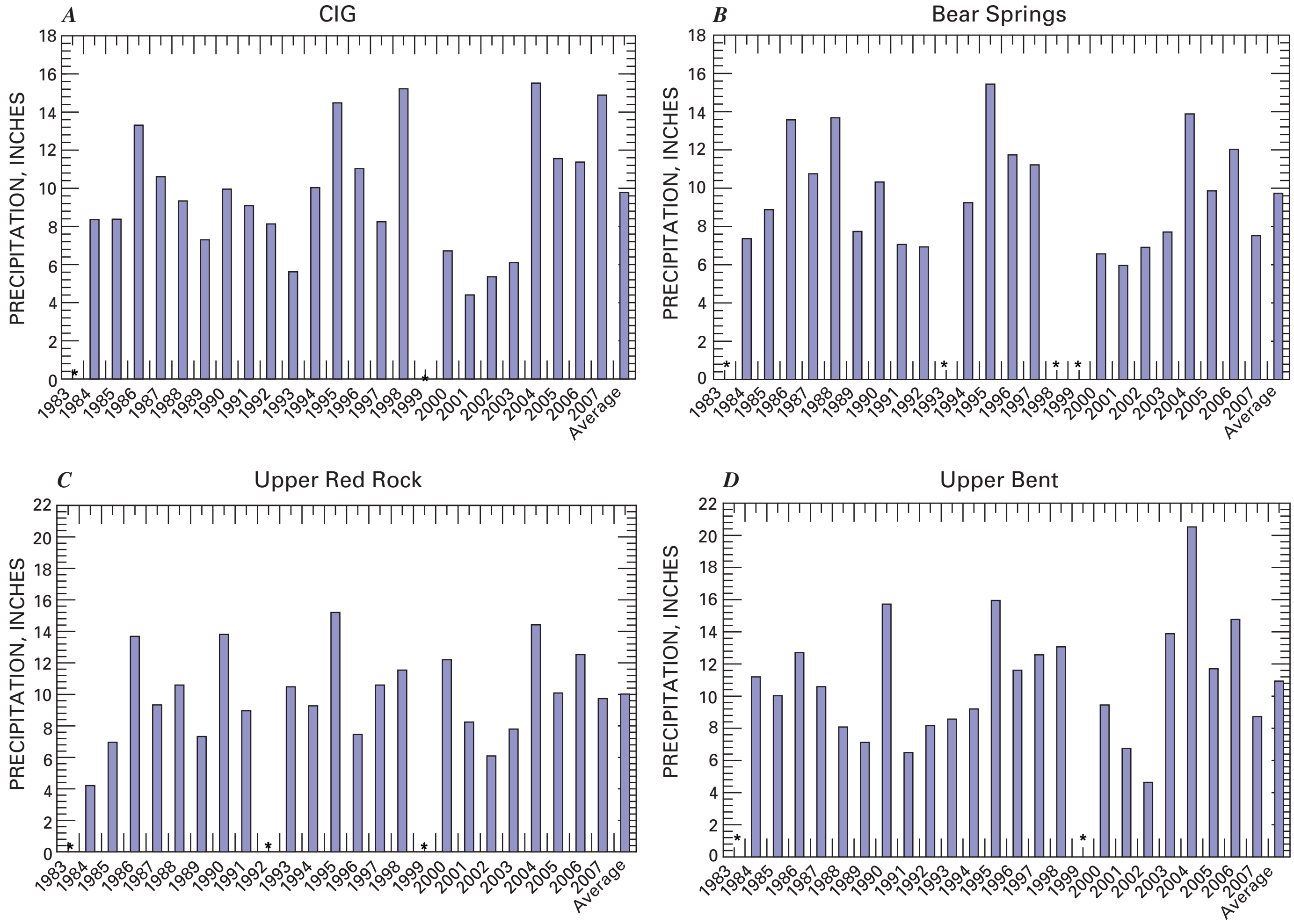

Figure 2. Annual precipitation from April through October at long-record precipitation monitoring stations: (*A*) Colorado Interstate Gas (CIG); (*B*) Bear Springs; (*C*) Upper Red Rock; and (*D*) Upper Bent 1983–2007, Colorado (*, incomplete year).

Monthly precipitation is usually less than 1 inch per month from November through March (von Guerard and others, 1993). The accumulation of a substantial snowpack and subsequent spring snowmelt runoff is limited due to intermittent melt and sublimation that occurs on warm winter days. Winter snowfall (November through March) and spring precipitation (April through June) provide important moisture for vegetation growth, which may partially reduce the effects of erosion later in the summer in these semiarid landscapes (von Guerard and others, 1993). The intensity of convective storms during July through September is more effective at producing runoff to streams than winter and spring precipitation at the PCMS (von Guerard and others, 1993). Other important factors that affect runoff include wind (Appendix 1), evapotranspiration, and soil moisture; however, these parameters were not measured at PCMS and, except for a discussion that includes wind in the LCTA section, are not included in analysis in this report. Variation in precipitation during monthly periods at CIG (fig. 3*A* to 3*D*) indicates a climate setting at PCMS that is characterized by episodic and intermittent precipitation. Departures from the mean quarterly precipitation are commonly less than 1 inch in a given year for the periods October through December and January through March (figs. 3*A* and 3*B*). Departures from the mean quarterly precipitation are commonly more than 1 to 2 inches in a given year for the periods April through June and July through September (figs. 3*C* and 3*D*).

Monthly precipitation for the months April through October at the CIG precipitation-monitoring station was plotted to show differences in monthly statistics for precipitation during three different periods: 1983 through 2007 (fig. 4*A*), 1983 through 1990 (fig. 4*B*), and 2000 through 2007 (fig. 4*C*). Monthly precipitation for April through August generally ranged from 0.02 to 7.12 inches from 1983 through 2007. Monthly precipitation for September through October, the driest months, ranged from 0.00 to 3.80 inches for the 1983 through 2007 period. July and August were the wettest months with a range in monthly precipitation of 0.20 to 7.10 inches

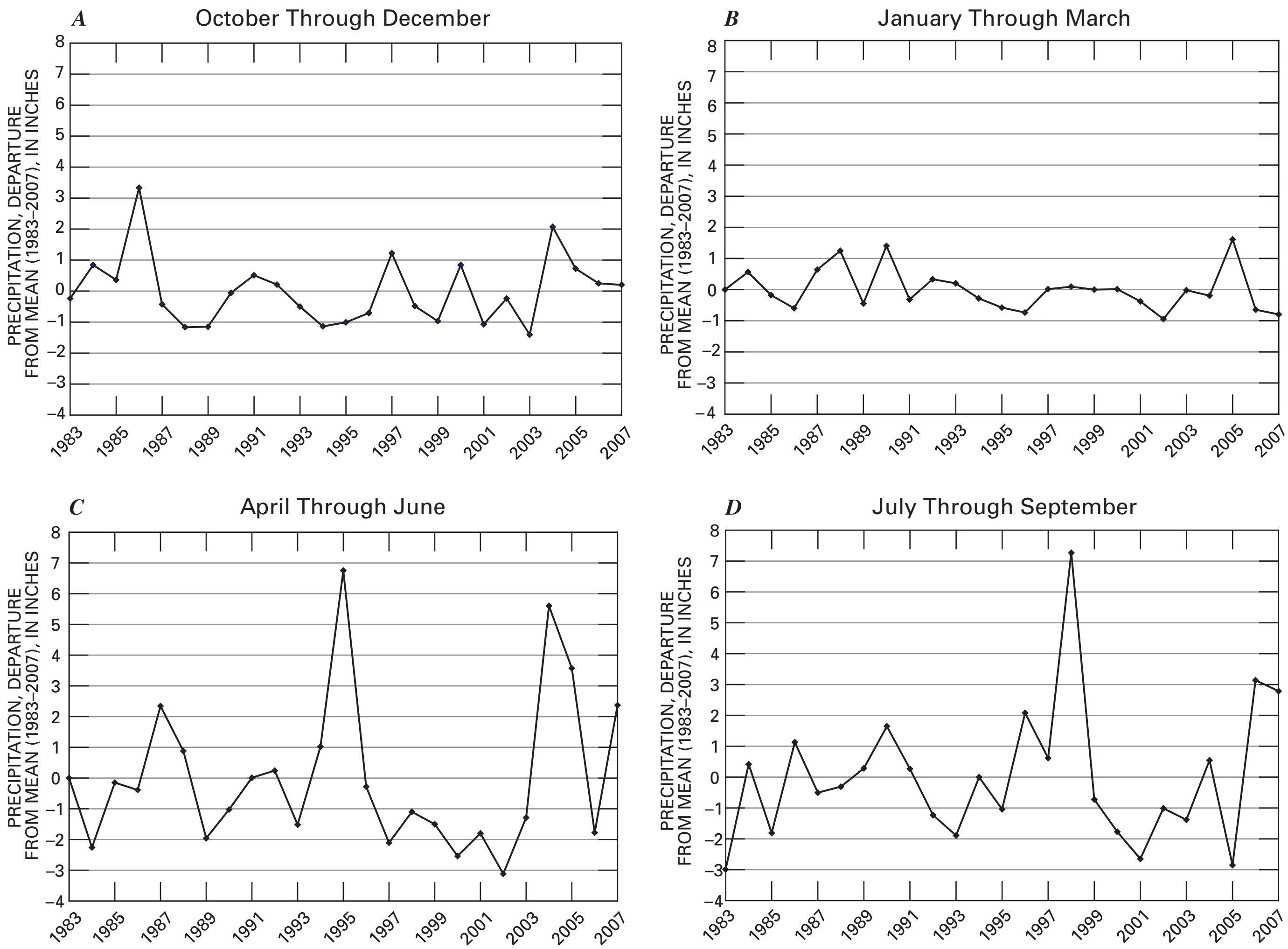

Figure 3. Precipitation departure from 1983 through 2007 mean at Colorado Interstate Gas (CIG): (*A*) October through December; (*B*) January through March; (*C*) April through June; and (*D*) July through September.

for the 1983 through 2007 period (fig. 4*A*). The primary difference between the 1983 through 1990 (fig. 4*B*) and 2000 through 2007 periods (fig. 4*C*) was that more precipitation fell during May and July during the 1983 through 1990 period. August precipitation was similar during both periods except for larger 75th percentile monthly precipitation during the 1983 through 1990 period.

Variations in Daily and Storm Precipitation

Precipitation occurs relatively infrequently at PCMS. A probability plot for CIG, Bear Springs, Upper Red Rock, and Upper Bent precipitation-monitoring stations indicated that there was little or no precipitation (less than 0.01 inch) about 80 percent of the 214-day period from April through October, 1983 through 2007 (fig. 5). Daily precipitation of 0.01 to 0.1 inch generally occurred about 10 percent of the days or on about 21 days. Daily precipitation of 0.1 to 0.5 inch generally occurred about 7 percent of the days or on about 15 days, and daily precipitation more than 0.5 inch generally occurred about 3 percent of the days, or about 6 days each year from April through October, for the period 1983 through 2007.

Storm-total precipitation at the CIG precipitation-monitoring station was less than 0.5 inch for about 79 percent of all storms (including runoff- and nonrunoff-producing storms) during April through October 1983 through 2007. Storms that produced more than 2.5 inches of storm-total precipitation represented about 8 percent of all storms at the CIG precipitation-monitoring station (table 3). While most of the storms were small, the larger storms produced most of the precipitation that fell at PCMS. Thirty-three percent of the runoff-producing storms smaller than 0.5 inch of storm-total precipitation and 45 percent of runoff-producing storms

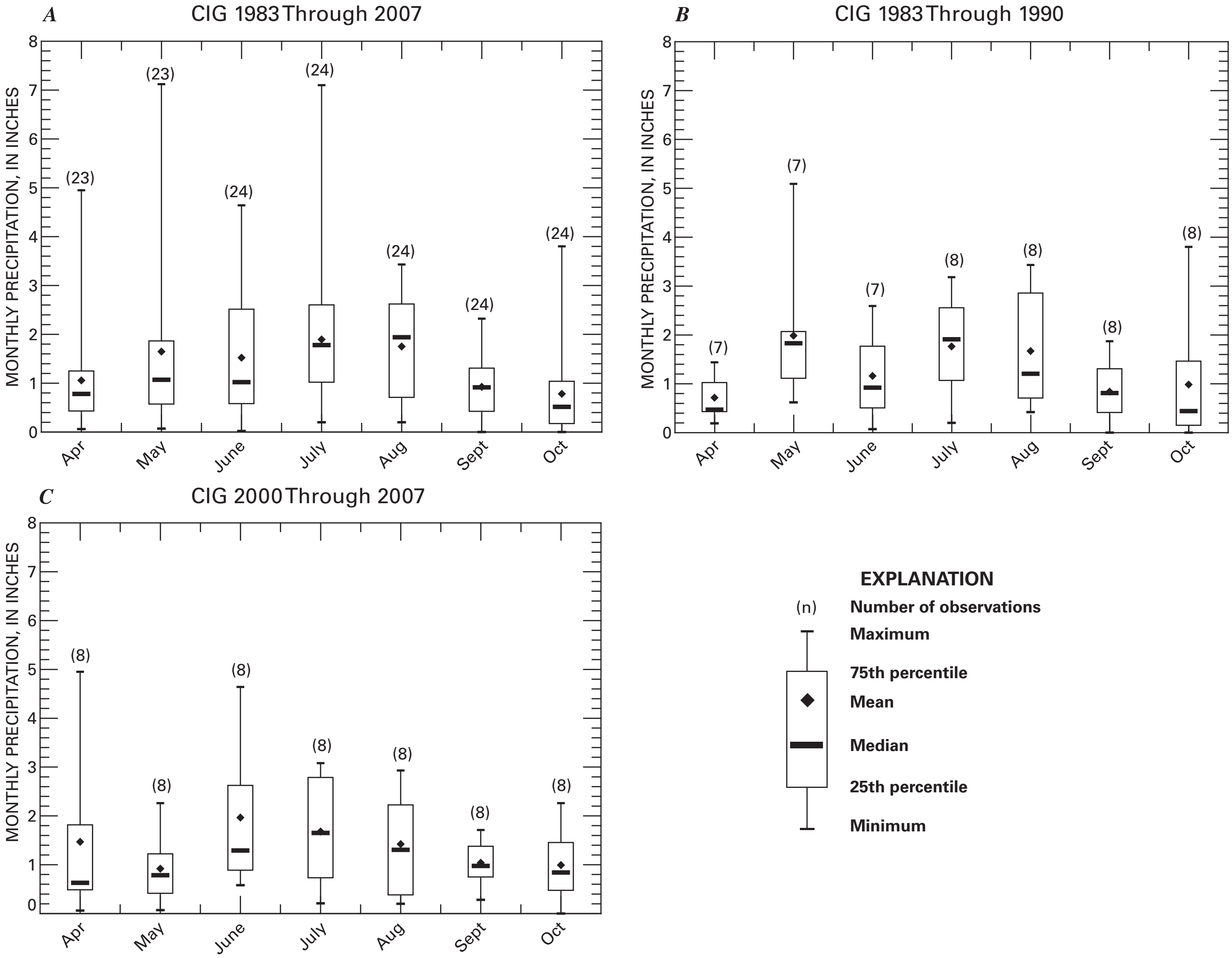

Figure 4. Distribution of monthly April through October precipitation at the Colorado Interstate Gas (CIG) precipitation-monitoring station, Las Animas County, Colorado, for the (*A*) 1983–2007 period (*B*) 1983–90 period and (C) 2000–2007 period.

larger than 1 inch of storm-total precipitation at the CIG precipitation-monitoring station were associated with runoff at the Taylor streamflow-monitoring station (table 3).

Temporal Trends

Monthly Precipitation

The seasonal Kendall test was used to identify temporal trends in monthly precipitation for the months April through October (seven seasons) from 1983 through 2007 at 4 stations and from 2000 through 2007 at 19 stations. Four significant upward temporal trends ($p<0.05$, 2-tailed) and two moderately significant upward temporal trends ($p<0.10$, 2-tailed) were identified in the 2000 through 2007 period among the 19 precipitation-monitoring stations (about 32 percent of the stations). Increases at four of the stations were larger than 5 percent of the median and ranged from 7 to 14 percent of the median precipitation during the 2000 through 2007 period. One moderately significant upward trend (out of the four long-term stations) was computed that indicated a change of about 5 percent of the median during the 1983 through 2007 period. This indicates that some upward temporal trends in streamflow might be explained by trends in precipitation at those stations, but most precipitation-monitoring stations show no statistical evidence of temporal trends (for all precipitation, not just runoff-producing storms).

Storm-Total Precipitation for All Storms

Storm-total precipitation for all storms at the CIG precipitation-monitoring station was tested for temporal trends for the 1983 through 2007 period by using the Mann-Kendall correlation and Theil slope computations. The tests indicated no significant or moderately significant monotonic trends in the magnitude of storm-total precipitation from 1983 through 2007. Storm-total precipitation for all storms at the Taylor

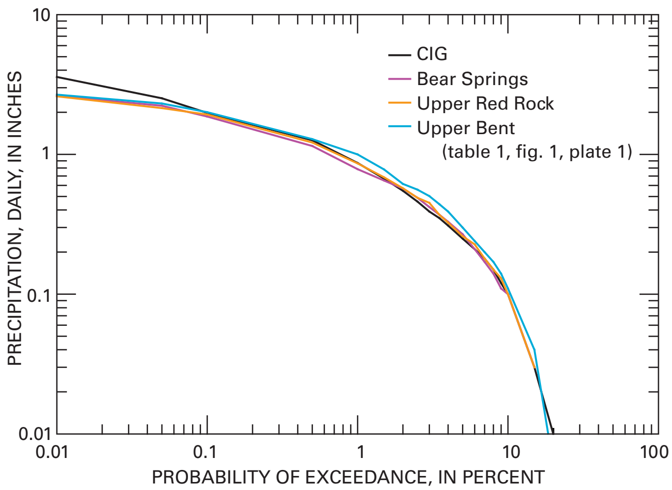

Figure 5. Daily precipitation probability for all days April through October 1983 to 2007 at four precipitation-monitoring stations: Colorado Interstate Gas (CIG), Bear Springs, Upper Red Rock, and Upper Bent, Las Animas County, Colorado.

precipitation-monitoring station was tested for temporal trends for the 2000 through 2007 period. The Mann-Kendall correlation and Theil slope computations indicated a significant upward monotonic trend in all storms ($p<0.05$) and a Theil slope of 0.013 inch per year, which indicated a nonsubstantial increase in the magnitude of storm-total precipitation of about 0.10 inch over the 8-year period. The temporal trend results indicated that trends in the magnitude of storm-total precipitation did not exist at CIG from 1983 through 2007 and were nonsubstantial at Taylor from 2000 through 2007 and would not cause an increase or decrease in storm-total streamflow in the Taylor watershed.

Storm-Total Precipitation for Runoff-Producing Storms

Storm-total precipitation for runoff-producing storms at the five tributary precipitation-monitoring stations was tested for temporal trends for the 2000 through 2007 period using the Mann-Kendall correlation and Theil slope computations. The tests indicated a significant monotonic downward trend ($p<0.05$) in the magnitude of runoff-producing storms at the Van Bremer precipitation-monitoring station and a substantial change in the median as indicated by the Theil slope of –0.085 inch per year, or a decrease of about 0.68 inch over the 8-year period. This trend also was evident at the Taylor precipitation-monitoring station, where analysis by Mann-Kendall correlation computations indicated a moderately significant ($p<0.10$) monotonic downward trend in the magnitude of runoff-producing storms and a substantial change in the median as indicated by the Theil slope of –0.253 inch per year, or a decrease of about 2 inches of storm-total precipitation, over the 8-year period from 2000 through 2007. The trends from 2000 through 2007 of storm-total precipitation for runoff-producing storms at Van Bremer and Taylor precipitation-monitoring stations might be used to explain any downward trends in the magnitude of storm-total streamflow at the Van Bremer and Taylor streamflow-monitoring stations. Because the sediment record was computed for the 2000 through 2006 period (table 1), this period also was tested, and the results indicated that the trends in precipitation were still significant at Van Bremer and Taylor.

Storm-total precipitation of runoff-producing storms was analyzed from the 1983 through 2007 period at the CIG precipitation-monitoring station using the Mann-Kendall correlation and Theil slope computation. A moderately significant

Table 3. Summary of April through October storm-total precipitation for storms at long-term precipitation-monitoring stations from 1983 through 2007, and storm-total streamflow and suspended-sediment load at the Taylor monitoring station from 1983 through 2006 by range of storm-total precipitation.

[Precipitation, inches; April to October only; storm-total precipitation ranges in inches; percentages may not add up to 100 percent due to rounding; CIG, Colorado Interstate Gas; <, less than; >, greater than; ≤, equal to or less than]

Station name and attribute	Total number of storms	Percentage of total variable in each range of storm totals					
		<0.5	>0.5 and ≤1.0	>1.0 and ≤1.5	>1.5 and ≤2.0	>2.0 and ≤2.5	>2.5
Precipitation (1983 through 2007)							
Bear Springs Hills, number of storms	608	76	14	5.8	1.8	1.6	0.5
Upper Red Rock, number of storms	609	74	16	6.4	2.8	0.7	0.7
Upper Bent, number of storms	617	73	16	6.2	3.1	1.5	1.0
CIG, number of storms	652	79	13	3.5	2.2	1.7	0.9
CIG, storm-total precipitation for all storms	652	35	25	12	10	11	8.0
CIG, number of runoff-producing storms at Taylor	94	33	22	14	13	12	6.4
CIG, precipitation total for runoff-producing storms at Taylor	94	4.7	15	16	20	25	19
Streamflow (1983 through 2007)							
Taylor storm-total streamflow for each range of runoff-producing storm at CIG	94	2.6	11	7.1	21	27	23
Suspended-sediment load (1983 through 2006)							
Taylor storm-total suspended-sediment load for each range of runoff-producing storm at CIG	94	2.7	16	3.8	28	24	21

($p<0.10$) monotonic upward trend in the magnitude of storm-total precipitation from runoff-producing storms indicated a substantial change of 0.027 inch per year, or a total increase of about 0.5 inch from 1983 through 2007 in storm-total precipitation. This trend in runoff-producing storms at CIG may be used to explain any upward trends in storm-total streamflow in the Taylor watershed during the 1983 through 2007 period.

Spatial Variations

Frontal storms generally produce precipitation over large areas, whereas convective storms tend to produce precipitation over smaller areas. Large landscapes commonly have differences in storm paths and geographic features that contribute to large variations in the amount of precipitation that occurs over relatively short distances. At PCMS, storms have been documented that have large variations in precipitation at scales of less than a square mile (von Guerard and others, 1993). However, spatial variation can be different depending on the time-scale of interest. For example, spatial difference may be large among locations for a particular storm, but the large variability will diminish over a period of years as more precipitation events occur.

Monthly Precipitation

The Mann-Whitney rank-sum test was used to test for spatial differences in monthly precipitation between precipitation-monitoring stations for the 1983 through 2007 period. The results of the rank-sum test indicate there were no statistically significant spatial differences in monthly precipitation between the four long-term precipitation-monitoring stations (CIG, Bear Springs, Upper Red Rock, and Upper Bent), indicating that long-term, monthly precipitation was spatially similar. For the 2000 through 2007 period a significant ($p<0.05$) difference in monthly precipitation was computed between Taylor and the following precipitation-monitoring stations: Van Bremer, Red Rock, and Bent. However, there were no statistically significant differences between Van Bremer, Red Rock, and Bent. These results are relevant because streamflow commonly is related to precipitation volume, so the spatial trends in monthly precipitation may contribute to spatial trends in monthly streamflow between Taylor and the other three streamflow-monitoring stations—Van Bremer, Red Rock, and Bent.

Storm-Total Precipitation

Storm-total precipitation from each of the four long-term precipitation-monitoring stations was compared for each storm (all storms including runoff- and nonrunoff-producing storms). Associating the precipitation recorded at a particular station with the streamflow at the mouth of a watershed assumes that the areal distribution of precipitation is representative of the precipitation that falls on the watershed. This assumption is probably inaccurate and can be misleading. This assumption may result in weak correlations between precipitation and streamflow. However, precipitation and streamflow are probably correlated when co-located within smaller watersheds.

For a particular storm during the 1983 through 2007 period, storm-total precipitation was rarely similar among precipitation-monitoring stations. Precipitation-monitoring stations are roughly 6 to 7 miles apart, and the longest distance between precipitation-monitoring stations is more than 20 miles (fig. 1, pl. 1). One measure of the spatial variability is the coefficient of variation of storm-total precipitation among the four long-term precipitation-monitoring stations. For the months April through October during the 1983 through 2007 period, the mean and median coefficient of variation was 86 percent and 92 percent, respectively, for a particular storm. These large coefficients of variation indicate large spatial variability among these stations for any particular storm.

A comparison of the magnitude of runoff-producing storms was made using a boxplot of storm-total precipitation from 2000 through 2007 at the five precipitation-monitoring stations: Van Bremer, Taylor, Lockwood, Red Rock, and Bent (fig. 6). The median storm-total precipitation from runoff-producing storms for Van Bremer, Taylor, Lockwood, and Bent precipitation-monitoring stations were 1.05, 0.81, 0.90 and 0.85 inch, respectively (fig. 6). The 0.33-inch median storm-total precipitation computed at Red Rock (fig. 6) ranged from 31 to 41 percent of the medians at the other four stations. These differences in storm-total precipitation indicate both spatial similarity (among Van Bremer, Taylor, Lockwood, and Bent), and spatial differences (between Red Rock and the other four precipitation-monitoring stations).

Large spatial variability occurred in storm-total precipitation among precipitation-monitoring stations during particular storm events from 1983 through 2007, as well as differences in magnitudes of storms in the boxplot distributions of storm-total precipitation of runoff-producing storms from 2000 through 2007. However, the probability distributions of daily precipitation at the precipitation-monitoring stations with long-term (1983 through 2007) records were similar among precipitation-monitoring stations (fig. 5). The implication was that, over the long-term, spatial differences at the smaller time scales diminished as a longer period of years and more precipitation events were included.

Streamflow

Storm-runoff events are episodic at PCMS and are a result of intermittent precipitation patterns. Storm runoff that reached the streamflow-monitoring stations was affected by several factors including storm intensity, soil permeability,

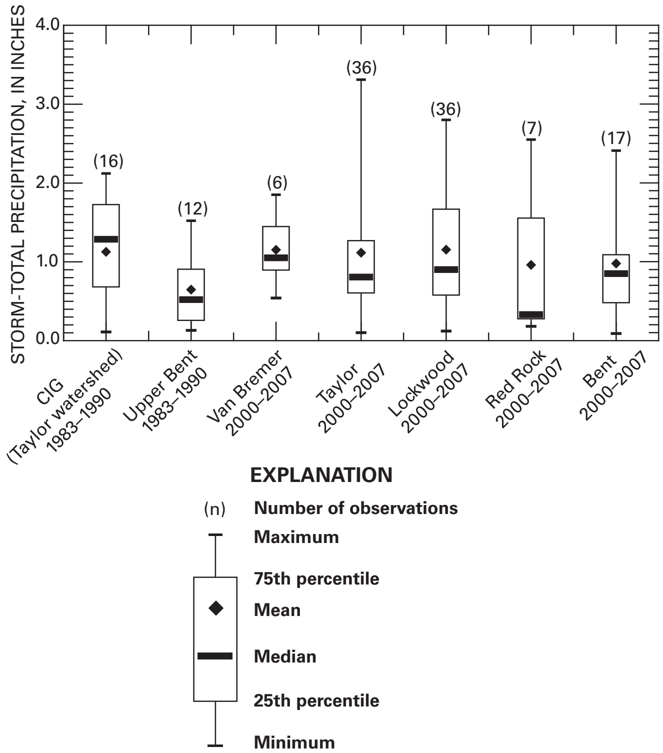

Figure 6. Distribution of storm-total precipitation for runoff-producing storms at selected tributary streamflow-monitoring stations in Colorado during the periods from 1983 through 1990 and 2000 through 2007.

soil-moisture status, topography, land-cover type and condition, and the number, location, and storage status of erosion-control ponds that intercept runoff and sediment. Transit losses (channel storage and infiltration of water into the channel alluvium) are variable depending on the particular location of a storm within an individual watershed. Transit losses contribute to the variability of the runoff response to precipitation (von Guerard and others, 1987). The closer precipitation occurs to the streamflow-monitoring station, the larger the corresponding runoff response (von Guerard and others, 1987). In August 1985, the transit loss for one storm in the Taylor watershed was estimated to be 6.2 acre-ft/mi of stream channel (von Guerard and others, 1987). Insufficient transit-loss estimates were available to characterize the effects of transit loss on a broader temporal or spatial basis.

Definition of Terms

The term "annual streamflow" is defined as the sum of the streamflow recorded at a streamflow-monitoring station during the months April through October. The term "mean annual streamflow" refers to the average of annual streamflows for a period of years. The term "monthly streamflow" is defined as the sum of the streamflow computed at a streamflow-monitoring station during a particular month. Daily streamflow is defined as the sum of the streamflow recorded at a streamflow-monitoring station during a single day. Storm-total streamflow is defined for the report as the sum of the streamflow volume for a particular storm runoff event as determined by examination of the precipitation and streamflow-monitoring station records. Streamflow was classified into storm totals (volumes) based on streamflow and precipitation hydrograph evidence. The term "magnitude" is used to describe the volume of storm-total streamflow rather than the areal coverage, peak flow, or duration. The term "storm-total streamflow yield" is defined for this report as one of two types: (1) the storm-total streamflow divided by the watershed area (acre-feet per square mile); or (2) the storm-total streamflow divided by the storm-total precipitation and watershed area (acre-feet per inch per square mile). For this report the term "base flow" is defined as streamflow that has a groundwater source and typically sustains streamflow during rainless periods (Bossong and others, 2003).

Data from the Van Bremer and Lockwood streamflow-monitoring stations were classified as either stormflow or nonstormflow days. These two streamflow-monitoring stations were the only stations where streamflow occurred unassociated with a storm. Stormflow is defined in this report as streamflow associated with any rise and fall in the streamflow hydrograph associated with precipitation. A stormflow day was classified as 100-percent stormflow whether the storm runoff event was a partial or full day. This was not considered to bias the stormflow volume because the nonstormflow volume was usually very small compared to the total stormflow volume. The other streamflow-monitoring stations, Taylor, Red Rock, and Bent, were assumed to flow only during storms.

Variations in Annual and Monthly Streamflow

Annual streamflow patterns for tributaries draining the PCMS follow the general patterns of annual precipitation. Large variations in annual and monthly streamflow are typical of the episodic precipitation patterns that occur. For example, the mean annual streamflow at the Taylor streamflow-monitoring station (drainage area of 48.4 mi^2) from April through October for the 1983 through 2007 period was 269 acre-ft, which included two years with no annual streamflow during the 2000 through 2007 period. The annual streamflow ranged from 0.00 to 2,820 acre-ft (fig. 7*A*) and exhibited much larger year-to-year variability than annual precipitation on a percentage basis (fig. 2). This occurs, in part, because not all precipitation events of the same magnitude produce the same net runoff at a streamflow-monitoring station. A single large storm that generates storm runoff in a particular watershed can produce both large and small volumes of storm runoff depending upon soil-moisture conditions and other factors that affect storm runoff. The Purgatoire River

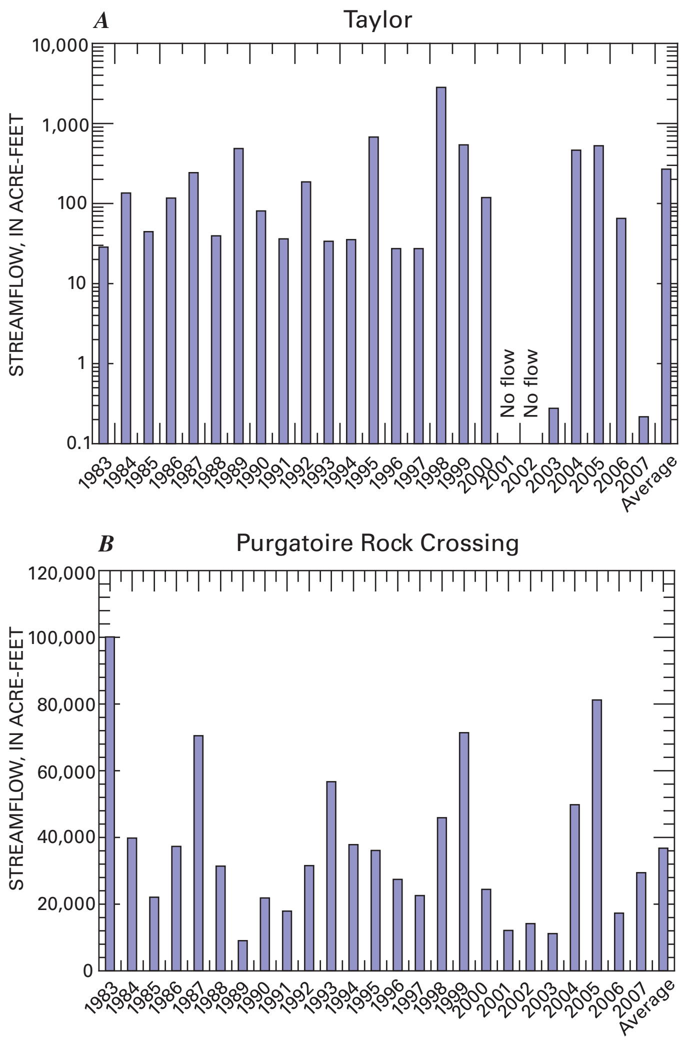

Figure 7. Annual streamflow for the months April through October during the 1983 through 2007 period at (*A*) Taylor and (*B*) Purgatoire Rock Crossing streamflow-monitoring stations, Colorado.

(drainage area of 2,623 mi^2), in contrast to Taylor, exhibits different streamflow patterns and has gone dry only periodically during the months April through October in 1990, 2002, and 2003. The streamflow in the Purgatoire River can be explained by the availability of a variety of upstream water sources that sustain streamflow in this large watershed. Annual streamflow from April through October at the Purgatoire Rock Crossing streamflow-monitoring station from 1983 through 2007 ranged from 9,070 to 100,000 acre-ft, and the mean annual streamflow was 36,800 acre-ft (fig. 7*B*).

The months November through March tend to produce little runoff at the tributary streamflow-monitoring stations or in the Purgatoire River because precipitation is mainly snow. Sublimation and slow melting remove water from the snowpack during warm periods of the winter. These processes might increase soil moisture, but they also decrease the volume of surface runoff. Precipitation from April through October generally is in the form of snow that melts rapidly or rain, which produces the vast majority of the streamflow in the tributaries. Snowmelt from the mountains upstream from PCMS generally produces high flow in the Purgatoire River during the months May through June, and storm runoff that originates beyond the PCMS boundary also generates streamflow in the Purgatoire River.

The streamflow patterns at Taylor for the three periods of streamflow (1983 through 2007, 1983 through 1990, and 2000 through 2007) are dissimilar. The 1983 through 2007 and 1983 through 1990 periods indicated most of the streamflow occurred in July and August (figs. 8*A* and 8*B*). The 2000 through 2007 period (fig. 8*C*), however, showed relatively less flow in May than in the other two periods. The large April mean monthly streamflow for 2000 through 2007 was caused by snowstorms that produced large volumes of runoff in April 2005 that affected the mean for the period. In general, streamflow was less during the 2000 through 2007 period because of the regional drought in the early 2000s (Kuhn, 2005). This may reflect differences in soil moisture, land-cover conditions, and erosion-control pond storage status. The Purgatoire River conveys the most streamflow in August (figs. 9*A* to 9*C*). Generally the increased streamflows in August were a result of mountain snowmelt stored in upstream reservoirs that was subsequently released for downstream irrigation needs. The August increased streamflows also may be a result of convective storms that commonly occur during the late July through August summer monsoon.

Variations in Daily and Storm-Total Streamflows

Streamflow occurred at PCMS tributaries only a fraction of each season but flowed most of the time in the Purgatoire River. Streamflow generally occurred fewer than 20 days per year on average at the five tributary streamflow-monitoring stations. Streamflow at Taylor (the longest tributary streamflow record) occurred about 6 percent of the time (an average of about 13 days out of the 214-day season). Streamflow at Purgatoire Rock Crossing occurred about 99 percent of the time from April through October during the1983 through 2007 period. The total number of runoff-producing storms occurring each year during the months April through October generally also was small. From 1983 through 2007 a total of 139 runoff-producing storms were recorded at Van Bremer and 99 runoff-producing storms occurred at Taylor (the two tributary streamflow-monitoring stations with the longest records).

Storm-total streamflow at Taylor was categorized using a range of storm-total precipitation at the CIG precipitation-monitoring station (table 3). During the 1983 through 2007 period, storm-total precipitation larger than 1.0 inch at the CIG precipitation-monitoring station was associated with about 78 percent of storm-total streamflow at Taylor. During the same period, storm-total precipitation less than 0.5 inch at the CIG precipitation-monitoring station was associated with only 2.6 percent

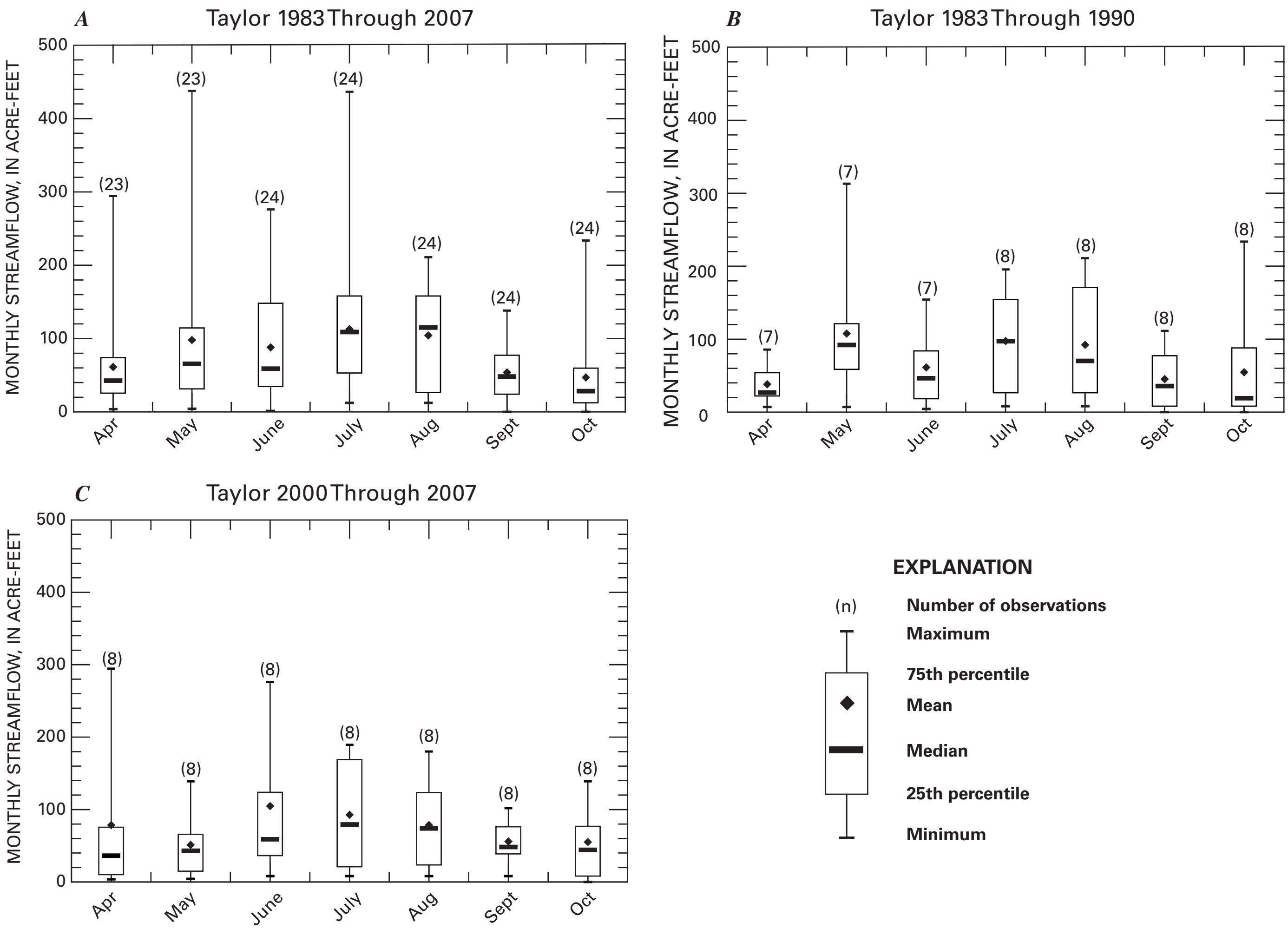

Figure 8. Distribution of mean monthly streamflow at the Taylor streamflow-monitoring station, Las Animas County, Colorado, for the months April through October during the (*A*) 1983 to 2007, (*B*) 1983 to 1990, and (*C*) 2000 to 2007 periods.

of the storm-total streamflow at Taylor. This indicates that larger storms contribute more to streamflow-runoff generation, despite occurring less frequently based on data from the CIG precipitation-monitoring station and the Taylor streamflow-monitoring station.

An analysis of storm-total streamflow was done for the months April through October during the 1983 through 1990 and 2000 through 2007 periods at all five tributary streamflow-monitoring stations (Van Bremer, Taylor, Lockwood, Red Rock, and Bent [1983 and 1985 data were missing at Bent]). The analysis indicated that (1) storm-total streamflows at Van Bremer, in general, were less for the same probability of exceedance during the 2000 through 2007 period than during the 1983 through 1990 period, but the probability of exceedance for the two periods was similar at storm-total streamflows larger than about 100 acre-ft (fig. 10*A*); (2) storm-total streamflow at Taylor was larger during the 2000 through 2007 period than the 1983 through 1990 period for storm-total streamflows larger than about 10 acre-ft (fig. 10*B*); (3) storm-total streamflows generally were larger at Lockwood and Red Rock during the 2000 through 2007 period than during the 1983 through 1990 period throughout the range of storm-total streamflows (fig. 10*C* and 10*D*); and (4) storm-total streamflows at Bent during the 1983 through 1990 period were larger than during the 2000 through 2007 period at storm-total streamflows larger than about 50 acre-ft (fig. 10*E*). Bent was influenced at the higher range of storm-total streamflows by large precipitation events that occurred August 21–22, 1984 (combined storm-total streamflow of about 600 acre-ft) (USGS National Water Information System database, *http://waterdata.usgs.gov/co/nwis/sw*, accessed February 2008).

The streamflow probability comparisons were made between the period 1983 through 1990 and the period 2000 through 2007. The comparisons indicate that despite the lack of many upward precipitation trends at Lockwood and Red Rock (discussed in the “Precipitation” section of the report), larger storm-total streamflows occurred in these tributaries during the 2000 through 2007 period than during the 1983 through 1990 period (fig. 10*C* and 10*D*). Downward trends in storm-total precipitation for runoff-producing storms at

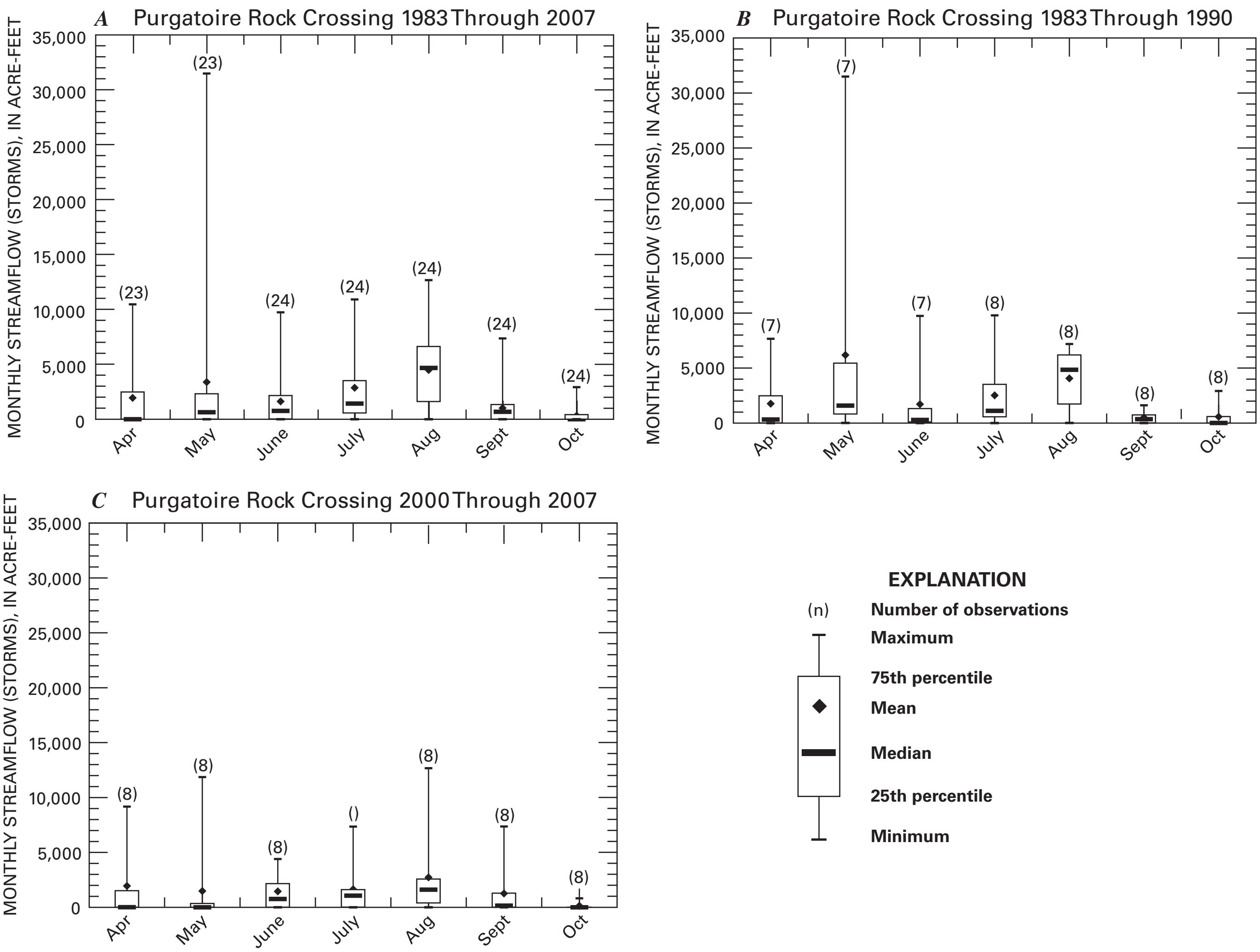

Figure 9. Distribution of mean monthly streamflow at the Purgatoire Rock Crossing streamflow-monitoring station, Las Animas County, Colorado, for the months April through October during the (*A*) 1983 through 2007, (*B*) 1983 through 1990, and (*C*) 2000 through 2007 periods.

Van Bremer and Taylor during the 2000 through 2007 period may explain the smaller, low to moderate flows at Taylor and the smaller storm-total streamflows at Van Bremer in the 2000 through 2007 period (fig. 10*A*).

Temporal Variation

Monthly Streamflow

Statistical tests for monotonic temporal trends in streamflow at streamflow-monitoring stations were done using the seasonal Kendall test on monthly streamflow for April through October during the 1983 through 2007, 1983 through 1990, and 2000 through 2007 periods. All temporal trends in this report are monotonic and will be referred to as temporal trends. The results indicate that there are no statistically significant ($p<0.05$) or moderately significant ($p<0.10$) upward or downward temporal trends in monthly streamflow for any period at the tributary streamflow-monitoring stations at PCMS. The variability in monthly streamflow and the relatively small number of streamflow events pose difficulties for detecting temporal trends.

Storm-Total Streamflow

Storm-total streamflow yield was normalized for drainage area and tested for temporal trends by using the Mann-Kendall and Theil slope method. During the 1983 through 1990 period at Taylor and Bent, the only streamflow-monitoring stations with sufficient record, no significant temporal trends in storm-total streamflow yield were identified. During the 2000 through 2007 period, no significant temporal trends were identified for the Van Bremer, Lockwood, Red Rock, or Bent streamflow-monitoring stations; but a moderately significant downward trend ($p<0.10$) with a substantial change of 59 percent of the median for the 8-year period was identified at Taylor. Because the sediment

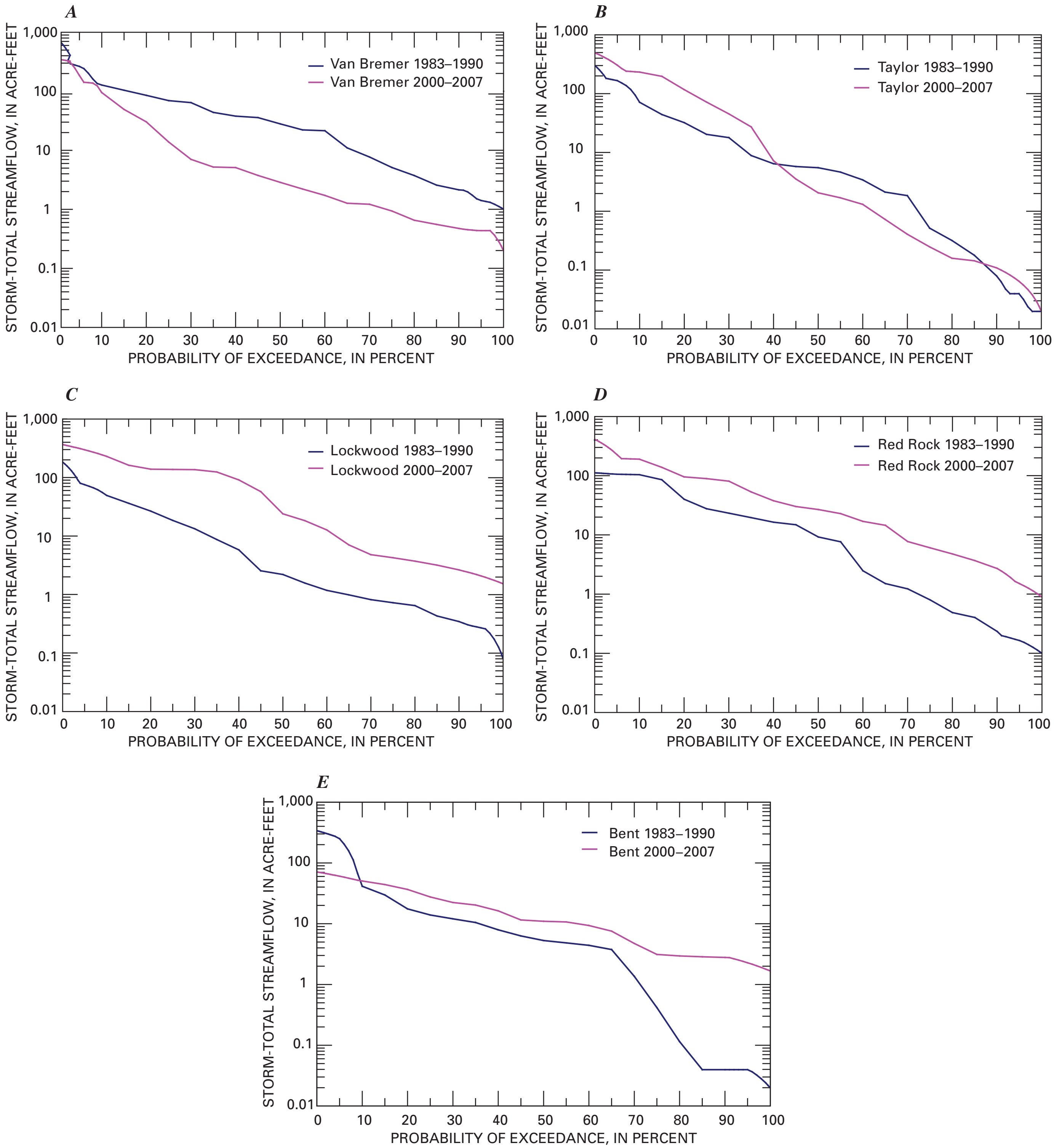

Figure 10. Probability (in percent) of exceeding storm-total streamflow for the months April through October during the 1983 through 1990 and 2000 through 2007 periods at (*A*) Van Bremer, (*B*) Taylor, (*C*) Lockwood, (*D*) Red Rock, and (*E*) Bent streamflow-monitoring stations, Las Animas County, Colorado.

record (to be discussed in the "Suspended-Sediment Load and Yield" section) is computed for the 2000 through 2006 period, this period also was tested and the results indicated no significant or moderately significant trends in streamflow yield. During the 1983 through 2007 period, the storm-total streamflow trend analysis at Taylor did not identify any significant temporal trends. The results indicated that there were no statistically significant ($p<0.05$) or moderately significant ($p<0.10$) upward or downward temporal trends in storm-total streamflow for any period at the tributary streamflow-monitoring stations at PCMS, except at Taylor during the 2000–2007 period.

Spatial Variation

Spatial variation in monthly streamflow and storm runoff measured at PCMS likely was caused by spatial variation in precipitation. Other factors such as land use and ground cover, soil, topographic variation, and the interception of runoff by erosion-control ponds also may affect spatial variability of storm runoff. Storm runoff also may be sensitive to rainfall intensity and the effects of wind, air temperature, and relative humidity on antecedent soil moisture, which affects vegetation growth and infiltration of precipitation.

Monthly Streamflow

The Mann-Whitney rank-sum test was used to test spatial differences in monthly streamflow, which was normalized to drainage area, between stations during the 1983 through 2007, 1983 through 1990, and 2000 through 2007 periods. For the 1983 through 2007 period a significant ($p<0.05$) difference in monthly streamflow was computed at Van Bremer and Taylor, the only tributary stations with complete streamflow data for the period. For the 1983 through 1990 period, significant ($p<0.05$) and moderately significant ($p<0.10$) differences in monthly streamflow were computed between Bent and the following streamflow-monitoring stations: Van Bremer, Taylor, and Lockwood. Several large storms at Bent during the 1983 through 1990 period may explain the differences in monthly streamflow among Bent, Van Bremer, Taylor, and Lockwood. There were no significant ($p<0.05$) differences in monthly streamflow between Red Rock and Bent. During the 2000 through 2007 period, the results of the rank-sum test indicated significant and moderately significant statistical differences in monthly streamflow (normalized to drainage area) between the Van Bremer and Lockwood tributary stations and the following streamflow-monitoring stations: Taylor, Red Rock, and Bent. Spatial variation in streamflow may be caused by rainfall patterns, land use and cover, soil, topographic differences, number and effectiveness of erosion-control ponds, and differences in rainfall intensity.

Storm-Total Streamflow

Spatial differences in storm-total streamflow yield exceeded four orders of magnitude at some streamflow-monitoring stations during the 1983 through 1990 and 2000 through 2007 periods. The 1983 through 1990 median storm-total streamflow yields normalized to precipitation at Van Bremer, Taylor, Lockwood, Red Rock, and Bent streamflow-monitoring stations did not follow a particular graphical pattern: 0.237, 0.025, 0.082, 0.330, and 0.029 acre-ft/in/mi^2, respectively (fig. 11*A*). The 2000 through 2007 median storm-total streamflow yields at Van Bremer, Taylor, Lockwood, Red

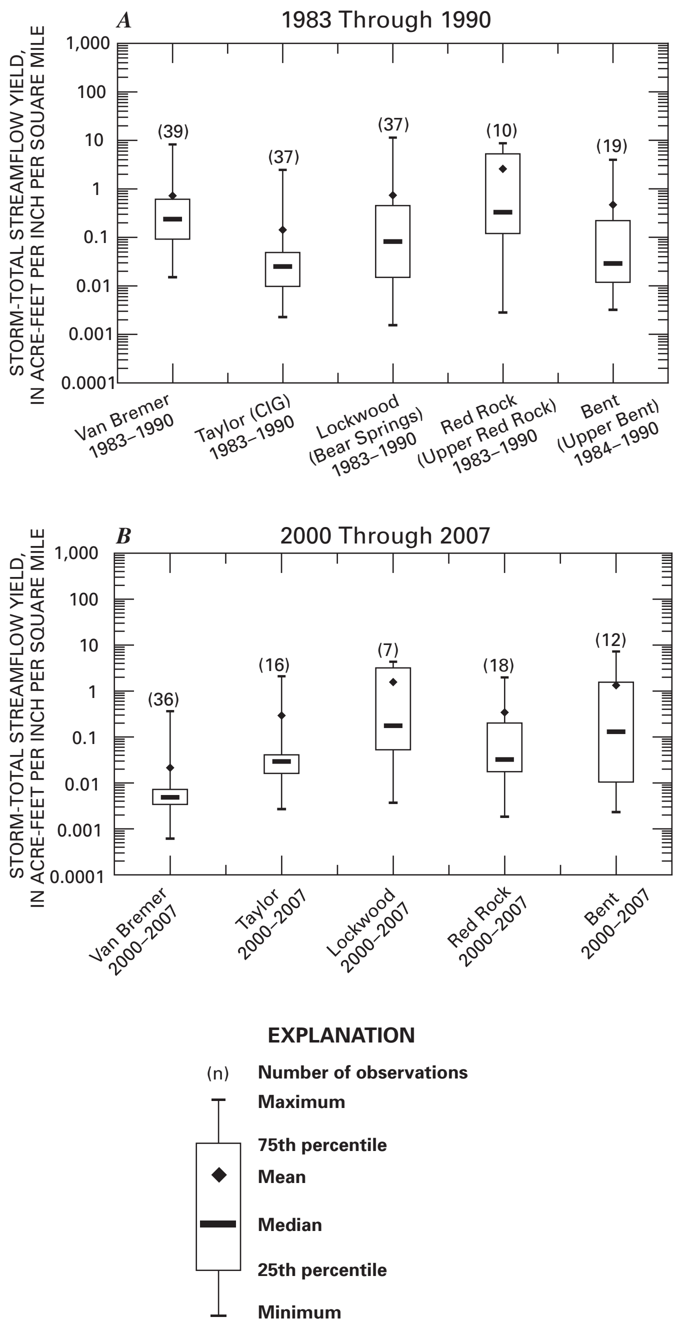

Figure 11. Variation in April through October storm-total streamflow yield normalized to storm-total precipitation and drainage area (acre-feet per inch per square mile) at selected streamflow-monitoring stations in Colorado during the periods (*A*) 1983 through 1990 (precipitation station in parentheses) and (*B*) 2000 through 2007 (precipitation station located at streamflow station).

Rock, and Bent streamflow-monitoring stations were 0.005, 0.029, 0.176, 0.032, and 0.130 acre-ft/in/mi^2, respectively (fig. 11*B*). The reason for the graphical variations among watersheds was not clear.

To assess spatial differences, storm-total streamflow yields were normalized to drainage area and precipitation for the 2000 through 2007 period and tested using the Mann-Whitney rank-sum test. Storm-total streamflow yields at Van Bremer were not significantly different from Taylor but were significantly different from Lockwood, Red Rock, and Bent. The storm-total streamflow yields at Taylor were significantly different from Lockwood, Red Rock, and Bent. The southernmost two stations (Van Bremer and Taylor) were statistically similar, and the northern three stations (Lockwood, Red Rock, and Bent) were statistically similar; but the two groups (southern and northern) were significantly different. The reason for the spatial variations among watersheds may be associated with differences in precipitation intensity among the watersheds, watershed morphology, topography, or geology, or differences in land condition, military training, and the intensity of pre-maneuver grazing and rates of post-grazing vegetation recovery.

Contribution of Tributary Streamflow to the Purgatoire River

Storm runoff from tributary watersheds to larger streams and rivers can be an issue if the storm runoff is larger compared to the streamflow in the receiving stream or river. The daily streamflow for the five monitored tributaries at PCMS (Van Bremer, Taylor, Lockwood, Red Rock, and Bent) was compared to the daily streamflow at Purgatoire Rock Crossing for April through October during the 2000 through 2007 period. The combined daily streamflow from the five tributaries was larger than 5 percent of the daily streamflow at Purgatoire Rock Crossing for 3 percent of the time during the 2000 through 2007 period, indicating that the flow contribution from the PCMS generally was small. Ungaged tributaries at PCMS contribute streamflow not included in this calculation. Transit losses from tributaries were not measured but may reduce the amount of water that actually reaches the river (von Guerard and others, 1993).

The streamflow contribution from tributaries to annual streamflow in the Purgatoire River also was determined during the water years 1984 through 1987 (a water year is the 12 months from October 1 to September 30 of the following year) (von Guerard and others, 1993). The analysis combined 12-month total annual streamflow (including storm and nonstorm streamflows) for the five monitored tributaries at PCMS (Van Bremer, Taylor, Lockwood, Red Rock, and Bent). The tributary contributions were about 9,000 acre-ft or about 4.0 percent of the total streamflow of the Purgatoire Rock Crossing (von Guerard and others, 1993). Irrigation return flow at the Van Bremer streamflow-monitoring station represented about 41 percent of the combined streamflow total from PCMS tributaries during the 1984 through 1987 period (von Guerard and others, 1993).

The combined annual runoff from the five tributaries ranged from 0.0 percent (2001) to 4.0 percent (2003) of the annual runoff at Purgatoire Rock Crossing for the months April through October during the 2000 through 2007 period (fig. 12). The drainage area of the five tributary watersheds represents 13.9 percent of the drainage area of the Purgatoire River watershed upstream from Purgatoire Rock Crossing.

Suspended-Sediment Load and Yield

Suspended-sediment data were collected at five tributary stations at PCMS (Van Bremer, Taylor, Lockwood, Red Rock, and Bent) and two stations on the Purgatoire River (Purgatoire Thatcher and Purgatoire Rock Crossing) from 1983 through 2006 (table 1, fig. 1, pl. 1). These data were used to describe the temporal and spatial variations in suspended-sediment load and yield, including suspended-sediment transport during storm runoff.

Definition of Terms

Suspended-sediment load and yield data are defined in this report as the suspended-sediment fraction of the total sediment load or yield. Suspended sediment is the fraction that is in suspension within the water column at the time and location of sampling and is further operationally defined as the fraction that can be collected by the use of a suspended-sediment sampler

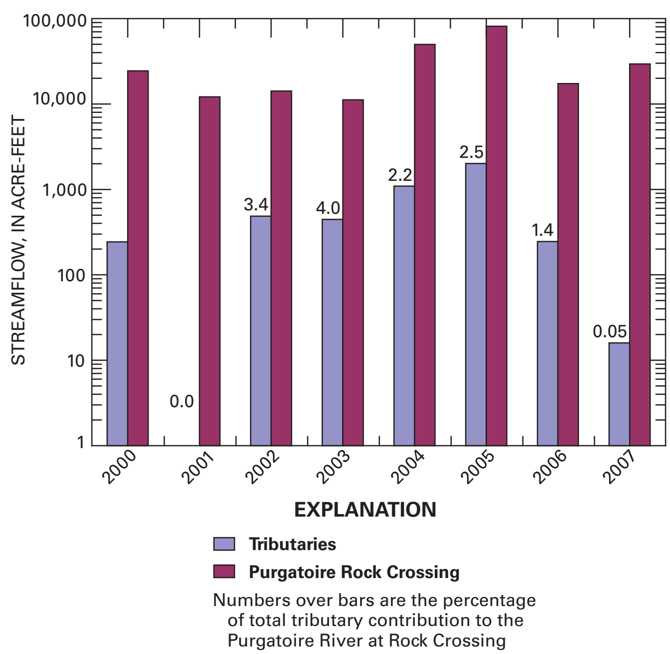

Figure 12. Comparison of April to October storm-total streamflow at Van Bremer, Taylor, Lockwood, Red Rock, and Bent streamflow-monitoring stations, Colorado, to annual storm-total streamflows at Purgatoire Rock Crossing streamflow-monitoring station, 2000 through 2006.

(Edwards and Glysson, 1988). The term "annual suspended-sediment load" is defined as the sum of the suspended-sediment load computed at a streamflow-monitoring station from April through October. The term "monthly suspended-sediment load" is defined as the sum of the suspended-sediment load computed at a streamflow-monitoring station during a particular month. Daily suspended-sediment load is defined as the sum of the suspended-sediment load computed at a streamflow-monitoring station during a single day. Storm-total suspended-sediment load is defined for the report as the sum of the suspended-sediment load for a particular stormflow event (may span one or more days) as determined by the duration of the storm-total streamflow event. The term "magnitude" when describing suspended-sediment load is used to denote the storm-total suspended sediment in terms of mass transported during a storm.

Storm-total suspended-sediment yield is defined for a particular stormflow event (may span one or more days) as determined by the duration of the storm-total streamflow event (suspended sediment is transported only when water is flowing). In this report, the term storm-total suspended-sediment yield is defined as one of three types: (1) the sum of the suspended-sediment load (defined previously) divided by the watershed area (tons per square mile); (2) the sum of the suspended-sediment load divided by the streamflow volume (tons per acre-foot); or (3) the sum of the suspended-sediment load divided by the streamflow volume and watershed area (tons per acre-foot per square mile). Yield computations are used to normalize or remove the effects of drainage area and streamflow, allowing comparison of suspended sediment among sediment-monitoring stations with dissimilar drainage areas or with dissimilar streamflow volumes. For purposes of this report the term "suspended sediment" will be referred to as sediment unless otherwise noted.

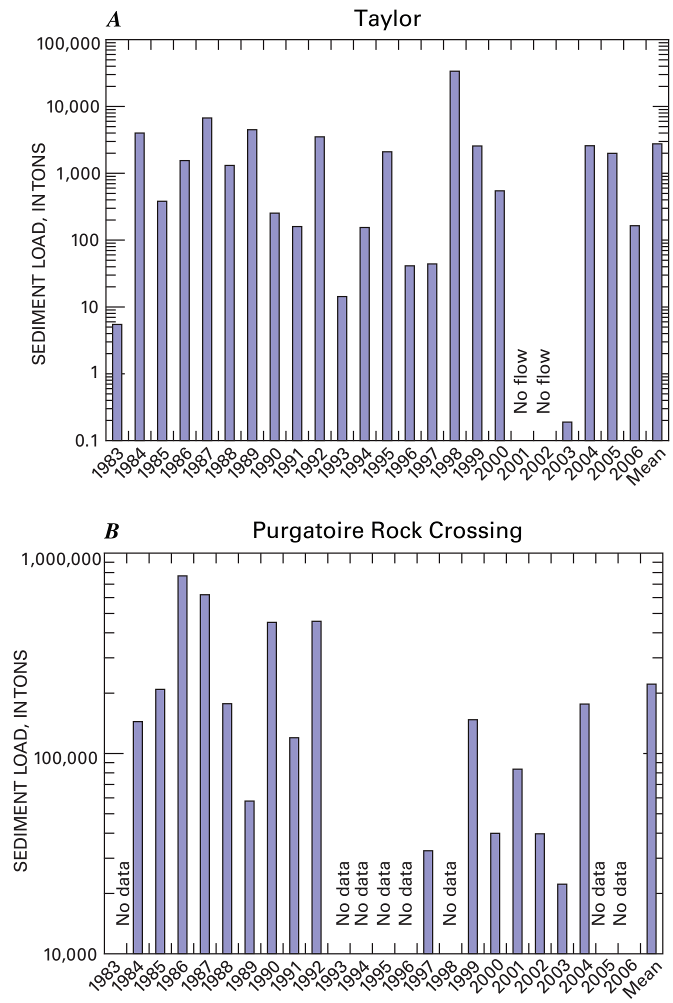

Figure 13. Annual suspended-sediment load produced by storms for the months April through October at the (*A*) Taylor and (*B*) Purgatoire Rock Crossing sediment-monitoring stations, Las Animas County, Colorado.

Variations in Annual and Monthly Sediment Load

Annual sediment load for the months April through October during the 1983 through 2006 period at Taylor ranged from 0.00 tons in 2001 and 2002, when there was no streamflow, to 33,800 tons in 1998. This indicated that large annual variations occurred in annual sediment loads (fig. 13*A*). The large annual variations in annual sediment loads may be related to spatial variability of runoff-producing storms at PCMS. In 1998, the annual sediment load was 33,800 tons and represented about one-half of the total sediment load of 66,400 tons transported at Taylor over the entire 24-year period. To put this in sediment load perspective, if the density of the sediment is assumed to be 2,700 pounds per cubic yard (approximately that of dry sand), then there are 1.35 tons per cubic yard of sediment. Assuming a large, dual-axle dump truck holds 10 yards of sediment, that dump truck would hold about 13.5 tons of sediment. In this example, it would take more than 2,500 dump trucks to haul off the estimated 33,800 tons of sediment transported by Taylor in that single storm event. The magnitude of this sediment load may partially have been affected by erosion from a streambank-stabilization project, which was located adjacent to the channel in the Taylor watershed. The streambank was damaged by storms in 1998 and may have contributed additional sediment to the stream channel (Department of the Army, written commun., May 2008).

The annual April through October sediment load at Purgatoire Rock Crossing during the 1983 through 2006 period ranged from 22,300 tons in 2003 to 770,000 tons in 1986, but data were not collected during 8 years of the period (fig. 13*B*). During water years 1984 and 1985 (12-month records), about 80 percent of the sediment load was transported at daily-mean streamflows larger than 200 ft^3/s at the Purgatoire Rock Crossing sediment-monitoring station, a streamflow that was exceeded only about 8 percent of the time during this period (von Guerard and others, 1987). The mean annual (average) sediment load for April through October during the 1983 through 2006 period at Purgatoire Rock Crossing was 222,000 tons (fig. 13*B*). The annual patterns for sediment loads at PCMS tributaries that discharge to the Purgatoire River were similar to the general annual patterns of precipitation (fig. 2) and streamflow (fig. 7*A*). Large variations in annual sediment loads were caused by the episodic rainfall and runoff during storm events in this hydrologic setting.

The mean monthly sediment loads at Taylor for the three periods (1983 through 2006, 1983 through 1990, and 2000 through 2006) are shown in figure 14*A*. Mean monthly sediment load for the months July and August for the 1983 through 2006 and 1983 through 1990 periods were similar and much larger than the mean monthly sediment loads during the 2000 through 2006 period (fig. 14*A*). The smaller mean monthly sediment load in July and August during the 2000 through 2006 period was the result of the 2001 through 2003 drought when no runoff or sediment transport occurred during those months.

Mean monthly sediment loads at Purgatoire Rock Crossing for the months May through August for the 1983 through 2006 and 1983 through 1990 periods were similar and much larger than the mean monthly sediment loads during the 2000 through 2006 period (fig. 14*B*). The smaller mean monthly sediment load in May through August during the 2000 through 2006 period was the result of the 2001 through 2003 drought.

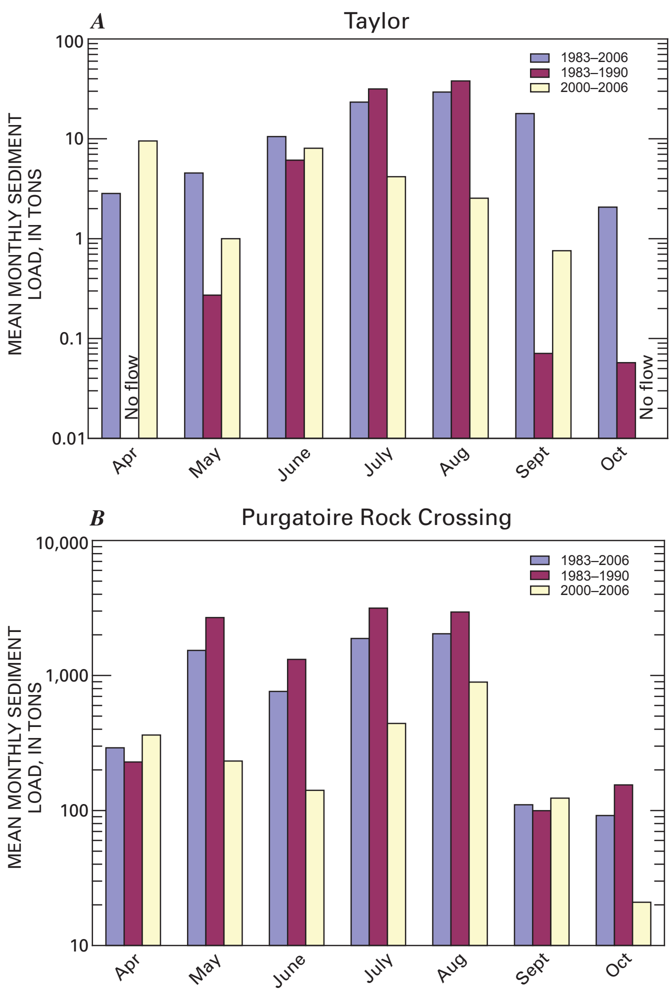

Figure 14. Mean monthly April through October suspended-sediment load for the 1983 through 2006, 1983 through 1990, and 2000 through 2006 periods for (*A*) Taylor and (*B*) Purgatoire Rock Crossing sediment-monitoring stations, Las Animas County, Colorado.

Variations in Daily and Storm-Total Suspended-Sediment Loads

The maximum daily sediment load of more than 12,000 tons occurred at Taylor on September 30, 1998. No sediment transport occurred 94 percent of the days at the PCMS tributary sediment-monitoring stations for the months April through October during the 1983 through 2006 period because episodic precipitation was the only source of runoff (USGS National Water Information System database, *http://waterdata.usgs.gov/co/nwis/sw*, accessed February 2008). On the Purgatoire River, which has many sources of streamflow and suspended sediment, the frequency of sediment loads was higher, with very few days of no flow (less than 1 percent April through October 1983 through 2007) (USGS National Water Information System database, *http://waterdata.usgs.gov/co/nwis/sw*, accessed February 2008). The maximum daily sediment load of 160,000 tons occurred at Purgatoire Rock Crossing on July 9, 1992.

Storm-total sediment load at Taylor was categorized using a range of storm-total precipitation at the CIG precipitation-monitoring station (table 3). During the 1983 through 2006 period, storm-total precipitation values larger than 1.5 inch at the CIG precipitation-monitoring station were associated with about 73 percent of the storm-total sediment load at Taylor. During the same period, storm-total precipitation less than 0.5 inch at the CIG precipitation-monitoring station was associated with only about 3 percent of the storm-total sediment load at Taylor despite accounting for 79 percent of the number of storms for the same period. The evaluation of storm-total sediment loads for categories of storm-total precipitation indicated that larger and more infrequent storms contributed more to suspended-sediment production than smaller and more frequent storms.

Temporal Variations

Annual Sediment Load

A comparison of temporal differences between the 1983 through 1990 and 2000 through 2006 periods for Taylor and Bent indicated a larger sum of annual sediment loads during the 1983 through 1990 period (18,700 tons at Taylor and 30,600 tons at Bent), than the sum of annual sediment loads during the 2000 through 2006 period (5,300 tons at Taylor and 1,600 tons at Bent) (fig. 15). A Mann-Whitney test of annual loads between the 1983 through 1990 and 2000 through 2006 periods at Taylor and Bent identified no significant or moderately significant temporal trends.

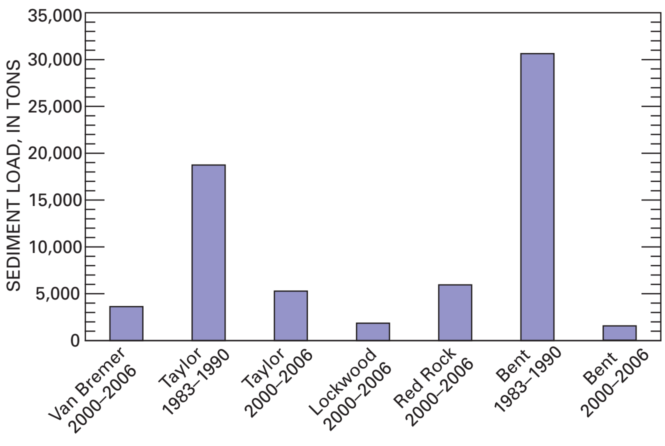

Figure 15. Sum of April through October sediment loads at selected tributary sediment-monitoring stations, Las Animas County, Colorado, (storms only) from 2000 through 2006.

Monthly Sediment Load

Temporal variations in sediment load and yield were assessed by statistical testing for monotonic trends using the seasonal Kendall and Mann-Kendall tests for the 1983 through 1990, 2000 through 2006, and 1983 through 2006 periods. Temporal differences for sediment loads and yields also were assessed by making comparisons between the 1983 through 1990 and 2000 through 2006 periods, using sum and median values, graphical plots, and the Mann-Whitney statistical test. Statistical tests for temporal trends in monthly sediment loads were done for the 1983 through 2006 period at Taylor by using the seasonal Kendall test because the longer record increases the statistical power to detect temporal trends. No significant or moderately significant temporal trends were identified at Taylor in monthly flow-adjusted sediment loads. Data for April through October for the 1983 through 1990 period at Taylor and Bent and from 2000 through 2006 at the five tributary sediment-monitoring stations (Van Bremer, Taylor, Lockwood, Red Rock, and Bent) were analyzed using the seasonal Kendall test. Temporal trends in monthly flow-adjusted sediment loads were not identified for either the 1983 through 1990 or 2000 through 2006 periods.

Storm-Total Sediment Load

Temporal trends in storm-total sediment loads at the five tributary stations during the 1983 through 1990 and 2000 through 2006 periods were tested using the Mann-Kendall test and the Theil slope method and were flow-adjusted for storm-total streamflow. The only significant temporal trend ($p<0.05$) for either period occurred at Bent during the 1983 through 1990 period, which indicated a downward trend in flow-adjusted storm-total sediment load. The slope of the downward trend was –6.1 tons per year, which was a decrease of about 49 tons during the 1983 through 1990 period. The median storm-total sediment load for the period also was about 49 tons and ranged from 0.02 to 21,700 tons.

Plots of the distribution of storm-total sediment yield normalized to both storm-total streamflow and drainage area, indicated that storm-total sediment yield were similar at Taylor for the 1983 through 1990 and 2000 through 2006 periods; whereas, at Bent, the distributions of storm-total sediment yields were larger for the 1983 through 1990 period (fig. 16). The storm-total sediment yields at Taylor and Bent for the 1983 through 1990 period were 30 and 55 tons/acre-ft, respectively, and for the 2000 through 2006 period were 4.6 and 8.6 tons/acre-ft, respectively, at a 10-percent probability of exceedance (fig. 17). The graphical time-series comparison of temporal differences in storm-total sediment yields between the 1983 through 1990 and 2000 through 2006 periods indicated differences at Taylor and Bent sediment-monitoring stations (fig. 18). The storm-total sediment yields for Taylor and Bent during the 2000 through 2006 period were relatively small when compared with the larger storm yields at Taylor and Bent during the 1983 through 1990 period. The 1983 through 1990 period at Bent was characterized by several storms (more than 25 percent of all storms) with relatively large storm-total sediment yields per acre-ft of runoff exceeding 20 tons/acre-ft (fig. 18). Similarly,

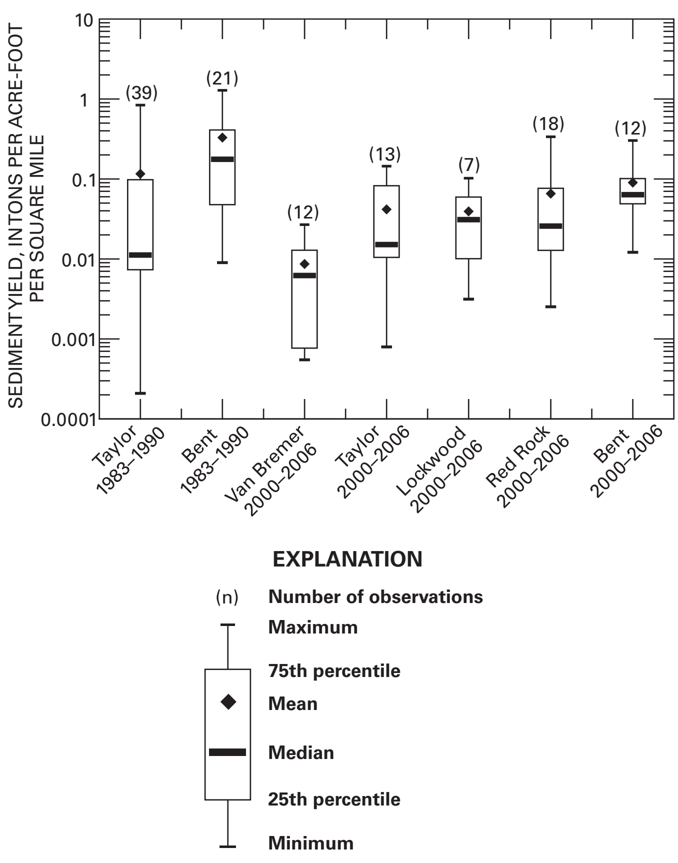

Figure 16. Variation in storm-total suspended-sediment yield normalized to storm-total streamflow (tons per acre-foot per square mile) at tributary sediment-monitoring stations for the months April through October for the 1983 through 1990 period at Taylor and Bent and the 2000 through 2006 period at Van Bremer, Taylor, Lockwood, Red Rock, and Bent, Las Animas County, Colorado.

large storm-total sediment yields at Taylor were produced by storms that occurred during 1984 and 1986 (fig. 18). However, a comparison of temporal differences between the 1983 through 1990 and 2000 through 2006 periods using the Mann-Whitney test indicated that storm-total sediment yields normalized for storm-total streamflow were not significant at Taylor but were moderately significant at Bent.

Long-term decreases in sediment transport were indicated by differences in storm-total sediment yield at the Taylor and Bent monitoring stations between the 1983 through 1990 and 2000 through 2006 periods using graphical methods (figs. 16, 17, and 18). However, testing of the 1983 through 2007 sediment load at Taylor did not indicate a temporal trend. When trends or differences are indicated, the implication is that either precipitation and streamflow have changed, or that another set of factors have changed such as land-cover condition including vegetation, soil condition, disturbance of the land surface, antecedent soil moisture, or differences in the form of precipitation. For streamflow, there was a lack of statistically significant, substantial monthly or storm-total streamflow temporal trends for the 1983 through 2007 period at Taylor. This indicates that for the 24-year period from 1983 through 2006, temporal trends and differences in storm-total suspended-sediment load and yield were not explained by temporal trends in monthly streamflow or storm-total streamflow. For precipitation, which affects both streamflow and sediment erosion, an analysis indicated a significant upward monotonic temporal trend in monthly precipitation at only one of four precipitation stations from 1983 through 2007. Also, an upward trend in the magnitude of runoff-producing storms at CIG (in Taylor watershed) was identified. Trends in monthly precipitation indicated increasing monthly precipitation over the 24-year period from 1983 through 2006 at one precipitation-monitoring station and a 5-percent increase in the magnitude of runoff-producing storms at CIG during the same period. The implication is that changes in land-cover conditions and possibly precipitation were responsible for some of the changes in storm-total sediment load rather than changes in streamflow. However, precipitation may not be related to long-term changes in streamflow, and thus the relation between precipitation and sediment load is unclear.

For short-term trends, precipitation and streamflow affect sediment transport but can be more difficult to interpret because of fewer data. Short-term temporal trends in sediment transport during the 1983 through 1990 or 2000 through 2006 periods were not identified at any monitoring stations using monthly or annual sediment loads. Temporal trends in storm-total sediment load were not significant except for a downward trend at Bent during the 1983 through 1990 period that might indicate a trend toward smaller storms during the period. The relative lack of 1983 through 1990 or 2000 through 2006 temporal trends in sediment load and yield was consistent with no temporal trends in streamflow for the same periods but was not consistent with the finding of significant downward trends in precipitation at Van Bremer and Taylor during the 2000 through 2006 period, indicating that the processes of precipitation, runoff, and sediment erosion are complex.

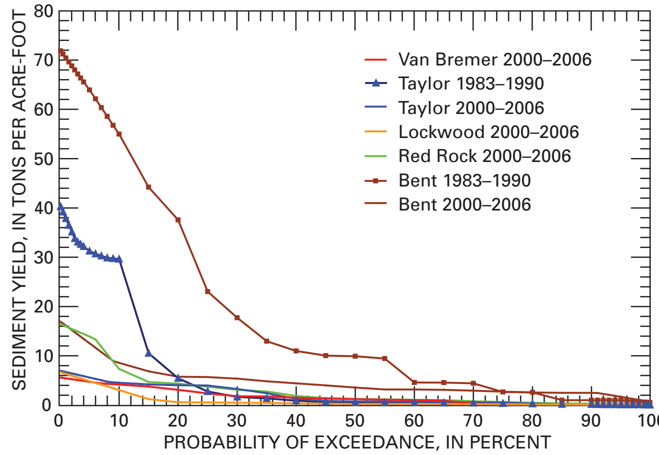

Figure 17. Probability of exceeding storm-total suspended-sediment yield for April through October at selected tributary site suspended-sediment monitoring stations, Las Animas County, Colorado.

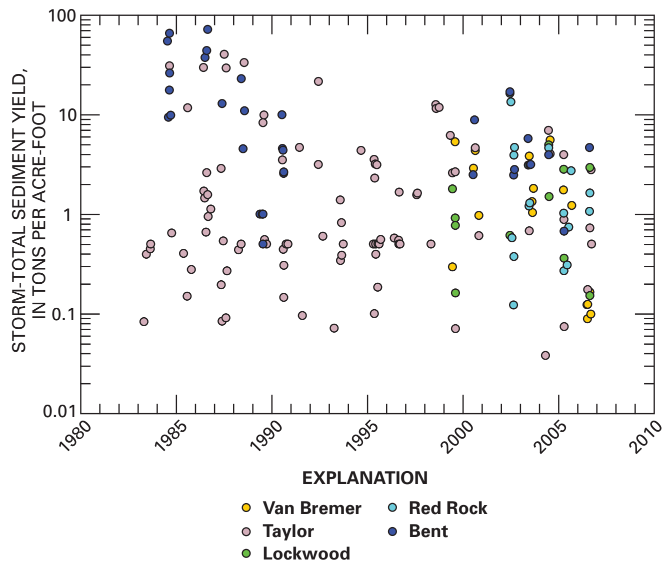

Figure 18. Time-series of suspended-sediment yield at Van Bremer, Lockwood, and Red Rock sediment-monitoring stations for the 2000 through 2006 period, Taylor sediment-monitoring station for the 1983 through 2006 period, and Bent sediment-monitoring station, Las Animas County, Colorado, for the 1983 through 1990 and 2000 through 2006 periods.

Spatial Variations

Suspended-sediment loads were calculated at all five tributary sediment-monitoring stations during the 2000 through 2006 period, which allowed comparison of the spatial variation among stations. Sediment load also was calculated for the 1983 through 2006 period at Taylor and Bent sediment-monitoring stations, the only two stations that had sediment measured for the entire period.

Monthly Sediment Yield

The Mann-Whitney rank-sum test was used to test for spatial statistical differences in monthly sediment yield (tons per square mile) between stations for the 1983 through 2006, 1983 through 1990, and 2000 through 2006 periods. The results of the test indicated significant ($p<0.05$) and moderately significant ($p<0.10$) statistical differences in monthly sediment yield between Lockwood and the other four tributary stations (Van Bremer, Taylor, Red Rock, and Bent) during the 2000 through 2006 period.

Storm-Total Sediment Yield

When sediment load was normalized to storm-total streamflow and drainage area (fig. 16), the storm-total sediment yields (tons per acre-foot per square mile) increased northward from Van Bremer to Bent. Variations in geology and the differences in soil types or depths derived from the rocks in each of the watersheds, the topography and relief developed from that geology, the rainfall intensity, and the number of erosion-control ponds all might contribute to the spatial differences in sediment transport. The proportion of watershed area with topographic relief and canyon physiographic landforms as a proportion of the drainage area increased from Van Bremer northward to Bent. Geology maps showed a decreasing proportion of upland shale and limestone rock types and an increasing proportion of sandstone northward from Van Bremer to Bent (von Guerard and others, 1987). Soil maps also showed a decreasing proportion of Penrose-Manzanola-Midway group soil types, which have substantial erosion potential, northward from Van Bremer to Bent (von Guerard and others, 1987). Differences in land use or cover also may have contributed to the increasing south-to-north pattern in sediment yield during the 2000 through 2006 period. Military training takes place more commonly in the Taylor and Lockwood watersheds (Jeff Linn, U.S. Department of the Army, written commun., 2008). Active revegetation of soil damage and the higher density of erosion-control ponds in the Taylor and Lockwood watersheds (southern and central PCMS) also could have influenced the trend of smaller sediment yields in the southern tributaries (pl. 1).

The Mann-Whitney rank-sum test also was used to test for spatial statistical differences in storm-total sediment yield (tons per square mile). No significant spatial difference was identified between Van Bremer and Taylor. However, significant spatial differences were identified between Van Bremer and the three northern tributaries: Lockwood, Red Rock, and Bent. The evidence for a north-south pattern was more tenuous without evidence of spatial differences between Taylor and the northern tributaries. These differences may be caused by differences in watershed characteristics such as land use and cover conditions; soil, geology, topographic, and relief differences; differences in the number, sediment-trapping efficiency, and storage status of erosion-control ponds; and differences in the location of precipitation and intensity of precipitation.

Contribution of Tributary Suspended Sediment to the Purgatoire River

Sediment transport from tributary watersheds to larger rivers and streams may or may not be an issue, depending on whether the sediment load is larger when compared to the transported sediment load in the receiving stream. When it is deposited, excess sediment may affect aquatic habitat or cause infilling of downstream reservoirs. It was not possible to calculate the actual combined contribution of daily sediment from the five tributaries to the Purgatoire Rock Crossing sediment-monitoring station over the entire 2000 through 2006 period because sediment data from storms were collected only from 2000 through 2004 at the Purgatoire Rock Crossing sediment-monitoring station.

As a surrogate for the sediment load for the 2000 through 2006 period at Purgatoire Rock Crossing, the 1983 through 2004 daily sediment (in tons) and daily streamflow at Purgatoire Rock Crossing were regressed. Two best-fit linear equations of the logarithm of sediment load and the logarithm of streamflow were developed for daily streamflows smaller than 5 ft^3/s and larger than 5 ft^3/s, which had r-squares of 0.66 and 0.83, respectively. Equations (1) and (2) (sediment transport curves) were used to estimate the daily sediment (all flow regimes, including storms) for April to October during the 2000 through 2006 period at the Purgatoire Rock Crossing sediment-monitoring station:

If ($Q<5$),

$$S = 10^{(0.7157\log_{10}(Q))-0.6045} \tag{1}$$

If ($Q\geq5$),

$$S = 10^{(2.1601(\log_{10}(Q))-1.9973)} \tag{2}$$

where

Q is daily mean streamflow

and

S is daily mean sediment load.

The combined PCMS daily sediment from the five tributaries was larger than 20 percent of the daily sediment at Purgatoire Rock Crossing for 2 percent of the 2000 through 2006 period. There are ungaged tributaries at PCMS that contribute sediment not included in this calculation. Deposition of sediment along reaches of the tributaries or the Purgatoire River upstream from the Purgatoire Rock Crossing sediment-monitoring station also may not be included in these calculations because deposited sediment was not measured by suspended-sediment sampling although sediment may not be stored permanently.

The combined annual sediment load from the five PCMS tributaries ranged from 0.0 (2001) to 5.7 percent (2003) of the annual sediment load at Purgatoire Rock Crossing for April through October during the 2000 through 2006 period (fig. 19). The tributary watersheds at PCMS are 13.9 percent

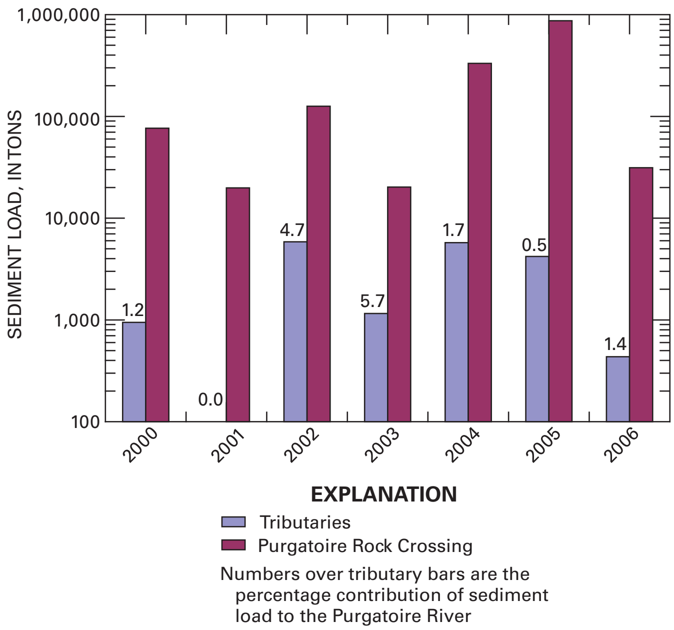

Figure 19. Comparison of April through October annual suspended-sediment load at Van Bremer, Taylor, Lockwood, Red Rock, and Bent sediment-monitoring stations to the annual suspended-sediment load at Purgatoire Rock Crossing sediment-monitoring station during the 2000 through 2006 period, Las Animas County, Colorado.

of the drainage area of the Purgatoire Rock Crossing station (table 1). The stormflow sediment load contribution of the tributaries to stormflow loads at the Purgatoire Rock Crossing station was about 3.5 percent during the 2000 through 2006 period, indicating that the sediment load contribution from the PCMS generally was small.

Land-Condition Trend Analysis

As technology has enhanced the firepower, mobility, and range of modern weaponry, the size of the anticipated battlefield and of the lands needed for military training and weapons testing have greatly expanded. These increases, along with limited available acreage, have led to intensive use of some military training areas (U.S. Department of the Army, 1978). Concerns regarding effects on natural resources prompted the U.S. Army Construction Engineering and Research Laboratory (CERL) to launch the Integrated Training Area Management (ITAM) program and to develop methods to monitor military lands (Diersing and Severinghaus, 1984; Goran and others, 1983; Johnson, 1982; Schaeffer and others, 1986).

The ITAM program inventoried land condition on military reservations using Land-Condition Trend Analysis (LCTA) protocols, developed at Ft. Hood, Texas, and at Ft. Carson, Colorado, during the mid-1980s (Diersing and others, 1992; Tazik and others, 1992). In the LCTA sampling the diversity and the percent composition of plant communities were catalogued. Also, the condition of other natural resources was documented. Uniform and repeated data collection provides military land managers with a standardized strategy of monitoring the effectiveness of management activities when compared to a base year. The LCTA data also guide other ITAM operations, such as land revegetation, implementation of runoff and soil-erosion control methods, and development of decision support methods for scheduling military training and reclamation.

Land Disturbance

For the purpose of this investigation, land disturbance is calculated as a count of all line-transect intercepts that were coded as maintained roads, nonmaintained roads, and tracks from training activities or excavation types of training-related disturbance for each year that LCTA data were collected. It should be emphasized that the LCTA “land disturbance” metric includes not only training-related disturbance (which must be remediated) but also disturbance by permanent access corridors such as roads. Disturbance is assessed each year by observations and is not cumulative from year to year in this analysis.

Land disturbance measured at PCMS ranged annually from an overall high of 26.6 percent in 1989 to a low of 4 percent in 1994 (fig. 20). The mean overall disturbance was 12.9 percent for the 6 years that had LCTA data from 1989 through 1999.

Climate data from the CIG precipitation-monitoring station indicated that 1989 was drier (7.30 inches) than the 1983 through 2007 mean annual precipitation (9.77 inches), a factor that may have led to the relatively larger percentage of overall land disturbance measured that year (1989) because of water stress on vegetation. It also is likely that the large land disturbance measured during the first year of LCTA data collection documented both military use and overall rangeland

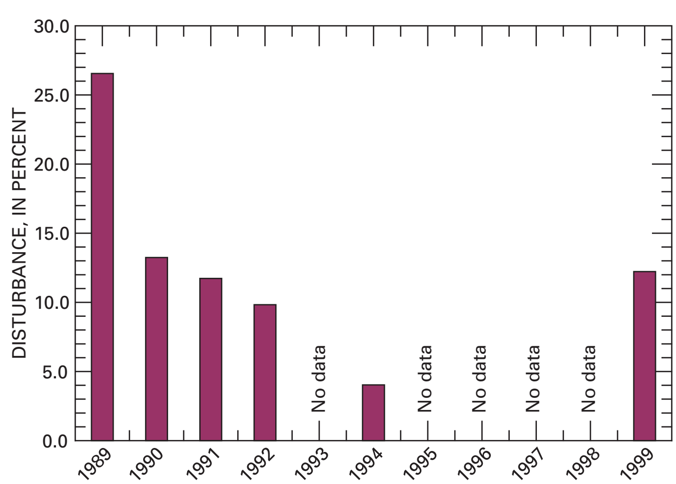

Figure 20. Mean disturbance calculated from Land-Condition Trend Analysis data, by year, at Piñon Canyon Maneuver site, Las Animas County, Colorado.

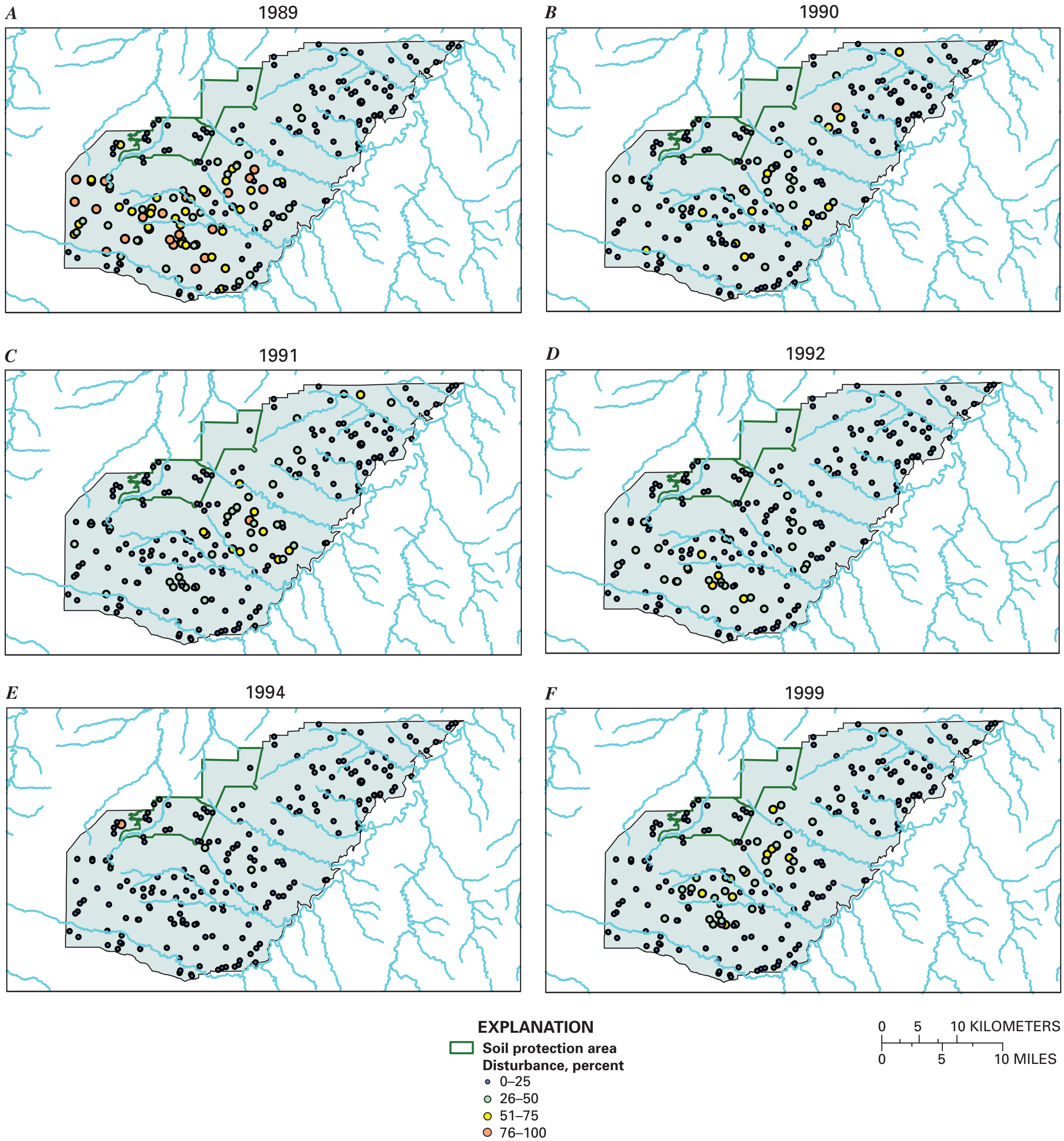

Figure 21. Land disturbance (including maintained access roads, nonmaintained roads, and tracks and excavations from maneuvers) for Piñon Canyon Maneuver Site, Las Animas County, Colorado, for Land-Condition Trend Analysis data-collection years: (*A*) long-term monitoring year 1989, (*B*) short-term monitoring year 1990, (*C*) short-term monitoring year 1991, (*D*) long-term monitoring year 1992, (*E*) long-term monitoring year 1994, and (*F*) long-term monitoring year 1999.

conditions before systematic revegetation and erosion-control methods were implemented. This conclusion is supported by the lower overall ground cover and higher bare ground also recorded for 1989. The largest land disturbance in 1989 was concentrated in grasslands in the southern one-half of PCMS, where many of the permanent transects had land disturbance of more than 75 percent (fig. 21*A*). By 1990, overall land disturbance had been reduced by one-half, dropping to an overall 13.2 percent, and the land disturbance in the southern PCMS transects was much less (fig. 21*B*). Land disturbance in the central and south-central part of PCMS had decreased substantially in 1991 except for an area of renewed land disturbance between Taylor and Lockwood arroyos (fig. 21*C*). By 1992, the land had recovered between these two arroyos, but a new, smaller disturbed area could be observed between Van Bremer and Taylor (fig. 21*D*). In 1994, less than 25 percent of the land was disturbed along 97.5 percent of the transects, and less than 10 percent of the land was disturbed along 87 percent of the transects (fig. 21*E*). The average land disturbance declined overall for the measured period until 1999, when land disturbance again increased in the central part of PCMS (fig. 21*F*).

In general, relatively large disturbance areas formed a persistent spatial pattern in the grasslands in the south-central part of PCMS in the Van Bremer, Taylor, and Lockwood watersheds (figs. 21*A* to 21*F*). This spatial pattern of larger disturbance percentage also correlated with mostly Penrose-Manzanola-Midway soils (von Guerard, 1987). Also, transects in the Soil Protection Area (SPA) (pl. 1, figs. 21*A* to 21*F*) where nonvehicular training generally occurred, and the eastern one-half of the Red Rock and Bent Canyon watersheds, where much of the land area was either a restricted training area or unsuitable for vehicular training, had a general spatial pattern of less disturbance in all years of LCTA measurements.

Ground-Cover Measurements

A ground-cover metric is derived as a count of transect-line intercepts that had either plant or litter cover. Ground cover ranged from a maximum of 76.6 percent in 1992 to a minimum of 51.2 percent in 1994 (fig. 22). The average for this metric at PCMS for the 6 years of data collection was 66.8 percent. Percent ground cover remained about the same for the first four LCTA measurement years (average 72.5) but dropped to an overall average of 51.2 percent in 1994 and was up slightly to 59.9 percent in 1999 (fig. 22).

The spatial pattern of the smallest ground cover percentages, which occurred during 1989 (fig. 23*A*), was reflected in the spatial distribution of the largest land-disturbance percentages, which also occurred during 1989 (fig. 21*A*). An east-west band of sparser ground cover observed in the southern PCMS in 1989 persisted throughout most LCTA years

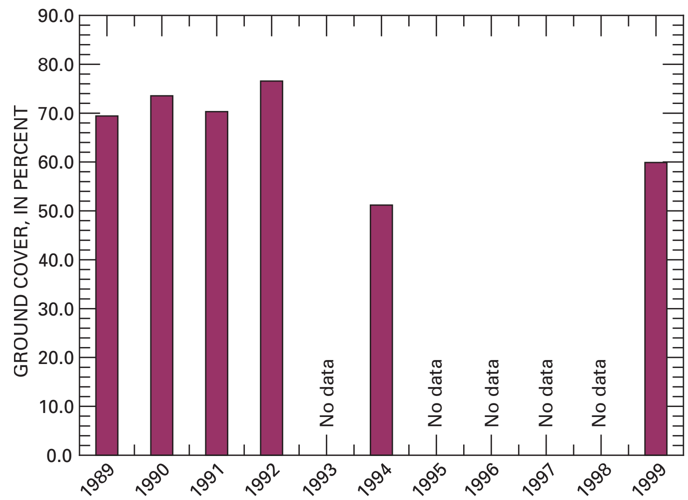

Figure 22. Mean ground cover calculated from Land-Condition Trend Analysis data, by year, at Piñon Canyon Maneuver site, Las Animas County, Colorado.

(figs. 23*A* to 23*F*). By 1990, ground cover had improved in the central PCMS area, with more transects documenting ground cover exceeding 60 percent (fig. 23*B*). In 1994 ground cover was measured as being much sparser over much of PCMS relative to all previous LCTA years (fig. 23*E*). Because land disturbance fell to its smallest level in 1994 (fig. 23*E*), military training may not have been the trigger for the decrease in ground cover. The cause for this decrease is unknown. Although the 10.04 inches of precipitation at CIG for the months April through October in 1994 was slightly above the 1983 through 2007 mean of 9.79 inches, the annual mean temperature measured in 1994 at the Springfield, Colorado, weather station (65 mi to the east of PCMS) was more than 2°F above the mean annual temperature for the 1961 through 1990 period (National Oceanic and Atmospheric Administration, 1994). Also, in 1994, data collection began about 2 weeks later than any other year except for 1989 and ended almost 2 weeks later than in 1989. For the years 1990, 1991, 1992, and 1999, data collection began between April 29 and May 2; data collection ended between June 27 and July 2 for those same years. In 1994, data collection began on May 17 and ended August 21. In 1989, LCTA measurements began May 18 and ended August 10. It is possible that the combination of warmer summer months and data collection that occurred later in the year produced some of the measured decline. For instance, growth declines in many plant species, especially grasses, during the warmest months of the summer. In 1999, land disturbance increased and the ground cover was greater in the northeastern corner of PCMS (figs. 19 and 23*F*) than 5 years earlier (figs. 19 and 23*E*). However, ground cover in 1999 remained low in the areas of heaviest land disturbance (figs. 21*F* and 23*F*).

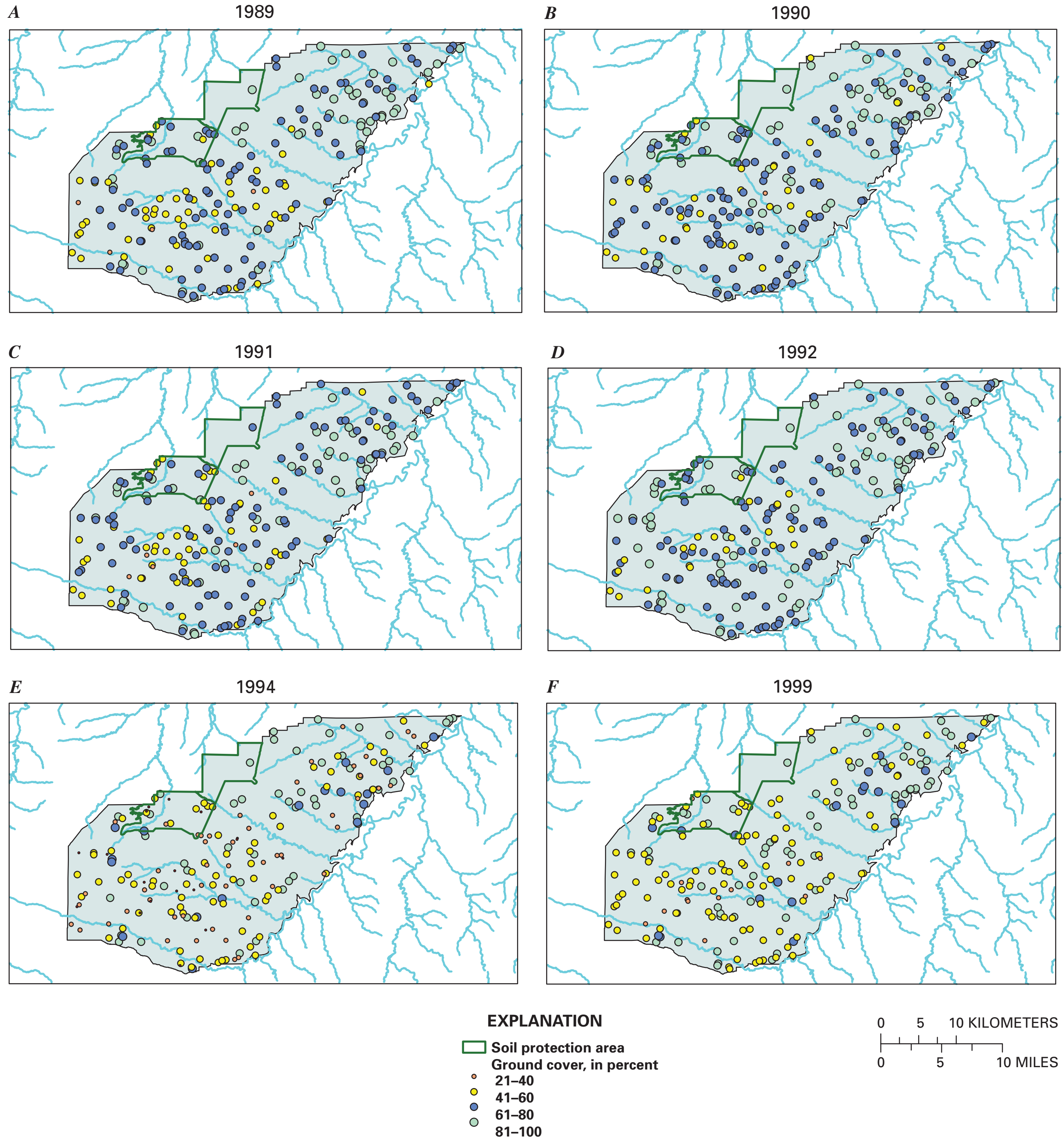

Figure 23. Ground cover for Piñon Canyon Maneuver Site, Las Animas County, Colorado, for Land-Condition Trend Analysis data-collection years: (*A*) long-term monitoring year 1989; (*B*) short-term monitoring year 1990; (*C*) short-term monitoring year 1991; (*D*) long-term monitoring year 1992; (*E*) long-term monitoring year 1994; and (*F*) long-term monitoring year 1999.

For spatial patterns in LCTA ground cover (figs. 23*A* to 23*F*), there seems to be less of a distinction between the SPA and the area between Van Bremer and Lockwood streams than the patterns of LCTA disturbance. But in the eastern one-half of the area between Red Rock and Bent streams, LCTA ground cover was generally a higher percentage and was less variable from year to year than in the more heavy-use training areas between Van Bremer Arroyo and Lockwood Canyon.

Bare-Ground Measurements

Bare ground that lacked overhead canopy cover also was counted in each transect. Bare ground without canopy cover averaged 15.4 percent during the six LCTA years between 1989 through 1999 (fig. 24). At its maximum in 1989, bare ground without canopy cover was 17.5 percent but dropped to a minimum of 12.9 percent in 1992.

Similar to areas of larger land disturbance and poorer ground cover (to a lesser degree), relatively large bare-ground areas form a persistent spatial pattern in the grasslands in the south-central part of PCMS (figs. 25*A* to 25*F*). This spatial pattern of larger bare ground percentage also correlates with Penrose-Manzanola-Midway soils (von Guerard, 1987). The transects in the SPA and also the transects in the eastern one-half of the Red Rock and Bent Canyon watersheds seem to have a pattern of less bare ground than the areas between Van Bremer Arroyo and Lockwood Canyon, which may be a result of less mechanized training use. Like land disturbance, the percentage of bare-ground areas lacking any overhead canopy peaked in 1989 (fig. 24), and those areas were similar in spatial pattern to the land disturbance areas (fig. 21*A*). Relative to 1992, the overall percentage of bare ground without canopy cover increased in 1994 (fig. 25*E*), the year of the smallest measured average ground cover (fig. 22) and the smallest land disturbance (fig. 25*E*). The larger percentage of bare ground, like the measurements in 1994 that indicated sparser ground cover (fig. 23*E*), may have been the result of warmer summer temperatures coupled with a later data-collection period. In spite of slightly larger land disturbance in 1999, the overall average bare ground metric for 1999 was one of the smallest (13.2 percent), and the spatial pattern indicated more ground cover in the central PCMS area (fig. 25*F*). Above-average precipitation of 16.07 inches occurred from 1997 through 1999, which is greater than 11.53 inches, the 61-year average from 1945 through 2006 (Western Regional Climate Center, 2007). The wetter years may account for the relatively small percentage of bare ground without plant canopy cover during 1999, a year of relatively larger land disturbance. Also, revegetation of plant cover by the Army and long-term recovery from livestock grazing are factors that make analysis of LCTA bare-ground data difficult to interpret.

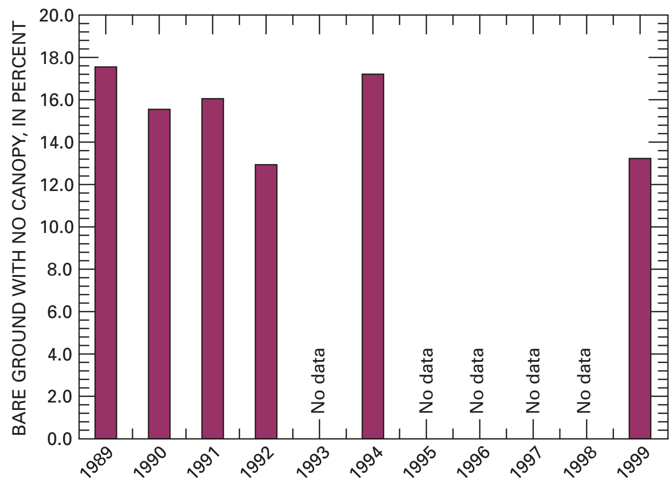

Figure 24. Overall bare ground with no canopy measured from Land-Condition Trend Analysis data, by year, at Piñon Canyon Maneuver site, Las Animas County, Colorado.

Other Land-Condition Trend Analysis Metrics

Aerial cover, or percentage of measurement points (every meter along each 100-meter transect) that had overhead canopy cover, generally increased from an overall 65 percent in 1989 to 75.2 percent in 1999 (fig. 26), although years when no LCTA data were collected limit this analysis. The average for the aerial cover metric for all six LCTA data-collection years was 68.3 percent.

An erodibility status metric was calculated from the Universal Soil Loss Equation (USLE) erosion rate and from soil-loss tolerances (Ward and Elliott, 1995). The USLE erodibility status, A/T, is shown in figure 27. The “A” metric measures the computed annual soil loss in tons per acre from sheet or rill erosion. The estimated erosion rate is calculated by the USLE. The “T” metric is the soil-loss tolerance, which ranges from 1 to 5 for most soils. The metric “A/T” (unitless) is the erodibility status, defined as the estimated erosion rate divided by the soil-loss tolerance. Larger values of A/T mean that the erosion rate was relatively larger with respect to tolerance than the erosion rate indicated by a smaller value of A/T. The average for this metric was 24.8 for all 6 years that were evaluated during the 1989 through 1999 period, ranging between 37.7 in 1994 and 17.7 in 1992 (fig. 27). Soil erodibility has been relatively constant except for the increase in 1994. Soil erodibility in 1999 (28.8) also was above average during this year of relatively high land disturbance (fig. 27).

Belt transect data include a count of the major woody species that exceed 1 m in height. Overall counts of junipers more than 1 m high have remained constant during the LCTA data-collection years (only data for 1989, 1992, 1994, and 1999 were available), indicating that the juniper populations in the transects are stable and that military training has had little

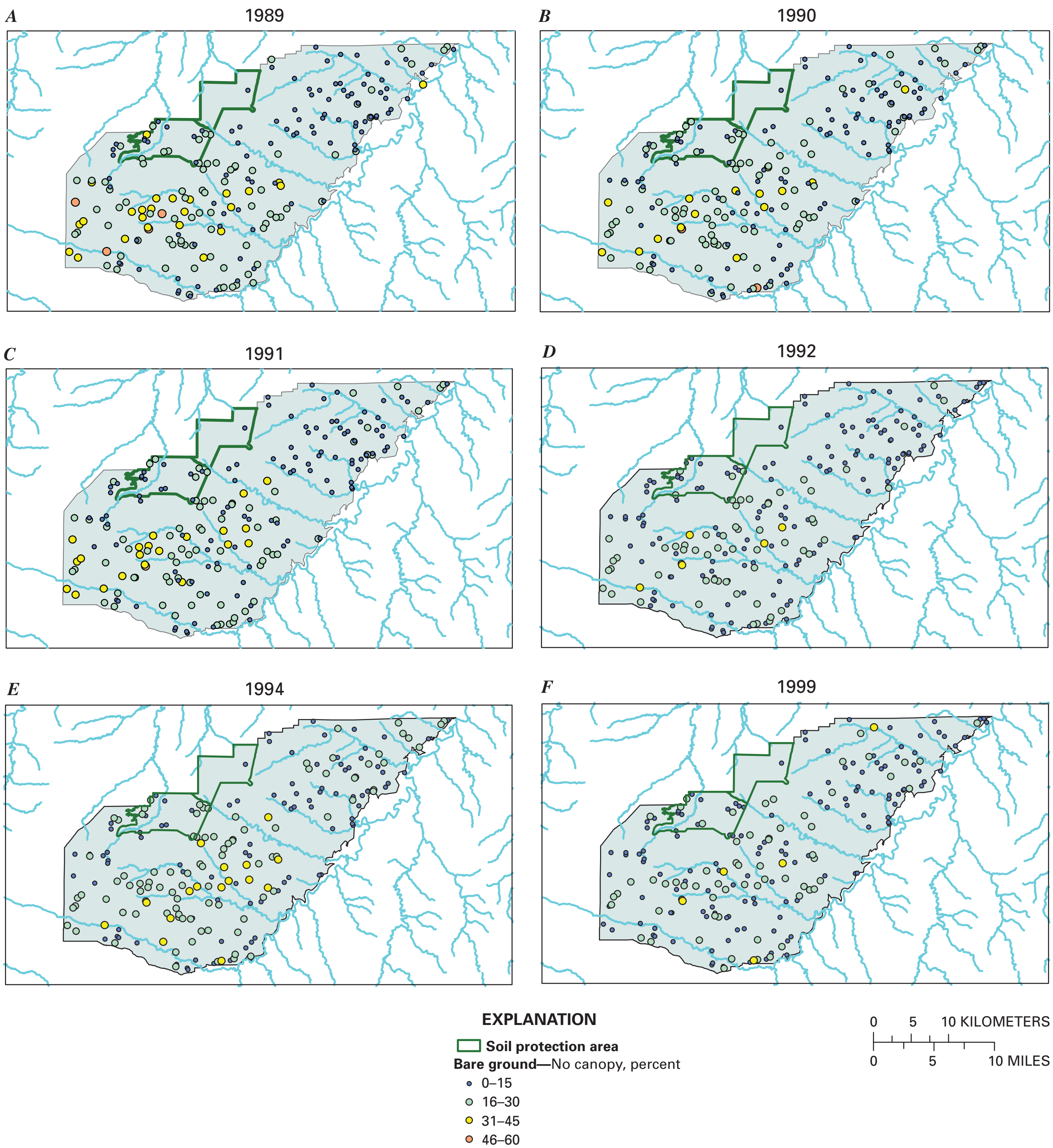

Figure 25. Bare-ground areas without canopy cover for Piñon Canyon Maneuver Site, Las Animas County, Colorado, for Land-Condition Trend Analysis data collection years: (*A*) long-term monitoring year 1989; (*B*) short-term monitoring year 1990; (*C*) short-term monitoring year 1991; (*D*) long-term monitoring year 1992; (*E*) long-term monitoring year 1994; and (*F*) short-term monitoring year 1999.

overall effect on the numbers of these trees along the transects (fig. 28). The average counts in the belt transect was 9.8, with a minimum of 9.8 and a maximum of 9.9. The flat counts over the years of LCTA data collection presumably reflect ITAM prohibitions regarding destruction of such trees during training activities.

General sitewide LCTA spatial patterns indicated larger and more variable disturbance and bare ground, and a tendency for less ground cover in the area between the Van Bremer and Lockwood streams. Because the SPA and the eastern one-half of the area between Red Rock and Bent had areas that were off-limits to vehicular mechanized training, these plots indicated that areas with less mechanized training generally had less disturbance and bare ground and, in the Red Rock-Bent area, also relatively more ground cover.

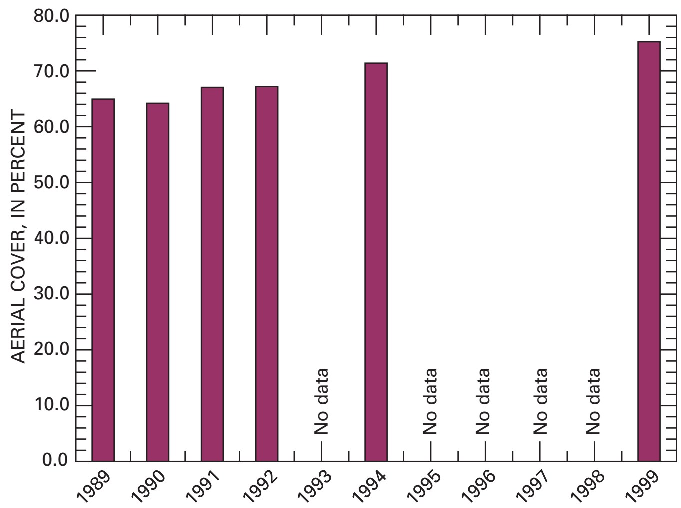

Figure 26. Overall aerial cover measured from Land-Condition Trend Analysis data, by year, at Piñon Canyon Maneuver site, Las Animas County, Colorado.

Comparison of Land-Condition Trend Analysis Metrics to Hydrologic and Military Training Data

LCTA data were collected during the 1989 through 1999 period, which did not coincide with the collection of most of the hydrologic data from 1983 through 1990 or the 2000 through 2007 periods. Because hydrologic data were available at Taylor and precipitation data were available at CIG during the 1983 through 2007 period, which includes the 1989 through 1999 LCTA period, the LCTA transects located within the Taylor drainage area were evaluated as a subset of all PCMS LCTA transects (fig. 29).

In general, both ground cover and bare ground metrics decreased over time in the Taylor watershed from 1989 through 1999 (fig. 30). This fact is counterintuitive to a degree because it would make sense that they should be inversely proportional (as ground cover increases, bare ground should decrease). By closer examination of the individual year-to-year changes, the two metrics are usually inversely proportional, but the relative changes in each are not proportional (fig. 30). This results in some contradictions in long-term patterns. Neither ground cover nor bare ground seem to share a consistent pattern with disturbance (fig. 30) probably because disturbance does not necessarily mean the ground is bare or that ground cover is absent. Sediment and streamflow yields showed some similarity in pattern with both ground cover and bare ground changes from 1989 through 1994 (fig. 30). The disturbance metric showed patterns that were more similar to streamflow yield than to sediment yield (fig. 30). The analysis of LCTA metrics, streamflow, and sediment transport indicated that only a small similarity exists in the temporal patterns at Taylor during the 1989 through 1999 period. Streamflow may not be sensitive to the effects of military disturbance in terms of the effects of soil compaction by military vehicles on the saturated hydraulic conductivity of the soil. A sensitivity analysis assuming a 10-percent decrease in porosity and a

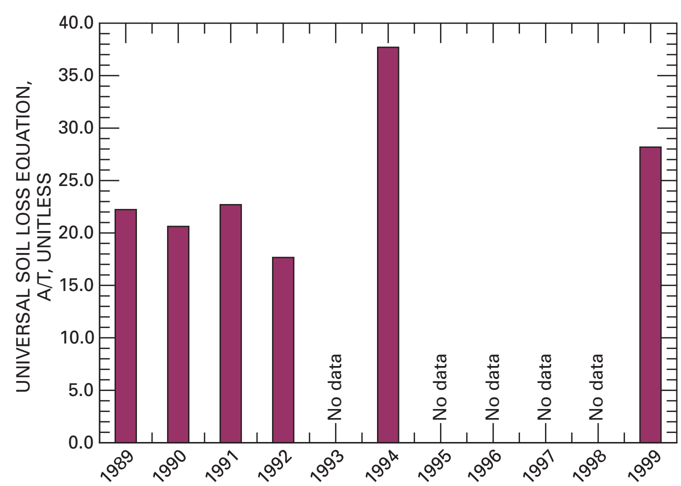

Figure 27. Annual soil loss (*A*) from Universal Soil Loss Equation, divided by soil-loss tolerance (*T*) from Universal Soil Loss Equation measured from Land-Condition Trend Analysis data, by year, at Piñon Canyon Maneuver site, Las Animas County, Colorado.

computation of the resulting decrease in saturated hydraulic conductivity of the soil for disturbed areas in the Taylor watershed was done for precipitation measured during the August 9, 1987, storm. The analysis indicated that the simulated peak flow increased only 1.2 percent as a result of the military disturbance (von Guerard and others, 1993). However, the effects on sediment erosion and delivery to streams by the reduction of aerial canopy and ground cover and the increase in the connectivity of patches of bare ground by military disturbance were not accounted for in that semiquantitative analysis.

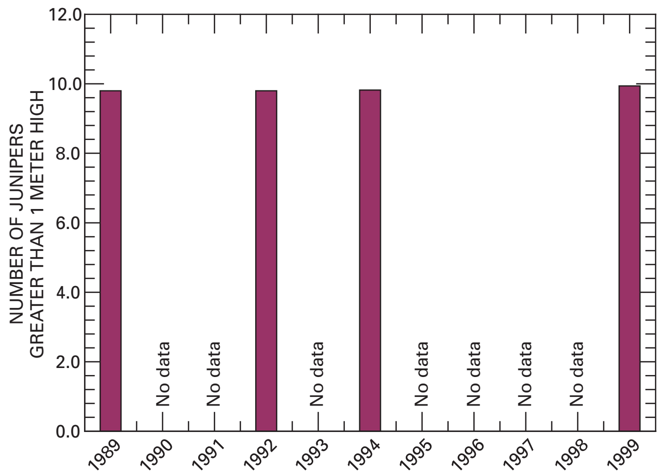

Figure 28. Overall counts of junipers greater than 1 meter in height measured from Land-Condition Trend Analysis data, by year, at Piñon Canyon Maneuver site, Las Animas County, Colorado.

Ground cover and bare ground may be related to climate variables such as wind and precipitation, which are factors in the quantity and quality of vegetative cover (von Guerard and others, 1993). Patterns of relative increases or decreases in wind movement (departure from the mean) at Springfield, Colorado (fig. 31 Appendix 1), were somewhat consistent and proportional to bare ground patterns and, similarly, relatively inversely proportional to ground cover (fig. 31) in the Taylor watershed. However, the relative changes in each were not proportional (fig. 31). This results in some contradictions in long-term patterns, such that a certain wind value was not the same for a certain ground cover or bare ground value over a period of years despite showing similarity in the direction of the change in any particular year. Departure from the mean precipitation at CIG was plotted for quarterly periods to evaluate the effects of seasonal precipitation on ground cover and bare ground metrics. Some pattern similarity (relative increase [or less departure] in precipitation and relative increase in ground cover and relative decrease in bare ground)

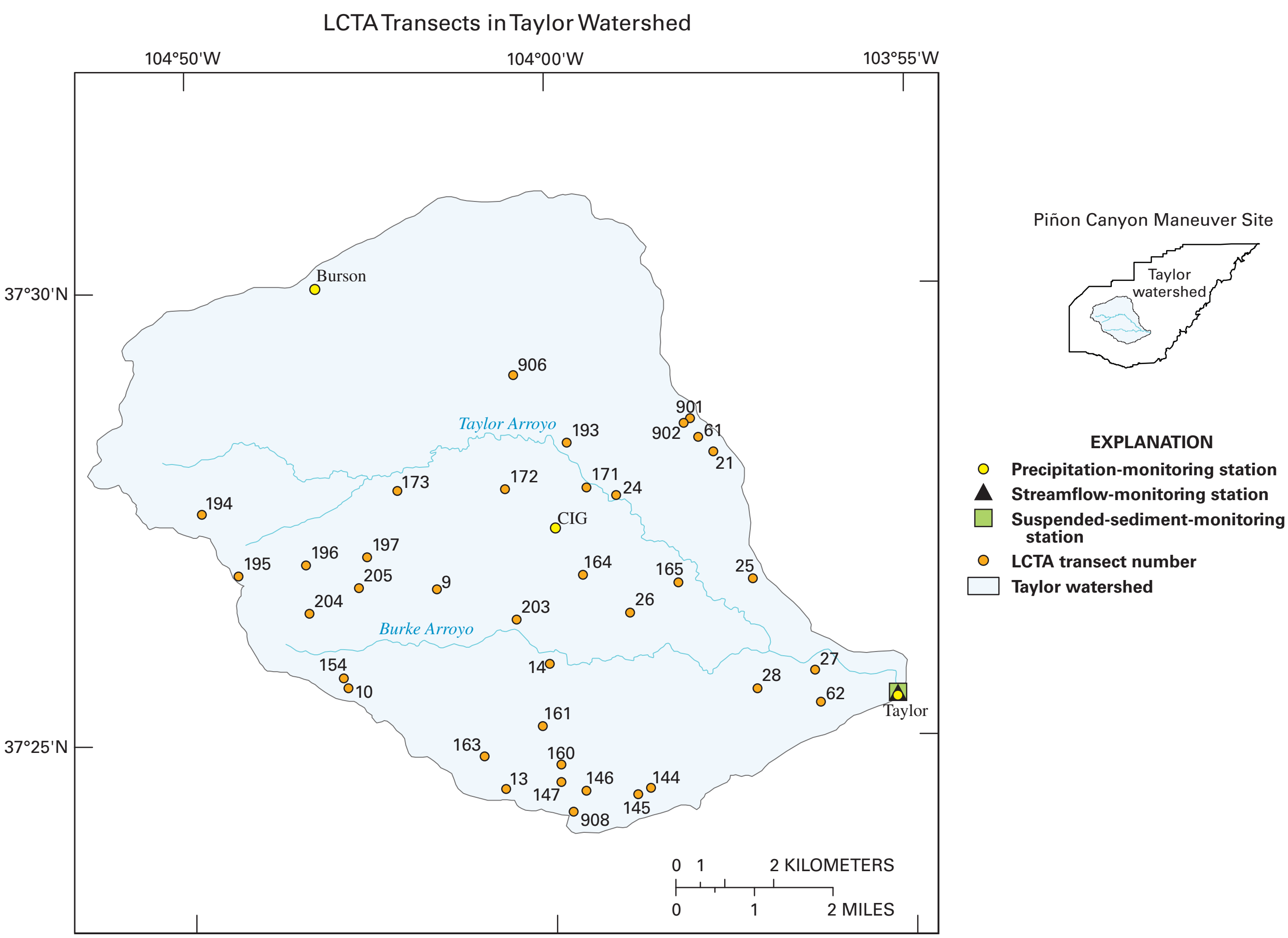

Figure 29. Location of Land-Condition Trend Analysis (LCTA) transects within the Taylor watershed, Las Animas County, Colorado.

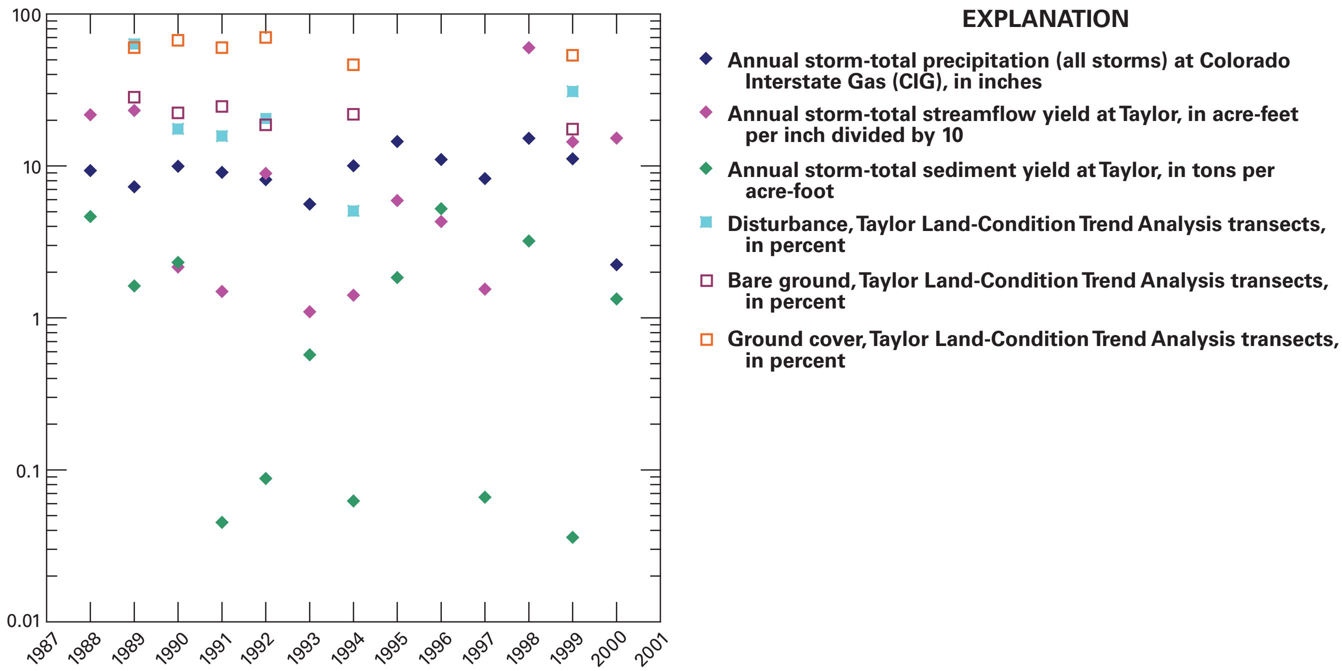

Figure 30. Annual storm-total precipitation from runoff-producing storms, and storm-total streamflow yield and storm-total sediment yield for April through October, and mean annual disturbance, bare ground, and ground cover during the 1988 through 2000 period, at the Taylor watershed, Las Animas County, Colorado.

between the January through March precipitation and the LCTA ground cover and bare ground metrics was evident, but the relative changes in each were not proportional over time (fig. 31 and Appendix 2 and 3). April through June precipitation departure had similarities in pattern with 1989 through 1992 ground cover and bare ground metrics in the Taylor watershed (fig. 31). July through September precipitation departure was not similar to patterns in ground cover and bare ground metrics.

The lack of correlation between the LCTA metrics and the hydrologic characteristics may be related to the missing years of LCTA information for many of the years during the 1989 through 1999 period. Another explanation may be that sediment delivery to the sediment-monitoring stations requires a longer period than the assumed same-year response. Because the Army training can occur in the fall of the year, the full effects of training also might be observed the following year if no substantial precipitation occurred during the year of training. If runoff-producing precipitation does not occur for multiple years, the effects may not be evident in the streamflow or suspended-sediment data. Shorter term effects such as damage and recovery of rangeland plant cover may be difficult to characterize by the evaluation of streamflow and sediment if a sufficient number of storms of large magnitude do not occur in a given year. Each storm could be thought of as an opportunity to assess rainfall-runoff and sediment-loading processes as well as the influence of land condition and land disturbance on those processes.

General comparisons were made between training activity and LCTA disturbance, bare ground, and ground-cover metrics. Land disturbance seemed to be the most logical metric to assess training effects because of the direct connection to training and because it was the most variable metric from year to year. From available information, training occurred in the Taylor watershed from 1985 through 1987, 1989, 1992, 1993, 1996, 1998, and 1999 (von Guerard and others, 1993; Jeff Linn, U.S. Department of the Army, written commun., 2008). Land that was affected during maneuver exercises and required repair beyond fair wear-and-tear use generally increased from 1989 through 1999 in the Taylor and adjacent watersheds. Other watersheds were often included in the affected-area estimate for Taylor from after-action reports, so acreages in each watershed were not specified. The largest land-area repairs occurred in 1998, 1999, and 2000 (1,700, 2,550, and 8,200 acres, respectively) (Jeff Linn, U.S. Department of the Army, written commun., 2008). Disturbance at Taylor LCTA transects was more than 60 percent in 1989, was about 20 percent in 1990, 1991, and 1992, was only about 5 percent in 1994, and increased again to about 30 percent in 1999 (fig. 30). Training was more sporadic in the early 1990s than in the 1980s, possibly explaining the larger disturbance percentages in 1989 compared with those in the 1990s. The larger land-area repairs as a result of training in 1998 and 1999 may have increased the LCTA disturbance metric for the 1999 survey.

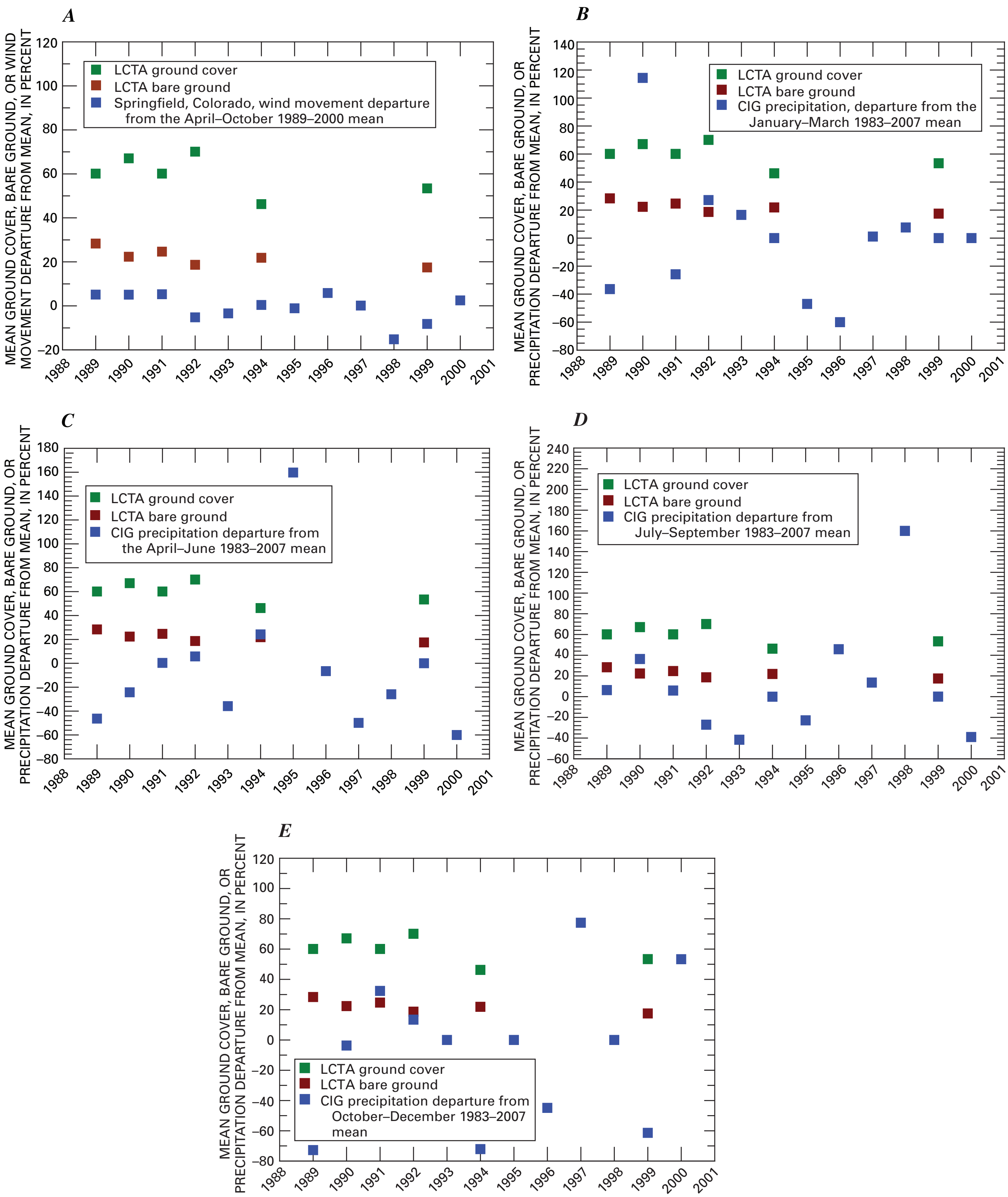

Figure 31. Relations among Land-Condition Trend Analysis (LCTA) annual mean percentage of bare ground, and ground cover, and (*A*) wind movement at the Springfield Colorado 7 WSW climate station; and the Colorado Interstate Gas (CIG) precipitation departure from the 1983 through 2007 mean for (*B*) January through March; (*C*) April through June; (*D*) July through September; and (*E*) October through December, during the 1988 through 2000 period, for the Taylor watershed, Las Animas County, Colorado.

Summary

In 2007, the U.S. Geological Survey, in cooperation with the U.S. Department of the Army, began an assessment of the spatial and temporal variations in precipitation, streamflow, suspended-sediment loads and yields, changes in land condition, effects of the tributaries on the Purgatoire River, and the possible relation of effects from military training to hydrology and land conditions that have occurred at Piñon Canyon Maneuver Site (PCMS) from 1983 through 2007.

Data were collected for precipitation (19 stations) and streamflow and sediment load (5 tributary and 2 main-stem Purgatoire River stations) during the 1983 through 2007 period for various time periods and year-round, seasonal, and stormflow-only data-collection strategies. The 1983 through 1990, 2000 through 2006 or 2007, and 1983 through 2006 or 2007 periods were extensively used for assessment of temporal and spatial variation and trends.

A land-condition trend analysis (LCTA) data-collection program was conducted by Army personnel from 1989 through 1999 using assessment of ground disturbance, ground cover, and bare-ground conditions recorded every meter along a 100-meter transect centerline at 206 locations (1989, 1990, 1991, 1992, 1994, 1998, and 1999), along with aerial measurements of overhead canopy and juniper trees.

Streamflow and sediment transport at PCMS were dependent upon precipitation because ground-water contributions to surface flow were essentially absent at the tributaries flowing from PCMS except for Van Bremer and Lockwood, where ground-water contributions were minor. A probability plot indicates that precipitation of less than 0.01 inch generally occurs about 80 percent of the days of the 214-day period from April through October. While the majority of the storms are small, the larger storms produce most of the precipitation that falls on PCMS given that about 45 percent of runoff-producing storms were larger than 1 inch.

Temporal trends (Mann-Kendall) in storm-total precipitation from runoff-producing storms (2000 through 2007) were significant and substantial at Van Bremer and Taylor and might be related to any downward trends in the size of storm-total streamflows or storm-total sediment yields at those stations. Variation in the timing and amount of irrigation return flow also may affect storm-total streamflow at Van Bremer. The upward trend in the 1983 through 2007 size of runoff-producing storms at Colorado Interstate Gas (CIG) (Taylor watershed) of about 0.5 inch in the median storm precipitation total over the 25-year period might be related to any upward trend in the size of streamflow or sediment-transport storm total at Taylor watershed.

Storms producing greater than 1.0 inch of precipitation were associated with about 78 percent of total runoff during the period 1983 through 2007 at the Taylor station. Small storms, less than 0.5-inch total, were associated with only 2.6 percent of the total runoff in the same period. This indicates that larger storms are generally more important to streamflow-runoff generation, despite occurring less frequently.

Seasonal Kendall tests for temporal trends in monthly streamflow indicated that there were no statistically supported temporal trends at the tributary streamflow sites at PCMS for the 1983 through 1990, 2000 through 2007, or 1983 through 2007 periods. The lack of substantial temporal trends in total streamflow is important because trends in sediment transport cannot be statistically explained by trends in streamflow, and this is consistent with the finding of no substantial significant temporal trends in monthly mean precipitation.

Results of temporal trend testing of storm-total streamflow yield normalized for drainage area by using the Mann-Kendall and Theil slope method indicated that there were no statistically significant ($p<0.05$) or moderately significant ($p<0.10$) upward or downward temporal trends in storm-total streamflow for any period at the tributary streamflow-monitoring stations at PCMS except at Taylor during the 2000–2007 period.

To assess spatial differences, storm-total streamflow yields were normalized to drainage area and precipitation for the 2000 through 2007 period and tested using the Mann-Whitney rank-sum test. Storm-total streamflow yields at Van Bremer were not significantly different from Taylor but were significantly different from Lockwood, Red Rock, and Bent. The storm-total streamflow yields at Taylor were significantly different from Lockwood, Red Rock, and Bent. The southernmost two tributary stations (Van Bremer and Taylor) were statistically similar, and the northern three stations (Lockwood, Red Rock, and Bent) were statistically similar; but the two groups (southern and northern) were significantly different. The reason for the spatial variations among watersheds may be associated with differences in precipitation intensity among the watersheds, watershed morphology, topography or geology, or differences in land condition, military training, and the intensity of pre-maneuver grazing and rates of post-grazing vegetation recovery.

Streamflow from tributary watersheds to larger streams and rivers as a result of storm runoff can be an issue if the flow is excessive when compared to the flow in the receiving stream or river. During the April through October period the cumulative daily tributary streamflow was greater than 5 percent of the daily streamflow at the Purgatoire Rock Crossing station only 3 percent of the time, indicating that the flow contribution from the Piñon Canyon Maneuver Site generally was small.

Storm-total sediment loads for storms with total precipitation greater than 1.5 inch were associated with about 73 percent of total suspended-sediment load from 1983 through 2006. Smaller storms less than 0.5-inch total were associated with only 2.7 percent of the sediment load, despite accounting for 79 percent of the number of storms for the same period. This indicates that larger, less frequent storms generally contribute much more to sediment transport than smaller, more frequent storms.

Seasonal Kendall test for temporal trends in monthly flow-adjusted sediment loads for the 1983 through 2006, 1983 through 1990, and 2000 through 2006 periods indicated no significant or moderately significant monotonic temporal trends. A comparison of temporal differences between the 1983 through 1990 and 2000 through 2006 periods using the Mann-Whitney test indicated that storm-total sediment yields were larger at both Taylor and Bent during the 1983 through 1990 period.

Long-term decreases in sediment transport were indicated by differences in storm-total sediment yield at the Taylor and Bent monitoring stations between the 1983 through 1990 and 2000 through 2006 periods. When trends or differences are indicated, the implication is that either the physical drivers of precipitation and streamflow have changed or that another set of factors has changed such as land-cover condition including vegetation, soil condition, disturbance of the land surface, antecedent soil moisture, or differences in the form of precipitation. For streamflow, one of the physical drivers, there was a lack of statistically significant, substantial monthly or storm-total streamflow temporal trends for the 1983 through 2007 period at Taylor. This indicates that, for the 24-year period from 1983 through 2006, temporal trends and differences in storm-total suspended-sediment load and yield were not explained by temporal trends in monthly streamflow or storm-total streamflow. For the other physical driver, precipitation, which affects both streamflow and sediment erosion, an analysis indicated a significant upward monotonic temporal trend in monthly precipitation at only one of four precipitation stations from 1983 through 2007. Also, an upward trend in the magnitude of runoff-producing storms at CIG (in Taylor watershed) was identified. Trends in monthly precipitation indicated increasing monthly precipitation over the 24-year period from 1983 through 2006 at one precipitation-monitoring station, and a 5-percent increase in the magnitude of runoff-producing storms at CIG during the same period. The implication is that changes in land-cover conditions and possibly precipitation caused some of the changes in storm-total sediment load rather than changes in streamflow. However, precipitation does not seem to be related to long-term changes in streamflow, and thus the relation between precipitation and sediment load is unclear.

The relative lack of 1983 through 1990 or 2000 through 2006 temporal trends in sediment load and yield was consistent with no temporal trends in streamflow for the same periods but was not consistent with the finding of significant downward trends in precipitation at Van Bremer and Taylor during the 2000 through 2006 period, indicating that the processes of precipitation, runoff, and sediment erosion are complex, especially on short time scales.

Graphical distributions among tributary monitoring stations of suspended-sediment load normalized to storm-total streamflow and drainage area (tons per acre-foot per square mile) indicated an upward trend northward from Van Bremer to Bent during the 2000 through 2006 period. Mann-Whitney rank-sum test results supported the north-to-south differences by indicating differences between Van Bremer and the three northern tributaries of Lockwood, Red Rock, and Bent. However, no significant spatial differences between Taylor and the northern tributaries were indicated. Variations in geology and the differences in soil types or depths derived from the rocks in each of the watersheds, the topography and relief developed from that geology, the rainfall intensity, and the number of erosion-control ponds all might contribute to the spatial differences in suspended-sediment transport. The proportion of basin area with topographic relief and canyon physiographic landforms as a proportion of the drainage area increased from Van Bremer northward to Bent. Geology maps showed a decreasing proportion of upland shale and limestone rock types and an increasing proportion of sandstone northward from Van Bremer to Bent. Soil maps also showed a decreasing proportion of Penrose-Manzanola-Midway group soil types, which have substantial erosion potential, northward from Van Bremer to Bent. Differences in land use or cover also may have contributed to the increasing south-to-north pattern in sediment yield during the 2000 through 2006 period. Military training takes place more commonly in the Taylor and Lockwood watersheds. Active revegetation of soil damage and the higher density of erosion-control ponds in the Taylor and Lockwood watersheds (southern PCMS) also could have contributed to the trend of smaller sediment yields in the southern tributaries.

Sediment transport from the PCMS tributaries to the Purgatoire River is an important issue because excess suspended sediment may affect aquatic habitat or cause infilling of downstream reservoirs. During the 2000 through 2006 April through October period, only 2 percent of the time was the daily tributary sediment load greater than 20 percent of the daily load in the estimated sediment-load time series at Purgatoire River at Rock Crossing. On a total annual April to October basis for the 2000 through 2006 period, suspended-sediment loads from the combined tributaries ranged from 0.0 (2001) to 5.7 percent (2003) of the annual (April to October) loads in the Purgatoire River at Rock Crossing during the same period. The tributary watersheds at PCMS are 13.9 percent of the drainage area of the Purgatoire Rock Crossing station. The stormflow sediment load contribution of the tributaries to stormflow loads at the Purgatoire Rock Crossing station was about 3.5 percent during the 2000 through 2006 period, indicating that the sediment load contribution from the PCMS generally was small.

General sitewide LCTA spatial patterns indicated larger and more variable disturbance and bare ground and a tendency for less ground cover in the area between the Van Bremer and Lockwood streams. Because the Soil Protection Area (SPA) and the eastern one-half of the area between Red Rock and Bent had areas that were off-limits to vehicular mechanized training, these plots indicated that areas with less mechanized training generally had less disturbance and bare ground and, in the Red Rock-Bent area, also relatively more ground cover.

Because hydrologic data were available at Taylor and precipitation data were available at CIG during the 1983 through 2007 period, which includes the 1989 through 1999 LCTA period, the LCTA transects located within the Taylor drainage area were evaluated as a subset of all PCMS LCTA transects. Sediment and streamflow yields at Taylor showed some similarity in pattern with both ground cover and bare ground changes from 1989 through 1994. The disturbance metric showed patterns that were more similar to streamflow yield than to sediment yield. The analysis of LCTA metrics, streamflow, and sediment transport indicated that only a small similarity exists in the temporal patterns at Taylor during the 1989 through 1999 period.

In general, both ground cover and bare-ground metrics seem to decrease over time in the Taylor watershed from 1989 through 1999. This fact is counterintuitive to a degree because it would make sense that they should be inversely proportional (as ground cover increases, bare ground should decrease). If closer examination of the individual year-to-year changes is made, the two metrics are usually inversely proportional, but the relative changes in each are not proportional. This results in some contradictions in long-term patterns. Neither ground cover nor bare ground seems to share a consistent pattern with disturbance, probably because disturbance does not necessarily mean the ground is bare or that ground cover is absent. Sediment and streamflow yields show some similarity in pattern with both ground cover and bare-ground changes from 1989 through 1994.

The lack of correlation may be related to the missing years of LCTA information for many of the years during the 1989 through 1999 period. Another explanation may be that sediment delivery to the sediment-monitoring stations requires a longer period than the assumed same-year response. Because the training can occur in the fall of the year, the full effects of training also might be observed the following year if no substantial precipitation occurred during the year of training. If runoff-producing precipitation does not occur for multiple years, the effects may not be evident in the streamflow or suspended-sediment data. Shorter term effects such as damage and recovery of rangeland plant cover may be difficult to characterize by the evaluation of streamflow and sediment if a sufficient number of storms of large magnitude do not occur in a given year. Each storm can be thought of as an opportunity to assess rainfall-runoff and sediment-loading processes as well as the effects of land condition and land disturbance on those processes.

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Appendixes

Appendix 1. Monthly wind movement departure from the 1989 through 2000 mean monthly wind movement, at the Springfield 7 WSW climate station near Springfield, Colorado.

[Departure in percentage of the mean monthly wind movement; wind movement units originally in miles per month of total movement over evaporation pan; Springfield 7 WSW climate station located at latitude: 37°22' North, and longitude (National Oceanic and Atmospheric Administration, 1989–2000): 102°45' West, or about 65 miles east of PCMS; April through October departure computed by dividing the sum of the monthly departures by the total number of miles of wind movement]

Year	April	May	June	July	August	September	October	April through October
1989	–5.5	16.8	–0.6	6.3	14.5	14.0	–7.3	5.1
1990	10.3	10.0	19.2	–2.3	–3.4	–6.1	4.7	5.1
1991	10.0	11.4	18.3	–3.0	0.8	11.0	–13.1	5.3
1992	–1.9	1.0	–5.7	–6.2	–8.9	2.8	–17.8	–5.2
1993	0.9	–19.0	–10.0	10.8	15.7	–8.3	–7.8	–3.4
1994	4.3	–14.0	–3.4	7.8	10.1	–5.9	8.0	0.4
1995	–1.0	–7.9	–6.3	–7.8	16.9	–6.0	8.4	–1.1
1996	15.0	12.6	–10.3	0.4	12.2	5.7	7.5	5.8
1997	–0.6	–6.4	–5.1	20.7	–12.6	–4.9	10.2	0.1
1998	–31.3	nd	nd	–11.2	–36.7	7.8	7.3	–15.2
1999	nd	–4.4	–11.7	–4.1	–8.5	–10.0	nd	–8.2
2000	nd	nd	15.6	–11.5	nd	nd	nd	2.5

Appendix 2. Monthly precipitation 1983 through 2007, at Colorado Interstate Gas (CIG), Las Animas County, Colorado.

[Precipitation, inches; nd, no data]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1983	nd	nd	nd	nd	nd	nd	0.20	1.27	0.08	0.31	0.45	0.58
1984	0.13	0.64	1.02	0.43	0.62	0.92	1.58	2.78	0.60	1.43	0.40	0.59
1985	0.30	0.36	0.39	1.44	2.27	0.37	1.28	0.43	1.02	1.57	0.14	0.23
1986	0.10	0.15	0.38	0.19	1.06	2.59	2.24	3.43	0.00	3.80	1.06	0.05
1987	0.98	0.46	0.43	0.43	5.09	1.05	0.43	3.09	0.52	0.00	0.60	0.55
1988	0.45	0.10	1.92	0.79	1.83	2.49	2.51	0.42	1.30	0.00	0.23	0.18
1989	0.08	0.45	0.25	0.47	1.16	0.64	2.70	0.80	1.33	0.20	0.02	0.21
1990	1.30	0.42	0.91	1.26	1.87	0.07	3.18	1.14	1.87	0.57	0.20	0.75
1991	0.13	0.12	0.66	1.09	0.28	2.87	1.77	2.57	0.47	0.04	1.62	0.43
1992	0.05	0.16	1.35	0.80	0.74	2.93	1.29	1.87	0.15	0.35	1.01	0.43
1993	0.02	0.34	1.07	0.78	1.65	0.28	0.33	2.32	0.00	0.26	nd	nd
1994	nd	0.10	0.57	0.85	4.14	0.26	1.07	3.27	0.20	0.25	0.14	0.05
1995	0.22	0.11	0.32	1.24	7.12	2.62	1.99	0.37	1.14	0.00	nd	0.05
1996	0.10	0.03	0.36	0.42	1.86	1.67	2.57	2.41	1.64	0.46	0.29	0.12
1997	0.40	0.71	0.13	0.36	0.31	1.45	1.79	2.10	1.27	0.97	1.03	0.80
1998	0.01	0.65	0.66	2.03	0.52	0.58	7.10	2.39	2.32	0.28	nd	nd
1999	nd	nd	nd	nd	nd	0.02	1.14	nd	nd	0.58	0.02	0.01
2000	0.00	nd	0.97	0.61	0.47	0.61	1.29	1.20	0.28	2.26	0.03	0.13
2001	0.09	0.11	0.65	0.17	1.68	0.58	0.86	0.38	0.65	0.09	0.32	0.10
2002	0.12	0.11	0.05	0.06	0.07	0.98	2.01	0.38	1.14	0.72	0.23	0.39
2003	0.11	0.30	0.80	0.65	0.70	1.59	0.34	2.01	0.81	0.00	0.09	0.08
2004	0.09	0.48	0.46	4.95	0.24	4.64	2.90	1.41	0.78	0.60	2.81	0.24
2005	0.72	0.08	2.04	3.46	2.26	2.08	0.21	0.20	1.28	2.07	0.20	0.03
2006	0.36	0.00	0.22	0.59	0.87	0.99	3.08	2.93	1.67	1.25	0.06	0.52
2007	0.26	0.07	0.10	1.27	1.07	4.26	2.75	2.87	1.71	0.96	nd	nd

Appendix 3. Monthly precipitation departure, from the 1983 through 2007 mean monthly precipitation, at Colorado Interstate Gas (CIG), Las Animas County, Colorado.

[Precipitation, inches; nd, no data]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1983	nd	nd	nd	nd	nd	nd	–1.66	–0.48	–0.85	–0.45	–0.07	0.28
1984	–0.14	0.37	0.34	–0.63	–1.03	–0.60	–0.28	1.03	–0.33	0.67	–0.12	0.29
1985	0.03	0.09	–0.29	0.38	0.62	–1.15	–0.58	–1.32	0.09	0.81	–0.38	–0.07
1986	–0.17	–0.12	–0.30	–0.87	–0.59	1.07	0.38	1.68	–0.93	3.04	0.54	–0.25
1987	0.71	0.19	–0.25	–0.63	3.44	–0.47	–1.43	1.34	–0.41	–0.76	0.08	0.25
1988	0.18	–0.17	1.24	–0.27	0.18	0.97	0.65	–1.33	0.37	–0.76	–0.29	–0.12
1989	–0.19	0.18	–0.43	–0.59	–0.49	–0.88	0.84	–0.95	0.40	–0.56	–0.50	–0.09
1990	1.03	0.15	0.23	0.20	0.22	–1.45	1.32	–0.61	0.94	–0.19	–0.32	0.45
1991	–0.14	–0.15	–0.02	0.03	–1.37	1.35	–0.09	0.82	–0.46	–0.72	1.10	0.13
1992	–0.22	–0.11	0.67	–0.26	–0.91	1.41	–0.57	0.12	–0.78	–0.41	0.49	0.13
1993	–0.25	0.07	0.39	–0.28	0.00	–1.24	–1.53	0.57	–0.93	–0.50	nd	nd
1994	nd	–0.17	–0.11	–0.21	2.49	–1.26	–0.79	1.52	–0.73	–0.51	–0.38	–0.25
1995	–0.05	–0.16	–0.36	0.18	5.47	1.10	0.13	–1.38	0.21	–0.76	nd	–0.25
1996	–0.17	–0.24	–0.32	–0.64	0.21	0.15	0.71	0.66	0.71	–0.30	–0.23	–0.18
1997	0.13	0.44	–0.55	–0.70	–1.34	–0.07	–0.07	0.35	0.34	0.21	0.51	0.50
1998	–0.26	0.38	–0.02	0.97	–1.13	–0.94	5.24	0.64	1.39	–0.48	nd	nd
1999	nd	nd	nd	nd	nd	–1.50	–0.72	nd	nd	–0.18	–0.50	–0.29
2000	–0.27	nd	0.29	–0.45	–1.18	–0.91	–0.57	–0.55	–0.65	1.50	–0.49	–0.17
2001	–0.18	–0.16	–0.03	–0.89	0.03	–0.94	–1.00	–1.37	–0.28	–0.67	–0.20	–0.20
2002	–0.15	–0.16	–0.63	–1.00	–1.58	–0.54	0.15	–1.37	0.21	–0.04	–0.29	0.09
2003	–0.16	0.03	0.12	–0.41	–0.95	0.07	–1.52	0.26	–0.12	–0.76	–0.43	–0.22
2004	–0.18	0.21	–0.22	3.89	–1.41	3.12	1.04	–0.34	–0.15	–0.16	2.29	–0.06
2005	0.45	–0.19	1.36	2.40	0.61	0.56	–1.65	–1.55	0.35	1.31	–0.32	–0.27
2006	0.09	–0.27	–0.46	–0.47	–0.78	–0.53	1.22	1.18	0.74	0.49	–0.46	0.22
2007	–0.01	–0.20	–0.58	0.21	–0.58	2.74	0.89	1.12	0.78	0.20	nd	nd

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