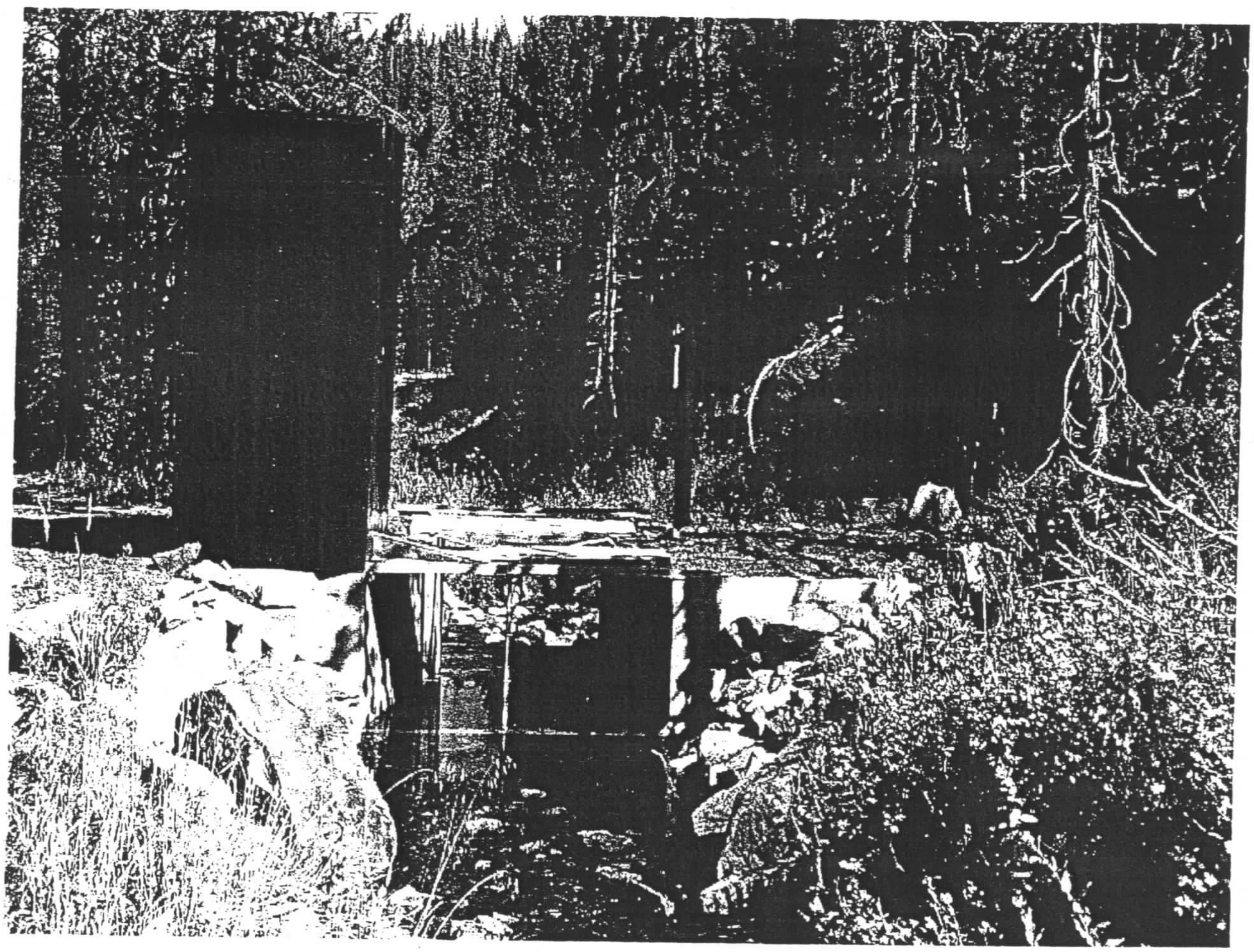
Flumes, Historic Water Yield and Climatological Data for Tenderfoot Creek Experimental Forest, Montana



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for

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Montana

Final Report

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Between

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Introduction

The objectives of this Research Joint Venture Agreement (RJVA) were to install and calibrate three flumes on Tenderfoot Creek Experimental Forest (TCEF) in central Montana; check calibration of the existing seven flumes on TCEF; estimate the influence of fire on water yields over the 400-year fire history period; and estimate back records of monthly temperature, monthly snow water equivalent, monthly precipitation for TCEF, and monthly streamflow for the lower Tenderfoot Creek flume (Tenderfoot Creek below Stringer Creek). Because of the potential for high streamflows in 1997, and the potential for low flows in 1998, we postponed this report so that 1997 and 1998 streamflow data could be included in the streamflow analysis. The information shown in this report completes the requirements for this RJVA.

Pack Creek Flume Installation (Pack Creek Near Mouth)

A 2-foot Parshall flume was obtained from the Beaverhead National Forest. To accommodate higher streamflows, additional sidewall extensions were constructed and bolted to the flume, an inlet nipple for attaching the stilling well was welded to the flume, a staff gage was installed in the flume across from the stilling well inlet and the stilling well and water level recorder cover were constructed. The flume and all installation materials were shipped to the site on July 17, 1996, with a helicopter contracted through the White Sulphur Springs District Office (Jet Ranger II operated by Charlie Rogers of Central Air Service of Lewistown, Montana). The flume was installed between August 5 and 22, 1996. The recorder was installed and a rating table developed by September 5, 1996, making the site fully operational. Detailed information is on file at the Forestry Sciences Laboratory in Bozeman, Montana.

Upper Stringer Flume Installation (Stringer Creek Above East Fork)

A 3-1/2-foot H-flume stored at the Forestry Sciences Laboratory in Bozeman, Montana, was readied for installation. A stilling well and instrument shelter cover were constructed and a staff gage was installed in the flume. The flume and shelter were disassembled and shipped to the site on July 17, 1996, by helicopter. All installation materials were also prepared and shipped to the site by helicopter the same day. The flume and instrument shelter were installed between August 5 and 22, 1996. The recorder was installed and a rating table developed by September 5, 1996, making the site fully operational. Detailed information is on file at the Forestry Sciences Laboratory in Bozeman.

Passionate Creek Weir Installation (Passionate Creek Near Mouth)

A 4-foot Cipolletti weir was constructed by Midwest Welding of Bozeman, Montana, and prepared for installation. A stilling well and instrument recorder cover were constructed. A staff gage was installed on the flume. The flume, stilling well and all installation materials were prepared and shipped to the site on July 17, 1996, by helicopter. The weir and stilling well were installed between August 5 and 22, 1996. The recorder was installed and a rating table developed by September 5, 1996, making the site fully operational. Detailed information is on file at the Forestry Sciences Laboratory in Bozeman.

Calibration of Existing Flumes

Current meter readings were made at existing flumes. Some problems were encountered since cross-sections from which to accurately gage the streamflow were poor, except at the flume sites. At the flume sites, particularly the H-flumes and Cipolletti weir, the flow regime was disrupted by the flumes. It was decided that the standard calibration values for these flumes were more accurate than the streamflow estimates that could be made with the current meter. It was concluded that the existing calibrated ratings would be the most accurate method to use to obtain flow data, particularly throughout the full range from low to high flows. Also, access was difficult during high flows, and fluctuations from wave action during high flows made it difficult to obtain accurate staff gage readings which were compared to current meter readings. In general, flows measured with the current meter were within 5 to 10 percent of flows determined with rating curves.

Influences of Historic Fire on Water Yield

Records of fire history, interception of snow and precipitation and relationships with runoff were used to develop a formal presentation on "Historic Role of Fire in Determining the Natural Variability of Annual Water Yield in Mountain Watersheds" which was presented at the Western Snow Conference in Banff, Alberta, in May 1997. Principal investigators in this RJVA were co-authors. A copy of this paper is included in Appendix I.

Historic Monthly Temperatures

Average maximum (TMax) and minimum (TMin) monthly temperatures were estimated by comparing weather station records at Onion Park with climatological stations at White Sulphur Springs, Neihart and Kings Hill and SNOTEL sites at Spur Park and Deadman Creek. Estimates of historic monthly average TMax and TMin temperatures for Onion Park are shown in Appendix II. Relationships and techniques used to estimate historic temperatures are on file at the Forestry Sciences Laboratory in Bozeman.

Historic Monthly Snow Water Equivalent

Snow water equivalent (SWE) measured at snow courses on TCEF were summarized and compared to NRCS snow pillows at Spur Park (8,100 ft) and Deadman Creek (6,450 ft) located approximately 15 miles ESE of TCEF. The Kings Hill snow course (7,500 ft) about 12 miles ESE of TCEF was also compared. Correlations between individual snow courses and the average of eight TCEF open snow courses and estimated historic SWE for TCEF are shown in Appendix III. Procedures and techniques used to estimate historic SWE are on file at the Forestry Sciences Laboratory in Bozeman.

Historic Monthly Precipitation

Monthly precipitation values measured at storage gages and electronic tipping buckets at data sites on TCEF were summarized and compared to NRCS SNOTEL stations at Spur Park and Deadman Creek, and the discontinued climatological station at Kings Hill. Correlations between individual stations and the average of eight sites and estimated historic monthly precipitation for TCEF are shown in Appendix IV. Relationships and techniques used to estimate historic precipitation are on file at the Forestry Sciences Laboratory in Bozeman.

Historic Monthly Streamflow

Because of the potential for high streamflows in the spring of 1997 and low flows in 1998, it was decided to wait until 1998 records were available to complete correlations. The only long-term stream gage records available for cross-correlation are from Sheep Creek near White Sulphur Springs. Flows were divided into periods to represent base, winter, spring and summer flows. Correlations and estimates of historic flow for Tenderfoot Creek below Stringer Creek (lower Tenderfoot flume) are shown in Appendix V. Procedures and techniques used to estimate historic streamflow data are on file at the Forestry Sciences Laboratory in Bozeman.

Applications Research

To date, the data provided by this study has been used by Chad Moore for his master's thesis, "Snow Accumulation Under Various Successional Stages of Lodgepole Pine", Earth Sciences Department, Montana State University; Tess Brennon, Earth Sciences Department, Montana State University, who is doing her master's thesis on whitebark pine; and Jeff Boice, Earth Sciences Department, Montana State University, for his master's thesis on "Analysis of Morphometric Variability for First and Second Order Streams in the Tenderfoot Creek Experimental Forest". There are also various other ongoing studies by USFS researchers.

APPENDIX I. INFLUENCE OF HISTORIC FIRES ON WATER YIELD OF TENDERFOOT CREEK EXPERIMENTAL FOREST

The historic role of fire relative to runoff in the Tenderfoot Creek Experimental Forest was investigated. The results were presented in a technical paper. This paper was presented at the 66th Annual Western Snow Conference, May 5-8, 1997, in Banff, Alberta, Canada, and was published in those proceedings. An updated copy of this technical paper is included.

HISTORIC ROLE OF FIRE IN DETERMINING THE NATURAL VARIABILITY OF ANNUAL WATER YIELD IN MOUNTAIN WATERSHEDS

by

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ABSTRACT

Management of forested watersheds should be based on information that accurately reflects the historic natural range of variability of historic water yields. Water yields from mountain watersheds depend on total precipitation input, the type and distribution of precipitation, canopy interception, and losses to evaporation, transpiration and groundwater. A systematic approach was developed to estimate the natural range of variability of average annual runoff based on historic fire patterns, habitat cover types and precipitation patterns on the Tenderfoot Creek Experimental Forest, Montana USA. The systematic approach developed correlations between measured values of average annual runoff and precipitation, forest canopy cover and precipitation reduction, forest canopy cover and habitat cover type, winter precipitation reduction and habitat cover type and effective precipitation and average annual runoff. Historic average annual runoff was then estimated for fire-generated stands before and after a fire year.

A fire history study on the experimental forest indicates that much of the watershed burned in the 1700s and 1800s. Two fires occurred in the 1700s and six in the 1800s covering more than 45 percent and 65 percent of the experimental forest, respectively. Only three small fires totaling 19 ha have occurred since the initiation of fire suppression in the early 1900s.

Annual water yield was estimated for the experimental forest for the past 400+ years. Maximum average annual runoff was estimated at 12.48 X 10^6 cubic meters (m^3) for the late 1500s after a considerable portion of the watershed was burned and the 1581 to 1997 average water yield was estimated to be 11.68 X 10^6 m^3. The maximum average water yield if all timber were removed, is estimated to be 13.24 X 10^6 m^3. The minimum average annual runoff if the entire forest consisted of mature lodgepole pine is estimated to be 11.23 X 10^6 m^3. The present yield of 11.36 X 10^6 m^3 approximates the lowest yield of 11.25 X 10^6 m^3 and is near the minimum possible for this experimental forest. Current fire suppression coupled with succession has decreased water yields close to minimum levels in many watersheds and created forest conditions conducive to catastrophic fires. Forest management that reflects natural variability could create a mix of successional stages, reduce fire potential and maintain increased water yields within natural hydrologic limits.

INTRODUCTION

This paper presents the computational procedures for estimating 400 years of average annual water yields and provides estimates of the natural range of water yield variability based on fire history patterns, annual precipitation and habitat cover types. Current hydrologic models predict effects from vegetation management but do not adequately reflect the natural range of variability of annual water yield from watersheds. Hydrologists use computer models to predict the potential effects of vegetation manipulation on water yield from watersheds. Watershed models such as WATSED (Water and sediment yield model—USDA Forest Service 1991) and WATBAL (Water balance model) provide hydrologists with information on projected water and sediment yields based on levels of vegetation management. Information from these models are used in the management of watersheds where hydrologic limits are placed on management activities based on bank full and peak flows estimates.

There are no known models that incorporate fire history into water yield predictions.

Historic water yield information is needed to determine the natural range of variability of water yields so that hydrologic limits can be correctly determined. Decisions to manage vegetation within watersheds are based on a variety of factors including protection of threatened or endangered species, wildlife habitat protection and the hydrologic limits. Hydrologists have minimal to no long-term historic streamflow data on undisturbed or disturbed watersheds. Streamflow data for only the past 20 to 80 years may not accurately indicate the natural range of variability of historic water yields from mountain watersheds because of fire suppression.

Snowmelt accounts for 50 to 70 percent of the total annual runoff in lodgepole pine and spruce/fir stands of the Northern Rockies (Farnes 1978). Water yield can be increased in subalpine forests through the use of prescribed fire or other management techniques such as harvesting. Openings created by fires or through forest management increase snow accumulation, decrease sublimation losses and increase water yields (Gary and Troendle 1982). Partial cutting reduces winter interception loss and summer soil water depletion due to shading effects of the remaining overstory (Troendle 1986).

Precipitation inputs, water yield outputs and forest canopy interception data have been collected on the Tenderfoot Creek Experimental Forest (TCEF), Montana USA, since 1992. The experimental forest was used for this study because it is representative of subalpine fir (*Abies lasiocarpa*) forests composed primarily of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*). This forest type covers six million hectares (ha) of commercial forest lands in the Rocky Mountains (Koch 1996; Wheeler and Critchfield 1984), and therefore the results of this study have wide geographic applicability. Mountain watersheds are important catchment basins for precipitation used for irrigation, hydroelectric generation and recreation. These watersheds provide high quality drinking water for municipalities and aquatic and riparian habitats for fish, aquatic insects, waterfowl and a host of wildlife species such as beaver (*Castor canadensis*), moose (*Alces americana*) and dippers (*Cinclus mexicanus unicolor*).

STUDY LOCATION

The Tenderfoot Creek Experimental Forest covers 3,709 ha of the headwaters of the Tenderfoot Creek watershed located in the Little Belt Mountains in central Montana. The experimental forest, established in 1961 for watershed research, has an average annual precipitation of 890 millimeters (mm) that varies from 595 mm in the lower elevations to 1,050 mm in the higher elevations. Elevations range from 1,838 to 2,421 meters (m) with an average of 2,206 m. Fire suppression since the early 1900s has reduced the effects of fires on the experimental forest (Barrett 1993).

The experimental forest is currently about 9 percent non-forested, 42 percent is in single-aged stands and 49 percent is in two-aged stands. The geology, soils, and stand conditions within the experimental forest are fairly consistent, providing a near-optimum site to isolate the influence of canopy coverage and habitat cover type on runoff. The oldest stands on TCEF were last burned in 1580, and the most recent burn affecting a large area occurred in 1902 (Table 1). The 1580 burn is currently a mature Engelmann spruce/subalpine fir (*Picea engelmannii/Abies lasiocarpa*) stand with a few isolated mature lodgepole pine found where mortality has created gaps in the overstory. From 1580 to 1902, ten fires occurred with an average fire size of 621 ha and an average of 32 years between fires. Three small burns (average size of six ha) in 1921, 1947 and 1996 (32 years between fires on the average) have affected less than 20 ha or less than 1 percent of the experimental forest in the last 95 years. In contrast, 1,660 and 2,415 ha have burned in each of the two preceding centuries (Table 1).

Table 1. Year of fire, area burned and percent burned of total area of Tenderfoot Creek Experimental Forest (Barrett 1993, unpublished report).

Year	Size (ha)	Percent of total area
1580	1900	51
1676	32	1
1726	1108	30
1765	552	15
1831	41	1
1845	1008	27
1873	1317	36
1882	30	1
1889	19	<1
1902	206	6
1921	8	<1
1947	11	<1
1996	0.4	<1

METHODS

We used a six-step approach to estimate average annual runoff on the Tenderfoot Creek Experimental Forest. This process involved the development of mathematical relationships between a variety of variables. In step one, average annual runoff measured on Tenderfoot Creek over the past five years was correlated with accumulation and precipitation data from nearby weather stations and SNOw survey TELemetry (SNOTEL) sites. These correlations were used to estimate the averages for 30 years(1961-1990) of average annual runoff, April 1 snow water equivalent (SWE), April through June precipitation (rain) and average annual precipitation on TCEF (Figure 1). July through September precipitation was not considered to affect runoff in this study. This late summer precipitation added little to stream runoff because of high evaporation rates, increased water use by vegetation and high soil moisture deficits.

In step two we developed a relationship between forest canopy and the reduction in accumulation of SWE due to canopy interception. Snow interception is expressed as the reduction of snow water equivalent (SWE) in lodgepole pine and spruce/fir stands as compared to snow accumulation in openings. Snow water equivalent was measured at six canopy-covered and eight open sites on the experimental forest since 1993. Since 1994 daily SWE has been recorded from two snow pillows on the experimental forest, one in the open and one under a forest canopy. Forest canopy has been measured and comparisons made between canopy cover and SWE at Natural Resource Conservation Service snow courses in Montana since the early 1960s (Farnes 1971). The effect of a logging altered forest canopy on SWE in Montana was studied by Hardy and Hansen-Bristow in 1990. After the 1988 fires in Yellowstone National Park, additional measurements were made in burned and unburned forest stands and compared to forest canopy (Farnes 1989; Farnes and Hartman 1989). Canopy cover and SWE data for stands with varying densities of canopy cover on the experimental forest were combined with data from these other studies (Hardy and Hansen-Bristow 1990; Skidmore et al. 1994 Moore 1997; Moore and McCaughey 1997). Measurements were made of canopy coverage using a photocanopyometer (Codd, 1959) that yielded a correlation (R^2 = 0.62) with snow interception.

In step three, data from TCEF and other studies (Farnes 1989; Farnes and Hartman 1989; Hardy and Hansen-Bristow 1990; Moore 1997; Moore and McCaughey 1997; Skidmore et al. 1994) were used to develop a relationship between percent forest canopy and habitat cover type (HCT) based on Despain, 1990. Habitat cover type classification is a method of classifying plant communities that result from a continuous successional process. The lower the HCT number designation the younger the stand. For example, an LP0 HCT represents a recently burned forest where lodgepole pine is expected to colonize the site or has done so already. An LP3 HCT is a mature stand containing extensive lodgepole pine mortality and high amounts of large and small seedlings and saplings of Engelmann spruce and subalpine fir. The species designation for a particular habitat cover type depends on the species that dominates a successional stage. The habitat type for a fire generated stand was combined with stand age, as determined by fire history, to obtain a numerical habitat cover type index value which more accurately reflects the successional stage of the stand. For example, a recently burned lodgepole pine stand is classified as an LP0. An LP1 is a mature forest and may be from 50 to 150 years old depending on site growing conditions. An LP3 is an overmature stand, generally older than 300 years with many dead and dying trees and is at climax. Likewise, an SF1 is a mature spruce/fir stand approximately 150 to 200 years old and an SF2.5 stand is near climax and approximately 400 to 500 years old. The age of mature stands was assumed to be 100 for lodgepole pine and 200 for spruce/fir stands on the experimental forest. Therefore, the HCT for a lodgepole pine stand is computed by dividing the age by 100 (150-year-old stand = LP1.5 HCT) and the HCT for a spruce/fir stand is the stand age divided by 200.

Data from steps one, two and three were combined in step four to quantify the reduction in SWE due to canopy interception and HCT index for lodgepole pine and spruce/fir stands. Habitat cover type and precipitation throughfall data from TCEF and other studies (Arthur and Fahey 1993; Fahey et al. 1988; Wilm and Niederhof 1941) were used in this process.

Average annual runoff was calculated in step five for each 5-centimeter precipitation increment which had been measured and delineated for the precipitation gradient of the experimental forest. Runoff from watersheds adjacent to the experimental forest (Farnes 1971, 1978; Farnes and Hartman 1989) was used to estimate past runoff for the experimental forest. The maximum and minimum annual runoff was computed for each precipitation zone assuming no forest canopy cover or complete canopy coverage. The canopy interception reduction in SWE and rain throughfall for each HCT was then used to calculate runoff for each habitat cover type in all precipitation zones. For example, the reduction in SWE and April - June precipitation was used to compute the runoff for the 900 mm (maximum) precipitation zone within a lodgepole pine HCT (Table 2). Average annual runoff for each precipitation zone and lodgepole pine HCT was then computed (Table 3) from values obtained from Table 2. Although changes in snowfall totals may have occurred over time, the reconstruction of the past 400+ years was based on the recent 30-year average period (1961 to 1990).

In the final step, we estimated average annual runoff from each fire-generated stand using habitat cover type before and after each fire. An HCT index value was assigned for each stand immediately prior to a fire. The stand was then reassigned a lower index value for the year after the fire, reflecting the stand's new open canopy condition. Net precipitation accumulation for each HCT and precipitation zone was estimated by taking the total precipitation input and estimating the reduction due to canopy interception of snow (SWE) and April to June rain. Average annual runoff was computed for all HCT stands and open areas based on precipitation zone and accumulated to obtain average annual runoff for the entire watershed for the year before and after each fire.

RESULTS AND DISCUSSION

Average annual runoff, the amount of precipitation falling as snow (April 1 SWE) and the amount falling as rain (April - June) increased at different rates as the average annual precipitation increased (Figure 1). Runoff is a function of precipitation received and the amount remaining after vegetation use, soil and groundwater recharge, evaporation and sublimation losses. Vegetation significantly affects soil and groundwater recharge and subsequent runoff. From the soil surface to a depth of 1.2 m, clearcuts or openings retain the highest percentage of soil moisture and mature stands the lowest (Newman and Schmidt 1980). Evaporation losses can be considerable in warm dry years. Sublimation is a function of the area in the forest, the age and species structure of the forest canopy, and the season in which precipitation occurs. April 1 SWE gives the greatest contribution to annual runoff because of saturated soils and minimal vegetation water use at the time of snowmelt. Average annual precipitation was positively correlated to elevation on TCEF.

Regression coefficients of percent canopy cover and SWE calculated as a percent of an open condition were not significantly different and were combined (Figure 2). The SWE showed a linear relationship and had a minimum accumulation of 69 percent of that measured in adjacent open areas in lodgepole pine and spruce/fir stands with 70 percent canopy cover.

Canopy cover increases quickly as lodgepole pine and spruce/fir stands approached maturity (HCT of 1 to 1.5) and decreased slowly as stands advanced into late successional stages (Figure 3). Mortality due to age, disease, windthrow and insects create gaps in late successional stands allowing increased amounts of snow and rain to reach the forest floor. Spruce/fir stands had a greater canopy coverage than lodgepole pine stands throughout all successional stages because of their denser foliage and shade tolerance characteristics, enabling multi-structured stands to develop.

Table 2. Calculations of the runoff for a lodgepole pine habitat cover type (HCT) for a 900 mm precipitation zone.

Precipitation zone 900 mm
April 1 SWE = 338 mm
April - June precipitation 246 mm

Annual runoff 378 mm
Runoff ÷ precipitation 42 %

HCT LP	SWE reduction[1]	Precipitation reduction[2]	Total reduction[3]	Net precipitation[4]	Runoff[5] mm
.0	0	0	0	900	378
.1	7	7	14	886	372
.2	16	17	33	867	364
.3	24	25	49	851	357
.4	30	33	63	837	352
.5	37	41	78	822	345
.6	44	49	93	807	339
.7	49	58	107	793	333
.8	55	65	120	780	328
.9	61	69	130	770	323
1.0	65	71	136	764	321
1.1	69	71	140	760	319
1.2	72	71	143	757	318
1.3	75	71	146	754	317
1.4	77	70	147	753	316
1.5	78	69	147	753	316
1.6	78	69	147	753	316
1.7	78	68	146	754	317
1.8	78	66	144	756	318
1.9	77	65	142	758	318
2.0	77	64	141	759	319
2.1	76	64	140	760	319
2.2	75	63	138	762	320
2.3	74	62	136	764	321
2.4	73	60	133	767	322
2.5	72	59	131	769	323
2.6	71	59	130	770	323
2.7	69	58	127	773	325
2.8	67	57	124	776	326
2.9	65	55	120	780	328
3.0	63	54	117	783	329

[1]338 - (% open x 338)
[2]246 - (% open x 246)
[3]Sum SWE and precipitation reduction
[4]Precipitation zone minus total reduction
[5]Net precipitation times 0.42

The amount of snow (SWE) and rain (April - June precipitation) that reached the forest floor decreased sharply as lodgepole pine and spruce/fir stands approached maturity (Figures 4 and 5). Precipitation throughfall and SWE remained constant for a short period after stands matured and then increased slowly as stands approached late successional stages. A higher percentage of snow reaches the forest floor under lodgepole pine than under spruce/fir stands because of the dense foliage characteristics of spruce and fir (Figures 4 and 5). Precipitation throughfall as rain is nearly equal for lodgepole pine and spruce/fir stands.

Table 3. Average annual runoff for lodgepole pine habitat cover types (HCT) and average annual precipitation zones.

HCT	Average annual precipitation zones, mm									
LP	600	650	700	750	800	850	900	950	1000	1050
				Runoff	(mm)					
.0	126	169	210	255	296	340	378	418	460	504
.1	124	166	206	251	291	334	372	411	453	496
.2	121	162	202	245	285	328	364	403	444	486
.3	118	159	198	240	280	322	357	396	436	478
.4	116	156	194	236	275	316	352	389	428	470
.5	114	153	190	232	270	310	345	382	421	462
.6	111	150	187	227	264	304	339	376	414	454
.7	109	147	183	223	259	299	333	369	407	446
.8	107	144	180	219	255	294	328	363	400	440
.9	105	142	177	216	252	290	323	359	396	434
1.0	104	141	176	214	249	288	321	356	392	431
1.1	104	140	175	213	248	286	319	354	390	429
1.2	103	139	174	212	247	285	318	352	389	427
1.3	103	139	173	211	246	284	317	351	387	425
1.4	103	139	173	211	246	284	316	351	387	424
1.5	103	139	173	211	246	284	316	351	387	425
1.6	103	139	173	211	246	284	316	351	387	425
1.7	103	139	174	212	247	284	317	352	388	425
1.8	103	139	174	212	247	284	318	352	388	427
1.9	104	140	175	212	248	285	318	352	389	427
2.0	104	140	175	214	248	286	319	353	390	428
2.1	104	140	175	214	248	286	319	354	391	428
2.2	104	140	176	214	249	287	320	355	391	430
2.3	105	141	176	215	250	288	321	356	392	431
2.4	105	142	177	216	251	289	322	357	394	432
2.5	105	142	177	216	252	290	323	358	395	433
2.6	105	142	178	217	252	290	323	359	395	433
2.7	106	143	178	218	253	292	325	360	397	435
2.8	106	144	179	218	254	293	326	362	398	437
2.9	107	144	180	219	256	294	328	363	400	439
3.0	108	145	181	220	256	295	329	364	402	440

Average annual runoff was estimated at 12.48 X 10^6 m^3 when fires burned 51 percent of TCEF in 1581, producing the highest estimated average annual runoff during the past 400 years (Table 4 and Figure 6). The average annual runoff from 1581 to 1997 was estimated to be 11.68 X 10^6 m^3. If all timber from TCEF were removed, the annual runoff is estimated to be 13.24 X 10^6 m^3 in an average precipitation year, 21.19 X 10^6 m^3 in a wet year (160 percent of average based on data from gaged streams near TCEF) and 6.62 X 10^6 m^3 in a dry year (50% of average). The annual runoff was estimated at 11.23 X 10^6 m^3 in an average year, 17.97 X 10^6 m^3 in a wet year and 5.62 X 10^6 m^3 in a dry year if all stands on TCEF were mature lodgepole pine (HCT of 1). The 1997 estimate of average annual runoff (11.36 X 10^6 m^3) approaches the minimum yield value of 11.23 X 10^6 m^3 occurring under mature forest conditions (Figure 6).

Table 4. Estimated annual runoff in cubic meters (m^3).

Period		m^3
1581-1997	Average annual runoff =	11.678
1961-1990	Average annual runoff =	11.458
1997	Average annual runoff =	11.360
1581-1997	Maximum average annual runoff (1581) =	12.485
1581-1997	Minimum average annual runoff (1873) =	11.247
	Average annual runoff with all forest burned =	13.241
	Average annual runoff with 91% mature forest =	11.230
	Maximum annual runoff, no forest, wet year =	21.186
	Minimum annual runoff, 91% mature forest, dry year =	5.615

SUMMARY

Fire has played a significant role in determining the average annual runoff patterns for Tenderfoot Creek Experimental Forest over the past 400+ years and throughout the North American west. Prior to fire suppression, when average annual runoff approached a minimum level in a mature forest, fires removed large portions of the forest canopy, resulting in increased runoff (Figure 6). Fire suppression and succession over the last 90 years has allowed the forested areas to remain in a mature stage, resulting in water yields that are now approaching the minimum estimated level. Continued fire suppression will create a fuel buildups that could result in catastrophic fires. The effects of a major fire event would severely impact stream channels, fisheries, wildlife and recreation. This study shows that it is possible to estimate the historic variability in runoff in lodgepole pine and spruce/fir forests using past fire patterns, average annual precipitation, April SWE, April - June precipitation and habitat cover type. We feel that this approach to estimate historic runoff patterns can be used in other forest types if precipitation throughfall and other input variables are known. Management strategies can be applied that create a mixture of successional stages which reduce fire potentials, and thereby influence water yields.

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Presented at the 66th Annual Western Snow Conference, May 5-8, 1997, Banff, Alberta, Canada. Updated 12/3/97.

FIGURES

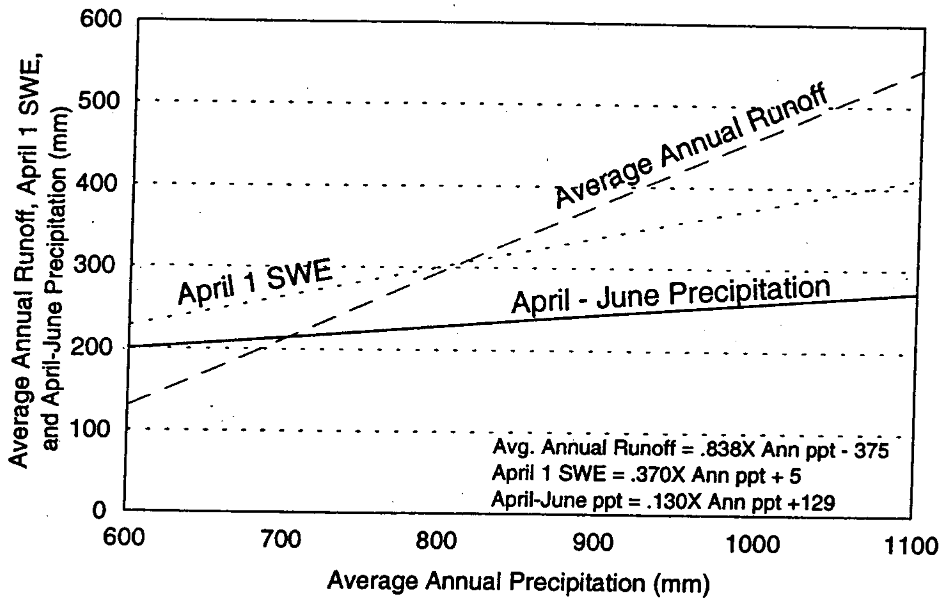

Figure 1. Relationship of average annual runoff, April 1 snow water equivalent (SWE) and April - June precipitation in open canopy areas to average annual precipitation.

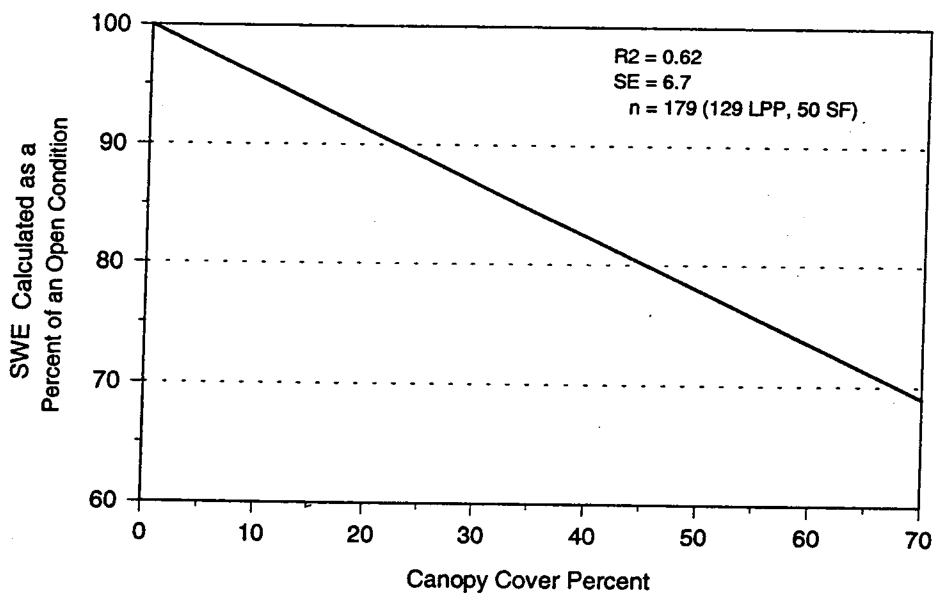

Figure 2. Snow water equivalent calculated as a percent of an open condition compared to percent canopy cover for lodgepole pine and spruce/fir stands in and near the Tenderfoot Creek Experimental Forest. Canopy cover is measured with a photocanopyometer with a 30° cone.

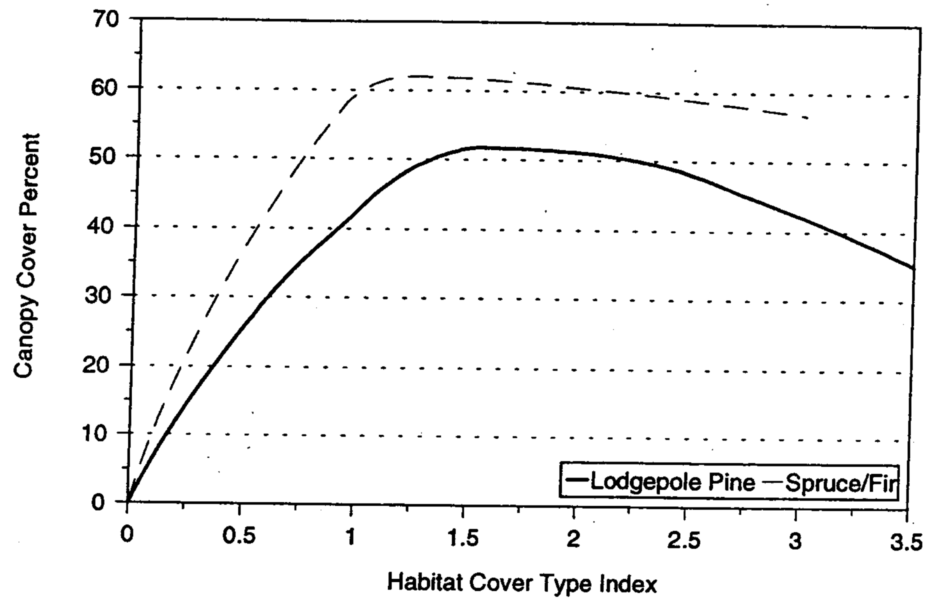

Figure 3. Relationship between canopy cover measured with a photocanopyometer and the habitat cover type index for lodgepole pine and spruce/fir stands.

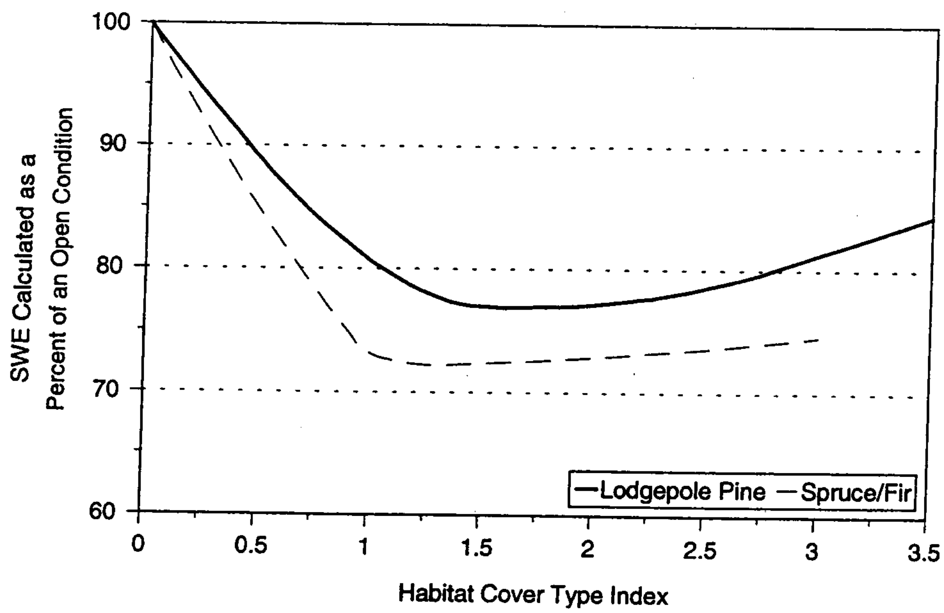

Figure 4. Relationship between snow water equivalent (SWE) calculated as a percent of an open condition and habitat cover type under lodgepole pine and spruce/fir stands.

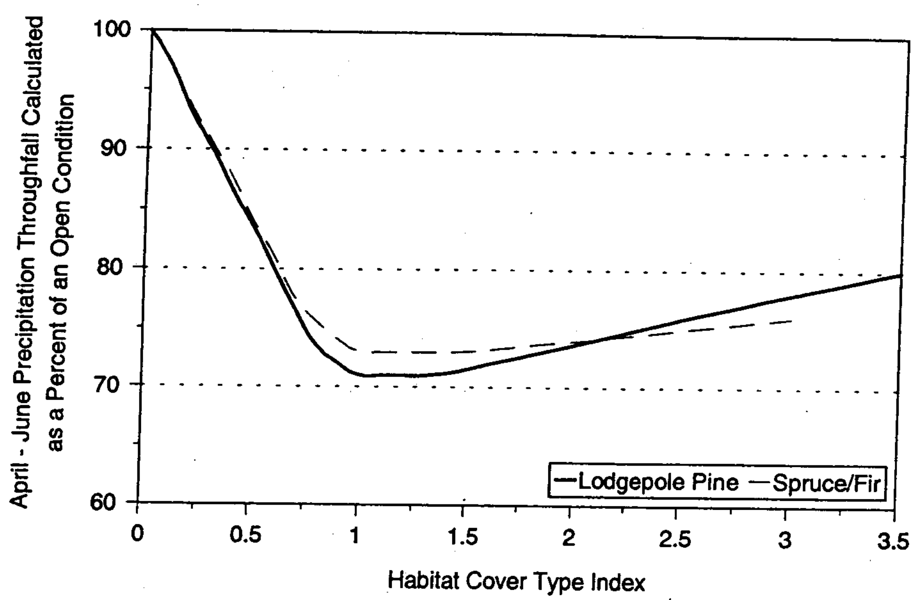

Figure 5. Relationship between April - June precipitation (rain) throughfall calculated as a percent of an open condition and habitat cover type index under lodgepole pine and spruce/fir stands.

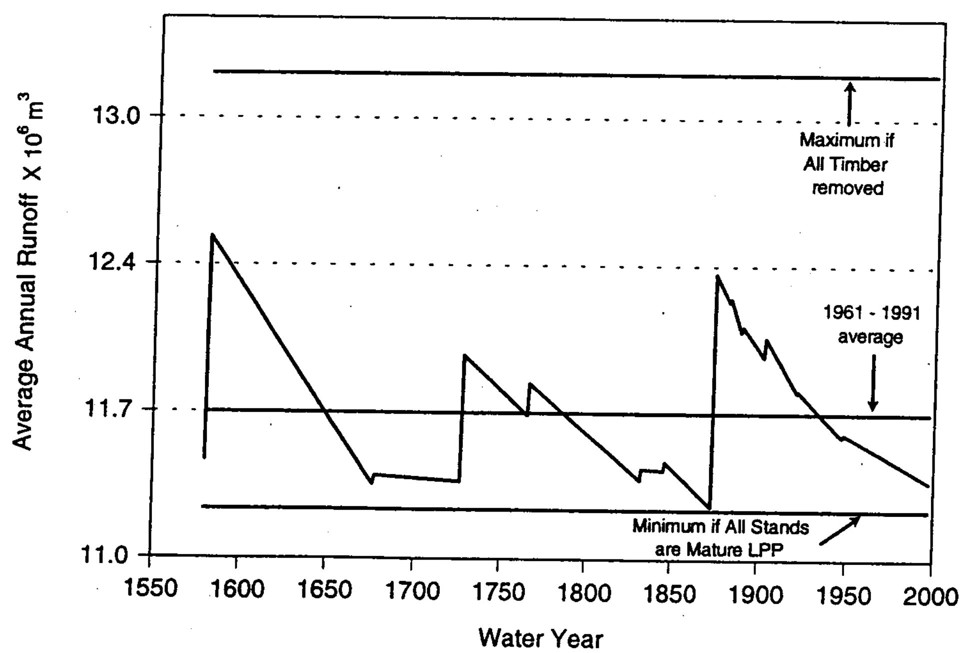

Figure 6. Average annual runoff based on fire history data and canopy cover/precipitation/runoff relationships under the 1961-1990 average precipitation regime.

APPENDIX II. HISTORIC MONTHLY TEMPERATURES FOR ONION PARK, TENDERFOOT CREEK EXPERIMENTAL FOREST

The following stations were used to estimate historic average maximum (TMax) and minimum (TMin) monthly temperature for the Onion Park site (7,410 ft) on TCEF. Daily temperatures at this site have been recorded since the 1992 water year (WY).

Name, Type, Elevation and Period of Record for Temperature Station

Station	Type	Elev. Ft.	Period of Record (WY)
Deadman Creek	SNOTEL	6,450	1992-present
Kings Hill	CLIM	7,310	1949-1965
Neihart 8NNW	CLIM	5,230	1968-present
Spur Park	SNOTEL	8,100	1983-present
White Sulphur Springs	CLIM	5,160	1912-1978
White Sulphur Springs 2	CLIM	5,200	1979-present

SNOTEL = Snow Survey Telemetry station maintained and operated by NRCS.
CLIM = Climatological station operated by NWS and cooperative observers.

Temperature records have been collected at the Stringer Creek site (6,550 ft) on Tenderfoot Creek Experimental Forest starting in the 1996 water year. Not enough data has been collected yet to develop a historic data set, but the following equation has been developed using 1996-1998 data ($R^2 = .927$) to estimate average temperature (TAvg). TMax and TMin data for Stringer Creek has not been analyzed. Stringer Creek TAvg = 1.01 x Onion Park TAvg + 0.5. Temperatures are in degrees Fahrenheit correlations, and estimating equations used to determine historic temperatures for Onion Park are on file at the Forestry Sciences Laboratory in Bozeman, Montana.

Tenderfoot Creek Experimental Forest
Average Maximum and Minimum Monthly Temperatures for Onion Park, °F

Average TMAX

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Average
1961	44	31	26	27	32	34	36	50	65	68	70	48	44
1962	43	29	19	19	21	29	46	48	58	62	63	53	41
1963	48	36	29	17	32	32	39	51	56	67	67	62	45
1964	50	32	22	22	26	26	39	48	55	70	60	50	42
1965	50	29	21	26	24	21	39	44	55	63	60	39	39
1966	50	32	27	21	24	32	38	53	55	68	63	60	44
1967	43	31	24	24	27	26	32	48	53	65	67	60	42
1968	43	31	17	21	27	36	38	44	53	65	60	51	41
1969	43	29	19	10	21	26	44	53	53	63	68	58	41
1970	32	36	27	19	31	26	31	50	60	67	68	50	41
1971	39	31	22	19	26	27	39	51	55	63	70	50	41
1972	39	31	19	15	27	38	39	48	60	60	65	51	41
1973	41	29	15	19	26	32	36	50	58	67	65	51	41
1974	43	24	26	17	27	29	43	43	63	68	58	55	41
1975	50	32	26	19	21	24	29	44	53	65	60	55	40
1976	41	27	27	24	27	29	41	53	55	67	62	58	43
1977	43	32	26	17	31	29	48	48	62	65	63	56	43
1978	46	29	22	19	22	36	41	48	60	63	63	55	42
1979	48	22	15	7	22	32	38	50	60	65	65	63	41
1980	48	29	31	17	26	29	48	53	58	65	60	55	43
1981	46	32	29	34	27	36	39	44	53	63	70	58	44
1982	41	36	22	17	21	29	36	46	55	63	67	53	41
1983	41	27	22	29	27	34	43	48	56	65	72	53	43
1984	43	27	14	22	31	32	44	50	58	70	72	50	43
1985	32	27	19	22	17	34	44	56	60	74	62	44	41
1986	38	17	21	27	24	41	44	51	67	62	68	44	42
1987	48	26	24	22	31	32	53	56	63	65	62	62	45
1988	48	34	21	17	24	31	46	56	68	72	68	55	45
1989	50	26	22	21	15	31	41	50	60	72	63	56	42
1990	41	27	21	22	22	36	46	50	58	68	68	67	44
1991	39	31	12	17	32	31	39	48	58	68	72	58	42
1992	41	27	27	27	36	43	46	53	60	58	63	53	45
1993	44	26	21	21	26	36	41	55	51	55	58	51	40
1994	43	24	24	26	21	36	44	54	60	68	70	63	44
1995	40	25	24	25	28	31	37	49	56	64	66	53	41
1996	37	31	24	20	24	28	46	48	62	73	68	52	43
1997	40	28	21	22	27	33	38	52	57	64	65	61	42
1998	39	32	26	24	32	34	43	52	50	72	71	64	45
1961-90 average:	44	29	23	20	25	31	41	49	58	66	65	54	42

Average TMIN

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Average
1961	22	13	6	10	13	13	17	27	38	42	42	24	22
1962	17	8	3	-3	3	6	19	27	33	36	34	27	18
1963	24	15	11	-12	11	11	17	26	34	36	36	34	20
1964	26	15	3	6	6	4	17	29	34	42	34	27	20
1965	22	11	3	11	4	-3	22	24	33	38	38	22	19
1966	26	15	10	3	4	11	15	27	33	40	34	34	21
1967	22	11	8	8	10	6	13	26	34	38	36	33	20
1968	26	11	-3	1	11	17	15	24	33	38	34	29	20
1969	22	13	-3	-8	1	3	22	27	31	38	36	33	18
1970	15	15	10	3	11	8	15	27	36	40	38	26	20
1971	17	10	6	4	10	10	19	27	33	34	42	26	20
1972	19	13	-1	-5	10	17	17	26	36	36	38	27	19
1973	17	13	-1	-1	3	13	17	24	34	38	38	29	19
1974	24	10	11	-1	13	11	22	24	36	40	34	26	21
1975	22	17	10	3	-1	6	11	26	33	43	34	26	19
1976	22	11	11	6	11	6	19	29	33	40	38	29	21
1977	19	11	10	-1	13	11	19	27	38	38	36	29	21
1978	22	10	3	-3	3	13	22	26	29	38	36	31	19
1979	22	4	1	-10	6	15	22	27	34	38	38	33	19
1980	27	10	13	1	13	11	26	31	36	38	34	34	23
1981	24	17	8	13	11	15	22	27	34	36	38	33	23
1982	22	19	10	-1	6	15	19	26	36	42	40	31	22
1983	22	10	4	13	15	13	13	24	31	40	43	27	21
1984	24	13	-10	6	10	13	15	22	31	42	43	26	20
1985	17	11	3	3	-1	6	19	29	33	43	34	24	18
1986	17	-1	4	13	4	17	17	24	38	34	40	27	20
1987	27	8	10	6	11	11	22	31	36	38	33	34	22
1988	24	19	6	1	6	10	19	27	40	40	38	29	22
1989	27	11	8	6	-6	8	17	26	33	42	38	31	20
1990	24	13	6	8	3	10	19	24	33	40	42	38	22
1991	20	17	-6	3	15	8	17	24	33	38	43	36	21
1992	22	13	15	13	20	22	24	31	40	38	40	33	26
1993	27	15	4	6	6	17	20	31	33	36	38	31	22
1994	26	8	12	14	2	15	22	32	38	43	45	37	25
1995	25	10	12	11	10	12	17	27	35	42	41	34	23
1996	23	17	10	3	6	8	22	27	37	43	42	32	23
1997	23	15	9	7	10	12	14	28	37	41	42	37	23
1998	24	15	9	9	13	12	22	30	32	46	44	40	25
1961-90 average: 1961-90 average:	22	12	5	3	7	10	18	26	34	39	37	29	20

1961-90 Average Monthly Temperatures (TAVG)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
33	21	14	12	16	21	30	38	46	53	51	42	31

Note: 1983-1993 estimated from Spur Park SNOTEL site. Prior years estimated from a combination of stations. TAVG = (TMAX + TMIN) / 2

APPENDIX III. HISTORIC SNOW WATER EQUIVALENT ON TENDERFOOT CREEK EXPERIMENTAL FOREST

Snow water equivalents (SWE) have been measured at eight open and six closed-canopy snow courses on Tenderfoot Creek Experimental Forest starting in the 1993 water year (WY). Three snow pillows have been installed on TCEF. At Onion Park, one snow pillow is in the open with no canopy and a second is under the forest canopy; both were installed in 1993. At Stringer Creek, one snow pillow was installed in 1995 in the open. First-of-the-month SWE for January through May has been estimated for the snow courses using snow pillow data from Onion Park, Stringer Creek, Deadman Creek and Spur Park.

Correlations and procedures used to estimate the average of eight snow courses on Tenderfoot Creek Experimental Forest for 1961-1992 is on file at the Forestry Sciences Laboratory in Bozeman, Montana.

Correlations between individual stations and the average of eight sites and between individual adjacent stations is shown in this appendix.

Name, Elevation and Period of Record for Snow Water Equivalent Stations

Snow Course	Elevation (ft)	Period of Record (WY)
*Bubbling Springs[1]	7,430	1993-present
*County Line[1]	7,810	1993-present
*Dry Park	7,420	1993-present
*Farnes Meadow[1]	7,400	1993-present
*Lonesome Creek[1]	6,970	1993-present
*Onion Park[1]	7,410	1993-present
Onion Park Open Pillow	7,410	1994-present
Onion Park Canopy Pillow	7,410	1994-present
*Stringer Creek	6,550	1993-present
Stringer Creek Open Pillow	6,550	1996-present
*Sun Creek[1]	7,040	1993-present
Deadman Creek Pillow	6,450	1961-present
Kings Hill	7,500	1934-present
Spur Park Pillow	8,100	1961-present

*Eight original open snow courses, average elevation 7,254 ft. Average elevation of TCEF is 7,236 ft and average elevation of Deadman Creek and Spur Park is 7,275 ft.

[1]Locations also having snow courses in forest canopy.

Tenderfoot Creek Experimental Forest
First-of-the-month SWE*, inches

Water Year	Jan 1	Feb 1	Mar 1	Apr 1	May 1
1961	3.8	4.2	5.8	8.9	12.7
1962	6.0	8.8	10.8	13.8	9.7
1963	3.2	7.7	9.0	11.0	13.0
1964	3.7	8.6	12.3	16.6	17.7
1965	6.4	12.4	15.3	17.7	18.9
1966	3.1	6.7	10.1	10.1	11.0
1967	5.7	12.1	16.4	19.9	22.9
1968	8.8	10.9	13.3	14.8	13.8
1969	5.1	10.3	11.6	12.4	7.4
1970	6.6	12.4	15.0	19.4	22.8
1971	5.7	11.7	14.3	18.3	18.6
1972	9.7	15.6	20.3	21.5	19.9
1967	3.9	5.6	6.6	8.1	9.6
1974	7.4	11.1	14.4	17.1	14.9
1975	5.6	10.5	12.2	15.6	18.3
1976	7.8	10.8	13.6	14.5	14.8
1977	5.8	11.1	14.6	18.7	16.0
1978	9.7	12.7	15.0	16.0	13.8
1979	6.1	10.0	12.1	13.1	12.0
1980	5.5	9.9	12.4	16.5	14.8
1981	5.1	9.1	11.3	14.5	13.7
1982	8.1	14.4	18.1	20.9	20.2
1983	4.0	5.7	7.1	8.4	9.1
1984	6.6	9.7	12.4	15.8	14.3
1985	6.4	9.8	12.1	15.4	14.0
1986	7.2	10.2	13.1	13.5	12.1
1987	3.9	6.2	7.8	11.1	7.9
1988	7.9	12.0	14.6	16.7	13.7
1989	4.0	8.5	10.1	13.6	13.4
1990	7.0	10.7	12.4	15.0	11.1
1991	6.3	10.1	11.5	15.0	16.5
1992	5.3	7.1	8.2	8.6	7.0
1993	7.0	10.5	11.9	13.3	15.5
1994	8.8	13.3	14.5	16.6	14.7
1995	7.0	9.6	10.5	14.6	18.4
1996	5.9	8.9	11.2	15.6	16.0
1997	10.7	13.5	16.8	18.7	19.6
1998	4.4	7.8	8.7	11.4	9.8
1961-90 average:	6.0	10.0	12.5	15.0	14.4
1961-98 min:	3.1	4.2	5.8	8.1	7.0
1961-98 max:	10.7	15.6	20.3	21.5	22.9

* Average, minimum and maximum first-of-the-month SWE values averaged from Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek and Sun Creek snow courses. 1961-1992 values estimated from Spur Park and Deadman Creek snow pillows.

Estimated 1961-1990 Average January 1 Through May 1 Snow Water Equivalent, Inches

	Station							
Date	Bubbling Springs	County Line	Dry Park	Farnes Meadow	Lonesome Creek	Onion Park	Stringer Creek	Sun Creek
Jan 1	6.5	7.4	6.9	6.6	5.1	6.2	4.0	5.5
Feb 1	10.7	11.9	10.7	11.0	8.6	10.7	7.0	9.5
Mar 1	13.3	14.7	13.1	13.8	10.8	13.5	8.9	12.0
Apr 1	16.0	17.6	15.5	16.5	13.0	16.3	10.8	14.4
May 1	15.3	16.9	14.9	15.8	12.5	15.6	10.3	13.9

	Onion Park Open Pillow	Onion Park Canopy Pillow	Stringer Creek Pillow
Jan 1	4.9	3.5	4.0
Feb 1	8.7	6.3	6.8
Mar 1	11.1	8.0	8.6
Apr 1	13.4	9.8	10.3
May 1	12.9	9.8	9.9

Tenderfoot Creek Experimental Forest
Historic SWE for Snow Courses
First Month SWE, inches (based on data through 5/98)

		R^2
Average 8* TCEF snow courses	= 0.93 x Average Spur Park Pillow and Deadman Creek Pillow - 0.9	.98
Bubbling Springs	= 1.05 x Average 8TCEF + 0.2	.97
County Line	= 1.13 x Average 8TCEF + 0.6	.98
Dry Park	= 0.96 x Average 8TCEF + 1.1	.98
Farnes Meadow	= 1.10 x Average 8TCEF ± 0	.99
Lonesome Creek	= 0.88 x Average 8TCEF - 0.2	.99
Onion Park	= 1.12 x Average 8TCEF - 0.5	.99
Onion Park Pillow	= 0.95 x Average 8TCEF - 0.8	.99
Stringer Creek	= 0.76 x Average 8TCEF - 0.6	.89
Stringer Creek Pillow	= 0.70 x Average 8TCEF - 0.2	.90
Sun Creek	= 0.99 x Average 8TCEF - 0.4	.98

*Average of Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek and Sun Creek snow courses.

Tenderfoot Creek Experimental Forest
Estimating Equations for Missing SWE for Snow Sites
First Month SWE, inches (based on data through 5/98)

		R^2
Bubbling Springs	= 0.92 x County Line - 0.2	.97
	= 1.09 x Dry Park - 1.0	.98
	= 0.95 x Farnes Meadow + 0.3	.95
	= 1.17 x Lonesome Creek + 0.5	.95
	= 0.93 x Onion Park + 0.8	.95
	= 1.10 x Onion Park Pillow + 1.0	.98
County Line	= 1.05 x Bubbling Springs +0.7	.97
	= 1.16 x Dry Park = 0.6	.98
	= 1.03 x Farnes Meadow + 0.6	.99
	= 1.00 x Onion Park + 1.2	.97
	= 1.18 x Onion Park Pillow + 1.6	.99
Dry Park	= 0.90 x Bubbling Springs + 1.2	.98
	= 0.85 x County Line + 0.8	.98
	= 0.87 x Farnes Meadow + 1.2	.98
	= 0.86 x Onion Park + 1.6	.98
	= 1.01 x Onion Park Pillow + 2.0	.99
Farnes Meadow	= 1.01 x Bubbling Springs + 0.3	.95
	= 0.97 x County Line - 0.5	.99
	= 1.12 x Dry Park - 1.1	.98
	= 0.98 x Onion Park + 0.5	.99
	= 1.14 x Onion Park Pillow + 1.0	.99
Lonesome Creek	= 0.82 x Bubbling Springs ± 0	.95
	= 1.18 x Stringer Pillow + 0.8	.94
	= 0.89 x Sun Creek + 0.3	.98

Estimating Equations for SWE (continued)

Onion Park	= 1.03 x Bubbling Springs - 0.2	.95
	= 0.98 x County Line - 0.8	.97
	= 1.15 x Dry Park - 1.6	.98
	= 1.01 x Farnes Meadow - 0.4	.99
	= 1.16 x Onion Park Pillow + 0.6	.99
Onion Park Pillow	= 0.89 x Bubbling Springs - 0.8	.98
	= 0.84 x County Line - 1.2	.99
	= 0.98 x Dry Park - 1.8	.99
	= 0.86 x Farnes Meadow - 0.8	.99
Stringer Creek	= 0.80 x Lonesome Creek - 0.2	.94
	= 1.10 x Stringer Creek Pillow - 0.4	.99
Stringer Creek Pillow	= 0.80 x Lonesome Creek - 0.2	.94
	= 0.90 x Stringer Creek + 0.5	.99
	= 0.72 x Sun Creek ± 0	.94
Sun Creek	= 1.11 x Lonesome Creek - 0.2	.98
	= 1.32 x Stringer Creek Pillow + 0.6	.94

APPENDIX IV. HISTORIC MONTHLY PRECIPITATION ON TENDERFOOT CREEK EXPERIMENTAL FOREST

Precipitation has been measured at eight storage gages since October 1992 (1993 WY). Two additional storage gages were installed more recently at Passionate Creek and Upper Stringer Creek.

Monthly data has been correlated between the ten data sites and the average of the eight original gages has been correlated with SNOTEL precipitation data from Deadman Creek and Spur Park. Data and procedures used to estimate historic precipitation data is on file at the Forestry Sciences Laboratory at Bozeman, Montana.

Tipping bucket precipitation gages are at Onion Park and Stringer Creek, but only summer precipitation had been collected from 1993 to 1997. In 1997, these gages were modified with a tipping bucket storage gage (TIPSTOR) to collect both frozen and non-frozen precipitation; however, this tipping bucket data has not been analyzed.

*The TIPSTOR is a storage type gage that mounts above the tipping bucket gage. It has an antifreeze solution with an oil layer that floats atop the solution. Overflow from this container is proportional to the precipitation that is falling; overflow is directed through the tipping bucket mechanism and measured similarly to rainfall passing through the tipping bucket. The TIPSOR (Tipping Bucket Storage Gage) was developed by Farnes and McCaughey and reported in McCaughey and Farnes. (1996). [Measuring winter precipitation with an antifreeze-based tipping bucket system. In: Troendle, Charles, ed. 64th Annual Meeting of the Western Snow Conference; 1996 April 15-18; Bend, OR. Fort Collins, CO: Colorado State University: 130-136.]

Name, Elevation and Period of Record for Precipitation Stations

Precipitation Station	Elevation (ft)	Period of Record (WY)
Tenderfoot Creek Experimental Forest		
*Bubbling Springs	7,430	1993-present
*County Line	7,810	1993-present
*Dry Park	7,420	1993-present
*Farnes Meadow	7,400	1993-present
*Lonesome Creek	6,970	1993-present
*Onion Park	7,410	1993-present
Passionate Creek	6,250	1995-present
*Stringer Creek	6,550	1993-present
*Sun Creek	7,040	1993-present
Upper Stringer	6,870	1997-present
SNOTEL		
Deadman Creek	6,450	1967-present
Spur Park	8,100	1967-present

*Eight original storage precipitation gages with average elevation of 7,254 ft. Average elevation of Tenderfoot Creek Experimental Forest is 7,236 ft and average elevation of Deadman Creek and Spur Park is 7,275 ft.

Tenderfoot Creek Experimental Forest
Monthly Precipitation*, inches

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1967	1.4	2.8	3.6	8.0	5.0	4.3	3.8	2.3	4.7	0.9	0.9	1.8	39.3
1968	2.4	2.4	5.5	2.4	2.7	1.6	2.3	5.4	3.2	2.0	2.3	3.6	35.7
1969	1.2	3.2	2.2	5.7	1.6	1.2	2.3	2.2	3.5	1.6	3.9	1.1	29.5
1970	4.2	1.9	2.9	6.1	2.6	4.9	4.1	5.0	3.1	1.6	0.9	2.2	39.3
1971	1.2	3.5	2.5	6.2	3.3	4.2	3.9	2.5	2.7	1.4	2.0	0.8	34.2
1972	1.2	2.2	7.6	6.8	4.7	3.1	2.0	2.4	2.0	2.6	3.0	0.6	38.2
1973	1.0	1.5	3.0	1.8	1.1	2.0	2.8	1.6	2.7	2.0	2.3	2.4	24.0
1974	2.3	4.1	4.0	4.0	3.4	3.2	3.5	6.4	1.2	2.1	4.7	0.9	39.8
1975	1.1	1.8	4.3	5.2	1.9	3.6	3.9	4.5	6.9	2.2	2.9	1.7	40.1
1976	5.1	4.6	2.4	3.2	2.8	1.4	4.1	2.0	3.8	1.7	2.0	1.7	34.9
1977	0.4	2.9	3.0	3.1	1.9	4.5	2.2	3.6	1.7	2.7	1.6	1.8	29.3
1978	2.2	3.6	7.5	4.4	2.8	2.7	2.2	3.3	4.2	5.0	2.7	2.9	43.4
1979	0.3	3.3	4.7	2.2	3.8	1.8	2.8	1.6	4.4	1.1	1.4	0.6	28.1
1980	1.3	1.4	1.7	2.7	2.0	4.2	1.5	5.7	4.1	1.0	2.4	0.9	28.8
1981	3.5	1.4	3.0	1.1	2.0	3.4	2.7	6.7	4.0	2.9	0.7	0.5	32.0
1982	3.0	2.3	2.7	5.0	1.8	3.8	3.7	4.2	3.6	2.7	0.7	2.6	36.2
1983	1.0	2.5	3.6	1.9	2.0	3.3	2.3	3.0	3.9	3.6	0.6	2.9	30.6
1984	2.2	2.9	2.7	2.1	1.8	4.3	3.1	2.3	2.7	0.0	1.5	2.5	28.0
1985	2.4	2.8	3.1	1.2	3.0	3.5	2.2	2.6	1.2	0.2	4.1	5.6	31.9
1986	3.3	3.7	2.4	2.8	3.5	1.8	3.4	3.3	3.4	4.2	1.6	2.7	36.1
1987	0.7	2.5	1.2	1.3	1.4	3.1	0.5	4.5	0.9	3.5	0.8	1.0	21.3
1988	0.5	0.5	2.8	3.5	3.6	3.4	3.1	2.5	1.9	1.5	0.7	1.8	25.9
1989	1.7	1.9	3.3	5.0	1.8	3.9	3.1	2.5	3.7	3.4	3.6	2.0	35.8
1990	1.6	3.4	5.7	3.9	1.8	3.1	2.5	5.3	1.7	1.1	2.6	0.3	32.9
1991	2.2	2.5	3.5	3.8	1.1	4.5	7.0	5.6	2.1	1.0	0.6	2.6	36.4
1992	1.4	3.1	2.6	1.9	1.2	1.4	3.6	2.5	4.3	2.3	1.2	2.1	27.5
1993	1.8	2.0	2.4	2.9	1.3	2.2	3.3	4.3	6.2	8.7	7.1	2.7	44.9
1994	2.3	1.9	2.5	3.8	2.0	1.9	3.8	2.5	2.5	1.5	0.5	0.5	25.6
1995	0.5	3.2	1.7	3.1	1.1	3.5	4.3	4.1	6.2	5.1	2.3	2.5	37.6
1996	2.7	2.5	1.2	2.6	2.4	2.6	2.8	6.2	2.1	1.3	0.9	2.4	29.9
1997	1.4	2.6	4.4	2.4	2.6	2.7	2.6	4.7	5.8	2.8	3.8	1.3	36.9
1998	1.7	0.9	1.7	3.1	0.6	2.4	2.0	3.8	7.1	2.4	2.8	0.5	29.0
1961-1990 average:	1.9	2.6	3.7	3.9	2.8	3.1	2.9	3.7	3.2	2.2	2.0	1.8	33.8

* Average of Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek and Sun Creek storage gages. 1967-1992 and 1961-1990 averages estimated from Spur Park and Deadman Creek SNOTEL sites.

Tenderfoot Creek Experimental Forest
Historic Precipitation Estimates for Storage Gages
Monthly totals, inches (based on data through 6/98)

		R^2
Average 8TCEF	= 0.98 x Average Spur Park and Deadman Creek ± 0	.81
Bubbling Springs	= 0.97 x Average 8TCEF + 0.1	.96
County Line	= 1.03 x Average 8TCEF + 0.1	.94
Dry Park	= 0.95 x Average 8TCEF + 0.1	.99
Farnes Meadow	= 1.07 x Average 8TCEF - 0.1	.99
Lonesome Creek	= 0.91 x Average 8TCEF ± 0	.97
Onion Park	= 1.04 x Average 8TCEF ± 0	.99
Passionate Creek	= 0.92 x Average 8TCEF - 0.3	.96
Stringer Creek	= 0.97 x Average 8TCEF - 0.1	.96
Sun Creek	= 1.03 x Average 8TCEF - 0.1	.98
Upper Stringer	= 1.03 x Average 8TCEF - 0.1	.97

Average 8TCEF = Average monthly precipitation for Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek, and Sun Creek
Spur Park = Monthly precipitation at Spur Park SNOTEL site
Deadman Creek = Monthly precipitation at Deadman Creek SNOTEL site

Estimated 1961-1990 Average Monthly Precipitation, Inches

Month	Station							
	Bubbling Springs	County Line	Dry Park	Farnes Meadow	Lonesome Creek	Onion Park	Passionate Creek	Stringer Creek
Oct	2.0	2.1	1.9	1.9	1.7	2.0	1.5	1.8
Nov	2.7	2.8	2.6	2.7	2.4	2.8	2.1	2.5
Dec	3.7	3.9	3.6	3.8	3.3	3.8	3.1	3.5
Jan	3.9	4.1	3.8	4.0	3.5	4.0	3.3	3.7
Feb	2.8	3.0	2.8	2.9	2.5	2.9	2.3	2.6
Mar	3.1	3.3	3.0	3.2	2.8	3.2	2.5	2.9
Apr	2.9	3.1	2.8	3.0	2.6	3.0	2.4	2.7
May	3.7	3.9	3.6	3.8	3.3	3.8	3.1	3.5
Jun	3.2	3.4	3.1	3.3	2.9	3.3	2.6	3.0
Jul	2.2	2.4	2.2	2.3	2.0	2.3	1.7	2.0
Aug	2.1	2.2	2.1	2.1	1.9	2.1	1.6	1.9
Sep	1.9	2.0	1.9	1.9	1.7	1.9	1.4	1.7
Annual	34.2	36.2	33.4	34.9	30.6	35.1	27.6	31.8

	Sun Creek	Upper Stringer
Oct	1.9	1.9
Nov	2.6	2.6
Dec	3.7	3.7
Jan	3.9	3.9
Feb	2.8	2.8
Mar	3.1	3.1
Apr	2.9	2.9
May	3.7	3.7
Jun	3.2	3.2
Jul	2.2	2.2
Aug	2.0	2.0
Sep	1.8	1.8
Annual	33.8	33.8

Tenderfoot Creek Experimental Forest
Equations for Estimating Missing Precipitation Data for Storage Gages
Monthly totals, inches (based on data through 6/98)

		R^2
Bubbling Springs	= 1.00 x Dry Park + 0.1	.93
	= 0.90 x Farnes Meadow + 0.2	.94
	= 1.04 x Lonesome Creek + 0.1	.93
	= 0.92 x Onion Park + 0.2	.95
	= 0.92 x Sun Creek + 0.3	.94
County Line	= 1.08 x Dry Park ± 0	.95
	= 0.97 x Farnes Meadow + 0.1	.96
	= 0.98 x Onion Park + 0.1	.93
Dry Park	= 0.94 x Bubbling Springs + 0.1	.93
	= 0.88 x County Line + 0.1	.95
	= 0.89 x Farnes Meadow + 0.1	.99
	= 0.91 x Onion Park + 0.1	.98
	= 0.90 x Upper Stringer + 0.2	.95
Farnes Meadow	= 1.06 x Bubbling Springs ± 0	.94
	= 0.99 x County Line ± 0	.96
	= 1.11 x Dry Park - 0.1	.99
	= 1.01 x Onion Park ± 0	.98
	= 1.01 x Upper Stringer + 0.1	.96
Lonesome Creek	= 0.90 x Bubbling Springs ± 0	.93
	= 0.91 x Stringer Creek + 0.2	.96
	= 0.87 x Sun Creek + 0.2	.97
Onion Park	= 1.03 x Bubbling Springs ± 0	.95
	= 0.95 x County Line + 0.1	.93
	= 1.08 x Dry Park ± 0	.98
	= 0.97 x Farnes Meadow + 0.1	.98
	= 0.99 x Sun Creek + 0.2	.96

Estimating Equations for Missing Precipitation Data (continued)

Passionate Creek	= 0.99 x Lonesome Creek - 0.3	.94
	= 0.94 x Stringer Creek - 0.2	.97
Stringer Creek	= 1.05 x Lonesome Creek - 0.1	.96
	= 1.03 x Passionate Creek + 0.2	.97
	= 0.93 x Sun Creek ± 0	.97
	= 0.93 x Upper Stringer ± 0	.97
Sun Creek	= 1.02 x Bubbling Springs - 0.1	.94
	= 1.11 x Lonesome Creek - 0.1	.97
	= 0.97 x Onion Park - 0.1	.96
	= 1.04 x Stringer Creek ± 0	.97
	= 0.99 x Upper Stringer ± 0	.98
Upper Stringer	= 1.06 x Dry Park - 0.1	.95
	= 0.95 x Farnes Meadow ± 0	.96
	= 1.04 x Stringer Creek + 0.1	.97
	= 0.99 x Sun Creek + 0.1	.98

APPENDIX V. HISTORIC MONTHLY STREAMFLOW FOR TENDERFOOT CREEK BELOW STRINGER CREEK

Daily streamflow has been measured at Sheep Creek near White Sulphur Springs since 1942. This drainage heads in the Little Belt Mountains about 12 miles ESE of Tenderfoot Creek headwaters. There are some hydrologic differences between Sheep Creek and Tenderfoot Creek. Timber harvesting has occurred in the Sheep Creek drainage which might also affect the relationship. However, this is the only active long term streamflow measuring station on streams flowing out of the Little Belt Mountains that can be used for correlations.

Streamflows have been measured on Tenderfoot Creek Experimental Forest beginning with the 1993 WY. For this report, only the Lower Tenderfoot station (Tenderfoot Creek below Stringer Creek) was analyzed. Correlations and estimating equations were developed for monthly flows April through July. The August and September flows were analyzed together as were the October through March flows.

Correlations, procedures and analyses are on file at the Forestry Sciences Laboratory in Bozeman, Montana.

Following are monthly flows for Tenderfoot Creek below Stringer Creek in acre-feet starting in 1942 WY. The estimated flows (1942-1992) can be used to determine variability by month, season and year, but should be viewed with caution when referring to the streamflow for any specific month.

Tenderfoot Creek Experimental Forest
Tenderfoot Creek below Stringer Creek
Monthly Streamflow in Acre-feet

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	sum Oct-Mar	sum Apr-Sept	sum Oct-Sept
1942	100	80	75	70	65	70	162	2884	3441	322	251	141	460	7201	7661
1943	93	120	110	110	90	95	304	1750	3990	281	218	128	618	6671	7289
1944	120	115	110	105	100	110	142	1167	1402	300	204	150	660	3365	4025
1945	140	130	120	110	95	105	157	688	3738	281	210	187	700	5261	5961
1946	86	80	75	70	65	60	384	2592	3233	413	299	181	436	7102	7538
1947	203	131	75	70	65	75	154	3263	3823	281	244	177	619	7942	8561
1948	131	170	150	130	115	125	139	3453	3966	471	450	260	821	8739	9560
1949	233	169	130	115	100	110	177	2836	1919	315	175	136	857	5558	6415
1950	89	85	80	70	60	75	152	679	4304	394	365	212	459	6106	6565
1951	157	99	80	60	55	65	136	3115	3418	279	227	150	516	7325	7841
1952	93	40	85	75	70	80	287	3430	1515	381	187	121	443	5921	6364
1953	100	90	80	70	65	75	140	1786	3580	471	260	170	480	6407	6887
1954	70	60	50	50	50	70	143	1422	2207	289	191	138	350	4390	4740
1955	76	68	60	55	50	70	162	1150	4182	705	292	185	379	6676	7055
1956	125	110	103	100	95	120	136	2055	857	532	139	116	653	3835	4488
1957	105	78	60	40	38	70	150	2343	2366	300	191	143	391	5493	5884
1958	70	70	65	60	55	57	150	2234	-20	506	147	106	377	3123	3500
1959	80	65	60	58	62	70	144	1793	4944	297	216	166	395	7560	7955
1960	163	63	43	55	60	63	143	1547	2106	390	193	141	447	4520	4967
1961	70	60	55	50	50	55	152	853	708	631	104	113	340	2561	2901
1962	100	80	75	70	65	70	151	2607	2961	328	218	143	460	6408	6868
1963	128	120	110	100	90	95	137	2049	3628	324	235	187	643	6560	7203
1964	125	115	110	105	100	110	140	3454	4818	407	299	231	665	9349	10014
1965	153	130	120	110	95	105	136	3410	3955	1685	490	425	713	10101	10814
1966	446	262	160	140	130	233	172	3296	2443	278	278	187	1371	6654	8025
1967	119	86	75	70	65	75	149	3109	3836	644	362	257	490	8357	8847
1968	197	170	150	130	115	125	136	3366	4582	388	375	242	887	9089	9976
1969	224	147	130	115	100	110	370	2395	620	278	227	170	826	4060	4886
1970	163	102	80	70	60	75	152	3339	4304	444	360	222	550	8821	9371
1971	150	96	63	60	55	65	136	3425	3628	285	229	177	489	7880	8369
1972	122	96	85	75	70	80	136	3125	4757	278	275	154	528	8725	9253
1973	100	90	80	70	65	75	136	461	442	375	189	150	480	1753	2233
1974	70	60	50	50	50	70	1147	3144	4749	512	388	235	350	10175	10525
1975	115	73	60	55	50	70	144	1728	2705	1674	461	237	423	6949	7372
1976	224	150	115	100	95	120	446	3131	2795	317	340	257	804	7286	8090
1977	109	66	46	40	38	70	287	3197	1704	315	206	164	369	5873	6242
1978	212	163	191	163	184	215	324	3217	4833	3546	617	407	1128	12944	14072
1979	319	197	247	178	163	200	285	3350	4347	403	332	231	1304	8948	10252
1980	178	169	147	120	99	253	163	862	1390	307	246	154	966	3122	4088
1981	230	197	209	150	181	236	156	3379	3593	295	253	171	1203	7847	9050
1982	172	147	242	115	106	89	140	2360	4854	772	391	260	871	8777	9648
1983	271	259	265	256	221	224	139	1373	1834	717	481	242	1496	4786	6282
1984	227	188	166	288	227	332	237	2900	3217	278	255	193	1428	7080	8508
1985	135	200	96	119	109	271	1100	2534	800	477	299	264	930	5474	6404
1986	419	378	163	150	169	200	534	3440	4463	330	315	308	1479	9390	10869
1987	265	212	209	175	147	194	146	650	600	575	116	127	1202	2214	3416
1988	419	280	250	200	150	166	136	2435	700	537	123	108	1465	4039	5504
1989	80	70	65	55	50	75	155	2343	2237	315	244	206	395	5500	5895
1990	141	236	125	125	112	178	541	3217	4323	297	294	212	917	8884	9801
1991	218	112	102	99	131	131	136	3407	4560	286	251	193	793	8833	9626
1992	206	102	125	119	89	119	137	400	420	359	199	170	760	1685	2445
1993	92	83	80	74	61	74	144	3292	1962	2845	1398	1172	464	10813	11277
1994	571	444	417	376	287	240	1121	3861	993	396	234	196	2336	6801	9137
1995	162	184	151	139	116	118	121	1313	4912	1292	400	254	870	8292	9162
1996	239	207	193	174	144	142	253	2841	3864	552	282	179	1099	7971	9070
1997	221	210	193	179	114	123	176	3424	4335	672	396	256	1040	9259	10299
1998	229	198	193	179	114	129	230	2111	2520	1306	424	249	1042	6840	7882
1961-1990 average:	189	153	131	117	107	141	273	2605	2994	600	300	214	838	6986	7826

1942-1992 estimated from Sheep Creek near White Sulphur Springs