SNOW FENCING TO INCREASE STREAMFLOW: PRELIMINARY RESULTS

By

David L. Sturges[1]

INTRODUCTION

Enormous quantities of water evaporate from blowing snow. Estimates are that more than half the water in snow returns to the atmosphere over a 3,000-m transport distance, and 83% of water is lost by evaporation over a 9,000-m transport distance (Tabler 1975). Snow fences are an effective tool to trap drifting snow. Fences not only redistribute snow, but also provide "new" water that otherwise would not be available for beneficial uses because of evaporation during transport. The concept of trapping snow to provide a local water source or to increase streamflow is not new. Various aspects of using snow fences for water development have been discussed by many authors (Lull and Orr 1950; Berndt 1964; Tabler 1968; Swank and Booth 1970; Tabler and Johnson 1971; Martinelli 1973; Rechard 1973; Saulmon 1973; Sturges and Tabler 1981).

Three watershed-based studies used snow fences in an attempt to increase water yield, but all were unsuccessful in showing a treatment effect. The U. S. Forest Service placed about 3 km of 3.7-m tall snow fences on Lake Creek watershed in Colorado during the late 1960's as part of the Barometer Watershed Study Program, but the study was terminated before completion. In Idaho, a 97.5-m-long fence was placed on a 0.5-km^2 sagebrush-covered watershed at the Reynolds Creek Study Area (Cooley et al. 1981). The fence changed the configuration of the drift, but not total snow accumulation. Placement of a snow fence 3.8 m tall and 396 m long parallel to the drainage channel on a 50-ha watershed in Wyoming more than doubled snow accumulation (Tabler 1971). However, meltwater percolated through soil and into fractured bedrock, completely bypassing the streamgage (Tabler and Sturges 1986). The Wyoming study illustrates that local soil and geologic characteristics must be considered when snow fences are used to develop additional water.

OBJECTIVES

This paper discusses results from a paired watershed study in which a large snow fence was placed on a sagebrush-covered watershed to trap drifting snow and increase water yield. Streamflow and sediment transport characteristics were measured 10 years preceding fence installation and the specific conductance of water was measured for 2 years. Study results are reported here for the first 2 years after fence construction.

STUDY AREA

The study was conducted about 32 km west of Saratoga, Wyoming, at the Stratton Sagebrush Hydrology Study Area; it utilized the Loco Creek, Sane Creek and North Draw drainages (Figure 1). Elevations range between 2,320 m and 2,470 m. Annual precipitation averages 53.5 cm and the average annual temperature is 2.4°C. Nearly half of the precipitation falls between November and March when snow redistribution by wind is an important hydrologic process. Average monthly windspeeds exceed 5 m/s between November and March when air temperatures are well below freezing. To avoid the deleterious effects of wind on gage performance, winter precipitation was measured in an aspen grove located 0.7 km from the boundary of Loco Creek watershed (Figure 1). Other meteorological information was collected at a weather station on the Loco-Sane Creek watershed divide.

Soils at the Stratton site are derived from the Browns Park Formation and typically have a loam or sandy loam texture in A and B horizons. Soil surface stability is good. Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) about 60 cm tall inhabits sites with well-developed soils which correspond to areas of moderate or deep snow

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[1] Research Forester, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Laramie, in cooperation with the University of Wyoming. Station headquarters is at Fort Collins, in cooperation with Colorado State University.

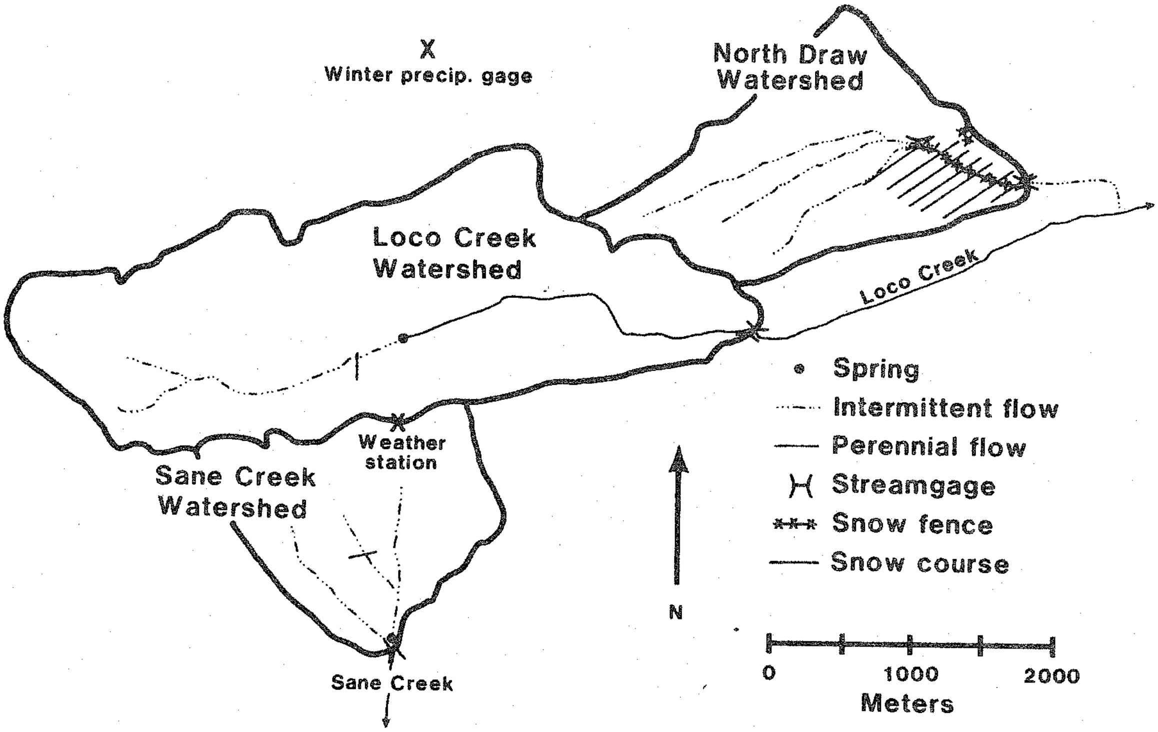

Figure 1. The Stratton Sagebrush Hydrology Study Area. A snow fence 800 m long was built on North Draw watershed. Loco Creek watershed remained in an undisturbed state and was paired with North Draw watershed.

accumulation. Uplands and ridges are characterized by stands of Wyoming big sagebrush (A. t. ssp. wyomingensis) 10 to 20 cm tall; the wind scours snow from these sites, and effective precipitation is much less than in snow depositional areas.

STUDY METHODS

Hydrologic Measurements

Streamgages were installed on the Loco and Sane Creek drainages (663 ha and 238 ha, respectively) in 1967, and North Draw watershed (306 ha) was gaged in 1972. North Draw flows ephemerally during snowmelt while Loco Creek and Sane Creek have perennial flow. North Draw watershed was snow-fenced in 1983 and was paired with the Loco Creek watershed to evaluate the effect of fencing on water yield. The Loco Creek watershed remained in an undisturbed state throughout the study. The channels of Loco Creek and North Draw watersheds slope easterly on a 2% to 3% gradient and channel bottoms are stable and well-vegetated.

Streamgaging stations have a 120-degree, V-notch control section that was placed in a cutoff wall extending about 3 m below the ground surface. The depth of water in the V-notch was continuously recorded. The entire gaging station at Loco Creek (stilling pond, control section, and apron area) was covered by a multiplate arch to prevent burial under snow. The North Draw gaging station was built within a multiplate pipe arch that forms the walls and bottom of the stilling pond and the apron area, in addition to providing protection from snow (Johnson and Tabler 1973). In 1983, a Parshall flume with a throat width of 30 cm was installed above the snow-fenced portion of North Draw watershed to measure discharge originating above the snow fence. About 80% of the watershed was above the flume. A cutoff wall 30 m wide and 4 m deep directed surface as well as subsurface flow through the flume.

The volume of sediment deposited in stilling basins was determined annually by a rod and level survey in late-summer or fall. The concentration of suspended sediment in water samples about 400 ml in size that were collected manually at the North Draw V-notch was determined between 1976 and 1982. A PS-67 pumping sediment sampler was installed prior to snowmelt runoff in 1983 and thereafter 400-ml samples were collected at 0600 and 1800 each day. Suspended sediment samples were processed by standard analysis procedures using filters with pores 45 microns in diameter (American Public Health Assoc. 1980). Water samples were occasionally collected at the V-notch while the sampler was in operation to develop a regression relationship to adjust sediment content in samples taken from the stilling basin to sediment content of water flowing over the V-notch. Water samples were also collected manually at the V-notch to measure specific conductance.

Index snow transects crossing major topographic catchment zones for wind-deposited snow were installed on Loco and Sane Creek watersheds in 1968. Drift cross-sectional areas were measured each year at maximum accumulation. Similar measurements began in 1969 on two index snow transects crossing the North Draw channel. The location of transects on Loco and Sane Creek watersheds that had similar snow accumulation characteristics as the North Draw transects is shown on Figure 1. In anticipation of the snow fence treatment, seven additional snow courses, 500 m in length, were installed on North Draw watershed in 1978 to better quantify channel snow storage (Figure 1). Snow depths were determined by probing with an aluminum rod (Jairell 1975) or from an elevational survey. The density of snow on selected transects within Loco and Sane Creek watersheds was measured with a Federal sampler at the time of maximum accumulation. However, the Federal sampler overestimates density, and the relationship between snow density and snow depth for wind deposited snow described by Tabler (1985) was used to determine water content of the North Draw drift. Monthly snow accumulation was also measured through the winter on four transects crossing the North Draw channel beginning in the 1978-79 winter.

Design and Construction of the Snow Fence

An incised channel about 6 m deep extended 815 m upstream from the North Draw streamgage, and snow deposited in this reach was the source of most streamflow. The channel usually filled with snow early in the winter and then developed a smooth, concave surface that had a low trapping efficiency for additional blowing snow. This channel reach was selected for treatment because storage of additional snow on top of that accumulating naturally would minimize conveyance and soil recharge water losses. Perforated plastic pipe 15 cm in diameter was placed in the channel between the flume and the main streamgage to insure that flow would not be obstructed in years when snow filled the channel.

A 3.78-m-tall Wyoming snow fence was used for treatment. The fence has horizontal wood boards 15 cm wide that alternate with 15-cm open spaces (Tabler 1974). A gap equal to 16% of fence height was left at the bottom of the fence to reduce the likelihood of structural damage from burial by snow. The fence was built in panels 4.9 m long that incline 15° in a downwind direction.

The snow fence was placed approximately 38 m upwind of the channel centerline (ten times fence height) and was 800 m in length (Figure 2). It was built in 1983 after snowmelt runoff was completed. The combined storage capacity provided by the fence and channel was large enough to hold expected snow transport in more than 96 out of 100 winters. Estimates of snow arriving at the channel were based on snow retention characteristics on the upwind fetch and average winter precipitation falling between November and March (Sturges and Tabler 1981). Tabler and Sturges (1986) fully describe the criteria used to design the fence.

Another snow fence, also 3.78 m tall, but only 112 m long, was installed 200 m downwind of the North Draw channel in order to evaluate the trapping efficiency of the main fence (Figure 1). This fence was placed near the watershed boundary and should have a negligible effect on streamflow because of the small size of the drift and the 161-m distance between the fence and the channel.

ANALYSIS OF DATA

The study utilized the paired watershed approach to evaluate the effects of fencing on snowmelt discharge, the hydrologic parameter of primary interest. Snowmelt discharge on North Draw was considered total annual flow minus any rainstorm runoff that occurred after completion of snowmelt surface flow. Snowmelt runoff on Loco Creek watershed was calculated as total discharge from the first to the last day of surface snowmelt runoff, minus mean base flow during the interval. The streamflow pretreatment calibration period extended from 1974 to 1983. The effect of snow fencing on water yield will be tested for statistical significance by covariance analysis when additional years

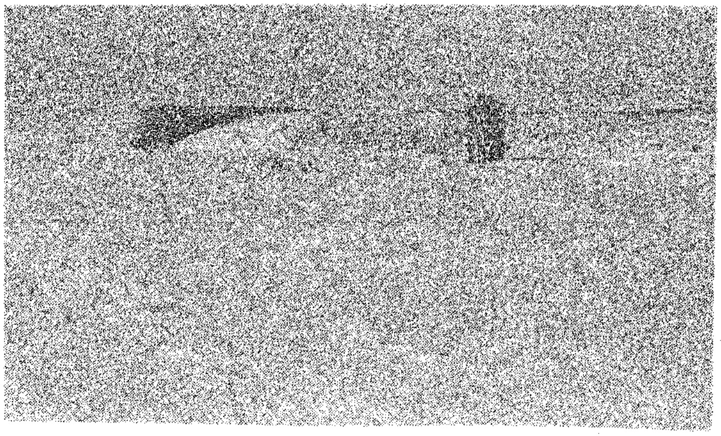

Figure 2. Upstream view on January 4, 1985 that shows the instrument tower of the streamgage, the 3.78-m-tall snow fence, and the drift developing behind the snow fence.

of posttreatment information are available. An estimate of treatment effect the first 2 years after fencing is available from the relative position of posttreatment data points and the 95% confidence belt about the pretreatment regression line.

Pretreatment regression relationships between North Draw and Loco Creek watersheds were also determined for snow deposition on index transects at the time of maximum accumulation and for the duration of snowmelt runoff.

RESULTS

Precipitation during the snow accumulation period the first year after fence installation (November 1, 1983-April 12, 1984) was the largest of any year in the study, and precipitation the second year (November 1, 1984-April 2, 1985) was slightly below average. Thus, study results are indicative of changes that occur in years with average or above-average precipitation. Precipitation from November 1 until the date of maximum snow accumulation was 35.9 and 21.7 cm, the first and second year after treatment, respectively. Average and median precipitation values for this interval were 23.9 and 25.3 cm.

Streamflow

The pretreatment regression relationship between Loco Creek and North Draw watersheds indicated snowmelt runoff on North Draw watershed in 1984 and 1985 should have been 1.05 cm and 0.66 cm, respectively, while actual discharge was 2.44 and 1.60 cm (Figure 3). The average increase in flow was 137% and both posttreatment values exceeded the upper 95% confidence interval about the pretreatment regression line.

The large volume of snow stored behind the fence should have minimal effect on maximum flow rates as the drift covers only a small portion of the entire watershed and water release from a large drift is limited by daily energy input. A quantitative analysis of the effect of fencing on discharge rates is not possible at this time because the drain pipe placed in the channel changed discharge characteristics in the early stages of runoff. The pipe provides an avenue for water movement under the snowpack that was absent prior to fencing and reduces the high discharge rates that occur at initiation of snowmelt in years with over-snow runoff. This phenomenon develops in intermittent channels when suddenly warming temperatures release large quantities of water from shallow upland snow (Sturges 1975a). It does not occur in drainages with perennial flow because melt water is immediately transported downstream after percolating through the snowpack.

The influence of the snow fence on flow duration is evident in Figure 4. Observed values in 1984 and 1985 exceeded the upper 95% confidence belt about the pretreatment relationship. Flow duration was extended 19 and 18 days in 1984 and 1985, respectively.

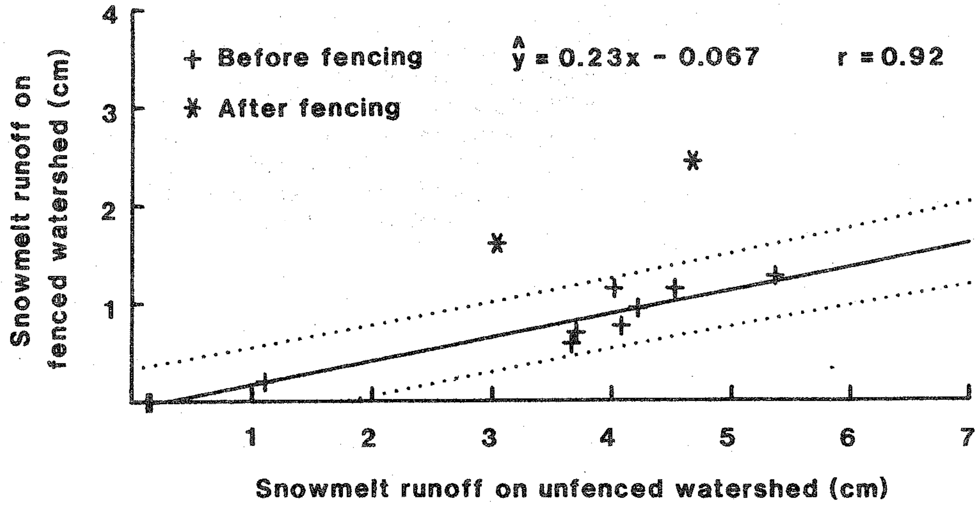

Figure 3. Yearly snowmelt discharge on the undisturbed watershed (Loco Creek) in relation to discharge on the fenced watershed. The pretreatment regression relationship is shown as a solid line and dotted lines indicate the 95% confidence interval.

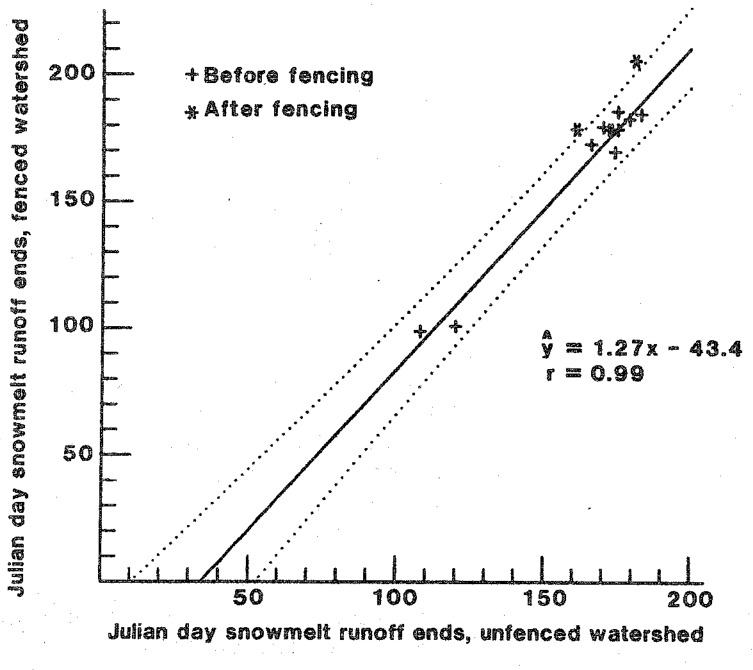

Figure 4. The last day of snowmelt runoff on the undisturbed watershed (Loco Creek) in relation to the last day of snowmelt runoff on the fence watershed. The pretreatment regression relationship is shown as a solid line and dotted lines indicate the 95% confidence interval.

Snow Accumulation

Snow accumulation in the fenced channel reach increased after fence installation, but the increase was not as large proportionately as the increase in streamflow. Figure 5 shows the pretreatment regression relationship between the cross-sectional area of snow drifts on Loco and Sane Creek watershed index transects and the cross-sectional area of the two North Draw index transects installed in 1968. The snow fence increased cross-sectional area of the drift 54% in 1984 and 62% in 1985, compared to predicted values without the fence. Maximum snow accumulation in these years was well above the 95% confidence interval about the pretreatment regression line.

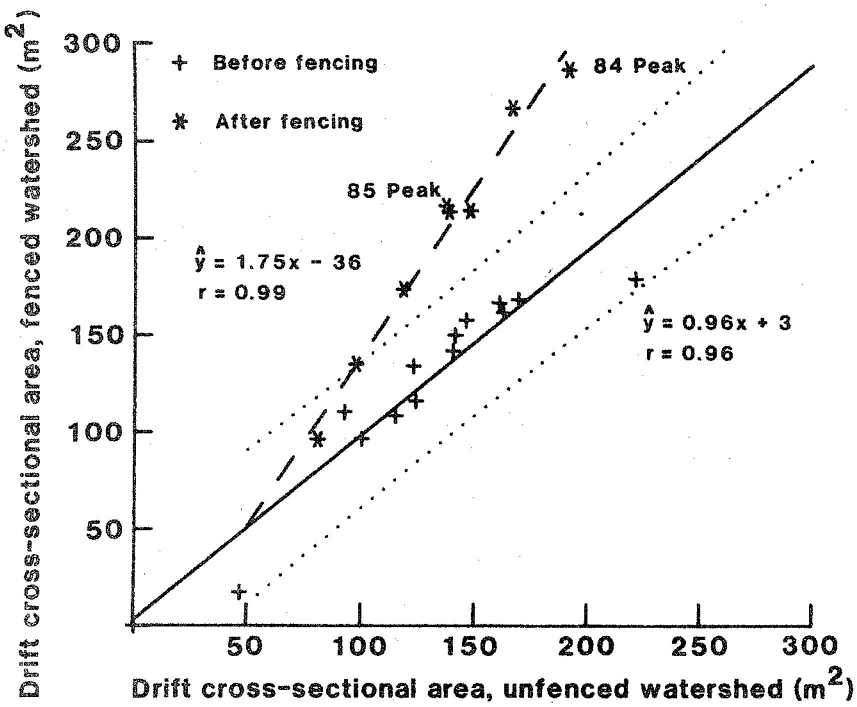

Figure 5. The relationship between cross-sectional area of snow deposited on index transects for unfenced (Loco and Sane Creek) watersheds and for the fenced watershed before (solid line) and after (broken line) construction of the snow fence. Dotted lines indicate the 95% confidence interval for the pretreatment regression. The relationships after fencing applies to drift areas greater than 50 m^2.

Data used to develop the pretreatment relationship in Figure 5 were collected annually at maximum accumulation. However, the relationship is probably indicative of snow accumulation through a single winter as well. Pretreatment data encompassed years with such low precipitation that there was no relocation of snow to years with heavy precipitation when most precipitation was redistributed by the wind.

The relationship between drift cross-sectional area on Loco and Sane Creek watersheds and the North Draw channel through the accumulation season in winters after treatment is also shown in Figure 5. The rate of snow deposition in the North Draw channel increased sharply after fence construction compared to pretreatment years, verifying that the unfenced channel was an inefficient trap for blowing snow. The regression coefficient for the pretreatment relationship was 0.96 (Figure 5) indicating that there was almost a 1 to 1 correspondence in snow deposition on Loco and Sane Creek transects compared to North Draw transects. The regression coefficient increased 82% after treatment to a value of 1.75, reflecting the increased efficiency with which blowing snow was deposited at the North Draw channel. The regression after fence construction was based on data collected after the storage capacity of sagebrush was satisfied which corresponded to a drift cross-sectional area of 50 m^2.

Trapping Efficiency of the North Draw Snow Fence

Snow retained on the fetch between the North Draw channel and the downwind snow fence was measured at monthly intervals in years after fence construction, as was the cross-sectional area of the snow drift cast by the downwind fence. This information plus information on interval precipitation was used to calculate a water balance for the drift at the downwind snow fence (Table 1). The water content of relocated snow arriving at the downwind fence was estimated with the relationship described by Sturges and Tabler (1981). If appreciable quantities of snow escaped the main fence, measured snow accumulation at the downwind fence would greatly exceed predicted storage. Water content of snow trapped by the downwind snow fence was about the same as predicted storage, evidence that little if any blowing snow escaped the main fence (Table 1).

Table 1. Measured and calculated water storage at the snow fence downwind from the North Draw channel.

		Cumulative	Water storage				
Winter	Msm date	precip. from 11/1	Calculated transport at fence*	Measured fetch storage	Calculated fence storage**	Measured fence storage	Difference (measured - calculated)
		cm	m^3/m				
1983-84	11/30	12.0	21.0	6.9	14.2	18.2	4.6
	01/05	19.2	33.9	2.3	31.5	31.2	-0.3
	02/02	21.6	37.6	2.0	35.6	35.3	-0.3
	03/08	26.1	47.7	2.1	45.5	44.2	-1.3
	04/12	35.9	64.9	4.3	60.6	59.6	-1.0
1984-85	11/30	3.8	5.9	1.1	4.8	4.7	-0.1
	01/03	9.8	16.0	3.4	12.6	14.6	2.0
	01/29	12.6	21.4	3.6	17.8	18.8	1.0
	03/06	17.1	29.6	0.4	29.2	25.5	-3.7

*Relocated precipitation minus in-transit evaporation plus precipitation falling directly on drift. Assumes all winter precipitation to date of measurement was relocated by the wind.

**Calculated transport minus water equivalent of snow retained on fetch.

Water-Yield Delivery Efficiency

Study measurements enabled the yield efficiency of snow stored in the North Draw channel to be determined. The water equivalent of snow stored in the channel and for a 50-m distance upwind from the snow fence was estimated from measurements taken on the seven snow courses established in 1978. Snowmelt discharge originating from this area was estimated by subtracting discharge originating above the snow-fenced portion of the watershed from total discharge. The overall water delivery efficiency for channel snow was 44% in 1984 and 42% in 1985.

Two prior studies measured evaporation losses from isolated drifts by placing an impervious membrane under the drift and comparing outflow with water equivalent of the drift prior to snowmelt. About 50% of initial water in the drift was lost by evaporation in a Montana study (Saulmon 1973), while evaporation accounted for 20% to 50% of initial drift water in a Wyoming study (Fletcher and Rechard 1976). Accepting a 50% evaporation loss from the North Draw drift, as suggested by these studies, indicates that water losses to soil recharge were about 7% of the initial drift water equivalent.

The ratio of the increase in streamflow to the increase in water equivalent of additional snow stored by the fence was calculated to determine the yield efficiency for additional snow. In 1984, 78% of this water was yielded as streamflow and 92% was yielded in 1985, considerably higher than the overall delivery efficiency for total channel snow. Direct evaporation from snow and from water flowing down the channel were the source of most water losses from the additional snow, because soil water recharge requirements were previously satisfied.

Sediment Movement

Annual deposition of bedload sediment in the North Draw stilling basin was so small that it was often within the accuracy of the rod and level survey, accounting for negative values in some years (Table 2). Fence installation had no discernible effect on sediment deposition. Deposition the year before and the year after fence installation (1983 and 1984, respectively) was the largest measured during the study. The deposition in 1983 was primarily associated with runoff triggered by intense summer rainfall. A suspended sediment concentration of 1,030 mg/liter was measured during this runoff event. Deposition in 1984 reflects soil disturbance the preceding year caused by construction activities at the upper streamgage and by opening sod in the channel to lay the drain pipe.

Bedload deposition at the North Draw stilling basin was much smaller than at Loco Creek, while deposition at Sane Creek was intermediate between North Draw and Loco Creek (Table 2). The perennial portion of Loco Creek extended about 1.6 km above the streamgage, but at Sane Creek the streamgage was located 45 m below the spring. Dense herbaceous vegetation growing in the North Draw channel helped filter sediment from water, as did herbaceous vegetation growing in the Sane Creek channel above the spring.

Suspended sediment levels in North Draw waters were very low. In pretreatment years, both median and average concentrations were 4-8 mg/liter and 4-10 mg/liter in years after fencing (Table 3). The higher suspended levels in 1984 reflect construction disturbances. The highest sediment level measured in snowmelt runoff water was 81 mg/liter in 1984. In 1985, sediment concentrations decreased to half those of 1984 as channel vegetation reestablished. There was a wide diurnal range in flow rates during snowmelt, but sediment concentrations in samples collected at 0600 in the morning and at 1800 in the evening were quite similar. In contrast, suspended sediment levels in Loco Creek water were often twice as great in the evening as in the morning during snowmelt (Sturges 1975b).

Average daily suspended sediment concentration in relation to daily streamflow before and after fencing is shown in Figure 6. The effect of over-the-snow flow is evident at the start of 1983 runoff when average daily discharge peaked at 44 liters/sec/km . Despite the high flow rates, sediment concentrations were only slightly elevated. The effect of fencing on streamflow is also evident in Figure 6. Flow in 1985 would have ended about 18 days sooner and seasonal snowmelt runoff would have been smaller than in 1983, if the snow fence had not been built.

Electrical Conductivity

Because only a limited number of electrical conductivity samples were collected each year, it was not possible to quantitatively evaluate the effect of fencing on this water quality parameter. Conductivity values were extremely low, ranging from about 150 to 760 micromhos/cm at 25°C, which indicates that flow originated from snowmelt surface

Table 2. Annual sediment deposition in Loco Creek, Sane Creek, and North Draw stilling basins.

Year	Loco Creek	Sane Creek	North Draw
	---- m^3/km^2 ----		
1974	1.29	0.16	0.08
1975	2.35	0.10	.00
1976	0.52	.05	-.03
1977	.13	.54	.03
1978	.49	.23	-.05
1979	1.32	.18	.05
1980	1.46	.05	-.08
1981	.31	.00	.03
1982	.97	.13	-.03
1983	.75	.26	.10
1984	1.15	.13	.10
1985	.28	.13	.05

runoff. Samples with conductivities greater than 500 micromhos/cm were collected in the last stages of runoff. Approximately 40% of the samples collected in years before and after fencing had conductivities between 300 and 400 micromhos/cm at 25°C. The calculated total dissolved solid load for water with a conductivity of 350 micromhos/cm is about 200 mg/liter using the generalized relationship cited by Hem (1970). The dissolved solid load of Loco Creek water was much greater than North Draw water. When flow originated from groundwater discharge, conductivity was about 2,500 micromhos/cm; it decreased to about 1,600 micromhos/cm during snowmelt runoff.

CONCLUSIONS

Treatment of North Draw watershed with a 3.78-m-tall snow fence increased snow accumulation, total snowmelt discharge, and the length of the flow period the first 2 years after fence installation. A complete assessment of average treatment effect must await collection of additional years of data. No apparent change in sediment movement occurred as a result of increased flow volumes. Water carried negligible suspended and dissolved solid loads in years before and after fence installation; transport of sediment as bedload was also negligible. The success of fencing resulted from use of scientific criteria to design the treatment, placement of additional snow over that deposited naturally in the channel to maximize water delivery efficiency, and to a favorable geologic setting that directed snowmelt water down the surface drainage network rather than allowing water to percolate vertically into bedrock.

The blowing snow resource has the potential to provide water for livestock, wildlife, and domestic uses on a local basis; augment surface flow in perennial or ephemeral streams; and even to recharge a groundwater aquifier. It may also be possible to improve the quality of water with an excessive concentration of dissolved solids by dilution with snowmelt water from induced snowdrifts.

Table 3. The number of suspended sediment samples collected each year, and the range, median, and average value of yearly sediment concentrations.

SAMPLES COLLECTED MANUALLY BEFORE FENCING

Year	No. samples	Range Low	Range High	Median	Avg.
		- - - - - - mg/liter - - - - - -			
1976	8	1	15	5	7
1977		No flow			
1978	9	2	27	6	9
1979	16	0	15	5	5
1980	15	1	7	4	4
1981		No flow			
1982	14	2	19	8	8

SAMPLES COLLECTED AUTOMATICALLY

		Time of collection							
		0600				1800			
Year	No. samples	Low	High	Median	Avg.	Low	High	Median	Avg.
		- - - - - - - - mg/liter - - - - - - - -							
		Before fencing							
1983	60	2	38	4	6	2	38	5	6
		After fencing							
1984	74	1	34	4	6	2	72	7	10
1985	79	1	6	3	3	2	14	4	5

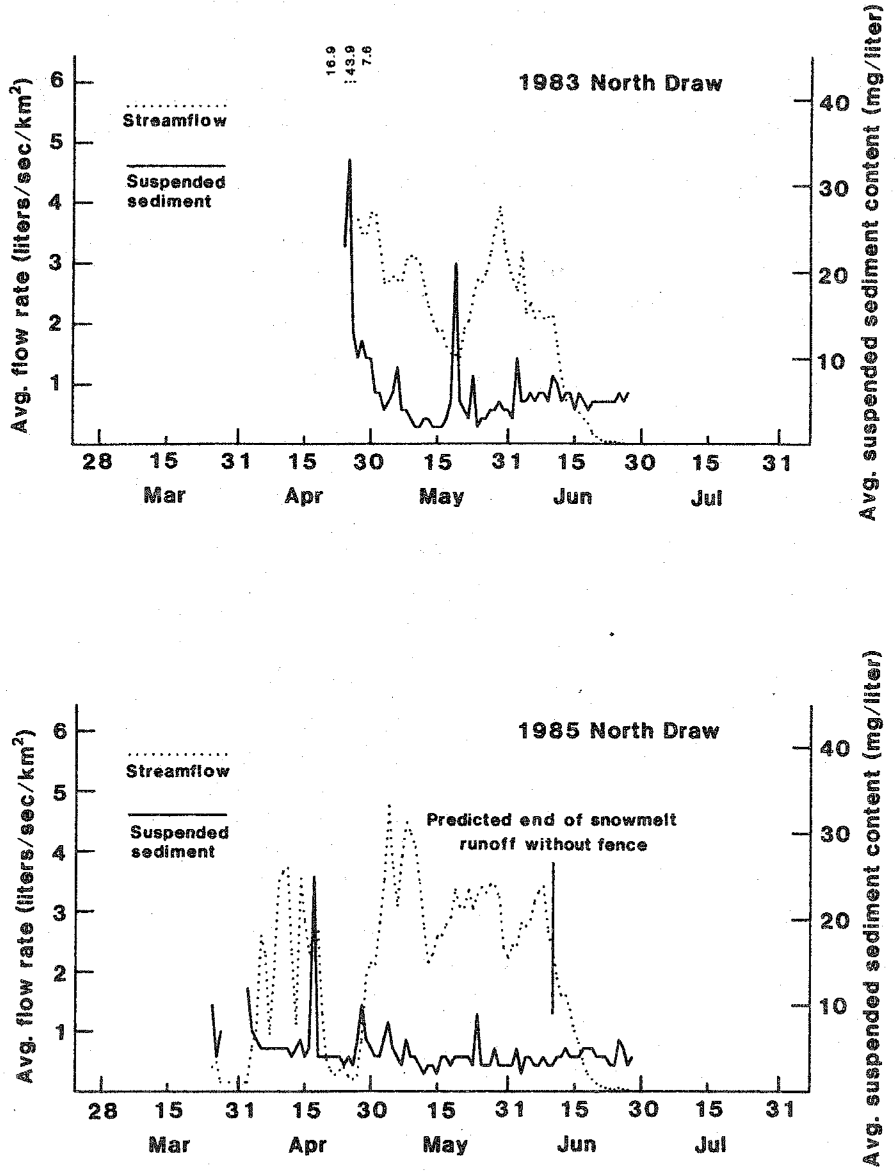

Figure 6. Average daily snowmelt discharge and average daily suspended sediment concentration for North Draw watershed the year before snow fence installation (upper), and the second year after fence installation (lower). Printed numbers on the upper figure are discharge values (liters/sec/km^2) for the first 3 days of runoff when there was over-the-snow flow.

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