EVAPORATION AND SEEPAGE FROM A LIVESTOCK RESERVOIR EQUIPPED WITH A SNOW FENCE FOR WATER RECHARGE

By

David L. Sturges[1/]

INTRODUCTION

Interest in utilizing the water in blowing snow continues to expand as the magnitude of the resource is more fully appreciated. Capturing blowing snow to provide water for small livestock reservoirs on western rangelands is one promising application of snow management, because water availability often limits proper forage utilization. The absence of groundwater or excessive drilling costs prevent use of wells in some locations. Reservoirs that depend upon surface runoff may not always fill, or fill in the wrong season to meet livestock needs. Snow fences effectively trap blowing snow and have a life expectancy of 25 or more years.

The purpose of this study was to compare evaporation and seepage losses at two small livestock reservoirs equipped with snow fences. The study was prompted by the author's experience that, though snow fences may deposit large large quantities of snow in a reservoir, the reservoir is often dry by the time water is needed for livestock use. Thus, even though the snow accumulation effort was successful, the objective of providing water for livestock use was not met.

LITERATURE REVIEW

The method to estimate the quantity of blowing snow arriving at a location presented by Tabler and Sturges (1986) provides the basis for scientific management of the blowing snow resource. Key parameters in the relationship are the upwind distance (fetch) contributing snow to a project site, snow retention characteristics of vegetation and terrain on the fetch zone, and precipitation received during the time snow is subject to relocation. The transport relationship was first utilized on a large scale to design snow fence protection for a 100-km section of Interstate Highway 80 in Wyoming. Snow fences were effective in reducing traffic accidents and winter maintenance expenditures (Tabler and Furnish 1982).

Snow drift characteristics for vertical-slat Canadian snow fences and Wyoming snow fences are well described (Tabler 1980). The Wyoming snow fence consists of horizontal boards 15 cm wide separated by a 15-cm space; a gap is left at the bottom of the fence equal to about 10% of fence height. The Wyoming fence can be built in heights ranging from 1.8 m to 4.2 m. Snow storage costs expressed on a unit volume basis decrease as fence height increases. Thus, use of a single tall fence with sufficient storage capacity to store seasonal snow transport is preferred over use of multiple rows of shorter fences (Tabler 1974).

Several strategies to utilize the blowing snow resource have been employed for rangeland water development projects. Sagebrush was mowed at one site to allow the wind to transport snow over a ridge where it deposited in a natural catchment (Sturges and Tabler 1981). Although a ditch was cut below the catchment to transport snowmelt water to a reservoir, melt water was absorbed by the soil before it reached the reservoir.

At a second project, estimates of snow transport were used to design a test panel of snow fence that deposited snow along a stream channel above an irrigation reservoir (Sturges and Tabler 1981). The fence was so successful that the rancher felt snow fencing would be a cost-effective method to increase reservoir inflow.

The nature of soil and parent material is a key factor in the success or failure of snow management projects. A snow fence 396 m long and 3.8 m tall built to increase water

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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.

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yield doubled snow deposition in the channel above a streamgage, but melt water failed to reach the gage site (Tabler and Sturges 1986). Soil was extremely permeable and was underlain by deeply fractured granite. Conversely, water yield more than doubled as a result of snow fencing in another watershed study where soil and parent material promoted surface channel flow (Tabler and Sturges 1986).

Information about the proportion of drift water that can be recovered for beneficial use is limited. Based on outflow measurements from isolated snow fence drifts, Fletcher and Rechard (1976) found that 20 to 50% of water in a drift at the start of ablation was lost to evaporation in a Wyoming study, and Saulmon (1973) measured evaporation losses of 50% in a Montana study. A rule of thumb states that about half of a drift evaporates, an additional 20% of water is lost to soil recharge and deep percolation, leaving about a third of the water available for beneficial use (Sturges and Tabler 1981). However, about 85% of water in the additional snow deposited by the snow fence in the successful watershed study was yielded as streamflow the first 2 years after fence installation (Tabler and Sturges 1986).

The information cited above suggests that the percentage of water that can be recovered from snow drifts is highly site specific. It is obvious that placing the drift as close as possible to the water use site increases the probability that snow management projects will be successful.

STUDY LOCATION

The study was conducted at a small livestock reservoir on the east and west side of the Medicine Bow Mountain Range in south central Wyoming. The site west of the Range, termed North Spring Creek Reservoir, is on sagebrush rangeland about 13 km west of Saratoga at an elevation of 2,260 m. The reservoir, 3,090 m^2 in size with a capacity of 2,450 m^3 of water, was built to collect surface runoff (Fig. 1). Maximum water depth is 1.98 m. In 1986, a Wyoming snow fence 2.7 m tall and 48.8 m long was installed 6.1 m upwind of the pond. A uniform fetch 1.6 km in length slopes gently towards the fence. The fetch is vegetated by a mixture of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and black sagebrush (*A. nova*) about 15 cm in height. Soils developed from sandstone parent material and have a loam texture in the A horizon.

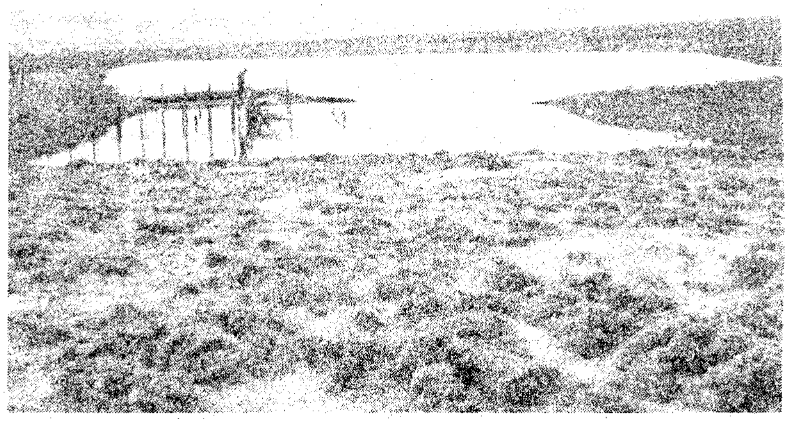

Figure 1. The Wyoming snow fence at North Spring Creek Reservoir was 48.8 m long and 2.7 m tall.

The reservoir lies within a grazing allotment administered by the Bureau of Land Management, and is used by cattle for about a month in early spring. The reservoir was constructed at least 20 years ago by placing an earthen dam across a drainage channel, and the pond was excavated to increase storage capacity. The rancher had to haul water to a tank at the site in most years because the reservoir was dry.

Climatological data for North Spring Creek Reservoir was collected at the Stratton Sagebrush Hydrology Study Area, which is 150 m higher in elevation and 19 km west of the reservoir. The Stratton location receives 50 cm of precipitation annually, and 40% falls between November and March, when drifting is likely. Average monthly wind speeds reach a maximum in January at 8 m/s and exceed 5 m/s from November through March. Average precipitation between November and March at the reservoir site was estimated to be 15 cm.

The second reservoir was located east of the Medicine Bow Mountains on the S and S Ranch. The Sims reservoir, 15.6 km southwest of Rock River at an elevation of 2,230 m, has a surface area of 1,600 m^2 and a capacity of 1,300 m^3; maximum water depth is 1.6 m (Fig. 2). An unobstructed fetch extends only about 120 m upwind to a ravine that stores large quantities of snow. Short-grass prairie vegetation is present on the fetch. June grass (Koeleria macrantha), blue grama (Bouteloua gracilis), and western wheatgrass (Agropyron smithii) are important species. The soil developed in residuum derived dominantly from shale, and has a sandy loam texture in the A horizon.

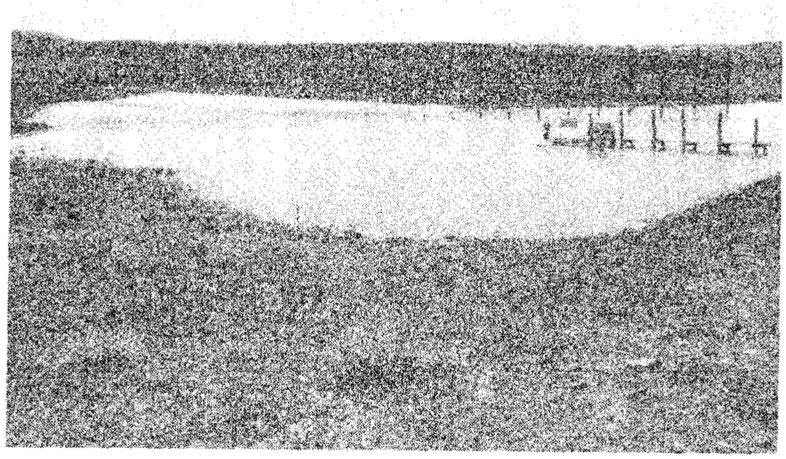

Figure 2. The snow fence at Sims Reservoir was 57 m long and 2.7 m tall, and was comprised of two rows of Canadian snow fence.

Weather records are available from a research site 13.5 km southwest of Sims Reservoir and 130 m higher in elevation. At this location, annual precipitation is about 60 cm; 25.5 cm of the total falls during the drifting season from November through March. Average monthly wind speeds during this period range from 7.3 to 8.6 m/s. Precipitation at the reservoir was estimated to be 15 cm during the drifting season.

The reservoir was constructed in 1981 when a small, abandoned underground coal mine was rehabilitated. Procedures involved plugging the mine shaft, terrain shaping, and reseeding. The reservoir was created by constructing an earthen dam across an intermittent drainage channel immediately below the mine site.

The ranch owner felt that a snow fence would provide a source of water for the pond which otherwise would be dry in most years. The fence, located about 7 m upwind of the pond, was constructed in 1984 utilizing second-hand materials. It is 57 m long and 2.7 m tall and is formed by two rows of 1.2 m vertical-slat Canadian snow fence wired to planks nailed on telephone poles. The bottom of the fence was raised 25 cm above the ground surface.

STUDY METHODS

The study was conducted during the 1988 snowmelt season utilizing identical methodology at both reservoirs. Measurements began in April after snowmelt was underway and ended with termination of pan evaporation measurements on July 6, at North Spring Creek Reservoir and on July 14, at Sims Reservoir. The ponds had been dry for some time before terminating evaporation measurements. There was no surface inflow to either reservoir during the study. Water inputs were from precipitation and snowmelt coming from the snow fence drift, while losses were from evaporation and seepage. Cattle also consumed water from Sims Reservoir during part of the study.

Seepage volume between two measurement dates was calculated as snowmelt inflow plus the decrease in pond storage, less net evaporation and water consumption by cattle. Average daily seepage expressed as cubic meters of water per square meter of pond area was calculated for each measurement period. Calculations were based on the number of days in the interval that the pond contained an appreciable volume of water. The water surface was below the water level recorder during a portion of four of the seven measurement periods at the North Spring Creek Reservoir, while Sims Reservoir contained water throughout the study. Daily seepage was also estimated on days without precipitation utilizing information about daily snowmelt, evaporation, cattle water consumption, and the change in pond storage.

Net evaporation included precipitation input and evaporation loss measured by an evaporation pan. Net evaporation from the pond and snow surface was estimated by multiplying the average pond and snow drift area in a measurement interval by net pan evaporation.

A continuous record of water level in each reservoir and evaporation pan was obtained using water level recorders. The pan was 1.22 m in diameter of the type used by the U.S. Weather Bureau and floated in the reservoir. The pan was placed in a wooden framework that contained a 1.2-m x 1.2-m x 5-cm sheet of styrofoam to provide floatation. Styrofoam outriggers were attached at each corner of the framework to prevent tipping. A band of styrofoam circled the pan to prevent water ripples from breaking into the pan. The splash guards proved unnecessary as waves never became large enough to overtop the rim. The rim extended about 8 cm above the water surface and the pan was filled with water from the pond to the same level as in the pond. The evaporation pan was loosely tethered between two posts so that it could rise and fall with changes in water level. The pan was located about a meter from the pond water level recorder.

The volume of water in the pond and the snowdrift was usually estimated at weekly intervals from a rod and level survey that referenced elevation to a permanent bench mark. Eight transects gridded the North Spring Creek Reservoir, and 10 transects gridded the Sims Reservoir. Ground elevation was measured at 3-m intervals along each transect in November 1987 when the ponds were dry. Snow elevation measurements coincided with location of ground elevation measurement points. Each measurement point represented a rectangular area that extended half way to adjacent measurement points on the transect and half way to adjacent transects. The elevation of the ground surface at each measurement point was subtracted from the elevation of the snow or water surface to determine the depth of snow and water.

Snow was assumed to contain 60% water as Tabler (1985) found for large snow fence drifts actively melting. Earlier studies also support the assumption of a 60% water content for melting snow (Fisher 1968; Rechard and Raffelson 1974; Bartos and Rechard 1974). The first 3 cm of snow above the water surface were assumed to be entirely water because water rises this distance by capillary action (Wankiewicz 1978). This assumption neglects the density of granular ice crystals in melting snow (about 920 kg/m^3). It was also assumed that condensation onto the snow surface was negligible in relation to other study variables. Atmospheric water content is low on Wyoming rangeland, and nighttime temperatures were above freezing during most of the study which limited the incidence of condensation.

A degree-day factor (calculated as the sum of maximum and minimum daily air temperature divided by two) was used to estimate the volume of water released each day by snowmelt. Each degree-day above 0^oC melts approximately 1 cm of snow (Tabler 1985) which in turn releases 0.6 cm of water per cm of snow depth. Calculated daily snowmelt volumes were adjusted to the volume of interval snowmelt as determined from the change in water content of the snow pack between two measurement dates. Average daily temperatures were estimated from offsite locations.

An unshielded recording precipitation gage and nonrecording pit gage (Johnson 1974) were also operated at each study site. Data from the recording gage was corrected to precipitation measured by the pit gage except for intervals when drifting snow rendered pit gage data useless.

Two bulls and 29 cows and calves watered from Sims Reservoir. Stock was placed in the pasture on May 18. There was another source of water in the pasture until mid-June which limited water usage from the reservoir at the beginning of the grazing season. Water consumption by cattle was estimated from information given by Fox and Olson (undated) which relates water intake by animals of differing age and sex classes to average daily temperature.

RESULTS

Interval Seepage Rates

North Spring Creek Reservoir--The reservoir filled with snowmelt runoff from shallow upland snow in late March before the snow fence drift had begun to melt. Approximately 50% of water in the pond had already drained when study measurements began April 13. Water elevation fell 0.8 m in the first week of the study; thereafter the water surface remained near the bottom of the pond and fluctuated within a range of 0.25 m. There was sufficient water in the pond to float the evaporation pan in just the first week of study. Thus, at this location evaporation pan measurements were similar to those at a standard meteorological station where the evaporation pan rests on a platform slightly elevated above the ground surface. The drift finished melting on May 28.

Water balance components at the North Spring Creek Reservoir are tabulated in Table 1 for each measurement interval. The volume of water lost through seepage greatly exceeded water losses from net evaportion in all measurement periods. For the entire study interval, net evaporation from the pond and snow surface amounted to about 14% of water released by snowmelt. The drift released 1956 m^3 of water, but none of this water was available for livestock consumption even though the grazing season began a few days after snowmelt ended.

Average seepage rates within measurement intervals were highly variable, and ranged from 0.06 to 0.58 m^3 of water per m^2 of water surface per day. No trends in seepage rates were evident. The highest rates were found between April 22 and May 12 when the pond was intermittently dry, which may have allowed surface cracks in the reservoir to reopen.

Sims Reservoir--This reservoir also filled with water in late March; thereafter water overflowed from the pond until April 22, when about half of the drift had melted. Snowmelt was completed May 18. Sufficient water remained in the pond to float the evaporation pan until the middle of June; on June 29, water receded below the water level recorder.

The primary source of water loss from Sims Reservoir, as at North Spring Creek Reservoir, was seepage but rates were lower at Sims Reservoir (Table 1). During the time this pond remained relatively full because of snowmelt input, daily seepage was about 0.03 m^3/m^2 of pond area, but seepage gradually decreased to less than 0.01 m^3/m^2 of pond area as the pond decreased in size. Net evaporation exceeded seepage in late June. Net evaporation from the pond and snow surface was 20% of snowmelt volume for the entire study interval (4/20-6/29). Water consumption by cattle was about 5% of water released by snowmelt.

Table 1. Interval change in pond storage, snowmelt, seepage, and cattle water consumption and seepage rates for the North Spring Creek and Sims Reservoirs.

Interval	Pond area	Decrease pond storage	Snowmelt	Cattle consumption	Net evaporation	Seepage	No. days pond held water	Average daily — Seepage —		Average daily — Net evap. —	
	m^2	m^3						m^3	m^3/m^2	m^3	m^3/m^2
					North Spring Creek Reservoir						
4/13-4/22	1162.8	1114.2	478.8	0	80.4	1512.6	9	168.1	0.450	8.9	0.008
4/22-4/27	397.4	85.1	158.6	0	11.6	232.1	1*	232.1	.584	11.6	.029
4/27-5/5	295.7	+27.8	492.2	0	87.8	376.6	3*	125.5	.424	29.3	.099
5/5-5/12	420.0	+28.6	252.8	0	31.0	193.2	3*	64.4	.153	10.3	.025
5/12-5/19	557.1	+59.6	360.8	0	27.4	273.8	7	39.1	.070	3.9	.007
5/19-5/24	577.6	45.8	139.4	0	13.6	171.6	5	34.3	.059	2.7	.005
5/24-6/1	377.2	71.6	73.1	0	23.6	121.2	3*	40.4	.107	7.9	.021
Total		1200.7	1955.7	0	275.4	2881.1					
					Sims Reservoir						
4/20-4/27	1577.4	81.8	249.7	0	8.3	323.2**	7	46.2**	.029**	1.2	.001
4/27-5/6	1543.1	61.1	375.1	0	23.5	412.7	9	45.9	.030	2.6	.002
5/6-5/13	1477.6	171.3	232.3	0	24.5	379.1	7	54.2	.037	3.5	.002
5/13-5/24	1258.9	414.1	74.6	0	10.8	477.9	11	43.4	.034	1.0	.001
5/24-6/2	941.6	236.2	0	2.2	55.6	178.4	9	19.8	.021	6.2	.007
6/2-6/8	698.8	109.7	0	3.7	30.0	75.9	6	12.7	.018	5.0	.007
6/8-6/15	555.4	66.3	0	7.6	17.2	41.4	7	5.9	.011	2.5	.004
6/15-6/22	451.7	63.3	0	16.3	Missing	Missing	7	Missing	Missing	Missing	Missing
6/22-6/28	328.3	44.1	0	17.8	19.4	6.9	6	1.2	.004	3.2	.010
Total		1247.9	931.7	47.6	189.3	1895.5					

* Water level below recorder for part of interval

**Total includes a small amount of spillage from reservoir

Comparative Daily Seepage and Evaporation Losses

Daily water losses attributable to seepage and evaporation on days without precipitation at North Spring Creek and Sims Reservoirs are shown by Figures 3 and 4, respectively. Data emphasizes the magnitude of seepage in relation to evaporation, particularly at the North Spring Creek site. Seepage rates were highest when the pond was refilling following drainage of water that initially filled the reservoir. Seepage exceeded 20 cm on 8 days and was between 10 and 20 cm on 7 days. In contrast, maximum daily pan evaporation was 1.3 cm. Pan evaporation averaged 0.5 cm on days without precipitation in April and May and 0.8 cm in June and July (Table 2).

Table 2. Daily average and maximum pan evaporation each month on those days without precipitation, North Spring Creek and Sims Reservoirs.

Month	Monthly record period	No. days	Pan evap. Max.	Pan evap. Avg.
			cm	
	North Spring Creek Reservoir			
April	15-30	13	1.3	0.5
May	1-31	22	.9	.5
June	1-30	24	1.3	.8
July	1-5	4	.8	.8
	Sims Reservoir			
April	21-30	7	.5	.3
May	1-31	20	1.1	.5
June	1-30	16	1.4	.8
July	1-13	8	1.1	.9

Maximum daily seepage at Sims Reservoir was 6.6 cm/day. Average evaporation on days without precipitation in April, May, June, and July was 0.3, 0.5, and 0.8, and 0.9 cm, respectively (Table 2). Evaporation exceeded seepage during the last 5 days of study when only a little water remained in the pond (Fig. 4). The decrease in pond area was relatively constant from the end of snow melt until early in June when an appreciable slowing of pond surface shrinkage became evident. The depth of water in the pond driving seepage decreased through the study, but because of the shallow nature of the pond, changes in water depth were not large. The reduction in the rate of pond shrinkage primarily reflected a lower permeability coefficient for material in the bottom of the reservoir compared to the permeability coefficient for material in the upper reaches.

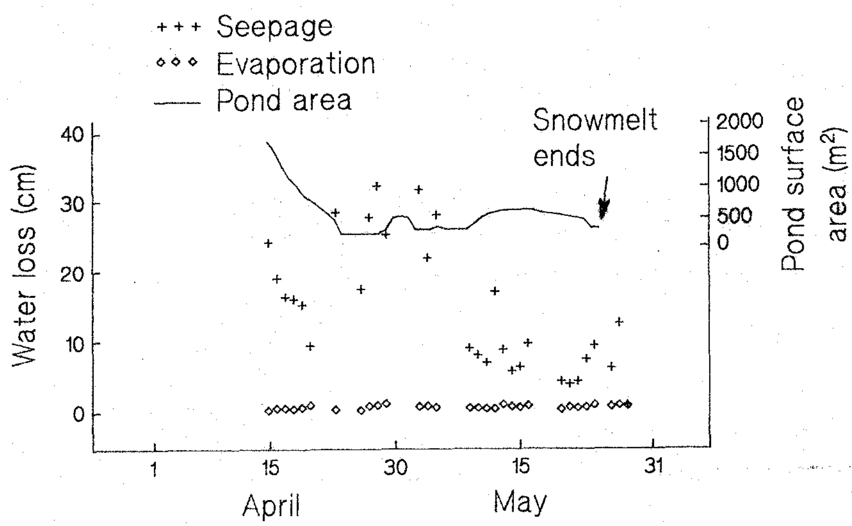

Figure 3. Seepage and evaporation at North Spring Creek Reservoir on days without precipitation. The reservoir became dry as soon as the snow drift finished melting.

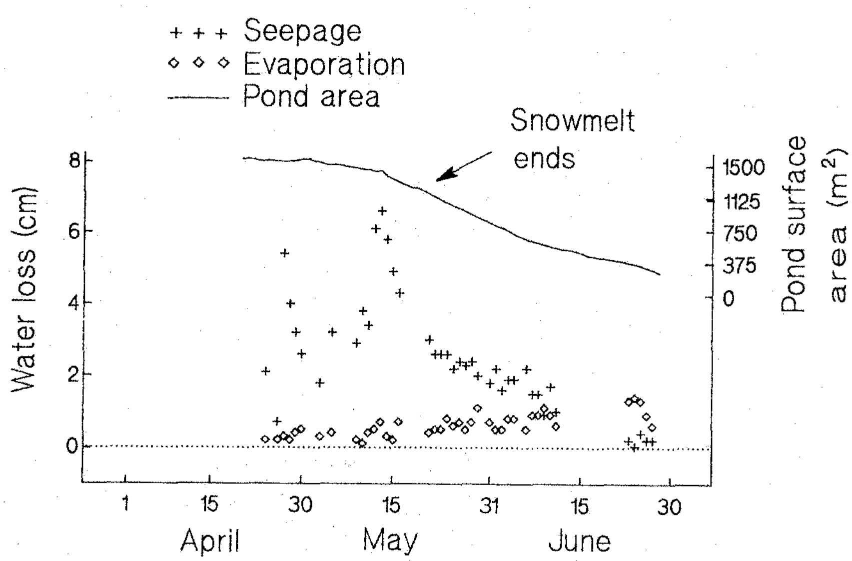

Figure 4. Seepage and evaporation at Sims Reservoir on days without precipitation. The reservoir held water for about 6 weeks after the snow drift melted.

Water Quality

Suspended solid levels in water at North Spring Creek Reservoir were less than 30 mg/l except for the last sample taken June 1, when the pond was almost dry (Table 3). Suspended solid content of water at the Sims Reservoir was comparable to that of North Spring Creek Reservoir while snow was melting and before cattle began drinking from the pond. Sediment levels increased sharply once cattle began to use the Sims pond, and exceeded 400 mg/l on the last sample date. The diminishing size of the reservoir combined with animals wading in the water elevated sediment content. The water was light brown at this time and appeared extremely muddy.

The specific electrical conductance of water can be used to estimate total dissolved solids (Hem 1985). Specific conductance of water in North Spring Creek Reservoir was very low and ranged from 16 to 51 µS/cm (Table 3). Calculated dissolved solid loads were 9 to 28 mg/l. Water at the Sims Reservoir also had a low specific electrical conductance during snowmelt, but conductance increased as evaporation and seepage gradually reduced water volume. Specific conductance was 328 µS/cm on the last measurement date (July 8), corresponding to a dissolved solid load of 180 mg/l.

Table 3. Suspended sediment, specific electrical conductance, and dissolved solid content of water from the North Spring Creek and Sim Reservoirs.

Date	Suspended sediment	Specific conductance	Calculated dissolved solids
	mg/l	µS/cm	mg/l
		North Spring Creek Reservoir	
4/22	6	23	13
4/27	4	24	13
5/5	29	22	12
5/12	15	21	12
5/19	—	16	9
5/24	9	19	10
6/1	60	51	28
		Sims Reservoir	
4/20	—	20	11
4/27	19	26	14
5/6	9	21	12
5/13	30	24	13
5/25	68	33	18
6/2	189	57	31
6/9	104	108	59
6/15	246	132	73
6/22	285	205	113
7/8	412	328	180

DISCUSSION

Actual and Estimated Snowmelt

The sum of daily snowmelt volumes estimated with the degree-day relationship at North Spring Creek Reservoir was usually close to interval snowmelt determined from weekly drift measurements. Calculated seasonal snowmelt was 8% less than measured snowmelt. Snowmelt was consistently undermeasured at the Sims location, indicating that air temperature at the reservoir was probably warmer than at the offsite location where temperature data were collected. The discrepancy between measured and calculated snowmelt was greatest in the first measurement interval, when estimates indicated there was snowmelt on only 4 of the 7 days in the interval. Calculated seasonal snowmelt was 30% less than measured snowmelt.

Effectiveness of Additional Water

The study clearly indicated that simply increasing water input to small livestock reservoirs will not necessarily provide a source of drinking water during the grazing season. Seepage essentially equaled the snowmelt rate at North Spring Creek Reservoir. Seepage rates were generally an order of magnitude less at Sims Reservoir. The pond retained water through June, about 6 weeks after snowmelt was complete. Because it was located in a pasture utilized early in the grazing season, some water was provided to livestock. However, the Sims Reservoir would not have retained water long enough to be of value for grazing in midsummer or fall.

Most soil material has poor drainage characteristics (Terzaghi and Peck 1948). The coefficient of permeability for material in the poor category ranges between 0.001 and 0.086 m/day. Rates measured at the Sims location fell within this span. The lower seepage rates measured at North Spring Creek Reservoir also fell within the poor category, but higher rates were in the good drainage category. Reservoirs must have a permeability coefficient at the lower end of the poor category to retain water for an appreciable length of time. Ideally, the permeability coefficient should fall within the practically impervious drainage category (≤ 0.001 m/day).

Cumulative water losses over a range of permeability values are plotted as a function of time in Figure 5. Also shown on the figure is cumulative water loss for an evaporation rate of 0.007 m/day which is representative of daily losses in this study and similar to average daily evaporation measured by Hanson (1989) on sagebrush rangeland in Idaho. Water losses by seepage would be 15 m for a 150-day time period if the coefficient of permeability was 0.1 m/day, but only 0.15 m if permeability was 0.001 m/day. At the seepage rate of 0.03 m/day that prevailed at Sims Reservoir for much of the study, 4.5 m of water would be lost after 150 days. Precipitation input would need to be subtracted from water loss figures in Figure 5 to estimate actual water loss over an interval of time.

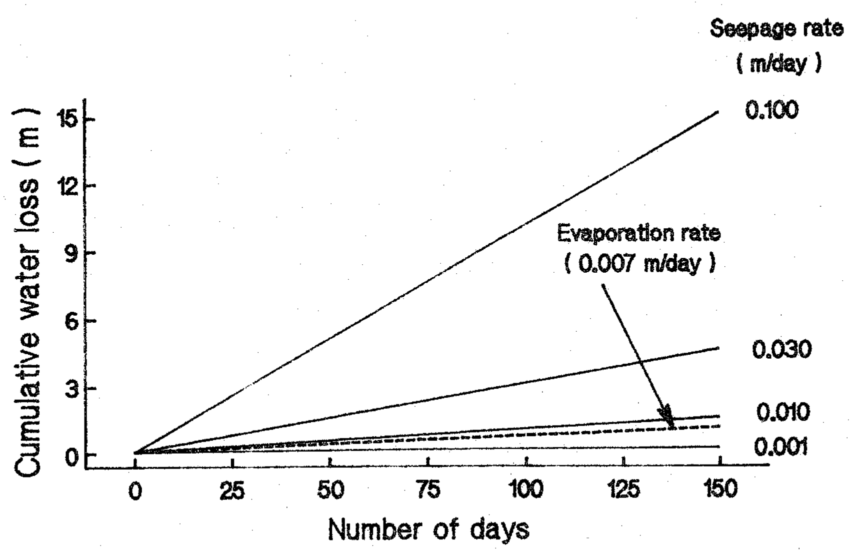

Figure 5. Cumulative water losses under four seepage regimes compared to cumulative evaporation losses based on a representative daily rate at the two study sites.

Seepage and evaporation data in Figure 5 also provide a way to estimate the length of time a reservoir will contain water, or to estimate the minimum depth of water a reservoir must have to contain water on a future date. As an example, assume a reservoir has a seepage rate of 0.03 m/day, evaporation is 0.007 m/day, and precipitation input is neglected. After 100 days, 3.7 m of water will have been lost. Thus, water must exceed 3.7 m in depth if the reservoir is to retain water after 100 days. Maximum water depths at the North Spring Creek and Sims Reservoir were 2.0 and 1.6 m, respectively. Reservoirs similar to these, cannot be expected to retain water for 100 days given their seepage rates.

Because snowmelt water carries a very low dissolved solid load, another application of snow management would be to dilute salt concentrations in brackish water. The highest dissolved solid level measured at the Sims Reservoir (Table 3) was well below the 500 mg/l level established by the Environmental Protection Agency as a reasonable goal for public water supplies (Office of the Federal Register 1980). Universal dissolved solid standards for water used by livestock have not been established. In Wyoming, the State Department of Agriculture recommends that water contain no more than 1,000 mg/l total dissolved solids, although levels as high as 5,000 mg/l usually are well-tolerated by livestock.

Data from the Sims Reservoir illustrate how livestock can increase the suspended solid content of water (Table 3). Water in the pond became progressively murkier as water volume shrank and bottom sediments were stirred up by cattle as they drank and waded in the pond. Fecal and urinary deposits further degraded water quality. Fencing reservoirs will eliminate livestock contact with water, but will require that water be piped to an offsite trough or tank. A side benefit from fencing would be to improve wildlife habitat values at the reservoir. The removal of grazing would allow vegetation to develop around the perimeter of the pond, particularly if water persisted through the growing season.

Reducing Seepage

The snow fence at each study location provided a large volume of water to the reservoir, but seepage limited the time the pond retained water. High priority should be given to minimizing seepage when constructing a new reservoir. A detailed site investigation of surface and subsurface soil and geologic conditions will help eliminate reservoir sites that cannot retain water.

Preventative measures to reduce seepage rest upon a knowledge of the composition of materials making up the bottom and sides of the reservoir. The least expensive method of sealing a pond is soil compaction, but the technique is successful only when a wide range of particle sizes are present. The compacted layer should be at least 20 cm thick if water will be less than 3 m deep and proportionately thicker as the depth of water impoundment increases (U.S. Dep. of Agric. 1982). Clay blankets, bentonite, and chemical additives such as sodium polyphosphates are effective for certain types of soil materials, but each treatment is progressively more expensive. A waterproof lining is the most expensive treatment to reduce seepage, but may be necessary in situations where soil or site conditions limit the effectiveness of other treatments.

Rehabilitation of existing reservoirs with excessive seepage involves the same engineering concepts used to minimize seepage from new reservoirs. Detailed soil analysis of bottom and bank material will provide a basis for prescribing remedial measures. Ponds that dry intermittently are especially difficult to seal. The use of a clay blanket or bentonite as a sealing agent is normally not recommended for ponds with a widely fluctuating water level or for ponds that become seasonally dry (U.S. Dep. of Agric. 1982). Clay particles swell when moistened to provide the sealing action, but return to their original volume upon drying. The resulting cracks can serve as conduits for water transmission until clay particles again expand after being moistened.

Rodent burrowing is often a serious problem around rangeland reservoirs. The holes dug by groundsquirrels, prairie dogs, and badgers, as well as by smaller burrowing rodents, can rupture a waterproof liner or breech clay blankets and compacted soil layers. The repeated wetting and drying cycles of intermittent ponds also gradually lessen the effectiveness of barrier layers. Thus, on rangelands, periodic retreatment of reservoirs may be necessary to maintain seepage at tolerable levels.

Acknowledgement

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