EDITORS FILE COPY

United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

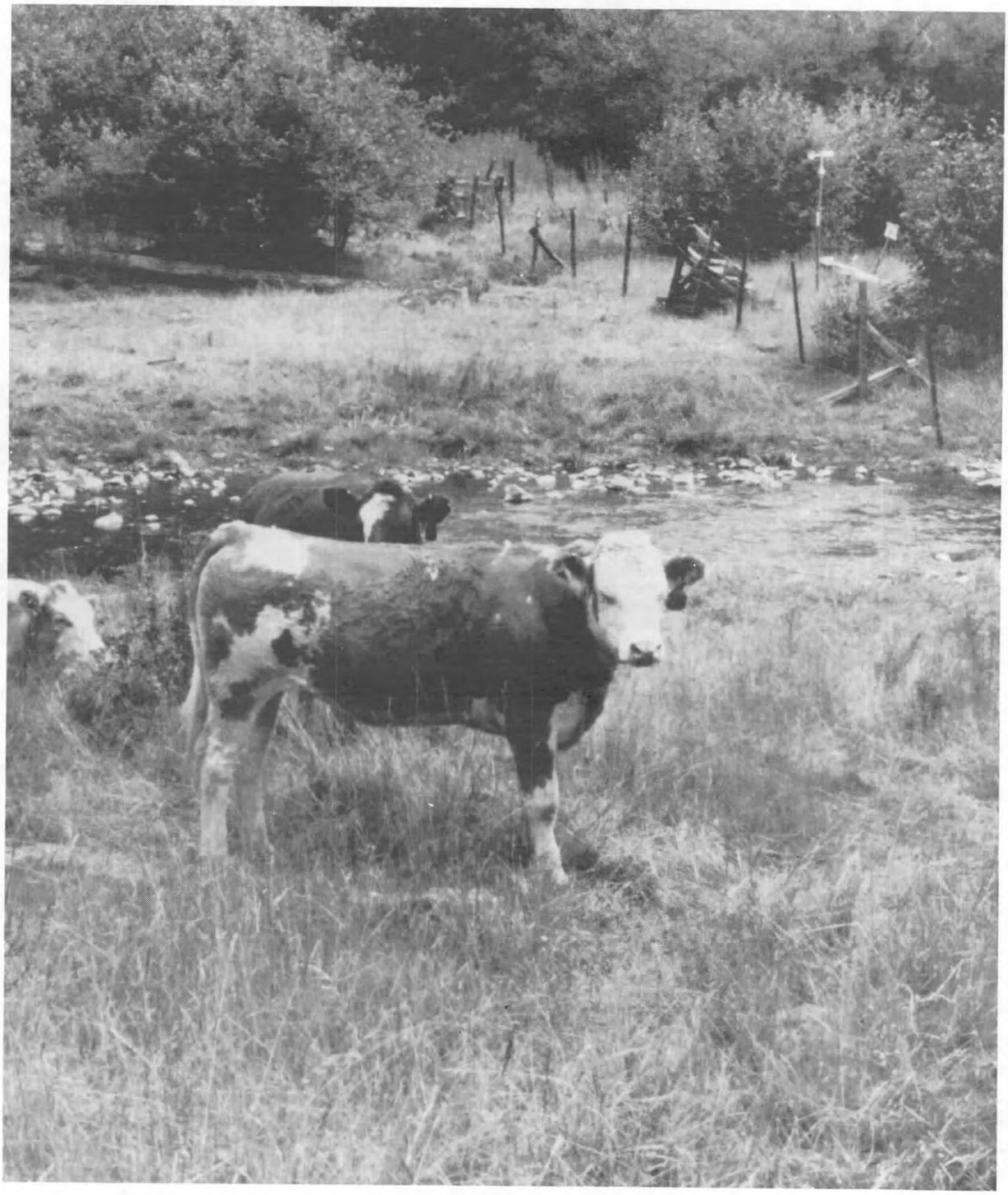
Research Paper
PNW-RP-413

April 1989

Stream Chemistry Responses to Four Range Management Strategies in Eastern Oregon

This file was created by scanning the printed publication.
Text errors identified by the software have been corrected;
however, some errors may remain.

A.R. Tiedemann, D.A. Higgins, T.M. Quigley,
and H.R. Sanderson



Authors

A.R. TIEDEMANN is a supervisory ecologist and T.M. QUIGLEY and H.R. SANDERSON are range scientists, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, Oregon 97850. D.A. HIGGINS is a hydrologist, Chequamegon National Forest, 1170 4th Avenue South, Park Falls, Wisconsin 54552.

Abstract

Tiedemann, A.R.; Higgins, D.A.; Quigley, T.M.; Sanderson, H.R. 1989. Stream chemistry responses to four range management strategies in eastern Oregon. Res. Pap. PNW-RP-413. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 9 p.

Responses of stream chemistry parameters, nitrate-N (NO_3-N), phosphate (PO_4), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and hydrogen ion activity (pH) were measured on 13 wildland watersheds managed at four different grazing strategies. Range management strategies tested were (A) no grazing, (B) grazing without control of livestock distribution (8.2 ha/AUM), (C) grazing with control of livestock distribution (7.7 ha/AUM), and (D) grazing with control of livestock distribution and cultural treatments to improve forage production (2.8 ha/AUM). Nitrate-N, PO_4, Ca, Mg, K, and Na were significantly ($p<0.001$) related to average daily streamflow as a covariate in the analysis of variance. None of the stream chemistry characteristics measured were influenced by increasing intensity of grazing management.

Keywords: Water quality, forest streams, streamwater pollution.

Summary

Four grazing management strategies, implemented as part of the Oregon Range Evaluation Project, provided an opportunity to assess effects of increasing intensity of grazing management on chemical quality of streamwater. Grazing management strategies used were as follows: no grazing, grazing without attempt to provide uniform livestock distribution (8.2 ha/AUM), grazing with management to attain uniform livestock distribution (7.7 ha/AUM), and intensive management to maximize cattle production and improve forage production (2.8 ha/AUM). Chemical characteristics and constituents measured were hydrogen ion activity (pH), nitrate-N (NO_3-N), orthophosphate (PO_4), and cations, calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na). Observed concentrations of chemical constituents indicated a level of chemical purity typical of small western U.S. watersheds. Nitrate-N concentrations were higher with watersheds that had dense stands of Sitka alder (*Alnus sinuata* (Reg.) Rydb.) adjacent to the streams suggesting a contribution of NO_3-N to streamwater by this species. There were, however, no significant differences among grazing management strategies for any chemical constituent. Results indicate that stocking at a rate of 2.8 ha/AUM, even in settings where cattle have access to the riparian zone, will not likely have an adverse effect on chemical water quality.

Contents

Introduction

Legislation regulating the impacts of wildland management activities on water quality has focused attention on livestock grazing as a nonpoint source of pollution to wildland streams (U.S. Laws and Statutes, etc. 1972, 1976, 1978). Much of the research on effects of grazing on water quality has emphasized responses of suspended sediment and bacterial concentrations (Coltharp and Darling 1973, Gaither and Buckhouse 1981, Moore and others 1979). Information on the relation between livestock grazing and chemical water quality of wildland streams is limited, and results differ among studies that have been done. Doran and others (1981) and Schepers and Francis (1982) observed increases in concentrations of nitrate-N (NO_3-N), total phosphorus (P), and soluble P in runoff during livestock grazing compared with the period before grazing began. Owens and others (1983) found no differences in concentrations of NO_3-N, total P, potassium (K), calcium (Ca), or sodium (Na) between grazed and ungrazed areas. Gary and others (1983) determined that concentrations of NO_3-N and ammonium-N (NH_4-N) are not affected by moderate grazing. Our review of the available literature indicated that information is limited on the chemical water quality effects of various grazing systems or various intensities of grazing management.

Range management strategies implemented as part of the Oregon Range Evaluation Project provided an opportunity to assess the effects of increasing intensities of grazing management on chemical quality of streamwater. The primary objective of the study was to determine the effects of increased intensity of range management and increased cattle use on chemical constituents in streamflow from 13 wildland watersheds.

Study Area and Background

This study was conducted as part of the Oregon Range Evaluation (EVAL) Project established in 1976 to implement known range management techniques and evaluate their impacts on range and associated resources (Sanderson and others 1988).

Four intensities of range management strategies were the basis for evaluations in this study:

A. Control—no cattle grazing.

B. Grazing with no attempt to attain uniform cattle distribution throughout a pasture; stocking rate = 8.2 ha/AUM (animal unit month).

C. Grazing management to attain uniform cattle distribution throughout a pasture with fencing and water developments; stocking rate = 7.7 ha/AUM.

D. Intensive grazing management to maximize cattle production with practices to attain uniform distribution and improve forage production with cultural practices such as seeding and fertilization; stocking rate = 2.8 ha/AUM.

EVAL studies were located in eastern Oregon near John Day and included about 140 000 ha on 19 USDA Forest Service grazing allotments and 21 private ranches. Study watersheds were in the northern part of the Malheur National Forest and were part of the larger grazing allotments managed at the same strategy level as the watersheds.

Watersheds ranged in size from 1.2 to 18.1 km^2 and in mean elevation from 1450 to 1992 m (table 1). Predominant vegetative habitats (ecosystems) were mountain meadow, western larch (*Larix occidentalis* Nutt.)-Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), fir-spruce (*Abies lasiocarpa* (Hook.) Nutt.-*Picea engelmannii* Parry ex Engelm.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.). Range management strategies before implementation of EVAL and strategies achieved within allotments containing study watersheds are shown in table 1. Geologic formations of the watersheds are dominated by volcanic material (primarily basalt), meta volcanics, and igneous intrusives.[1]

[1] Personal communication, Mark Lysne, geologist, USDA Forest Service, Malheur National Forest, 139 N.E. Dayton St., John Day, OR 97845.

Table 1—Range management strategy, grazing system, and characteristics of the 13 study watersheds

Watershed name	Range management strategy: Pre-EVAL	EVAL	Grazing system[a]	Eco-system[b]	Drainage area	Elevation above m.s.l.: Min.	Mean	Max.
					km^2	*Meters*		
Big Creek	(A)	A	None	FS	5.2	1817	1992	2225
Blackeye Creek	(B)	A	None	L	2.3	1599	1932	2344
Caribou Creek	(B)	C	DR	PP	6.3	1238	1493	1905
East Donaldson Creek	(B)	C	DR	L	4.1	1235	1478	1732
East Little Butte Creek	(B)	C	DR	L	3.0	1199	1487	2204
Flood Meadow	(C)	D	RR	LP/MM	18.1	1553	1678	1892
Keeney Meadow	(C)	D	DR	MM/PP	12.7	1638	1690	1862
Lake Creek	(B)	A	None	L	1.2	1532	1611	1732
Little Boulder Creek	(B)	C	DR	L	6.0	1453	1786	2301
Ragged Creek	(B)	A	None	L	8.8	1193	1559	1908
Tinker Creek	(B)	D[c]	DR	L	4.4	1472	1611	1886
West Donaldson Creek	(B)	C	DR	L	3.9	1235	1450	1659
West Little Butte Creek	(B)	B	SL	L	4.6	1199	1532	2277

[a] DR = Deferred rotation
SL = Season long
RR = Rest rotation

[b] FS = Fir spruce
L = Larch
MM = Mountain meadow
PP = Ponderosa pine
LP = Lodgepole pine

[c] Strategy D at Tinker Creek was attained in water year 1981; all other strategies were attained in water year 1979.

Climatic data from the Austin, OR, station, about 30 km to the west at 1280 m elevation, indicates that 70 percent of the 49 cm of annual precipitation is received as snow between November and April (National Oceanographic and Atmospheric Administration 1984). Average annual temperature is 2 °C; monthly means are -9 °C in January and 14 °C in July. Daily maxima may exceed 32 °C in the summer. During the winter, daily minima below -18 °C are common.

Runoff patterns are similar to those reported for other watersheds in the interior Pacific Northwest (Fowler and others 1979, Helvey and others 1976). Snowmelt runoff begins in March at lower elevation watersheds and in mid-May in higher elevation watersheds. Peak discharge occurs mid-April to early June, depending on elevation and aspect of watersheds. Flows diminish throughout the summer; lowest levels are in August and September. Peak flows on these watersheds ranged from 5.7 to 634 $L \cdot s^{-1} \cdot km^{-2}$. Late summer minimum flows ranged from 0.03 to 4.8 $L \cdot s^{-1} \cdot km^{-2}$.

Methods

Grab samples of streamflow were collected at monthly to bimonthly intervals at the gauging station on each watershed during calendar years 1979, 1980, 1981, 1982, and 1984. Although more samples were collected during the summer, samples were well distributed among winter, snowmelt runoff, and summer seasons (table 2). Hydrogen ion activity (pH) was measured at the site with pH paper beginning in July 1982. Wide-range paper was used to establish the pH to within 0.5 pH unit, and narrow-range paper was used to determine the pH to within 0.2 unit. Samples were packed in ice for transit and frozen until they were analyzed, usually in 2-3 months. Nitrate-N (NO_3-N) and orthophosphate (PO_4) were measured on all samples. Cations, calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were measured on samples collected during 1979 and 1984. Nitrate-N was measured by using cadmium reduction (Wood and others 1967). Orthophospate was measured by the ascorbic acid method and cations by atomic absorption spectroscopy (Rand and others 1975). Results for NO_3-N, PO_4, and cations are expressed in milligrams per liter. Nearly one-third of the samples analyzed for NO_3-N were below detection limits and were assigned a value of 0.0005 mg/L. This value was assigned to provide a best estimate of the NO_3-N concentration because the value lies somewhere between 0 and 0.001 mg/L and avoids the use of zero values in the analysis of variance. A small positive bias may be created by the use of this estimate.

Stream discharge was measured continuously with a water level recorder at a control structure on each watershed.

Table 2—Number of samples collected and analyzed for each chemical constituent, by season

	Constituent					
Season	NO_3-N	PO_4	Ca	Mg	Na	K
Snowmelt runoff	182	181	79	80	80	80
Summer	208	207	94	94	94	94
Winter	144	135	88	87	88	94

Data for concentrations of all nutrient constituents were transformed by using $\log_{10}$. Both nontransformed and transformed data were then subjected to a normality analysis distribution by using z-values. Kurtosis and skewness were used to determine whether to use nontransformed or transformed data (Snedecor and Cochran 1967). Frequency distributions of nontransformed and transformed data were also checked visually to determine the best distribution. Analyses of variance were conducted for each chemical constituent. To adjust for the possible effects of discharge on concentration of chemical constituents, $\log_{10}$ of average daily streamflow (liters per second) was used as a covariate. Main effects in the analysis were range management strategy, season (snowmelt runoff, summer, or winter), and water years. Range management strategy was tested by using watersheds within strategies as the error term. Interactions among these main effects were also tested. Where the F-test was significant for a main effect term or an interaction, the least significant difference (LSD) test was used to determine significant differences among means (Carmer and Swanson 1971).

Results and Discussion

Concentrations of chemical constituents in streams from these watersheds indicated a level of chemical purity typical of small western U.S. wildland watersheds (Tiedemann 1981). Average pH ranged from 5.7 to 6.4 among watersheds (table 3); the minimum observed pH was 5.2 and the maximum 7.0. Values for pH were lower than those observed for streams from watersheds with similar characteristics in the interior Pacific Northwest (Hicks 1976, Tiedemann and others 1978).

Average concentrations of NO_3-N ranged from 0.001 to 0.015 mg/L among watersheds (table 3). Maximum observed concentrations of NO3-N among watersheds ranged from 0.008 to 0.186 mg/L. Average and maximum concentrations of NO_3-N in streamflow from these watersheds were similar to levels observed in undisturbed watersheds in the interior Pacific Northwest (Tiedemann 1973, Tiedemann and others 1978) and for other watersheds in the Blue Mountains of eastern Oregon (Hicks 1976, Tiedemann and others 1988).

Average concentrations of NO_3-N were higher in east and west Donaldson streams than in streams from the other watersheds. We found several dense stands of Sitka alder (*Alnus sinuata* (Regel) Rydb.) adjacent to the streams on these two watersheds. Although alder was also present on some of the other watersheds, none of the stands were as dense and well developed as those on east and west Donaldson Creeks. Alder is a nitrogen-fixing species (Klemmedson 1979) that may contribute to the NO_3-N levels in streamwater (Coats and others 1976). Higher PO_4 levels in streamflow from these two watersheds may also be a result of deposition of alder leaves into the stream. Tiedemann and others (1988) reached a similar conclusion when substantially greater pretreatment levels of NO_3-N and PO_4 were observed in streamflow of one small watershed compared to three similar adjacent watersheds in the Blue Mountains of northeast Oregon. A large stand of alder was found at the point of origin of surface flow on the watershed with high concentrations of NO_3-N. Alder was not a prominent component of the vegetation of the other three watersheds.

Average concentrations of PO_4 ranged from 0.008 to 0.054 mg/L among watersheds (table 3). These values were consistent with those obtained in other interior Pacific Northwest studies (Hicks 1976, Tiedemann and others 1978).

Table 3—Average concentrations of chemical constituents and pH in streamwater from 13 wildland watersheds in eastern Oregon

Watershed	Strategy	NO_3-N[a]	PO_4[a]	Ca	Mg[a]	Na	K[a]	pH
Big	A	0.001	0.009	3.9	1.7	1.8	0.7	5.7
Blackeye	A	.002	.008	7.4	4.8	2.4	.7	6.1
Lake	A	.001	.042	16.6	6.7	6.9	1.6	6.4
Ragged	A	.001	.028	9.8	5.8	6.1	1.2	6.1
West Little Butte	B	.001	.022	9.9	2.8	3.5	.8	6.2
Caribou	C	.003	.015	9.0	10.1	4.8	1.0	6.2
East Donaldson	C	.008	.054	13.7	7.3	5.5	1.0	6.3
East Little Butte	C	.001	.022	6.4	2.2	2.9	.7	6.3
Little Boulder	C	.001	.017	9.1	7.1	3.5	.8	6.2
West Donaldson	C	.015	.052	13.1	8.6	5.4	1.0	6.2
Flood	D	.002	.039	5.2	2.1	5.7	2.0	6.0
Keeney	D	.006	.028	8.9	4.2	3.4	1.1	6.1
Tinker	D	.002	.036	14.3	6.7	6.3	1.6	6.3

[a] Geometric means.

Calcium is the predominant cation in these streams; average concentrations among watersheds ranged from 3.9 to 16.3 mg/L. Cation concentrations were arrayed Ca>Mg>Na>K. Levels of Ca and Mg in these streams were substantially greater than those observed in other studies in the interior Pacific Northwest (Hicks 1976; Tiedemann and others 1978, 1988).

Frequency distributions and tests for kurtosis and skewness indicated that NO_3-N, PO_4, K, and Mg were strongly skewed toward lower values. Transformation to $\log_{10}$ provided significant ($p<0.05$) improvement in distribution of the data for these constituents.

Concentrations of all chemical constituents were significantly related to the average daily streamflow covariate (table 4). Differences among grazing strategies for any chemical constituent were not significant after the average daily streamflow as a covariate was adjusted for; therefore, it appeared that there was no relation between intensity of grazing management as practiced in this study and the levels of measured chemical constituents in streamflow. Actual levels of use for the four strategies (averaged over the period of study) were 0, 8.2, 7.7, and 2.8 ha/AUM for strategies A, B, C, and D, respectively. Actual numbers of livestock may not be indicative, however, of animal use in the riparian area (Tiedemann and others 1987).

Table 4—Probability values for analysis of variance for strategy, season, and water year with log_{10} average daily streamflow as a covariate

Variable	Average daily flow	Strategy	Season	Water year	Strategy × season	Strategy × water year	Season × water year
NO_3-N	0.001	0.215	0.001	0.001	0.017	0.427	0.001
PO_4	.001	.421	.664	.001	.011	.190	.270
Ca	.001	.912	.001	.309	.655	.968	.001
Mg	.001	.194	.205	.048	.076	.227	.008
Na	.001	.780	.992	.088	.663	.659	.405
K	.001	.131	.186	.306	.875	.722	.032

After adjusting for average daily streamflow, we found highly significant differences ($p<0.001$) among seasons for NO_3-N and Ca. The statistically significant seasonal differences for NO_3-N were small (0.001 mg/L) and probably meaningless biologically. Differences were more substantial for calcium, however; concentrations were 13.7, 8.6, and 7.4 mg/L for summer, runoff, and winter seasons, respectively, and were significantly different among all seasons. Because streamflow-related effects were removed from the analysis by using average daily flow as a covariate, differences in Ca levels seemed to be a real seasonal effect. Different levels among seasons were probably the result of such factors as greater release of Ca from the ground-water matrix during summer and increased levels of CO_2 in the soil from biological activity accelerating movement of cations through the soil (McColl and Cole 1968).

Concentrations of NO_3-N, PO_4, and Mg varied significantly among years (table 4). The F-test for differences among years was probably not valid for the cations because only 2 years of data were represented. Factors such as timing of leaf fall of deciduous plants, differential precipitation, and timing of snowmelt runoff likely influenced yearly trends in concentrations of NO_3-N and PO_4 chemical constituents.

Conclusions

Levels of chemical constituents, NO_3-N, ortho PO_4, and the four measured cations were well below limits proposed by the U.S. Environmental Protection Agency (1973) for surface waters. Maximum levels of NO_3-N, the ion of major concern, was 0.18 mg/L on Flood Meadow and Tinker Creeks. The recommended standard maximum is 10 mg/L (U.S. Environmental Protection Agency 1973).

Grazing, regardless of the intensity of management encompassed in this study, has had no adverse effect on the levels of measured chemical constituents in these watersheds. There was concern that the constituents measured were, perhaps, not the most sensitive to the presence of livestock of those that are commonly measured. For example, because fecal material is high in organic N and organic phosphate, concentrations of these constituents in streamflow may be expected to be more responsive to deposition of fecal material in the stream channel and to overland transport by surface runoff than those measured in this study. The work of Owens and others (1983) suggests that this may be the case for organic N and total organic carbon. Even though concentrations remained low, these constituents increased markedly with grazing in their study. Stocking rates of this study may also have been too low for a detectable response—stocking rates studied by Owens and others (1983) were about 10X greater (0.25 ha/AUM) than that for the strategy D watersheds (2.8 ha/AUM) of this study.

Literature Cited

Carmer, S.G.; Swanson, M.R. 1971. Detection of differences between means: a Monte Carlo study of five pairwise multiple comparison procedures. Agronomy Journal. 63: 940-945.

Coats, R.N.; Leonard, R.L.; Goldman, C.P. 1976. Nitrogen uptake and release in a forested watershed, Lake Tahoe Basin, California. Ecology. 57: 995-1004.

Coltharp, G.B.; Darling, L.A. 1973. Livestock grazing—a nonpoint source of water pollution in rural areas? In: V.H. Jewell; R. Swan, eds. Proceedings of a symposium on Rural Environmental Engineering; [dates unknown]; [location of symposium unknown]. Hanover, NH: University Press of New England: 341-358.

Doran, J.W.; Schepers, J.S.; Swanson, N.P. 1981. Chemical and bacteriological quality of pasture runoff. Journal of Soil and Water Conservation. 36: 166-171.

Fowler, W.B.; Helvey, J.D.; Johnson, C. 1979. Baseline climatic and hydrologic relationships for the High Ridge Evaluation Area. Gen. Tech. Rep. PNW-91. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.

Gaither, R.E.; Buckhouse, J.C. 1981. Hydrologic outputs from woodland, shrubland, and grassland ecosystems in relation to grazing management strategies: an annotated bibliography. Spec. Rep. 640. Corvallis, OR: Oregon State University, Agriculture Experiment Station. 26 p.

Gary, H.L.; Johnson, S.R.; Ponce, S.L. 1983. Cattle grazing impact on surface water quality in a Colorado Front Range stream. Journal of Soil and Water Conservation. 38: 124-128.

Helvey, J.D.; Fowler, W.B.; Klock, G.O.; Tiedemann, A.R. 1976. Climate and hydrology of the Entiat Experimental Forest watersheds under virgin forest cover. Gen. Tech. Rep. PNW-42. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Hicks, M.E. 1976. The effect of the Douglas-fir tussock moth deforestation on the quality of streamflow and stream productivity parameters. Ellensburg, WA: Central Washington University. 79 p. M.S. thesis.

Klemmedson, J.O. 1979. Ecological importance of actinomycele-nodulated plants in the western U.S. Botanical Gazette. 140 (Suppl.): S91-S96.

McColl, J.G.; Cole, D.W. 1968. A mechanism of cation transport in a forest soil. Northwest Science. 42: 135-140.

Moore, E.L.; James, E.; Kinsinger, F. [and others]. 1979. Livestock grazing management and water quality protection (state of the art document). Seattle, WA; Denver, CO: U.S. Environmental Protection Agency. 910/9-79-67. 147 p.

National Oceanographic and Atmospheric Administration. 1984. Climatological data, annual summary, Oregon, 1984. Asheville, NC: National Climatic Data Center. 34 p. Vol. 90, no. 13.

Owens, L.B.; Edwards, W.M.; Van Keuren, R.W. 1983. Surface runoff water quality comparisons between unimproved pasture and woodland. Journal of Environmental Quality. 12: 518-522.

Rand, M.C.; Greenberg, A.E.; Taras, M.J. 1975. Standard methods for the examination of water and wastewater. 14th ed. Washington, DC: American Public Health Association. 1193 p.

Sanderson, H.R.; Quigley, T.M.; Spink, L.R. 1988. Development and implementation of the Oregon Range Evaluation Project. Rangelands. 10: 17-23.

Schepers, J.S.; Francis, D.D. 1982. Chemical water quality of runoff from grazing lands. I: influence of grazing livestock. Journal of Environmental Quality. 11: 351-359.

Snedecor, G.W.; Cochran, W.G. 1967. Statistical methods. Ames, IA: The Iowa State University Press. 593 p.

Tiedemann, A.R. 1973. Stream chemistry following a forest fire and urea fertilization in north-central Washington. Res. Note PNW-203. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 19 p.

Tiedemann, A.R. 1981. Stream chemistry, nutrient economy, and site productivity consequences of wildland management and wildfire. In: D.M. Baumgartner, comp., ed. Proceedings of a symposium, Interior West Watershed Management; 1981 April 8-10; Spokane, WA. Pullman, WA: Washington State University Cooperative Extension Service: 184-201.

Tiedemann, A.R.; Helvey, J.D.; Anderson, T.D. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. Journal of Environmental Quality. 7: 580-588.

Tiedemann, A.R.; Higgins, D.A.; Quigley, T.M. [and others]. 1987. Responses of fecal coliform in streamwater to four grazing strategies. Journal of Range Management. 40: 322-329.

Tiedemann, A.R.; Quigley, T.M.; Anderson, T.D. 1988. Effects of timber harvest on stream chemistry and dissolved nutrient losses in northeast Oregon. Forest Science 34: 344-358.

U.S. Environmental Protection Agency. 1973. Water quality criteria 1972. Ecological Research Series. EPA-R3-73-033. [Location of publisher unknown]: 594 p.

U.S. Laws and Statutes, etc; Public Law 92-500. 1972. [S2770]. [An act to amend the Federal Water Pollution Control Act.] 92d Congress, 2d Session, 1972.

U.S. Laws and Statutes, etc; Public Law 94-588.1976. [S3091]. [An act to amend the Forest and Rangeland Renewable Resources Planning Act of 1974 and for other purposes.] 94th Congress, 1st Session, 1976.

U.S. Laws and Statutes, etc; Public Law 95-514. 1978. [Public Rangelands Improvement Act of 1978.] Act of October 25, 1978. 92 Stat. 1806; 43 U.S.C. 1752-1753, 1901-1908; 16 U.S.C. 1333(b).

Wood, E.D.; Armstrong, F.A.J.; Richards, F.A. 1967. Determination of nitrate in seawater by cadmium-copper reduction to nitrate. Journal of Marine Biology Association. UK 47: 23-31.

GPO 691-133/82048

Tiedemann, A.R.; Higgins, D.A.; Quigley, T.M.; Sanderson, H.R. 1989. Stream chemistry responses to four range management strategies in eastern Oregon. Res. Pap. PNW-RP-413. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 9 p.

Responses of stream chemistry parameters, nitrate-N (NO_3-N), phosphate (PO_4), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and hydrogen ion activity (pH) were measured on 13 wildland watersheds managed at four different grazing strategies. Range management strategies tested were (A) no grazing, (B) grazing without control of livestock distribution (8.2 ha/AUM), (C) grazing with control of livestock distribution (7.7 ha/AUM), and (D) grazing with control of livestock distribution and cultural treatments to improve forage production (2.8 ha/AUM). Nitrate-N, PO_4, Ca, Mg, K, and Na were significantly ($p<0.001$) related to average daily streamflow as a covariate in the analysis of variance. None of the stream chemistry characteristics measured were influenced by increasing intensity of grazing management.

Keywords: Water quality, forest streams, streamwater pollution.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon 97208

Official Business
Penalty for Private Use, $300

BULK RATE
POSTAGE +
FEES PAID
USDA-FS
PERMIT No. G-40