Stream Water Nutrient Changes Associated With the Conversion of Arizona Chaparral[1]

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Abstract: Increased streamflow obtained by converting chaparral watersheds to grass is associated with increased nitrate concentrations in the stream water. Undisturbed chaparral watersheds are tight with respect to nitrogen, losing very little nitrate-nitrogen in streamflow; nitrate concentrations are usually less than 0.5 ppm. Converting chaparral watersheds from deep-rooted shrubs to shallow-rooted grasses through the use of herbicides allows the escape of nitrate ions through the soil mantle. Nitrate concentrations of 45-80 ppm occurred in stream water from treated watersheds; nitrate concentrations remained above normal for 10 years or longer.

Streamflow from chaparral watersheds in Arizona can be increased under certain conditions by converting brush to grass (Hibbert and others (1974). In conjunction with water yield investigations I am studying the effects of chaparral manipulation practices on stream water chemistry. The objective of the water chemistry studies is to identify the short- and long-term effects of the various water improvement treatments on the chemical composition of the stream water and of the watershed soil in order to assess their environmental and ecological impacts.

A mature chaparral ecosystem is normally tight with respect to plant nutrients, recycling them through the vegetation, organic debris, microorganisms, available nutrient supply, and the soil-rock compartments of the ecosystem. Killing the brush could prevent the normal uptake of nutrients by that vegetation and allow the dissolved nutrients to escape to bedrock and into subsurface runoff.

I found that major disruptions occurred in the nitrogen cycle of a converted chaparral watershed, causing marked increases in nitrate concentration above those found for the untreated control watershed. The accelerated loss of nitrogen was not accompanied by an increased loss of cations. Although all major anions and cations are being studied and play important roles in understanding the biogeochemical processes involved in a chaparral conversion, only major aspects of stream water nitrogen losses are presented.

EXPERIMENTAL AREA

The experimental chaparral watersheds are on the 3-Bar Wildlife Area in the Mazatzal Mountains of central Arizona at an elevation of 4,000-5,000 feet. The chaparral is predominately shrub live oak (Quercus turbinella) with a mixture of other sclerophyllous species such as birchleaf mountain-mahogany (Cercocarpus betuloides), yellowleaf silktassel (Garrya flavescens), sugar sumac (Rhus ovata), hollyleaf buckthorn (Rhamnus crocea), palmer oak (Quercus chrysolepis var. palmeri), Emory oak (Quercus emoryi), pointleaf manzanita (Arctostaphylos pungens), and desert ceanothus (Ceanothus greggii). Sprouting shrubs predominate with minor occurrence of nonsprouting species, producing a brush crown cover of about 70 percent. The precipitation pattern is biseasonal: summer and winter precipitation (with occasional snow) and spring and fall droughts. The driest months, May and June, are followed by summer monsoons beginning in July. Annual precipitation at the study area averaged 29 inches over the past 24 years.

The soils are very gravelly sandy loamy derived from granitic parent material. They are classified as Udic Ustochrepts, from the loamy skeletal, mixed, mesic family. The soils are slightly acid and very permeable with infrequent surface runoff. Seismic exploration on the watershed indicated the coarse-grained granite was weathered and fractured 20 to 40 feet deep.

METHODS

Nutrient losses associated with chaparral conversions are being studied in conjunction with water yield experiments using the paired watershed approach. Comparisons between treated and untreated watersheds provide a basis for determining treatment effects. After a wildfire swept over the 3-Bar watersheds in June 1959, watersheds D and F were allowed to recover for 10 years, at which time brush cover was about 90 percent of its prefire crown cover. The biomass had not recovered to the same extent. Watershed F contains 68.39 acres and D contains 80.47 acres. The pretreatment streamflow calibration period began in 1964

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and lasted for 5 years prior to the treatment of 3-Bar F in February 1969. 3-Bar D serves as an untreated control. Precipitation and streamflow data are based on an October-September water year. 3-Bar F soil was treated with karbutilate granules (20 lb. active ingredient per acre) by helicopter. After 3 years, by which time brush control was excellent, soil bioassays indicated that karbutilate residues in the soil had declined substantially, and the watershed was seeded with weeping lovegrass (*Eragrostis curvula*).

Streamflow samples were collected weekly at the gaging station weir, and more frequently during stormflow periods. Bulk precipitation samples (the composite of wet and dry fallout) were collected in a plastic pail within the housing of a recording rain gage. The samples were analyzed for the major cations and anions including nitrate and ammonium. Only nitrate results will be reported because it was the only ion that increased significantly after treatment.

Nitrate was determined with a Technicon AutoAnalyzer II utilizing a colorimetric method in which nitrate is reduced to nitrite, which then reacts with sulfanilamide to form a diazo compound. This compound then couples with N-1-naphthylenediamine dihydrochloride to form an azo dye.

Eleven years of posttreatment results are presented, which include a wide range in annual precipitation: 2 years of below-average amounts (15.7 and 16.9 inches), 5 years of nearly normal amounts (19.8-30.8 inches), and 4 years of very high amounts (44.3-53.1 inches).

RESULTS

Rainfall following the February 1969 treatment was ideal for leaching the karbutilate into the soil. Rain began within 2 hours after the application, and showers continued for the next 5 days. Rainfall after the treatment totaled 2.59 inches in February and 1.64 inches in March. The rainfall pattern was ideal for producing rapid injury to the brush in the spring.

Although the actual treatment year was from mid-February to mid-February, aberrations in nitrate concentration did not occur until November 1969, well into the treatment year. Data are presented, therefore, on the basis of the standard October-September water year.

The pretreatment data indicate that stream water chemistry for the paired watersheds was very similar. With 26.3 inches rainfall, the annual weighted mean nitrate concentrations were 0.18 ppm for 3-Bar F, and 0.10 ppm for 3-Bar D; nitrate losses were 0.06 lb/A from both watersheds (table 1). During six years of pretreatment calibration data, including one year in which chemical composition was measured, 3-Bar D outyielded 3-Bar F by a factor of 1.8 although it is just 1.2 times larger.

By May, following the February treatment, the brush, grasses, and forbs on 3-Bar F were severely injured, and an early treatment-response increase in streamflow became noticeable and continued throughout the spring drought. The increase in streamflow resulted from a less rapid recession of base flow for 3-Bar F than for 3-Bar D. Because there was a soil moisture deficit during the spring drought, the small amounts of rain received during the summer had no immediate effects on streamflow, and the stream water nitrate concentrations remained normal. The first increases in nitrate concentration came as flushes in November and December 1969 (1970 water year). Nitrate flushes of 10 ppm and 30 ppm were associated with 1.8-inch and 2.1-inch rainstorms. Subsequently during the year, seven additional rainstorms of 1.0 to 7.4 inches produced elevated nitrate concentrations. The maximum concentration was 56 ppm, caused by a 7.4-inch storm in September 1970. Annual precipitation during 1970 was 30.4 inches. The dramatic difference in nitrate release patterns that occurred as a result of controlling the brush is tabulated in the form of concentration frequency distributions (table 2). Nitrate concentrations in the 0-5 ppm range occurred on 72 percent of the days. The annual weighted mean nitrate concentration was 16.1 ppm (table 1). By contrast, the mean nitrate concentration in stream water from the untreated watershed (3-Bar D) was 0.24 ppm. The annual nitrate loss from 3-Bar F was 12.8 lb/A, while that from untreated 3-Bar D was only 0.06 lb/A.

During the second year (1971), there was 20.1 inches of rain and only four major nitrate flushes. The annual mean nitrate concentration was 5.6 ppm; 79 percent of the daily concentrations were less than 5 ppm (tables 1 and 2). The maximum concentration was 30 ppm. Nitrate losses from 3-Bar F and D were 3.4 lb/A and 0.04 lb/A, respectively.

During the third year (1972), the area received only 15.7 inches of rain and experienced an unusual 5-month drought from January through May. A 4.2-inch storm during the last 2 days of the 1971 water year (September 29 and 30) produced a flush of nitrate with a peak concentration of 69 ppm that dominated the entire year. The annual mean concentration increased to 26.5 ppm, and 71 percent of the daily concentrations ranged from 5 to 40 ppm (tables 1 and 2). The annual nitrate losses in streamflow were 17.9 lb/A from 3-Bar F and 0.03 lb/A from 3-Bar D.

During the fourth year (1973), the area received a record-breaking 53.1 inches of rainfall and provided conditions for what was to be the maximum annual nitrate loss from 3-Bar F (table 1). Nitrate concentrations in the stream water remained high during the entire year; 75 percent of the daily nitrate concentrations ranged from 20 to 60 ppm (table 2). The maximum concentra-

Table 1--Streamflow nitrate concentrations and losses from converted (3-Bar F) and untreated (3-Bar D) chaparral watersheds[1]

Year[2]	Converted (3-Bar F)				Untreated (3-Bar D)				F/D Nitrate ratio	
	Precipi-tation[3]	Stream-flow	Nitrate		Precipi-tation[3]	Stream-flow	Nitrate			
			Concn.[4]	Loss			Concn.[4]	Loss	Concn.	Loss
	- - - inches - - -		ppm	lb/A	- - - inches - - -		ppm	lb/A	ppm	lb/A
Pretreatment										
1969	26.30	1.40	0.2	0.06	26.60	2.63	0.1	0.06	2	1
Posttreatment										
1970	30.80	3.52	16.1	12.84	30.61	1.15	0.2	0.06	80	214
1971	20.06	2.66	5.6	3.35	19.50	0.46	0.4	0.04	14	84
1972	15.74	2.99	26.5	17.90	15.50	0.39	0.4	0.03	66	597
1973	53.08	15.07	33.0	112.66	52.68	11.44	0.6	0.74	110	152
1974	19.83	2.36	12.8	6.82	19.50	1.40	0.6	0.20	21	34
1975	29.85	3.21	13.2	9.58	29.12	1.64	0.6	0.20	22	48
1976	30.18	3.53	13.8	11.02	30.24	1.86	0.3	0.11	46	100
1977	16.92	0.82	5.2	0.97	16.86	0.37	0.6	0.05	9	19
1978	44.29	8.75	13.5	26.72	44.54	8.55	1.0	1.88	14	14
1979	49.20	13.66	13..8	42.69	49.59	14.46	0.6	1.92	23	22
1980	43.38	11.01	8.3	20.70	43.61	9.84	0.6	1.45	14	14
Posttreatment annual means	32.12	6.14	[5]14.7	24.11	31.98	4.69	[5]0.5	0.61	[6]29	[6]40

[1] Watershed areas: 3-Bar F, 68.39 acres; 3-Bar D, 80.47 acres

[2] Oct.-Sept. water year

[3] Weighted precipitation on watershed

[4] Annual volume-weighted mean concentrations

[5] Arithmetic mean of annual volume-weighted concentrations

[6] Based on the 11-year posttreatment annual means

tion was 60 ppm, and the annual mean was 33 ppm. This annual mean was not approached again during the course of the study. During this high rainfall year, the nitrate level in the stream water from the untreated watershed remained low (0.3 ppm). Nitrate exported in streamflow from the converted watershed amounted to 112.7 lb/A, whereas that from the untreated watershed was only 0.7 lb/A. This was a landmark year in the study, and nitrate concentrations did not drop below 1 ppm for the next 3 years.

For the next 3 years (1974-1976), precipitation was about normal, and 80-95 percent of the daily nitrate concentrations had fallen back to the 5-20 ppm range (table 2). Maximum concentrations were 16.1 to 19.5 ppm; annual mean nitrate concentrations ranged from 12.8 to 13.8 ppm; and annual nitrate losses were 6.8 to 11.0 lb/A (table 1). During these years stream water from the untreated watershed maintained normally low annual mean concentrations (0.3 to 0.6 ppm), and annual nitrate losses were 0.1 to 0.2 lb/A.

The eighth year (1977) was very dry (16.9 inches rainfall), and streamflow volume (0.82 inches) was less than it had been since the start of the study (table 1). Seventy-five percent of the daily nitrate concentrations were in the 1-10 ppm range, and the maximum concentration was 9.4 ppm (table 2). The annual mean nitrate concentration was 5.2 ppm, in contrast to 0.6 ppm for the untreated watershed. Nitrate loss from the converted watershed dropped to 1 lb/A, chiefly due to the lack of adequate rainfall to flush nitrate through the watershed. Likewise, nitrate loss from the untreated watershed was low (0.05 lb/A).

The 3 most recent years of the study (1978-1980) had extremely high amounts of precipitation (44.3, 49.2, and 43.4 inches, respectively). Precipitation and streamflow for these years was exceeded only by those for 1973 (table 1).

Table 2--Streamflow nitrate concentration frequency distributions for a converted chaparr1l watershed (3-Bar F) during the period 1969-1980[1]

Nitrate concn. (ppm)	Year and posttreatment year number											
	1969[2]	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
		1	2	3	4	5	6	7	8	9	10	11
	Number of days per year											
0- 1.0	365	190	154	70	5	0	0	0	91	101	0	5
1.1- 5.0		73	135	27	4	18	27	68	115	3	35	118
5.1-10.0		37	38	31	3	91	142	83	159	104	108	219
10.1-20.0		28	29	96	78	256	196	215		157	222	24
20.1-30.0		24	9	108	97							
30.1-40.0		6		25	57							
40.1-50.0		2		4	53							
50.1-60.0		5		2	68							
60.1-70.0		0		3								
≥45.0		6		6								
	ppm											
Max. nitrate concn.	0.3	56.0	30.0	69.0	60.0	16.1	18.3	19.5	9.4	17.6	18.3	10.6
	inches											
Precipitation	26.3	30.8	20.1	15.7	53.1	19.8	29.8	30.2	16.9	44.3	49.2	43.4

[1] Oct.-Sept. water year

[2] Pretreatment year

Because of the 3 consecutive years of high rainfall, nitrate flushing continued, and the annual mean nitrate concentrations were 13.5, 13.8, and 8.3 ppm, respectively. These concentrations, in conjunction with high streamflow volumes, combined to produce the 3 largest nitrate-loss years of the study except for 1973. Maximum nitrate concentrations for 1978-1980 were 17.6, 18.3, and 10.6 ppm, respectively (table 2). Seventy-two percent of the daily nitrate concentrations during 1978 and 1979 ranged from 5-20 ppm, while in 1980 (the eleventh posttreatment year) 92 percent of the samples had concentrations in the 1-10 ppm range. For the untreated watershed, the 1978-1980 years were also among the highest for precipitation and streamflow, average nitrate concentrations, and annual nitrate losses. Even so, annual mean nitrate concentrations were only 0.6 to 1.0 ppm, with nitrate losses of only 1.4 to 1.9 lb/A (table 1).

The arithmetic mean of annual volume-weighted nitrate concentrations in stream water from the converted watershed for the 11-year posttreatment period is 14.7 ppm, whereas that for the untreated watershed is 0.5 ppm, or 29-fold greater overall (table 1). After 3-Bar F was treated, the nitrate concentration of the stream water gradually shifted upward. For the first 4 years after treatment, a greater proportion of days of each succeeding year had concentrations in the higher nitrate concentration ranges (table 2). The third and fourth posttreatment years had the highest mean nitrate concentrations, the greatest proportion of samples in the 20-60 ppm range, and the two highest concentrations encountered during the study (tables 1 and 2). Interestingly, the third year (1973) had the least precipitation of the study, and the fourth year had the most precipitation. High streamflow and high nitrate concentrations during the fourth year combined to produce the maximum nitrate loss of the study (112.7 lb/A). Although the high nitrate concentrations were directly related to high rainfall amounts, they undoubtedly were also related to the length of time from treatment as it relates to the increasing availability of nitrogen from decaying organic matter in the soil, including the residual soil organic matter, and the organic matter from decaying shrub roots, leaves, twigs, and the more slowly decomposing branches.

Nitrate levels exceeded the current EPA standard for drinking water of 45 ppm on 6 days during

Table 3--Annual net gains and losses of nitrate-nitrogen associated with the conversion of a chaparral watershed to grass

Year[1]	Precipitation[2]	Nitrate-nitrogen		
		(stream- Loss flow)	Gain (bulk precip.)	Net gain (+) or loss (-)[3]
	Inches	- - - - - - - - - -	lb/A	- - - - - - - - - -
Pretreatment				
1969	26.30	0.01	3.21	+ 3.20
Posttreatment				
1970	30.80	2.90	4.74	+ 1.84
1971	20.06	0.76	4.59	+ 3.83
1972	15.74	4.04	2.92	- 1.12
1973	53.08	25.45	4.12	-21.33
1974	19.83	1.54	4.54	+ 3.00
1975	29.85	2.16	3.66	+ 1.50
1976	30.18	2.49	4.65	+ 2.16
1977	16.92	0.22	3.14	+ 2.92
1978	44.29	6.04	2.63	- 3.41
1979	49.20	9.64	2.16	- 7.48
1980	43.38	4.68	4.61	- 0.07
Posttreatment				
Totals		59.92	41.76	-18.16
11-Yr. ann. mean		5.45	3.80	- 1.65
10-Yr. ann. mean[4]		3.45	3.76	+ 0.31

[1] Oct.-Sept. water year.

[2] Weighted precipitation on watershed.

[3] Calculated as the difference between input in bulk precipitation and output in streamflow.

[4] 1973 data is excluded.

each of the first and third years, and on 97 days during the fourth year. Thereafter, nitrate levels did not exceed 20 ppm (table 2).

Although nitrogen was exported from the watersheds in streamflow, it was also added in bulk precipitation. The net nitrate-nitrogen gain and loss budget for the converted watershed for 12 years is calculated as the difference between input in bulk precipitation and output in streamflow (table 3). For the pretreatment year (1969), there was a net gain of nitrate-nitrogen of 3.2 lb/A. For the 11-year posttreatment period, there was a net loss of 18 lb/A, or an average yearly net loss of 1.6 lb/A. Although this overall net loss figure is relatively small, it is somewhat misleading in that it is heavily biased by the 21.3 lb/A net loss in 1973. If the aberrant 1973 year is omitted from the budget, then there is an average yearly net gain of 0.3 lb/A. This average includes the 3 unusually high rainfall years of 1978, 1979, and 1980, for which 99 percent of the loss occurred in 1978 and 1979. Based on this budget, it is apparent that in spite of the 40-fold greater loss of nitrate-nitrogen from the converted watershed than from the untreated watershed (table 1), the input of nitrate-nitrogen in bulk precipitation largely offset the loss in streamflow.

DISCUSSION

Elevated nitrate concentrations accompanied death and decomposition of the brush and increased water yield. For the first few years, the pattern of nitrate concentration followed a wave form in which nitrate increased only after rainstorms of sufficient duration and amount to leach nitrates through the regolith into base flow. Between storms, during the early posttreatment years, the nitrate concentration returned to pretreatment baseline levels (0-1 ppm). As the treatment became older, the reservoir of decaying soil organic matter in the regolith probably increased. During this second stage, nitrate concentrations in the stream water remained 10 to 100 times above normal, with rainfall conditions adequate to sustain increased water yields. The nitrate release pattern can be likened to a series of waves of increasing height and breadth in which wave height cannot exceed a certain level but wave breadth is unlimited. In this analogy, wave height corresponds to nitrate concentration, and wave breadth to duration of the increased concentrations. The frequency of the nitrate waves, or flushes, is determined by the frequency and magnitude of rainstorms, and by the nitrogen reservoir in the soil. Nitrogen supply in the soil is limited by the supply and quality of decomposable organic matter and by the release of nitrates through the process of nitrification. This process is regulated by the supply of organic matter, the abundance of nitrifying bacteria, and the temperature and moisture content of the soil. A third stage should ultimately be reached when the reservoir of nitrogen below the root zone of the established grass cover is exhausted and the nitrogen within the grass root zone is recycled between soil and grass. When this new steady state is reached, the nitrate concentration of the stream water should return to pretreatment levels. Eleven years after the treatment of 3-Bar F this stage has not been reached.

Some possible side effects of the nitrate-release phenomenon which have ecological or environmental implications are eutrophication of streams and reservoirs, loss of watershed soil fertility, and unsuitability of stream water for drinking purposes. Of these possible consequences, eutrophication of watercourses is probably of greatest practical concern. Its effects can be reduced, however, by designing projects so that streams from conversion areas are diluted by streams from untreated areas. If reservoirs or other water impoundments already contain near maximum allowable levels of nitrate, however, an added burden of nitrogen in entering streamflow could be undesirable. Soil fertility of converted areas may be reduced by the extent that nitrogen is exported in streamflow. However, since grass production on converted areas is generally good, and vastly superior to that on natural areas (Cable 1975, Pase and others 1967), there may be no reason for concern. The slow release of nutrients from decomposing aboveground vegetal material is a compensating factor in supplying nutrients for the developing grass cover. The nitrate content of stream water from converted areas is unlikely to represent a health hazard (Parsons 1977). Although there are occasional concentrations greater than 45 ppm in streams from converted areas during the first few years, downstream mixing and dilution with streams from natural areas would reduce the occasional flush of high nitrate.

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