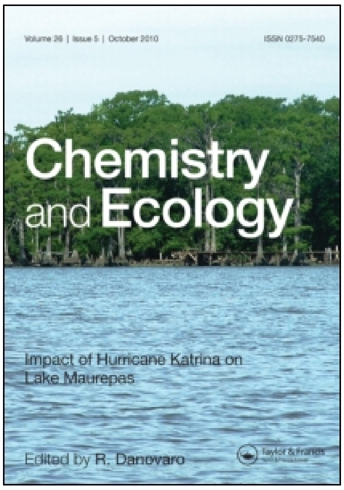

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TRENDS AND SEASONALITY IN THE NITRATE CONCENTRATIONS AND LOADS OF THE BERE STREAM (DORSET) FOR THE PERIOD 1966–1986

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1. INTRODUCTION

Chalk streams are the result of a particular combination of climate, geology, plant and animal species and human management. They arise from aquifers which in England extend east from Dorset through Hampshire running parallel with the south coast, then northwards to Yorkshire. Because up to 90% of the discharge can be derived from groundwater, violent floods are rare. These streams are traditionally regarded as stable biological habitats with a ratio of <6:1 maximum to minimum discharge, in contrast to mountain streams which can have ratios greater than 40:1.

The headwaters of most chalk streams in Dorset and Hampshire are now occupied by trout farms or watercress beds and natural undisturbed and unmanaged water sources are almost non-existent.

Study area. The Bere Stream is a small chalk stream in Southern England (Figure 1). The geology, general chemistry, discharge and the ecosystem has been described previously (Westlake *et al.*, 1970).

The stream originates from natural springs but a large proportion of its flow is made up of water flowing out of commercial watercress beds. In years of low flow the watercress beds can provide twice as much discharge as the natural source at Millum Head (Casey, 1981). In the catchment of the Bere Stream above the sampling site there is approximately 57,000 m^2 of watercress beds. The chalk borehole water feeding the watercress beds usually has sufficient nitrate present for watercress nutritional requirements, but cannot supply enough phosphorus or potassium for optimum growth. These elements are supplemented by addition either of commercial fertilisers or specially formulated fertilisers, which often include nitrates. In very intensively cultivated beds all nutrients are added as a concentrated solution. Because of the addition of these fertilisers one would expect the nitrate concentrations below watercress beds to be different and increased compared with natural streams above watercress beds. However, in many streams examined there were no significant differences in nitrate concentrations above and below watercress beds. In some cases the water leaving the

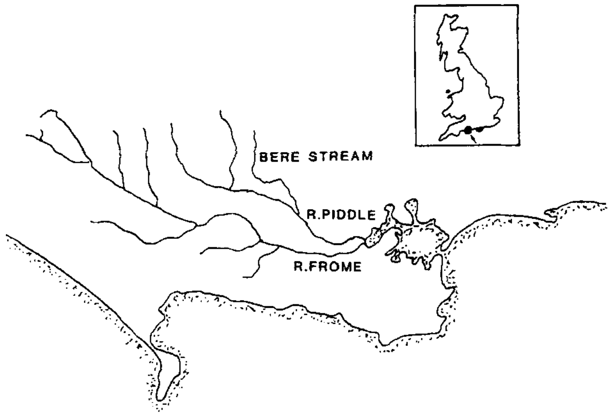

Figure 1 Location of Bere Stream catchment in Southern England.

watercress beds had a lower nitrate concentration than the stream water. Obviously nitrate concentrations in the outflow of watercress beds will alter as conditions vary, depending upon the state of the watercress crop, the time of the year and the amount of nutrients being added. In addition to the fertilisers being added to the water in the watercress beds, a large proportion of the land surrounding Bere Stream has changed from being rough pasture land in 1966 to intensively managed fertilised grassland by 1986. This will also have altered the nitrate concentration pattern in the stream.

2. METHODS

Weekly samples were taken at the same site on the Bere Stream below Bere Regis, Dorset (National Grid Reference SY 858923). Methods of chemical analysis have been described previously (Casey & Clarke, 1979).

3. RESULTS AND DISCUSSION

3.1. *Long-term Trends and Seasonality*

The long-term trends and variation in nitrate concentration over the 21 years 1966–1986 are shown in Figure 2 and summarised in Table 1. The annual average nitrate concentration appeared steady over the initial four years monitored, averaging 3.92 mg/l during the years 1966–69. In 1970, concentrations began increasing and since 1974 have risen fairly steadily to an annual mean of 6.02 mg/l by 1986. Each year's mean will be prone to statistical sampling error as it is still only estimated from 52 (i.e. weekly) samples. Also variation in annual rainfall patterns on runoff and dilution effects will also cause noise in detecting annual trends. Because it is difficult to estimate precisely the annual changes that have taken place, smoothed three-yearly means and increases are also given in Table 2.

Figure 2 Long-term trends and variation in nitrate concentration (NO_3N mg/l) for the Bere Stream over the period 1966–1986. For each year the annual mean, minimum and maximum are shown; vertical bars denote one standard error about the mean.

The average increase over the whole study period is 0.12 mg NO_3N/l per year. This is almost the same as that reported by Casey and Clarke (1979) for the nearby River Frome catchment, although concentrations were, and have remained, about 1.5 mg/l higher in the Bere Stream than at the River Frome site.

The minimum observed concentration in Bere Stream has similarly risen from 2.52 mg/l in 1966 to 4.90 mg/l in 1986 (Table 1). The highest recorded

Table 1 Yearly statistics for weekly sampled nitrate concentration (NO_3N mg/l) in the Bere Stream, Dorset

Year	*Mean*	*S.D.*	*Minimum*	*Maximum*
1966	4.02	0.50	2.52	4.82
1967	3.88	0.47	2.32	4.72
1968	3.82	0.33	2.86	4.45
1969	3.97	0.36	3.28	5.00
1970	4.25	0.42	2.94	5.10
1971	4.23	0.43	3.44	5.04
1972	4.23	0.47	3.20	5.34
1973	4.10	0.42	3.33	4.93
1974	4.39	0.52	3.18	6.16
1975	4.52	0.46	3.26	5.30
1976	4.77	1.00	3.72	7.28
1977	4.97	0.50	3.38	6.12
1978	5.01	0.55	3.63	7.40
1979	5.42	0.38	4.52	6.34
1980	5.22	0.42	4.14	6.05
1981	5.55	0.50	4.63	6.57
1982	5.72	0.71	3.72	7.56
1983	5.80	0.64	4.63	8.10
1984	5.80	0.71	4.30	7.56
1985	5.86	0.57	4.66	7.04
1986	6.02	0.65	4.90	7.78

Table 2 Three-yearly means and increases in nitrate concentration (NO_3N mg/l) in Bere Stream over the period 1966–86

Period	*Mean*	*Increase over past 3 years*
1966–68	3.91	
1969–71	4.15	0.24
1972–74	4.24	0.09
1975–77	4.77	0.53
1978–80	5.21	0.44
1981–83	5.69	0.48
1984–86	5.89	0.20

concentration was 8.10 mg/l in October 1983. The range in observed concentrations within a year varied between 1.6 mg/l in 1973 to 3.56 mg/l in 1976 and showed a tendency to increase with time (see Standard Deviations in Table 1).

As a means of showing any overall seasonal pattern in nitrate concentration, Figure 3 gives the mean, standard error, minimum and maximum concentration for each of the weeks (1–52) of the year, averaged over the period 1966–86. As is common elsewhere nitrate concentrations are on average higher in winter and lowest in mid-summer. However this seasonal pattern and annual cycle is much smaller than that found in other rivers (Casey & Clarke, 1979). The likely reason for this is that the site is close to the spring sources and the stable temperature regime and chemical composition of the chalk groundwater from the springs will have much more influence on the stream than rainfall.

The trend and seasonal periodicity in nitrate concentration described above can be summarised by the following simple regression model, as used by Casey and

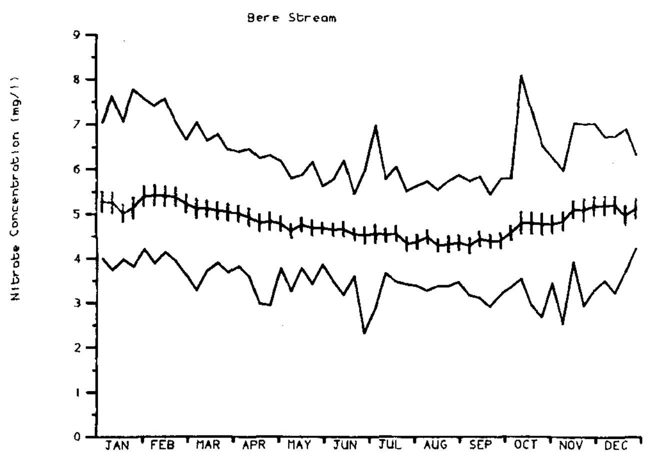

Figure 3 Seasonal variation in nitrate concentration (NO_3N mg/l). For each week (1–52) of the year, the mean, minimum and maximum concentrations over the period 1966–1986 are shown; vertical bars denote one standard error about the mean.

Clarke (1979):

$$N = 3.652 + 0.119\,YR + 0.453\,CW \quad (1)$$
$$(0.027)\ (0.0023)\quad (0.020)$$

where YR = Time since 1966 (Years), representing "Trend"

$$CW = \text{Cosine}((\text{sample week } -5)/52),$$

representing "seasonality" peaking in early February (week 5). Standard errors of regression coefficients are given in brackets.

These two deterministic components jointly explain 74% of the variation in individual nitrate concentration since 1966. However, 62% of the variation is explained simply by the long term linear increase alone.

This simple model suggests that the average seasonal cycle has an amplitude or range of about 0.9 mg/l. However, it seemed likely that as nitrate levels have risen, so the amount of seasonal variation would also increase. To assess this, an

Table 3 Seasonal Trends in nitrate concentration: (a) Quarterly means of nitrate concentration (mg/l) in the Bere Stream over the period 1966–86. (b) Linear regression of quarterly mean nitrate concentration (N) against year (T) since 1966, separately for each season of the year: Regression equation: N = a + b.T; SE(b) = Standard Error of slope b, r^2 = % variation in quarterly mean explained, r_s = Spearman rank correlation

Year	*JAN–MAR*	*APR–JUN*	*JUL–SEP*	*OCT–DEC*	*Annual mean*
(*a*)					
1966	4.11	4.38	3.74	3.86	4.02
1967	4.16	3.74	3.83	3.79	3.88
1968	4.05	3.69	3.56	3.97	3.82
1969	4.21	4.07	3.64	3.98	3.97
1970	4.43	4.35	3.89	4.35	4.25
1971	4.71	4.27	3.75	4.20	4.23
1972	4.55	4.33	3.90	4.11	4.23
1973	4.62	3.92	3.64	4.24	4.10
1974	4.70	4.33	3.83	4.70	4.39
1975	4.81	4.43	4.11	4.73	4.52
1976	4.84	4.07	3.94	6.36	4.77
1977	5.58	4.93	4.50	4.88	4.97
1978	5.40	4.95	4.59	5.01	5.01
1979	5.75	5.29	5.24	5.41	5.42
1980	5.52	5.03	4.88	5.47	5.22
1981	5.95	5.28	5.17	5.84	5.55
1982	6.43	5.71	5.12	5.61	5.72
1983	6.13	5.44	5.46	6.18	5.80
1984	6.43	5.61	5.27	5.84	5.80
1985	6.40	5.76	5.38	5.93	5.86
1986	6.87	5.83	5.39	5.60	6.02
(b)					
a	3.82	3.70	3.36	3.72	
b	0.1401	0.1033	0.1064	0.1254	
SE(b)	0.0076	0.0104	0.0096	0.0135	
r^2	95	84	87	82	
r_s	0.97	0.88	0.93	0.91	

extra term CWYR was added to above equation to represent the extent to which the seasonal variation increased with the trend.

Defining CWYR = CW × YR, led to a second descriptive model:

$$N = 3.650 + 0.119\,YR + 0.250\,CW + 0.021\,CWYR \quad (2)$$
$$(0.027) \quad (0.0023) \quad (0.038) \quad (0.0033)$$

which explained 76% of the total variation. The improvement was small but significant. This can be re-expressed as:

$$N = 3.650 + 0.119\,YR + (0.250 + 0.021\,YR)CW \quad (3)$$

If this model holds, it implies that as the annual mean has increased, so the smoothed seasonal variation within a year has increased from 0.5 mg/l in 1966 to about 1.3 mg/l by 1986.

The descriptive model suggests that the seasonal pattern of nitrate concentration may have changed over the period, perhaps due to changes in farming practice and timing of fertiliser application. Perhaps the increases have occurred more in some seasons than others. Obviously, such effects would not be great in this stream as the system is buffered by the important groundwater supply.

However, to examine this, Table 3 and Figure 4 show the changes in three-monthly mean nitrate concentration over the period 1966–1986. The linear trends for each quarter separately, given in Table 3, show that nitrate concentration has increased in all seasons of the year, but the increase is greatest in winter. Average summer (July–September) concentration has increased by about 1.5 mg/l from about 3.7 mg/l in the late 1960's, while average winter (January–March) concentration has increased by about 2.5 mg/l from about 4.1 mg/l.

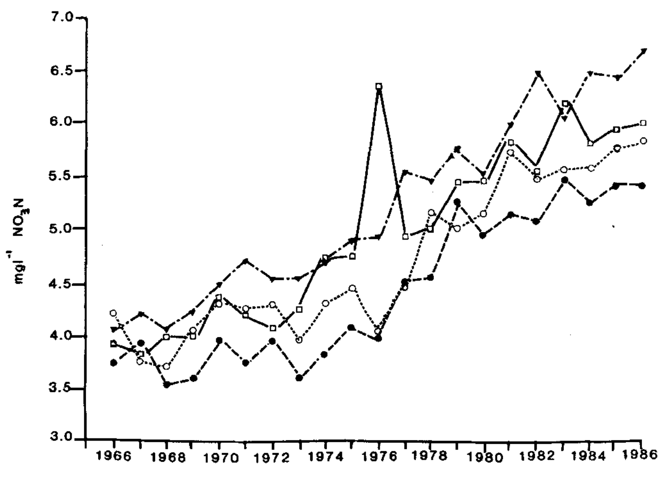

Figure 4 Quarterly trends in mean nitrate concentration for the Bere Stream over the period 1966–1986. ▼, ○, ●, □, denote the periods Jan–March, April–June, July–Sep, Oct–Dec.

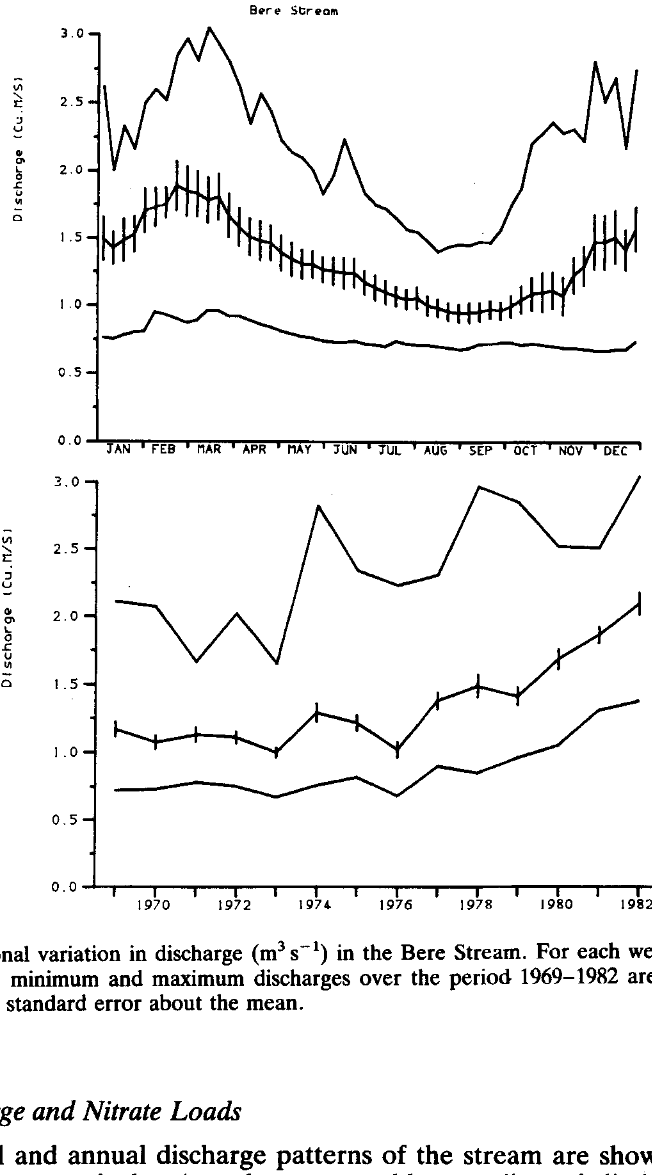

Figure 5 Seasonal variation in discharge ($m^3 s^{-1}$) in the Bere Stream. For each week (1–52) of the year, the mean, minimum and maximum discharges over the period 1969–1982 are shown; vertical bars denote one standard error about the mean.

3.2. *Discharge and Nitrate Loads*

The seasonal and annual discharge patterns of the stream are shown in Figure 5 and Table 4 respectively. An adequate weekly sampling of discharge was not available for all 21 years but the years covered show great stability, with discharges ranging only between 0.67 and 2.94 m^2s^{-1} over the whole 14 years sampled. The average discharge has steadily increased since the mid-1970's.

For those years with adequate discharge data, the long-term trends in nitrate loads are shown in Table 5 and the seasonal variation in loads is shown in Figure 6. Because there were relatively low discharges during the early 1970's in this catchment (Table 4), the nitrate loads did not start to increase until 1977.

Table 4 Yearly statistics for weekly sampled discharge (m^3/s) in the Bere Stream, Dorset

Year	*Mean*	*S.D.*	*Minimum*	*Maximum*
1969	1.17	0.39	0.72	2.02
1970	1.07	0.36	0.74	2.03
1971	1.12	0.21	0.87	1.65
1972	1.11	0.31	0.78	2.02
1973	1.00	0.26	0.67	1.67
1974	1.29	0.47	0.79	2.68
1975	1.21	0.40	0.82	2.32
1976	1.01	0.38	0.69	2.05
1977	1.38	0.44	0.90	2.33
1978	1.46	0.57	0.85	2.94
1979	1.44	0.41	0.97	2.19
1980	1.67	0.43	1.06	2.38
1981	1.87	0.34	1.32	2.38
1982	2.13	0.50	1.37	2.91

Table 5 Yearly statistics for nitrate load (tonnes NO_3N per week) in the Bere Stream, Dorset

Year	*Mean*	*S.D.*	*Minimum*	*Maximum*
1969	2.84	1.11	1.62	5.58
1970	2.80	1.08	1.63	6.07
1971	3.05	0.72	2.38	4.91
1972	2.81	0.95	1.61	6.11
1973	2.51	0.81	1.45	4.68
1974	3.47	1.53	1.75	8.02
1975	3.37	1.32	1.82	7.05
1976	3.09	1.91	1.56	8.04
1977	4.24	1.73	2.02	7.82
1978	4.74	2.18	2.08	10.08
1979	4.67	1.63	2.81	10.93
1980	5.46	1.71	2.95	8.32
1981	6.16	1.59	4.06	9.22
1982	7.42	2.46	4.03	12.01

Thereafter loads have steadily increased as a product of increased nitrate concentrations and discharges. In 1982 the last year with discharge available, the total annual nitrate load past the sampling point was estimated to be 391 NO_3N tonnes.

4. CONCLUSIONS

The mean yearly nitrate concentrations show a very similar increase to that of the River Frome (Casey & Clarke, 1979), the concentrations increasing at an average rate of 0.12 mg/l per year. The yearly mean concentration has increased from

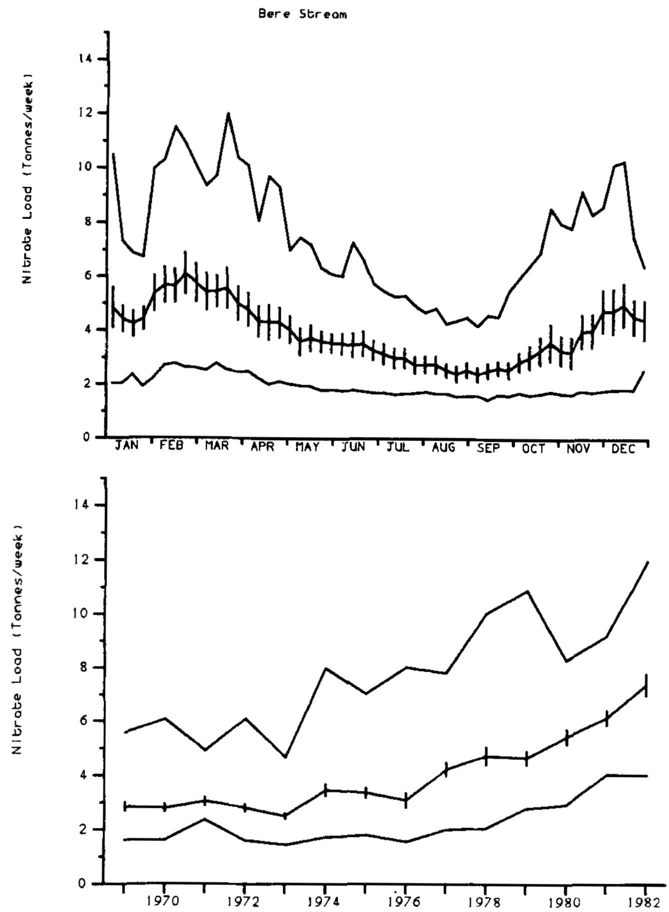

Figure 6 Seasonal variation in nitrate loads (NO_3N tonnes/week) in the Bere Stream. For each week (1–52) of the year, the mean, the minimum and maximum loads over the period 1969–1982 are shown; vertical bars denote one standard error about the mean.

4.02 mg/l in 1966 to 6.02 mg/l in 1986, the minimum value increased from 2.52 mg/l in 1966 to 4.90 mg/l in 1986 and the maximum yearly value increased from 4.82 to 7.78 mg/l.

The simple regression model predicts the mean nitrate concentration for the next two years, 1987 and 1988, to be 6.15 and 6.27 mg/l. In fact, the averages were 5.88 and 5.94 mg/l, suggesting that the increasing trend had possibly ceased. The maximum value found in 1988 was lower than that found in previous years, possibly showing a change in farming practice and or fertiliser applications.

An interesting observation is that in 1976, the year of a drought, unlike other streams and rivers in other parts of England and Wales, maximum and minimum values did not show the very extreme values found in other streams and rivers (Casey & Clarke 1979, Greene, 1978, Walling & Foster, 1978). Walling and Foster (1978) found a maximum of 80 mg/l within a small subcatchment of

1.6 km^2 of the Jackson Brook basin in the River Exe system that was 45 times higher than those previously encountered at that time of year.

The high groundwater component of the Bere Stream discharge acts as a buffer and prevents the occurrence of the extreme high nitrate concentrations occasionally found in other U.K. streams and rivers.

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