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Temperature observations in the River Wye and the River Elan an Impounded Tributary, for the Period 1977-1979

INTRODUCTION

Water discharged from impoundments, particularly from lower depths, may radically modify the downstream temperature regime (Lavis and Smith, 1972; Crisp, 1977; Bolke and Waddel, 1975). This report presents the results of temperature measurements made over three years (1977-1979) in the upper River Wye and the River Elan, an impounded tributary. The temperature regime of the impounded tributary is compared with that of the Wye above the confluence and its influence on downstream temperatures is considered.

STUDY AREA

The R. Wye is 250 km long and rises at Plynlimon (677m A.O.D.). Two major tributaries enter the Wye in its upper reaches: the R. Marteg, 28 km from the source and the R. Elan, 37 km from the source. The catchments of these tributaries contribute approximately 50 and 180 km^2 respectively to the total catchment area of 370 km^2 immediately downstream of the Elan confluence (185m A.O.D.). The impounded R. Elan receives a compensation flow of $1.34 m^3 s^{-1}$, but much higher flows may occur at times of impoundment overspill. At the confluence with the Elan the R. Wye is unregulated, and subject to wide natural fluctuations in flow; the A.D.F. at this point is $5.84\ m^3\ s^{-1}$. During 1977 for approximately 62% of the year (225 day) the flow of the Wye above the confluence was higher than the discharge from the impoundment into the R. Elan (Fig. 1).

METHODS

Maximum and minimum mercury thermometers (referred to as max-min thermometers) positioned at four sites on the R. Wye and two sites on the R. Elan (Fig. 2) were read to the nearest 0.5^{o}C, weekly from January 1977 to December 1979. Weekly mean temperatures were calculated as the mean of weekly maximum and minimum values. In addition, continuous temperature recorders (Rustrack, Cambridge Instruments Ltd.) were installed for certain periods in 1978 downstream of Caban Coch Reservoir on the R. Elan (El) and at two sites on the R. Wye, one above (W2) and the other below the confluence (W4).

When comparisons of mean temperatures were made from weekly readings of max-min thermometers and continuous recorders, agreement was extremely close. The correlation between mean weekly temperatures calculated from hourly readings and from max-min records was very high (r = 0.95) for W4 and E1 (Table 1). At W4 the weekly ranges in temperature, given by the two methods of temperature measurement, were also highly correlated (r = 0.68). At E1, however where weekly temperature ranges were low (3^{o}CP compared with potential instrument error and the measurement interval of the max-min thermometers (0.5^{o}C), the correlation was low (r = 0.17) (Table 1). Clearly any differences in ranges results in differences in primary measurements, there being no data reduction or conversion as there is with the derivation of mean values.

RESULTS

Annual-Mean Temperatures

Table 2 shows the annual mean temperature for the three years and also the 3-year average of the annual mean temperature at each site. Annual mean temperatures increase downstream in the R. Elan (7.4^{o}C) to 8.1^{o}C) and also to a lesser extent in the Wye (9.3^{o}C to 9.5^{o}C), except at W3 where annual mean temperature (8.7^{o}C) is lowered due to the influence of the Elan 3 km upstream.

Monthly-and weekly-mean temperatures

Mean-monthly temperatures, derived from weekly readings of max-min thermometers, reached lowest values (2-3^{o}C) in January or February at all sites (Fig. 3). Temperatures increased at similar rates at all sites until April after which site differences were marked. IN the Wye sites, particularly above the confluence (W1, W2), temperature rapidly increased and reached a peak of 14-19^{o}C by July. However, in the R. Elan, mean temperatures increased at a slower rate (0.8^{o}C month^{-1} compared with up to 1.8^{o}C month^{-1}) and the lower peak values (11-13^{o}C) were delayed until September. The greatest differences in the mean monthly temperatures (6-7^{o}C) between sites occurred during May – July, the period of major temperature increase.

Table 3 shows the value and time of the annual-maximum mean-weekly temperature at all sites. The annual-maximum for Elan sites was about 5^{o}C lower than sites in the Wye above the confluence (W1, W2), sites downstream of the confluence having intermediate values. The time of the annual-maximum temperatures in the Elan was delayed by between 70 and 110 days during the period 1977-9 (except for E2 in 1977) when compared with the upper Wye (W1, W2): below the confluence peak temperatures occurred at intermediate times.

Monthly and weekly temperature ranges

The monthly ranges were reduced in the R. Elan when compared with the Wye, consistently so at E1, and to a lesser extent at E2 (Fig. 4). At W1 and W2 the monthly ranges generally exceeded 10^{o}C for short periods during the summer months in contrast with E1 where the range rarely exceeded 6^{o}C.

Table 4 shows the weekly ranges averaged over three-monthly periods during 1978. In the R. Wye the range decreased downstream in contrast with the R. Elan where 1+ increased downstream. At the least variable site (e1) the average weekly range was less than 2^{o}C and compared with about 5.4^{o}C at the most variable (W1).

Both monthly maximum and minimum temperatures (Figs 5 and 6) showed the same general annual trends as monthly mean values but certain distinctive features are worth noting. During 1978 and 1979 minimum temperatures at E1 only fell below minimum values at other sites during May-August and were generally higher than at other sites from September to December. Invariably maximum values at E1 were lower than those at all other sites, and particularly so from April to August. Site differences between monthly minimum temperatures were low (2-4^{o}C) compared with monthly maximum temperatures, particularly during spring and summer months (up to 14^{o}C).

A difference in the timing of peak maximum and minimum temperatures occurred in the R. Wye, maximum temperatures (19-23^{o}C) generally being in July and a month earlier than peak minimum temperatures: such a difference was not evident in the R. Elan.

Diurnal Temperature Variation

The daily temperature range at E1 was significantly reduced (P = 0.01) compared with those at W2 and W4: this difference is shown in Table 5 for a period of high and one of low monthly temperature range during 1978. The daily ranges at W2 and W4 were not significantly different (P= 0.1) from each other. Single daily ranges at W2 are up to 7.5^{o}C, the highest daily range in the Elan was only 2.5^{o}C during the two periods examined (Fig. 7).

Cumulative Degree Days

The suppression and delay of mean and maxima temperatures at R. Elan sites is reflected in the values of cumulative degree days (c.d.d.) at these sites when compared with R. Wye sites (Fig. 8). In 1978 at the end of July the value for c.d.d. at E1 was only 63.4% of the maximum value for the Wye at W4 (Table 6). By the end of 1978, when temperatures at all sites were similar, the value for c.d.d. at E1 was still only 78% of that at W4. The c.d.d. values at W3 show the influence of the R. Elan, being reduced when compared with values for the Wye above the confluence: the influence is no longer apparent at W4 further downstream.

Temperature Models

Using multiple regression techniques, models of the mean weekly river temperatures at E2, W3 and W4 were constructed from the 1977 and 1979 temperature data at upstream stations of a reach i.e. W2, W3, E1 and E2, together with river flow and local air temperature (Institute of Hydrology, Moel Cynedd Weather station) data. These models were then used to predict mean weekly temperatures for 1979: only river temperatures at E1 and W2 were used – those at all downstream sites being predicted in sequential manner. Reasonably accurate prediction of temperature at E2 was only achieved using two equations for different periods of the year (Table 7): the periods November – April and May – October seemed most appropriate in view of the temperature and flow characteristics of the system. In contrast, satisfactory prediction was possible at other sites (W3 and W4) using only one equation for the whole year (Figs 9-11, Table 8). The retention time of water between sites, included in the construction of some models, did not improve the accuracy of the models appreciably – this is in part explained by the high positive correlation between retention time and air temperature (r – 0.44), the latter being included in the models also.

Discussion

Thompson (1954) has shown that temperature gradients exist in the Caban Coch Reservoir, such that differences of between 4^{o}C – 11^{o}C occur between the surface waters and the bottom layers. During the summer, water released from the bottom of the Caban Coch dam is relatively cool compared with natural river temperatures within the area at that time. By October the reservoir is usually thoroughly mixed, mainly by storms

(Thompson 1954), and the mean discharge temperature is similar to that in the natural river system. However, the minimum temperatures of the discharge are never so low as temperature minima of the main river: this disparity is maintained throughout the winter because of the high heat storage capacity of the reservoir (35.5 x 10^6 m^3).

The release of compensation water from the Caban Coch impoundment therefore has marked effects on the temperature regime in the R. Elan downstream and to a lesser extent on the R. Wye below the confluence.

The annual mean temperature was reduced by up to 2.1°C at E1 compared with W1, Lavis and Smith (1972) report only a 0.09°C drop in annual mean temperature between the R. Lune above Grassholme reservoir and the outlet of the Selset reservoir, downstream of both Grassholme and Selset.

The natural range of temperature in the R. Elan, considered on diurnal, weekly and monthly time scales, is greatly reduced by the impoundment discharge; mean maximum and minimum temperatures are also affected. This change is revealed by comparison of the temperature regimes at E1 and the upper sites on the R. Wye (W1, W2). Diurnal ranges of up to 7.5°C were found at W2 compared with only 0.5°C at E1, a similar difference in range (8.5°C) was found by Crisp (1977) when the regulated R. Tees, below Cow Green reservoir, was compared with the nearby, unregulated Maize Beck. Lavis and Smith (1972) found a 12°C difference in the daily range of natural and impoundment discharge temperatures in the catchment of the R. Lune. The reduction of temperature range in the R. Elan is mainly due to a lowering of the maximum temperatures. Crisp (1977) also noted a reduction in daily maxima of the regulated R. Tees.

The peak in weekly mean temperature at E1 was depressed by up to 6°C and delayed 66-108 days when compared with Wye sites. Crisp (1977) only observed a decrease of 1.3°C and a delay of 0-20 days in the mean monthly peak temperature of the R. Tees below Cow Green. However, Crisp (1977) does report a delay of 20-50 days in the spring temperature rise for the river below the dam, this effect was not noted in the present study or that of Lavis and Smith (1972). A delay in the monthly mean temperature peak and trough, together with a reduction in monthly temperature ranges (0°C – 19.5°C to 3.5°C – 10.0°C) was observed by Bolke and Waddel (1975) in the Green River before and after the construction of the Flaming Gorge reservoir upstream.

The effects of the impounded water discharge are still noticeable at W3 on the R. Wye, 3 km below the confluence with the R. Elan and 11 km below the Caban Coch dam outlets. The temperature ranges at W3 are smaller than the other R. Wye sites and the mean and maximum temperatures are reduced. However, at W4, 22 km downstream of the impoundment discharge, these effects appear to be largely dissipated. Lavis and Smith (1972) found summer maxima depressed by up to 3°C. 3 km downstream of the Selset reservoir outlets. Much larger effects were noted by Williams (1968) in the upper Delaware catchment; river temperatures were reduced by 14°C and 4°C, 13 km and 70 km respectively downstream of the Cannonsville reservoir.

Smith (1968) has suggested two basic patterns of river temperature regimes: firstly, in small spring fed rivers the temperature range increases downstream, largely in response to air temperature fluctuations, and secondly, in rivers fed by limited aquifers the temperature range decreases downstream as groundwater has an increasing effect and the river becomes larger and less responsive to changing air temperatures. The R. Elan and R. Wye fit these two categories respectively, W3 below the confluence being influenced by both sources.

References

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Thompson, R.W.S. (1954). Stratification and overturn in lakes and rivers. *J. Inst. Wat. Eng.,* **8**, 19-36.

Williams, O.O. (1968). Reservoir effect on downstream water temperatures in the Upper Delaware River Basin. *U.S. Geol. Surv. Prof. Paper* 600-B. 195-199.

Table 1

Regression and correlation statistics for the relationship between the weekly mean temperature and weekly temperature range calculated from the continuous recorders (hourly readings) and the max-min thermometers at E1 and W4 during 1978

Mean Weekly Temperature						
	n	**slope**	**intercept**	**r**	**r^2**	**sig r**
W4	28	1.04	0.14	0.98	0.95	0.00001
E1	19	0.94	0.52	0.95	0.89	0.00001
Weekly Temperature Range						
W4	28	0.55	1.79	0.68	0.46	0.00003
E1	19	0.18	1.50	0.17	0.03	> 0.05

Table 2

Annual Mean Temperature at sites on he R. Wye and R. Elan (From weekly max-min records)

Year	E1	E2	W1	W2	W3	W4
1977	7.6	8.2	-	9.4	9.0	9.7
1978	7.3	8.0	9.1	9.1	8.4	9.4
1979	7.4	8.1	9.5	8.8	8.8	9.3
Mean	7.4	8.1	9.3	9.1	8.7	9.5

Table 3

Relative times of annual peaks in mean weekly temperatures

Site	1977		1978		1979	
	Peak Temp. (°C)	Time from 1 January (days)	Peak Temp. (°C)	Time from 1 January (days)	Peak Temp. (°C)	Time from 1 January (days)
E1	13.0	259	13.3	263	12.5	274
E2	13.0	196	13.0	267	12.5	274
W1	ND	ND	18.5	155	18.5	208
W2	17.0	190	17.8	155	17.3	215
W3	17.5	183	14.0	246	15.3	215
W4	18.5	190	16.0	197	16.3	222

Table 4

Average weekly ranges (°C) for three-monthly periods 1978.

Period	Site					
	E1	**E2**	**W1**	**W2**	**W3**	**W4**
Jan-Mar	1.5	2.5	3.9	4.0	3.8	3.7
Apr-Jun	1.8	4.8	6.4	6.4	5.3	5.2
Jul-Sep	2.2	4.0	6.3	5.5	4.5	4.5
Oct-Dec	1.7	2.8	5.9	4.5	4.1	3.9

Table 5

Mean diurnal temperature ranges (°C) for E1, W2 and W4, during two periods; with low and high monthly temperature ranges

	Low Monthly Range (9/2/78 – 11/3/78)	**High Monthly Range (24/4/78 – 23/5/78)**
	Mean Diurnal range +95% C.L.	Mean diurnal range +95% C.L.
El	0.37 $\pm$ 0.19	0.67 $\pm$ 0.18
W4	1.19 $\pm$ 0.22	2.80 $\pm$ 0.62
W2	-	3.32 $\pm$ 0.57

Table 6

Cumulative Degree Days (% of W4 in parentheses)

Year	**Days from 1st Jan**	**E1**	**E2**	**W1**	**W2**	**W3**	**W4**
1977	212	1390	1584.7	-	1905.0	1792.0	1946.3
		(71.4)	(81.4)	-	(97.9)	(92.1)	
	350	2744.8	3027.5	-	3429.1	3283.2	3528.1
		(77.8)	(85.8)	-	(97.2)	(93.1)	
1978	212	1159.6	1419.2	1741.2	1792.0	1575.0	1828.8
		(63.4)	(77.6)	(95.2)	(98.0)	(86.1)	
	350	3671.6	2934.8	3312.8	3307.0	3059.0	3426.5
		(78.0)	(85.7)	(96.7)	(96.5)	(89.2)	
1979	212	1250.3	1460.3	1892.5	1726.3	1632.6	1801.6
		(69.4)	(81.1)	(105.1)	(95.8)	(90.6)	
	350	2546.8	2789.0	3217.8	3024.0	3010.8	3142.3
		(81.1)	(88.7)	(102.4)	(96.2)	(95.8)	
Mean (1977-1979)	212	1266.7	1488.1	1816.8	1807.8	1666.5	1858.9
		(68.1)	(80.1)	(97.7)	(97.3)	(89.7)	
	350	2987.7	2916.4	3265.3	3253.4	3117.7	3365.6
		(88.8)	(86.7)	(97.0)	(96.7)	(92.6)	

Table 7

Equations used to predict Mean Weekly Temperatures for 1979 at E2, W3 and W4 (r^2 gives the percentage variation in the 1977 and 1978 data explained by the equation).

Equation 1

Predicted Temperature, E2 (may-Oct) = 0.4194 (Temperature, E1) + 0.3739 (Air Temperature*) + 2.6509
r^2 = 95%

Equation 2

Predicted Temperature, E2 (Nov-Apr) = 0.9642 (Temperature, E1) – 0.087.
r^2 = 85%

Equation 3

$$\text{Predicted Temperature, W3} = 1.0203 \left(\frac{\text{(Flow, W2 x Temperature, W2) + (Flow, E1 + Temperature, E2)}}{\text{Flow, W2 + Flow, E1}} \right) - 0.1790$$

r^2 = 98%

*Air temperature at Moel Cynedd, Institute of Hydrology Weather Station.

Table 8

Accuracies of Equation in Table 7 in predicting 1979 temperatures at E2, W3 and W4 using regression statistics.

Temperature, E2 (using equation 1 and equation 2)

Slope = 0.9882 n.s. diff from 1 (P= 0.05)
mean residual sum of squares (m.r.s.s.) = 0.282

Temperature, W3

Slope = 0.9530 n.s. diff from 1 (P=0.05) m.r.s.s. = 0.980

Temperature, W4

Slope = 0.9754 n.s. diff from 1 (P = 0.05) m.r.s.s. = 1.280

Figure 1

Cumulative days that flow is less than at W2 and E1

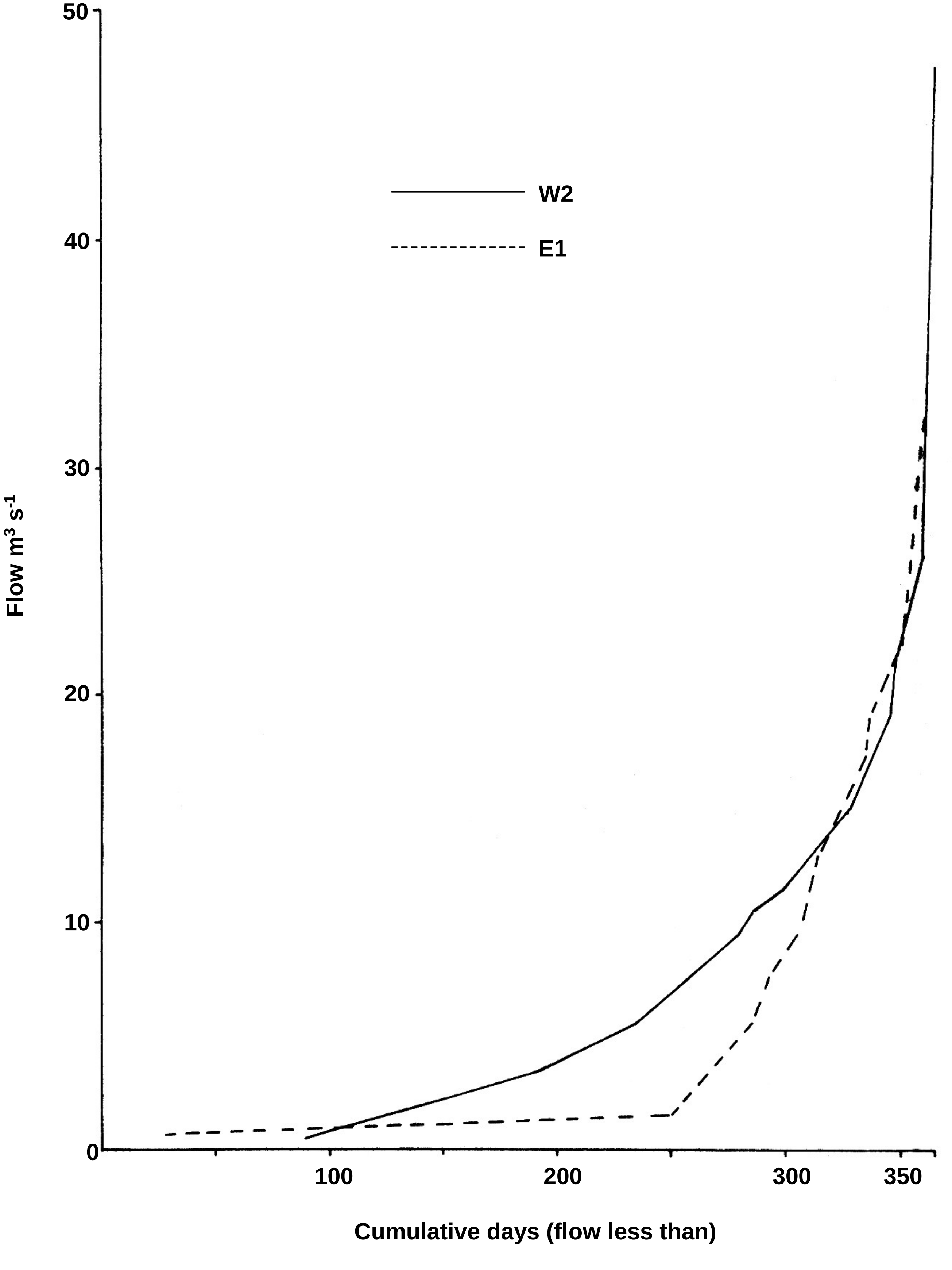

Figure 2

Location of Temperature and Flow monitoring stations on the R. Wye and R. Elan

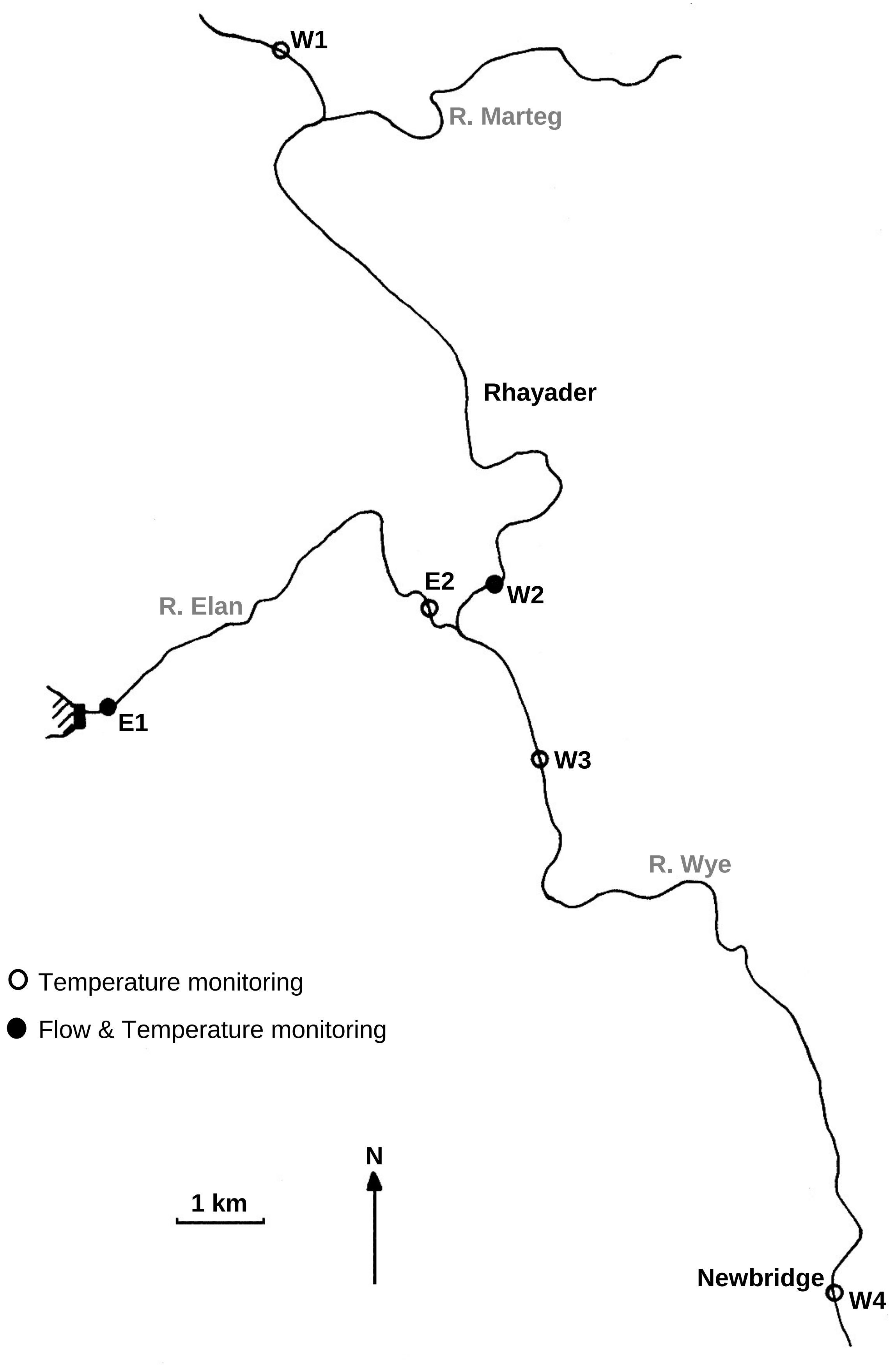

Figure 3

Mean monthly temperature (from max-min records for 1977-1979 at sites on the R. Wye and R. Elan)

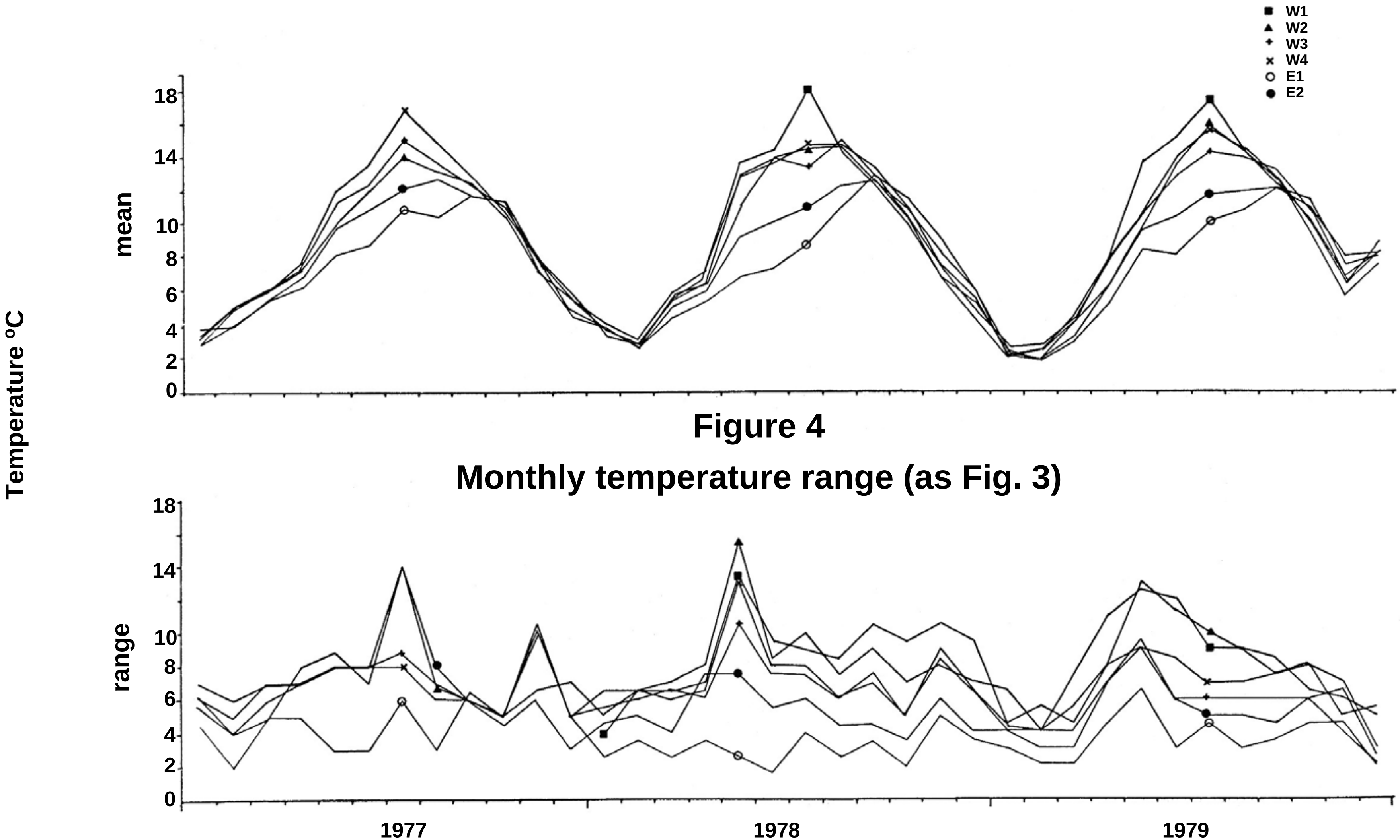

Figure 4

Monthly temperature range (as Fig. 3)

Figure 5

Monthly maximum temperature (as Fig. 3)

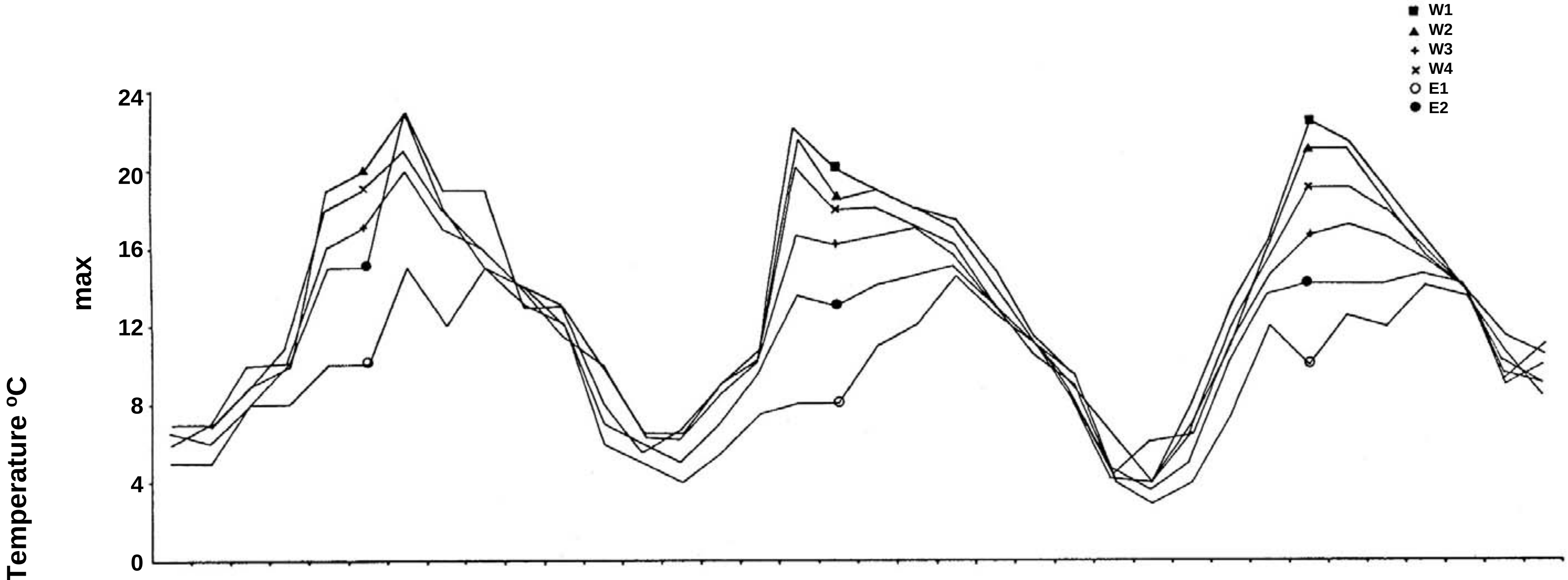

Figure 6

Monthly minimum temperature (as Fig. 3)

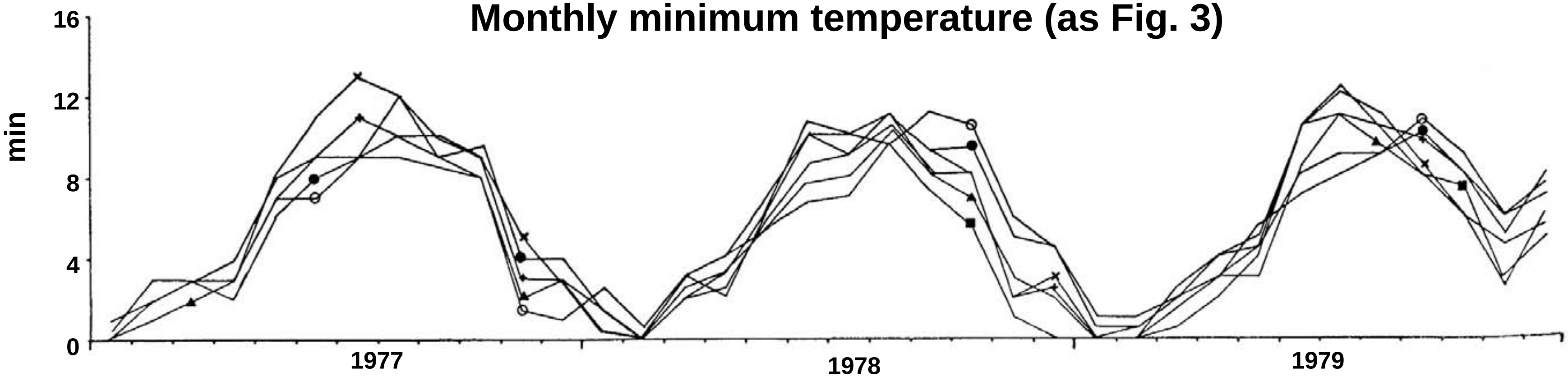

Figure 7

Diurnal temperature range at sites on the R. Wye and R. Elan for two 30-day periods; one period with a high range and one with a low range.

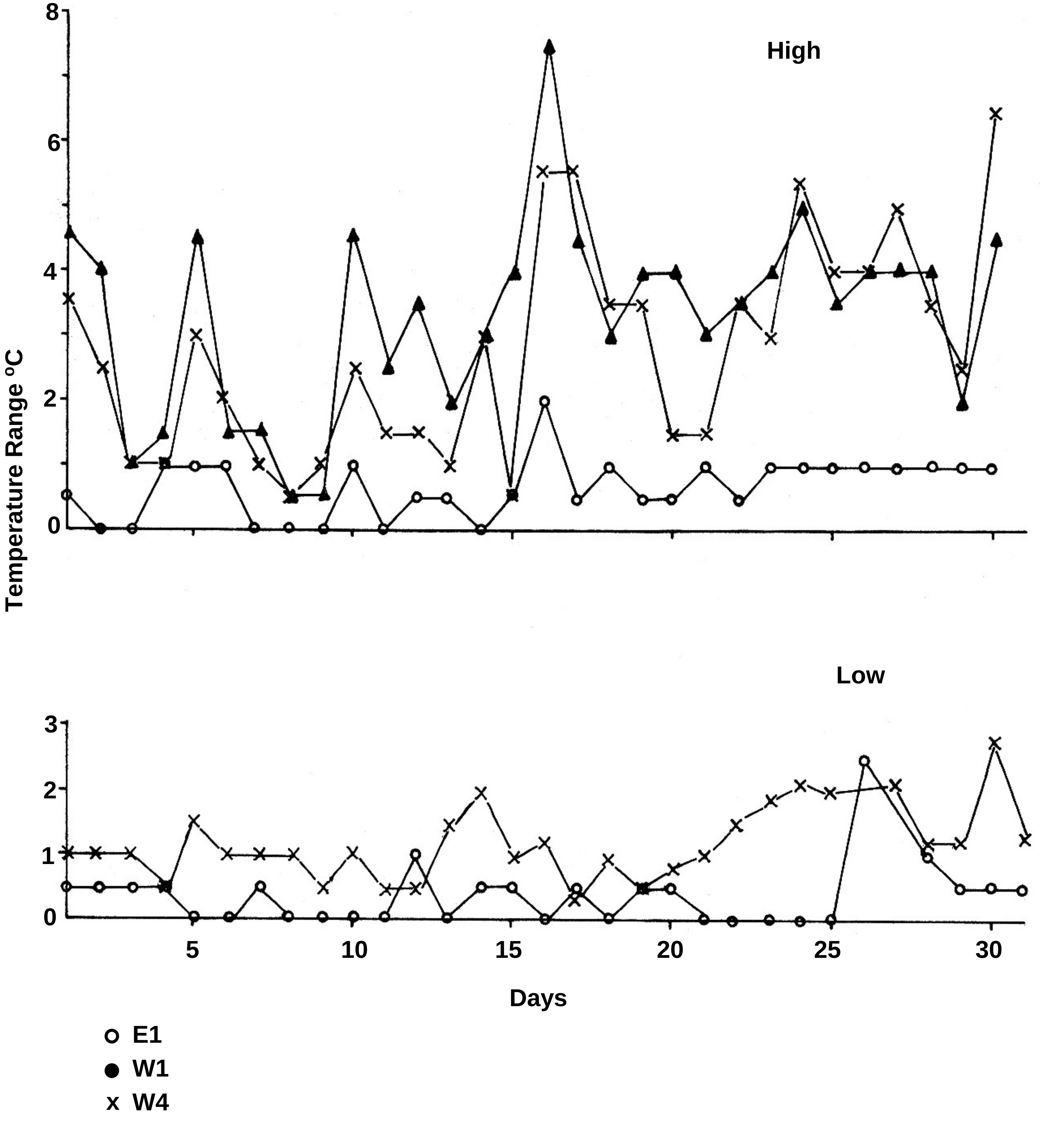

Figure 8

Cumulative degree days for 1977-1979 at sites on the R. Wye and R. Elan

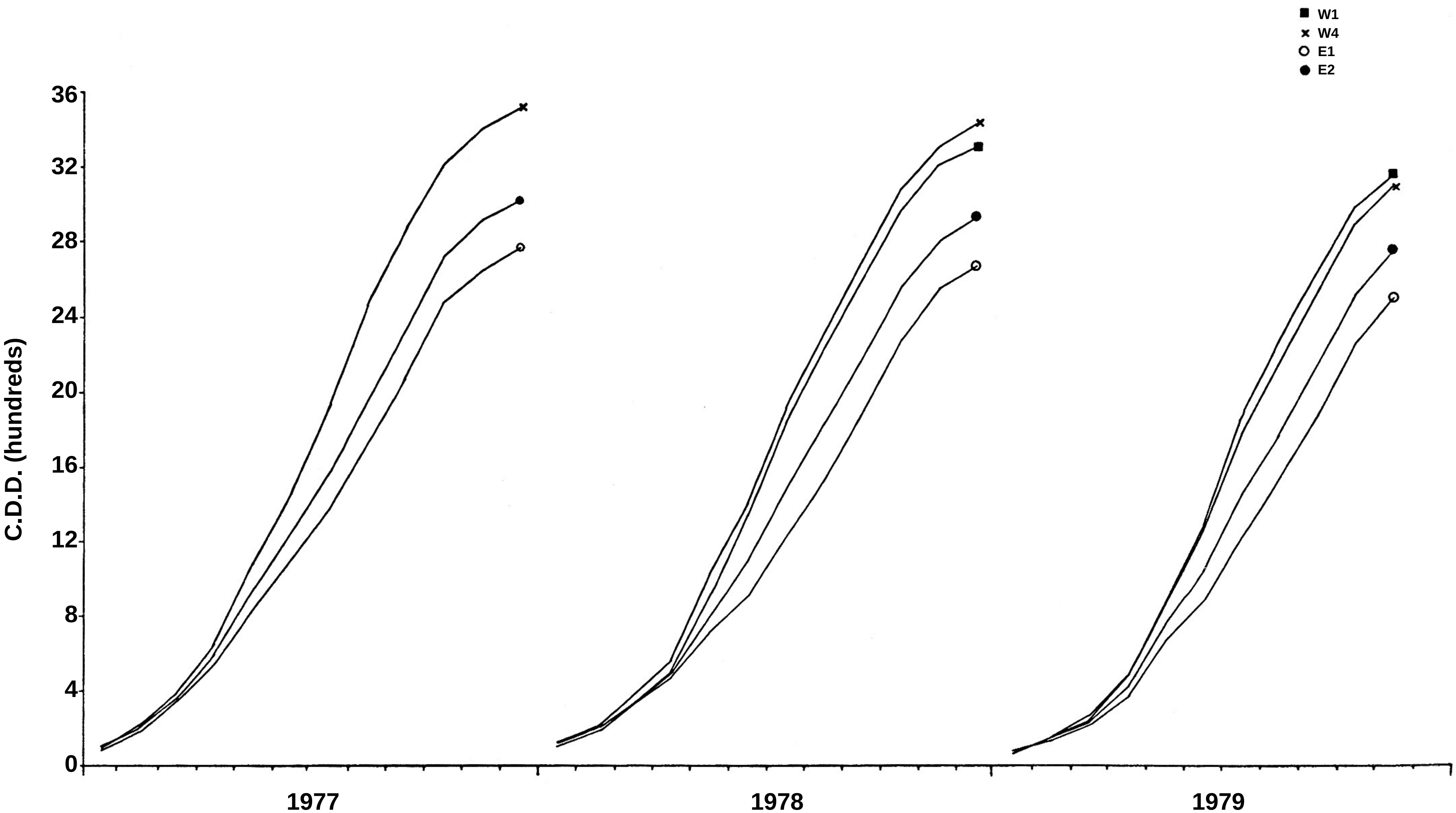

Figure 9

Observed and modelled weekly mean temperatures for 1979 at sites on the R. Wye and one of the R. Elan.

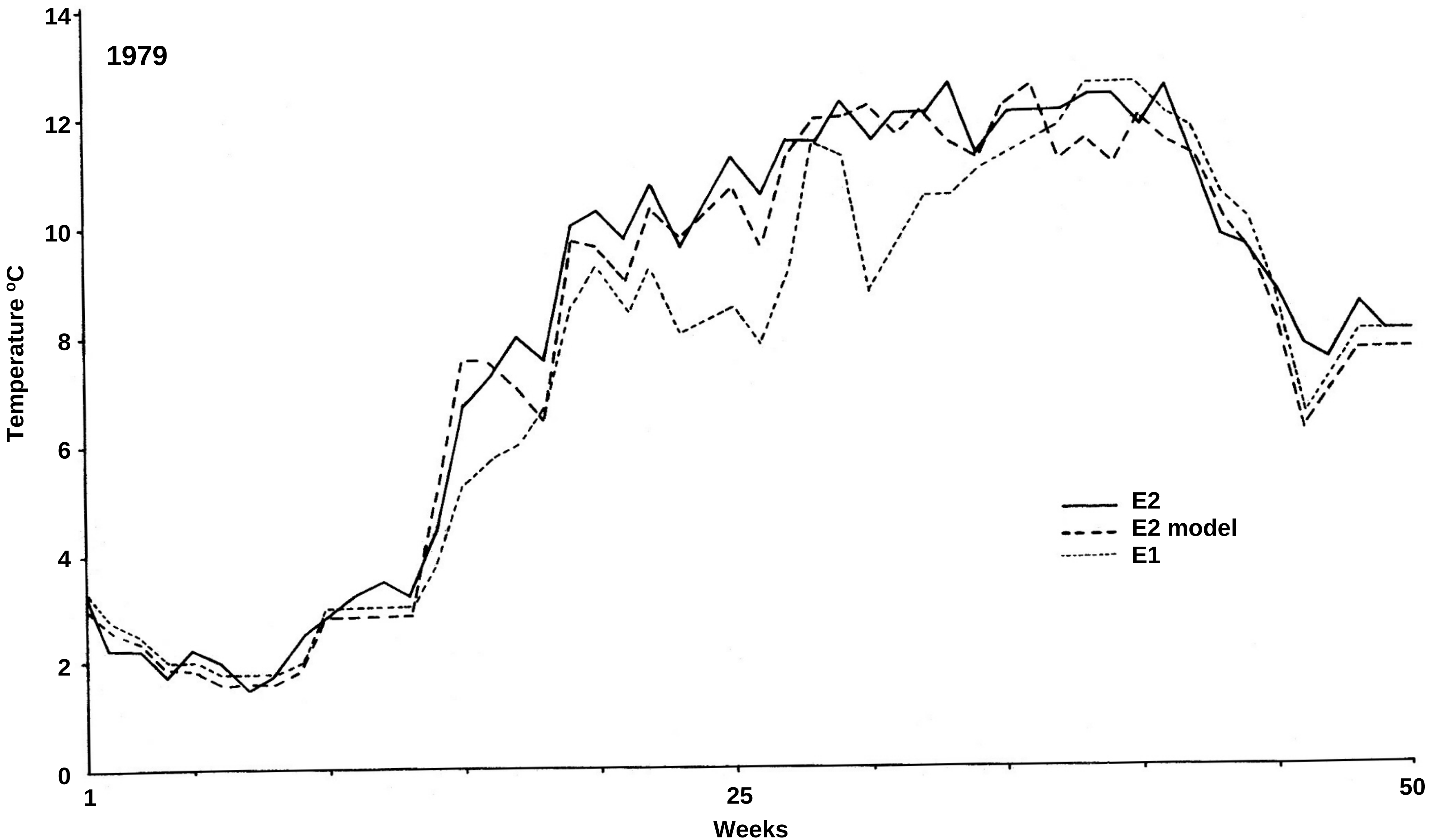

Figure 10

Observed and modelled weekly mean temperatures for 1979 at sites on the R. Wye and one of the R. Elan.

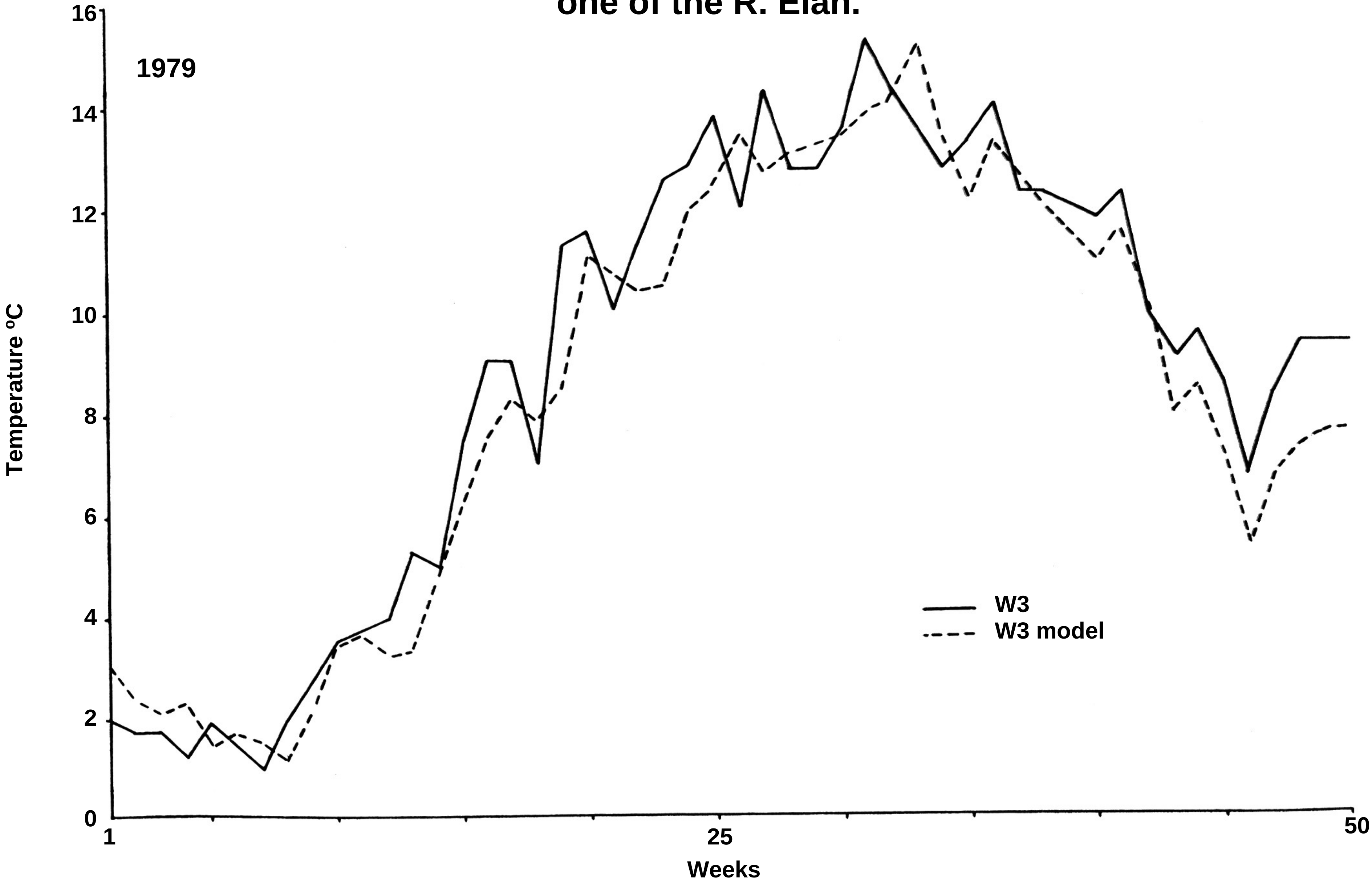

Figure 11

Observed and modelled weekly mean temperatures for 1979 at sites on the R. Wye and one of the R. Elan.