SOME APPLICATIONS OF FLOOD ROUTING METHODS WITH PARTICULAR REFERENCE TO SMALL STREAMS

by

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VOLUME II - APPENDICES

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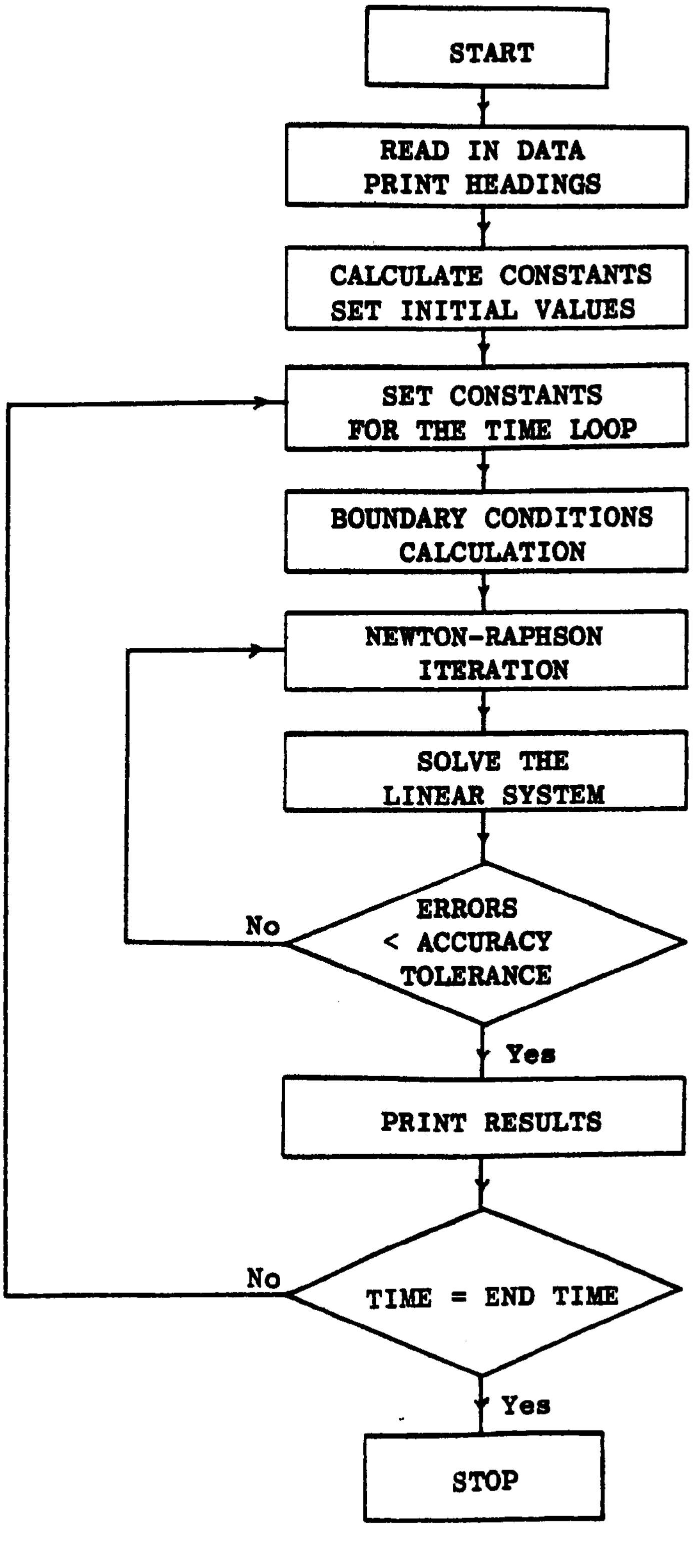
Appendix I Implic 6 Computer Program Flow Chart

The computer program solves the one-dimensional equations of unsteady flow using an implicit finite difference scheme with an irregular space network and a variable weighting factor.



Appendix II Solution of the Implicit Method Linear System

This appendix provides the mathematical details of the linear system solution technique described in Section 3.4.3. The coefficients of the linear system (Eqn. 3.38) are partial derivatives which must be calculated for each iteration.

The finite difference approximation to the continuity equation is written:

$$Ci = \tfrac{1}{2}\left((A_{i+1} + A_i) - (A'_{i+1} + A'_i)\right) + \frac{Dt}{Dx}\left(\theta(Q_{i+1} - Qi) + (1-\theta)(Q'_{i+1} - Q'_i)\right) - q\ Dt = 0. \qquad \text{- (II.1)}$$

The linear coefficients are obtained from partial differentiation:

$$\frac{\partial Ci}{\partial yi} = \frac{Bi}{2}, \quad \frac{\partial Ci}{\partial y_{i+1}} = \frac{B_{i+1}}{2} \qquad \text{- (II.2)}$$

$$\frac{\partial Ci}{\partial Qi} = -\frac{Dt}{Dx}\theta, \quad \frac{\partial Ci}{\partial Q_{i+1}} = \frac{Dt}{Dx}\theta \qquad \text{- (II.3)}$$

Similar coefficients are obtained from the finite difference approximation to the momentum equation:

$$\begin{aligned} Mi = {} & \tfrac{1}{2}\left((Q_{i+1} + Q_i) - (Q'_{i+1} + Q'_i)\right) \\ & + \frac{Dt}{Dx}\left(\theta\left(\left(\frac{Q^2}{A}\right)_{i+1} - \left(\frac{Q^2}{A}\right)_i\right) + (1-\theta)\left(\left(\frac{Q^2}{A}\right)'_{i+1} - \left(\frac{Q^2}{A}\right)'_i\right)\right) \\ & - g\frac{Dt\ So}{2}\beta \\ & + \frac{g\ Dt}{4}\beta\left(\theta\left(Sf_{i+1} + Sf_i\right) + (1-\theta)\left(Sf'_{i+1} + Sf'_i\right)\right) \\ & + \frac{g\ Dt}{2Dx}\beta\left(\theta\left(y_{i+1} - y_i\right) + (1-\theta)\left(y'_{i+1} - y'_i\right)\right) = 0, \end{aligned} \qquad \text{- (II.4)}$$

where $\beta = \theta\,(A_{i+1} + A_i) + (1-\theta)(A'_{i+1} + A'_i)$. - (II.5)

Partial differentiation with respect to water depth y gives:

$$\frac{\partial Mi}{\partial yi} = + \frac{Dt}{Dx}\,\theta \left(\frac{Q^2B}{A^2}\right)_i - \frac{g}{2}\,Dt\ So\ \theta\ Bi$$

$$+ \frac{\theta\ g\ Dt}{4}\,Bi \left(\theta\left(Sf_{i+1} + Sf_i\right) + (1-\theta)\left(Sf'_{i+1} + Sf'_i\right)\right)$$

$$+ \frac{\theta\ g\ Dt}{4}\,\frac{\partial Sf_i}{\partial y_i}\,\beta$$

$$+ \frac{g\ Dt\ \theta\ Bi}{2Dx}\left(\theta\left(y_{i+1} - y_i\right) + (1-\theta)\left(y'_{i+1} - y'_i\right)\right)$$

$$- \frac{g\ Dt\ \theta\ \beta}{2Dx} \qquad - (II.6)$$

$$\frac{\partial Mi}{\partial y_{i+1}} = - \frac{Dt}{Dx}\,\theta \left(\frac{Q^2B}{A^2}\right)_{i+1} - \frac{g}{2}\,Dt\ So\ \theta\ B_{i+1}$$

$$+ \frac{\theta\ g\ Dt}{4}\,B_{i+1} \left(\theta\left(Sf_{i+1} + Sf_i\right) + (1-\theta)\left(Sf'_{i+1} + Sf'_i\right)\right)$$

$$+ \frac{\theta\ g\ Dt}{4}\,\frac{\partial Sf_{i+1}}{\partial y_{i+1}}\,\beta$$

$$+ \frac{g\ Dt\ \theta\ B_{i+1}}{2Dx}\left(\theta\left(y_{i+1} - y_i\right) + (1-\theta)\left(y'_{i+1} - y'_i\right)\right)$$

$$+ \frac{g\ Dt}{2Dx}\,\theta\ \beta\ , \qquad - (II.7)$$

where $$Sf_i = \frac{Q_i^2\ n_i^2\ P_i^{4/3}}{A_i^{10/3}} \qquad - (II.8)$$

and $$\frac{\partial Sf_i}{\partial Y_i} = \frac{1}{3}\,Sf_i\left(\frac{4}{Pi}\,\frac{\partial Pi}{\partial Yi} - \frac{10\ Bi}{Ai}\right) . \qquad - (II.9)$$

Partial differentiation of Eqn. II.4 with respect to discharge gives:

$$\frac{\partial Mi}{\partial Qi} = \frac{1}{2} - 2\frac{Dt}{Dx}\theta\left(\frac{Q}{A}\right)_i + \frac{g\ Dt\ \beta\ \theta\ Sf_i}{2\ Q_i} \ , \qquad \text{- (II.10)}$$

$$\frac{\partial Mi}{\partial Q_{i+1}} = \frac{1}{2} + 2\frac{Dt}{Dx}\theta\left(\frac{Q}{A}\right)_{i+1} + \frac{g\ Dt\ \beta\ \theta\ Sf_{i+1}}{2\ Q_{i+1}} \ . \qquad \text{- (II.11)}$$

Additional coefficients are also obtained from partial differentiation of the algebraic external boundary conditions. Upstream boundary conditions and corresponding derivatives may be written:

Discharge hydrograph, $B_1 = Q_1 - Q(1)$, $\frac{\partial B_1}{\partial y_1} = 0.0$, $\frac{\partial B_1}{\partial Q_1} = 1.0$. - (II.12)

Depth hydrograph, $B_1 = y_1 - y(1)$, $\frac{\partial B_1}{\partial y_1} = 1.0$, $\frac{\partial B_1}{\partial Q_1} = 0.0$. - (II.13)

Similarly, for downstream boundary conditions:

Discharge hydrograph, $B_N = Q_N - Q(N)$, $\frac{\partial B_N}{\partial y_N} = 0.0$, $\frac{\partial B_N}{\partial Q_N} = 1.0$. - (II.14)

Depth hydrograph, $B_N = y_N - y(N)$, $\frac{\partial B_N}{\partial y_N} = 1.0$, $\frac{\partial B_N}{\partial Q_N} = 0.0$. - (II.15)

Rating curve, $B_N = y_N - \left(f_1 + f_2\ Q_N^{f_3}\right)$,

$$\frac{\partial B_N}{\partial y_N} = 1.0, \ \frac{\partial B_N}{\partial Q_N} = -\left(f_2\ f_3\ Q_N^{(f_3-1)}\right) \ . \qquad \text{- (II.16)}$$

The partial derivatives defined by Eqn. II.1 to II.16 comprise the coefficients of the linear system expressed in a 2N x 4 matrix.

$$A' = \begin{bmatrix} & & a_{1,3} & a_{1,4} \\ a_{2,1} & a_{2,2} & a_{2,3} & a_{2,4} \\ a_{3,1} & a_{3,2} & a_{3,3} & a_{3,4} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ a_{2N-2,1} & a_{2N-2,2} & a_{2N-2,3} & a_{2N-2,4} \\ a_{2N-1,1} & a_{2N-1,2} & a_{2N-1,3} & a_{2N-1,4} \\ a_{2N,1} & a_{2N,2} & & \end{bmatrix} \qquad \text{- (II.17)}$$

A technique based on Gaussian elimination is used to solve the linear system:

$$A'X = R \qquad \text{- (II.18)}$$

Two sets of recurrence formulae are applicable to alternate rows, and then components in the solution column vector X are found from a back-substitution process. Initial values are set:

$$t_{1,3} = a_{1,3}\ , \quad t_{1,4} = a_{1,4}\ , \quad z_1 = R_1\ . \qquad \text{- (II.19)}$$

Recurrence formulae for even numbered rows (i = 2,4,6, ... 2N) are written:

$$t_{i,2} = a_{i,1}\ \frac{ti-1,4}{ti-1,3} + a_{i,2}, \qquad \text{- (II.20a)}$$

$$z_i = a_{i,1}\ \frac{zi-1}{ti-1,3} + R_1\ . \qquad \text{- (II.20b)}$$

Recurrence formulae for odd numbered rows (i = 3,5,7 .... 2N-1) are written:

$$t_{i,2} = - a_{i,1} \frac{t_{i-2,4}}{t_{i-2,3}} + a_{i,2} , \qquad \text{- (II.21a)}$$

$$t_{i,3} = - a_{i-1,3} \frac{t_{i,2}}{t_{i-1,2}} + a_{i,3} , \qquad \text{- (II.21b)}$$

$$t_{i,4} = - a_{i-1,4} \frac{t_{i,2}}{t_{i-1,2}} + a_{i,4} , \qquad \text{- (II.21c)}$$

$$z_i = - t_{i,2} \frac{z_{i-1}}{t_{i-1,2}} - a_{i,1} \frac{z_{i-2}}{t_{i-2,3}} + R_i . \qquad \text{- (II.21d)}$$

Components of the solution vector X are now found from a back-substitution starting at i = 2N and continuing sequentially to i = 1. The initial value may be found from:

$$x_{2N} = \frac{z_{2N}}{t_{2N,2}} \qquad \text{- (II.22)}$$

The recurrence formula for odd numbered rows (i = 2N-1,2N-3 .... 5,3,1) may be written:

$$x_i = \frac{z_i - t_{i,4}\, x_{i+1}}{t_{i,3}} . \qquad \text{- (II.23)}$$

The recurrence formula for even numbered rows (i = 2N-2,2N-4 .... 6,4,2) may be written:

$$x_i = \frac{z_i - a_{i,4}\, x_{i+2} - a_{i,3}\, x_{i+1}}{t_{i,2}} \qquad \text{- (II.24)}$$

Hence all values of the solution vector X are found and the calculated increments dhi and dQi are used to produce an improved estimate for the value of the dependent variables Qi and yi.

This solution technique proved accurate and efficient in the solution of a number of simultaneous equations. A problem does, however, exist if a stage hydrograph is provided as the upstream boundary condition. From Eqn. II.12, $\partial Bi/\partial yi = 0.0$, and therefore from Eqn. II.19, $t_{i,3} = a_{i,3} = 0.0$. As $t_{i,3}$ occurs in the denominator of Eqn. II.20a, the solution technique fails.

As a remedial measure, when an upstream depth hydrograph is supplied, the symbols representing discharge and depth are transposed, to ensure that $t_{i,3} \neq 0.0$ and the solution proceeds correctly. The method described above can cope with all other boundary conditions. This method is principally contained with Subroutine MATRIX of IMPLIC 6.

APPENDIX III - TABLES

Flood Date	Peak flow at Erwood (cumecs)	Routing parameters				Peak Attenuation (cumecs)				Time Lag (hours)			
		K (hours)		x		Recorded	Predicted			Recorded	Predicted		
		(ii)	(iii)	(ii)	(iii)		(i)	(ii)	(iii)		(i)	(ii)	(iii)
Jan. 1969	360	11.0	24.0	0.46	0.25	35	25	25	115	13.0	13.5	12.5	15.0
Dec. 1965	1080	24.0	26.0	0.42	0.35	473	460	375	457	24.0	24.0	10.0	10.0
Dec. 1960	1210	20.0	20.0	0.45	0.40	220	250	142	210	21.5	19.0	11.0	11.0
Feb. 1950	620	20.0	19.0	0.39	0.20	193	170	135	130	20.5	22.0	15.5	15.0
Jan. 1948	815	21.0	-	0.45	-	258	180	150	-	20.0	19.5	10.0	-
Nov. 1939	710	21.0	25.0	0.39	0.25	256	255	170	275	20.0	19.0	10.0	12.0
Aug. 1939	525	14.0	-	0.43	-	163	169	172	-	13.0	14.0	10.5	-

Key: Case (i) - Muskingum-Cunge. Dx = reach length/10. Dt = 2.0 hours.
Case (ii) - Muskingum-Cunge. Dx = reach length. Dt = 6.0 hours.
Case (iii) - Muskingum. Dx = reach length. Dt = 6.0 hours.

Table 4.1. River Wye (Erwood to Belmont) - Muskingum simulation of attenuation and time lag.

Time step (hours)	Value of weighting factor (θ).		
	1.0	0.75	0.5
4	6.56	3.57	1.65
2	3.57	1.99	0.85
1	1.99	1.19	-0.07
0.5	1.19	0.67	0.37

Table 4.2. Implicit Method - Hydro (1)/Slope = 0.001 - peak discharge attenuation (cumecs).

Time step (hours)	Value of weighting factor (θ).		
	1.0	0.75	0.5
4	15.25	11.59	6.96
2	11.51	9.45	7.20
1	9.43	8.31	7.24
0.5	8.30	7.77	7.20

Table 4.3. Implicit Method - Hydro (1)/Slope = 0.0002 - peak discharge attenuation (cumecs).

Time step (hours)	Value of weighting factor (θ)		
	1.0	0.75	0.5
4	34.13	27.14	19.36
2	26.75	22.47	17.18
1	22.42	20.08	17.61
0.5	20.06	18.62	17.59

Table 4.4. Implicit Method - Hydro (2)/Slope = 0.0002 - peak discharge attenuation (cumecs).

Time step (hours)	Value of weighting factor (θ)		
	1.0	0.75	0.5
2	58.00	50.80	41.80
1	51.88	45.26	42.84
0.5	47.60	44.63	42.20

Table 4.5. Implicit Method - Hydro (3)/Slope = 0.0002 - peak discharge attenuation (cumecs).

Hydrograph/ Channel	Attenuation (cumecs)	Recorded peak travel time (hours)	Recorded wave speed (m/s)	Max. dynamic wave speed (m/s)	Kinematic wave speed (m/s)
Hydro (1)/ (i) Slope = 0.001	0.37	5.0	2.70	7.48	2.45
Hydro (1)/ (ii) Slope = 0.0002	7.20	9.0	1.54	8.49	1.35
Hydro (2)/ (iii) Slope = 0.0002	17.59	8.0	1.74	9.52	2.00
Hydro (3)/ (iv) Slope = 0.0002	42.20	8.0	1.74	9.52	2.00

Table 4.6. Implicit Method - Flood wave celerity and attenuation.

Tributary	Catchment Area (km^2)	Length (km)
Ifield Brook	7.8	6.5
Crawters Brook	9.1	10.5
Mans Brook	6.5	6.5
Gatwick Stream	33.7	12.1
Burstow Stream	39.0	15.8
Salfords Stream	60.8	11.6
Deanoak Brook	42.8	18.5
Leigh Stream	16.1	11.6
Gad Brook	8.5	8.4
Tanners Brook	12.4	6.9
The Rye	3.5	4.2
Downside Stream	4.0	4.9

Table 5.1 Principal Tributaries of the River Mole

Pervious Strata (km^2) 27½% of total area		Mixed Strata (km^2) 12½% of total area		Impervious Strata (km^2) 60% of total area	
Lower Greensand	42	Hastings Beds	37	Weald Clay	197
Upper Greensand	5	Reading Beds	3	Gault	10
Chalk	69	Alluvium	21	London Clay	75
Bagshot Beds	18				
Total	134	Total	61	Total	292

Table 5.2 River Mole Catchment Geological Strata

<u>Table 5.3</u> Flood Peak Discharge and Level Data.

Key: H/w - Head water level (m) P - Flood peak data only
T/w - Tail water level (m) RA - Automatic records for hydrograph definition
Q - Discharge (cumecs) RM - Manually recorded data for hydrograph definition

FLOOD EVENT	Horley			Kinnersley Manor		Sidlow Bridge	Castle Mill			Leatherhead	Stoke D'Ab Bridge	Downside Mill		Cobham Mill		Royal Mills		Esher S.W.	Wilder' Gates	
	H/w	T/w	Q	H/w	Q	H/w	H/w	T/w	Q	H/w	H/w	H/w	T/w	H/w	T/w	H/w	T/w	T/w	H/w	T/w
1. 14th – 16th Sept. 1968	54.41 P					51.79 P		43.03 P			26.42 P		23.28 P	21.18 P		14.24 P	12.95 P	11.43 P	10.39 P	10.08 P
2. 17th – 22nd Dec. 1968			22.1 RA			49.94 P					25.33 RM				19.54 P		11.61 P	10.93 P		
3. 20th – 23rd Feb. 1968			21.0 RA			49.81 P		40.26 P			24.99 P				19.34 P		11.17 P			8.48 P
4. 11th – 15th Mar. 1969			21.2 RA			49.87 P		40.21 P							19.34 P		11.16 P			8.48 P
5. 15th – 16th Nov. 1970						49.98 P		40.35 P			25.14 RM		22.77 P		19.54 P		11.15 P	10.71 P		
6. 18th – 19th Nov. 1970	53.35 P	53.29 P				49.94 P	40.87 P	39.72 P					22.35 P	20.02 P	19.26 P	12.81 P	10.69 P		9.28 P	8.32 P
7. 23rd – 24th Jan. 1971	53.18 P	53.14 P				49.85 P	41.13 P	40.11 P					22.90 P							
8. 15th – 19th Mar. 1971 a.			18.7 RA			49.67 RM														
Two peaks b.	53.10 P	53.00 P	17.8 RA			49.72 RM	41.15 RA	40.02 P	34.7 RA				22.73 RM	20.10 P	19.36 RM	12.89 P	10.77 RM	10.59 P		

Table 5.3 continued

Flood Event	Horley	K/ley Manor	Sidlow Bridge	Castle Mill	L/head	Stoke D'Ab Bridge	Downside Mill	Cobham Mill	Royal Mills	Esher S.W.	Wilder' Gates
9. 14th–16th June 1971	53.26 52.21 19.8 P P RA		49.93 RM	40.79 39.59 41.1 RA RM RA			22.39 RM	19.55 19.32 P RM	12.79 10.64 P RM		9.22 8.31 P P
10. 18th–20th June 1971	53.72 53.67 24.9 P P RA		50.12 RM	41.18 40.22 56.6 RA RM RA			22.72 RM	20.03 19.50 RM RM	12.85 10.92 RM RM		9.42 8.48 P P
11. 3rd–9th Mar. 1972	53.07 53.03 P P		49.75 P	40.75 39.65 P P			22.47 P				
12. 20th–22nd Sept. 1973	52.54 P	50.32 18.4 P P		39.67 38.74 18.3 RA P RA	29.87 RA						
13. 9th–12th Feb. 1974	53.66 RM		50.18 RM	41.36 40.87 RM RM	30.72 RA	25.18 RM	23.03 RM	20.26 19.67 RM RM	12.98 11.46 AM RM		9.70 8.85 RM RM
14. 13th–17th Feb. 1974	53.52 23.8 RM RA	50.89 29.7 RA RA	49.87 RM	41.15 40.42 55.2 RA RM RA	30.48 RA		22.88 RM	20.18 19.35 RM RM	12.89 10.97 RM RM		
15. 5th–7th Sept. 1974	53.70 RM	51.09 37.4 RA RA	50.08 RM	40.98 40.24 48.9 RA RM RA	30.76 RA	24.98 RM	22.68 RM	20.10 19.19 RM RM	12.79 10.90 RM RM		
16. 27th–29th Sept. 1974	53.09 P	50.76 26.8 RA RA	49.60 RM	40.83 39.91 42.1 RA P RA	30.63 RA		22.34 RM				
17. 13th–15th Nov. 1974	53.62 24.4 RM RA	51.10 37.4 RA RA	50.08 RM	41.21 40.48 59.5 RA RM RA	30.69 RA	25.12 RM	22.91 RM	20.18 19.54 RM RM	12.94 11.28 RM RM	10.97 RM	
18. 18th–19th Nov. 1974		50.84 28.9 RA RA	49.90 RM	41.06 40.11 50.7 RA RM RA	30.47 RA			20.17 19.26 RM RM	12.86 10.85 RM RM		
19. 20th–22nd Nov. 1974	53.79 53.79 29.7 RA P RA			41.36 40.81 79.3 RA RM RA	31.00 RA	25.21 RM		19.66 RM	12.03 RM	11.28 P	
20. 20th–22nd Jan. 1975					30.69 RA	25.18 RM				11.09 P	
21. 14th–17th Oct 1976	52.21 52.10 9.9 RA RA RA	49.91 13.2 RA RA		38.62 RA			22.52 RA		9.86 RA		

Table 5.3 continued

Flood Event	Horley	K/ley Manor	Sidlow Bridge	Castle Mill	L/head	Stoke D'Ab Bridge	Downside Mill	Cobham Mill	Royal Mills	Esher S.W.	Wilder' Gates
22. 11th - 15th Nov. 1976	53.73 53.71 27.0 RA RA RA	51.16 44.2 RA RA	50.13 RM	40.98 40.49 RM RA	30.71 RA	25.18 RM	23.36 RA	20.28 19.24 RM RM	12.92 11.23 RM RA	10.93 P	9.52 8.73 P P
23. 28th Nov. - 2nd Dec. 1976 a.	53.75 53.71 28.2 RA RA RA	51.08 44.1 RA RA	50.10 RM	41.09 40.57 RM RM	30.61 RA	25.15 RM	23.42 22.70 RA RM	20.30 19.51 RM RM	12.92 11.43 RM RA	11.13 P	9.65 8.85 RM RM
Two Peaks b.	53.38 21.5 RA RA	50.81 29.9 RA RA	49.91 RM	40.90 40.30 RM RM	30.54 RA	25.05 RM	23.36 22.62 RA RM	20.27 19.38 RM RM	11.28 RA		
24. 5th - 10th Dec. 1976	52.82 52.79 15.6 RA RA RA	50.40 18.1 RA RA					22.96 RA		10.85 RA		
25. 31st Dec. 1976 - 5th Jan. 1977	53.54 53.51 23.4 RA RA RA	50.81 30.0 RA RA		40.19 RA	30.47 RA		23.27 RA		10.97 RA		
26. 12th - 15th Jan. 1977	53.61 53.60 24.2 RA RA RA	50.95 35.4 RA RA	49.97 P	40.91 40.46 RM RA	30.57 RA		23.40 22.66 RA RM				
27. 3rd - 7th Feb. 1977	52.48 52.07 11.3 RA RA RA	50.12 15.6 RA RA		38.90 RA	29.93 RA		22.81 RA		10.29 RA		
28. 9th - 13th Feb. 1977	52.59 52.45 12.7 RA RA RA	50.30 17.0 RA RA	49.46 P	39.06 RA	30.07 RA		22.90 RA		10.42 RA		
29. 18th - 22nd Feb. 1977 a.	52.44 51.96 10.2 RA RA RA	50.05 14.4 RA RA		38.83 RA	29.90 RA		22.73 RA		10.24 RA		
Two peaks b.	52.33 51.55 6.8 RA RA RA	49.60 9.9 RA RA		38.62 RA	29.78 RA		22.56 RA		10.04 RA		
30. 6th - 10th Dec. 1977	53.93 31.2 RA RA	51.21 47.3 RA RA	50.17 RM	40.95 40.65 RM RM	30.94 RA	25.24 RM	23.42 22.93 RA RM	20.26 19.54 RM RM	12.92 11.42 RM RA		9.67 8.93 RM RM
31. 10th - 14th Dec. 1977	53.25 23.2 RA RA	50.70 27.8 RA RA			30.57 RA		23.15 RA		10.89 RA		
32. 11th - 15th Jan. 1978			50.05 RM	40.79 40.48 RM RM	30.75 RA		23.38 22.74 RA RM	20.24 19.52 RM RM	12.90 11.40 RM RM	11.09 RM	

Table 5.4 Flood peak travel times

Key: Top figure - Travel time between successive stations for which data are available (hours).

Bottom figure - Cumulative travel time from Horley Weir (hours).

* - No data available.

Ranking - estimate of relative size of flood.

EVENT	Ranking	Horley to Kinnersley	Sidlow Bridge	Castle Mill	Leatherhead	Stoke D'Ab Bridge	Downside Mill	Cobham Mill	Royal Mills	Esher S.W.	Wilderness Gates
1.	(1)	*	*	*	*	*	*	*	*	*	44.0 44.0
2.	(4)	*	5.5 5.5	*	*	7.0 12.5	*	2.75 15.25	12.25 27.5	0.5 28.0	
3.	(19)	*	3.0 3.0	8.0 11.0	*	4.5 15.5	*	3.0 18.5	7.5 26.0	*	2.5 28.5
4.	(17)	*	4.75 4.75	5.75 10.5	*	*	*	8.75 19.25	8.75 28.0	*	1.5 29.5
5.	(15)	*	5.0 5.0	6.5 11.5	*	7.0 18.5	3.5 22.0	1.0 23.0	8.0 31.0	1.5 32.5	
6.	(22)	*	3.0 3.0	8.0 11.0	*	*	7.0 18.0	1.0 19.0	10.0 29.0	*	2.0 31.0
7.	(20)	*	2.5 2.5	5.75 8.25	*	*	9.0 17.25				
8b.	(21)	*	*	9.5 9.5	*	*	9.25 18.75	0.25 19.0	8.0 27.0	2.0 29.0	
9.	(23)	*	8.5 8.5	6.5 15.0	*	*	5.5 20.5	2.0 22.5	7.0 29.5	*	4.25 33.75
10.	(9)	*	6.0 6.0	5.0 11.0	*	*	12.5 23.5	0.5 24.0	7.75 31.75	*	1.25 33.0
11.	(26)	*	4.75 4.75	2.75 7.5	*	*	7.5 15.0				
12.	(30)	4.25 4.25	*	6.5 10.75	6.0 16.75						
13.	(3)	*	2.5 2.5	4.0 6.5	4.5 11.0	3.0 14.0	2.5 16.5	*	7.0 23.5	*	2.0 25.5
14.	(12)	3.0 3.0	1.0 4.0	4.0 8.0	6.5 14.5	*	4.0 18.5	1.25 19.75	7.5 27.25	*	1.0 28.25
15.	(10)	3.0 3.0	1.0 4.0	7.0 11.0	5.25 16.25	2.25 19.5	2.0 21.5	1.5 23.0	9.0 32.0	*	1.0 33.0

Table 5.4 continued.

EVENT	Ranking	Horley to Kinnersley	Sidlow Bridge	Castle Mill	Leatherhead	Stoke D'Ab Bridge	Downside Mill	Cobham Mill	Royal Mills	Esher S.W.	Wilderness Gates
16.	(25)	4.75 4.75	1.5 6.25	5.75 12.0	4.75 16.75	*	3.5 20.25	*	*	*	10.0 30.25
17.	(11)	3.5 3.5	1.5 5.0	4.0 9.0	3.0 12.0	5.0 17.0	*	3.0 20.0	10.5 30.5	0.5 31.0	
18.	(16)	2.25 2.25	2.5 4.75	3.5 8.25	6.0 14.25	*	*	2.5 16.75	8.0 24.75		
19.	(2)	*	3.0 3.0	3.0 6.0	5.5 11.5	1.5 13.0	*	*	9.0 22.0	*	2.0 24.0
21.	(33)	5.0 5.0	*	6.0 11.0	*	*	5.0 16.0	*	4.0 20.0		
22.	(8)	3.5 3.5	0.5 4.0	4.5 8.5	3.5 12.0	5.0 17.0	2.5 19.5	2.0 21.5	8.5 30.0	0.5 30.5	1.0 31.5
23a.	(6)	4.0 4.0	1.0 5.0	4.5 9.5	6.5 16.0	2.0 18.0	1.0 19.0	0.5 19.5	8.5 28.0	0.5 28.5	
23b.	(18)	3.0 3.0	1.5 4.5	4.5 9.0	5.0 14.0	3.0 17.0	1.5 18.5	0.5 19.0	9.0 28.0		
24a.	(27)	3.5 3.5	*	*	*	*	11.0 14.5	*	8.0 22.5		
24b.	(28)	4.0 4.0	*	*	*	*	10.0 14.0				
25.	(14)	3.5 3.5	*	4.0 7.5	4.5 12.0	*	2.5 15.5	*	9.0 24.5		
26.	(13)	2.5 2.5	1.5 5.0	2.0 7.0	6.0 13.0	*	3.0 16.0				
27.	(31)	3.0 3.0	*	6.5 9.5	2.5 12.0	*	2.0 14.0	*	7.0 21.0		
28.	(29)	3.5 3.5	1.0 4.5	5.5 10.0	3.0 13.0	*	1.5 14.5	*	7.5 22.0		
29a.	(32)	2.5 2.5	*	7.5 10.0	2.0 12.0	*	1.0 13.0	*	5.0 18.0		
29b.	(34)	3.0 3.0	*	6.0 9.0	2.0 11.0	*	1.0 12.0	*	5.5 17.5		
30.	(5)	2.5 2.5	0.5 3.0	3.0 6.0	6.0 12.0	2.0 14.0	1.0 15.0	4.0 19.0	9.5 28.5	*	0.5 29.0
31.	(24)	4.0 4.0	*	*	8.0 12.0	*	2.0 14.0	*	9.0 23.0		
32.	(7)	*	5.0 5.0	4.0 9.0	2.5 11.5	*	4.5 16.0	1.5 17.5	8.0 25.5	0.0 25.5	

Stream	A(km^2)	L(km)	S1085 m/km	URB %	SAAR (mm)	RSMD (mm)	SOIL	Tp(hours)	T_B(hours)	Q_p(cumecs)
Upper Mole, Horley	90	13.3	2.80	9.0	850	33.0	0.43	9.4(7.7*)	20.6	24.1
Burstow Stream	51	15.7	2.25	3.0	800	32.4	0.44	11.8(9.7*)	25.7	11.0
Salfords Stream	68	15.7	3.60	13.0	750	28.4	0.45	8.6	22.9	16.4
Deanoak Brook	58	18.5	2.60	0.0	800	29.8	0.45	12.4	32.5	9.9
Leigh Stream	21	11.4	4.10	1.0	820	29.0	0.45	9.7	25.7	4.5
Gad Brook	12	8.4	4.75	1.0	810	29.0	0.45	8.8	23.4	2.8
Tanners Brook	16	6.9	6.10	1.0	800	29.0	0.45	7.8	20.9	6.9
Mole, Castle Mill	316	35.5	1.03	7.0	810	28.8	0.44	17.7(16.1*)	39.3	41.9
Mole, Molesey	487	76.3	0.85	9.0	770	27.6	0.36	20.9(35.3*)	87.7	29.9

Key: A - catchment area, L - mainstream length, S1085 - 'U.S. Geological Survey' channel slope, URB - %age urban area, SAAR - average annual rainfall, RSMD - 5 year return period 1 day net rainfall, SOIL - index defined by Eqn. 6.1, Tp - Time to UH peak, T_B - UH time base, Q_p - UH peak discharge.

Table 6.1 River Mole unit hydrograph data.

Event	Total Rainfall (mm)	Effective Rainfall (%)			
		Horley	Kinnersley Manor	Castle Mill	Kinnersley - Castle Mill
14	21.7	-	65.0	53.7	44.4
15	41.7	-	50.5	26.4	6.9
16	24.9	-	65.7	42.0	23.1
17	35.7	-	54.2	36.9	24.0
18	20.1	-	62.0	41.6	25.0
19	32.7	81.9	-	69.6	-
25	38.6	52.0	57.3	-	-

Table 6.2 Percentage effective storm rainfall.

Table 6.3 River Mole - Kinnersley Manor to Castle Mill geometry functions.

Cross-Section Chainage (m)	Channel Feature *Surveyed Section	Invert level (m) (ODN)	Bank height (m)		Channel area			Channel perimeter			Left flood plain			Right flood plain		
			yb_1	yb_r	a_C	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
000	Kinnersley Manor *	47·09	2·50	2·50	0·0	5·60	1·30	5·90	2·50	1·0	0·0	10·7	2·0	0·0	10·7	2·0
400	Salfords Stream	46·78	2·50	2·50	0·0	5·20	1·33	5·41	2·50	1·0	0·0	14·3	2·0	0·0	7·1	2·0
1360	Sidlow Br. *	46·17	3·20	3·20	6·84	1·00	1·76	6·58	2·50	1·0	0·0	11·5	2·0	0·0	11·5	2·0
2850	Deanoak Brook *	45·12	3·19	2·94	0·0	5·46	1·32	5·79	2·50	1·0	0·0	12·0	2·0	0·0	11·1	2·0
3820	*	44·66	2·86	3·05	0·0	4·07	1·50	5·11	2·42	1·0	0·0	13·5	2·0	0·0	13·5	2·0
4500		44·19	3·05	2·89	0·0	4·03	1·50	4·95	2·42	1·0	0·0	13·6	2·0	0·0	13·6	2·0
5480	Leigh Stream *	43·43	3·57	3·88	0·0	3·98	1·50	4·73	2·42	1·0	0·0	16·7	2·0	0·0	21·4	2·0
5910	Flanchford Br. *	43·14	3·25	3·95	10·73	3·00	1·59	13·00	3·37	1·0	0·0	12·5	2·0	0·0	30·0	2·0
6210	*	42·88	3·23	3·83	0·0	3·95	1·50	4·57	2·42	1·0	0·0	18·0	2·0	0·0	16·7	2·0
7420	*	42·24	3·75	2·85	0·0	5·10	1·36	5·56	2·26	1·0	0·0	25·0	2·0	0·0	8·3	2·0
8070	Rice Br. *	42·88	3·31	3·38	0·0	5·63	1·46	6·09	3·13	0·86	0·0	15·0	2·0	0·0	15·0	2·0
8360	*	42·24	3·53	3·43	0·0	5·88	1·51	6·33	3·52	0·80	0·0	12·5	2·0	0·0	12·5	2·0
9030		41·50	3·08	3·38	2·10	5·15	1·50	7·78	3·09	0·87	0·0	8·9	2·0	0·0	10·1	2·0
10380	*	41·24	3·41	3·78	6·34	3·67	1·48	10·73	2·25	1·0	0·0	15·3	2·0	0·0	10·0	2·0
10660	Betchworth Br. *	41·04	3·61	3·61	16·10	3·32	1·56	16·97	3·59	1·0	0·0	18·7	2·0	0·0	6·3	2·0
11340	*	40·86	3·33	3·43	6·83	1·50	2·00	6·38	3·18	1·0	0·0	7·6	2·0	0·0	14·3	2·0
11940	Betchworth Weir *	40·60	3·35	3·35	8·27	1·65	1·98	7·02	3·50	1·0	0·0	14·3	2·0	0·0	3·6	2·0
11960	Betchworth Weir *	40·32	3·57	3·05	2·84	4·43	1·74	9·23	2·72	1·0	0·0	3·6	2·0	0·0	14·3	2·0
12400	*	39·99	2·89	3·27	0·00	6·52	1·55	11·25	2·40	1·0	30·0	0·0	0·0	30·0	0·0	0·0

Table 6.3 continued.

Chainage	Feature	Level	yb_1	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
12940	Mill Hill Br. *	39·62	3·20	3·35	2·89	3·56	1·74	6·98	2·92	1·0	30·0	0·0	0·0	30·0	0·0	0·0
13220	*	39·44	3·44	2·83	4·39	2·04	1·84	4·78	3·20	1·0	30·0	0·0	0·0	20·0	0·0	0·0
13380	Tanners Brk.	39·33	3·34	3·34	5·60	6·10	1·55	11·76	4·08	1·0	0·0	5·0	2·0	0·0	10·0	2·0
13320	Brockham Br. *	39·38	3·51	3·50	6·34	6·35	1·54	12·49	4·22	1·0	0·0	5·0	2·0	0·0	10·0	2·0
13920	*	38·98	3·08	3·46	0·0	4·25	1·65	6·27	3·00	1·0	12·0	0·0	0·0	20·0	0·0	0·0
14440		38·71	3·26	3·26	3·27	4·41	1·59	10·04	2·67	1·0	20·0	0·0	0·0	20·0	0·0	0·0
14930	*	38·49	3·56	3·54	6·34	4·55	1·53	13·60	2·37	1·0	40·0	0·0	0·0	0·0	4·0	2·0
15220	Old Weir	38·37	2·71	3·23	4·09	5·51	1·59	12·55	3·34	1·0	20·0	0·0	0·0	20·0	0·0	0·0
15370	Deepdene Br. *	38·31	2·71	3·14	19·52	1·92	1·56	22·16	3·00	1·0	–	–	–	40·0	0·0	0·0
15700	Boxhill Br. *	38·22	2·74	3·00	6·35	7·50	1·49	14·47	4·84	1·0	–	–	–	40·0	0·0	0·0
16120	Castle Mill *	38·10	3·05	2·65	3·81	4·50	1·50	8·68	2·90	1·0	–	–	–	40·0	0·0	0·0

Table 6.4 River Mole - Castle Mill to Leatherhead geometry functions.

Cross-Section Chainage (m)	Channel Feature *Surveyed Section	Invert level (m) (ODN)	Bank height (m)		Channel area			Channel perimeter			Left flood plain			Right flood plain		
			yb_l	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
000	Castle Mill *	35·35	5·62	4·72	24·00	4·82	1·48	28·12	2·87	1·0	–	–	–	0·0	25·0	2·0
150			3·88	3·19	4·60	4·50	1·72	10·00	4·00	1·0	–	–	–	0·0	25·0	2·0
300	Rail Bridge *		2·75	2·14	4·90	4·77	1·72	10·36	4·06	1·0	–	–	–	–	–	–
590	Footbridge *		3·19	3·19	4·89	4·00	1·56	8·26	3·42	1·0	–	–	–	–	–	–
780	*	36·09	3·26	3·38	4·88	3·50	1·47	6·88	3·00	1·0	–	–	–	–	–	–
890	Pipp Brook	35·96	3·35	2·82	5·83	3·09	1·49	7·55	2·88	1·0	–	–	–	–	–	–
1020	Footbridge *	35·81	3·28	2·59	6·79	2·69	1·51	8·22	2·76	1·0	–	–	–	–	–	–
1640	Footbridge *	35·35	–	–	11·71	0·60	1·60	11·71	2·12	1·0	–	–	–	–	–	–
2390	Burford Br. *	34·29	2·71	4·04	9·08	1·62	1·83	8·50	3·05	1·0	60·0	5·0	2·0	–	–	–
2790	*	33·89	2·75	6·20	0·00	7·12	1·37	9·06	2·06	1·0	0·0	7·5	2·0	–	–	–
3080	Rail Bridge *	33·77	3·78	3·57	4·00	6·36	1·37	9·62	2·16	1·0	0·0	7·5	2·0	0·0	10·0	2·0
3700		33·59	2·99	3·54	6·10	4·74	1·38	10·81	2·36	1·0	–	–	–	60·0	7·5	2·0
4100	Footbridge *	33·37	2·96	3·35	8·78	3·70	1·39	11·58	2·50	1·0	–	–	–	60·0	7·5	2·0
4480	*	33·21	2·39	3·17	9·27	2·75	1·52	11·32	2·03	1·0	45·0	5·0	2·0	–	–	–
4900	Swanworth Br. *	32·46	4·11	2·97	10·25	2·22	1·50	11·57	2·25	1·0	–	–	–	0·0	10·0	2·0
5270	Rail Bridge. *	32·18	2·86	2·56	7·32	0·99	1·98	7·50	3·00	1·0	–	–	–	0·0	8·0	2·0
5430	*	32·05	3·20	2·62	6·34	5·67	1·39	12·75	2·05	1·0	20·0	5·0	2·0	–	–	–
5810	Mickleham Br. *	32·00	2·50	2·89	12·18	2·72	1·71	13·18	3·85	1·0	30·0	3·0	2·0	–	–	–
6430	*	31·80	2·10	2·32	3·90	5·42	1·45	10·77	2·08	1·0	0·0	21·0	2·0	–	–	–

Table 6.4 continued.

Chainage	Feature	Level	yb_1	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
6650	U/S Priory Weir *	31.70	2.53	2.28	14.00	2.06	1.44	14.00	3.07	1.0	0.0	22.0	2.0	-	-	-
6660	D/S Priory Weir *	31.54	2.34	2.43	16.50	1.40	1.60	16.50	2.85	1.0	0.0	22.0	2.0	-	-	-
6790	Priory Br. *	31.42	2.77	2.62	20.50	0.65	1.82	20.50	2.61	1.0	0.0	30.0	2.0	-	-	-
7240	*	30.90	2.30	2.30	10.98	0.23	1.90	8.91	2.04	1.0	0.0	30.0	2.0	0.0	50.0	2.0
8100	A246 Bridge *	30.07	2.00	2.00	8.94	1.08	1.70	9.08	2.29	1.0	0.0	25.0	2.0	0.0	50.0	2.0
8370	*	29.79	1.78	2.42	8.30	1.37	1.64	9.14	2.50	1.0	50.0	0.0	0.0	50.0	15.0	2.0
8870	Thorneycroft Br. *	28.65	2.75	2.75	0.00	10.65	1.51	11.33	5.27	1.0	180.0	5.0	2.0	110.0	3.0	2.0
9190	Leatherhead Weirs *	29.11	1.90	1.90	0.00	10.65	1.51	11.33	5.27	1.0	200.0	5.0	2.0	50.0	0.0	0.0

Table 6.5 River Mole - Leatherhead to Cobham Mill geometry functions.

Cross-Section Chainage (m)	Channel Feature *Surveyed Section	Invert level (m) (ODN)	Bank height (m)		Channel area			Channel perimeter			Left flood plain			Right flood plain		
			yb_1	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
-280	Timber Weir *	29.20	1.43	1.68	33.00	0.5	2.0	33.0	2.40	1.0	100.0	0.0	0.0	20.0	0.0	0.0
-190	Weir	29.11	1.77	2.01	35.00	0.5	2.0	35.0	2.14	1.0	75.0	0.0	0.0	15.0	0.0	0.0
000	Leatherhead Br. *	28.89	2.41	2.59	60.00	0.5	2.0	60.0	2.24	1.0	-	-	-	-	-	-
120	Waterway Rd Br. *	28.83	2.68	1.34	19.00	3.82	1.42	21.51	2.75	1.0	-	-	-	0.0	7.5	2.0
150	Rail Bridge *	28.71	2.80	1.46	24.89	1.62	1.63	25.00	3.02	1.0	15.0	0.0	0.0	0.0	7.5	2.0
200	Rail Bridge *	28.50	2.19	1.83	22.24	1.92	1.59	23.14	2.84	1.0	40.0	0.0	0.0	-	-	-
760	*	27.87	2.01	1.94	14.15	2.84	1.46	17.46	2.29	1.0	-	-	-	0.0	25.0	2.0
1300		26.97	2.50	2.50	13.51	2.87	1.48	14.94	2.35	1.0	50.0	30.0	2.0	0.0	21.0	2.0
1900	U/S oldmill Weir *	26.64	2.62	2.68	12.80	2.90	1.50	15.81	2.41	1.0	20.0	9.0	2.0	150.0	0.0	0.0
1920	D/S oldmill Weir *	26.88	2.56	2.62	14.10	2.80	1.50	15.00	2.40	1.0	20.0	9.0	2.0	150.0	0.0	0.0
2340	The Rye	25.80	2.30	2.30	6.86	4.65	1.44	6.97	2.96	1.0	35.0	25.0	2.0	0.0	15.0	2.0
2410	*	25.63	2.37	2.50	5.86	4.91	1.43	10.25	3.04	1.0	0.0	70.0	2.0	0.0	23.0	2.0
3000	Channel Split	24.99	2.13	2.44	6.10	3.96	1.44	8.37	3.16	1.0	45.0	0.0	0.0	10.0	35.0	2.0
3590	*	23.64	2.68	3.02	6.34	3.01	1.46	6.50	3.28	1.0	100.0	0.0	0.0	0.0	14.0	2.0
3970	Confluence	23.10	3.56	3.26	9.25	3.03	1.46	9.91	3.21	1.0	30.0	0.0	0.0	0.0	18.0	2.0
4400	Footbridge *	22.40	3.26	3.35	8.30	3.06	1.47	9.38	3.14	1.0	0.0	50.0	2.0	70.0	0.0	0.0
4900		22.43	3.08	2.86	9.51	3.09	1.47	11.38	3.07	1.0	0.0	90.0	2.0	80.0	0.0	0.0
5400		22.43	2.62	2.62	10.71	3.12	1.47	13.24	2.99	1.0	0.0	15.0	2.0	160.0	10.0	2.0
5850	Stoke D'Abernon Br. *	22.55	2.13	2.13	17.00	1.73	1.89	18.52	2.39	1.0	0.0	15.0	2.0	240.0	0.0	0.0

Table 6.5 continued.

Chainage	Feature	Level	yb_l	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
6010	*	22.39	2.38	2.06	12.20	3.16	1.48	15.52	2.89	1.0	0.0	12.0	2.0	0.0	18.0	2.0
6550		21.73	2.41	2.32	9.06	3.70	1.50	13.08	3.06	1.0	40.0	0.0	0.0	0.0	54.0	2.0
7100		20.97	2.99	2.71	8.91	4.24	1.52	13.63	3.24	1.0	0.0	12.0	2.0	60.0	80.0	2.0
7630	*	20.79	2.93	2.75	7.32	4.78	1.55	12.72	3.41	1.0	0.0	12.0	2.0	40.0	55.0	2.0
7830	Rail Bridge *	20.66	3.17	3.17	0.00	10.10	1.46	12.63	4.07	1.0	-	-	-	-	-	-
7850	Side Weir *	20.66	3.17	3.17	21.00	0.00	1.00	21.00	2.00	1.0	-	-	-	-	-	-
7970	U/S Downside Weir *	20.73	3.11	3.11	12.50	0.00	1.00	12.50	2.00	1.0	-	-	-	-	-	-
7980	D/S Downside weir *	19.35	3.15	2.69	18.50	0.89	1.63	18.50	2.38	1.0	30.0	15.0	2.0	120.0	0.0	0.0
8070	Relief Channel	19.05	2.86	2.86	10.00	2.27	1.64	10.31	2.96	1.0	100.0	15.0	2.0	70.0	28.0	2.0
8550		19.02	2.62	2.56	11.83	1.74	1.52	12.15	2.73	1.0	45.0	87.0	2.0	50.0	45.0	2.0
9040	*	18.35	2.62	2.56	13.66	1.22	1.41	14.00	2.50	1.0	35.0	100.0	2.0	10.0	42.0	2.0
9660	*	17.68	2.77	2.80	4.88	5.48	1.38	9.10	3.21	1.0	30.0	30.0	2.0	160.0	20.0	2.0
9890	Downside Stream	17.65	2.65	2.59	8.13	5.00	1.42	10.30	3.76	1.0	10.0	15.0	2.0	300.0	15.0	2.0
10120	Side weir	17.62	2.59	2.50	9.38	4.52	1.46	9.50	4.32	1.0	25.0	40.0	2.0	135.0	22.0	2.0
10580		17.62	2.44	2.68	6.50	4.50	1.45	6.50	4.28	1.0	40.0	15.0	2.0	10.0	20.0	2.0
10700	Cobham Weir *	16.27	3.93	3.93	7.00	4.02	1.44	7.00	3.31	1.0	25.0	25.0	2.0	0.0	7.5	2.0

Table 6.6 River Mole - Cobham Mill to Royal Mills geometry functions.

Cross-Section Chainage (m)	Channel Feature *Surveyed Section	Invert level (m) (ODN)	Bank height (m)		Channel area			Channel perimeter			Left flood plain			Right flood plain		
			yb_1	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
000	D/S Cobham Weir *	15.67	3.38	4.85	15.00	4.85	1.50	15.50	4.12	1.0	70.0	17.5	2.0	0.0	7.0	2.0
140		16.92	2.07	2.38	8.50	3.18	1.46	4.80	3.09	1.0						
350		16.61	2.83	3.38	10.10	2.70	1.47	11.10	3.16	1.0	70.0	14.0	2.0	0.0	8.5	2.0
600	Downside Br. *	16.52	2.32	2.56	15.30	2.13	1.49	16.00	3.25	1.0	56.0	10.5	2.0	130.0	7.5	2.0
900		15.39	3.20	3.20	9.40	2.03	1.48	10.30	2.83	1.0						
1260	*	15.33	2.93	2.86	6.83	1.92	1.46	7.55	2.32	1.0	35.0	24.0	2.0	56.0	28.0	2.0
1600		15.03	3.17	3.11	6.92	2.08	1.47	7.22	2.41	1.0						
1930		14.81	2.50	2.80	7.00	2.23	1.47	7.89	2.50	1.0	45.0	21.0	2.0	70.0	7.5	2.0
2250		13.96	2.83	3.08	7.08	2.39	1.48	8.03	2.58	1.0						
2580		13.23	3.72	3.87	7.17	2.54	1.48	8.19	2.67	1.0	0.0	70.0	2.0	0.0	24.0	2.0
3170	*	13.44	2.95	2.95	7.32	2.82	1.49	8.48	2.83	1.0	49.0	17.5	2.0	35.0	28.0	2.0
3600		13.15	2.96	2.94	7.02	3.11	1.50	7.81	3.67	1.0	67.0	7.0	2.0	18.0	18.0	2.0
4000	U/S Weir *	13.59	1.80	2.13	6.75	3.88	1.51	7.10	4.44	1.0						
4010	D/S Weir *	13.35	2.56	2.56	12.00	5.63	1.50	14.00	6.87	1.0	0.0	7.0	2.0	20.0	18.0	2.0
4320	Weir	12.53	5.76	3.35	6.50	2.60	1.59	7.00	3.42	1.0						
4620		11.86	5.09	4.05	7.25	2.72	1.57	7.96	3.22	1.0	0.0	5.0	2.0	25.0	18.0	2.0
5100	*	11.90	3.78	3.78	5.86	2.92	1.53	6.90	2.91	1.0	0.0	15.2	2.0	25.0	18.0	2.0
5590	*	11.65	4.05	3.96	5.80	3.71	1.56	8.28	2.93	1.0	0.0	14.0	2.0	0.0	20.0	2.0
5850		11.92	3.35	3.84	4.85	4.36	1.40	9.85	1.50	1.0						

Table 6.6 continued.

Chainage	Feature	Level	yb_1	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
6150	Channel Split	12·02	3·38	3·38	7·10	3·72	1·53	7·10	4·08	1·0	0·0	10·0	2·0	0·0	25·0	2·0
6300	Confluence	12·55	2·53	2·22	14·00	3·07	1·50	14·40	3·74	1·0						
6400	Painshill Weir *	12·89	2·47	2·10	16·50	1·85	1·60	16·50	3·40	1·0	0·0	7·5	2·0	0·0	20·0	2·0
6420	Painshill Br. *	12·19	3·17	2·80	12·69	3·52	1·52	12·90	4·92	1·0						
6750	A3 Bridge	11·31	3·60	3·35	4·53	4·28	1·46	6·56	4·08	1·0						
7160	*	11·18	3·65	3·65	0·00	5·24	1·39	4·30	3·04	1·0	0·0	7·5	2·0	0·0	18·0	2·0
7610		10·82	3·53	3·96	0·50	4·40	1·55	3·52	3·42	1·0	0·0	7·5	2·0	0·0	18·0	2·0
8060		10·52	3·72	4·15	1·00	3·57	1·71	3·94	3·80	1·0	0·0	10·0	2·0	0·0	16·0	2·0
8500	Burwhill Footbridge *	10·94	3·90	3·99	10·09	1·45	1·50	10·90	2·43	1·0						
8610	Footbridge *	11·37	3·51	3·51	12·69	1·45	1·53	13·40	2·43	1·0						
8800	*	10·45	3·61	3·99	3·66	2·19	1·98	3·64	4·42	1·0	0·0	7·5	2·0	0·0	19·0	2·0
8970	Footbridge *	10·88	3·51	3·51	8·31	3·20	1·38	10·57	2·57	1·0						
9420		10·64	3·36	3·78	4·15	4·92	1·44	7·40	3·38	1·0	0·0	22·0	2·0	0·0	20·0	2·0
9860	*	10·32	3·76	3·67	0·00	6·65	1·49	4·24	4·20	1·0	0·0	17·0	2·0	0·0	17·0	2·0
10320		10·15	3·23	3·44	1·54	4·08	1·62	4·84	3·70	1·0						
10550		10·25	3·55	3·55	2·02	3·79	1·68	5·14	3·96	1·0	0·0	20·0	2·0	0·0	11·0	2·0
10780		10·36	3·26	3·29	2·50	3·51	1·75	5·44	4·22	1·0						
11250	*	9·60	4·02	4·17	7·07	1·91	1·89	6·06	3·93	1·0	0·0	17·0	2·0	0·0	6·5	2·0
11600		9·63	3·90	3·60	8·21	2·17	1·92	7·41	4·65	1·0						
11950		10·09	3·20	3·47	7·35	2·43	1·94	6·78	5·37	1·0	0·0	5·0	2·0	80·0	10·0	2·0

Table 6.6 continued.

Chainage	Feature	Level	yb_l	yb_r	a_0	a_1	a_2	p_0	p_1	p_2	al_0	al_1	al_2	ar_0	ar_1	ar_2
12300		9.63	3.60	3.78	5.48	2.70	1.97	5.12	6.10	1.0						
12640	*	9.60	4.02	3.70	5.64	2.96	2.00	5.50	6.81	1.0	0.0	5.0	2.0	0.0	50.0	2.0
13120		9.94	3.38	3.47	4.99	4.22	1.83	9.70	5.28	1.0						
13600	Esher Footbridge *	9.66	3.63	3.70	5.34	5.48	1.66	13.93	3.75	1.0	0.0	25.0	2.0	80.0	45.0	2.0
13980		9.39	3.84	3.63	3.56	5.66	1.72	9.29	5.82	1.0						
14360	Albany Br. *	9.08	3.96	3.93	1.78	5.84	1.77	4.64	7.88	1.0	0.0	25.0	2.0	0.0	35.0	2.0
14740	*	9.67	3.49	3.60	0.00	6.03	1.83	0.00	9.95	1.0	0.0	65.0	2.0	-	-	-
15040		9.34	3.63	3.81	3.18	5.78	1.72	3.82	8.34	1.0						
15350		9.26	3.63	4.02	5.47	5.53	1.60	5.66	6.67	1.0	0.0	65.0	2.0	-	-	-
15660	Rail Bridge *	10.05	2.89	2.89	9.76	5.28	1.48	10.05	5.00	1.0						
15690	Royal Mills *	10.06	2.89	2.44	18.06	2.95	1.50	18.20	5.56	1.0	0.0	35.0	2.0	-	-	-

Event	Castle Mill peak (cumecs)	Peak Travel Time (hrs)		Attenuation	
		recorded	predicted	(cumecs)	%
12	18.5	3.5	3.0	0.1	0.5
14	55.0	6.0	5.25	2.6	4.7
15	49.0	5.25	5.25	2.0	4.0
16	42.0	4.75	4.25	1.0	2.4
17	59.0	3.0	5.15	2.3	3.9
18	50.0	5.25	4.75	2.7	5.4
19	79.0	5.5	6.25	5.3	6.7

Table 6.7 Castle Mill to Leatherhead flood wave travel time and attenuation.

Event	Peak flows (cumecs)			Peak Travel Time (hours)			
				Leatherhead - Cobham		Cobham - Royal Mills	
	recorded Leatherhead	predicted Cobham	predicted Royal Mills	Recorded	Predicted	Recorded	Predicted
15	47.1	54.9	-	5.75	6.0	9.0	-
17	57.0	63.8	67.3	6.5	7.5	10.5	9.5
22	56.9	63.4*	67.0	9.0	7.5	8.0	9.5
23a	53.0	60.5*	64.1	4.5	7.0	11.0	9.5
23b	43.9	49.2*	-	3.5	4.5	9.5	-
30	70.8	76.0*	77.5	5.0	8.0	10.0	8.5

*From Leatherhead rating curve.

Table 6.8 Leatherhead to Royal Mills flood peak discharge and travel time.

APPENDIX IV FIGURES

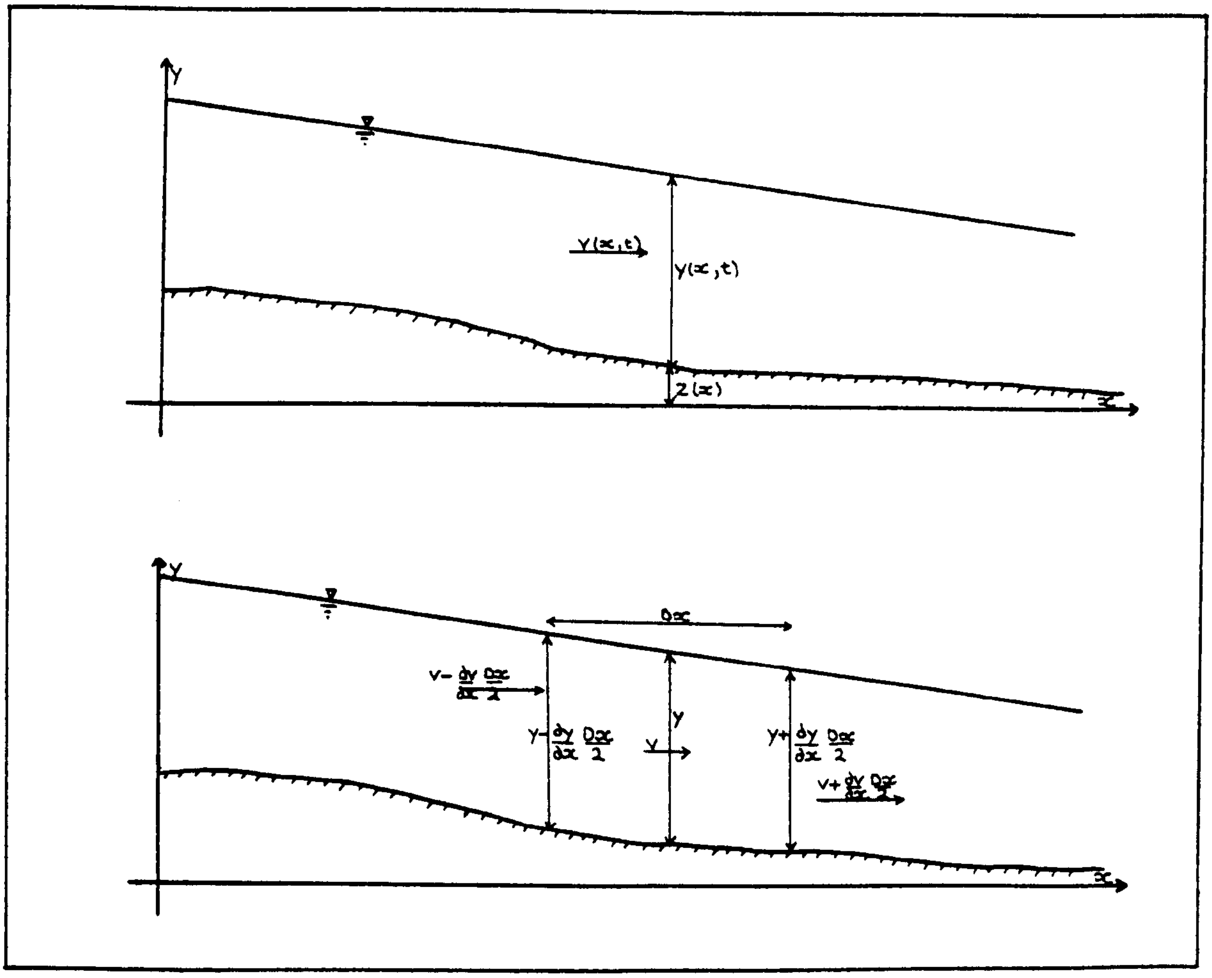


Fig. 2.1. Elementary one-dimensional control volume.

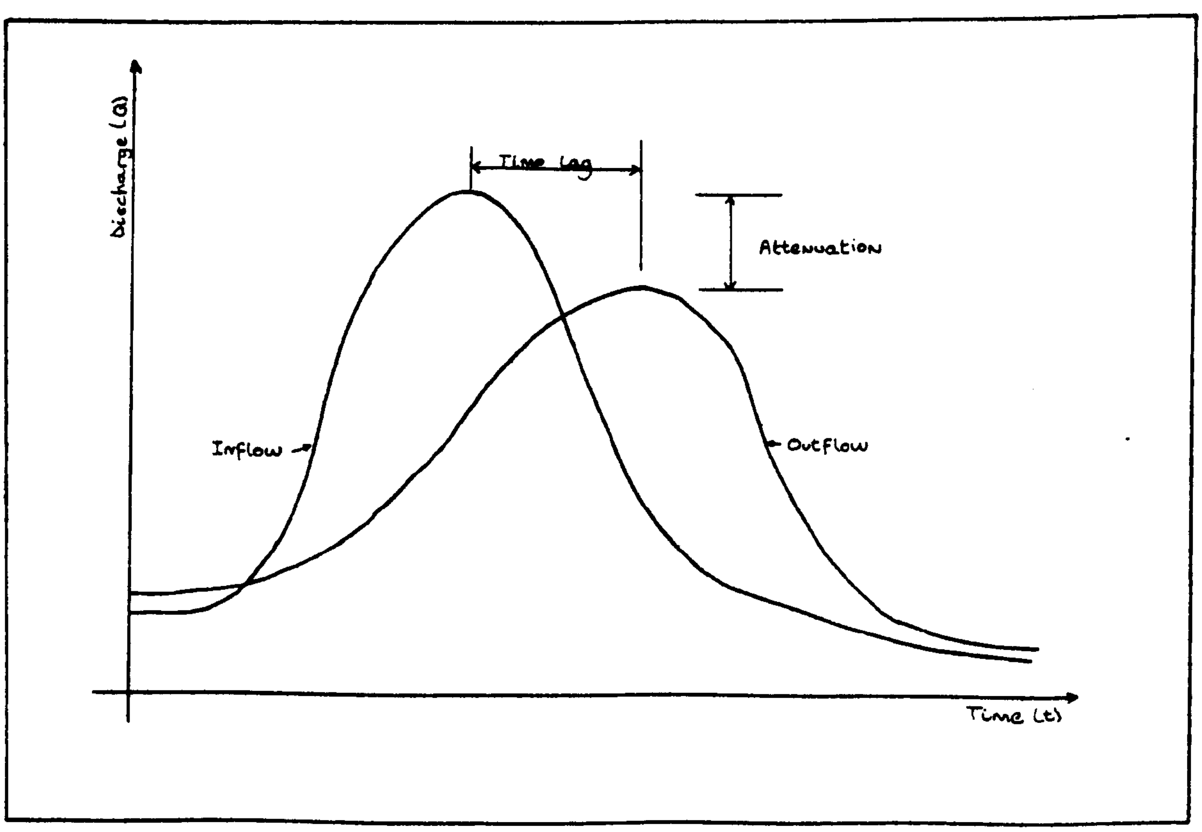


Fig. 2.2. Flood Wave time lag and attenuation.

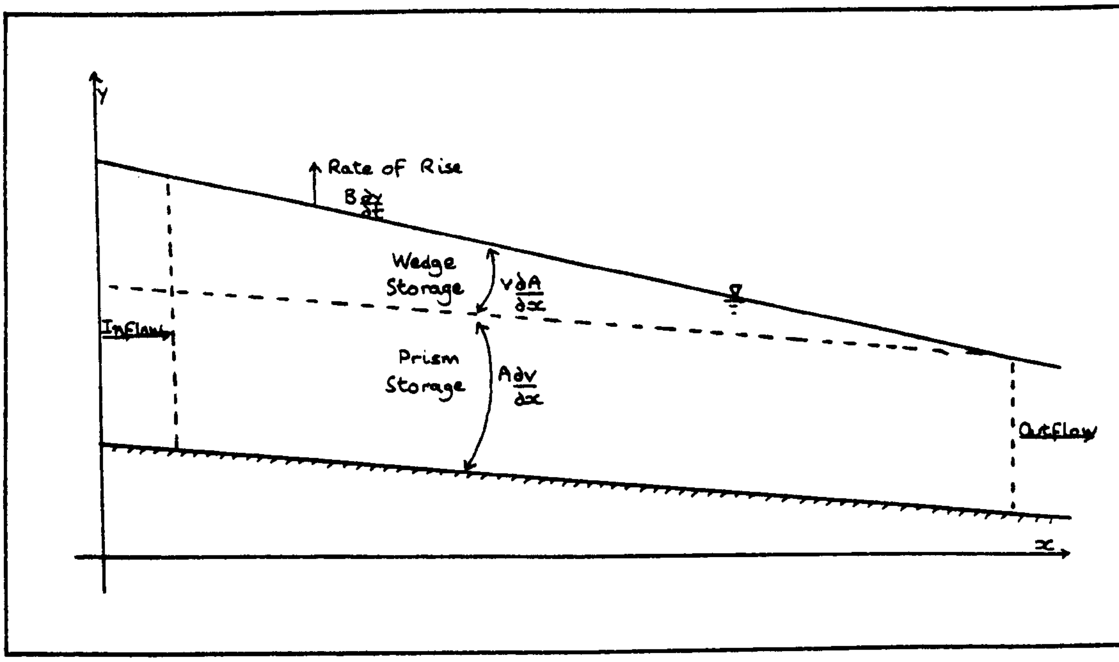


Fig. 2.3. Graphical representation of the continuity equation.

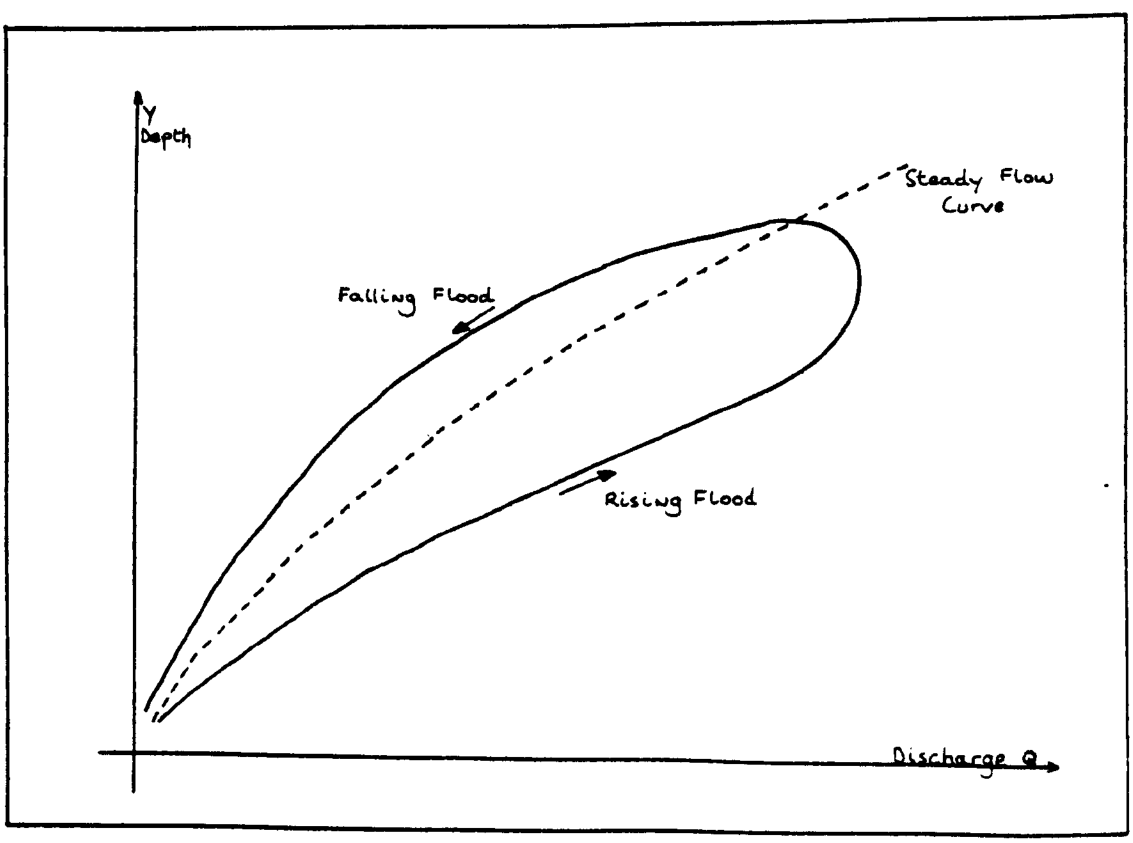
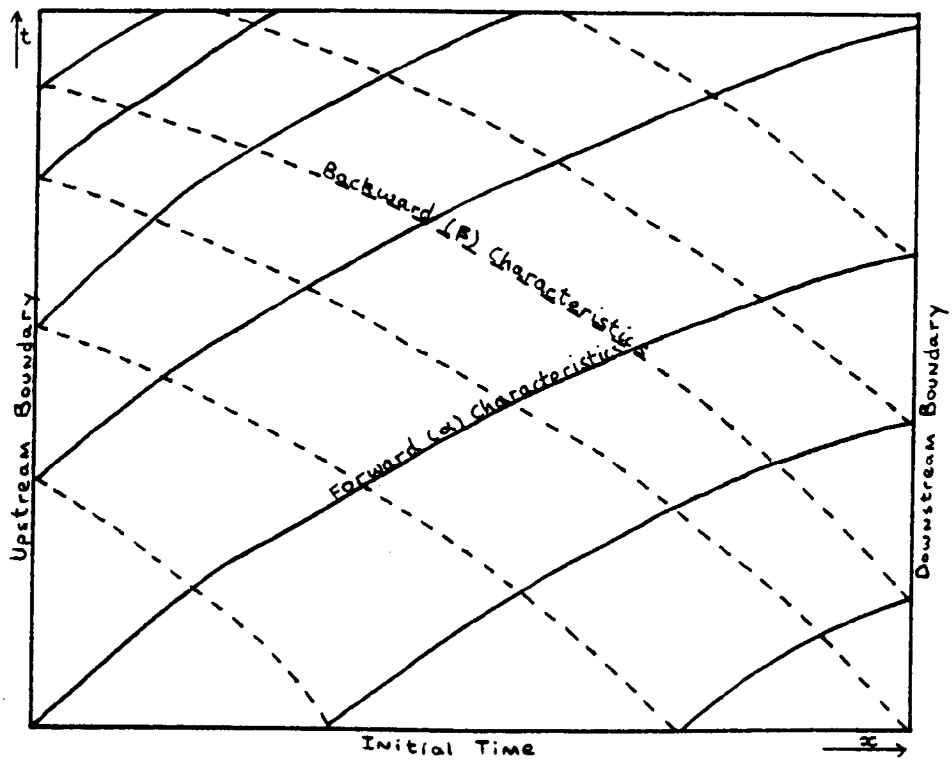
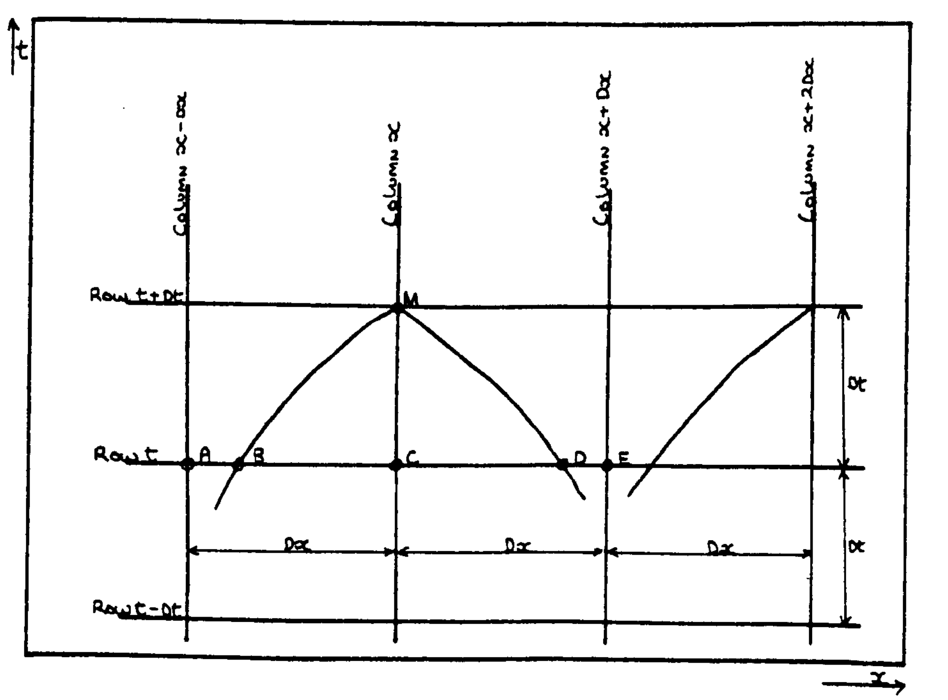


Fig. 2.4. Typical loop rating curve.



<u>Fig. 2.5.</u> Characteristics space/time grid.



<u>Fig. 2.6.</u> Rectangular grid for the characteristics method.

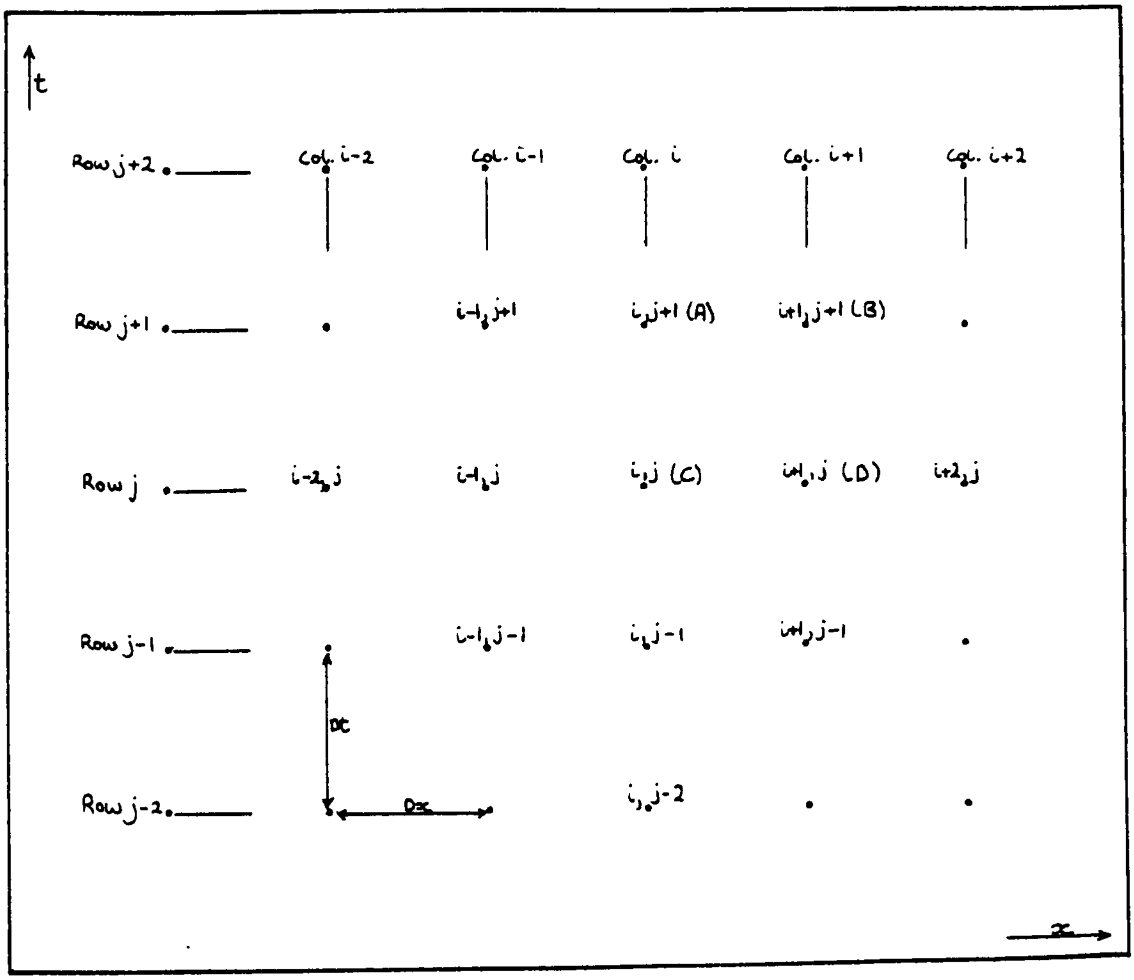


Fig. 2.7. Fixed rectangular space/time grid.

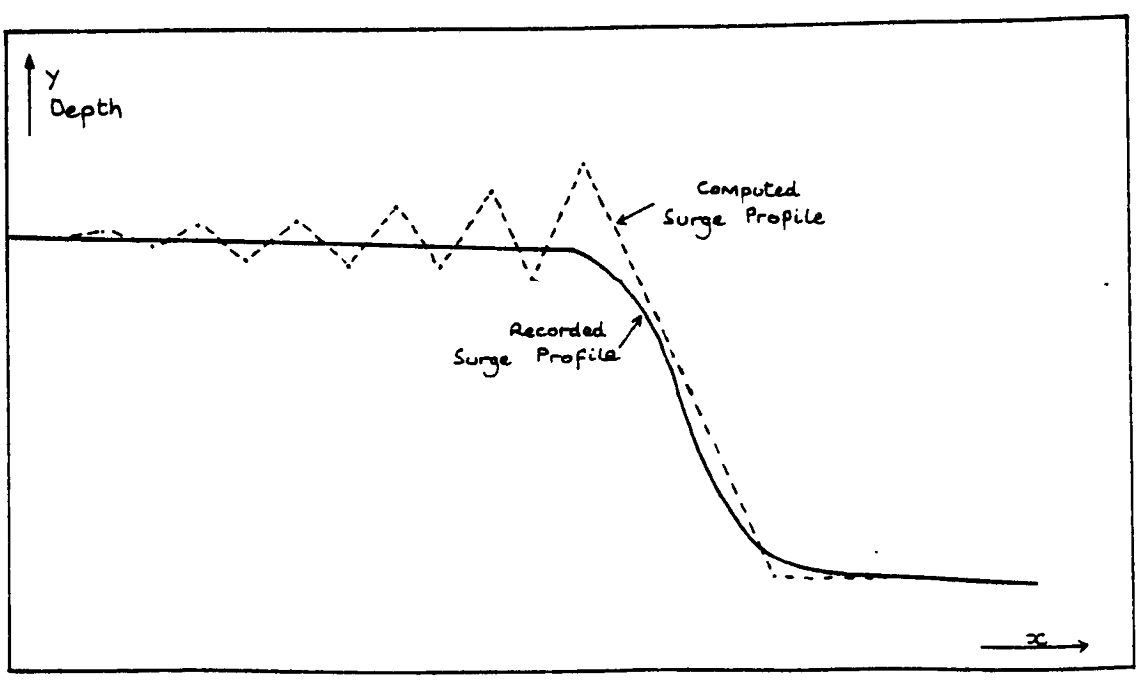
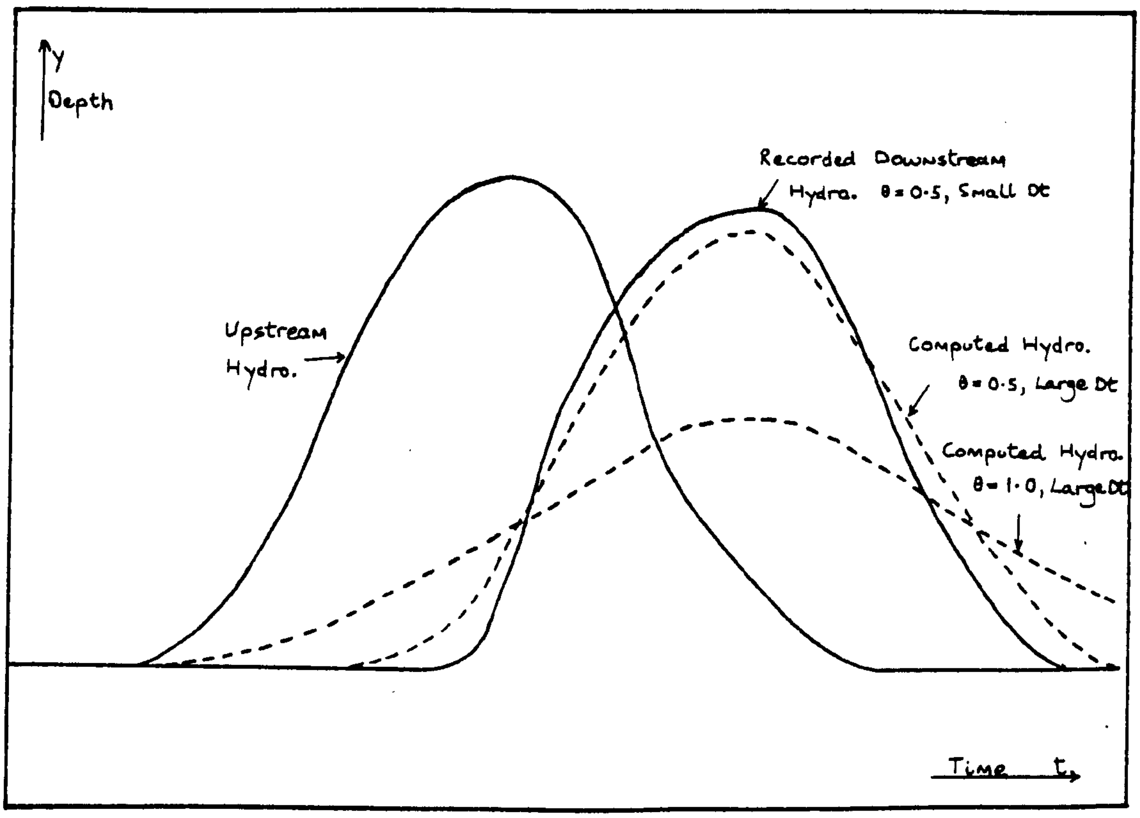


Fig. 2.8. Typical saw-tooth fluctuations (surge wave analysis).



<u>Fig. 2.9.</u> Variation of accuracy with θ and Dt (after Fread (Ref. 44)).

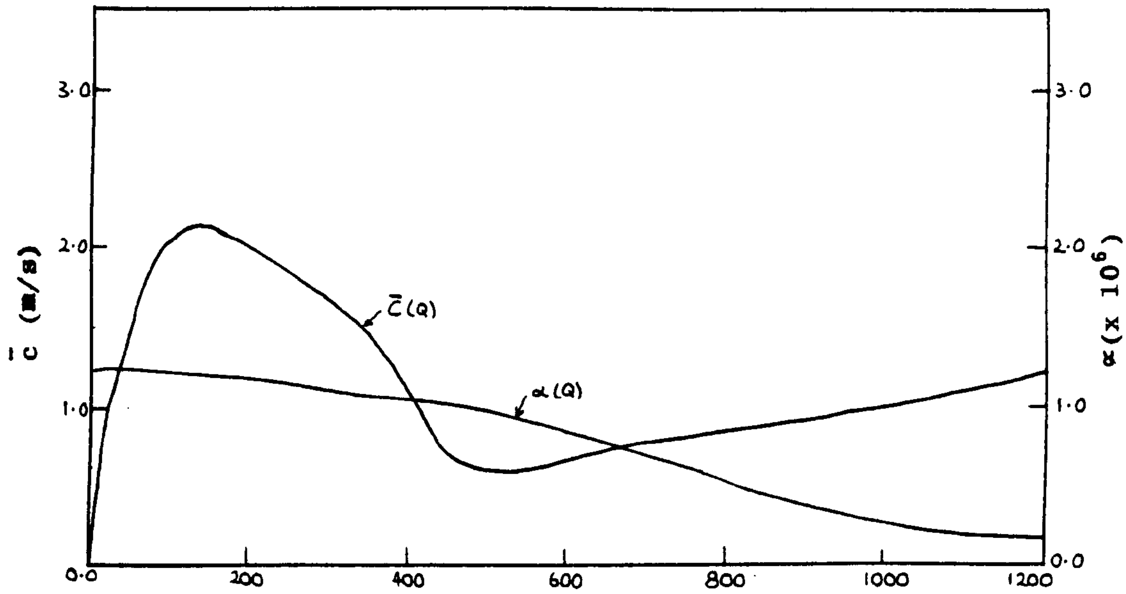


Fig. 3.1. Attenuation (α) and speed ($\bar{c}$) parameters for the River Wye between Erwood and Belmont (after Price (Ref. 90)).

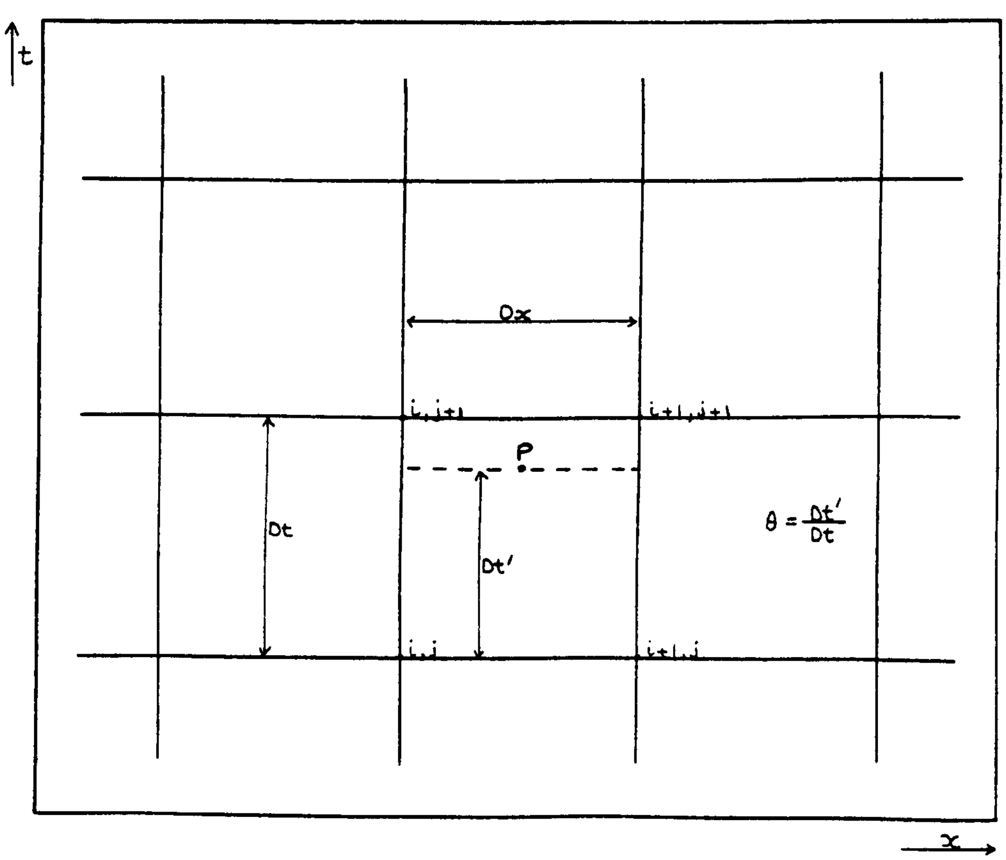


Fig. 3.2. Regular implicit method finite difference grid.

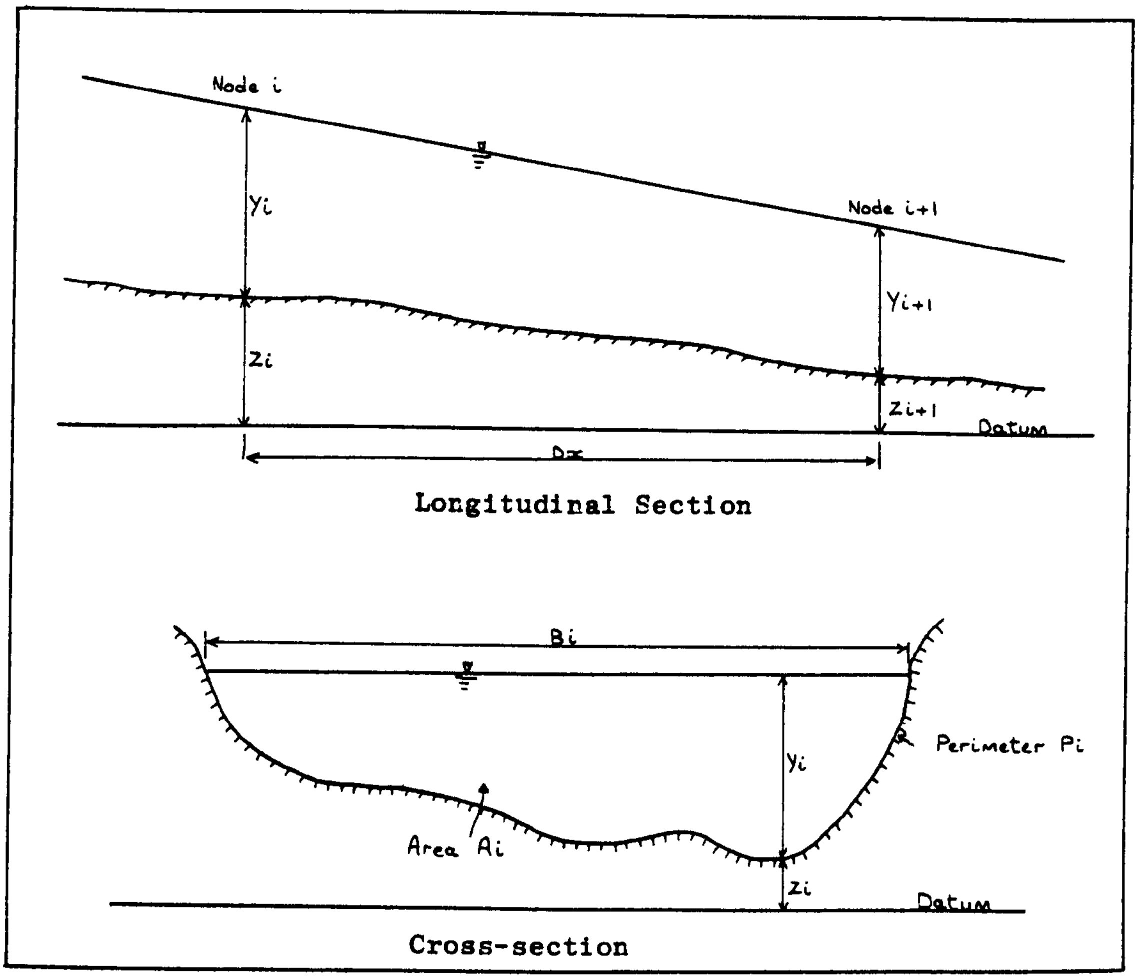


Fig. 3.3. Definition of channel geometry parameters.

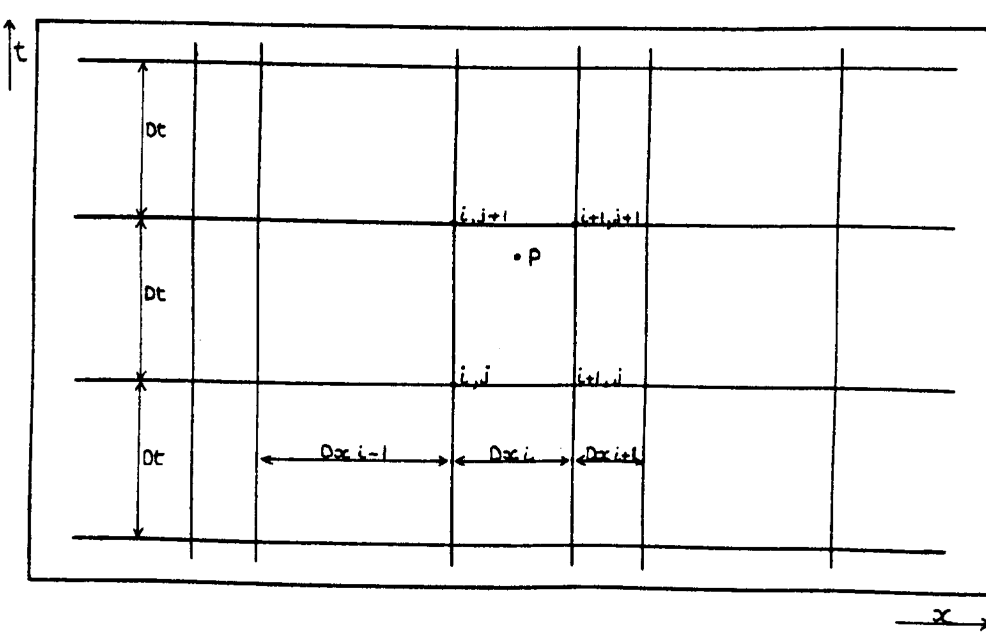


Fig. 3.4. Irregular implicit method finite difference grid.

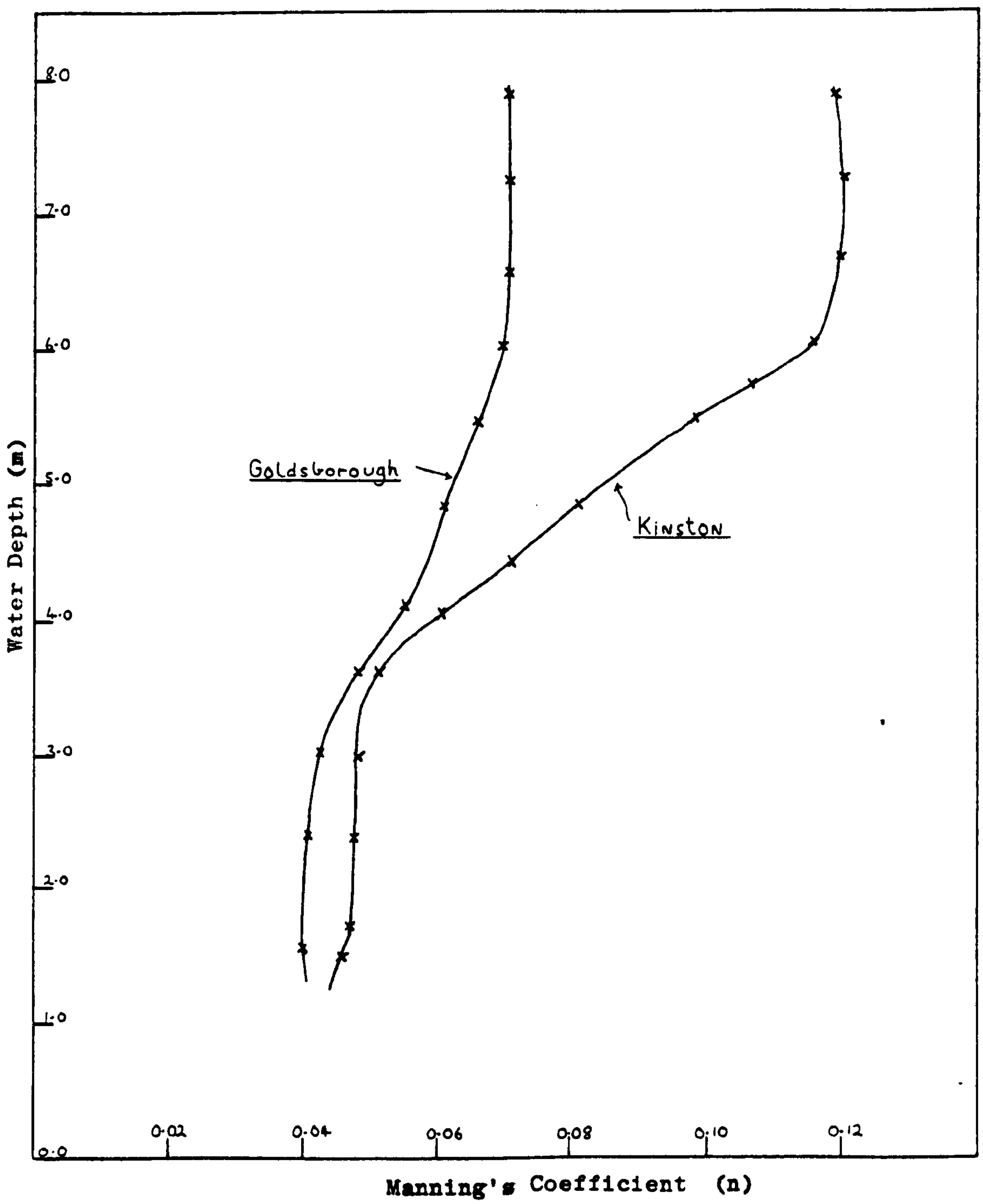


Fig. 3.5. Variation of Manning's n for the Neuse River, North Carolina (after Amein and Fang (Ref. 11)).

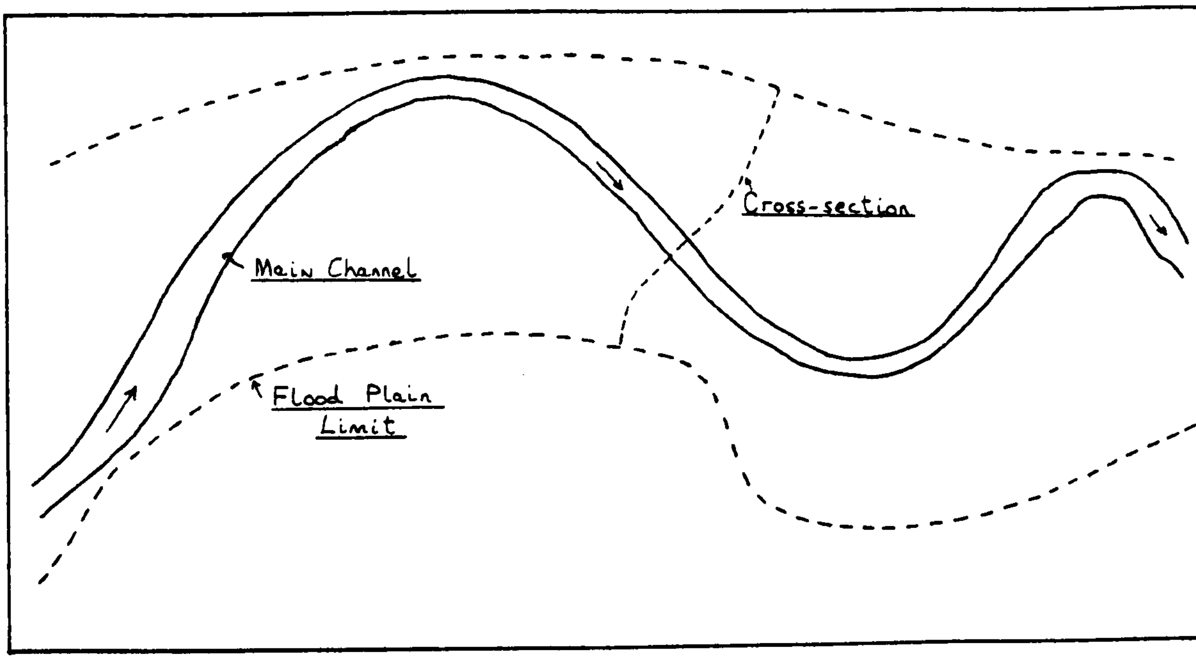


Fig. 3.6. Channel and flood plain meanders.

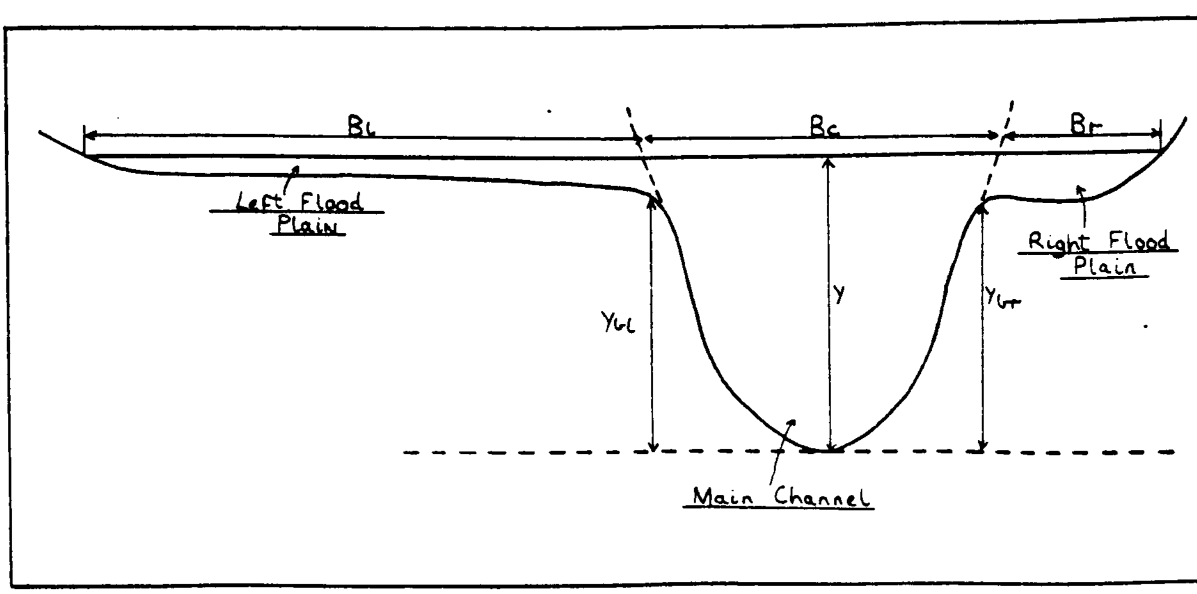


Fig. 3.7. Flood plain representation scheme.

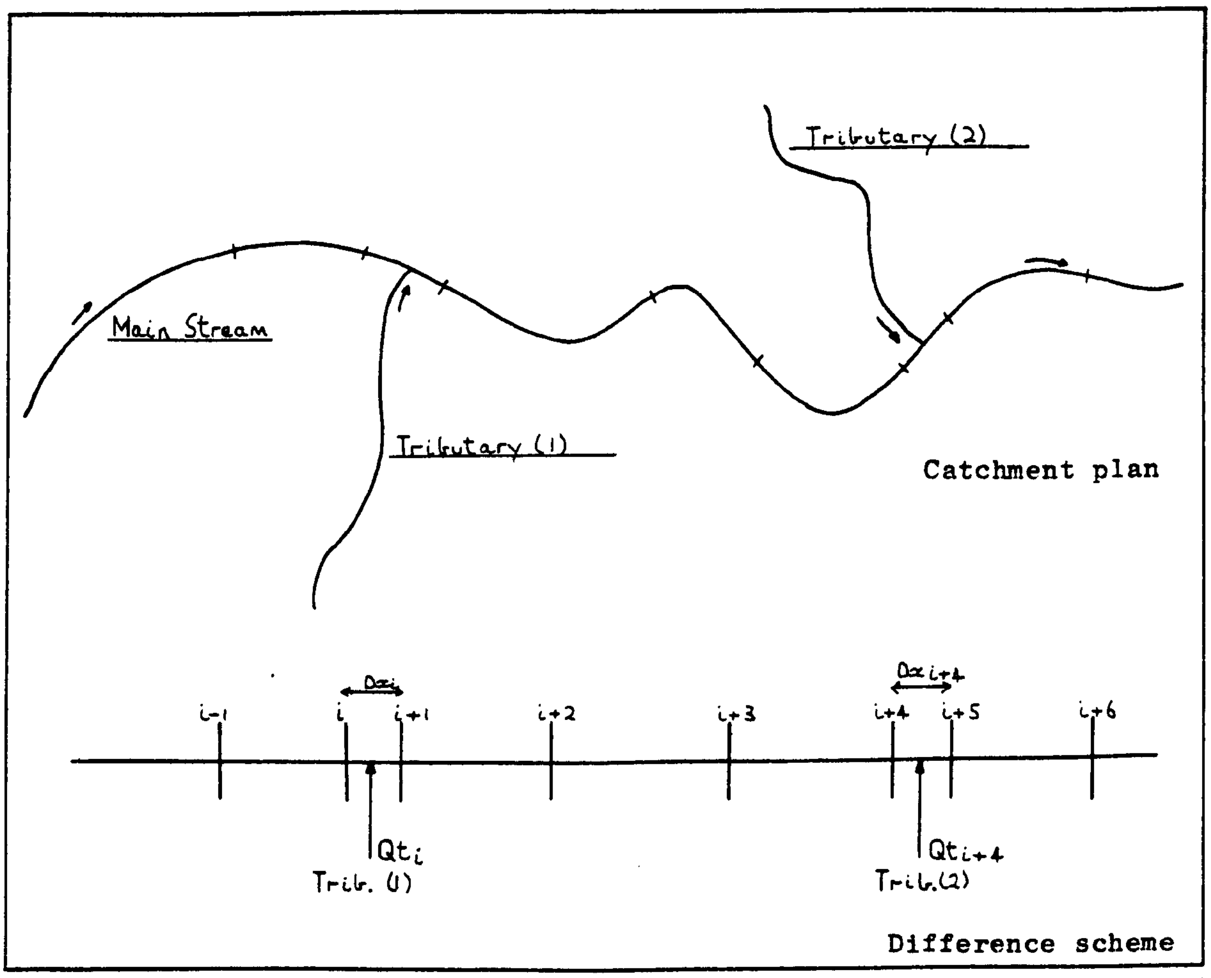


Fig. 3.8. Tributary inflow representation.

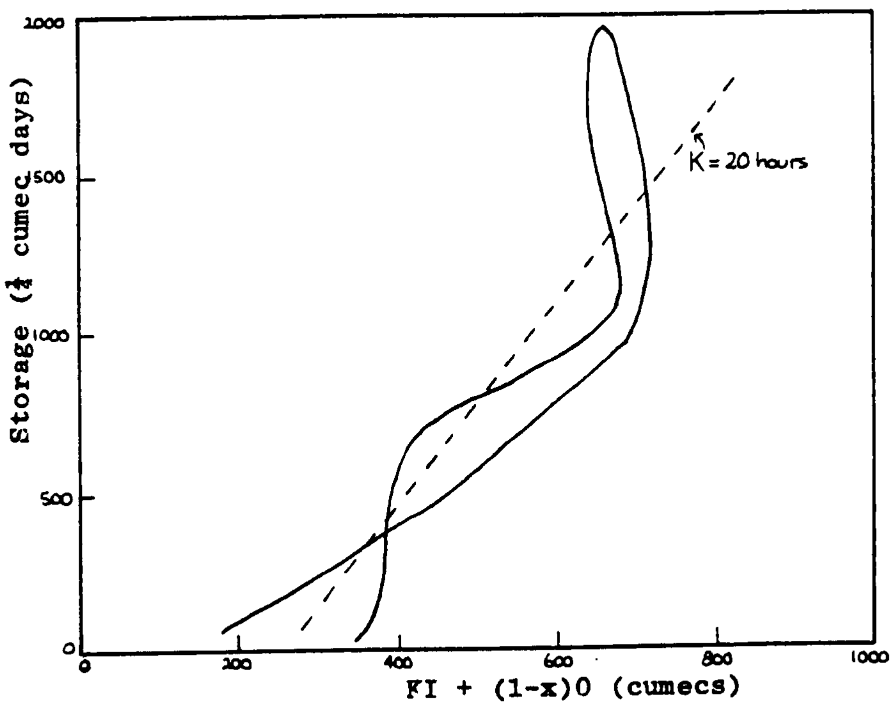


Fig. 4.1. River Wye - Erwood to Belmont: December 1960 storage curve.

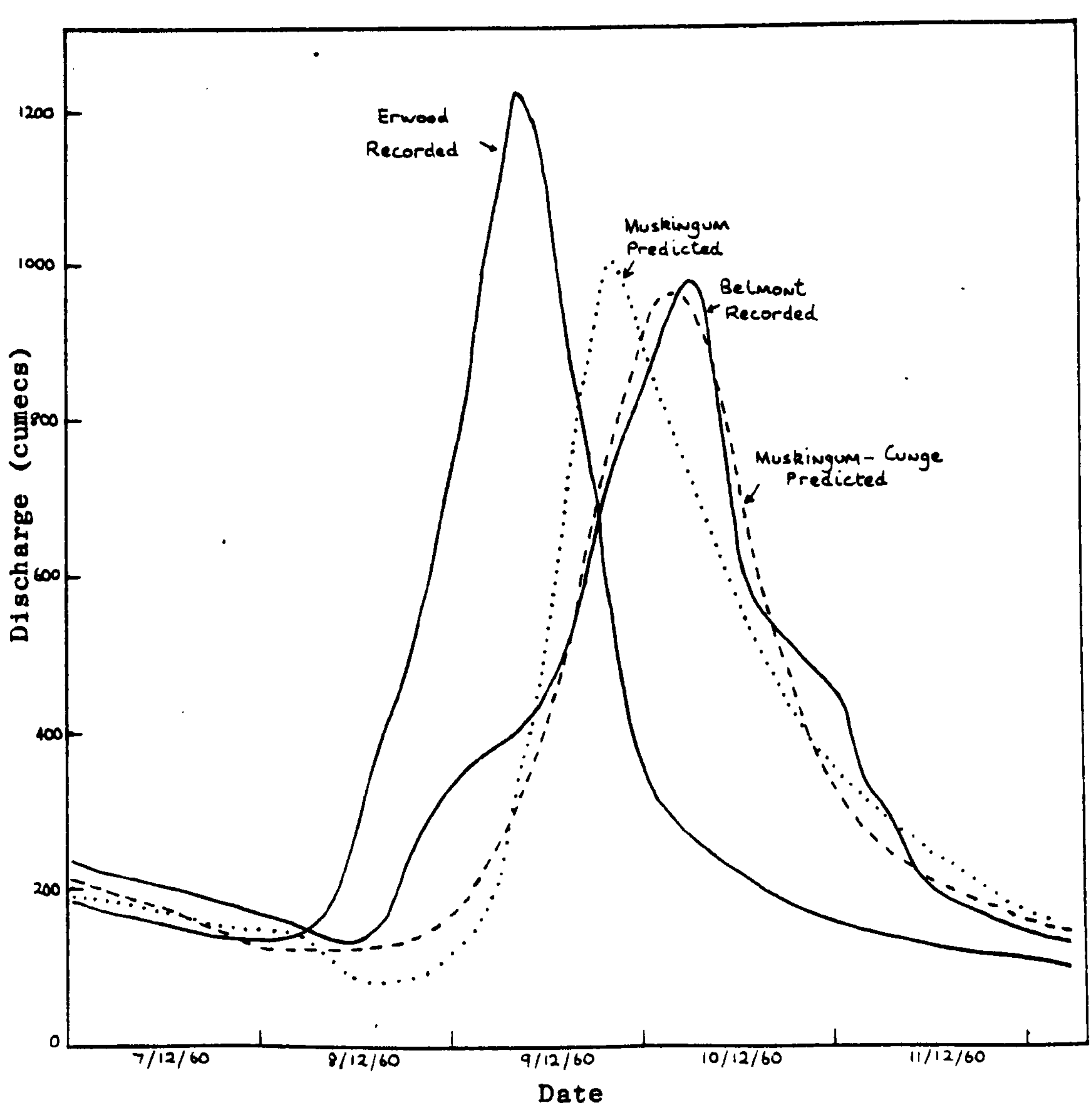


Fig. 4.2. River Wye - Muskingum simulation of December 1960 flood.

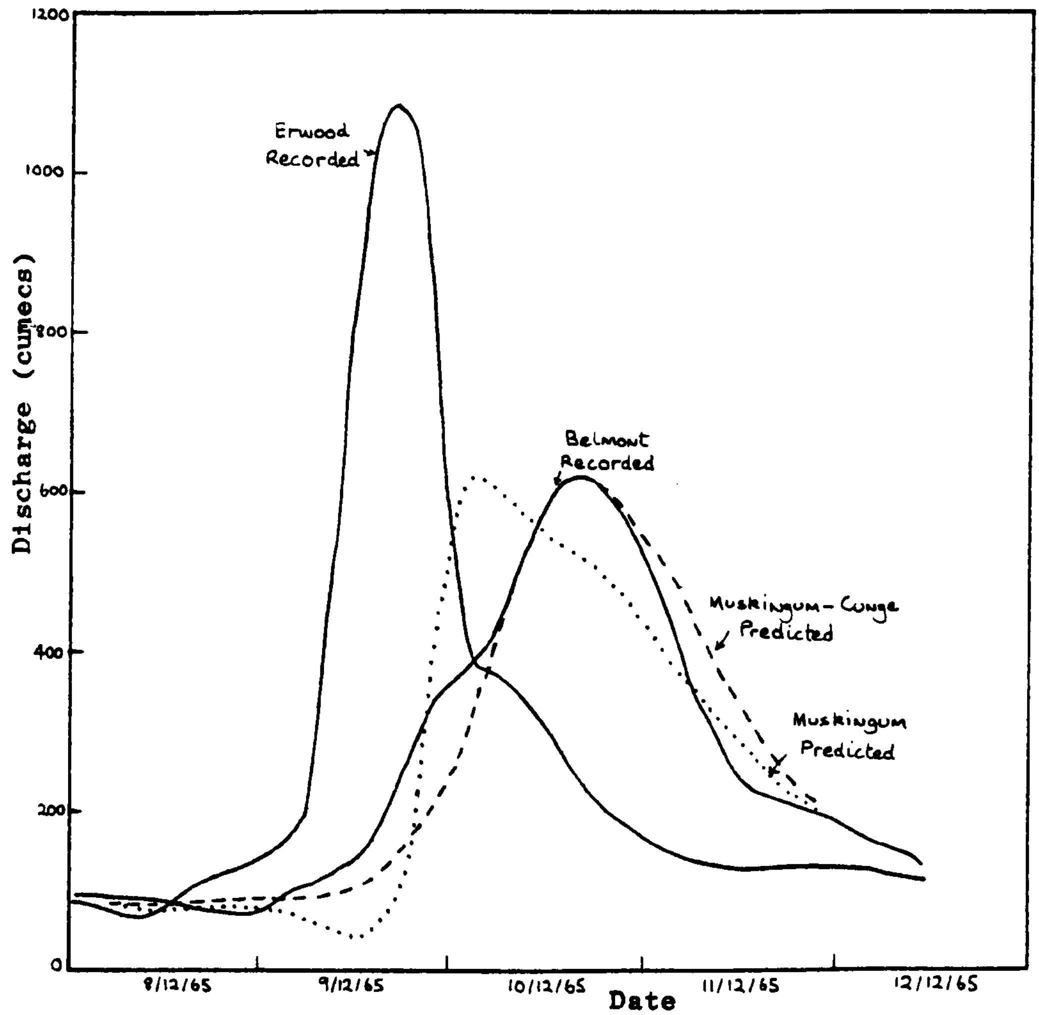


Fig. 4.3. River Wye - Muskingum simulation of December 1965 flood.

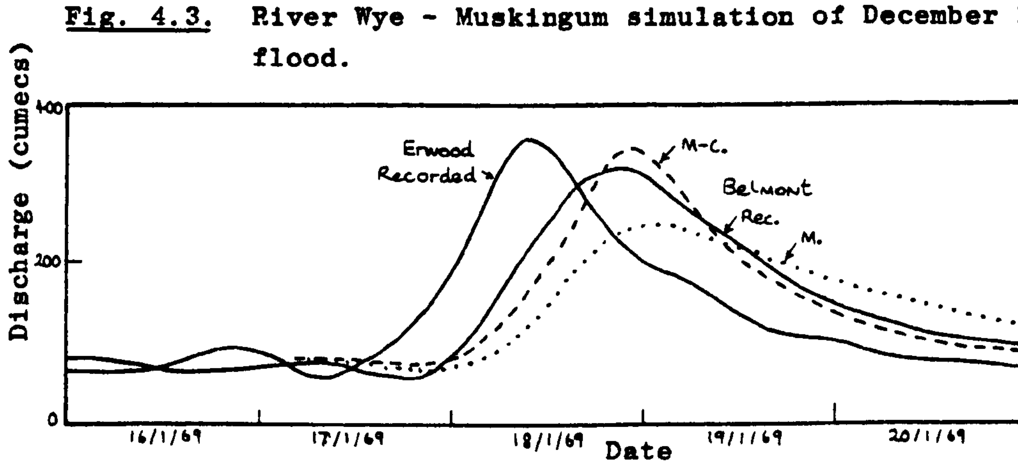


Fig. 4.4. River Wye - Muskingum simulation of January 1969 flood.

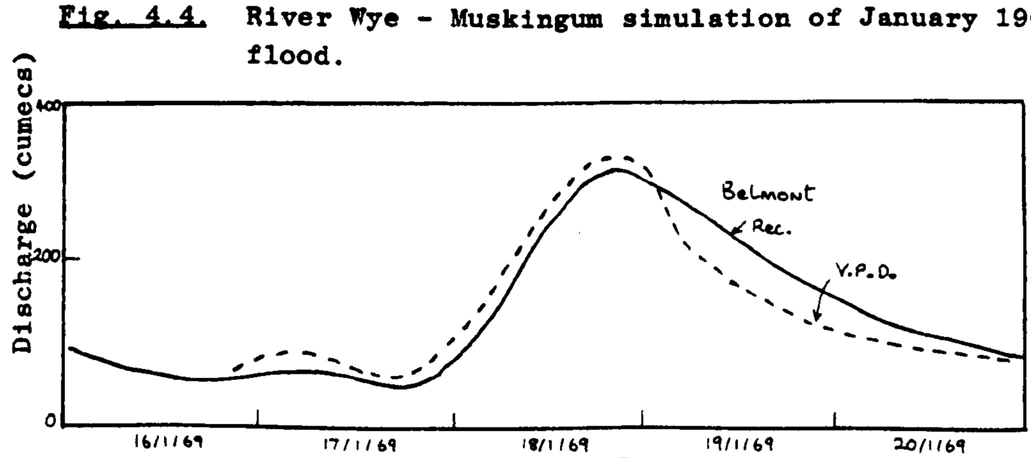


Fig. 4.5. River Wye - V.P.D. simulation of January 1969 flood.

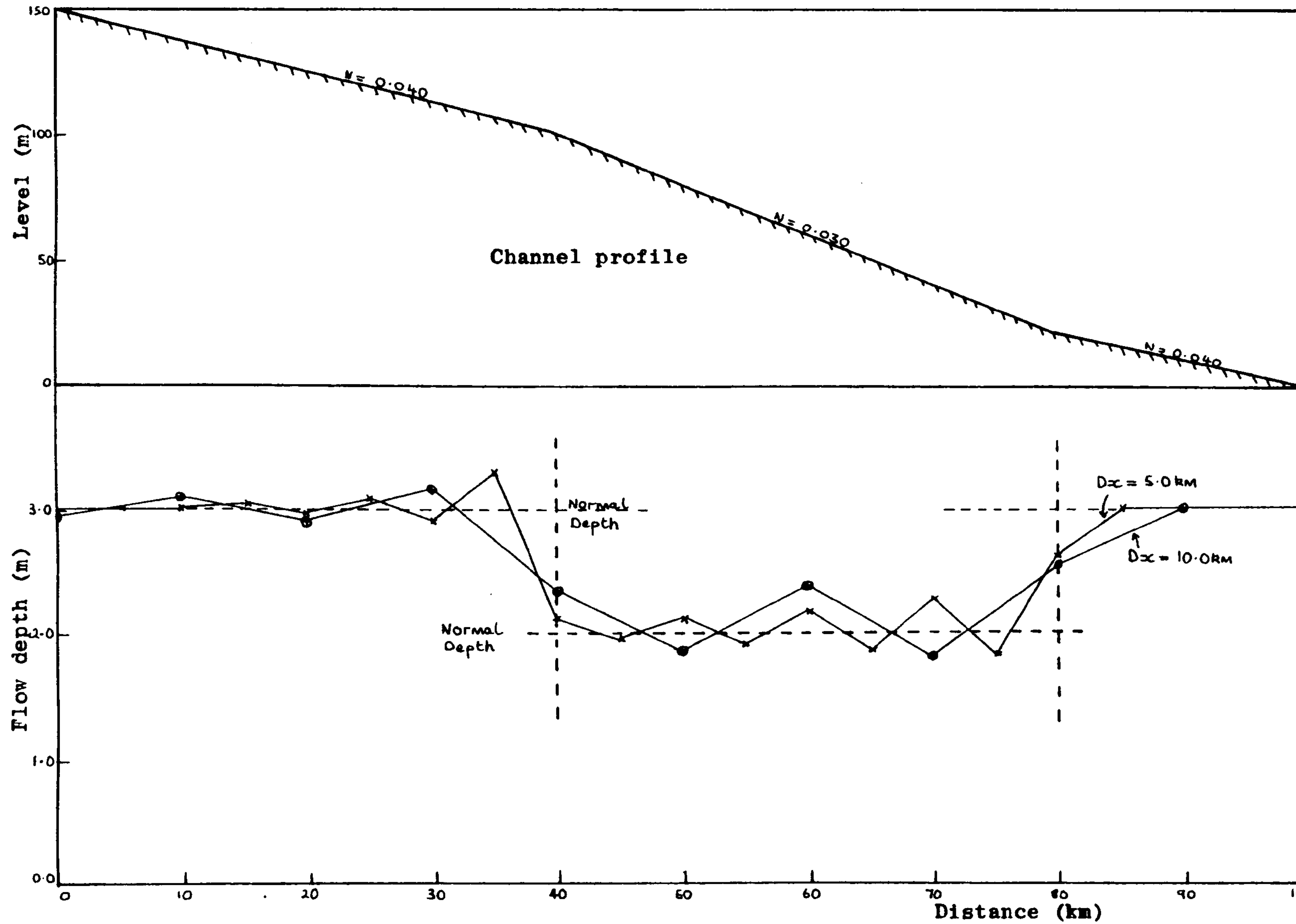


Fig. 4.6. Saw-tooth fluctuations for a hypothetical channel.

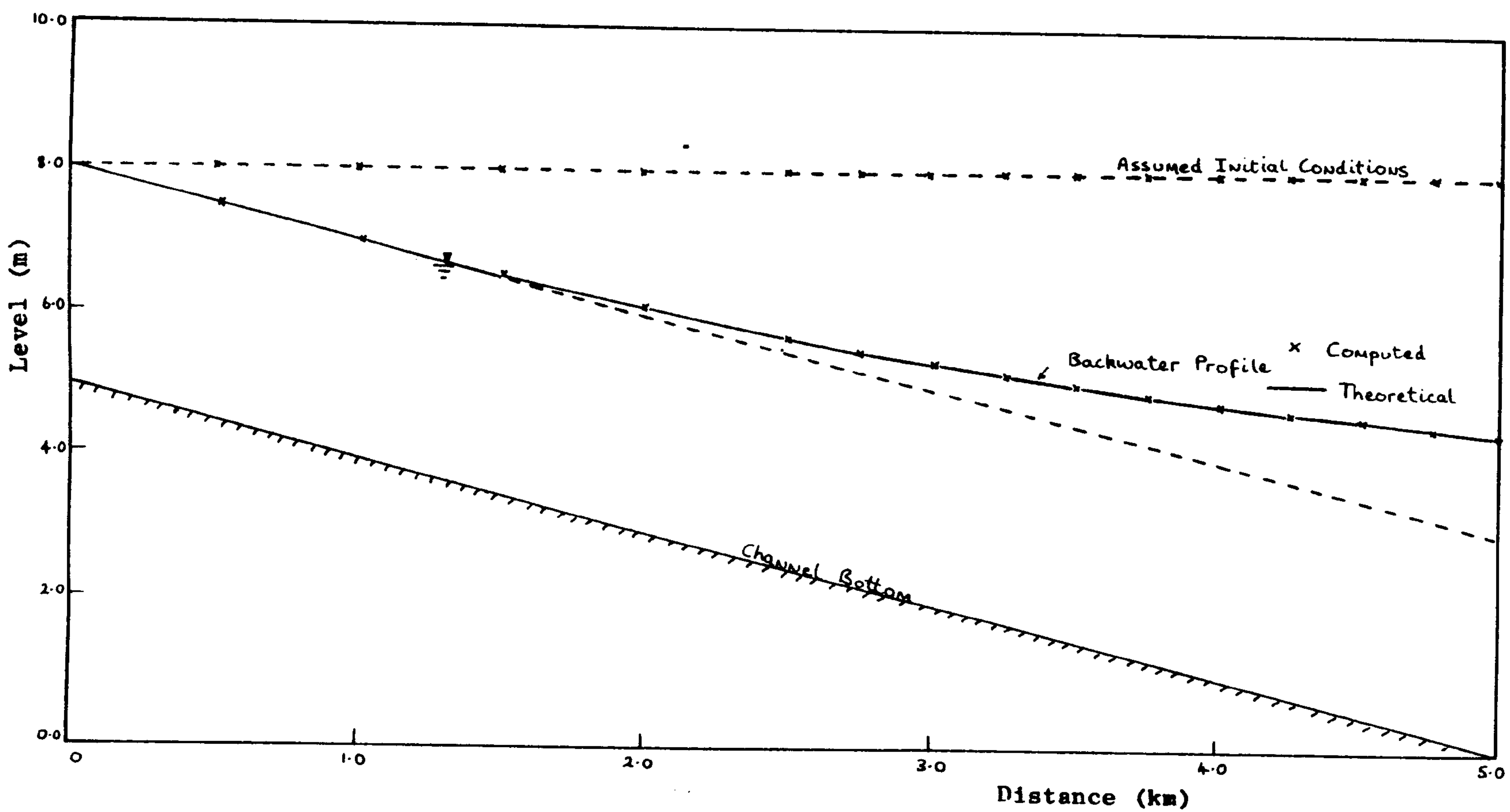
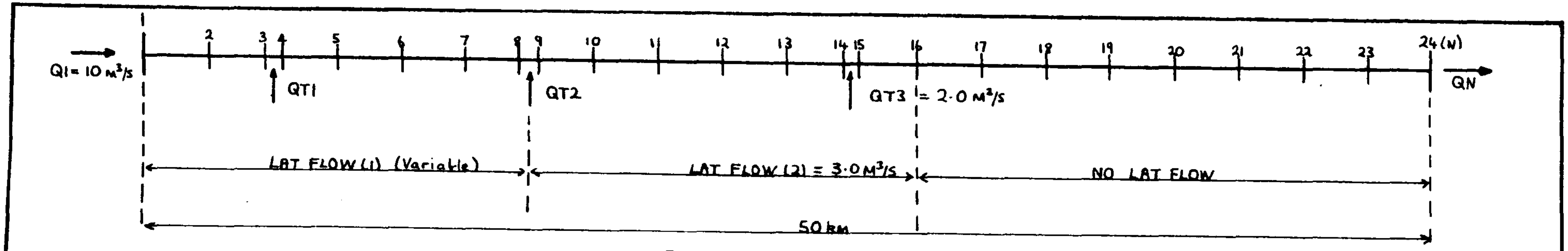


Fig. 4.7. Backwater profile prediction - hypothetical channel.



Space discretization

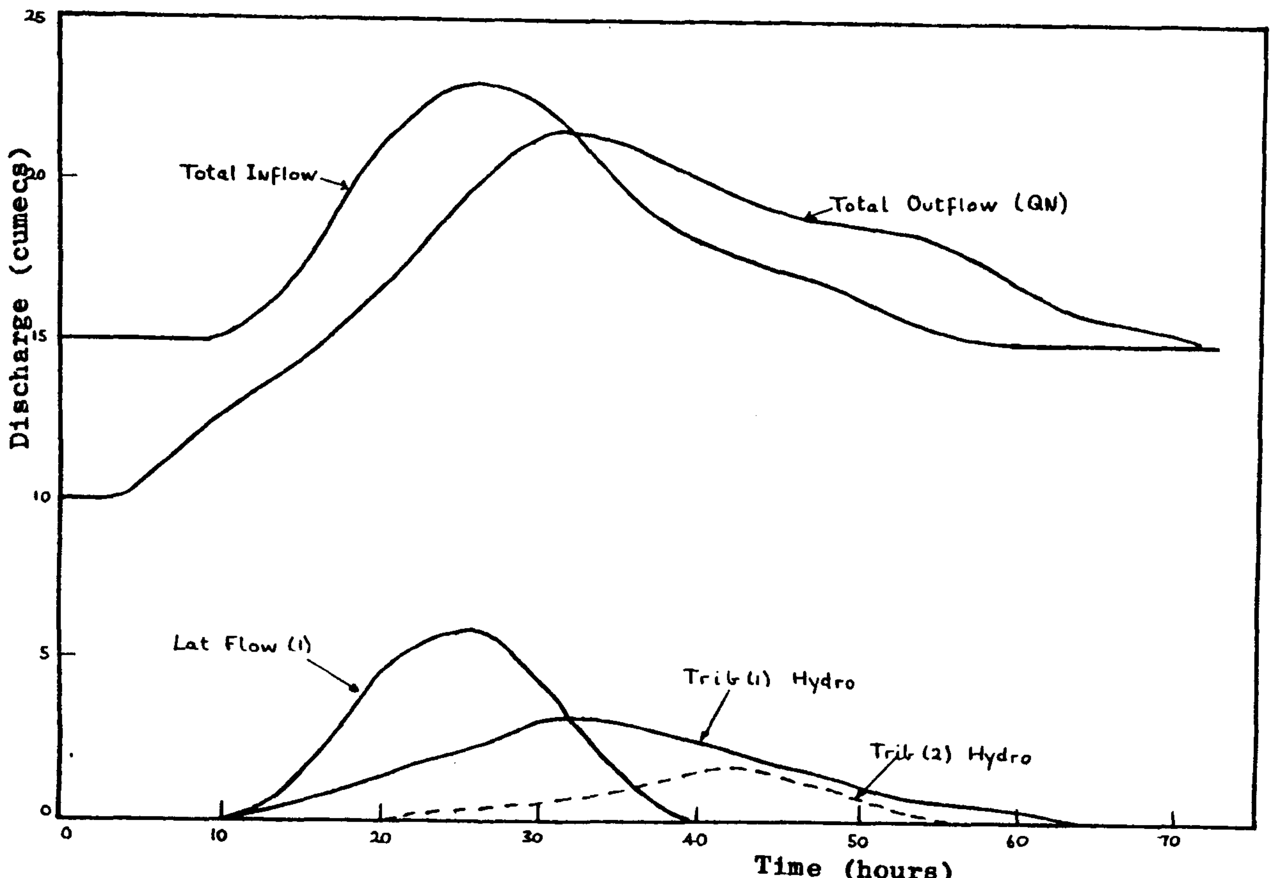


Fig. 4.8. Lateral inflow simulation - hypothetical channel.

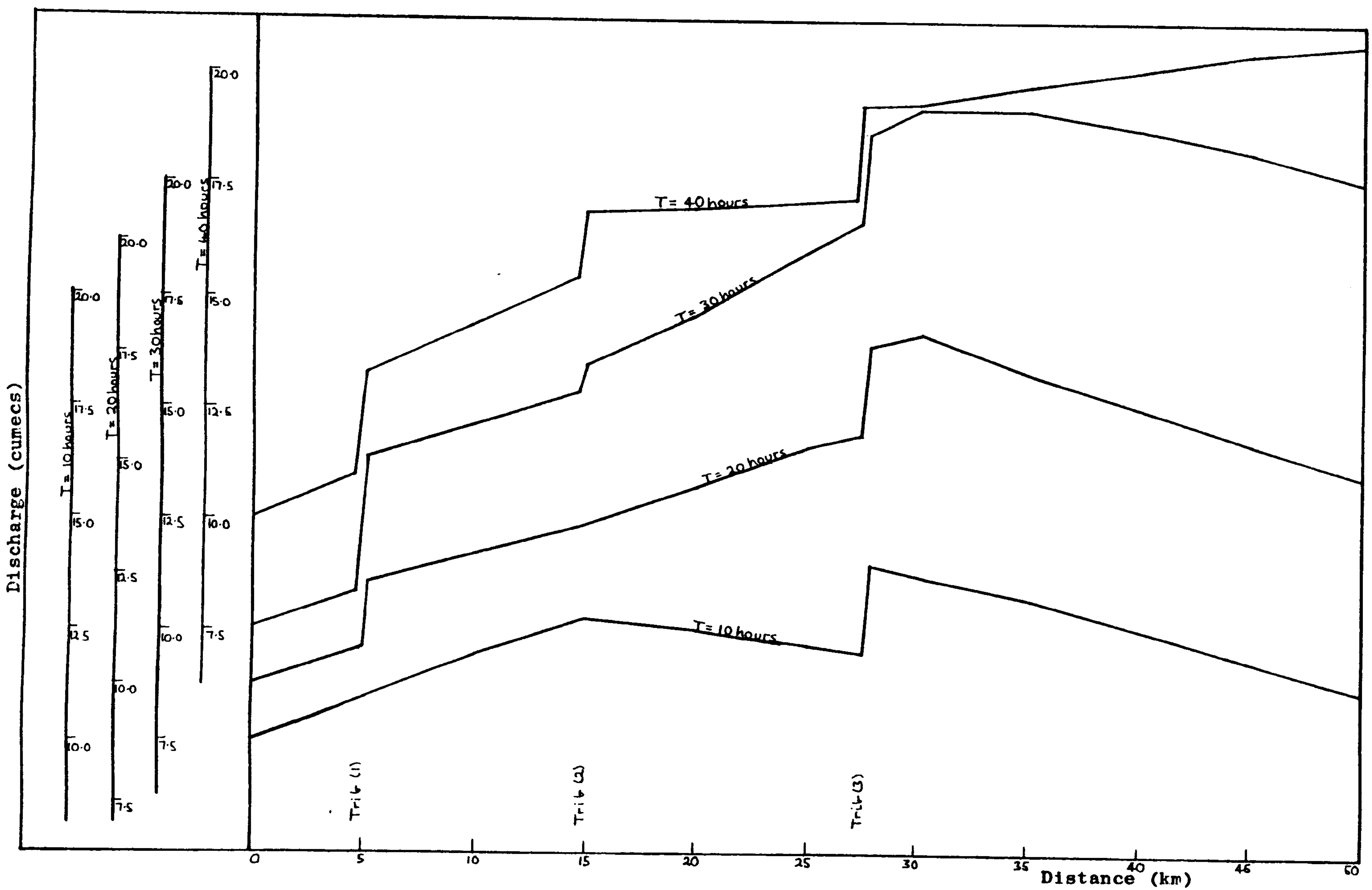


Fig. 4.9. Discharge profiles - hypothetical channel.

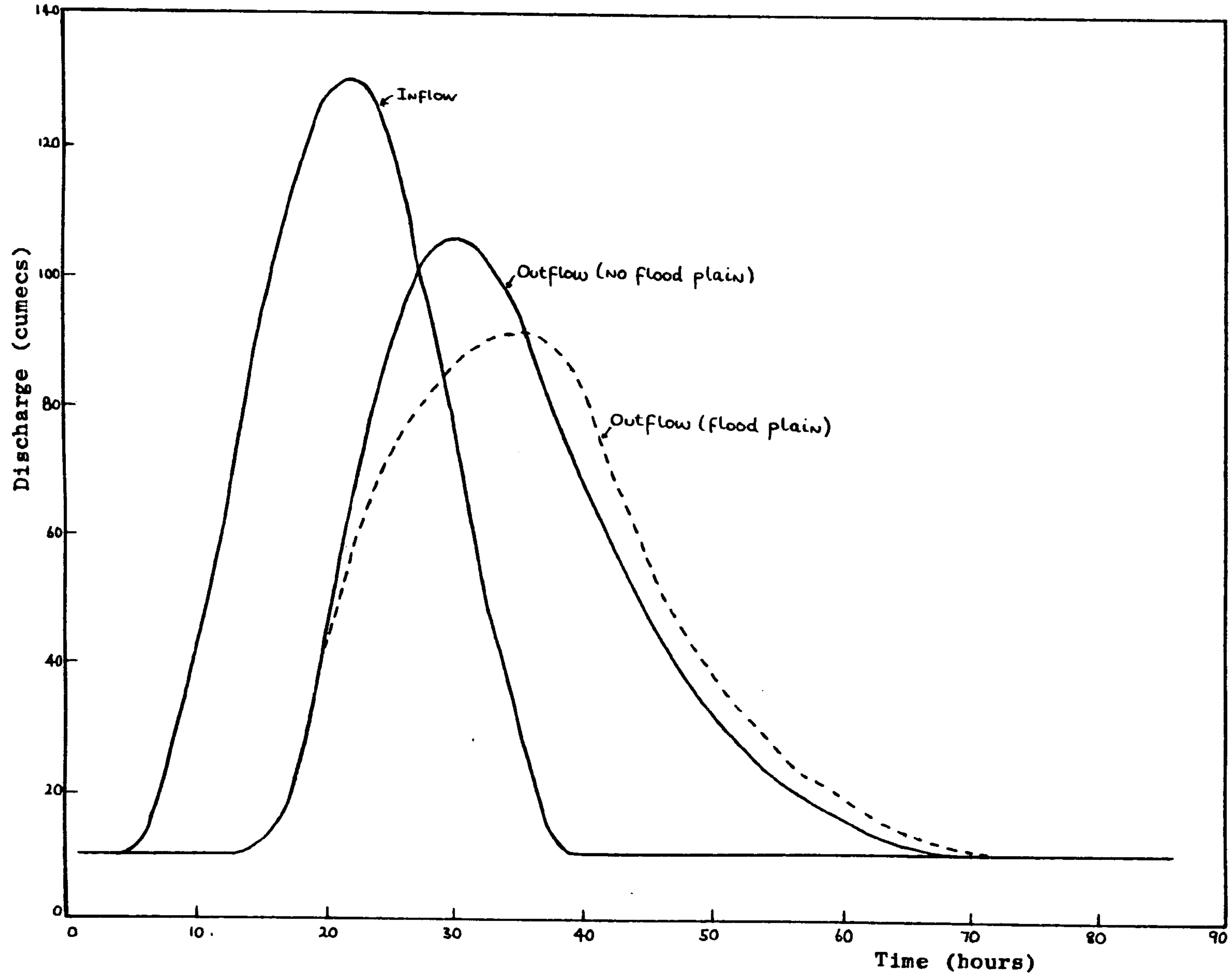


Fig. 4.10. Discharge attenuation due to flood plain storage.

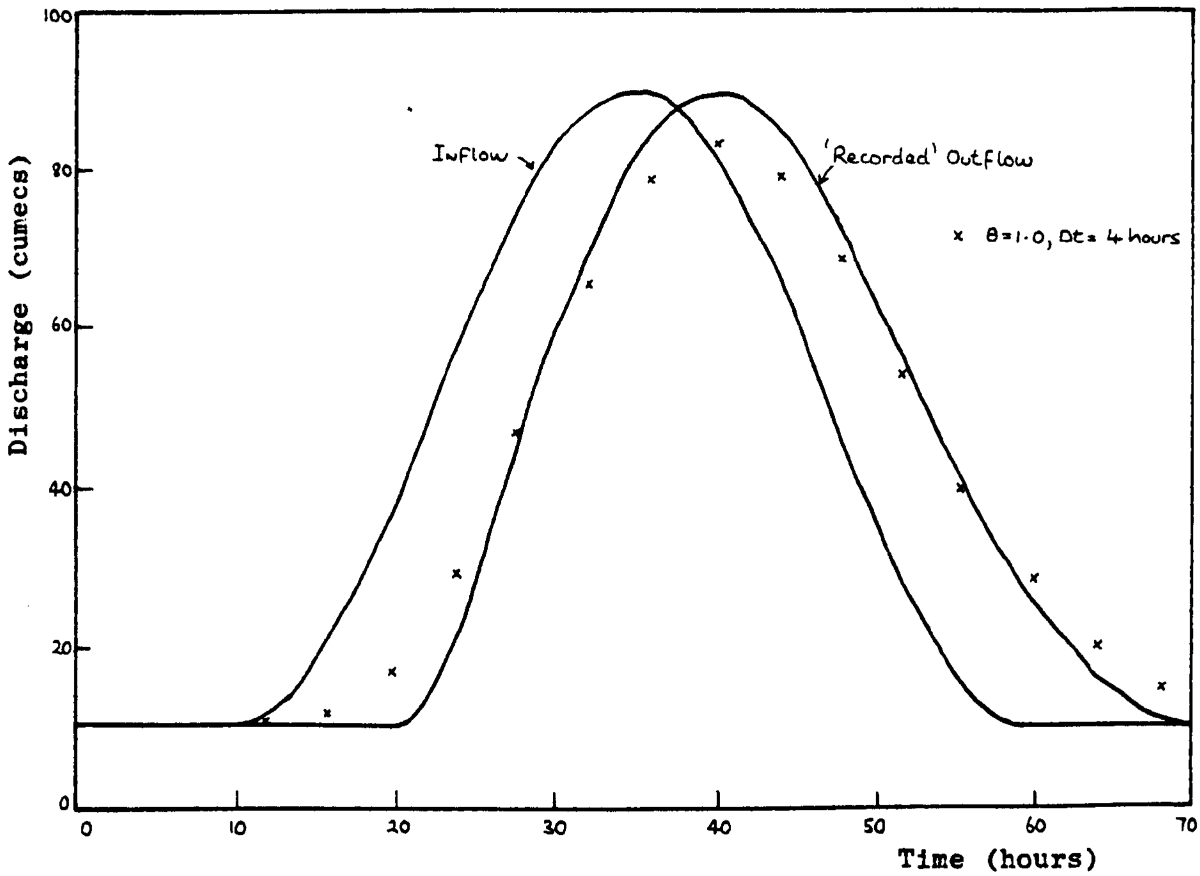


Fig. 4.11. Hydro (1), Slope = 0.001, Sine wave flood routing.

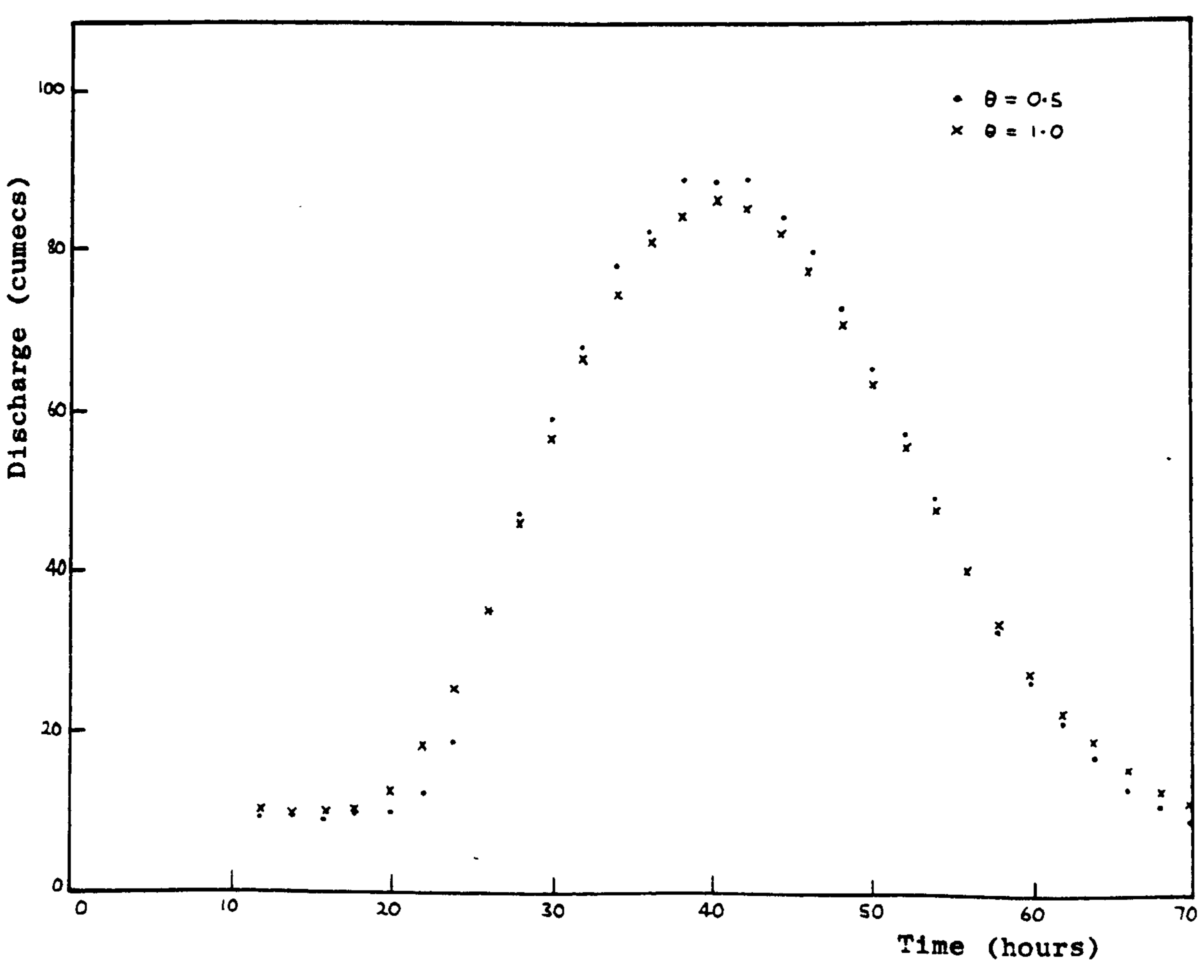


Fig. 4.12. Hydro (1), Slope = 0.001, Dt = 2.0 hours, Effect of varying θ.

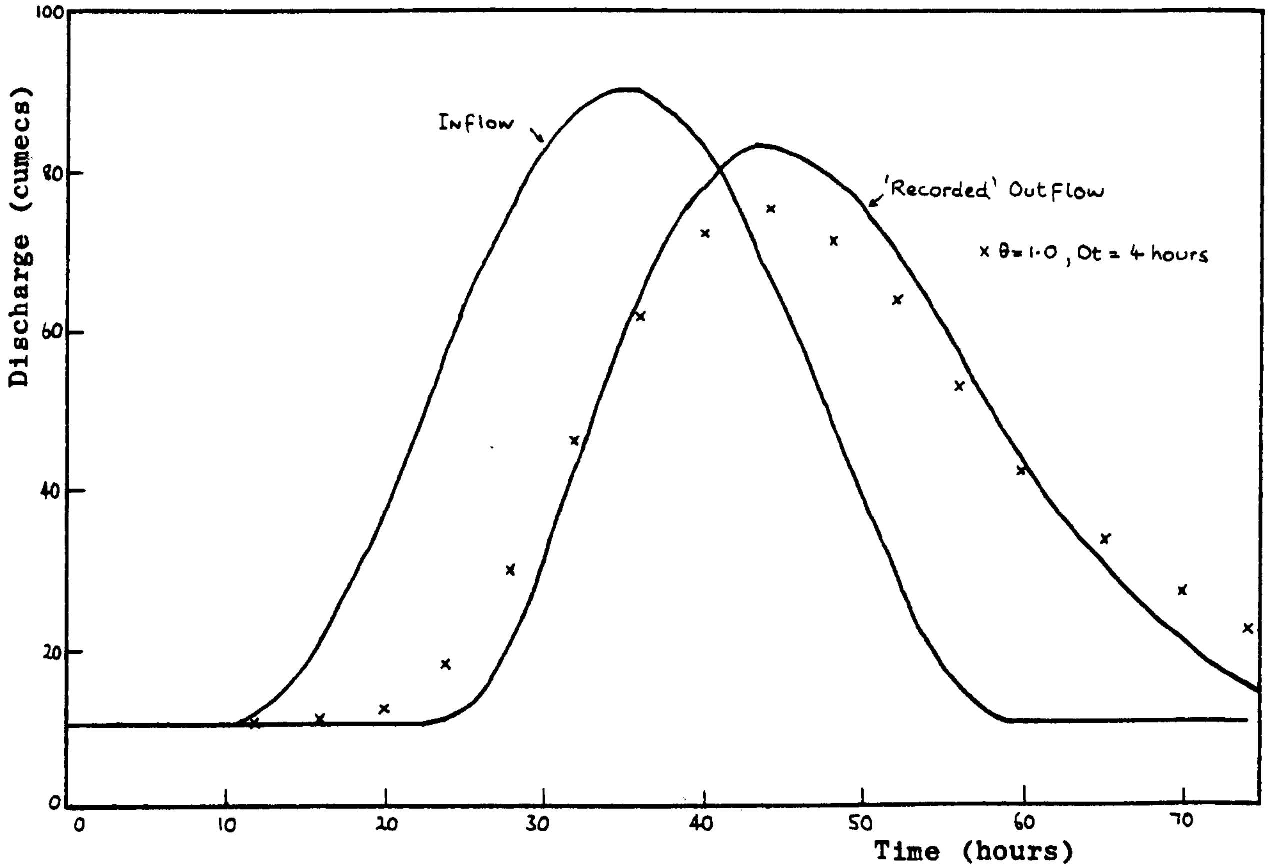


Fig. 4.13. Hydro (1), Slope = 0.0002, Sine wave flood routing.

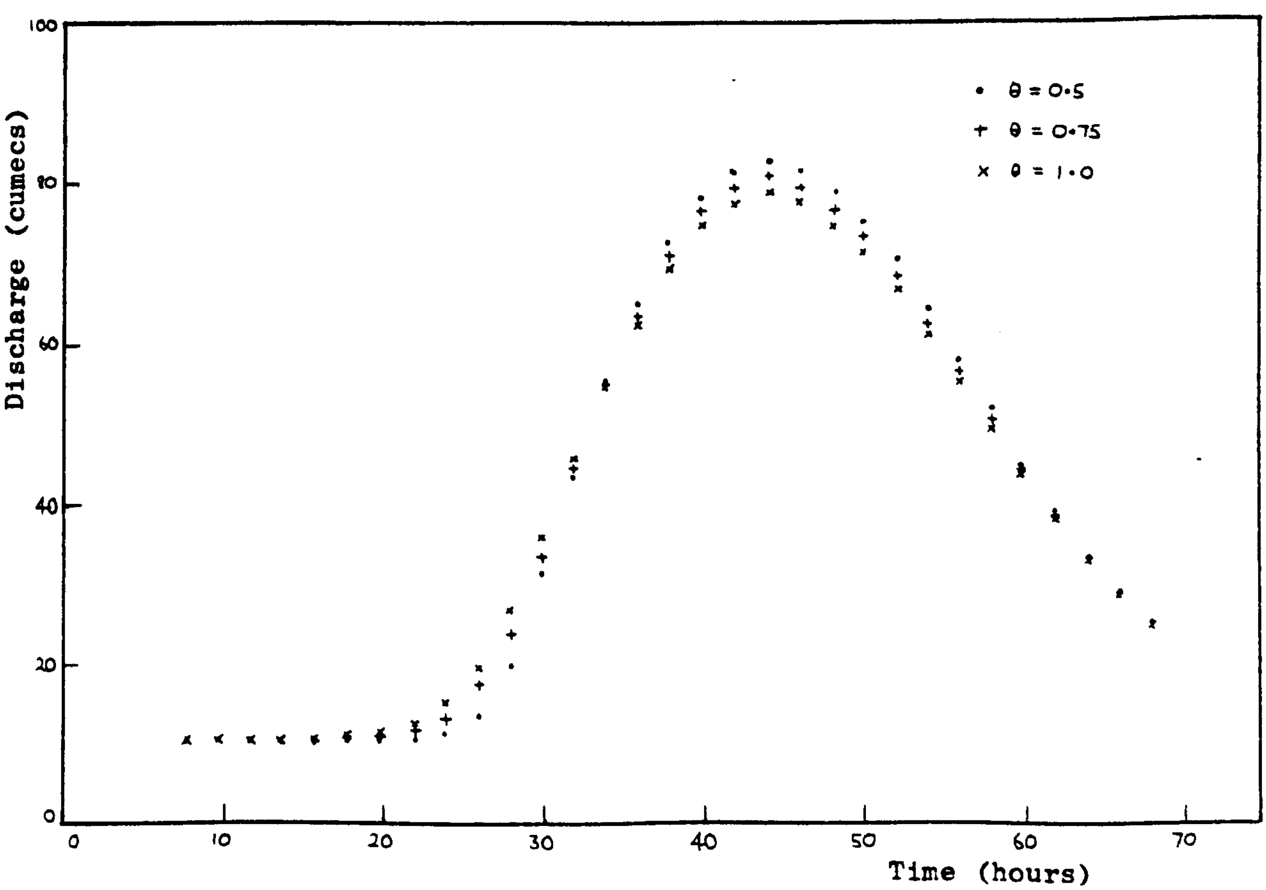


Fig. 4.14. Hydro (1), Slope = 0.0002, Dt = 2.0 hours, Effect of varying θ.

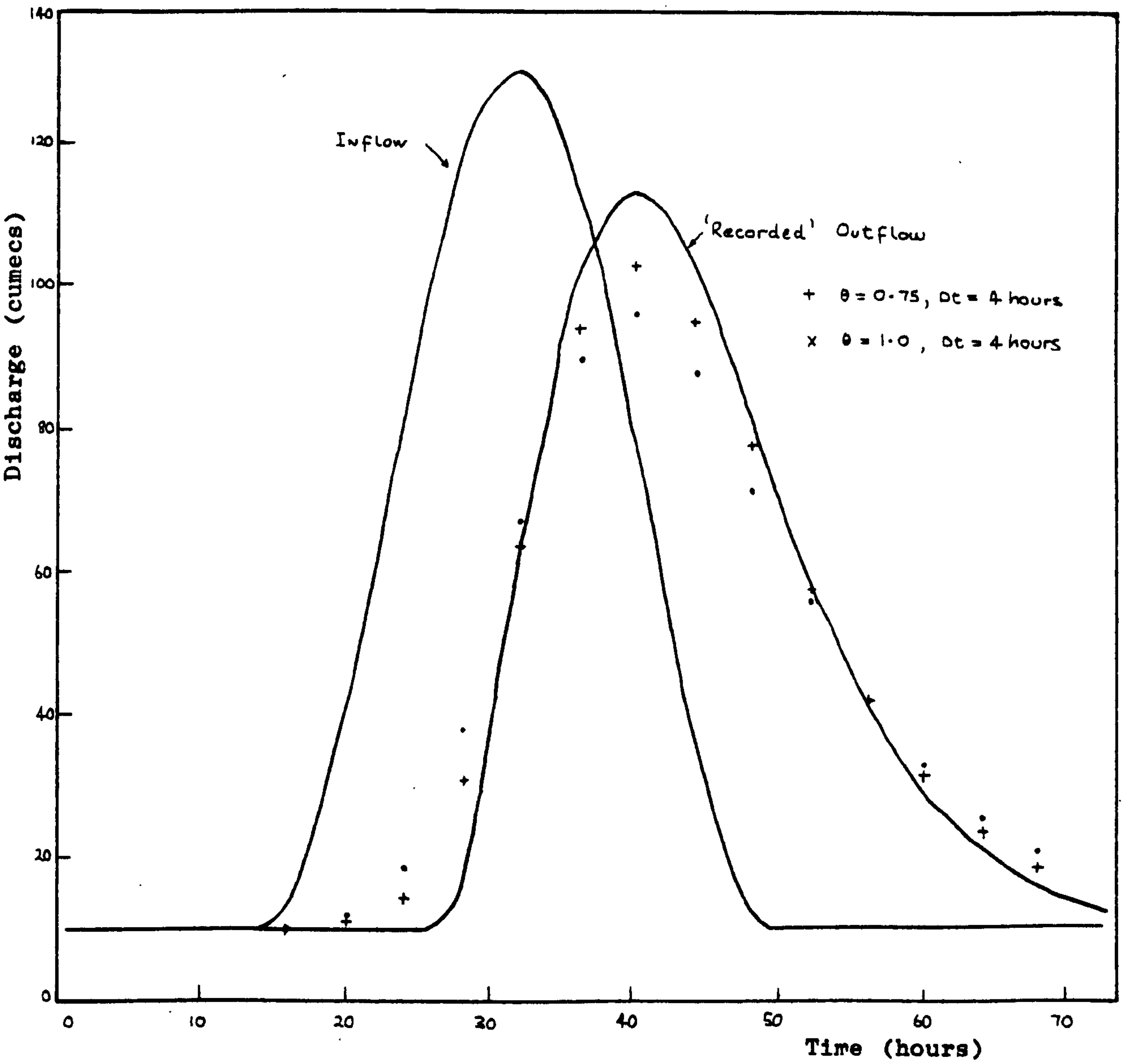
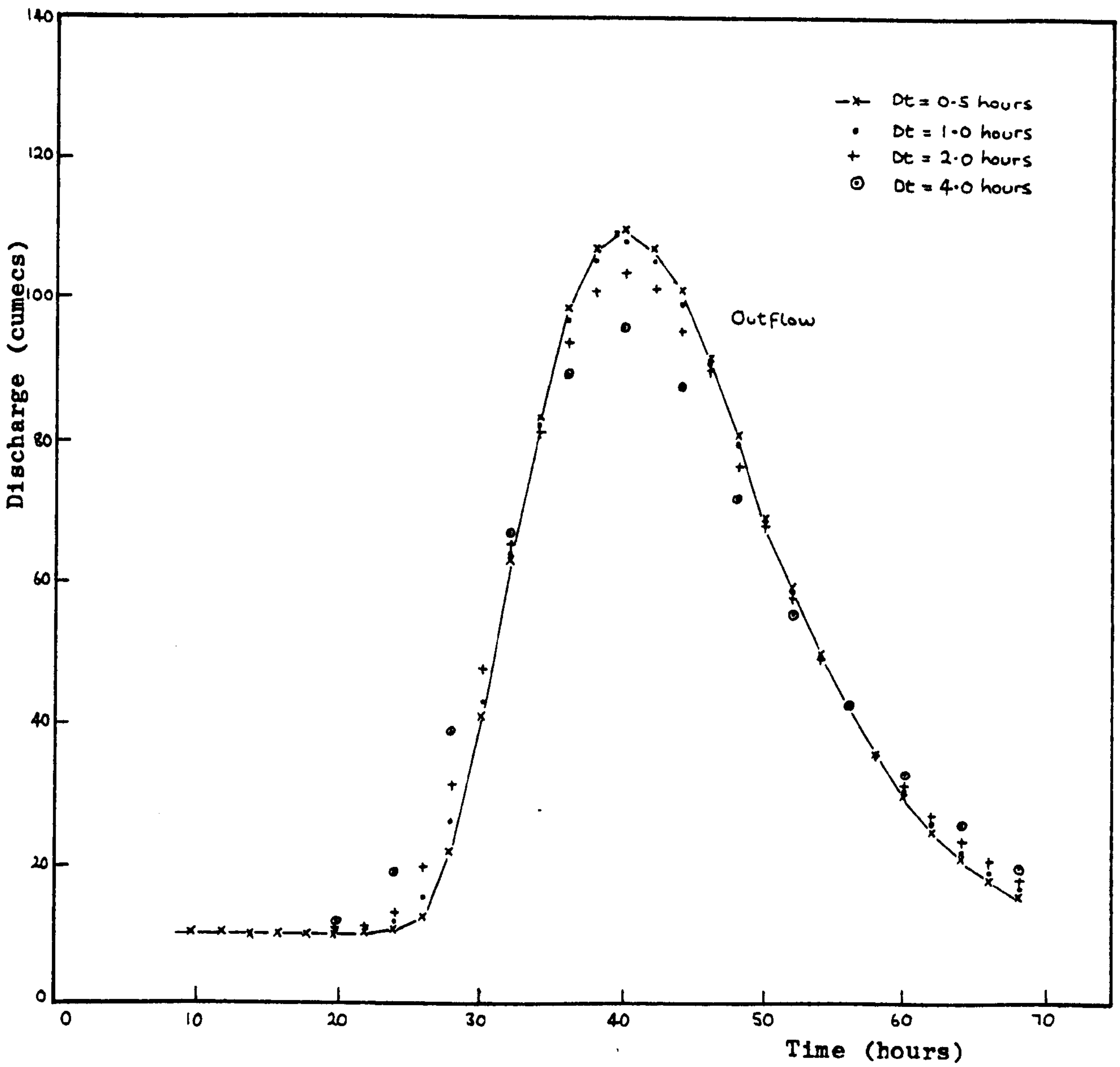


Fig. 4.15. Hydro (2), Slope = 0.0002, Sine wave flood routing.



<u>Fig. 4.16.</u> Hydro (2), Slope = 0.0002, θ = 1.0, Effect of varying Dt.

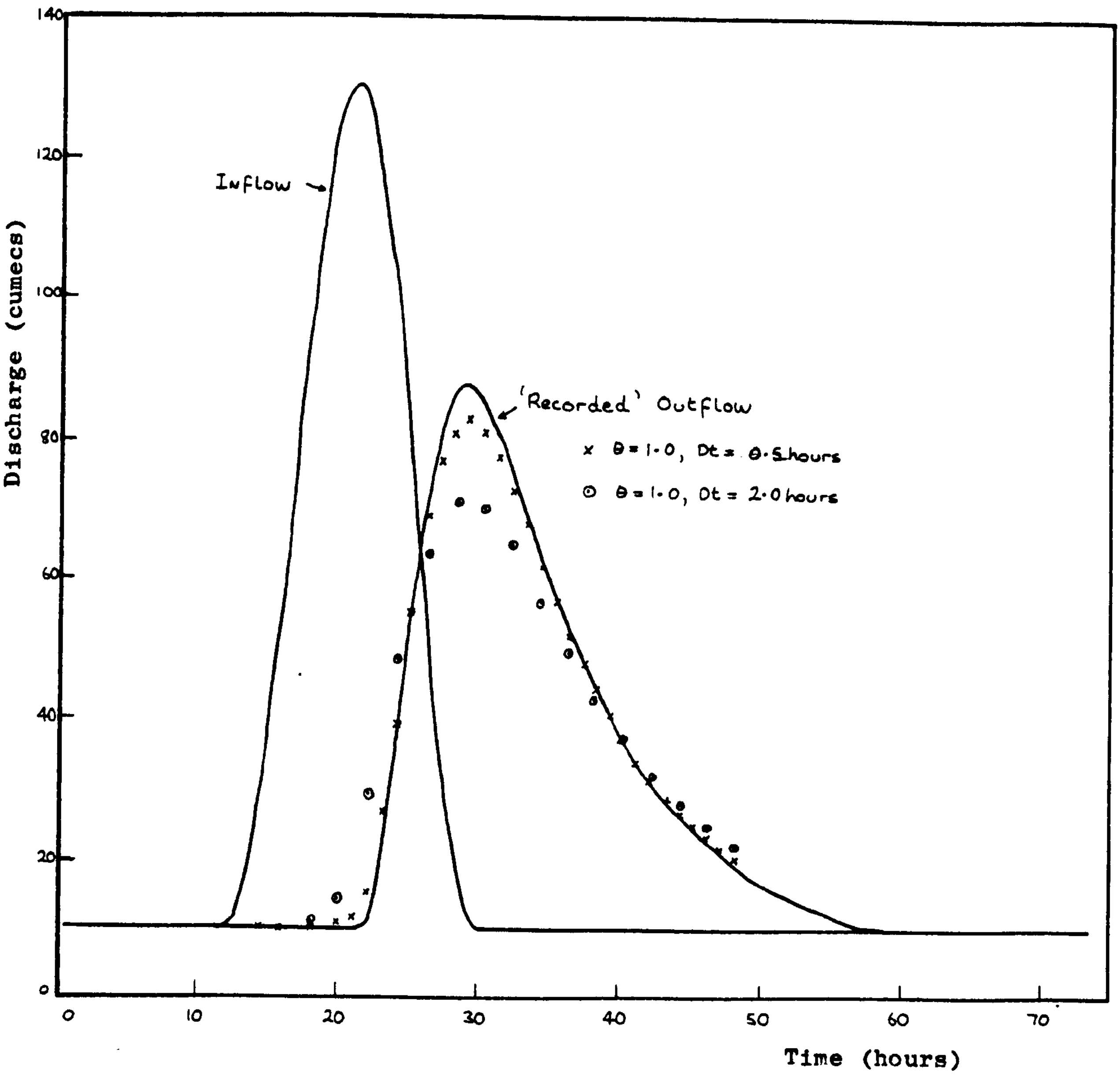


Fig. 4.17. Hydro (3), Slope = 0.0002, Sine wave flood routing.

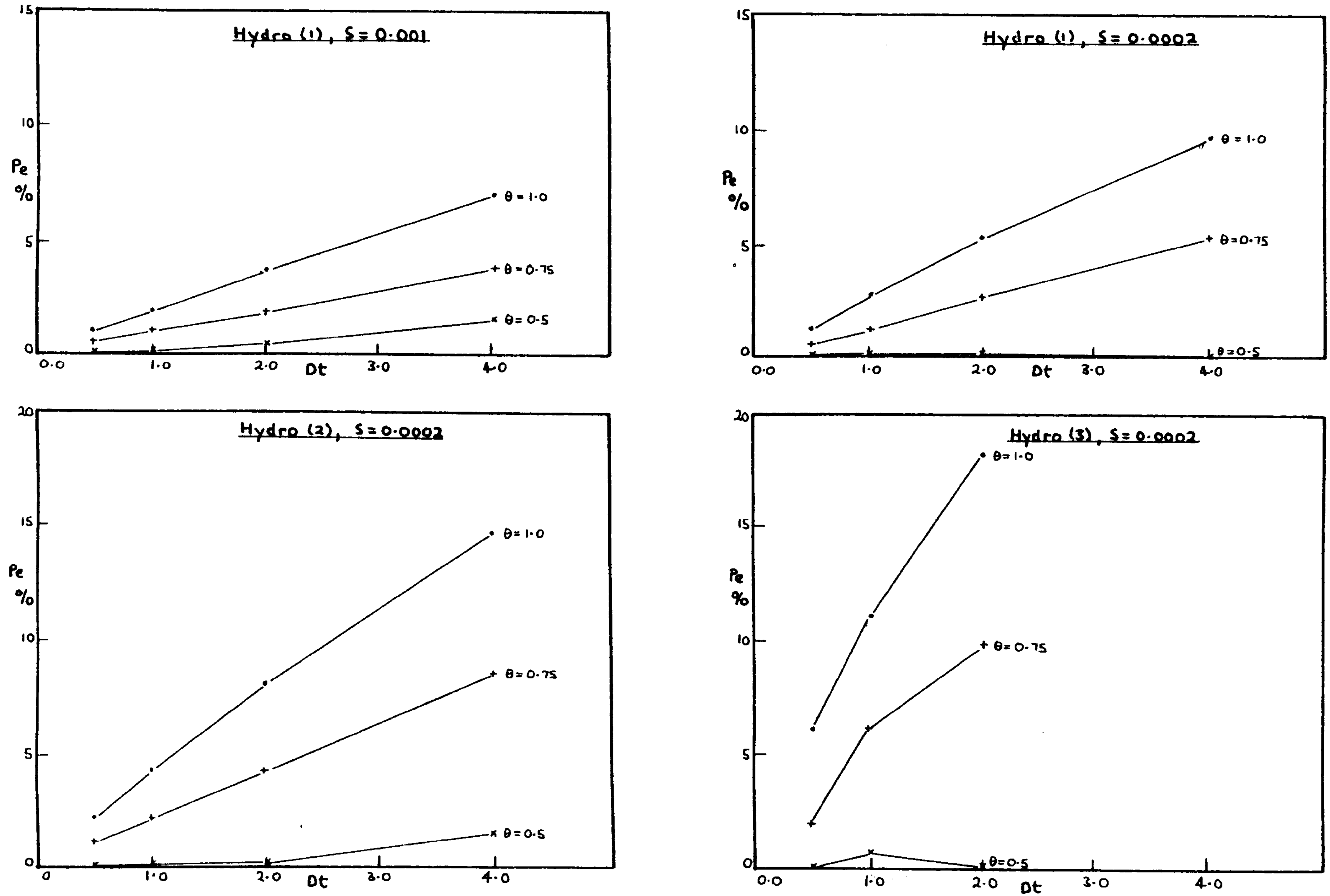


Fig. 4.18. Variation of peak error (Pe) with θ and Dt.

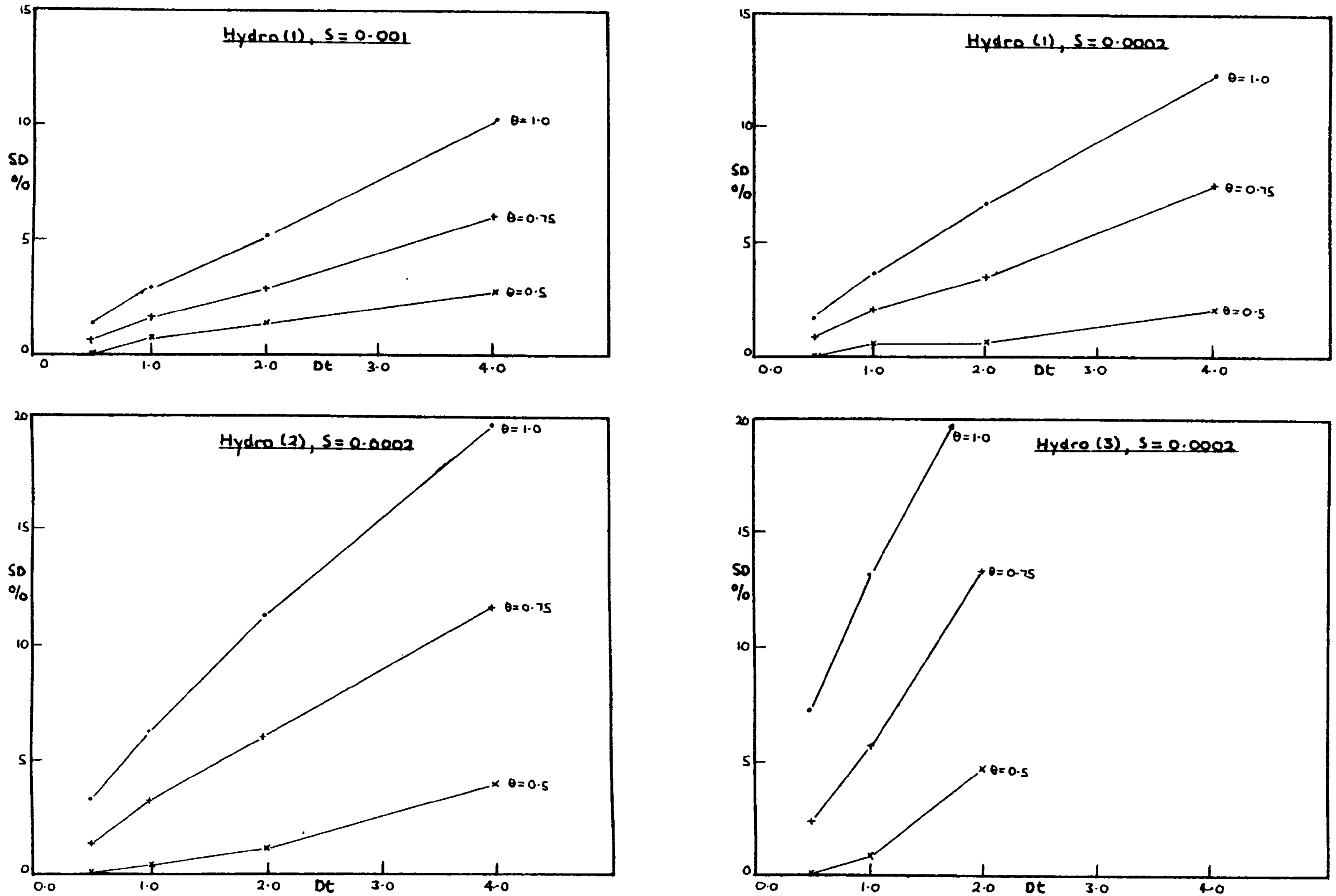


Fig. 4.19. Variation of standard deviation (SD) with θ and Dt.

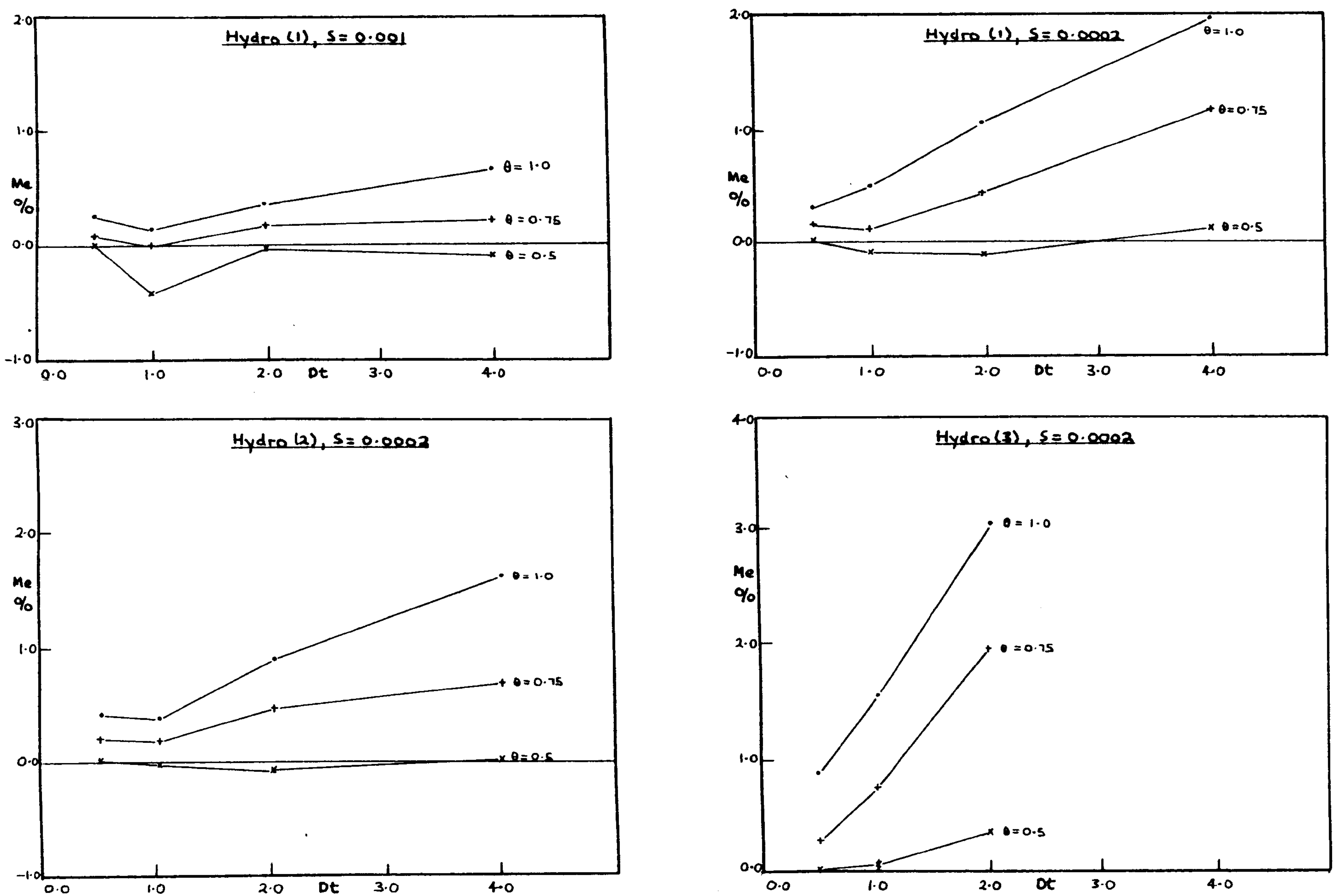


Fig. 4.20. Variation of mean error (Me) with θ and Dt.

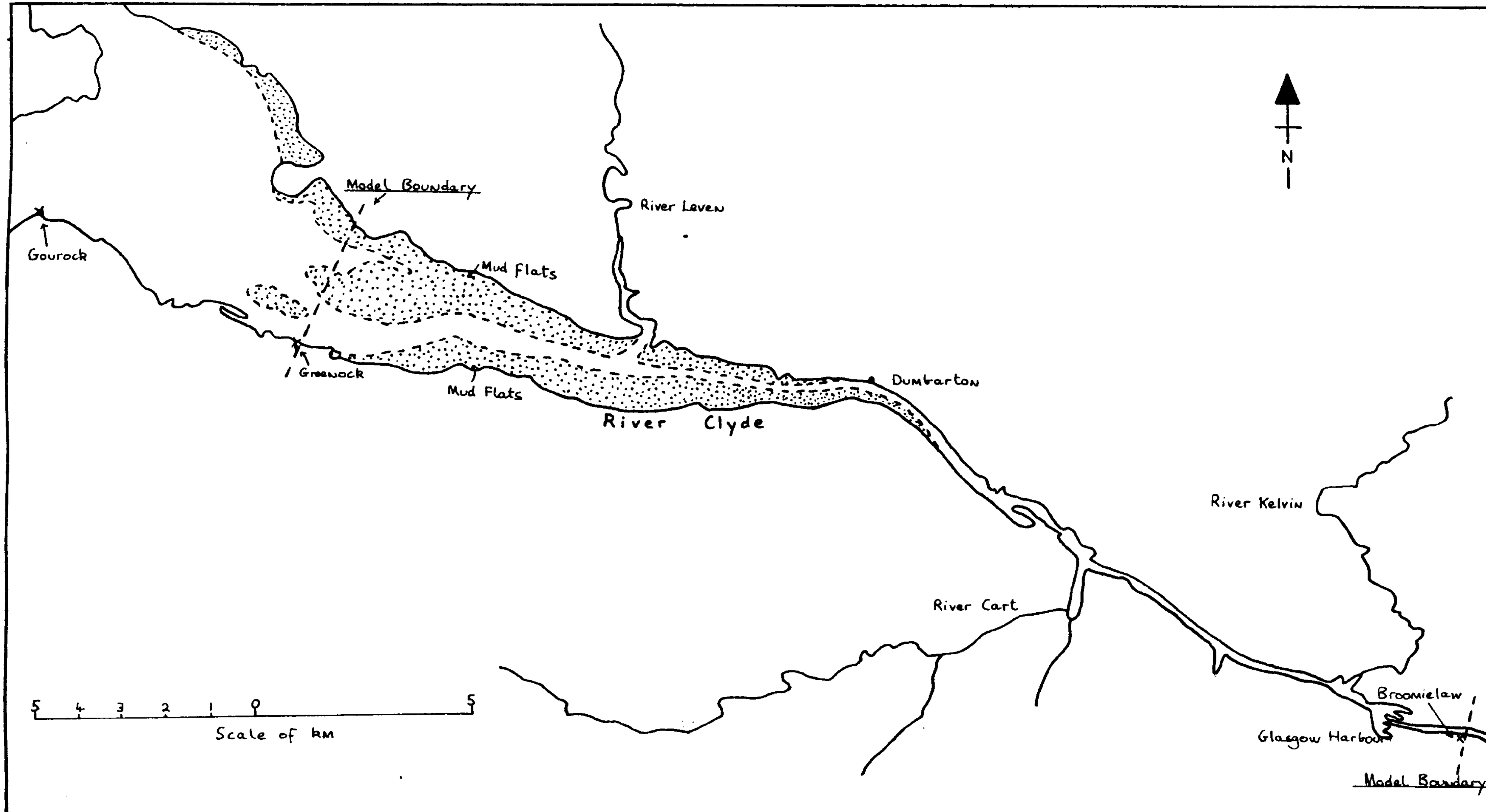


Fig. 4.21. River Clyde Estuary - modelled reach.

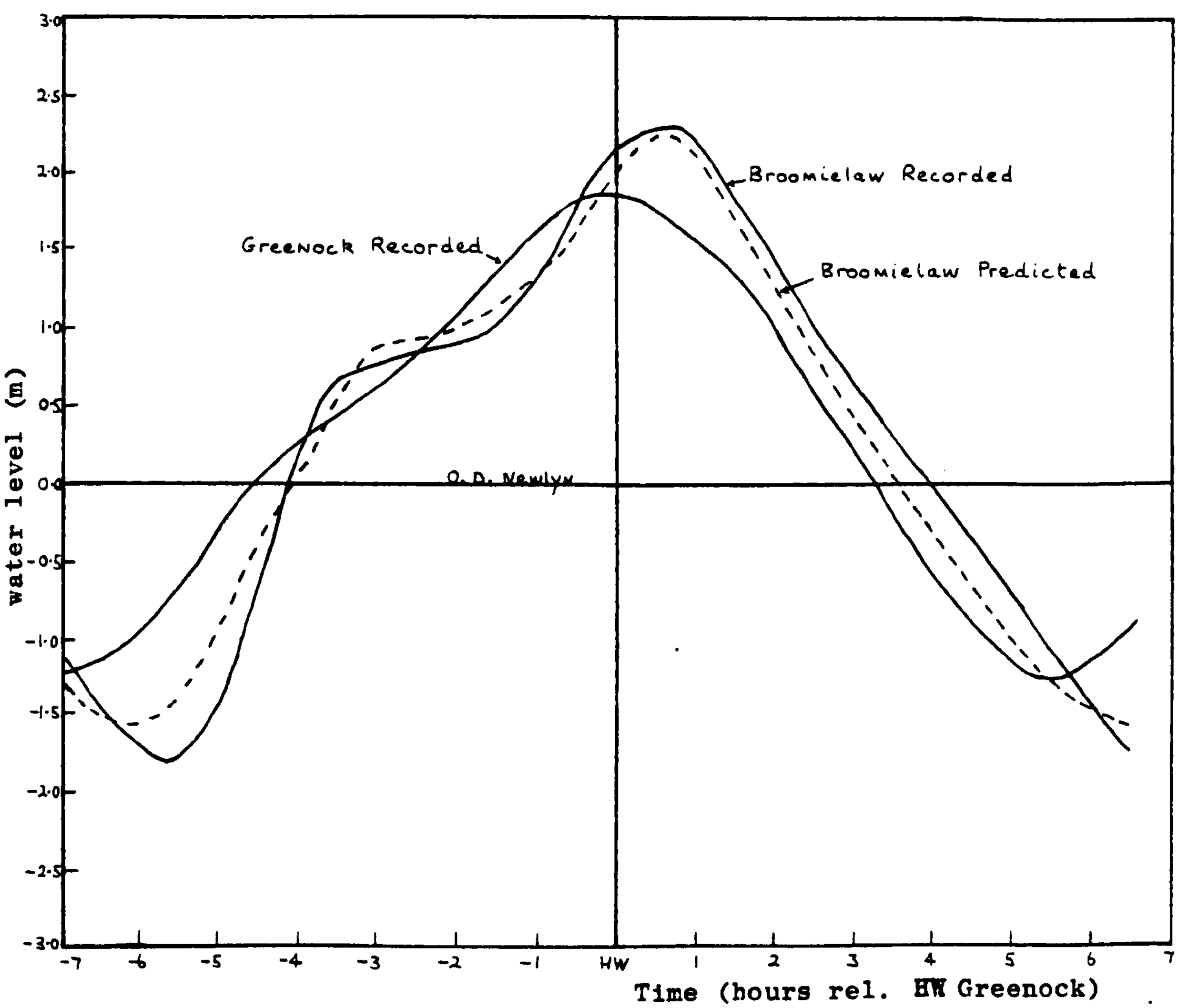


Fig. 4.22. River Clyde - Spring tidal curve prediction.

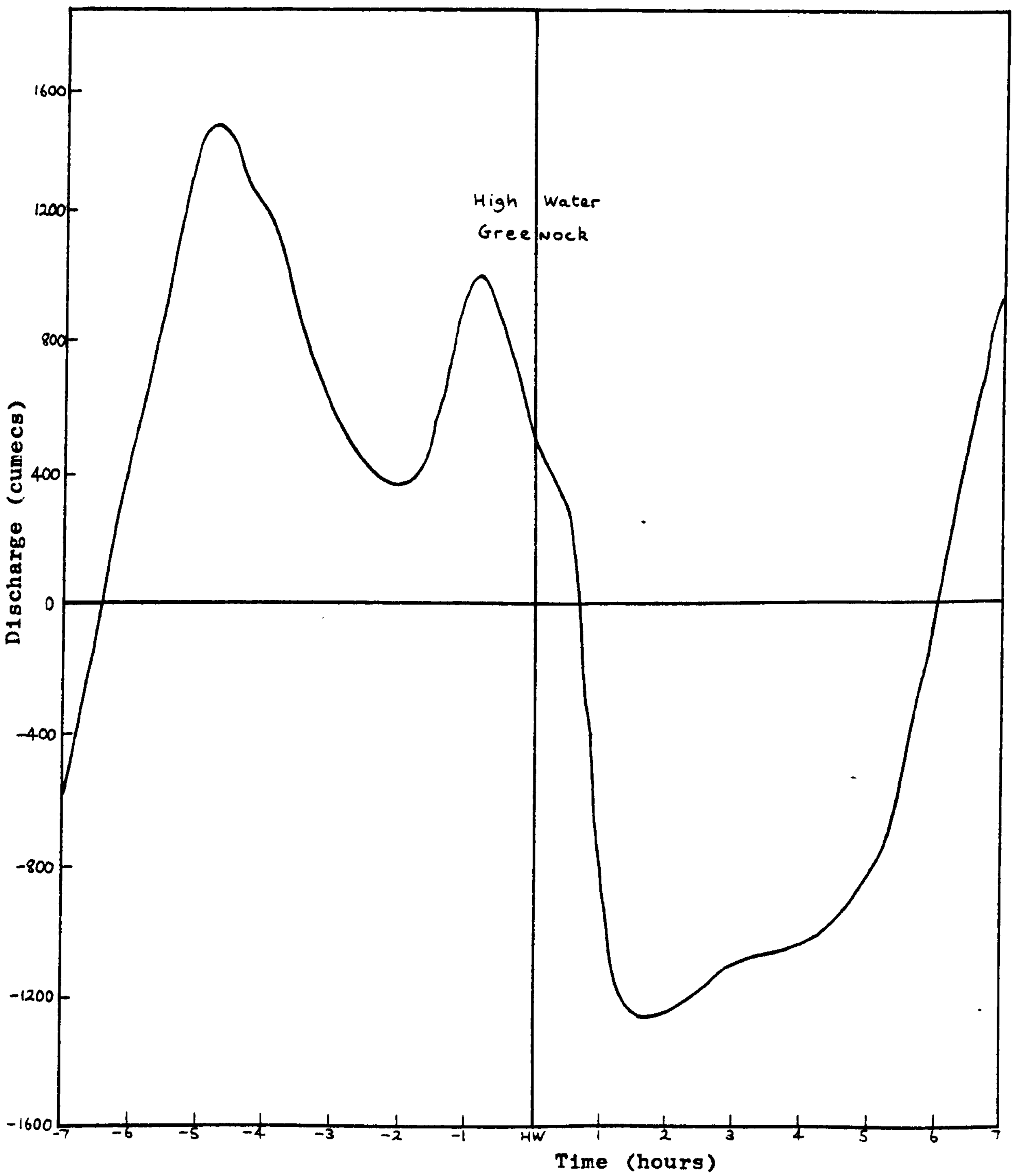


Fig. 4.23. River Clyde - Predicted spring tide discharge curve at Greenock.

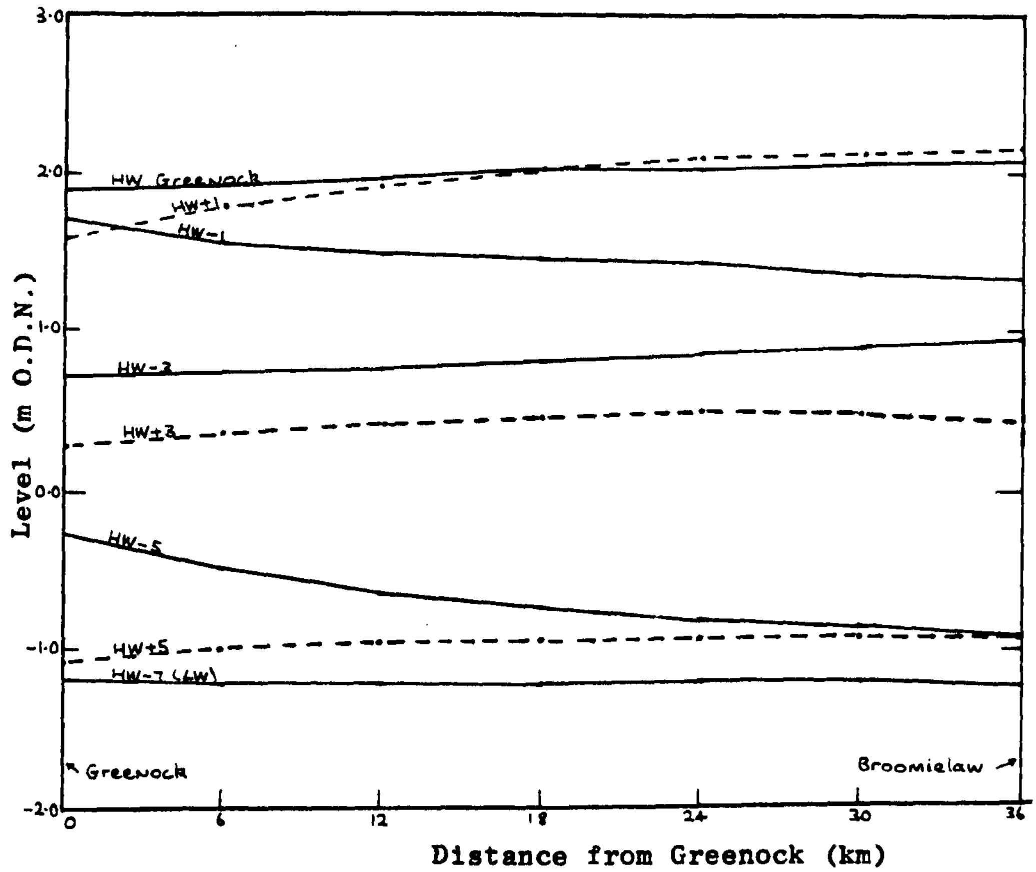


Fig. 4.24. River Clyde - Predicted spring tide water level profiles.

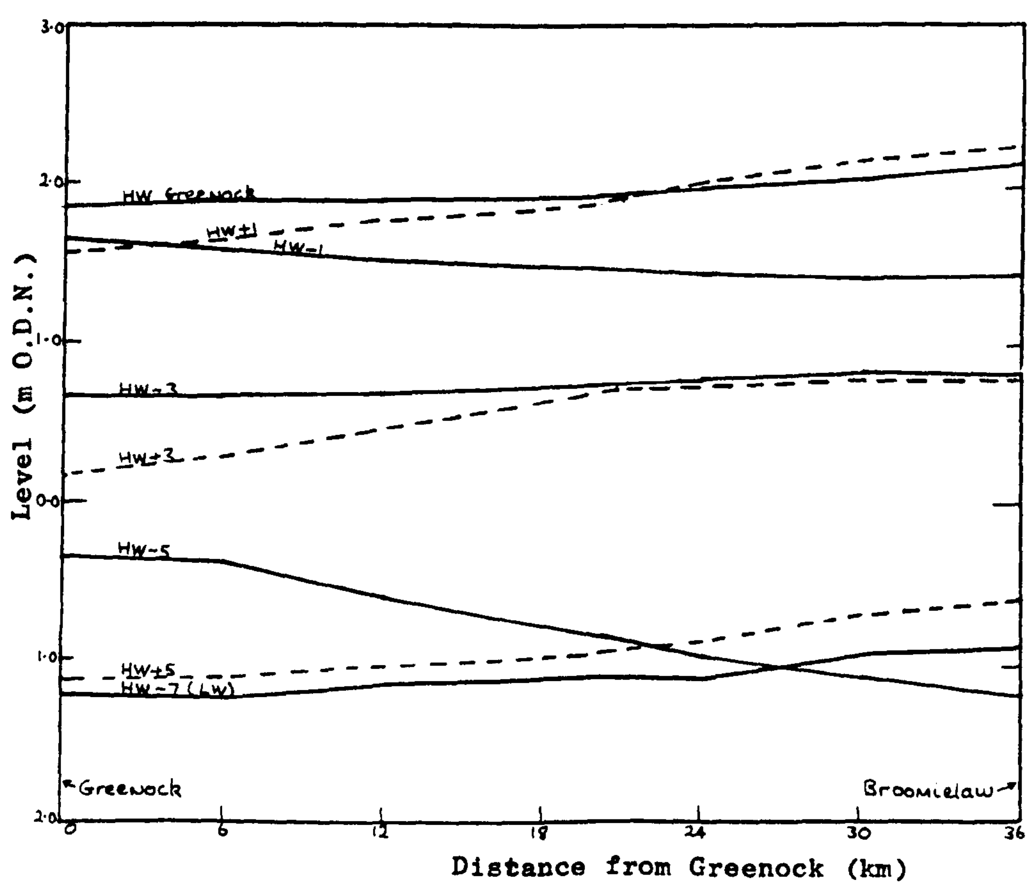
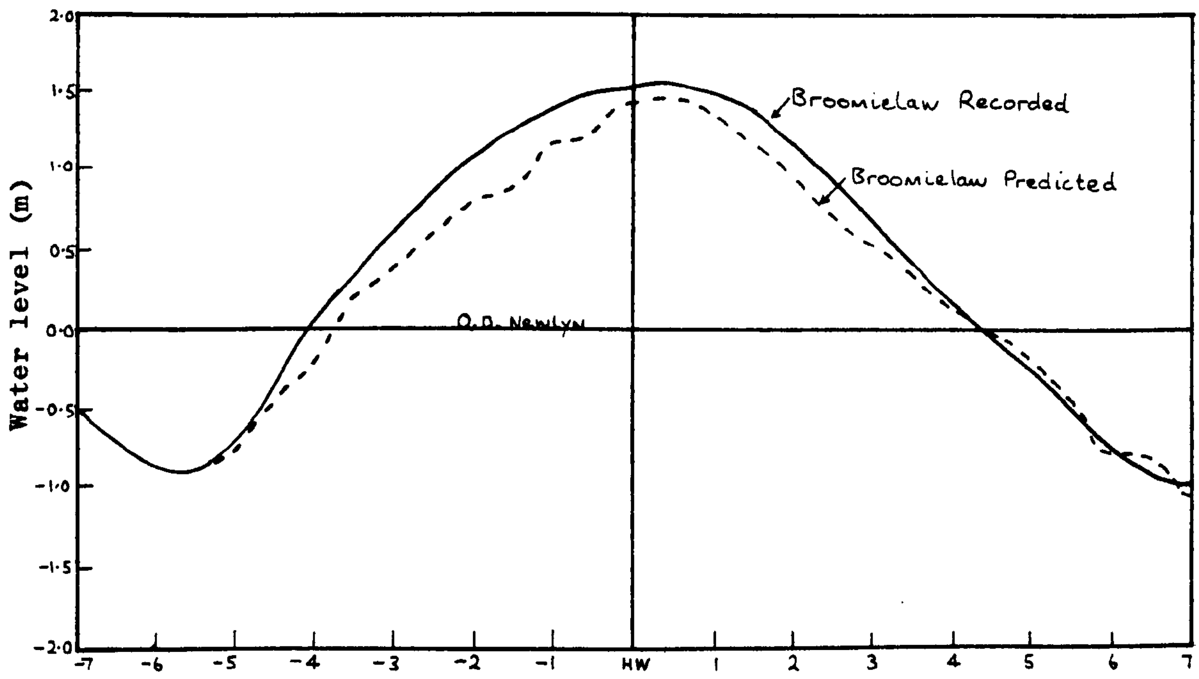
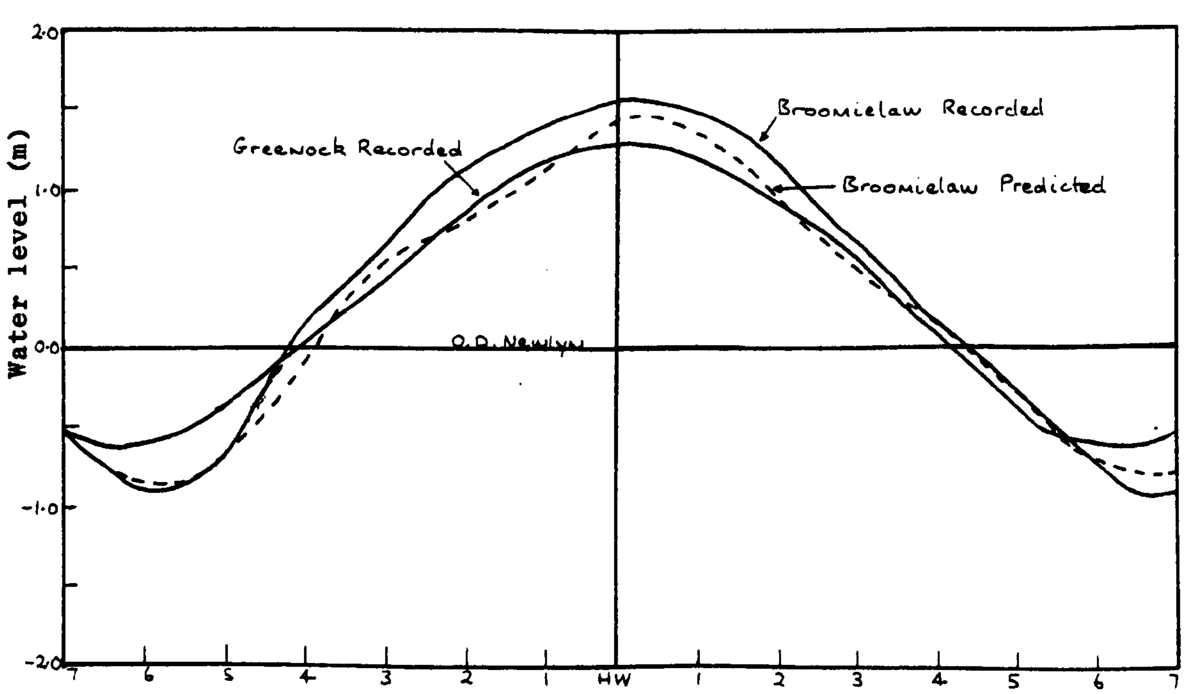


Fig. 4.25. River Clyde - Recorded spring tide water level profiles.



Time (hours)

Fig. 4.26. River Clyde - Numerical instability for θ = 0.5 (Neap tides).



Time (hours)

Fig. 4.27. River Clyde - Neap tidal curve prediction (θ = 0.6).

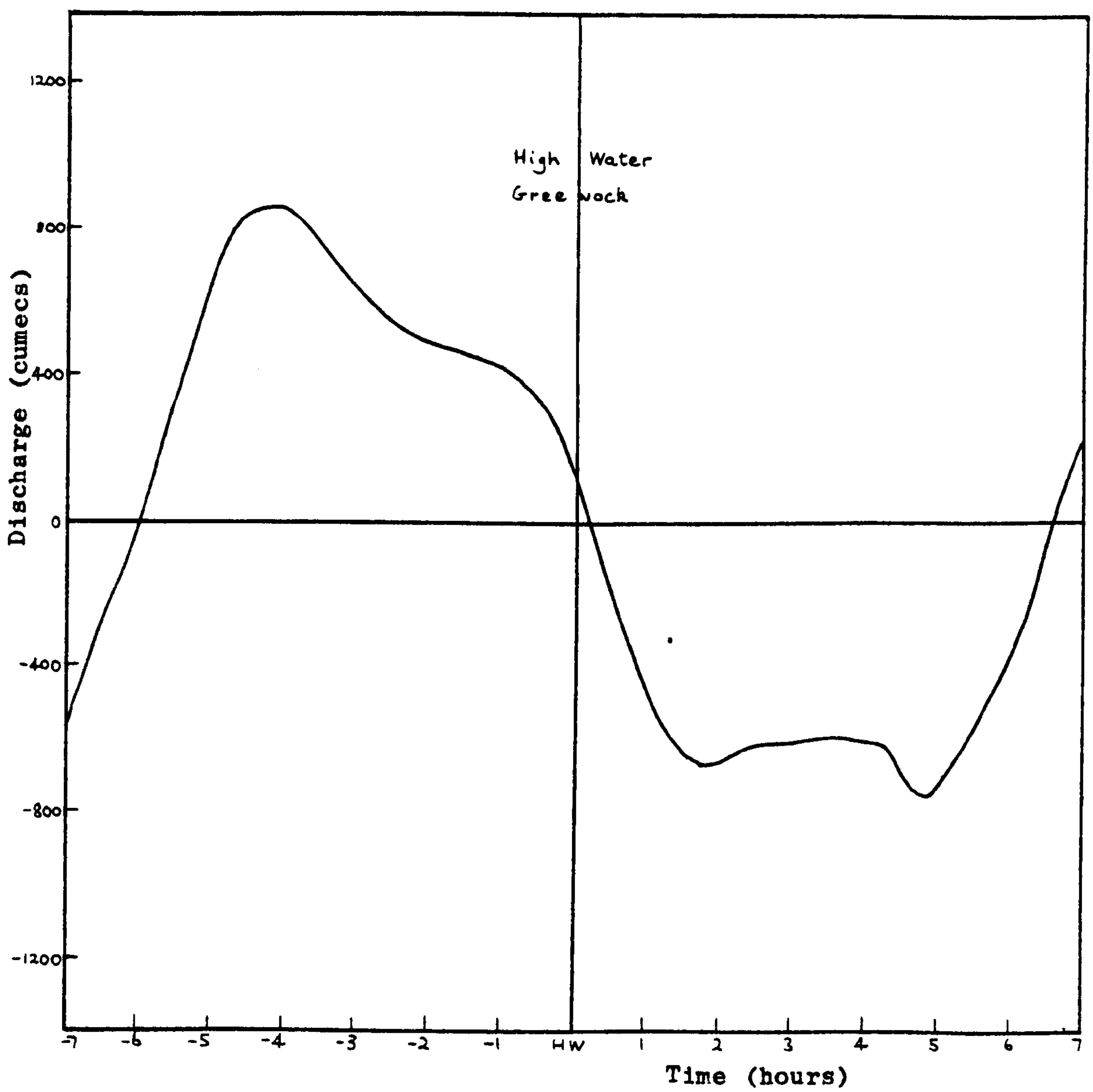
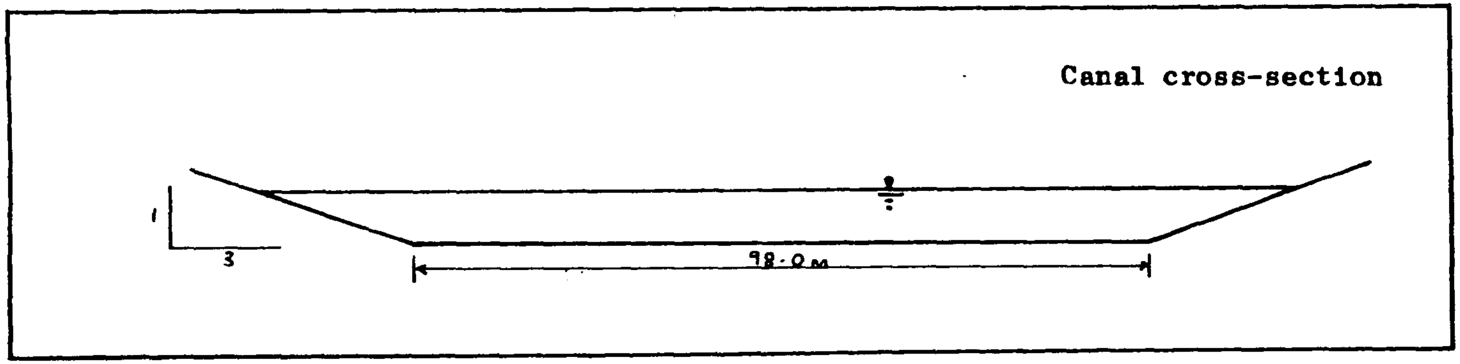


Fig. 4.28. River Clyde - Predicted neap tide discharge curve at Greenock.



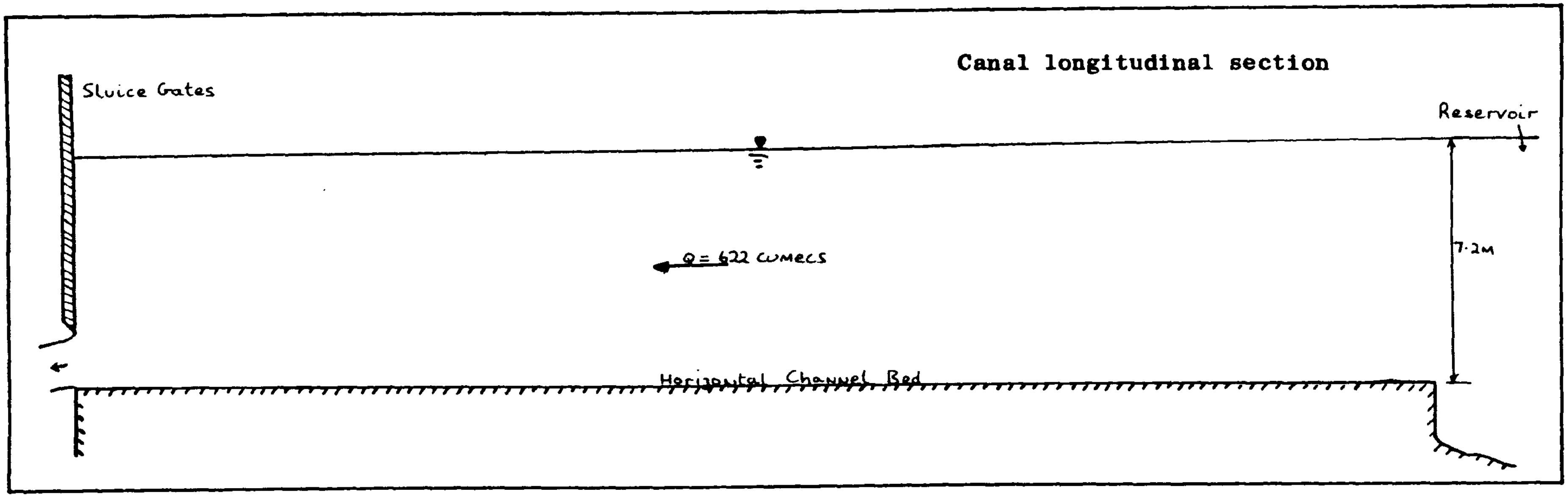


Fig. 4.29. Canal representation (Iraq).

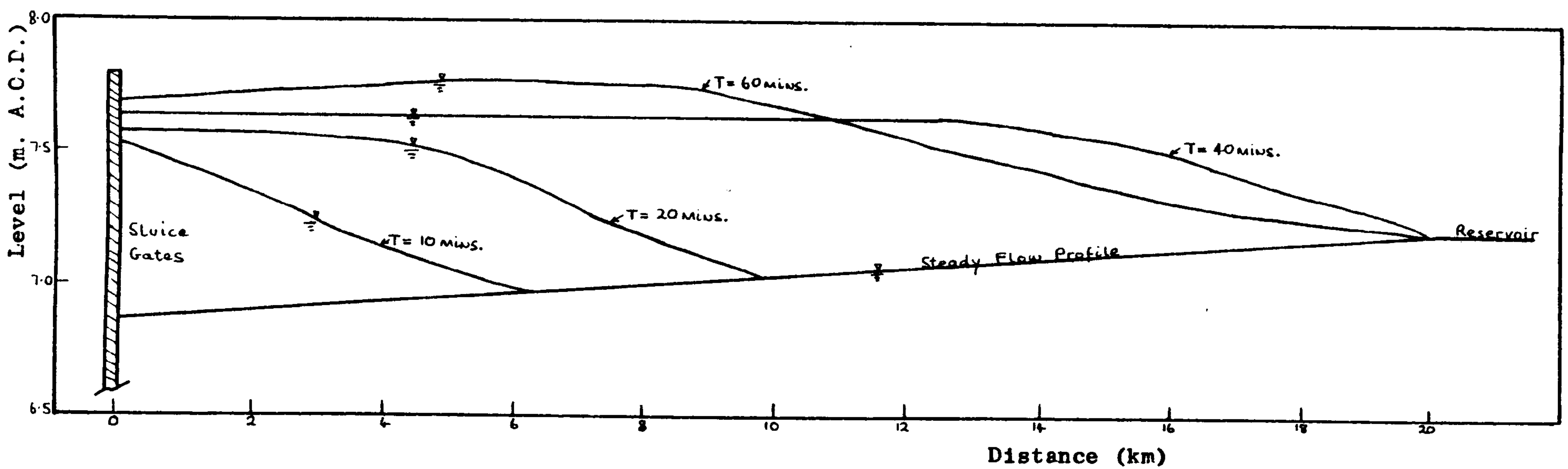


Fig. 4.30. Canal surge propagation.

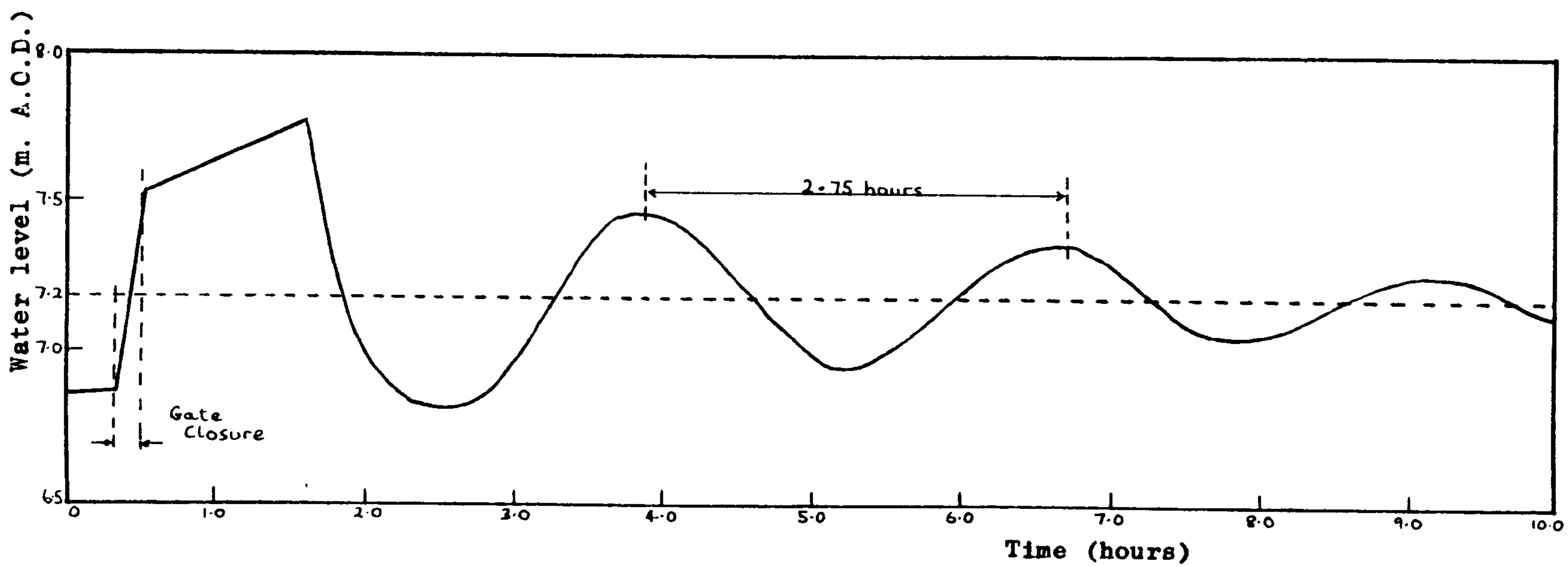


Fig. 4.31. Canal surge - Variation of water level at barrier.

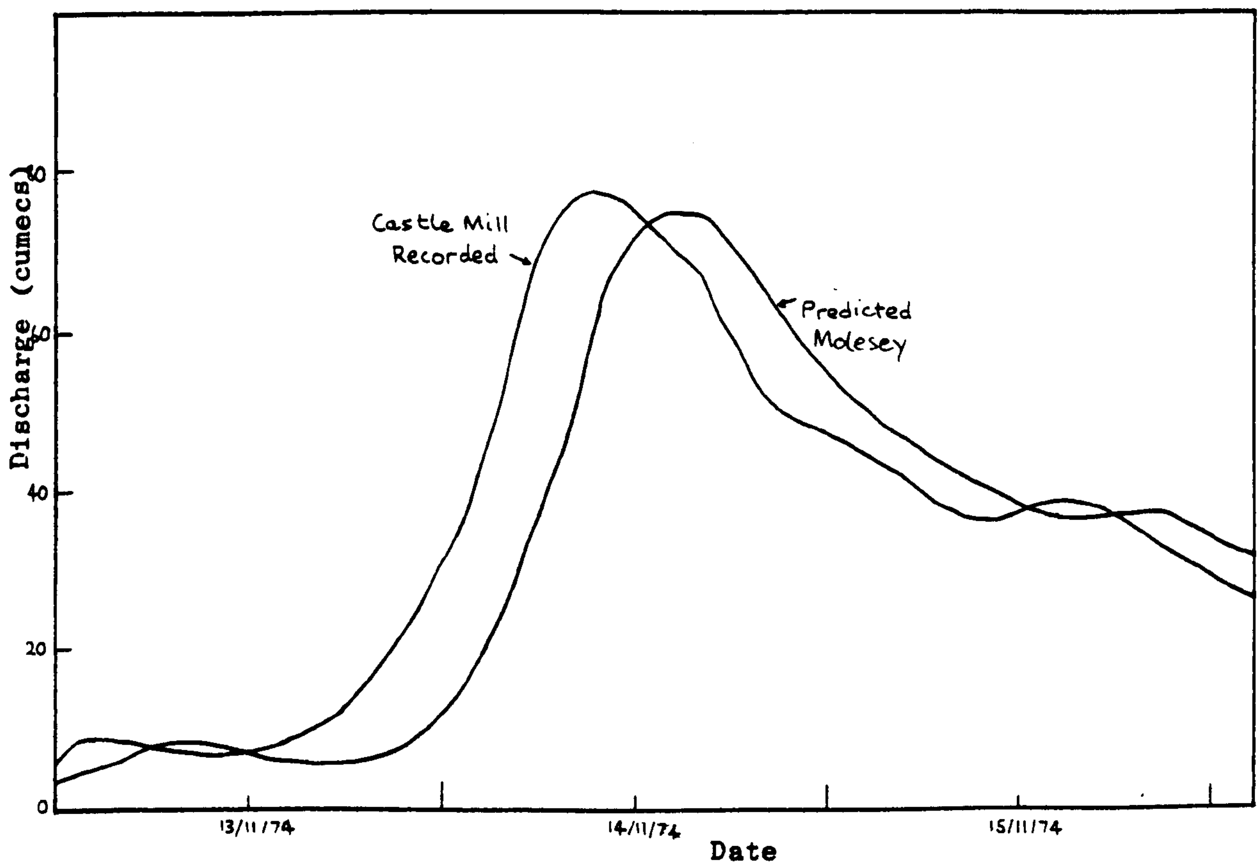


Fig. 4.32. Compound model of the River Mole - Implicit simulation of November 1974 flood.

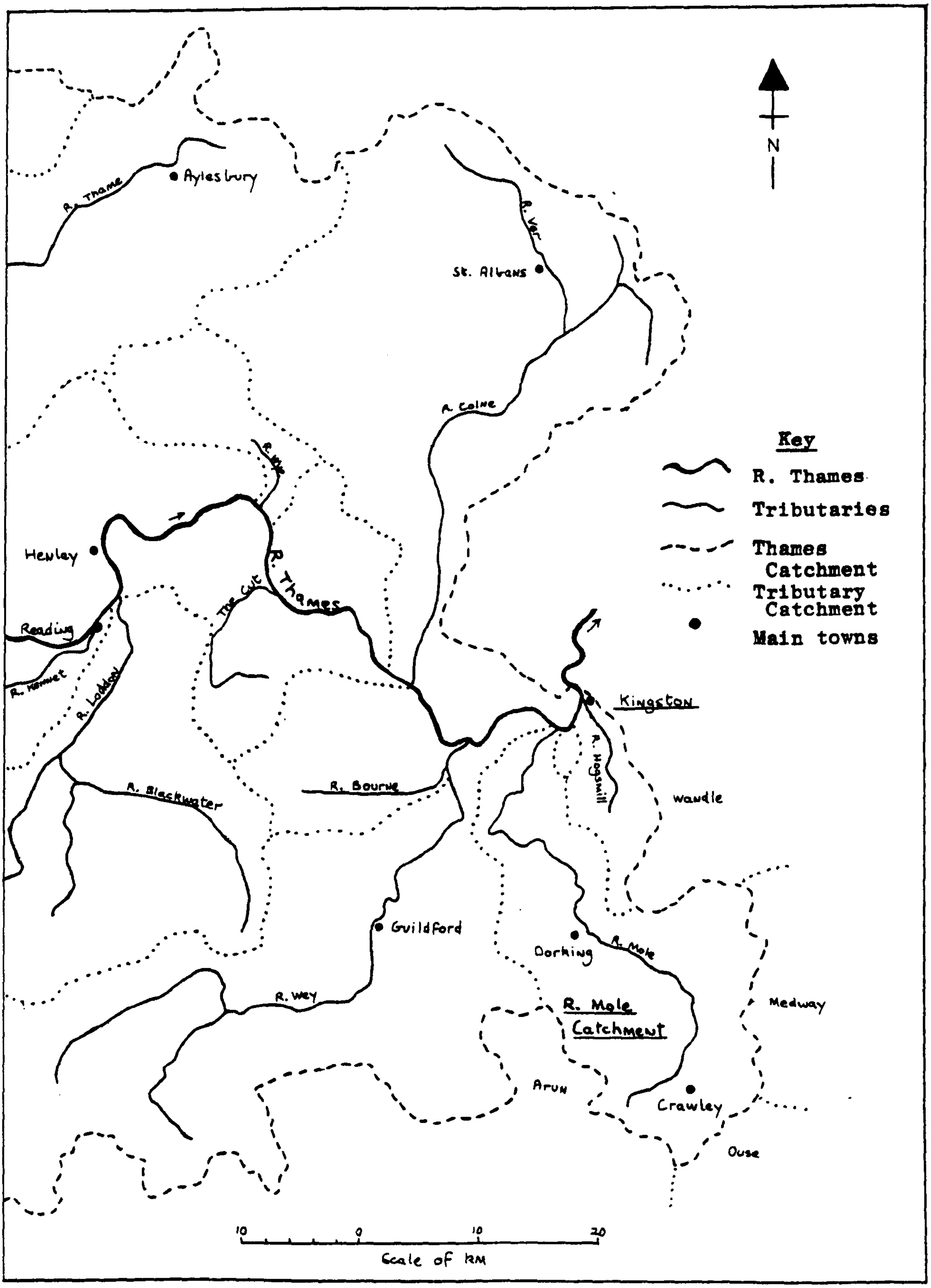


Fig. 5.1. The Lower River Thames Catchment.

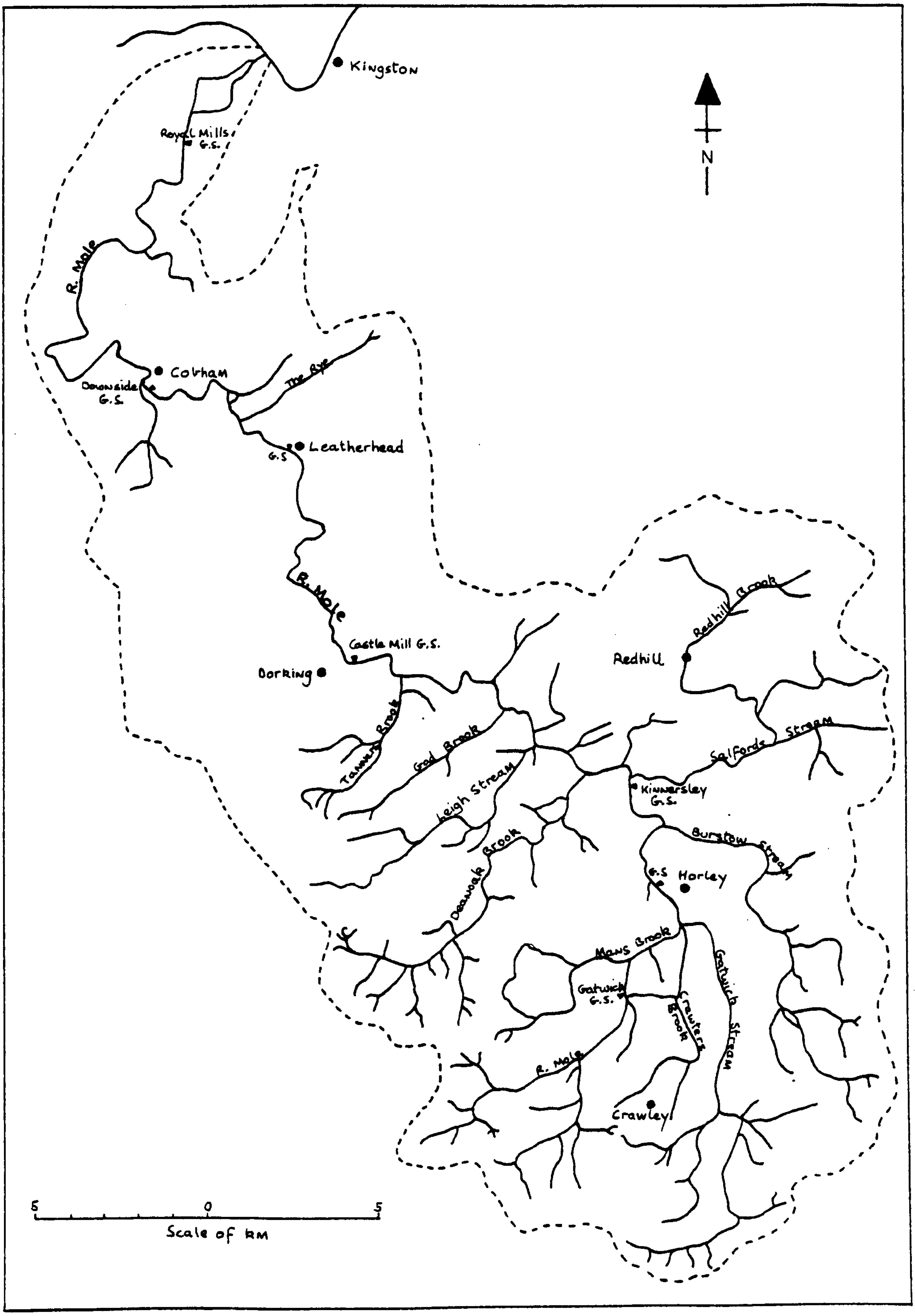


Fig. 5.2. The River Mole Catchment.

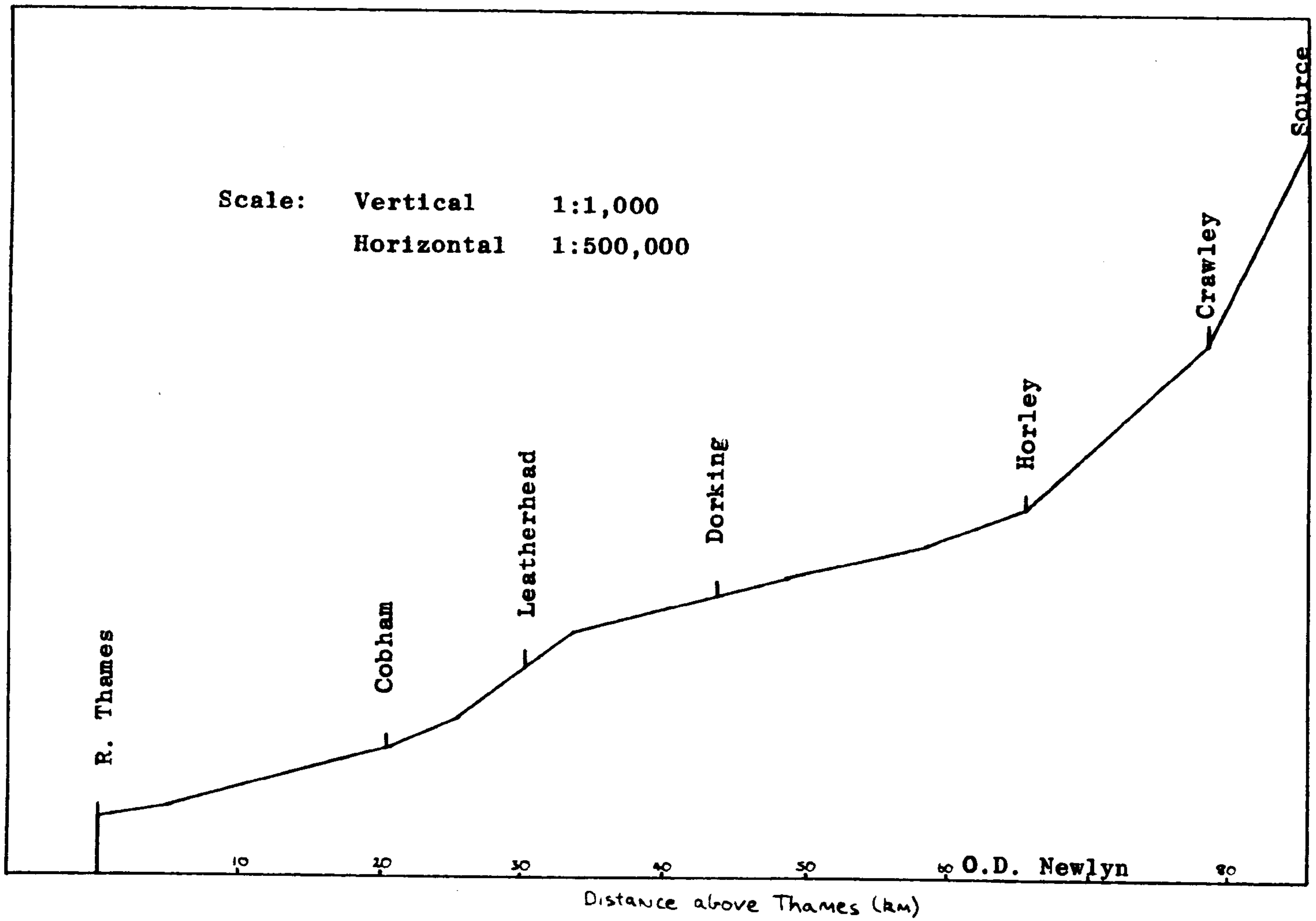


Fig. 5.3. River Mole longitudinal profile.

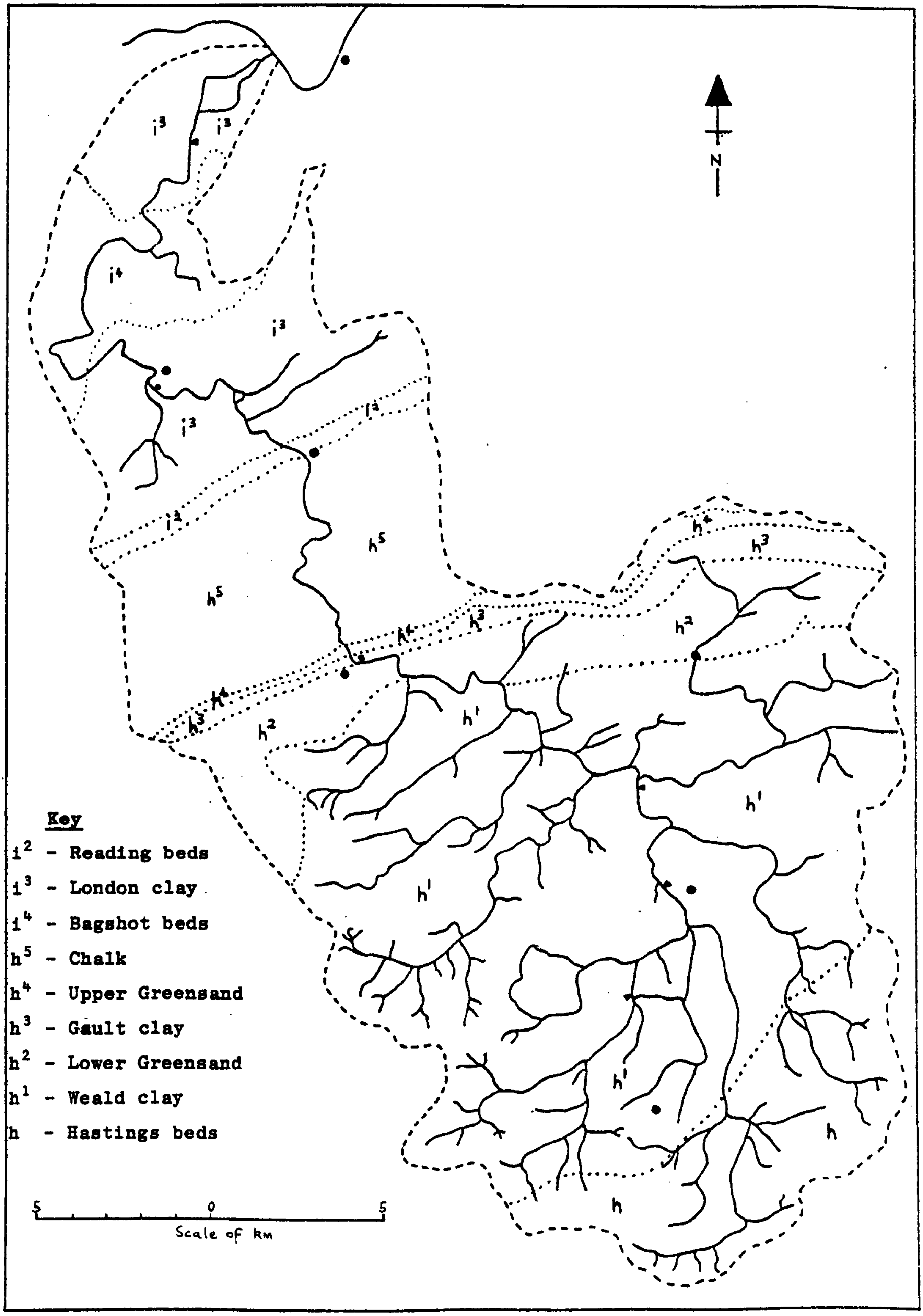


Fig. 5.4. River Mole - Catchment geology.

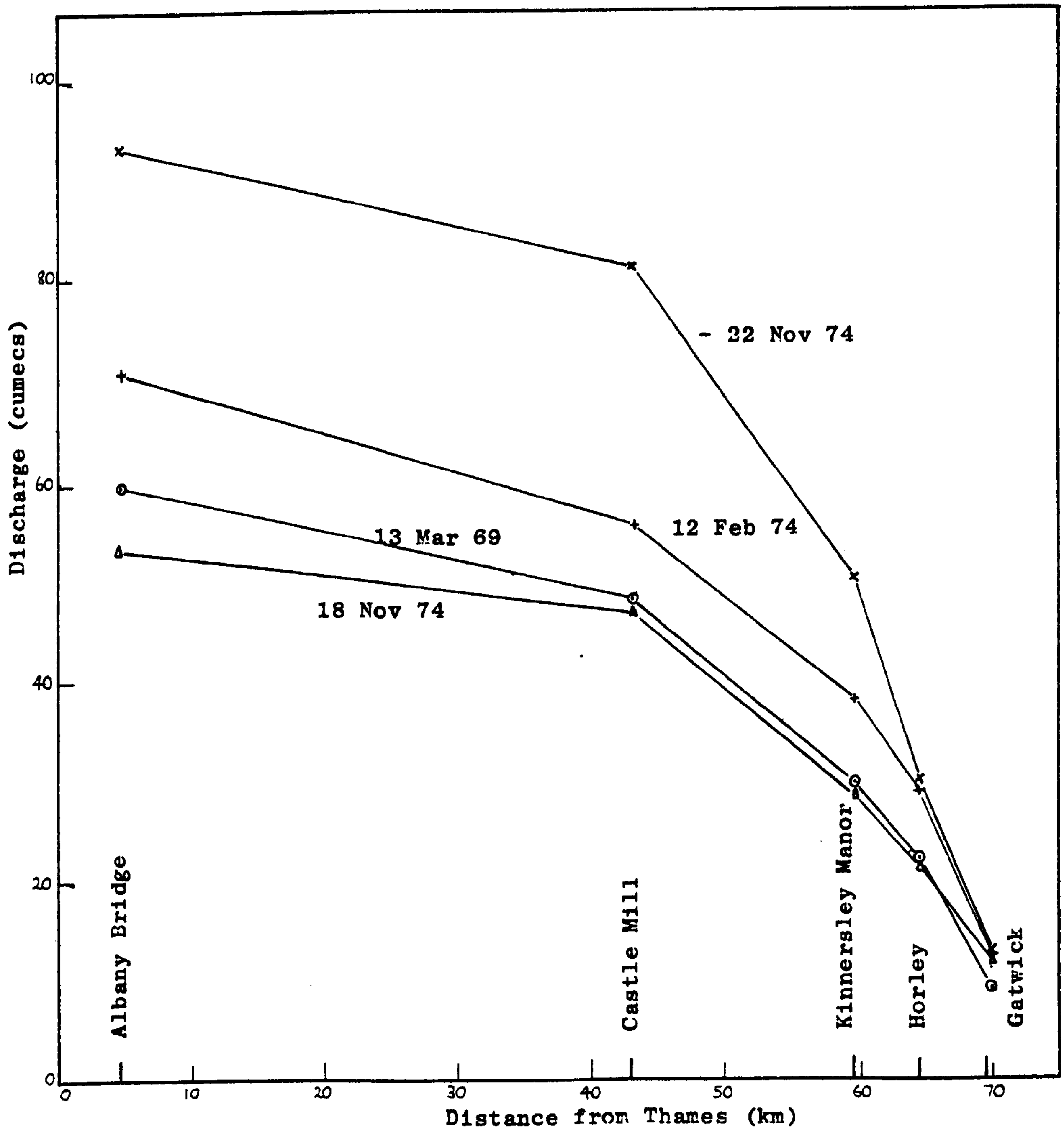


Fig. 5.5. River Mole - Flow accretion.

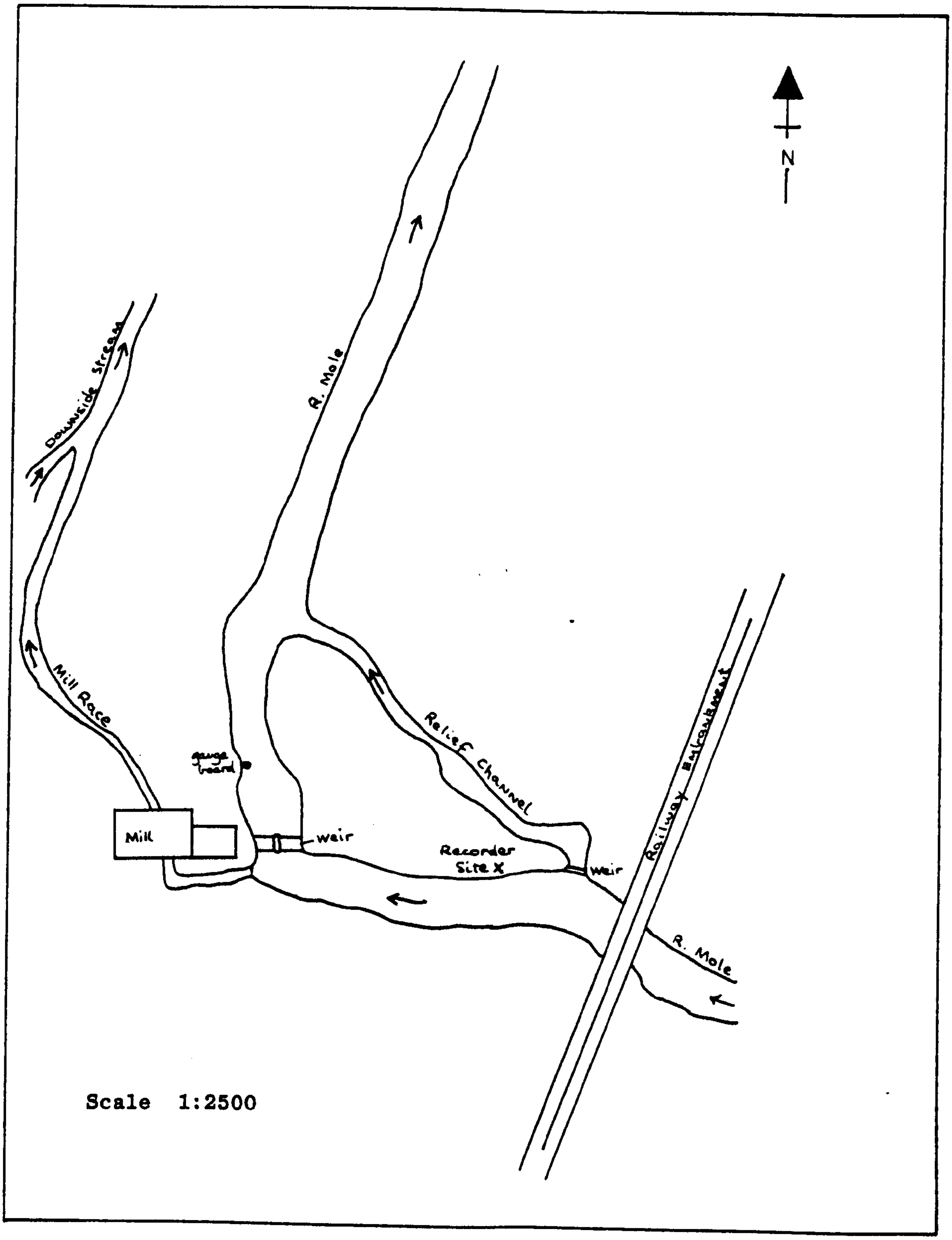


Fig. 5.6. Downside Mill level recorder site.

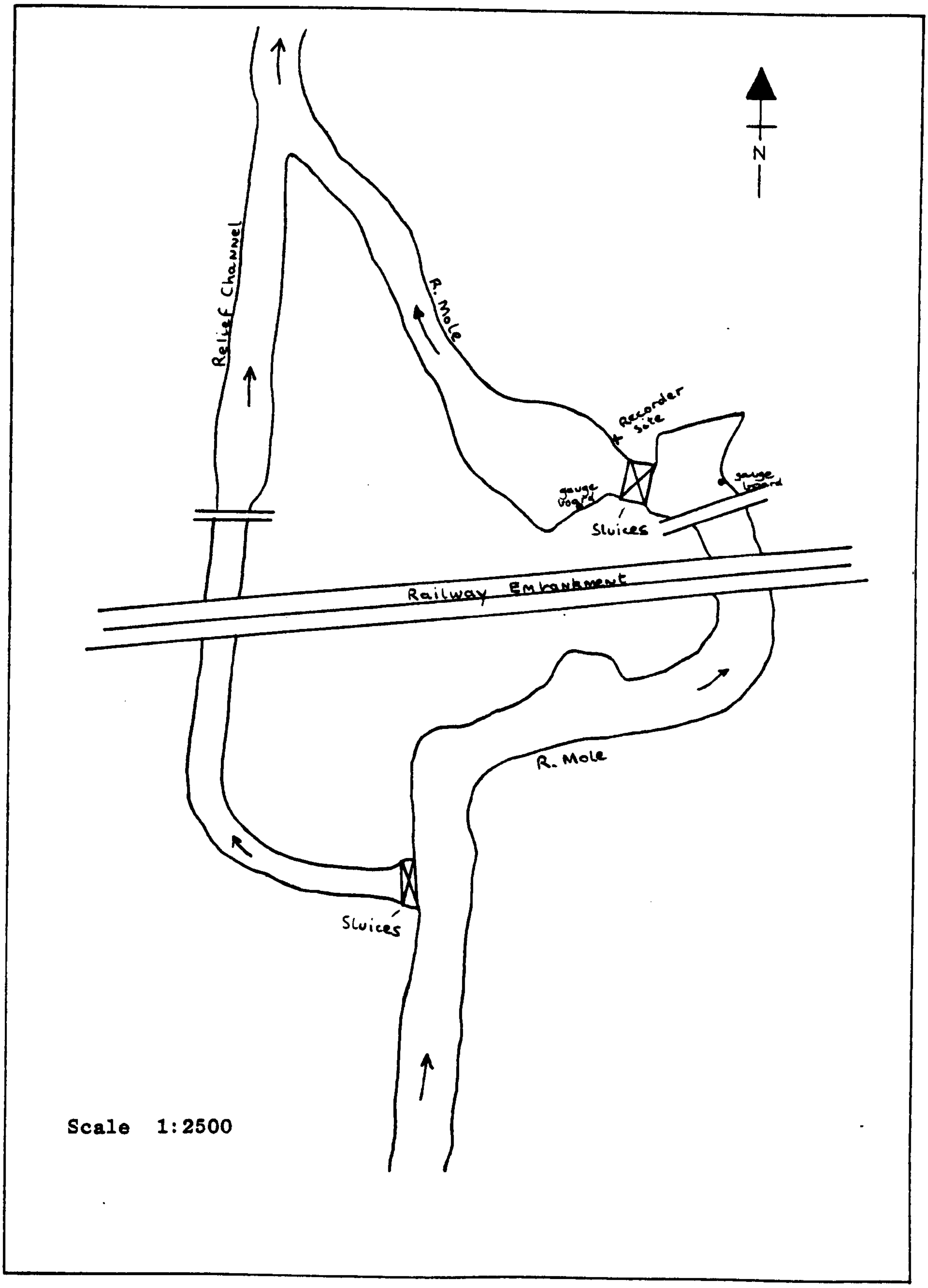


Fig. 5.7. Royal Mills level recorder site.

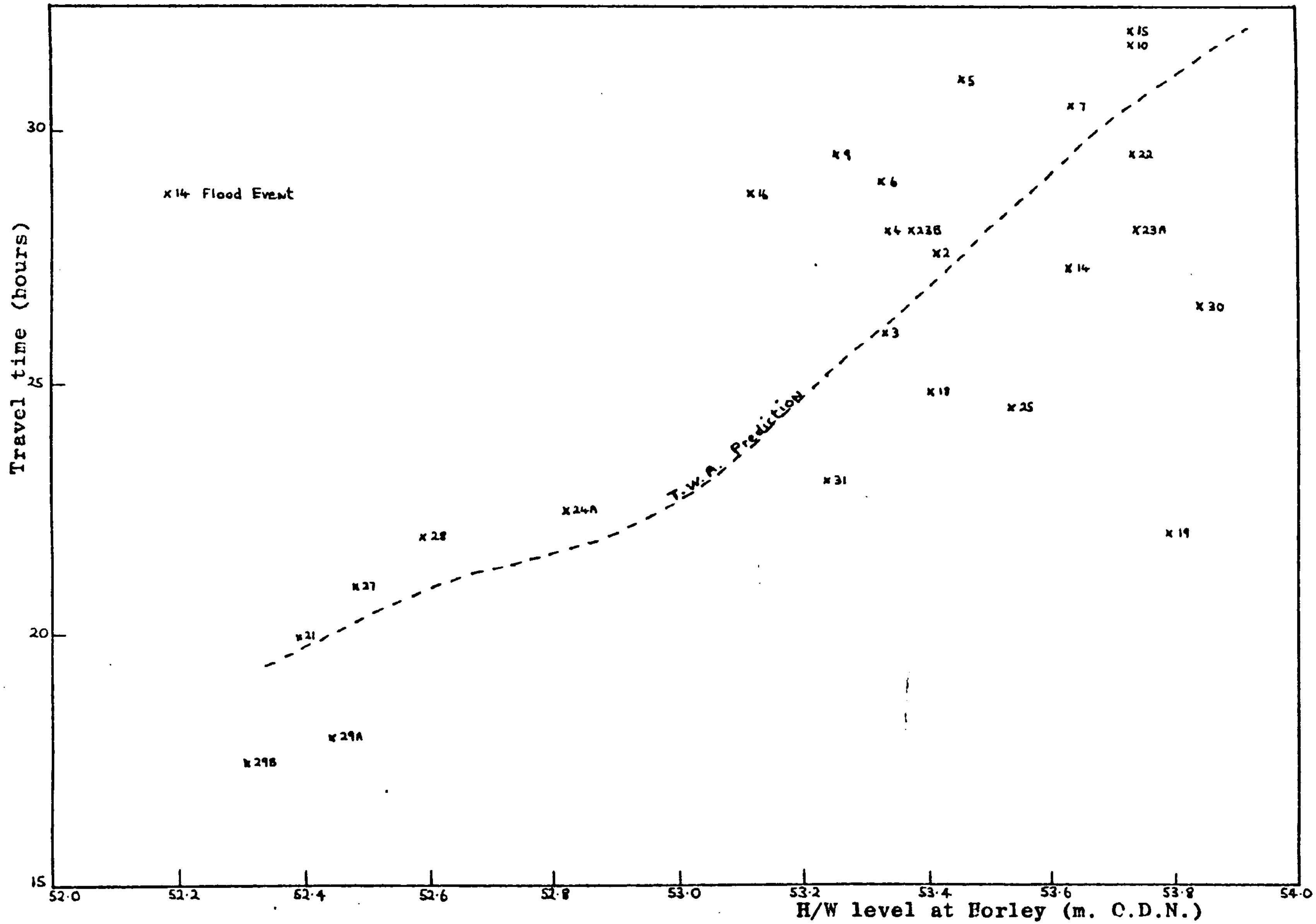
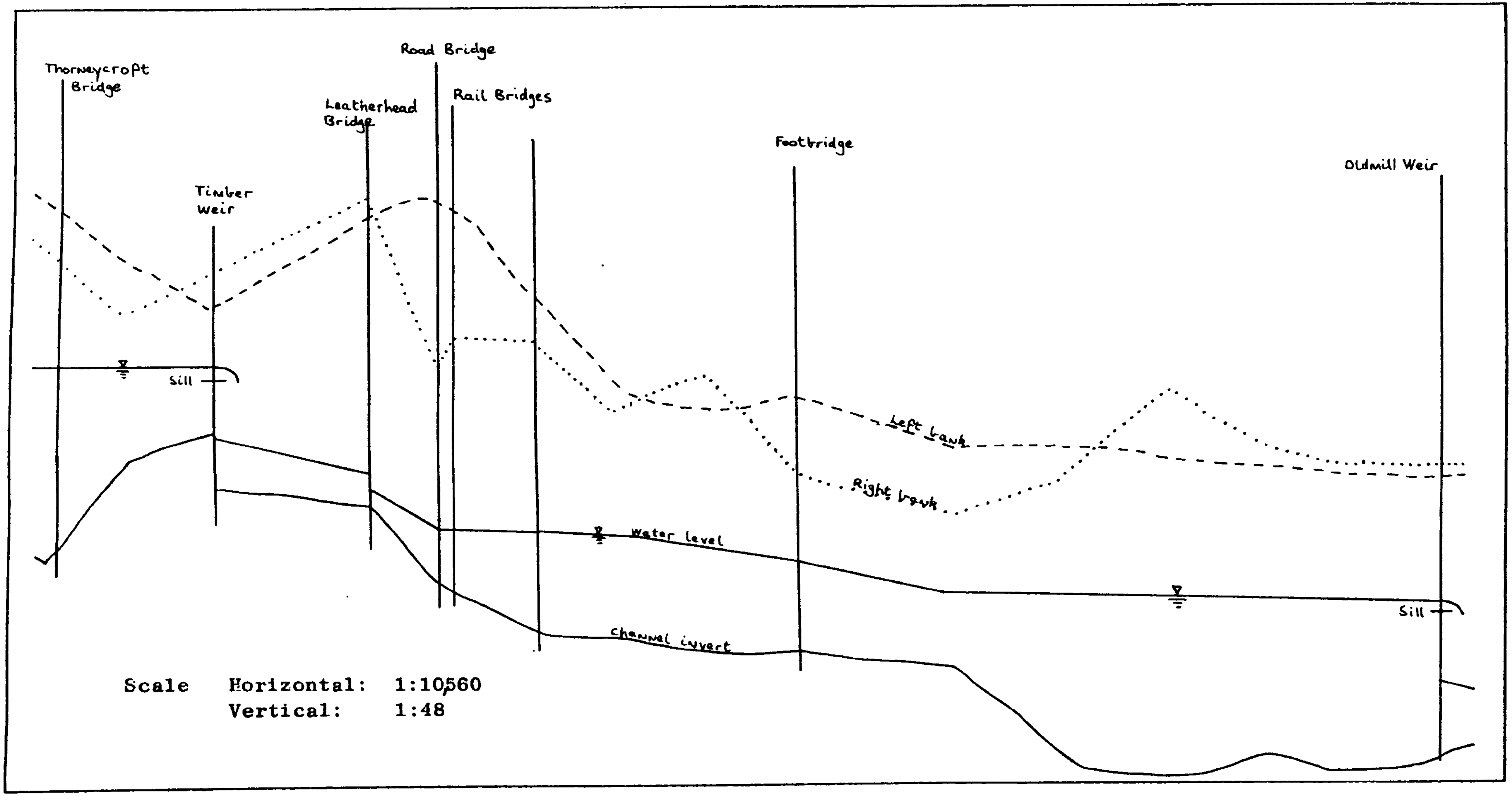


Fig. 5.8. River Mole - Flood wave travel time (Horley to Royal Mills).



Scale Horizontal: 1:10,560
Vertical: 1:48

Fig. 5.9. River Mole - Sample longitudinal section (Leatherhead).

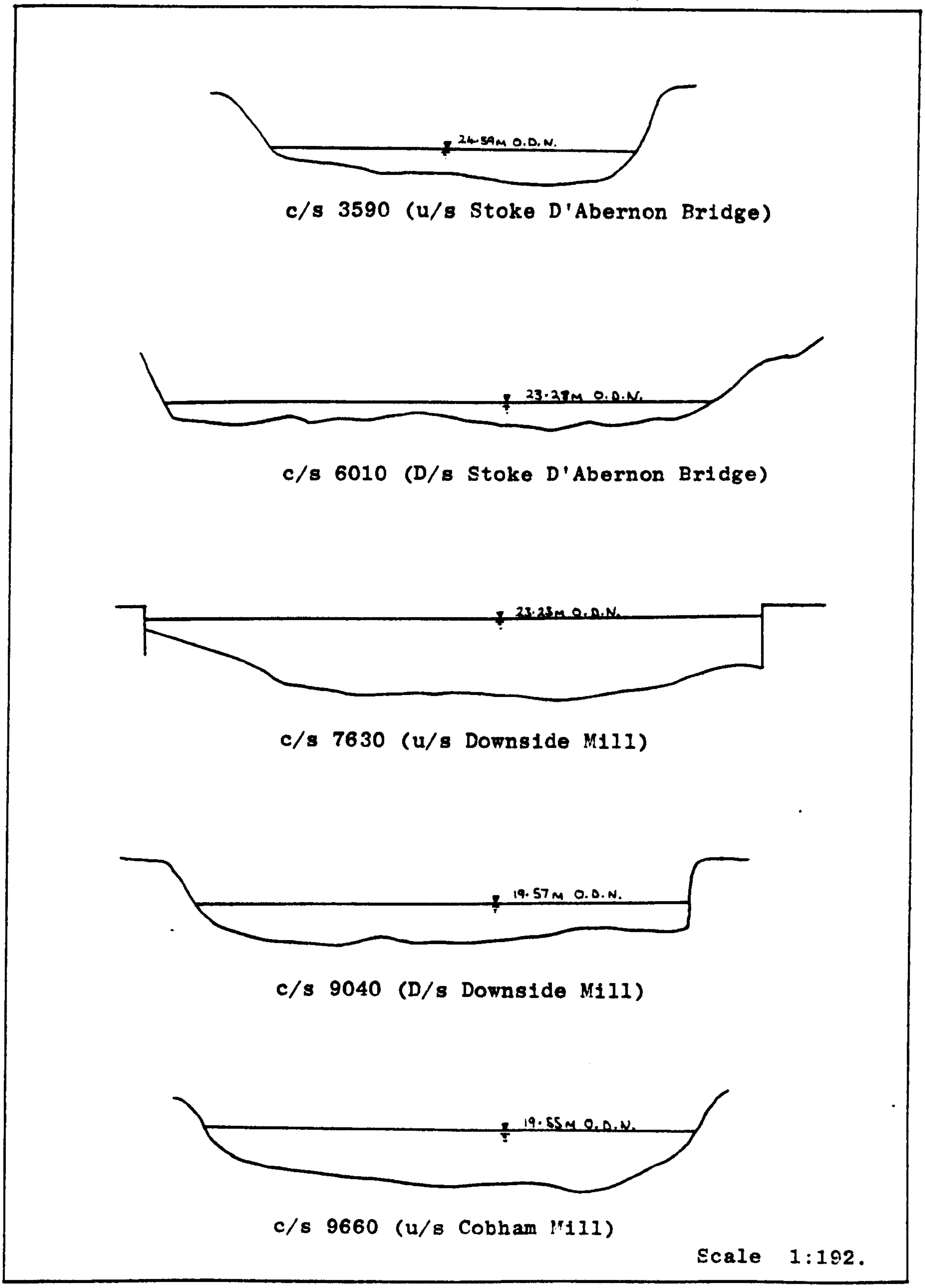


Fig. 5.10. River Mole - Sample channel cross-sections (Downside Mill).

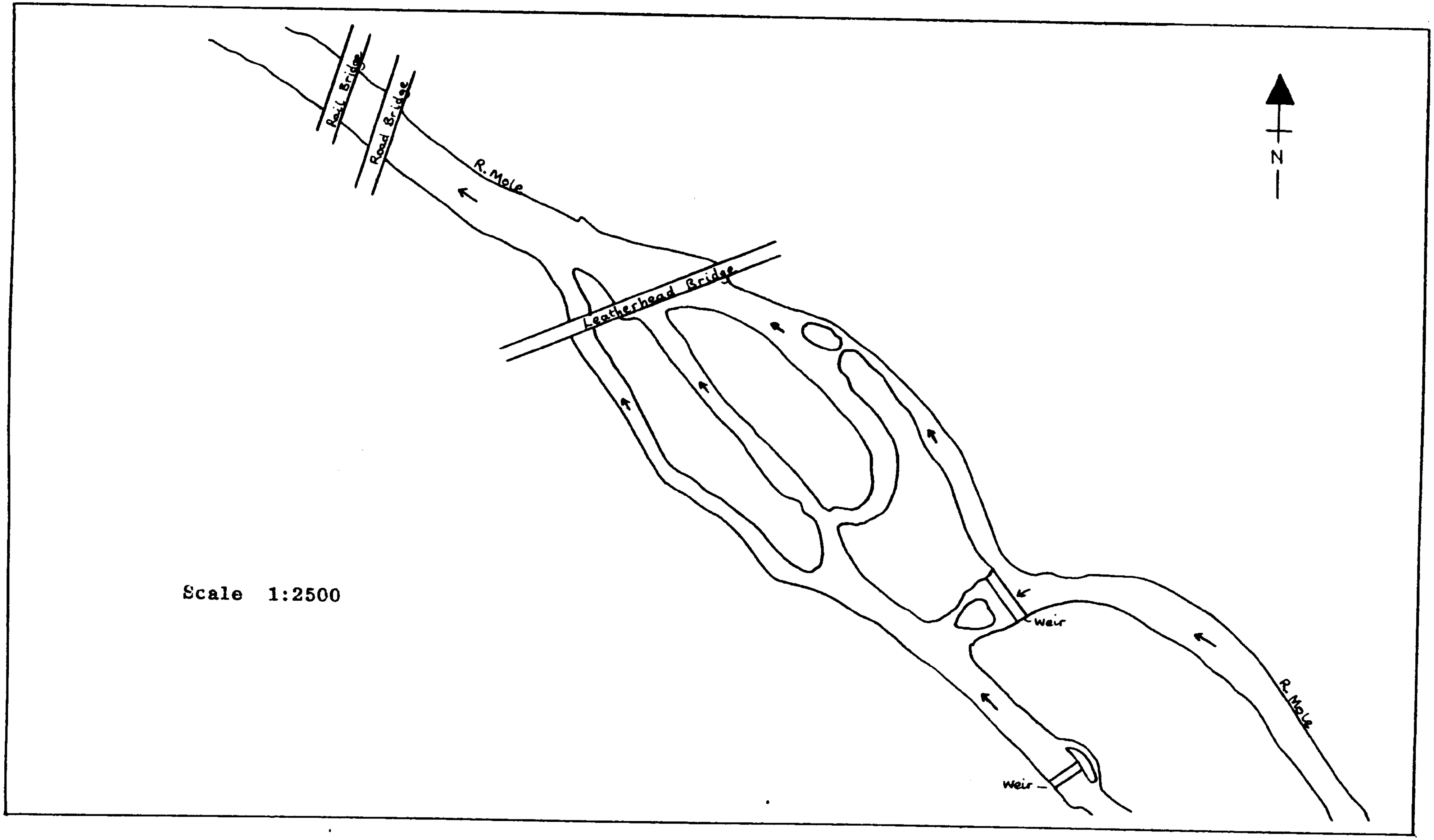


Fig. 5.11. River Mole - Sample large scale map (Leatherhead).

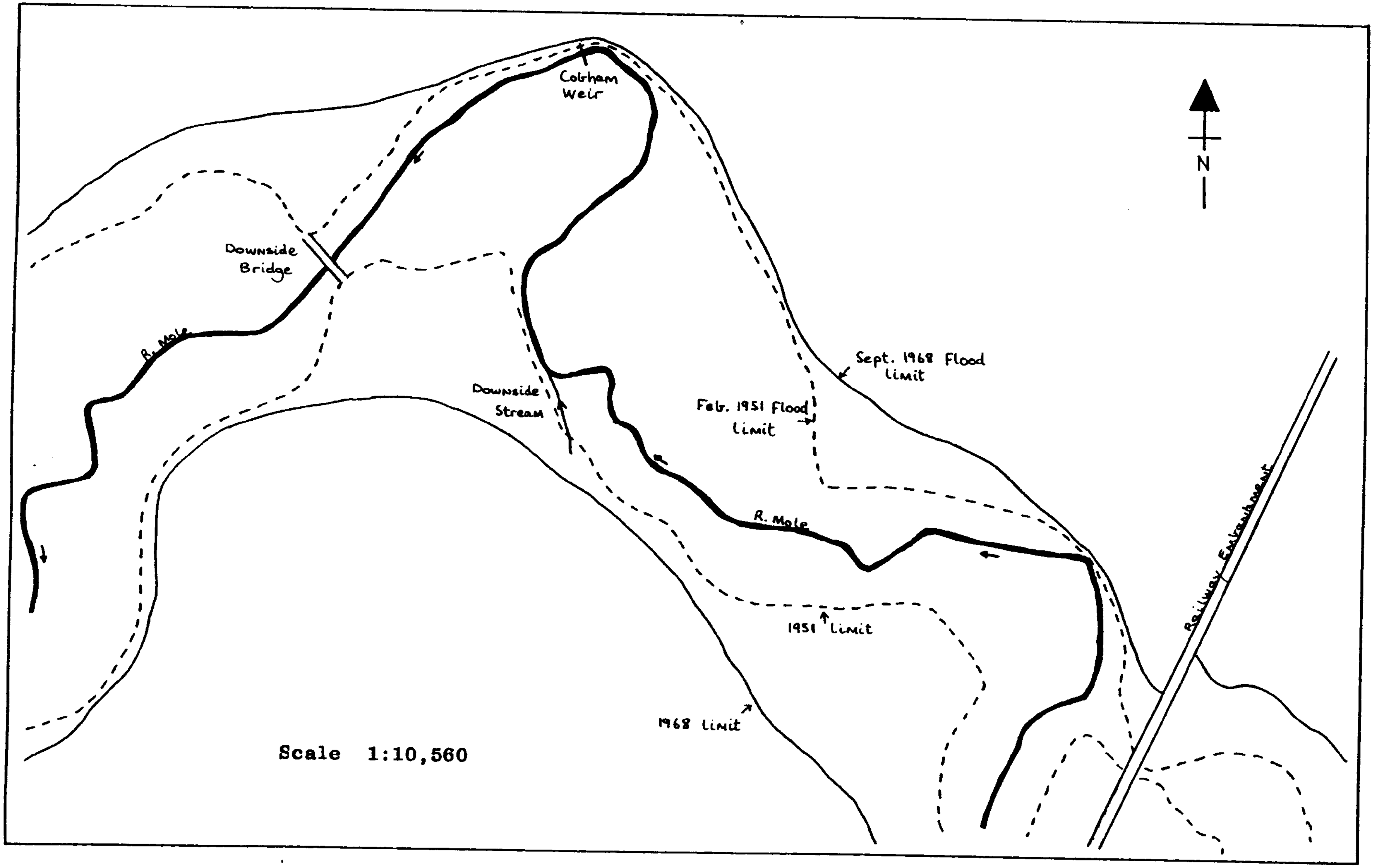


Fig. 5.12. River Mole - Sample flood map (Cobham).

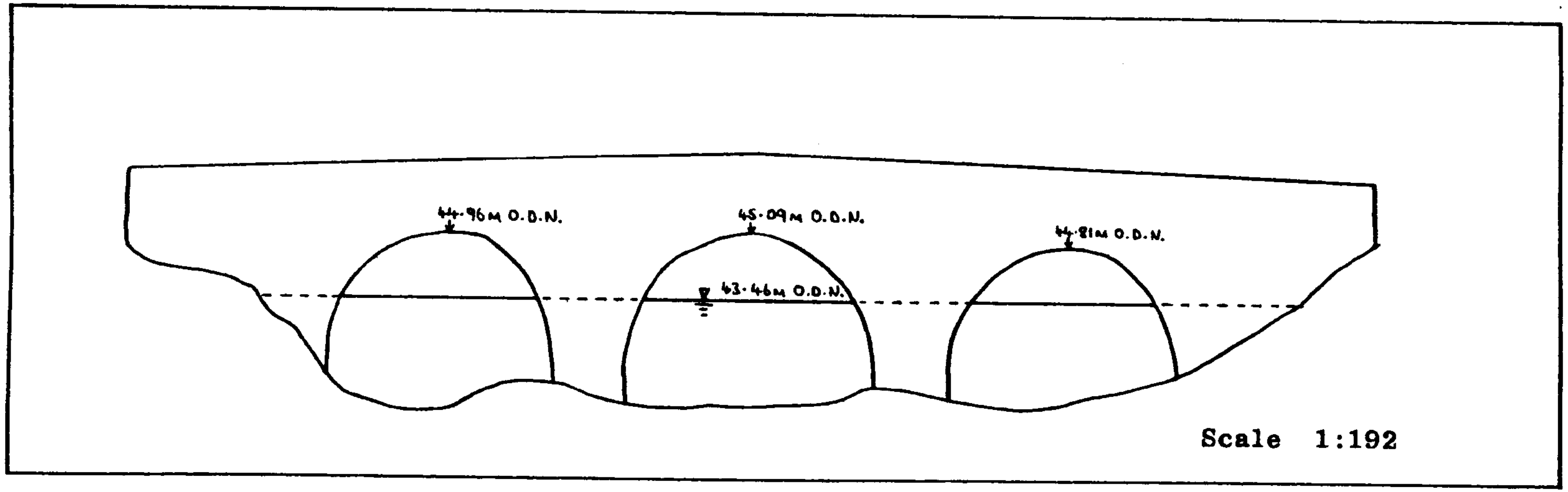


Fig. 5.13. Betchworth Bridge.

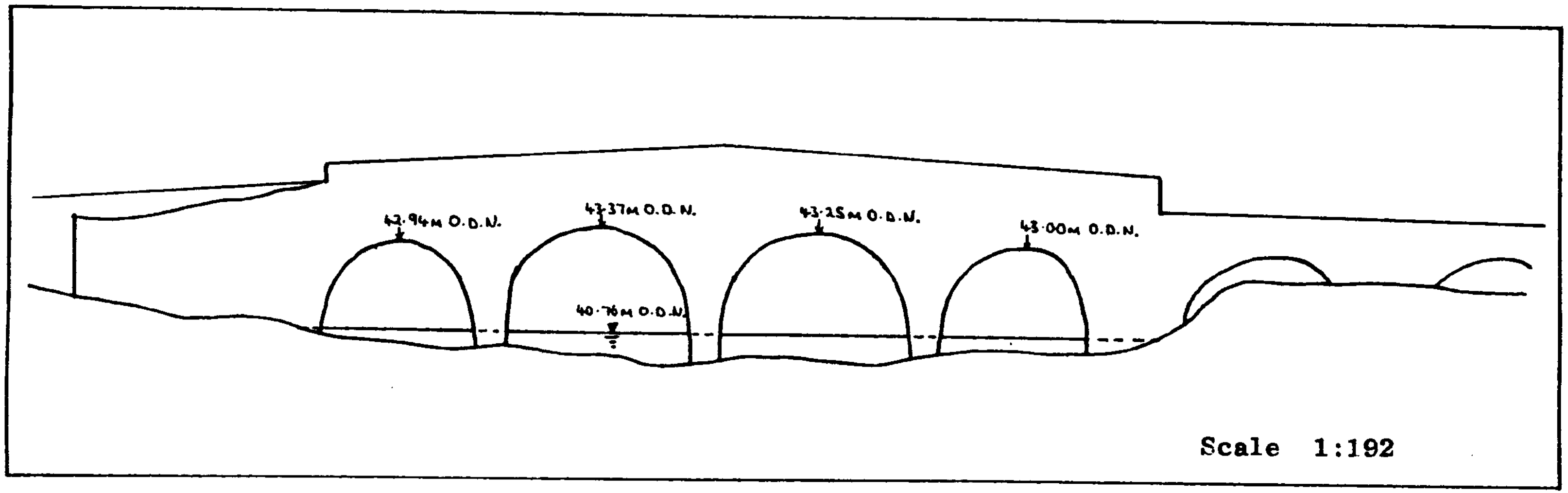


Fig. 5.14. Brockham Bridge.

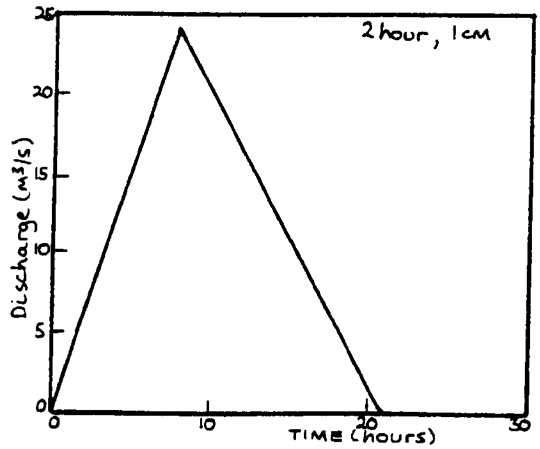


Fig. 6.1 River Mole - Unit Hydrograph at Horley.

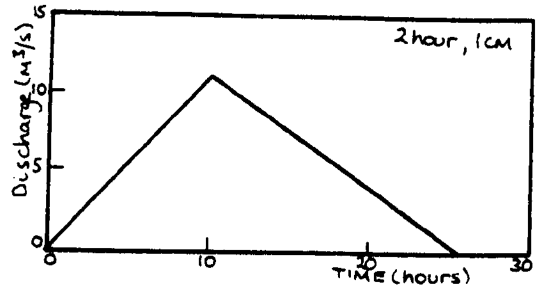


Fig. 6.2 Unit hydrograph for Burstow Stream.

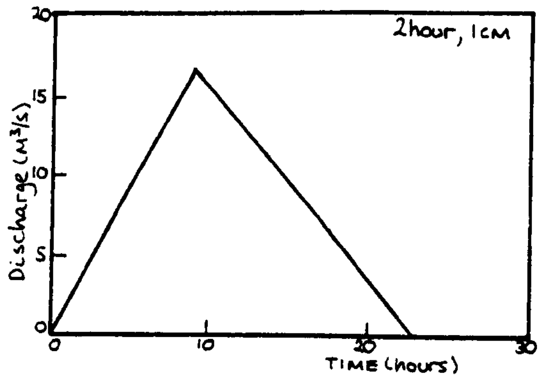


Fig. 6.3 Unit hydrograph for Salfords Stream.

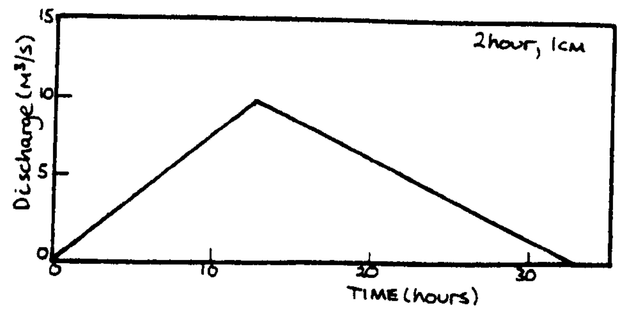


Fig. 6.4 Unit hydrograph for Deanoak Brook.

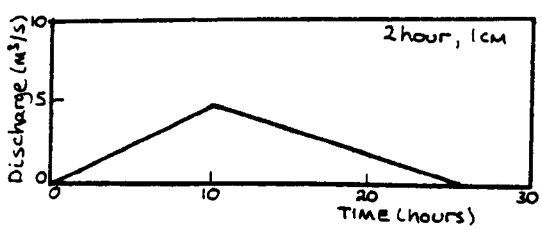


Fig. 6.5 Unit hydrograph for Leigh Stream.

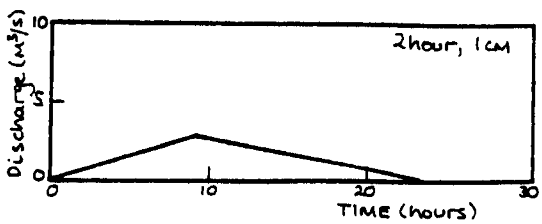


Fig. 6.6 Unit hydrograph for Gad Brook.

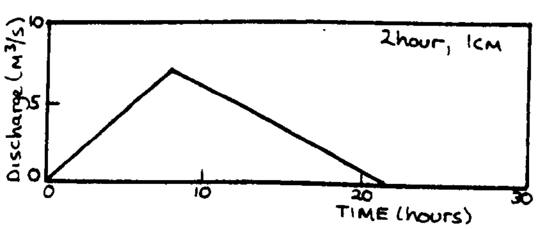


Fig. 6.7 Unit hydrograph for Tanners Brook.

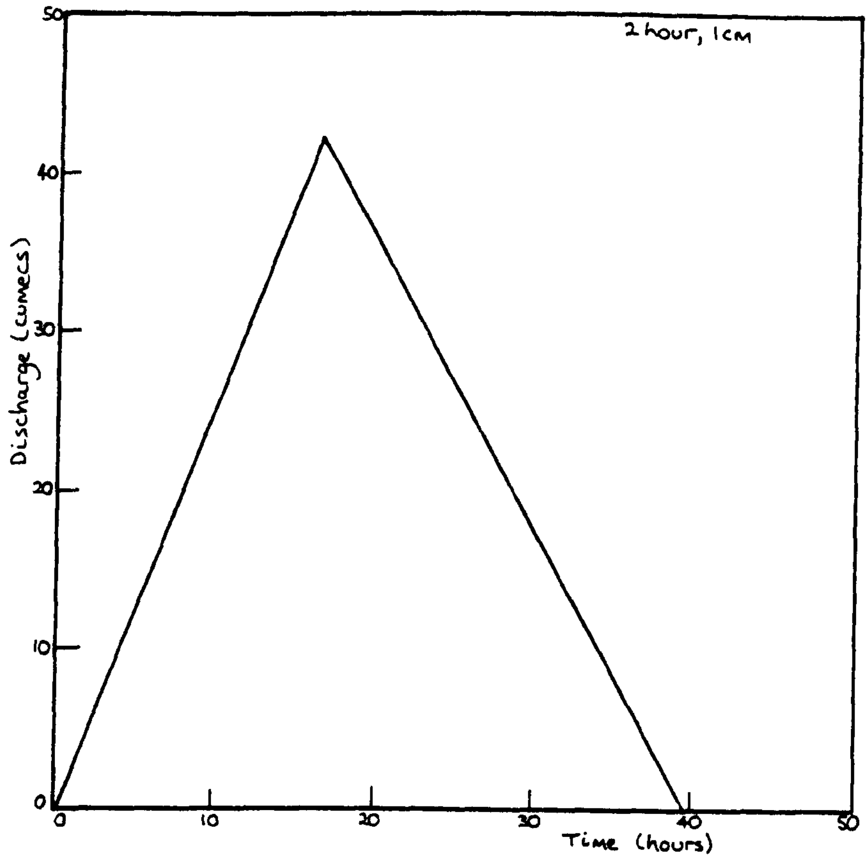


Fig. 6.8 River Mole - Unit hydrograph for Castle Mill.

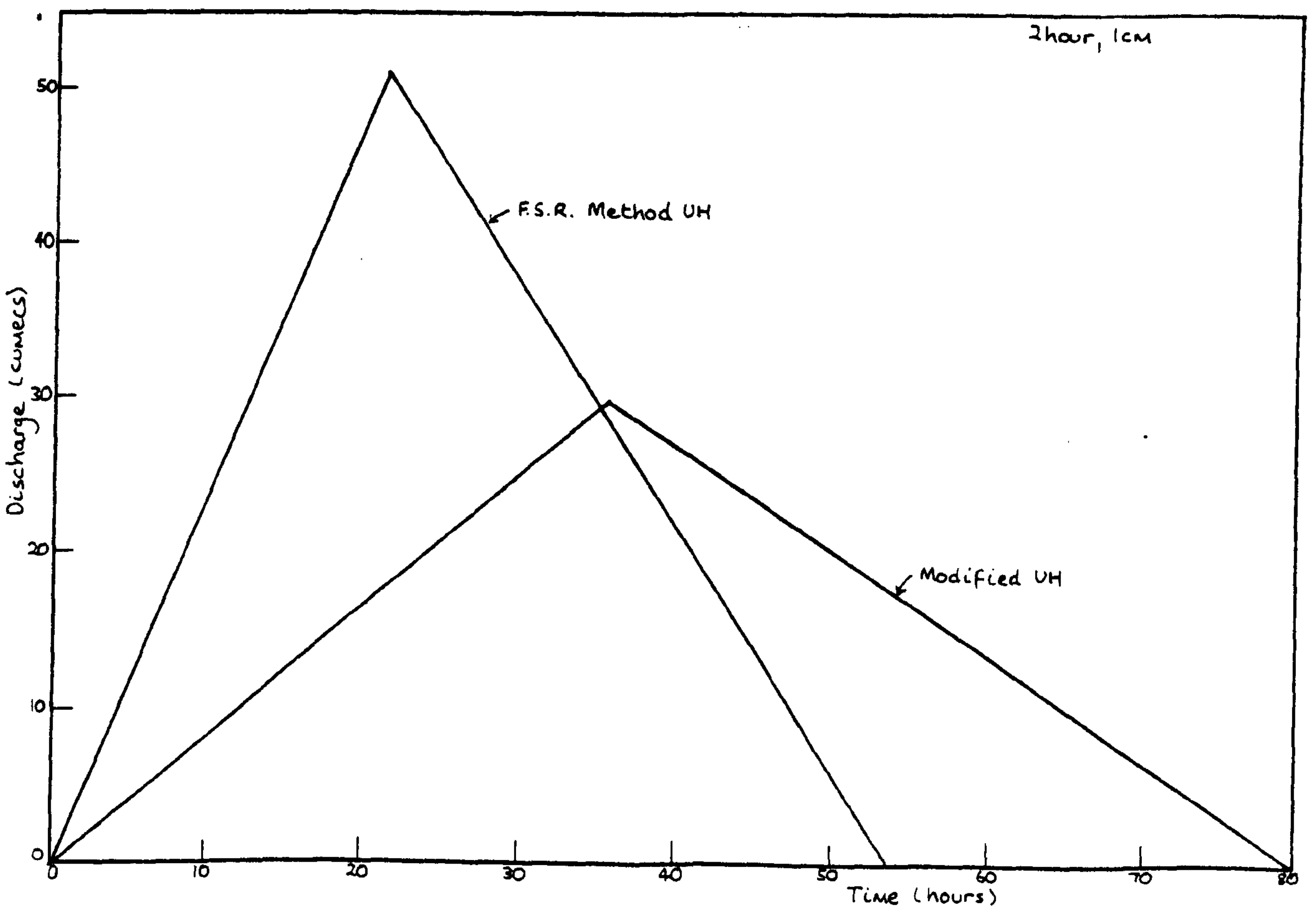


Fig. 6.9 River Mole - Unit hydrograph for Molesey.

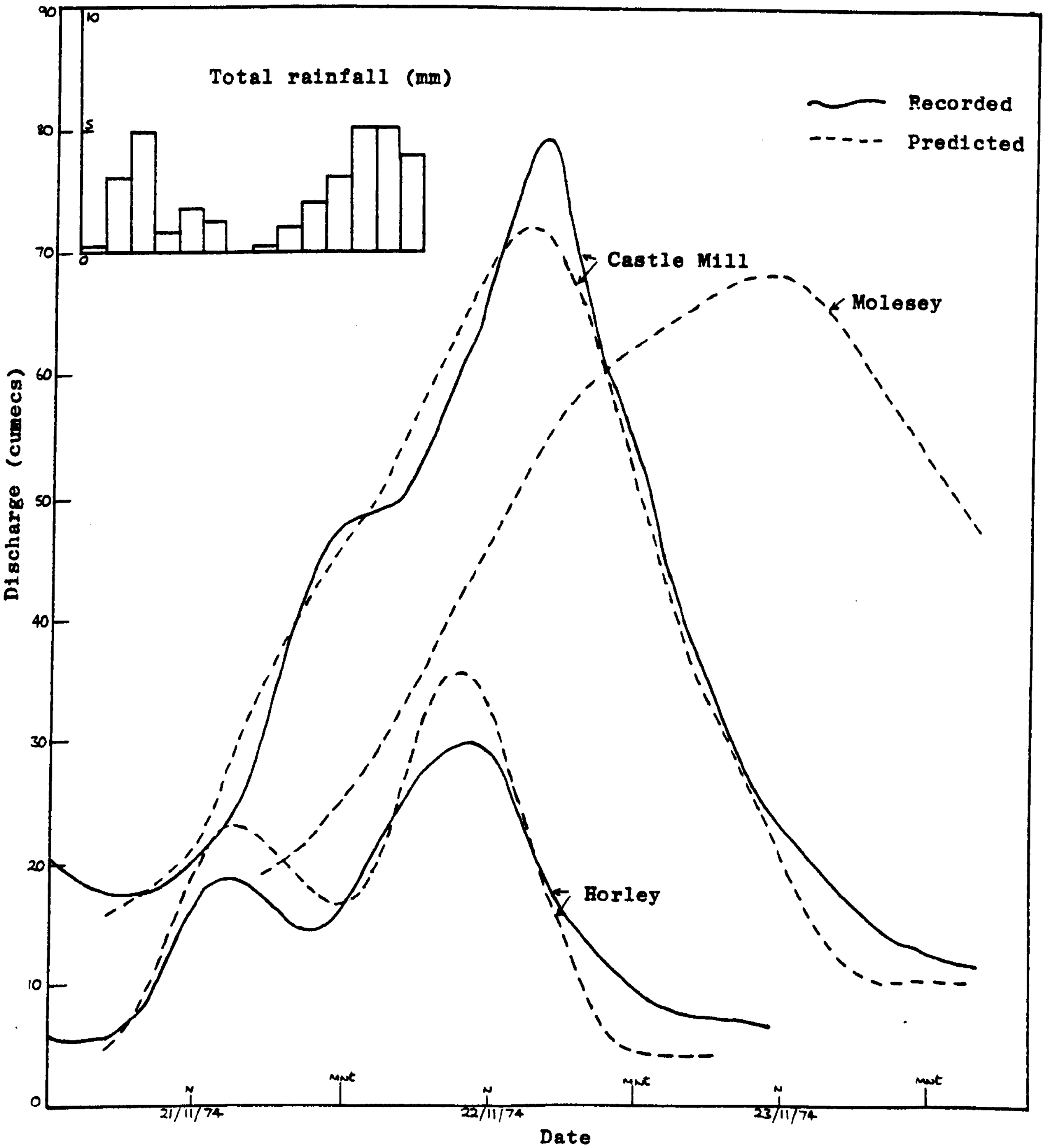


Fig. 6.10 Event (19) - UH predictions.

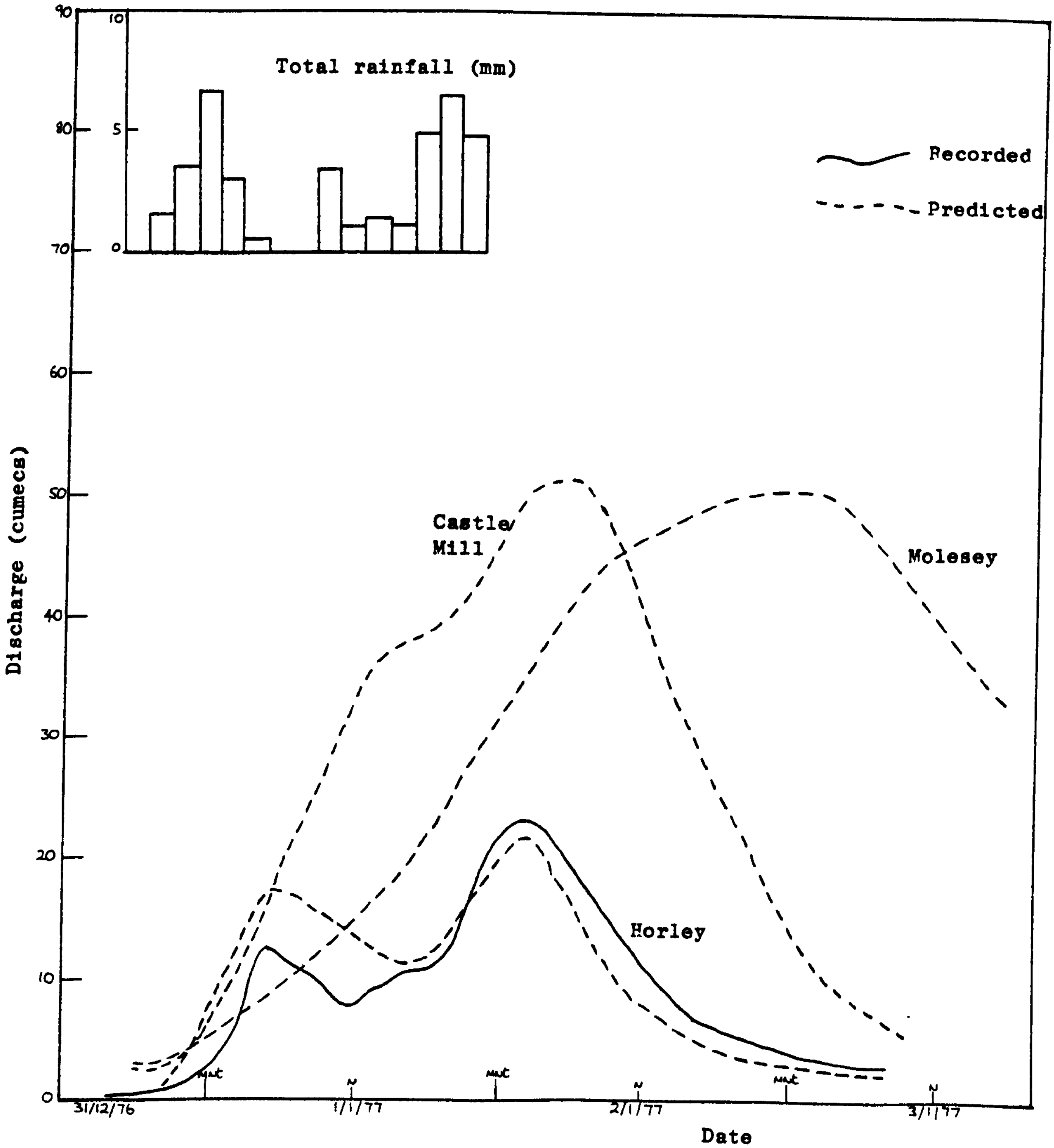


Fig. 6.11 Event (25) - UH predictions.

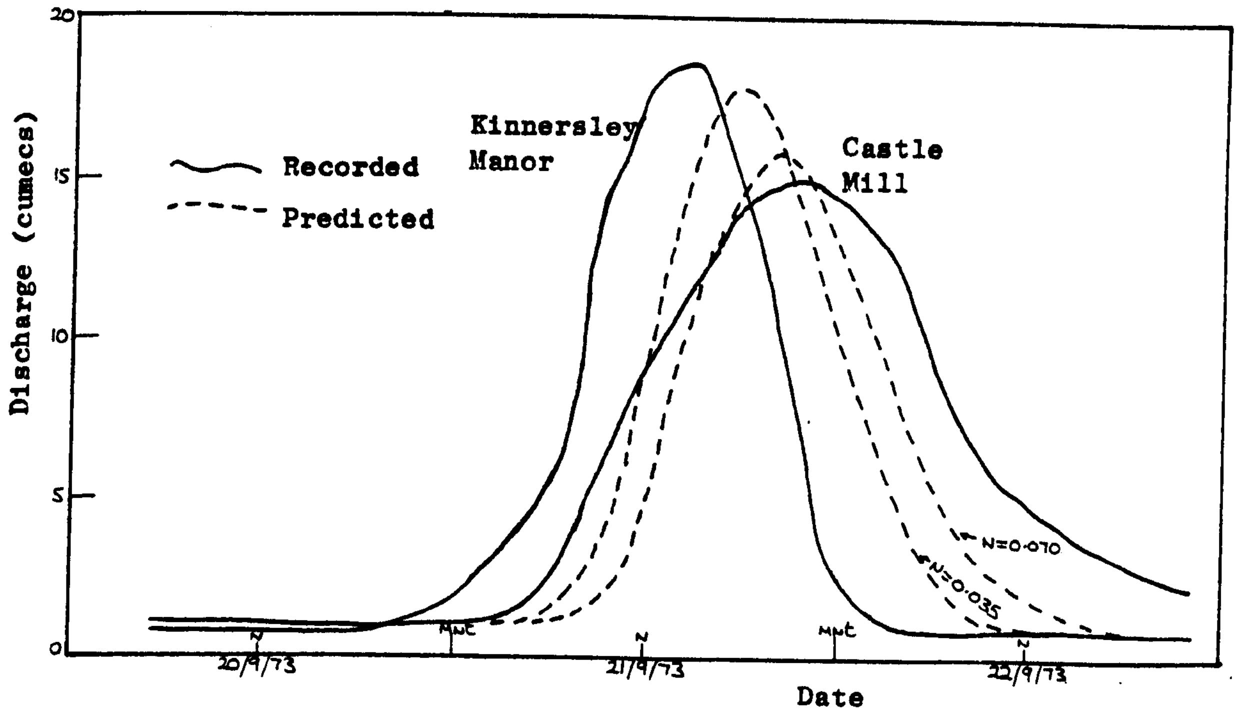


Fig. 6.12 Kinnersley Manor to Castle Mill - Event (12) simulation

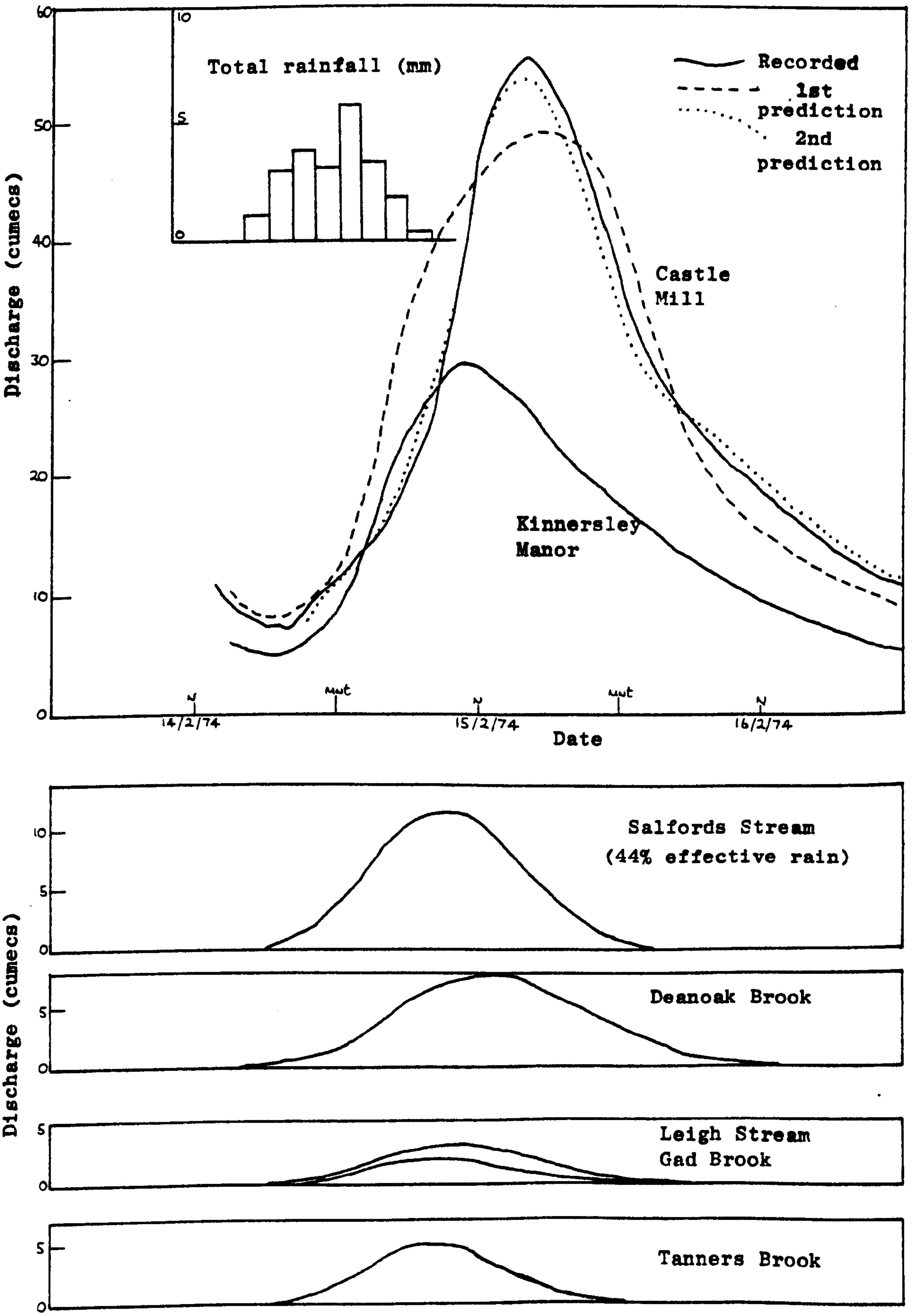


Fig. 6.13 Kinnersley Manor to Castle Mill - Event (14) simulation.

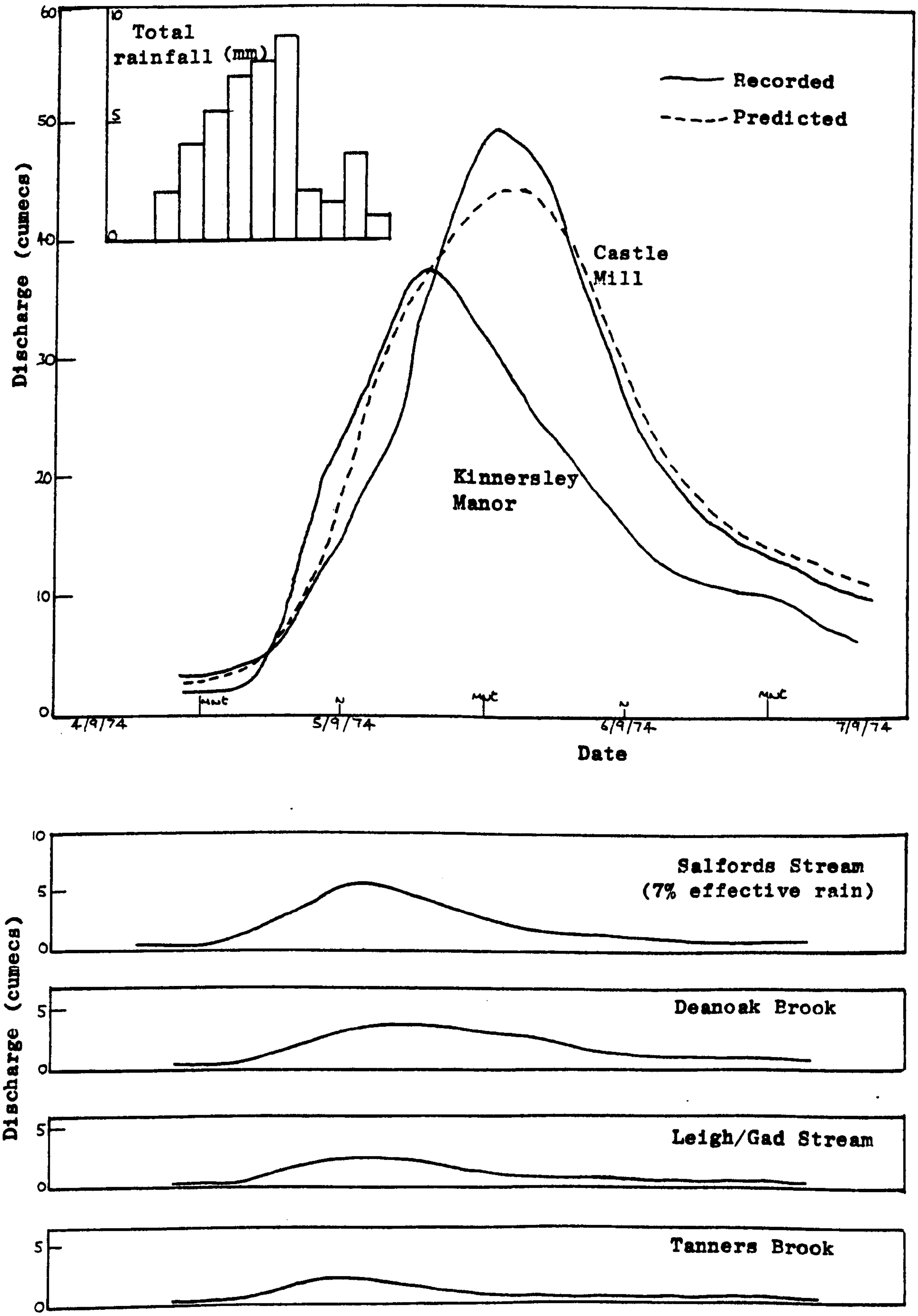


Fig. 6.14 Kinnersley Manor to Castle Mill - Event (15) simulation.

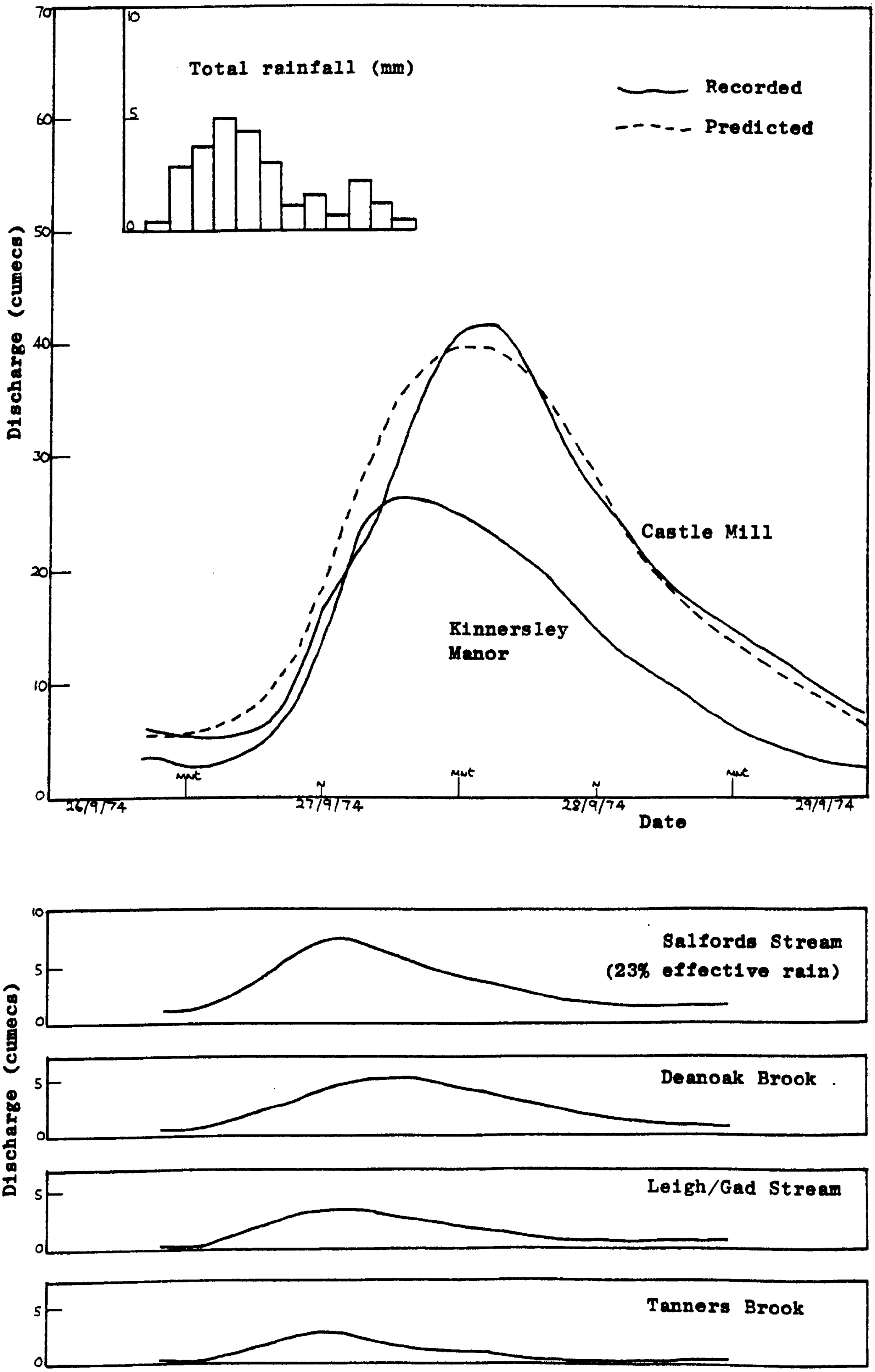


Fig. 6.15 Kinnersley Manor to Castle Mill - Event (16) simulation.

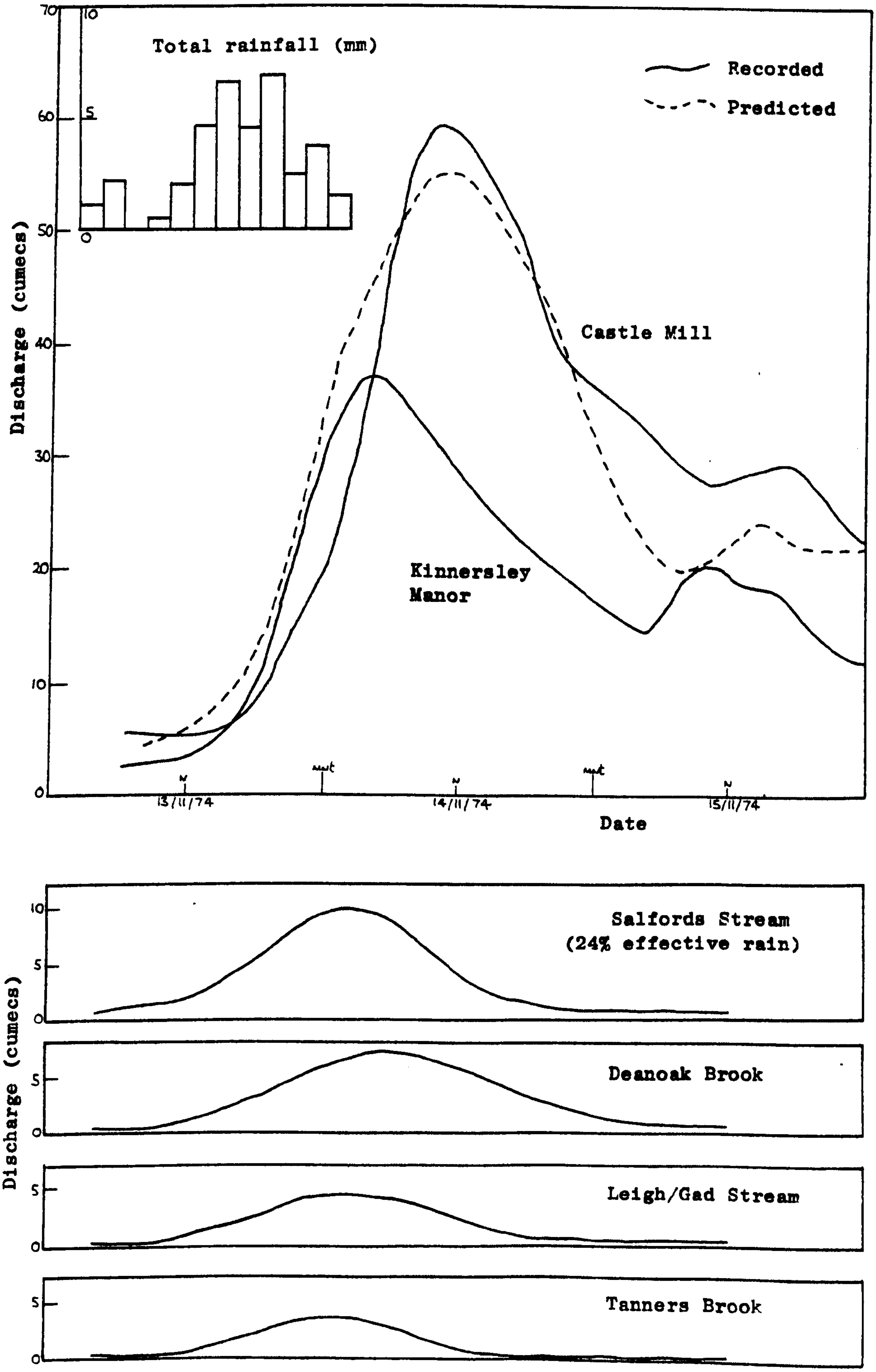


Fig. 6.16 Kinnersley Manor to Castle Mill - Event (17) simulation.

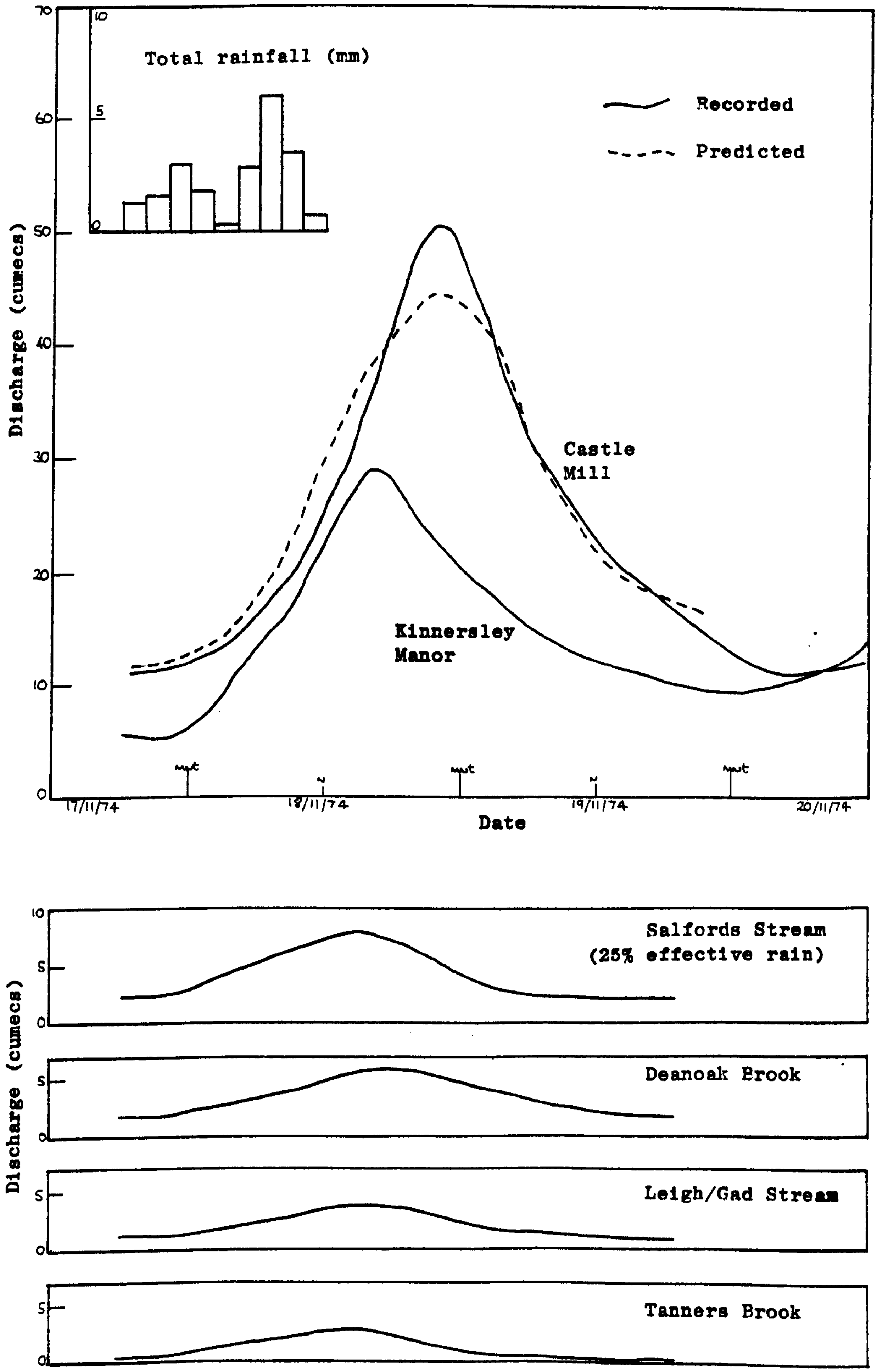
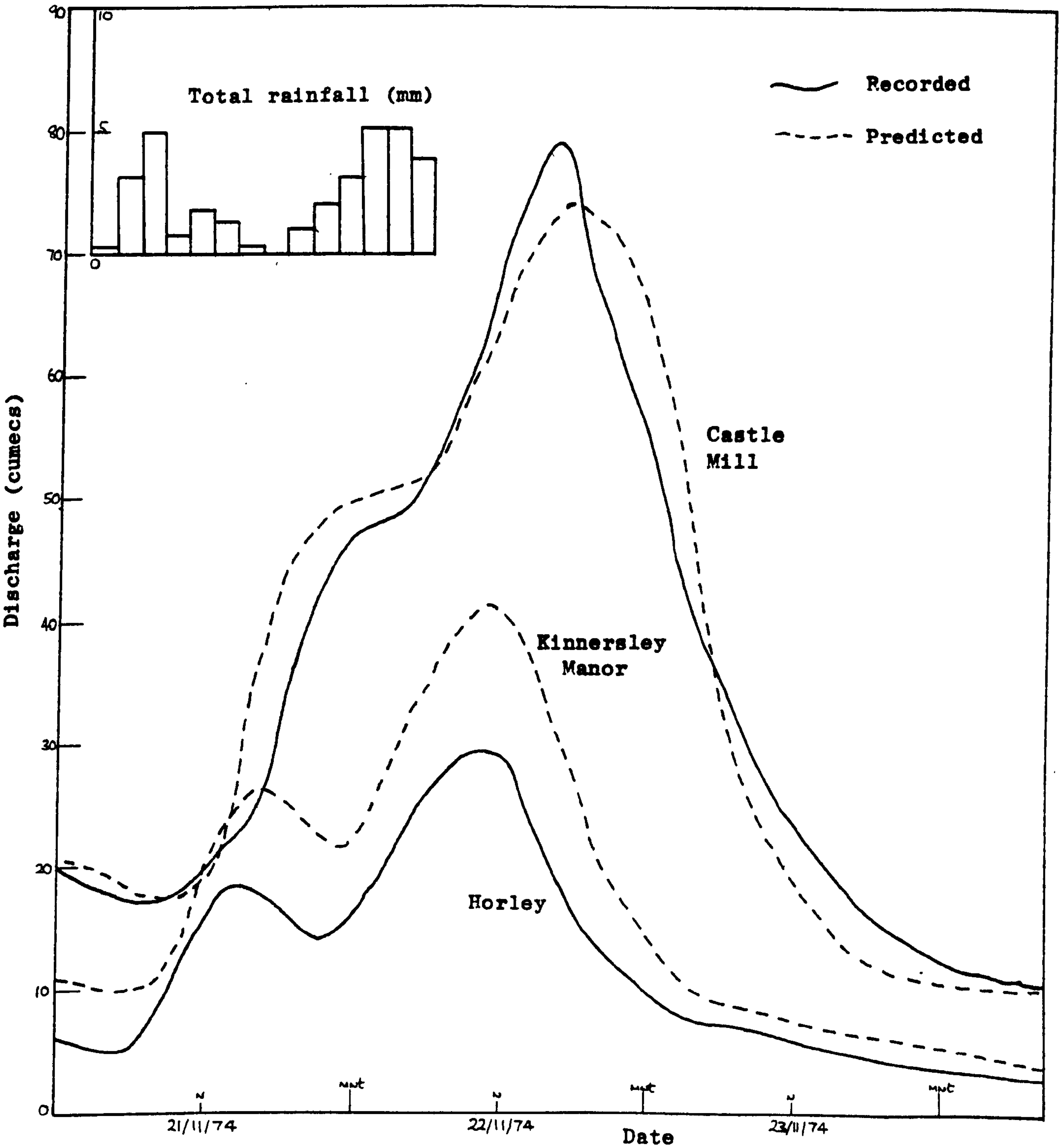
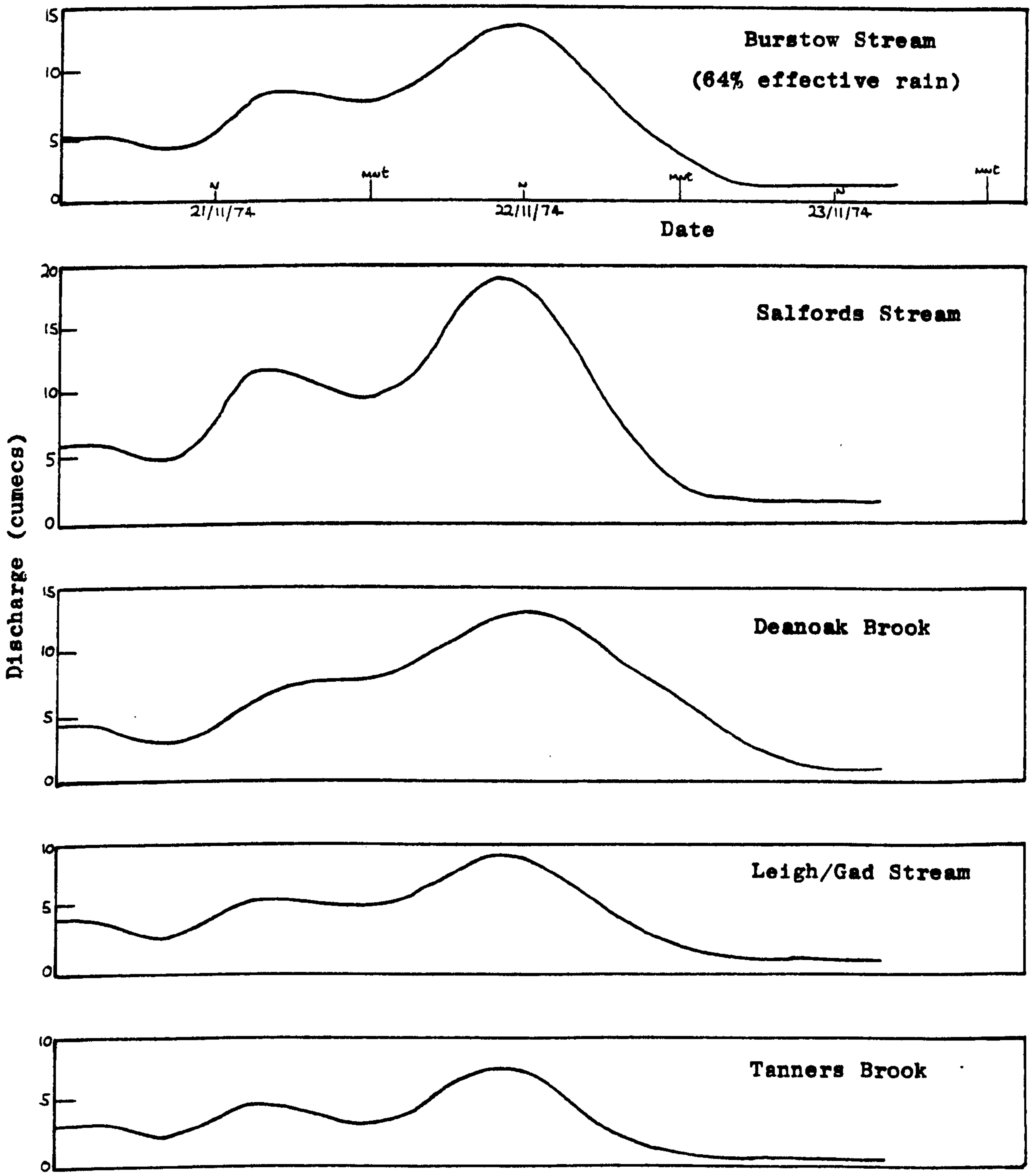


Fig. 6.17 Kinnersley Manor to Castle Mill - Event (18) simulation.



<u>Fig. 6.18</u> Horley to Castle Mill - Event (19) simulation.

continued ......



<u>Fig. 6.18 continued</u>. Horley to Castle Mill - Event (19) simulation.

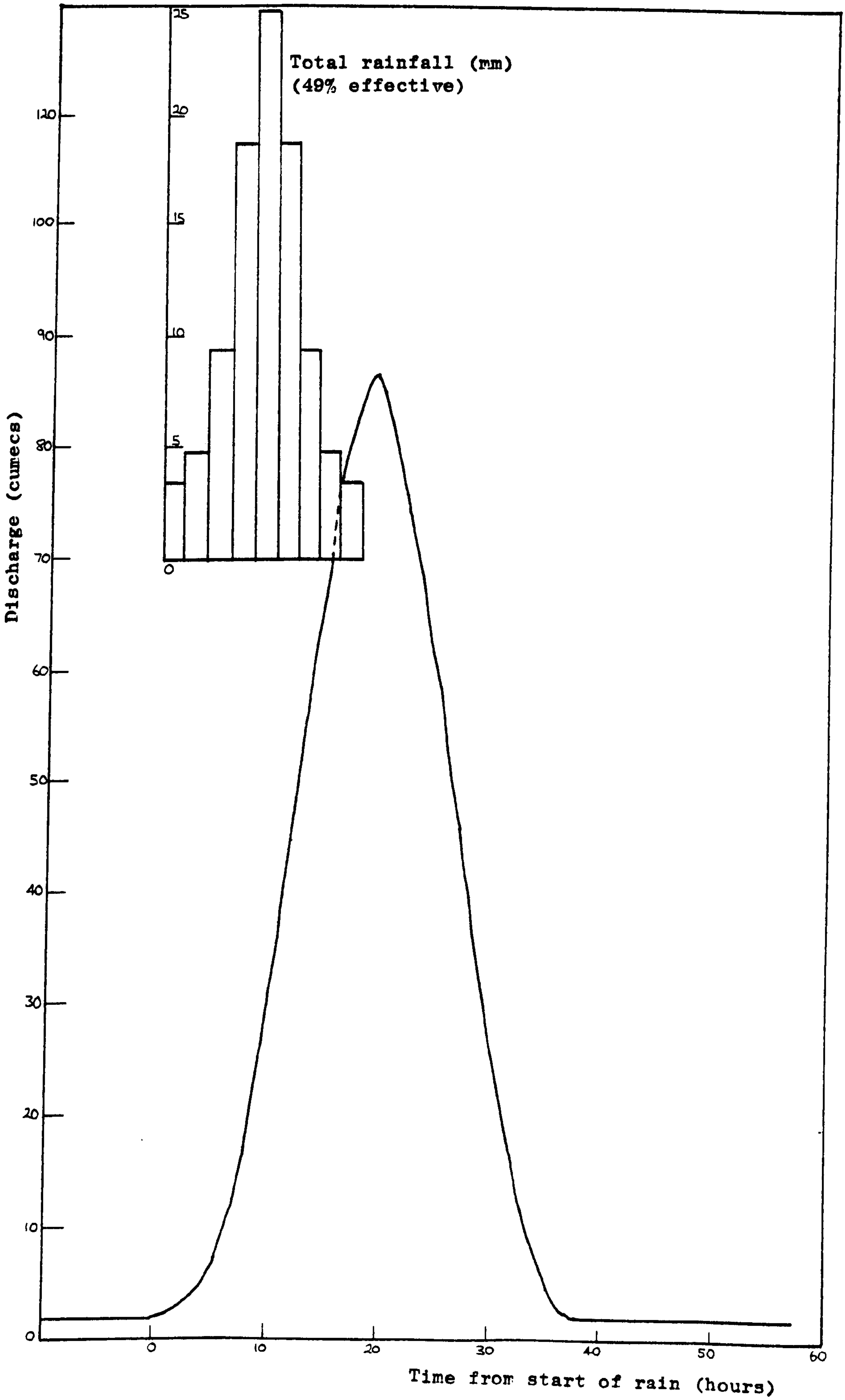


Fig. 6.19 500 year return period design flood for Horley

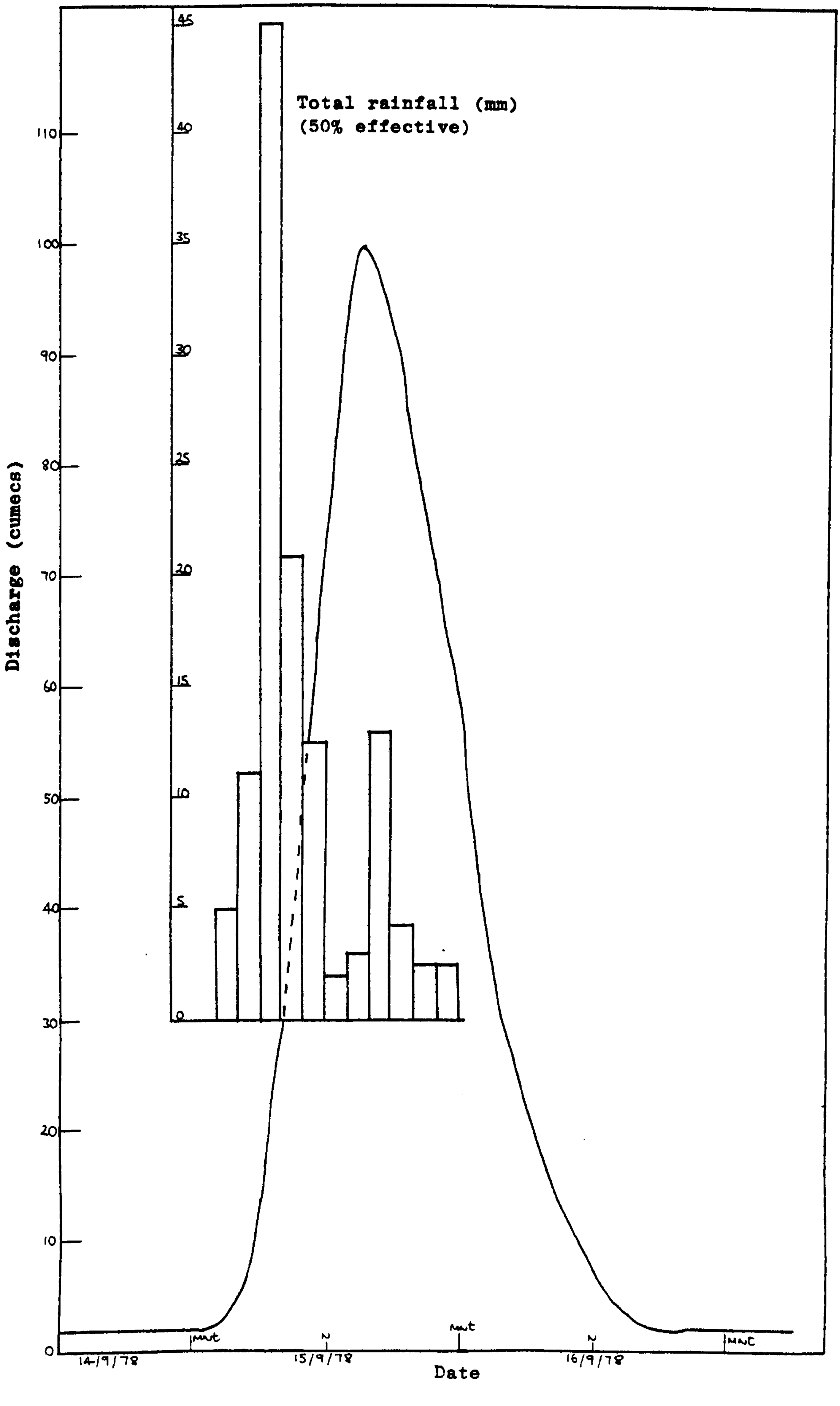
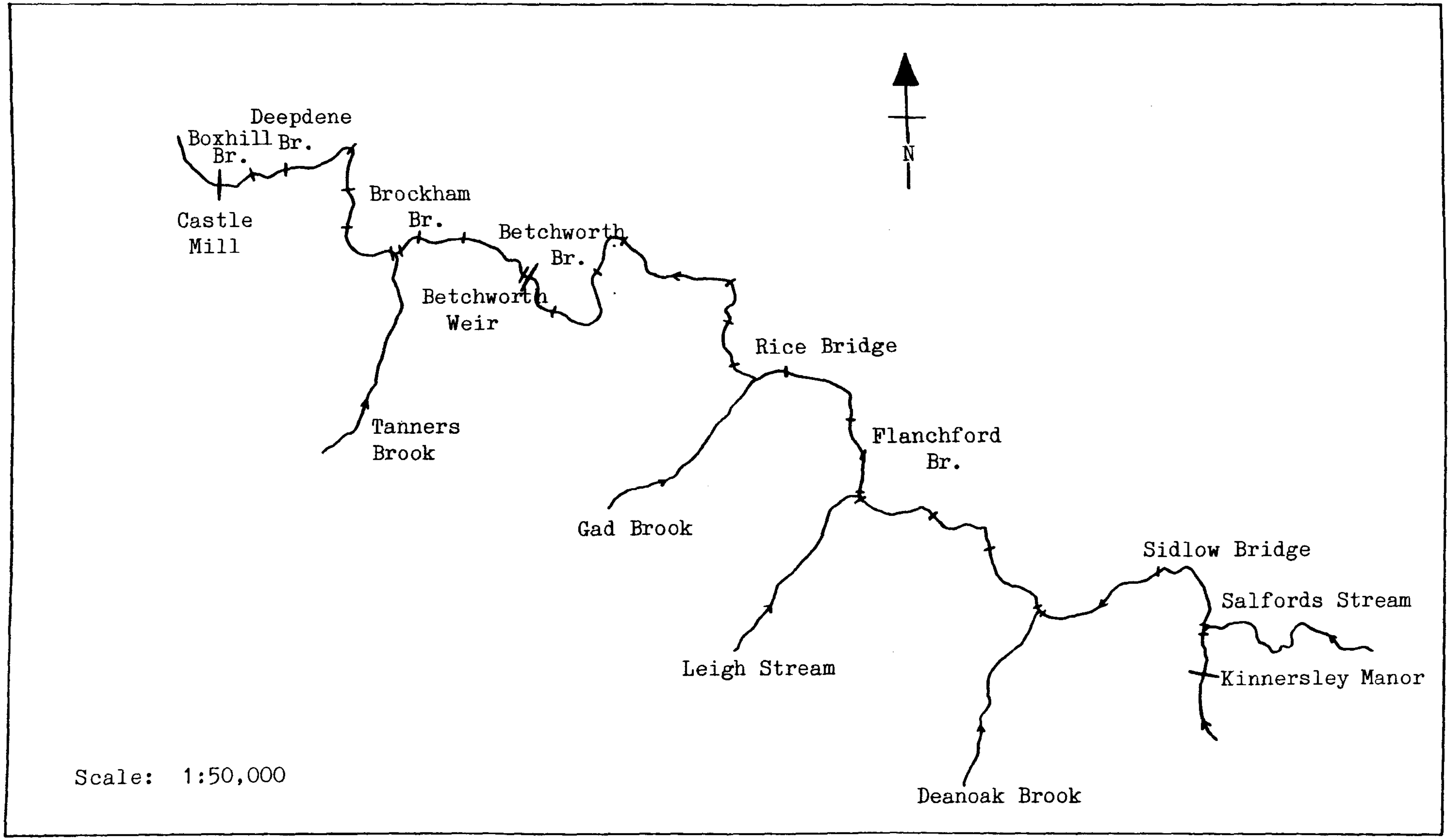


Fig. 6.20. Event (1) - UH predictions (Horley).



<u>Fig. 6.21</u> Kinnersley Manor to Castle Mill - **Model scheme**

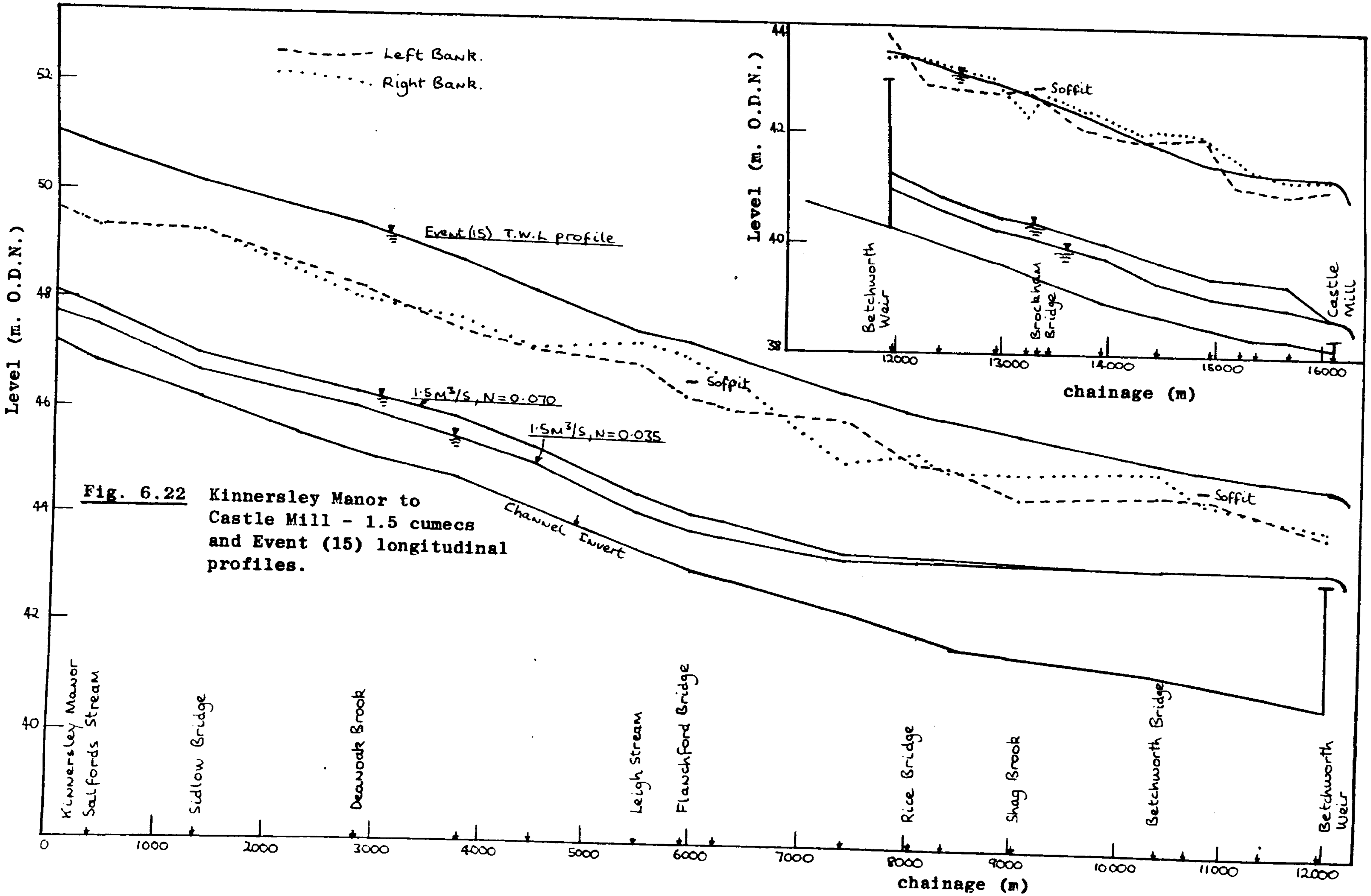


Fig. 6.22 Kinnersley Manor to Castle Mill - 1.5 cumecs and Event (15) longitudinal profiles.

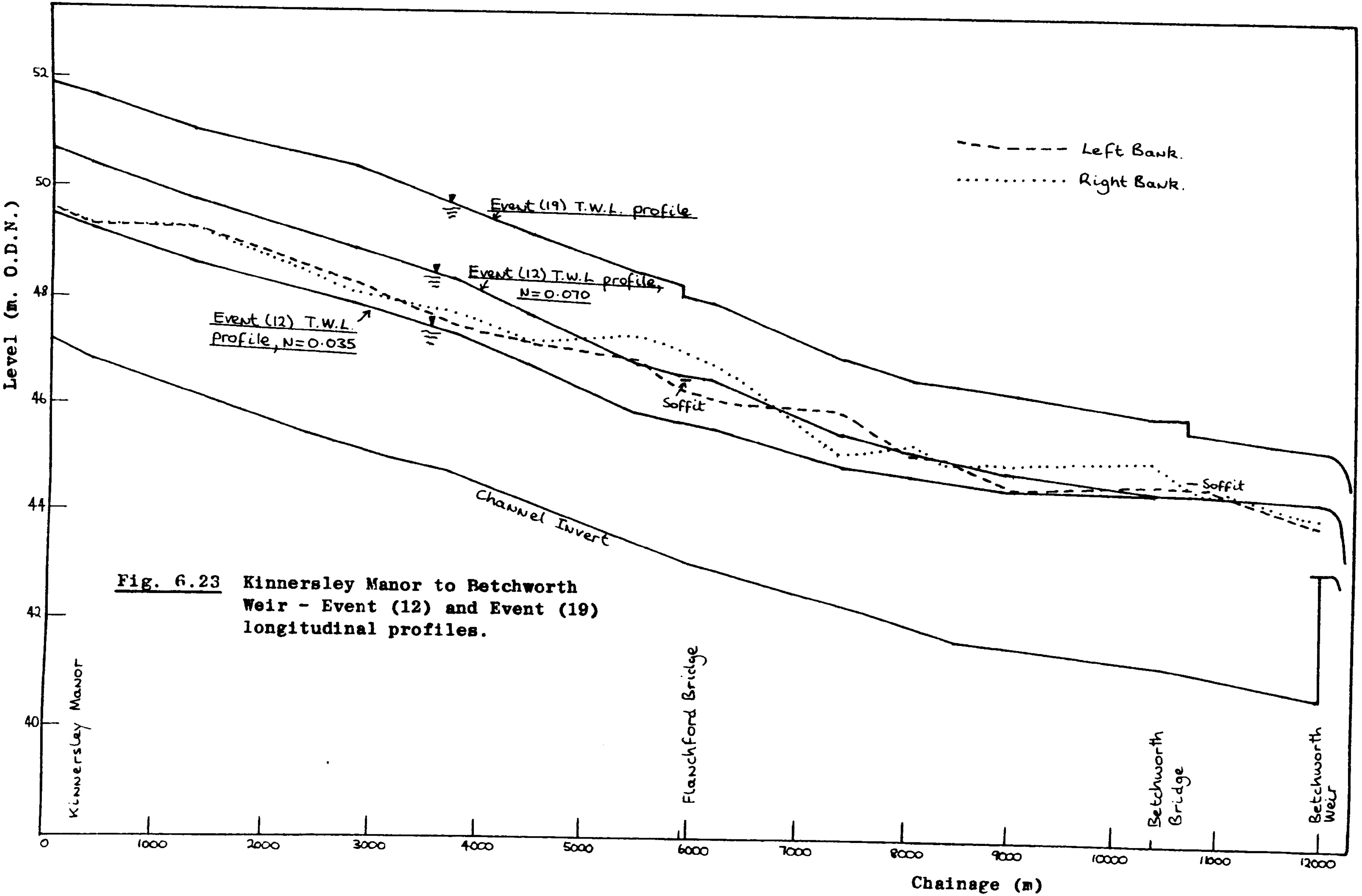


Fig. 6.23 Kinnersley Manor to Betchworth Weir - Event (12) and Event (19) longitudinal profiles.

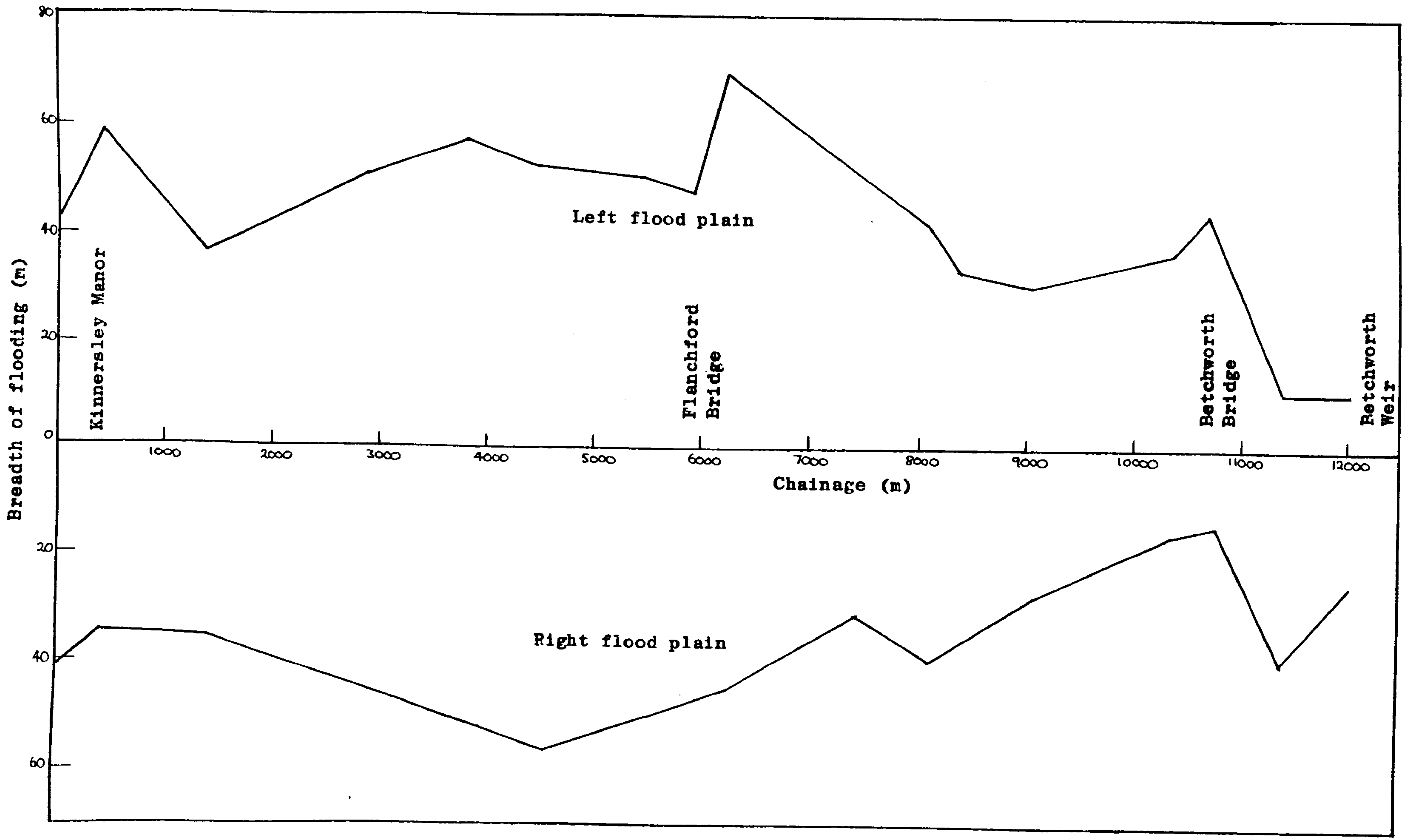


Fig. 6.24 Kinnersley Manor to Betchworth Weir - Event (19) simulated flood plain inundation.

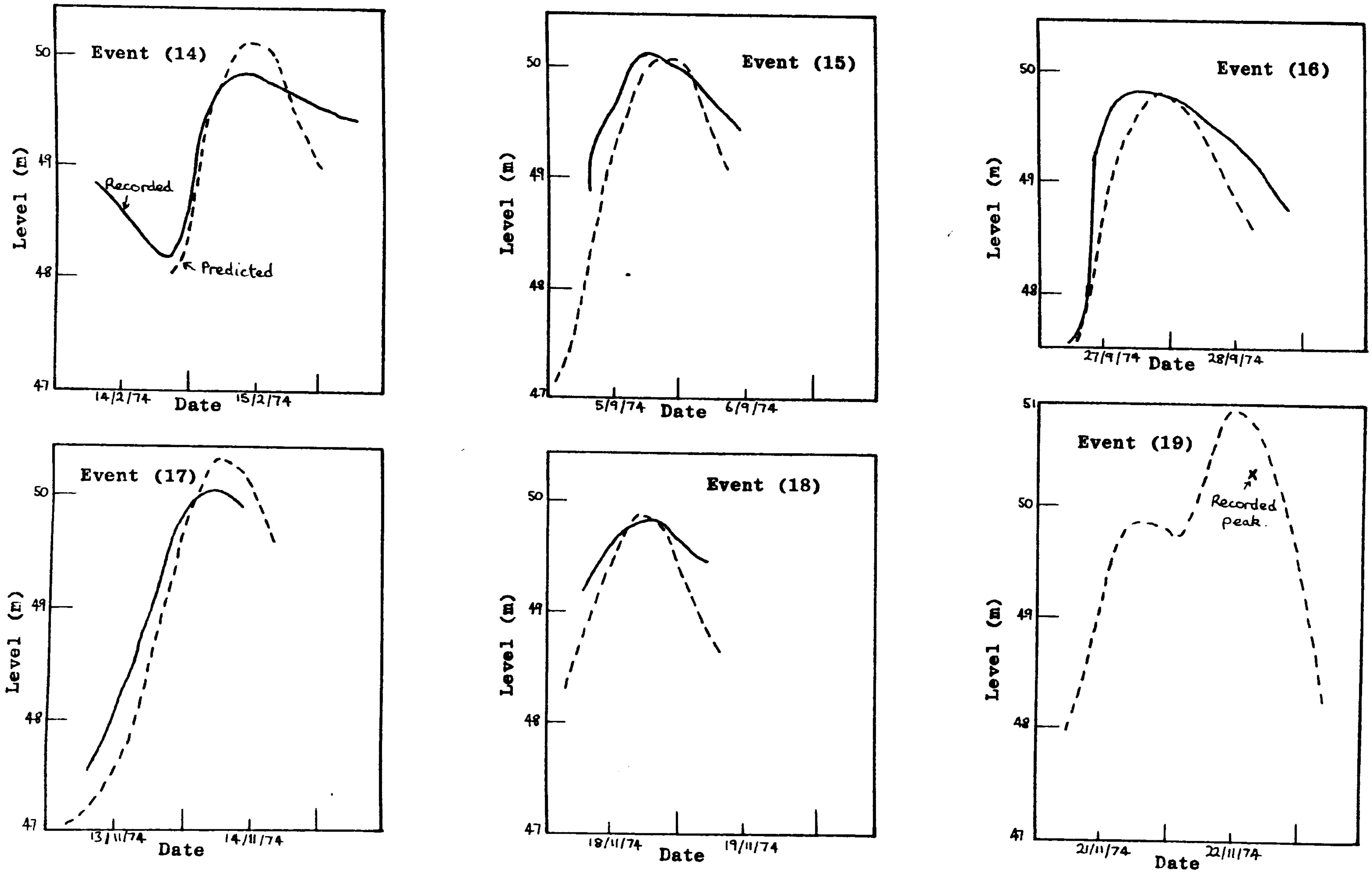


Fig. 6.25 Level hydrographs at Sidlow Bridge.

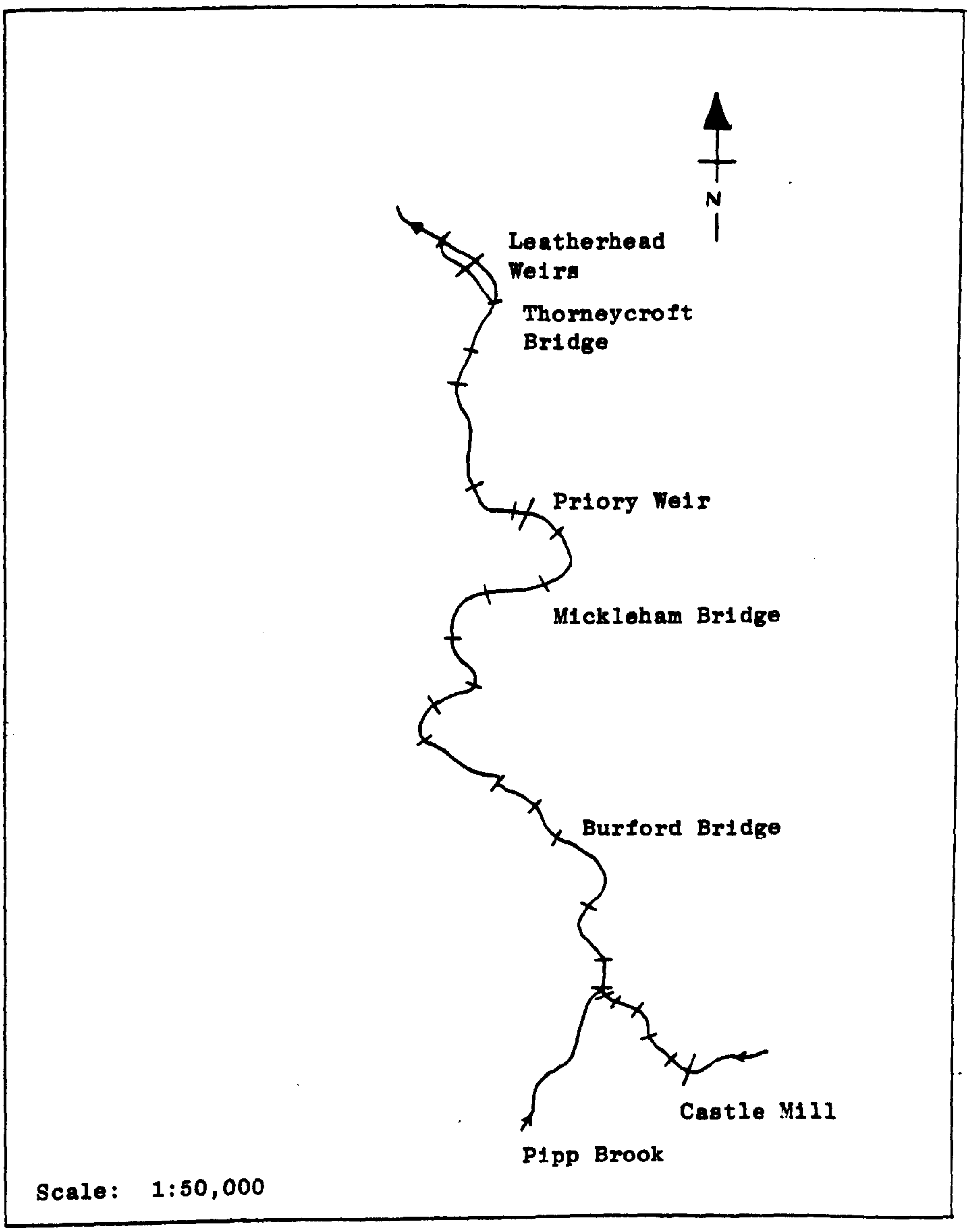


Fig. 6.26 Castle Mill to Leatherhead - Model Scheme

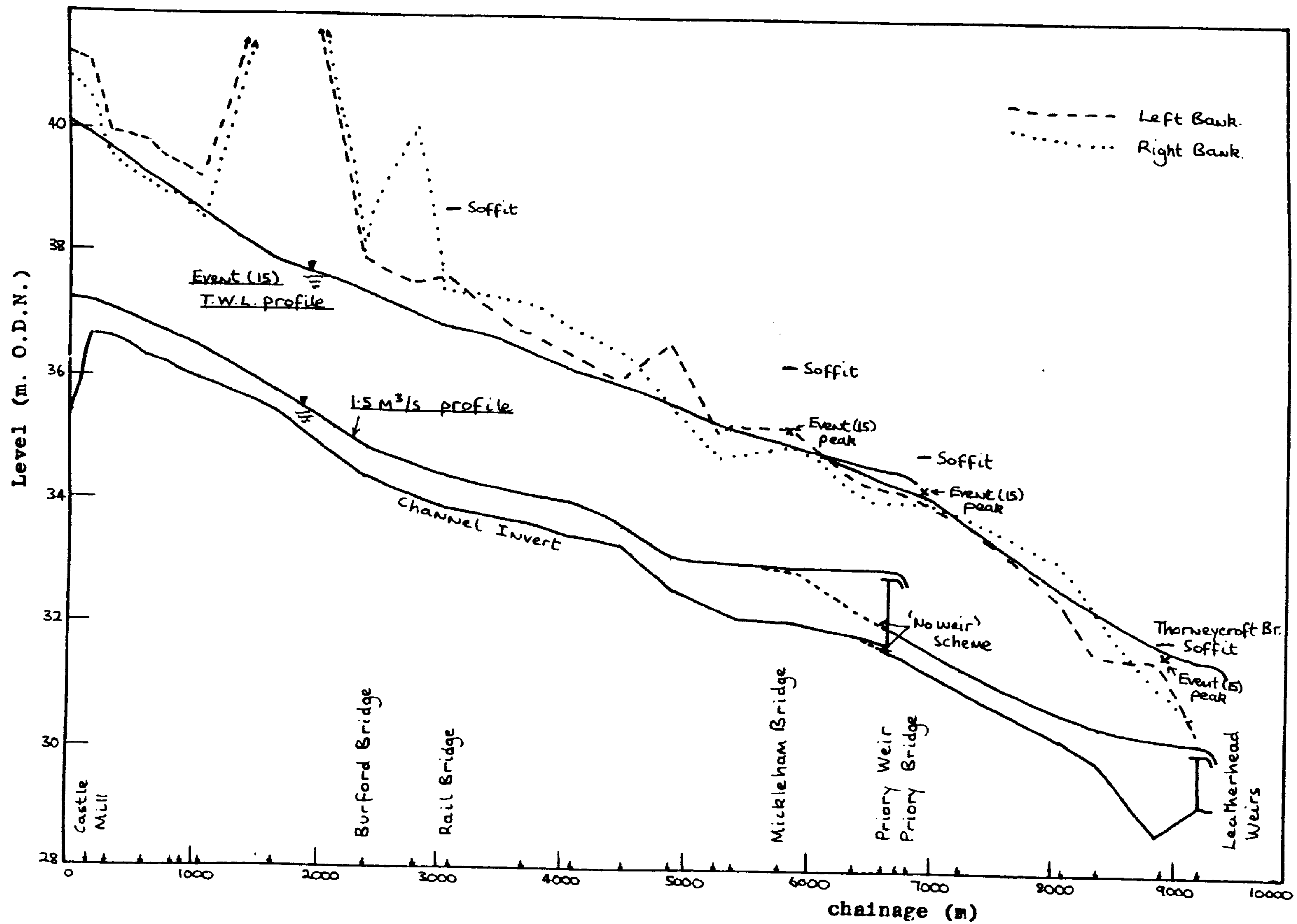


Fig. 6.27 Castle Mill to Leatherhead - 1.5 cumecs and Event (15) longitudinal profiles.

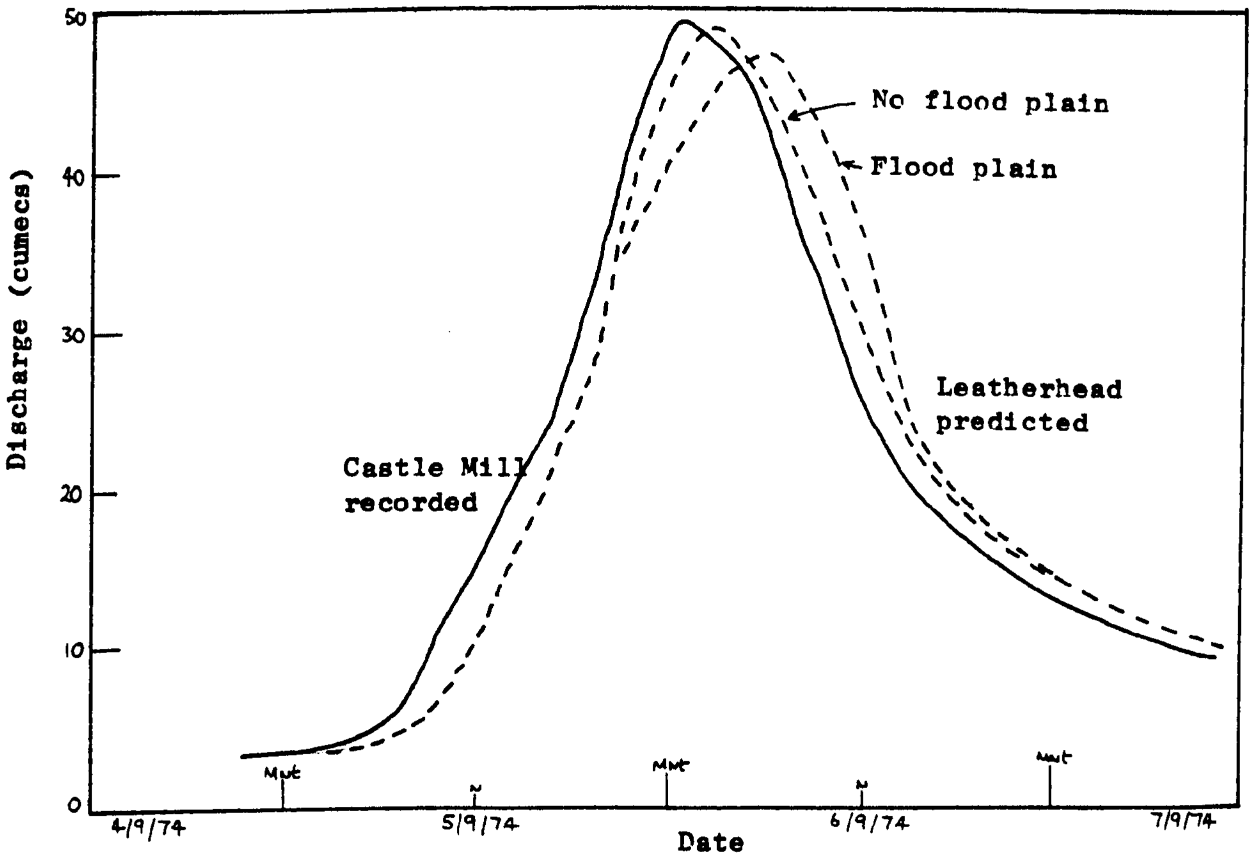


Fig. 6.28 Castle Mill to Leatherhead - Event (15) simulation.

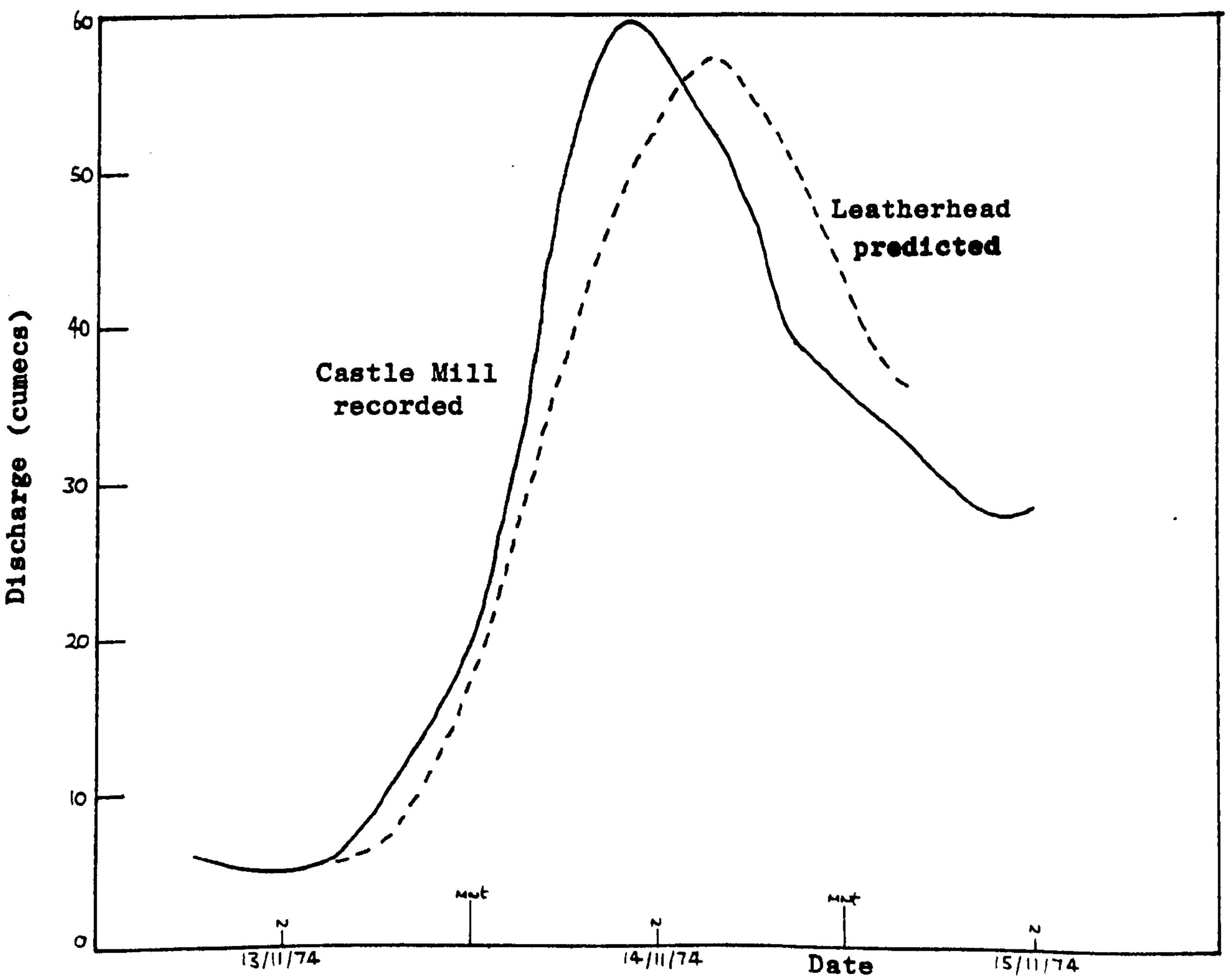


Fig. 6.29 Castle Mill to Leatherhead - Event (17) simulation.

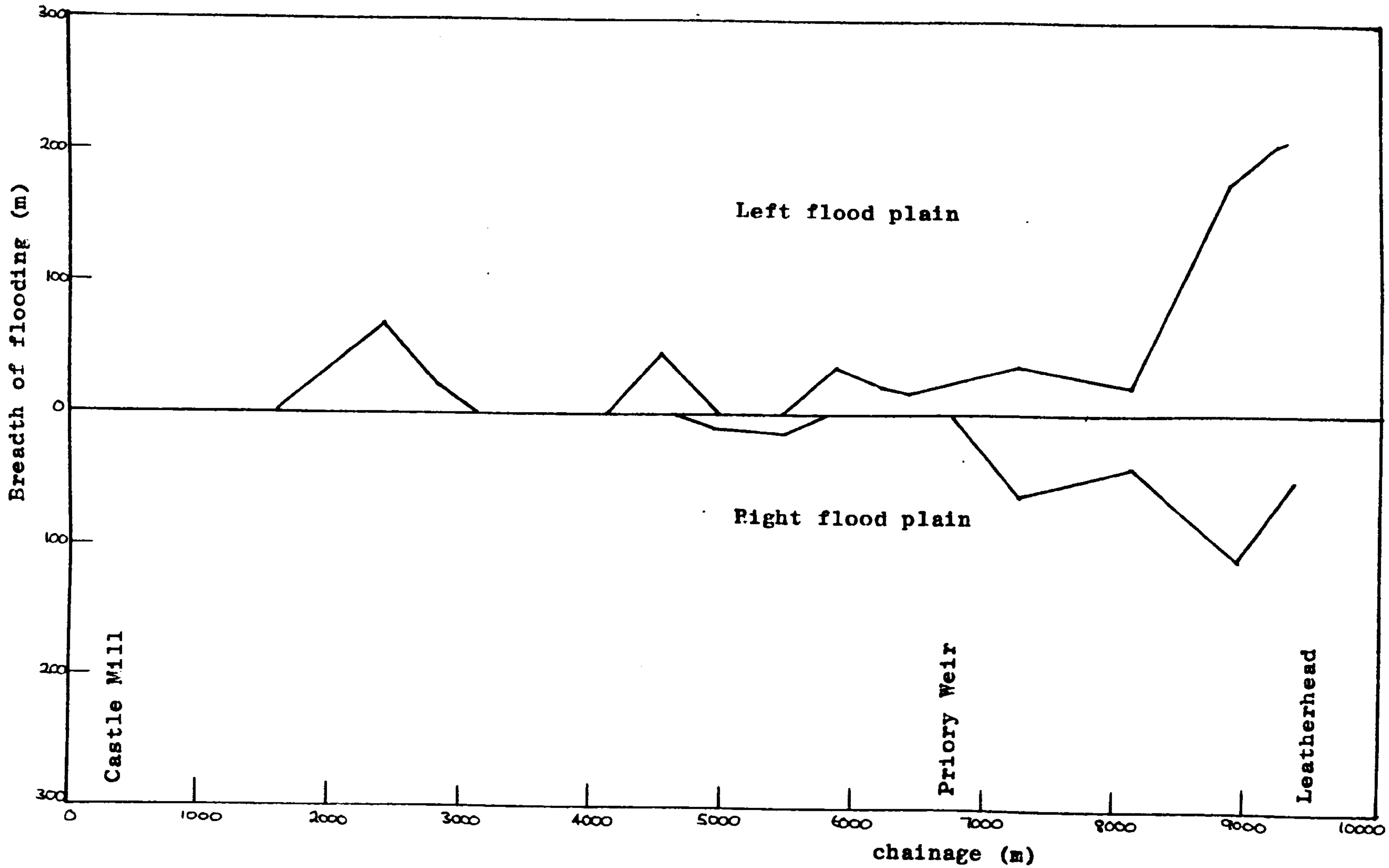


Fig. 6.30 Castle Mill to Leatherhead - Event (14) simulated flood plain inundation.

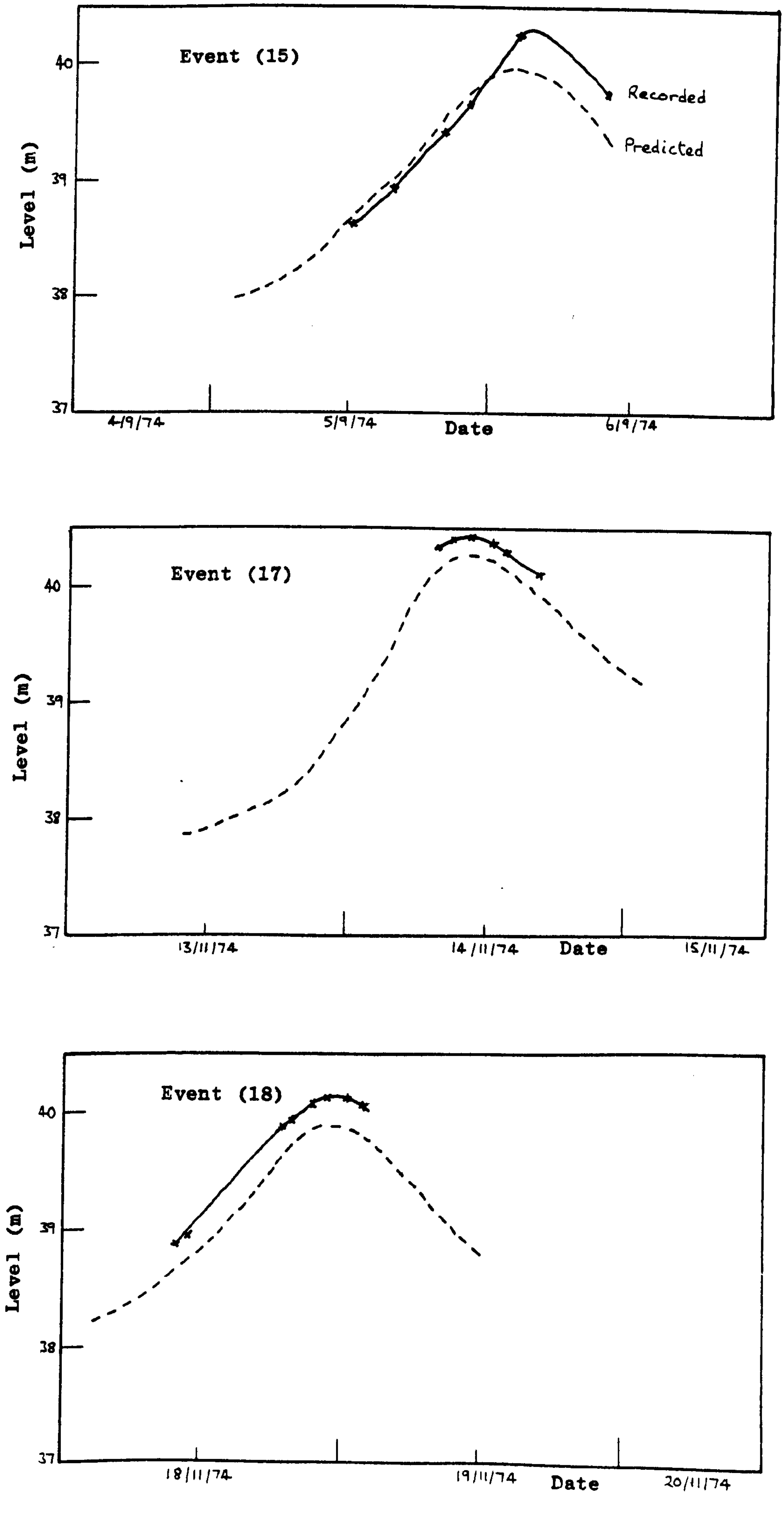


Fig. 6.31 **Tailwater level hydrographs at Castle Mill.**

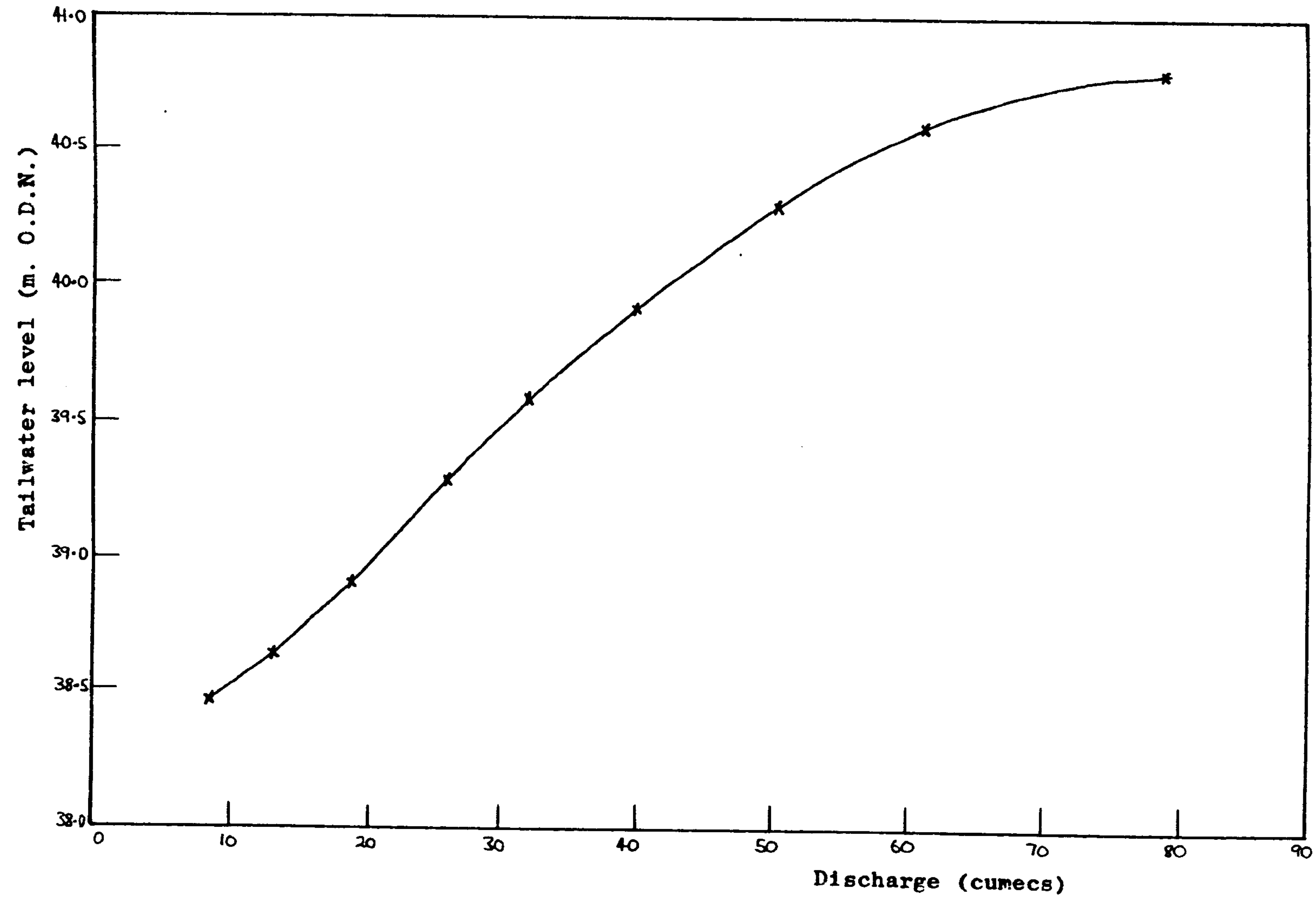


Fig. 6.32 Castle Mill tailwater rating curve.

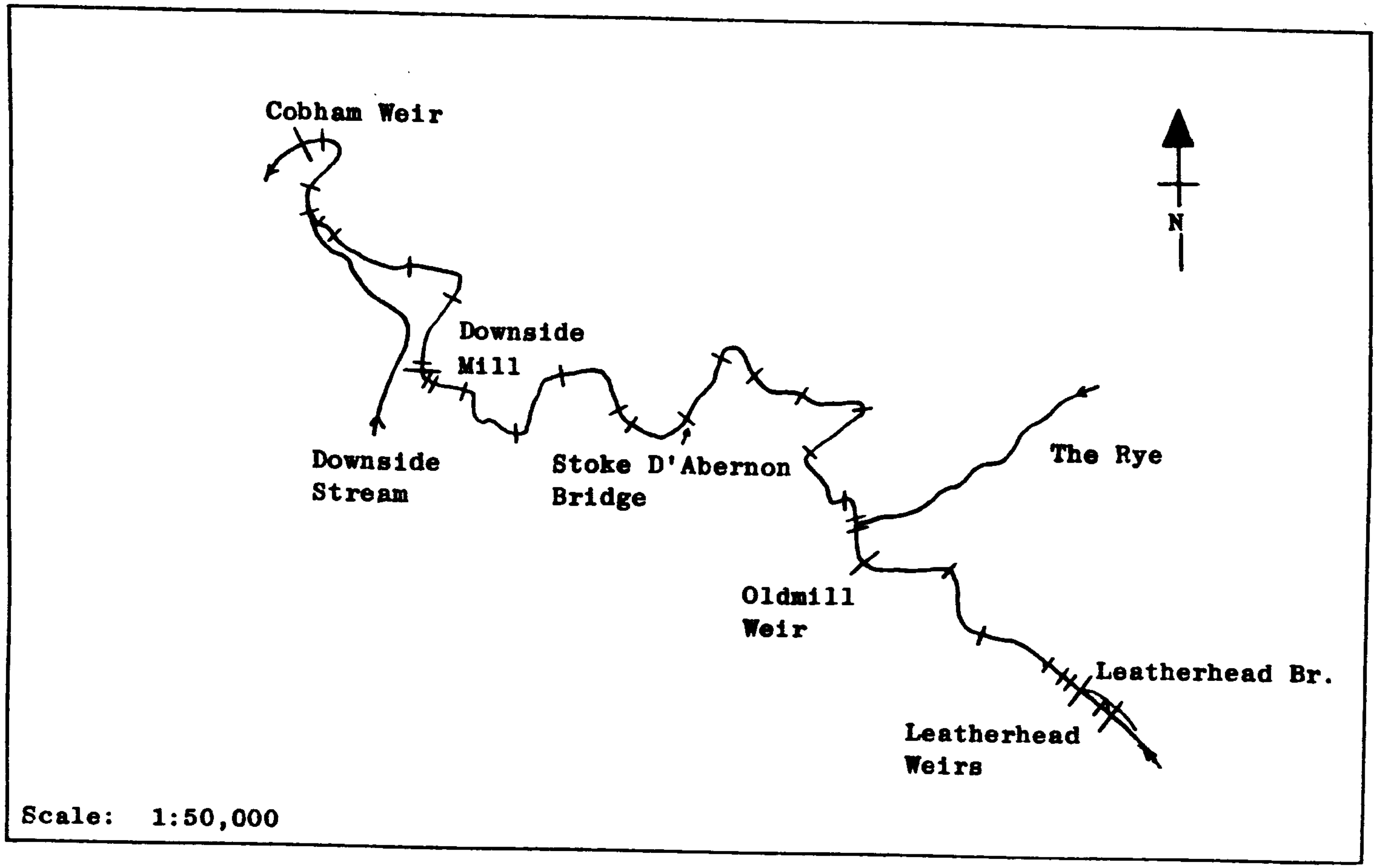


Fig. 6.33. Leatherhead Weirs to Cobham Mill - Model Scheme.

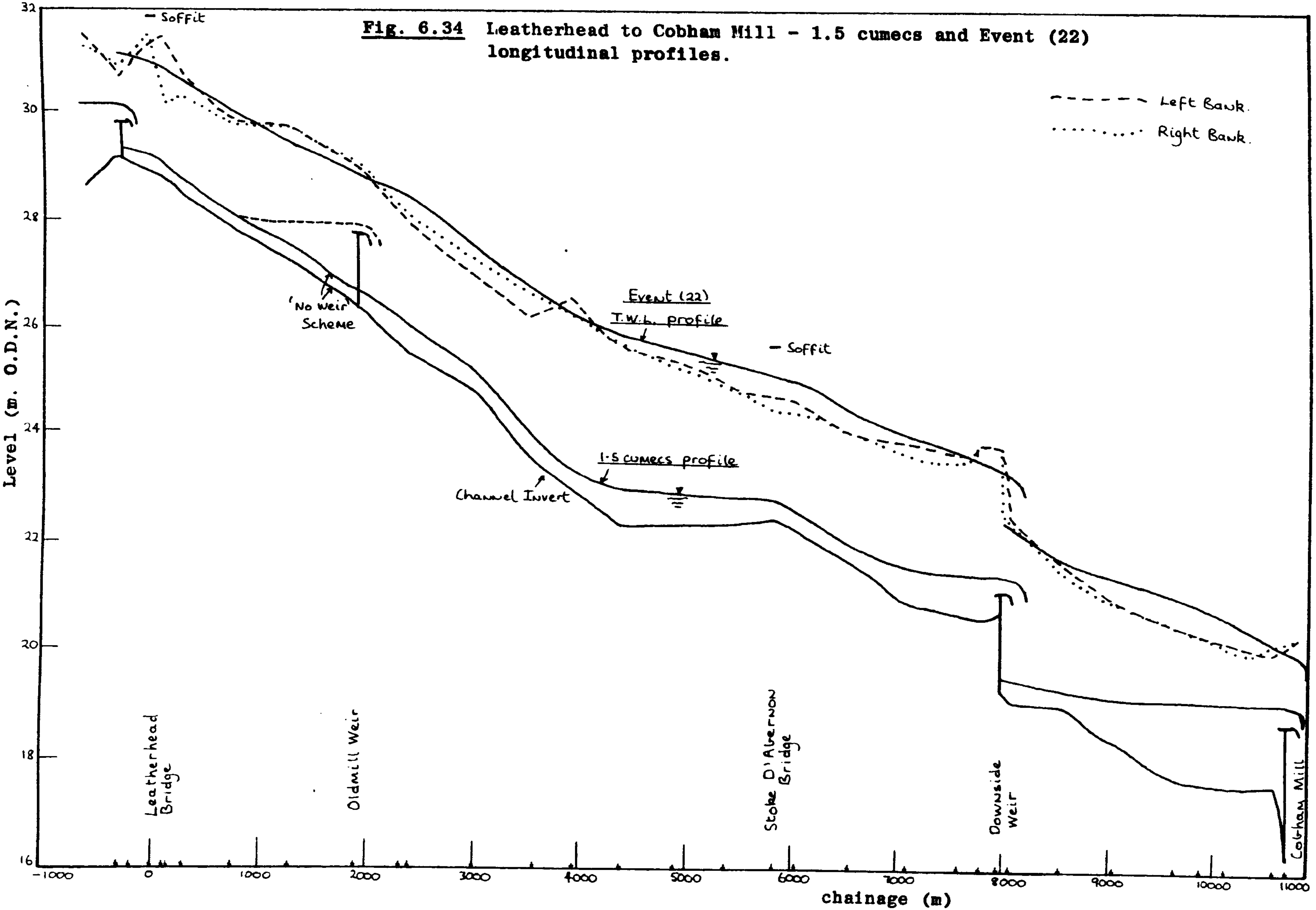


Fig. 6.34 Leatherhead to Cobham Mill - 1.5 cumecs and Event (22) longitudinal profiles.

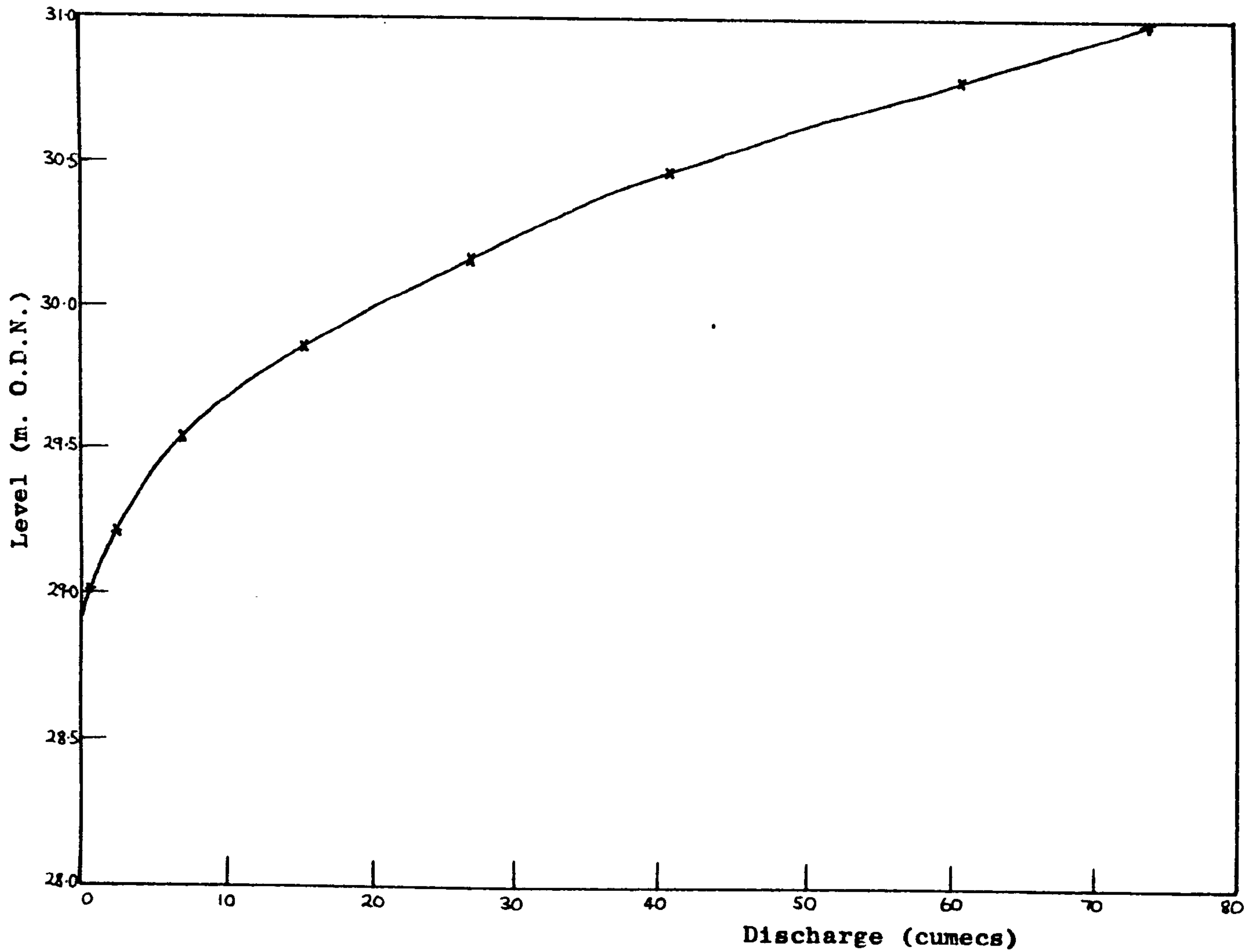
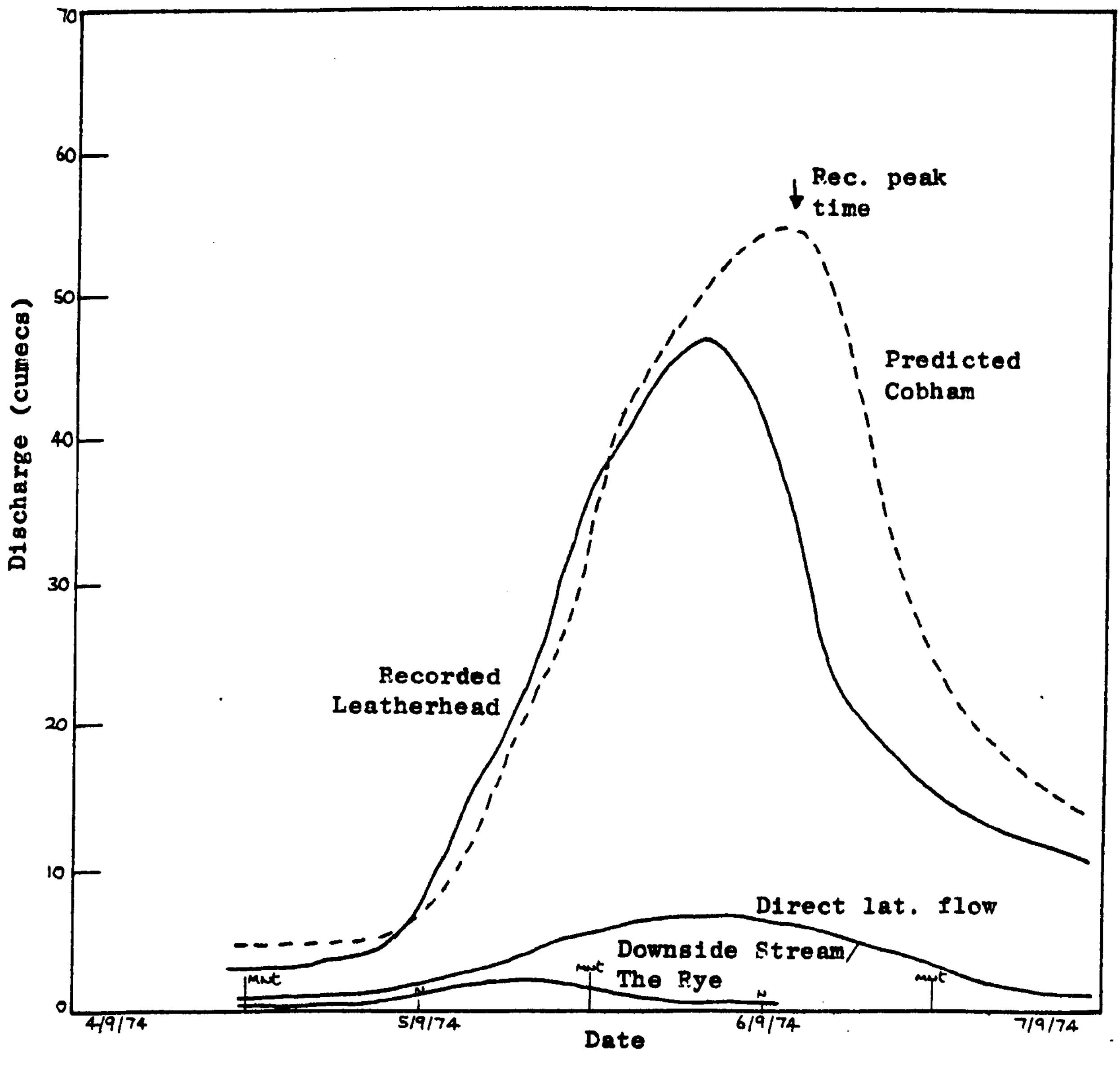


Fig. 6.35 Leatherhead tailwater rating curve.



<u>Fig. 6.36</u> Leatherhead to Cobham Mill - Event (15) simulation.

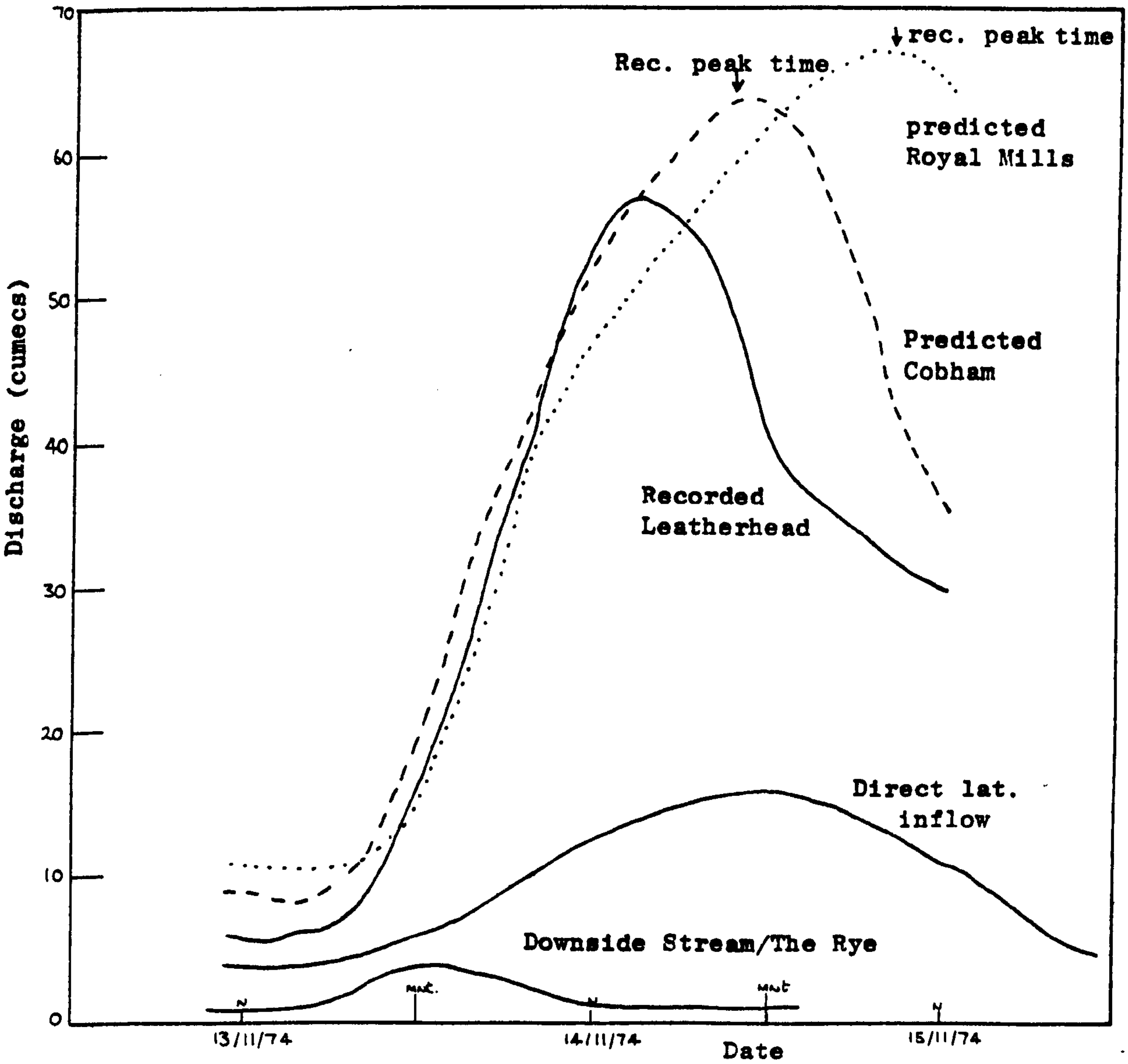


Fig. 6.37 Leatherhead to Royal Mills - Event (17) simulation.

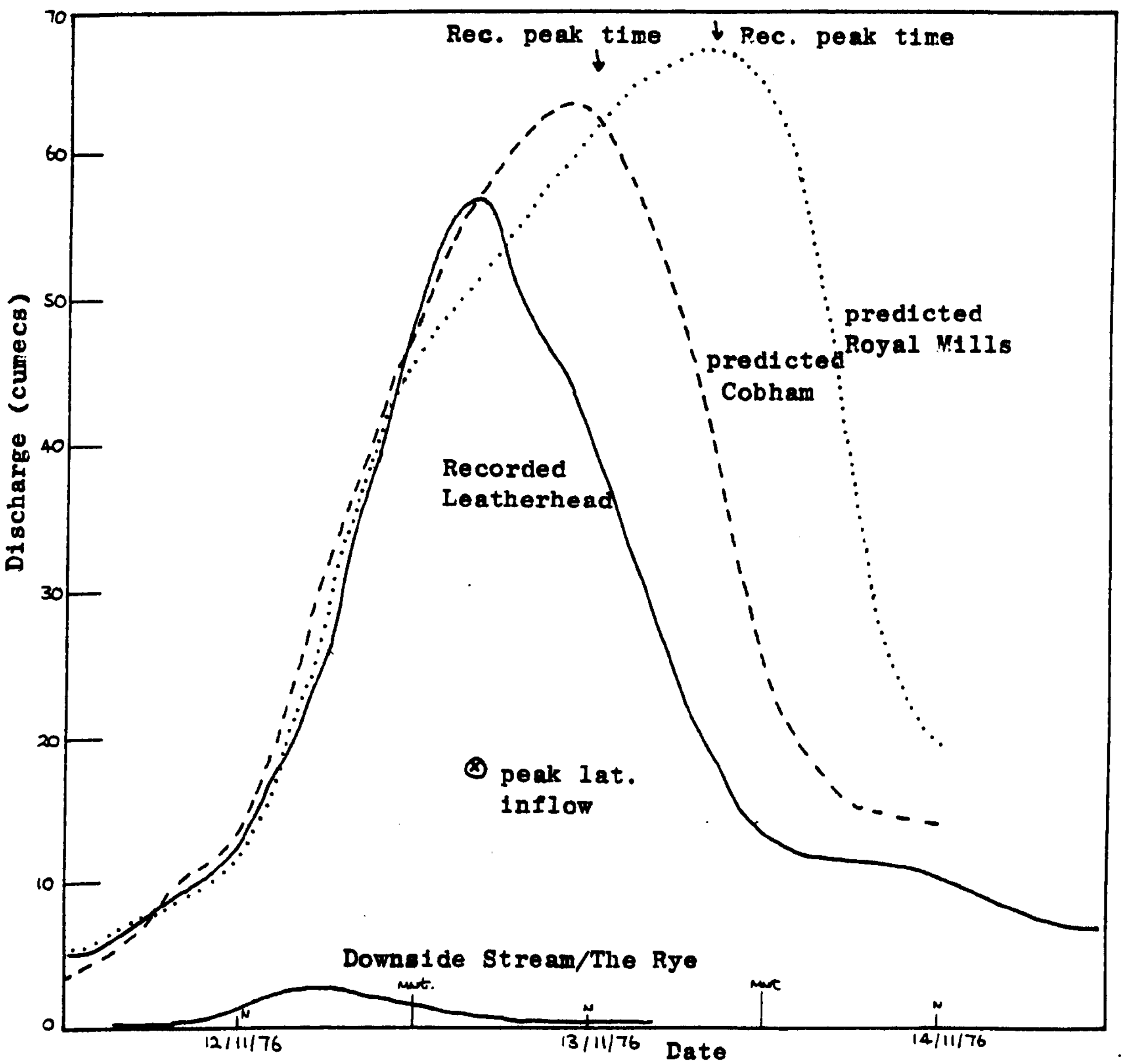


Fig. 6.38 Leatherhead to Royal Mills - Event (22) simulation.

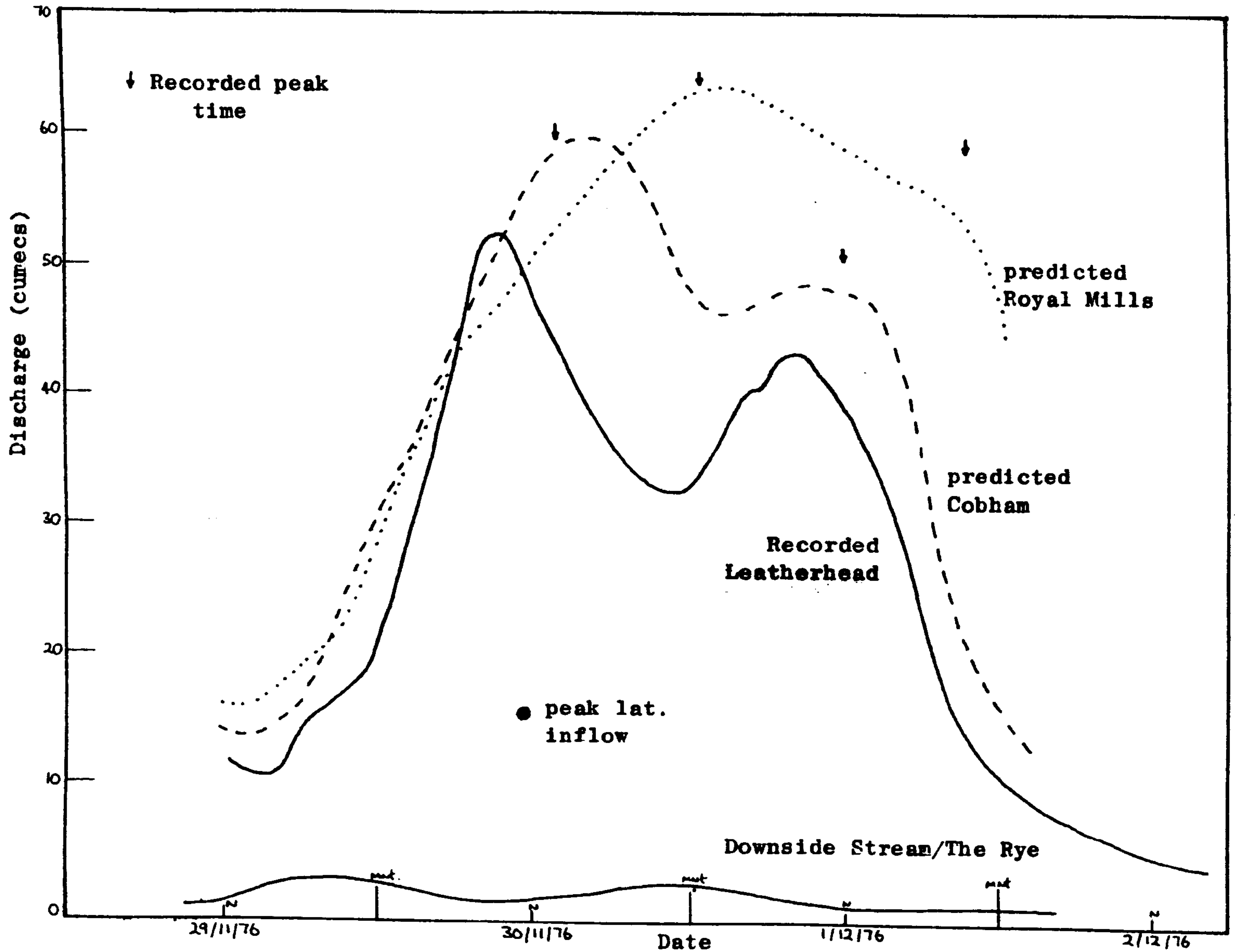


Fig. 6.39 Leatherhead to Royal Mills - Event (23) simulation.

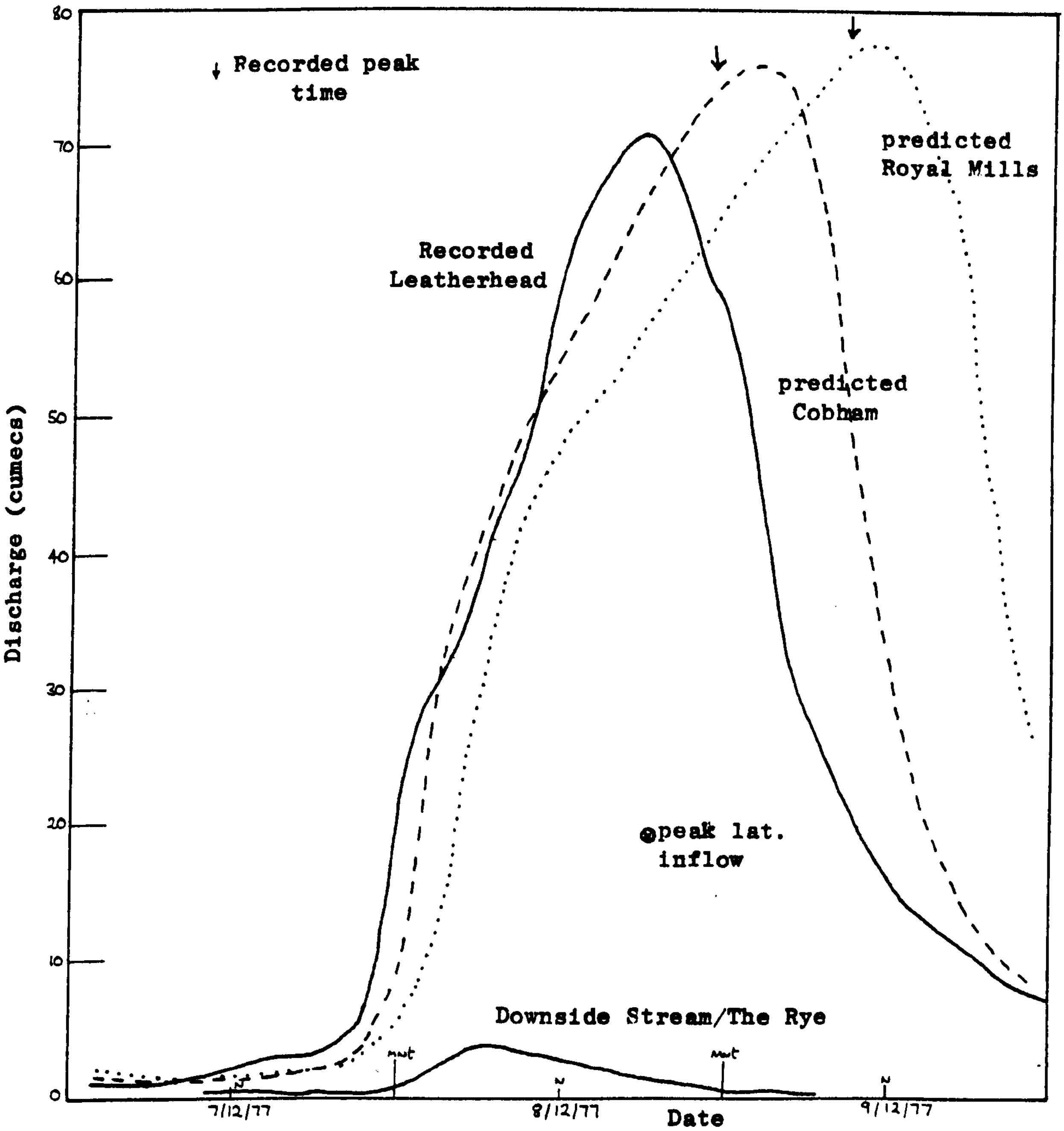


Fig. 6.40 Leatherhead to Royal Mills - Event (30) simulation

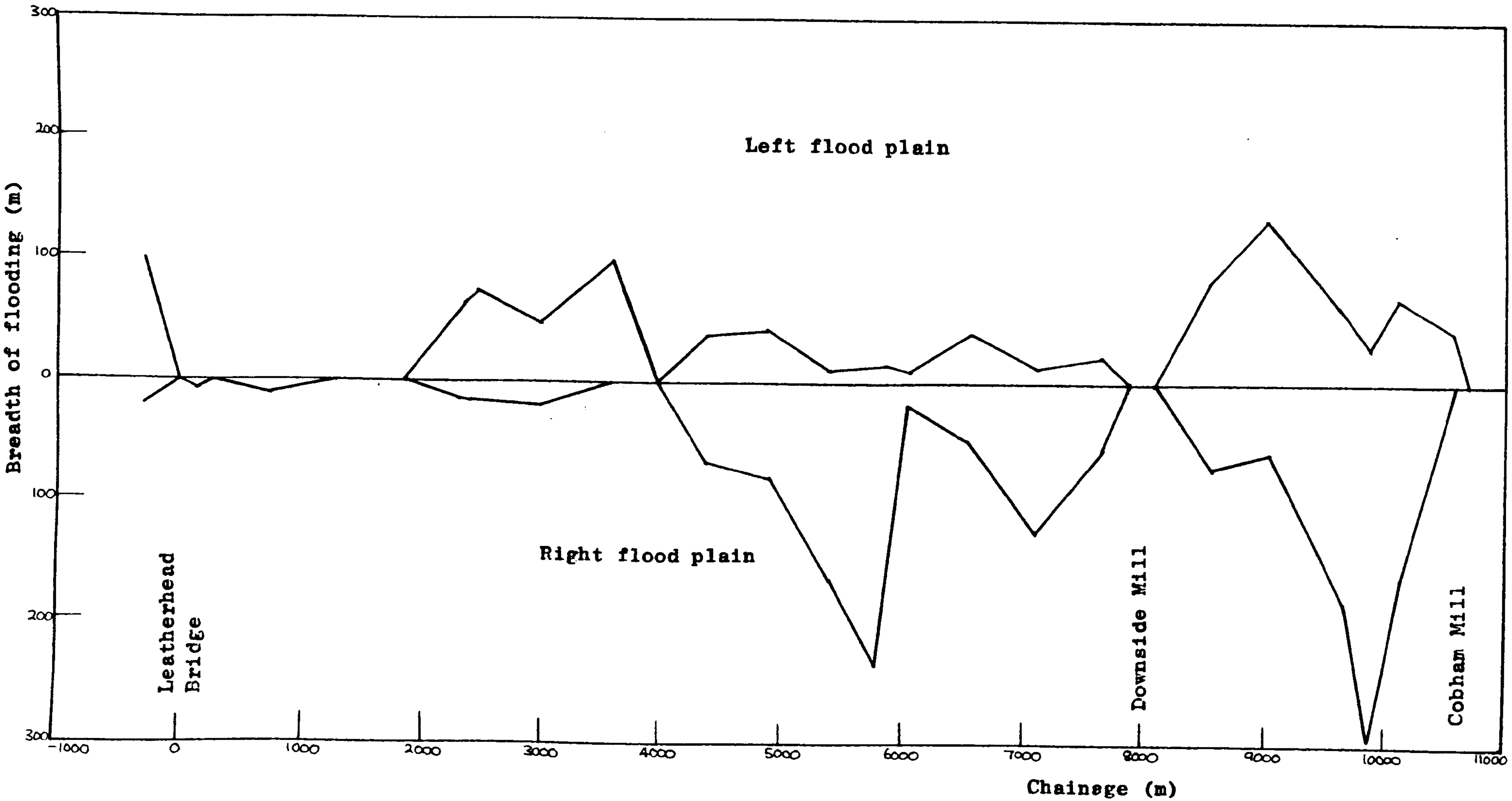


Fig. 6.41 Leatherhead to Cobham Mill - Event (22) simulated flood plain inundation.

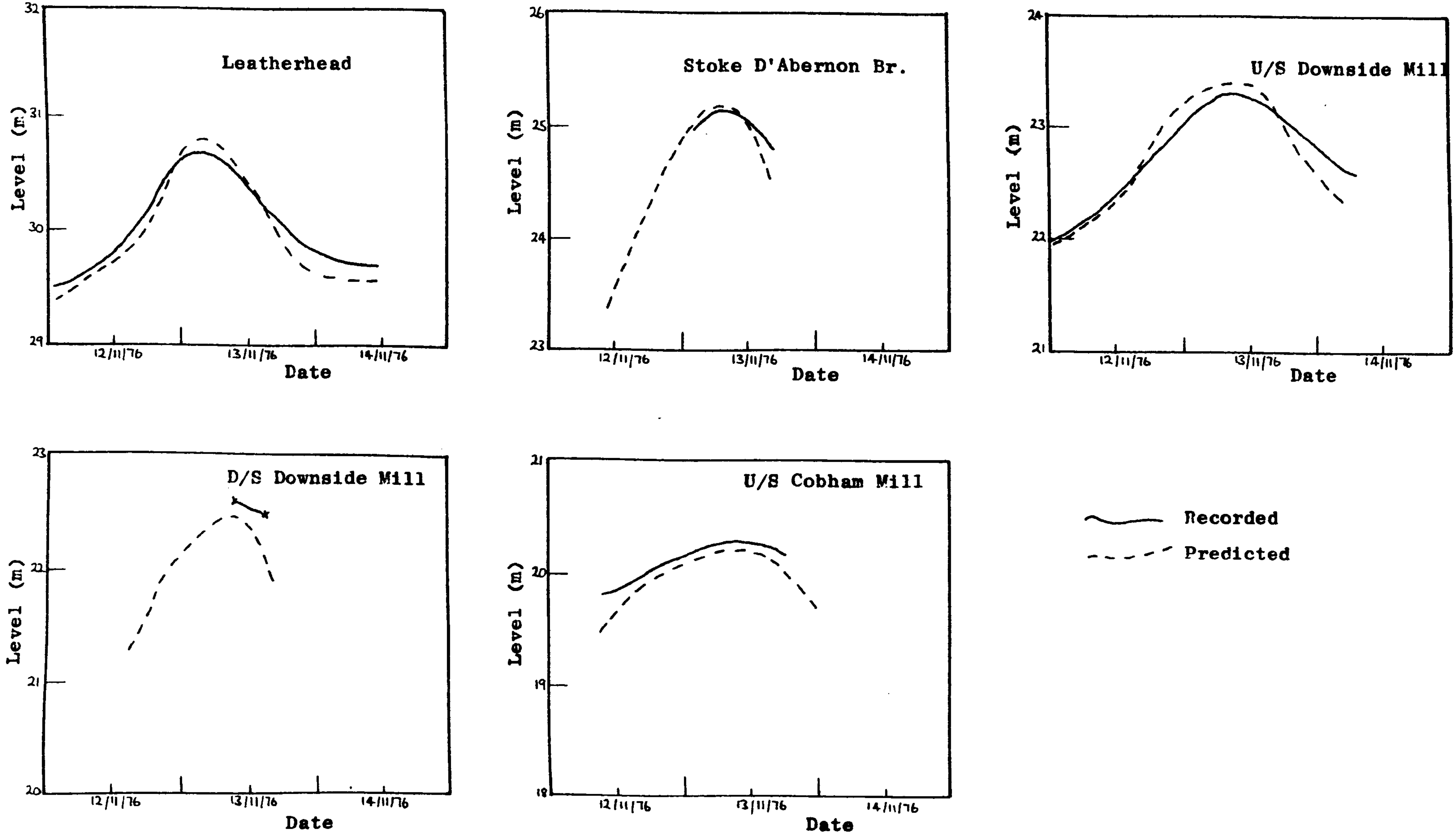


Fig. 6.42 Leatherhead to Cobham Mill - Event (22) level hydrographs

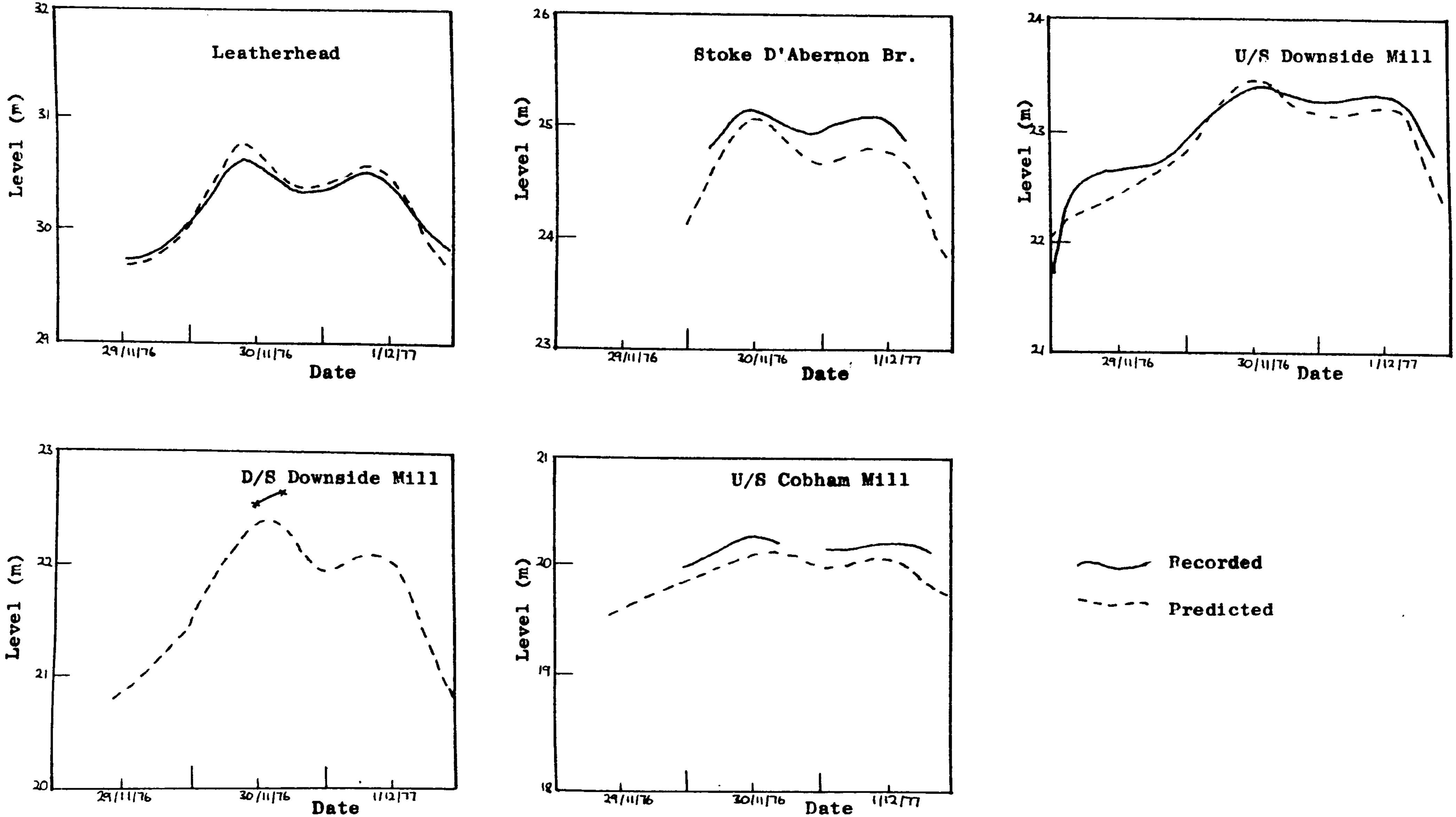


Fig. 6.43 Leatherhead to Cobham Mill - Event (23) level hydrographs.

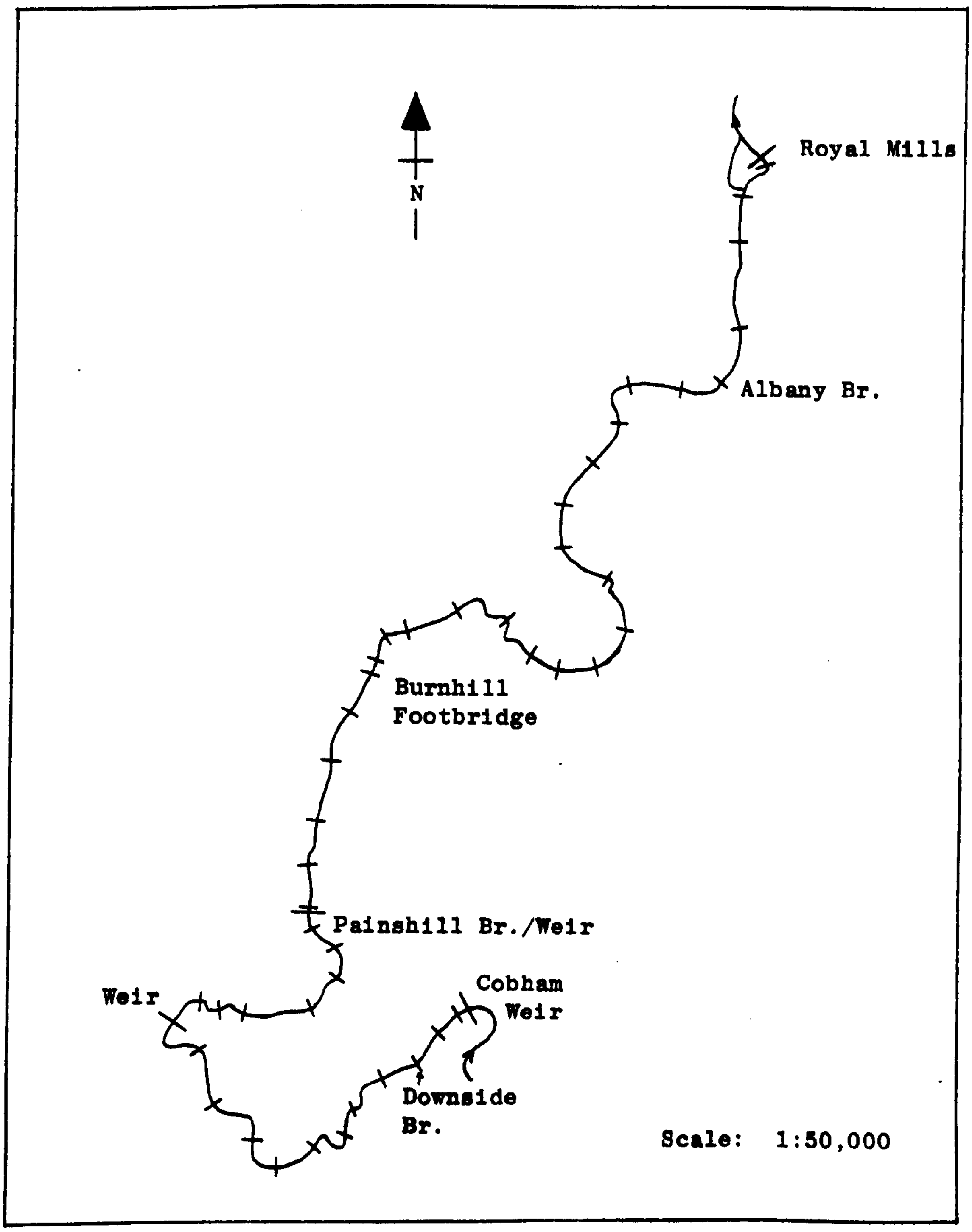
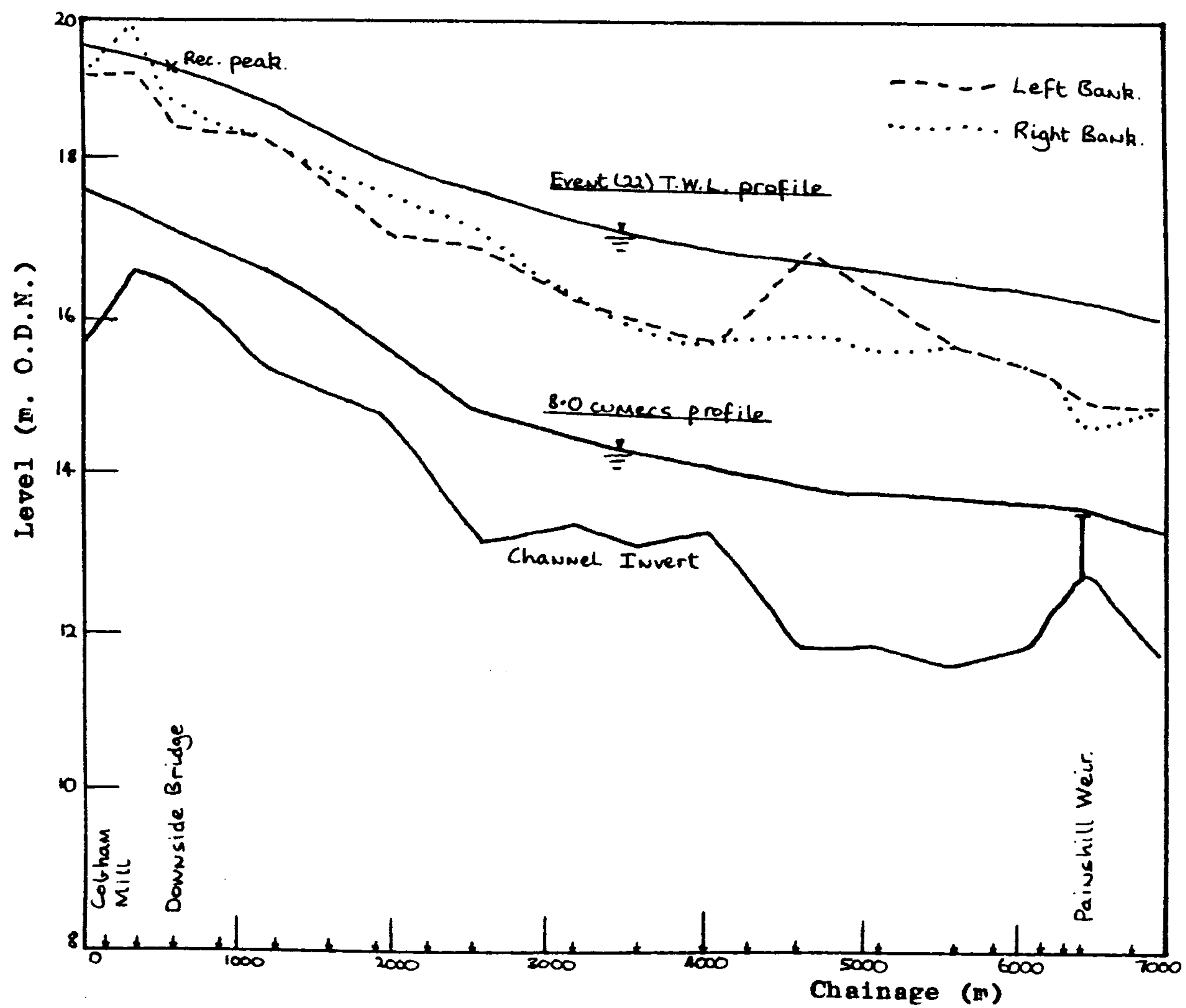


Fig. 6.44 Cobham Mill to Royal Mills - Model Scheme



continued ....

Fig. 6.45 Cobham Mill to Royal Mills - 8.0 cumecs and Event (22) longitudinal profiles.

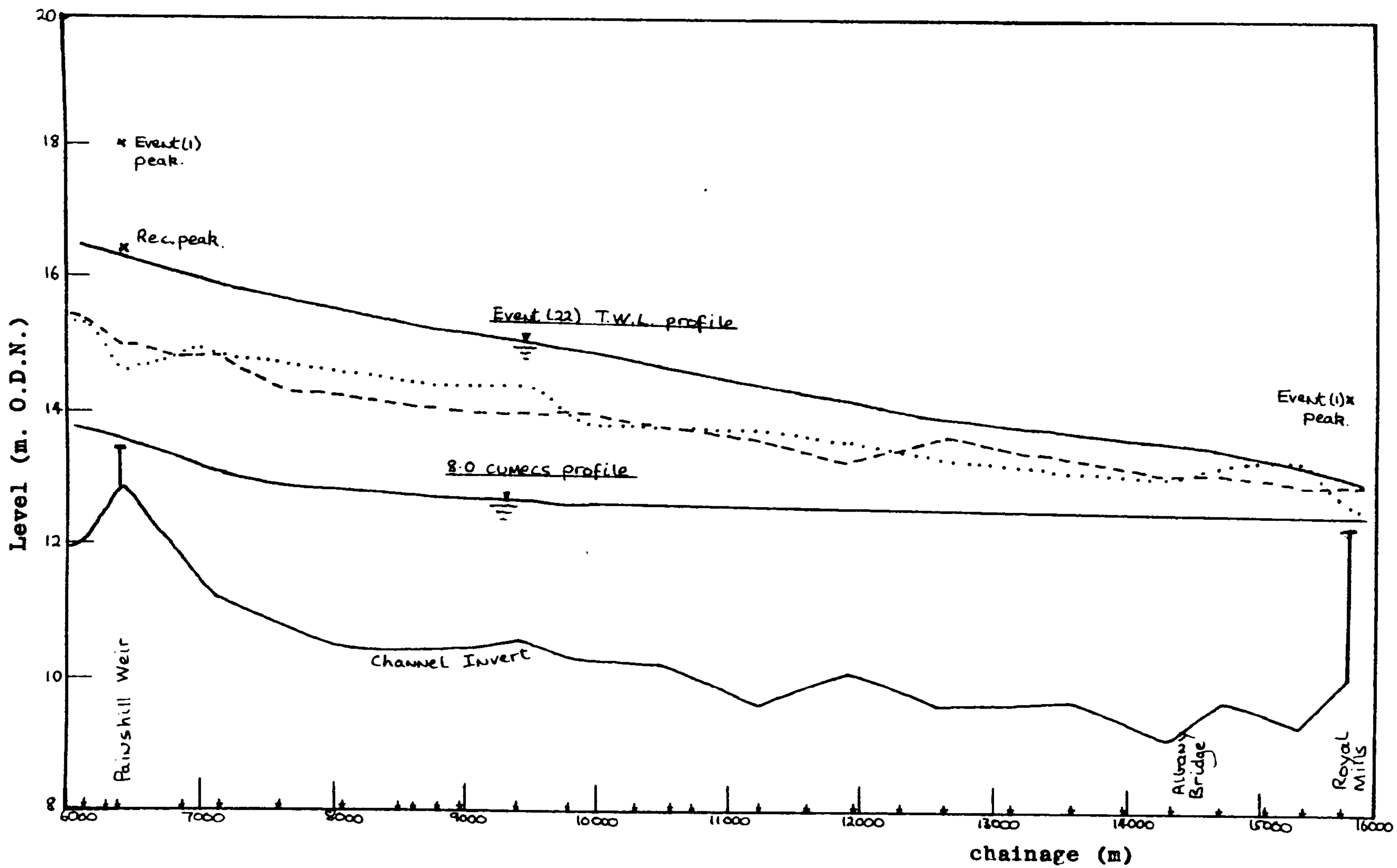


Fig. 6.45 continued. Cobham Mill to Royal Mills - 8.0 cumecs and Event (22) longitudinal profiles.

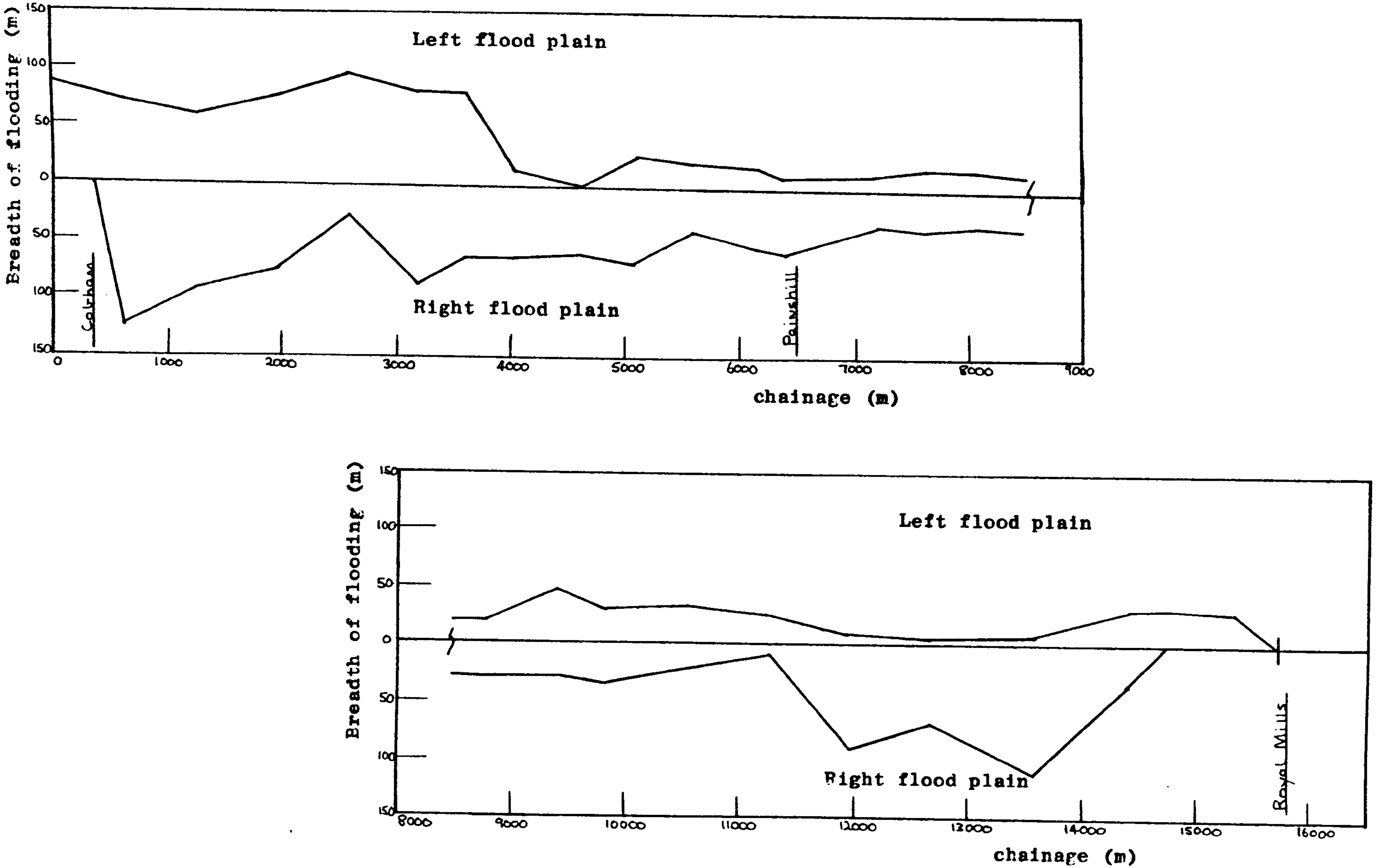


Fig. 6.46 Cobham Mill to Royal Mills - Event (22) simulated flood plain inundation.

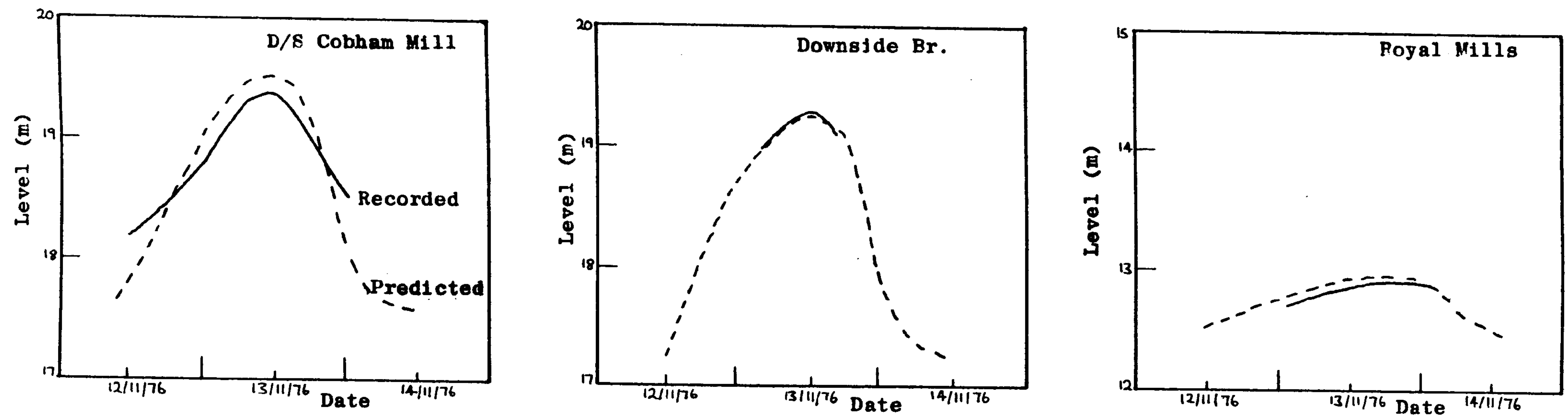


Fig. 6.47 Cobham Mill to Royal Mills - Event (22) level hydrographs.

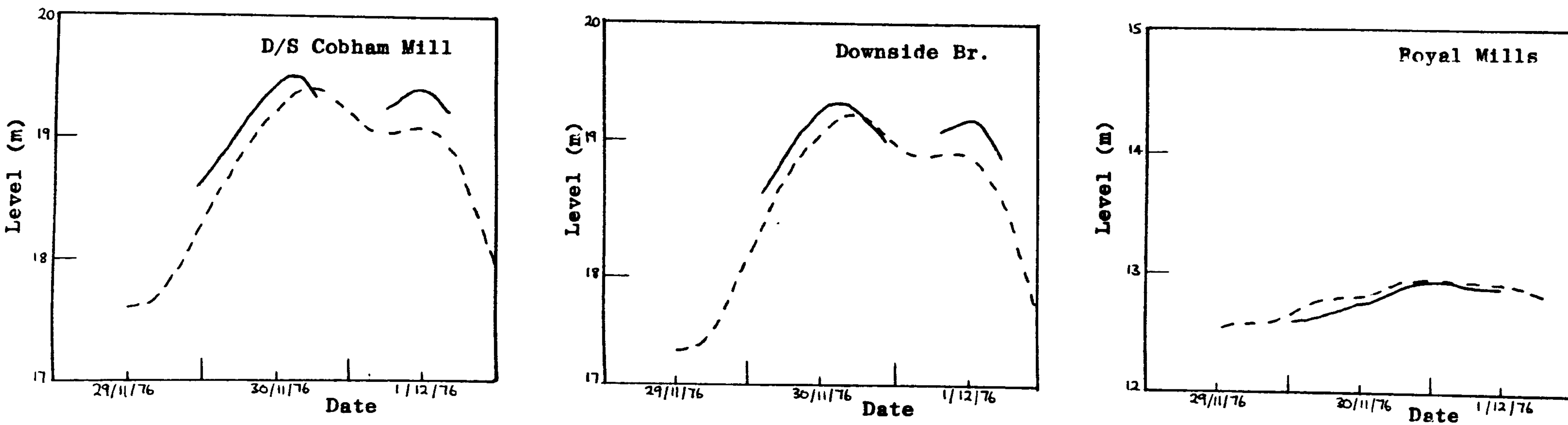


Fig. 6.48 Cobham Mill to Royal Mills - Event (23) level hydrographs.

APPENDIX V   PLATES

Plate 1. Horley Gauge Weir and Head Water Level Recorder.

Plate 2. Horley Gauge Weir and Tail Water Level Recorder.

Plate 3. Kinnersley Manor Weir and Head Water Level Recorder.

Plate 4. Kinnersley Manor Weir.

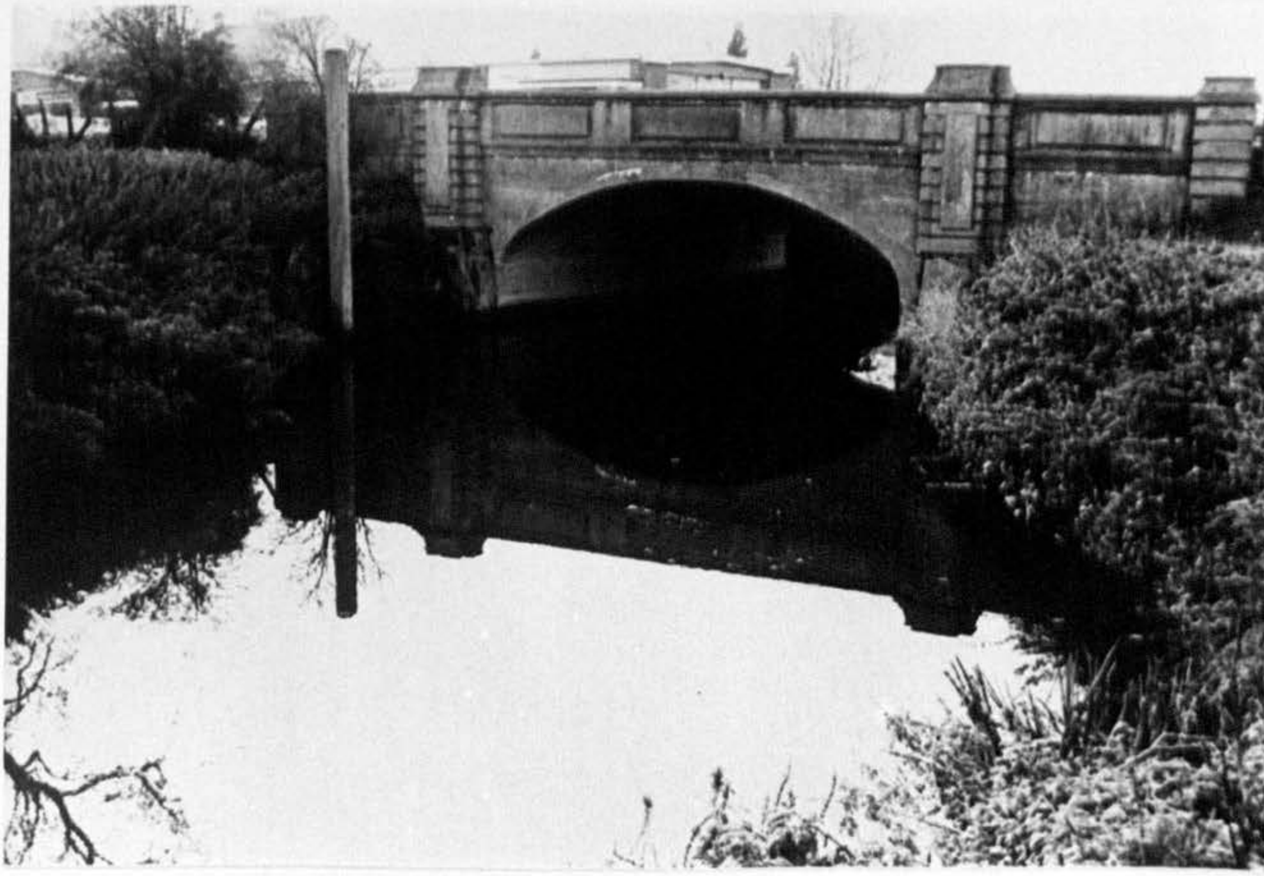


Plate 5. Sidlow Bridge and Gauge Board.

Plate 6. Channel Downstream of Sidlow Bridge.

Plate 7. Flanchford Bridge.

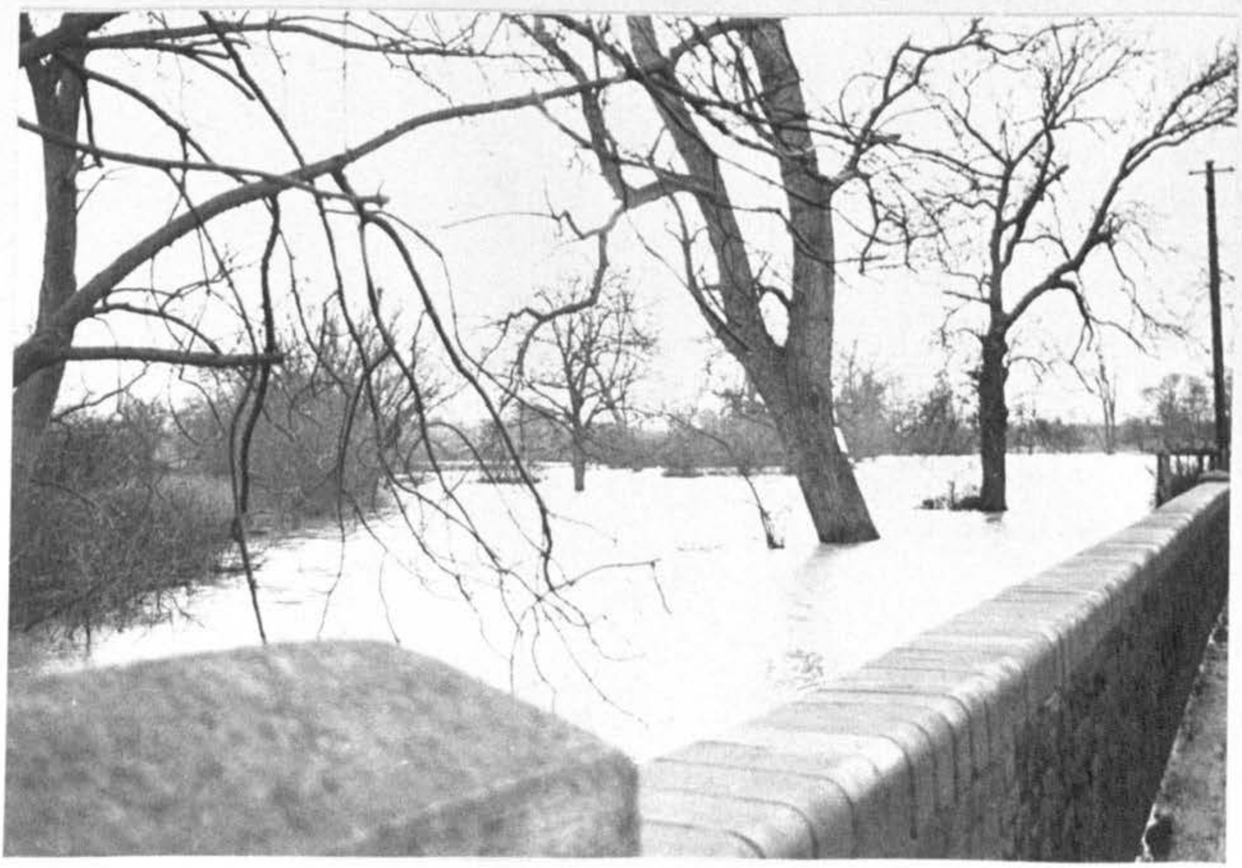


Plate 8. Flooding Upstream of Flanchford Bridge - Event 32.

Plate 9. Flooding Downstream of Flanchford Bridge - Event 32.

Plate 10. Flow through Betchworth Bridge - Event 30.

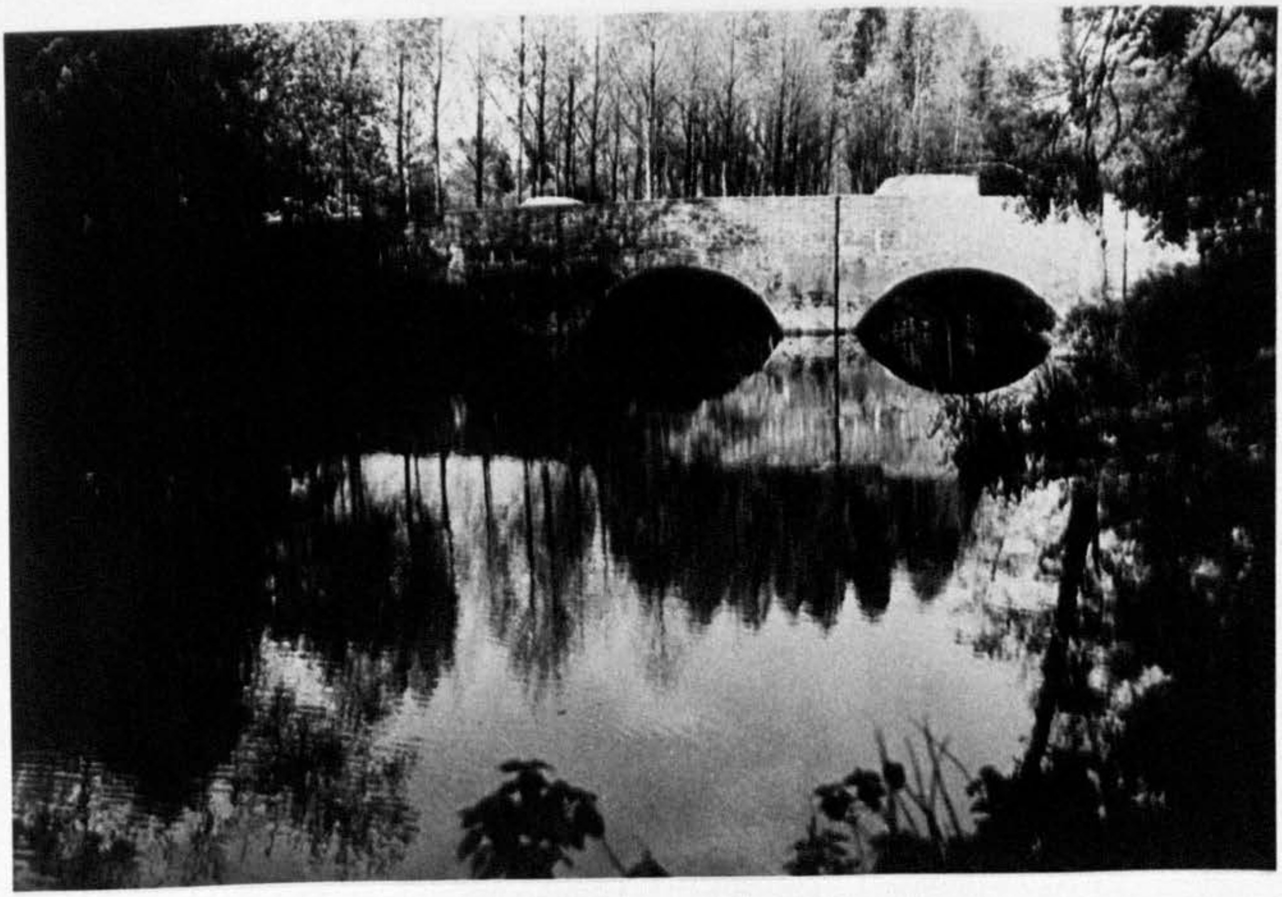


Plate 11. Downstream Face of Betchworth Bridge - Low Flow.

Plate 12. Flooding Downstream of Betchworth Bridge - Event 30.

Plate 13. Betchworth Weir - Low Flow.

Plate 14. Betchworth Weir Drowned Out - Event 30.

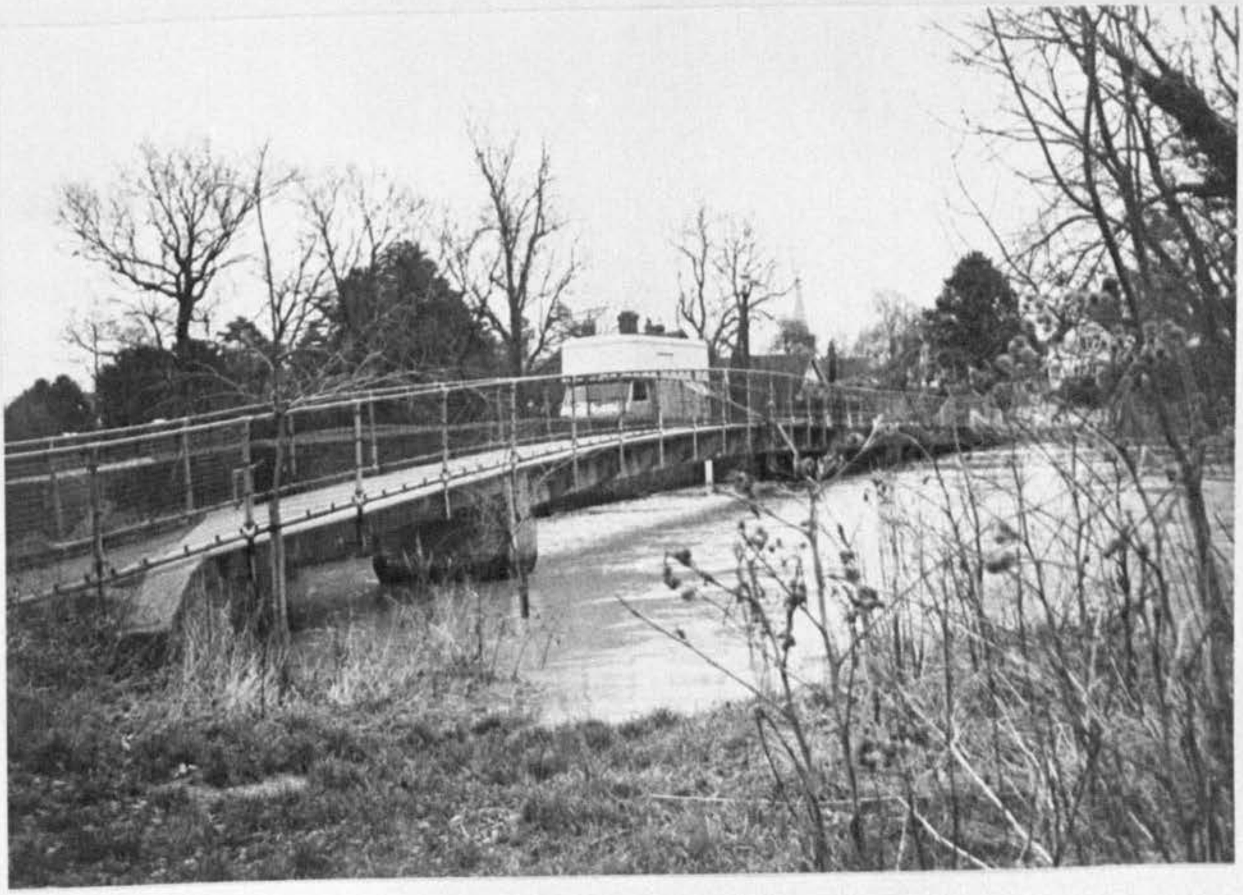


Plate 15. High Flow through Brockham (Borough) Bridge - Event 32.

Plate 16. Flooding Downstream of Brockham Bridge - Event 32.

Plate 17. Channel Upstream of Deepdene Bridge.

Plate 18. Flooding Upstream of Deepdene Bridge - Event 32.

Plate 19. New Crump Weir at Castle Mill - Event 32.

Plate 20. Burford Bridge.

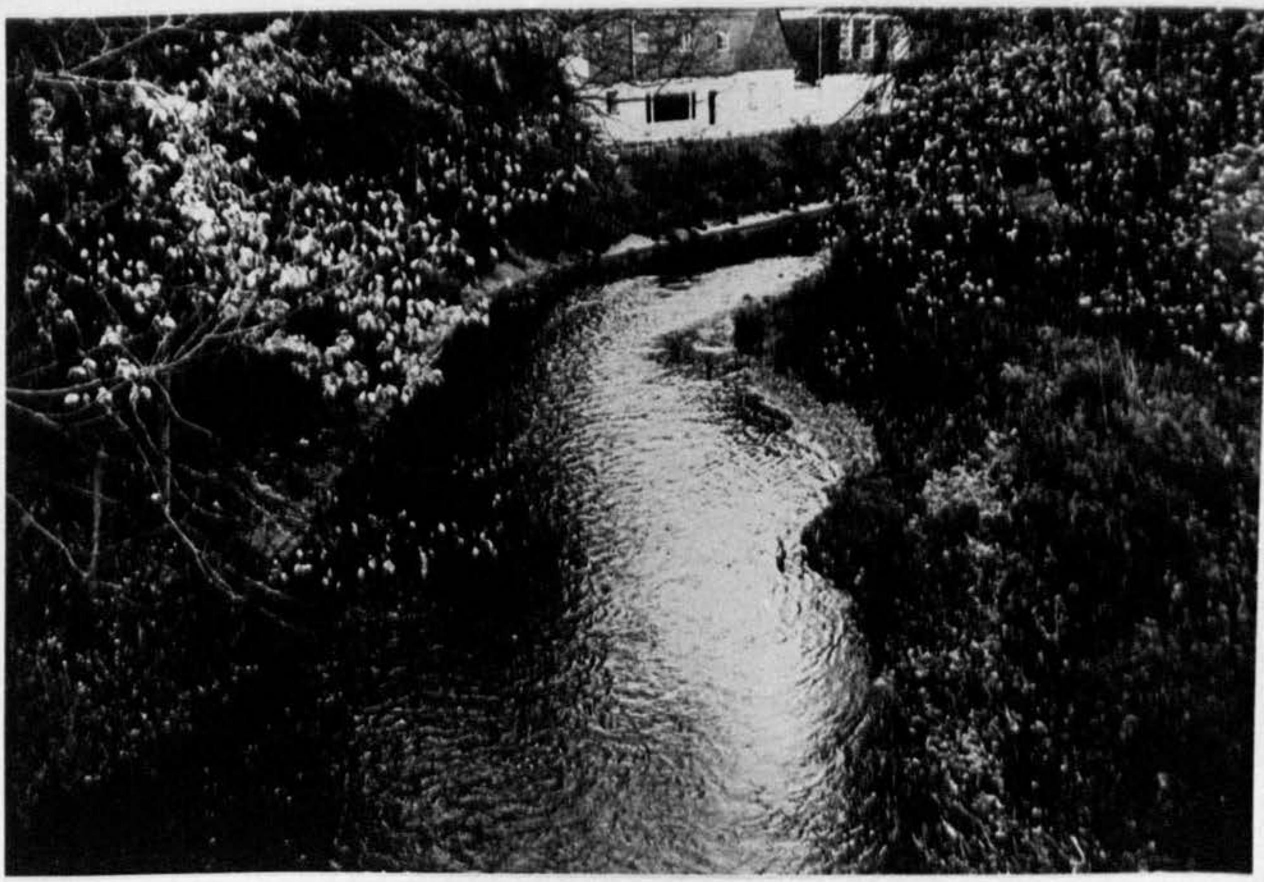


Plate 21. Channel Upstream of Burford Bridge.

Plate 22. Flooding Upstream of Burford Bridge - Event 32.

Plate 23. Flooding Upstream of Priory Bridge - Event 32.

Plate 24. Flooding Upstream of Leatherhead Bridge - Event 32.

Plate 25. High Flow through Leatherhead Bridge - Event 32.

Plate 26. Flooding Upstream of Stoke D'Abernon (Slyfield) Bridge - Event 30.

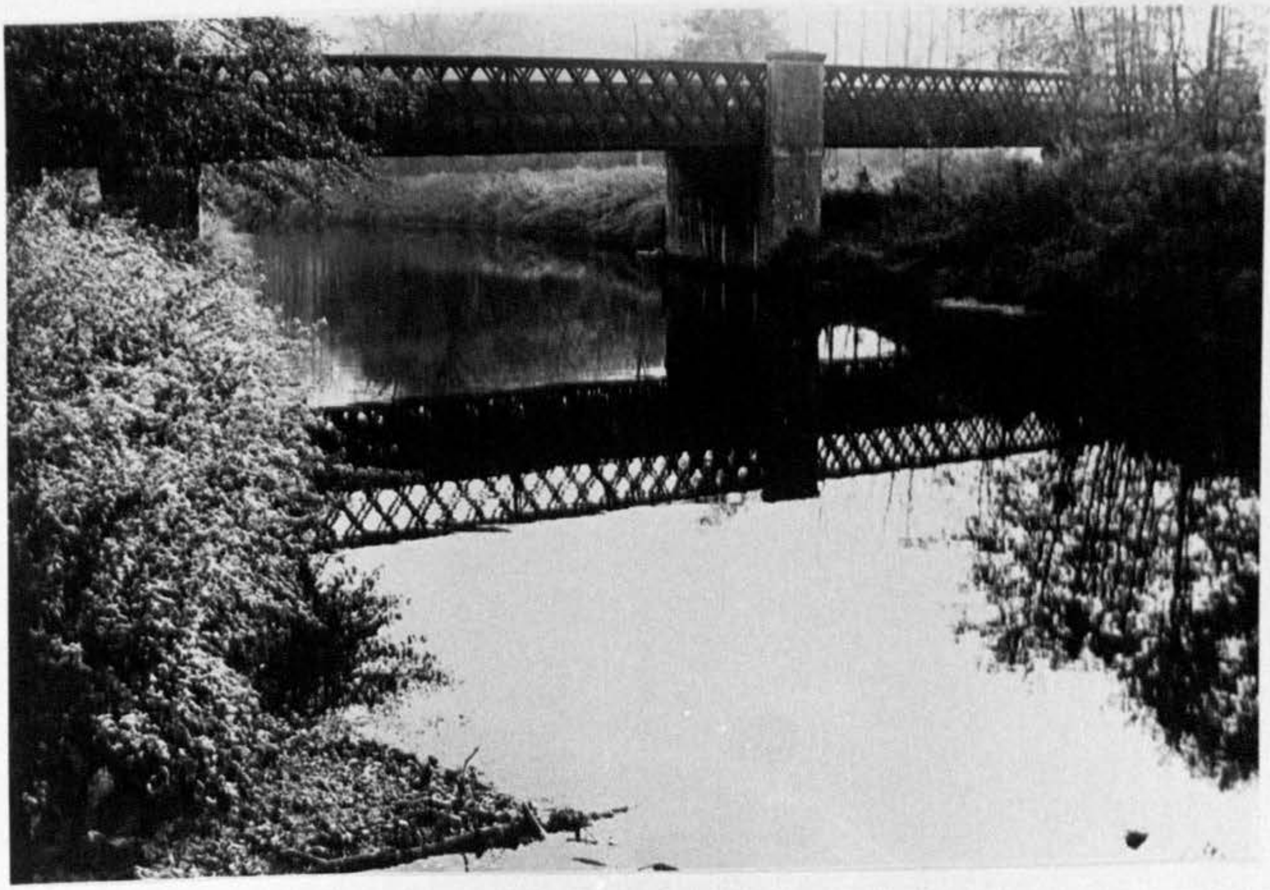


Plate 27. Site of Level Recorder at Downside Mill and Downside Rail Bridge.

Plate 28. Downside Mill Weir.

Plate 29. Cobham Mill Sluices.

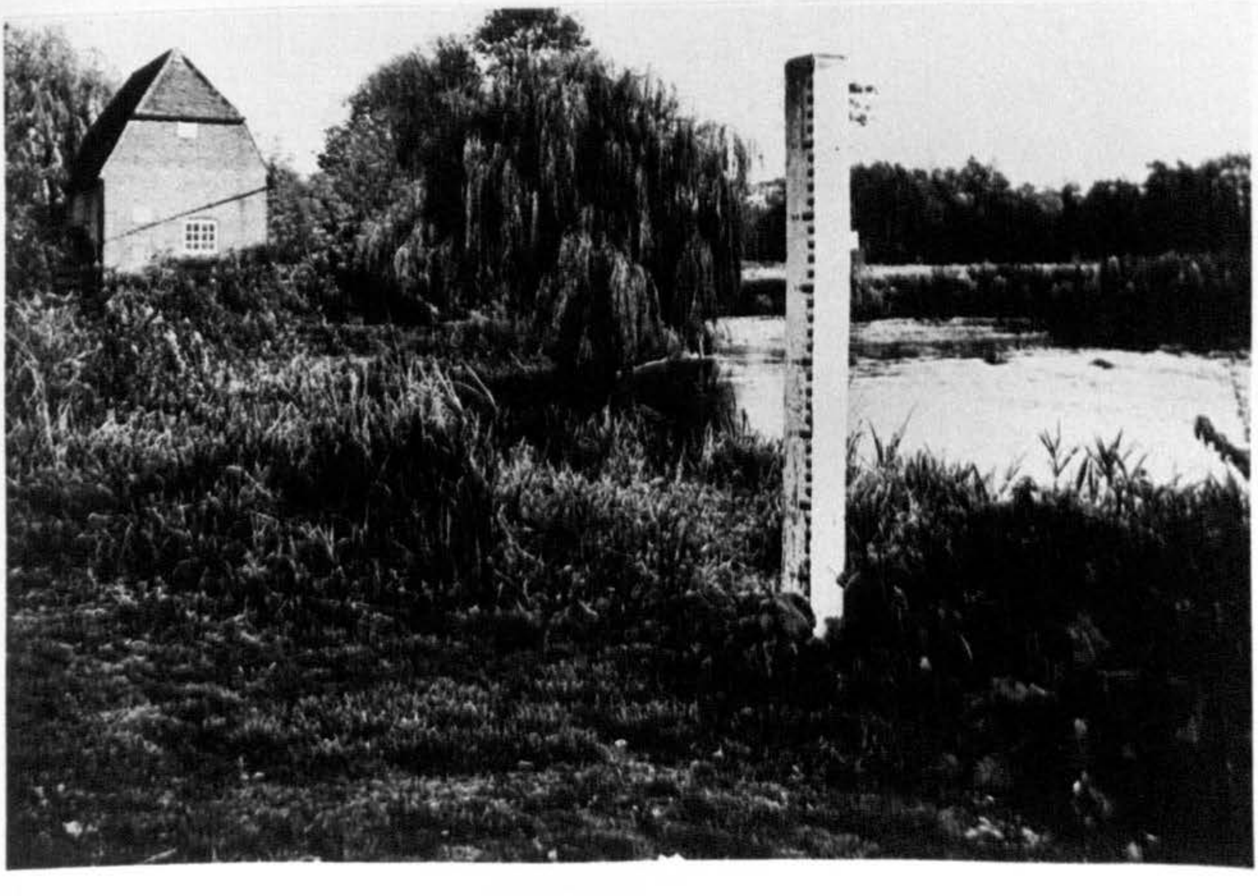


Plate 30. Channel Downstream of Cobham Mill.

Plate 31. Channel Upstream of Cobham Mill.

Plate 32. Flooded Road Upstream of Cobham Mill - Event 32.

Plate 33. New Downside Bridge and Gauge Board - Low Flow.

Plate 34. High Flow through Downside Bridge - Event 32.

Plate 35. Flooding Upstream of Downside Bridge - Event 32.

Plate 36. Flooding Downstream of Downside Bridge - Event 32.

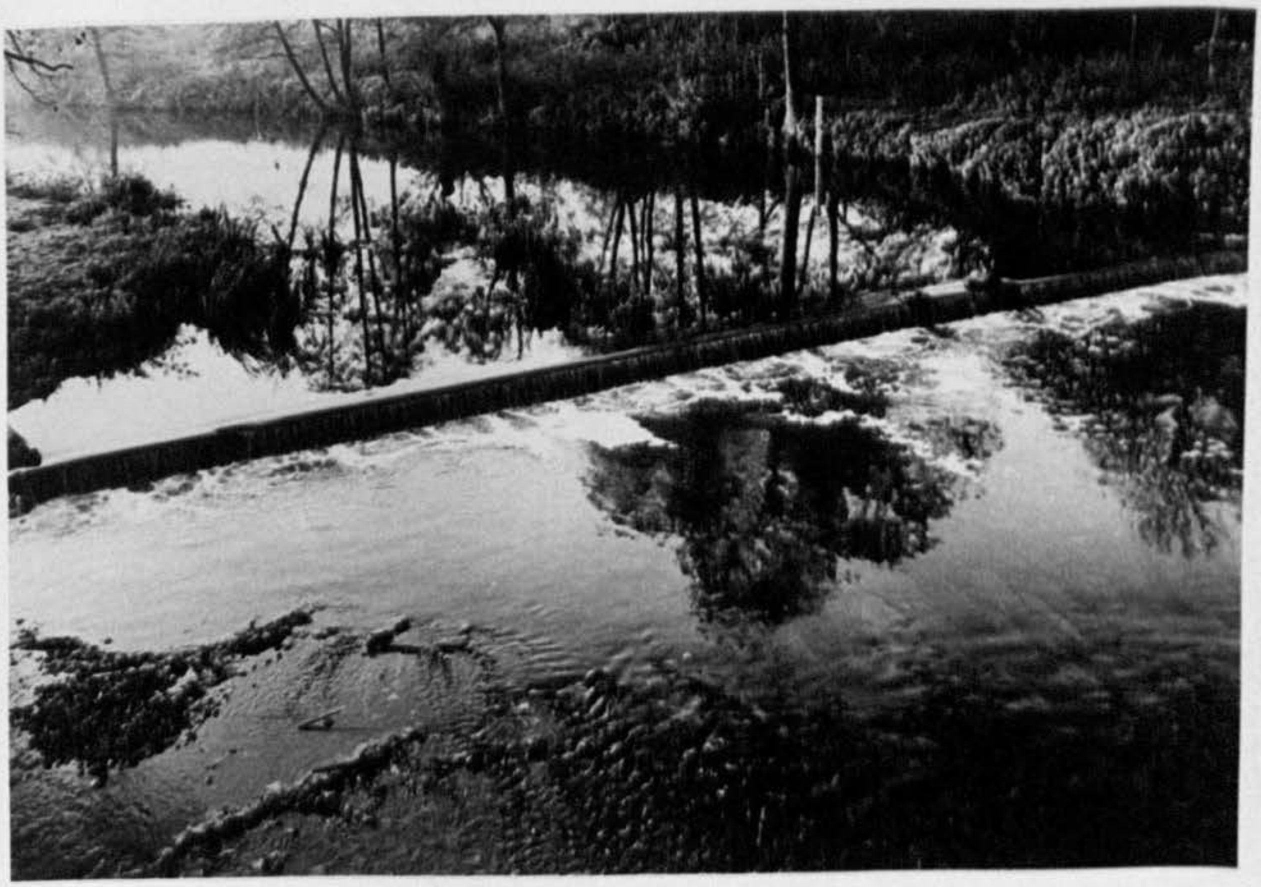


Plate 37. Painshill Weir and Gauge Board from Cobham Bridge.

Plate 38. Painshill Weir Drowned Out and Flooding Upstream of Cobham Bridge - Event 32.

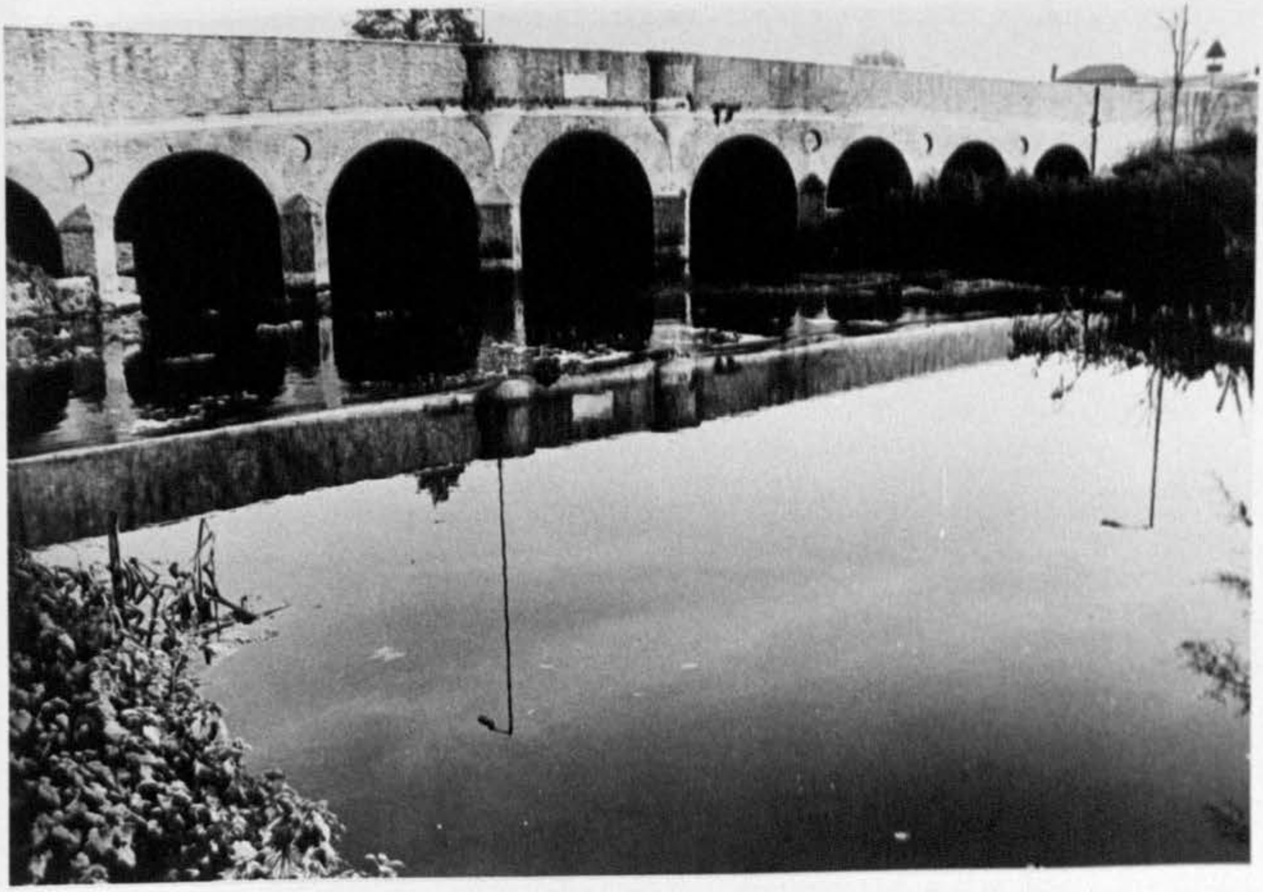


Plate 39. Cobham Bridge and Painshill Weir - Low Flow.

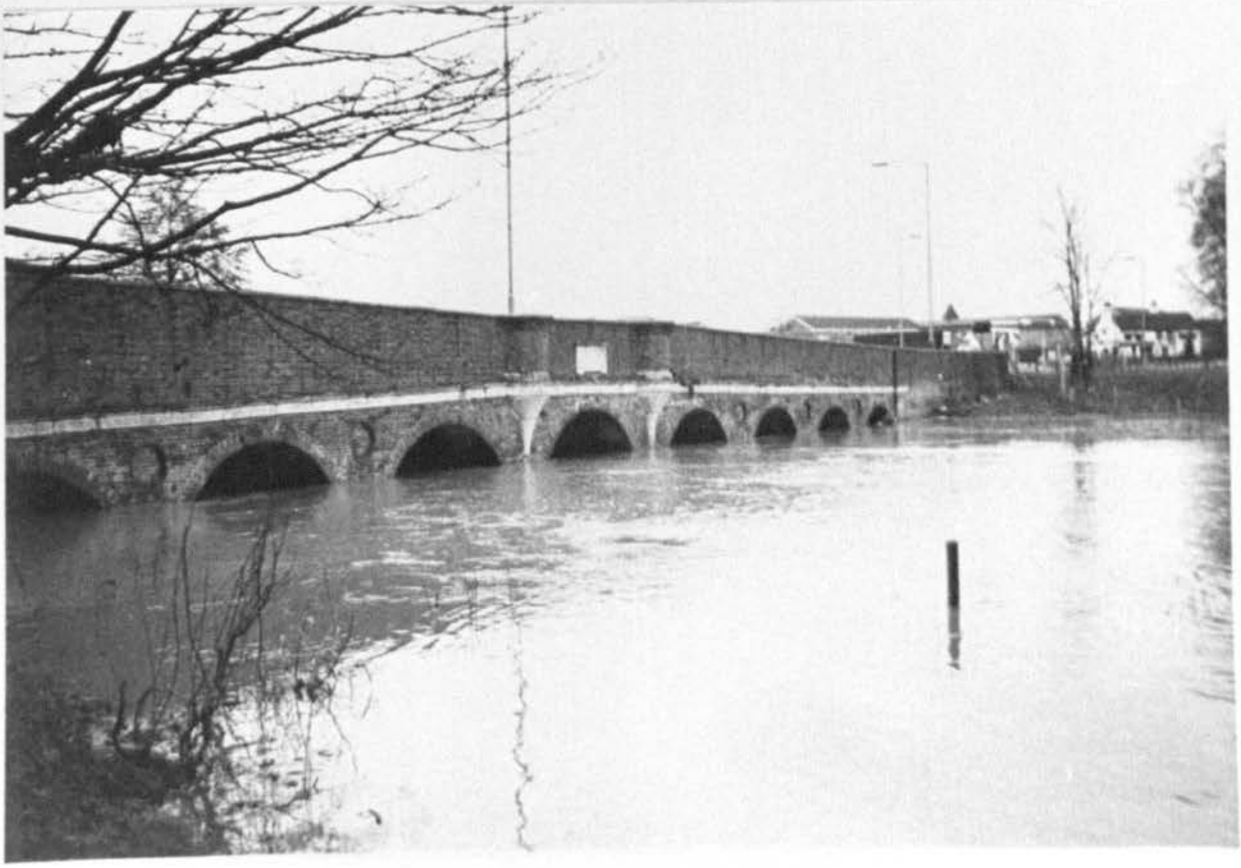


Plate 40. Cobham Bridge and Painshill Weir - Event 32.

Plate 41. Channel Downstream of Cobham Bridge.

Plate 42. Flooding Downstream of Cobham Bridge and New A3 Bridge - Event 32.

Plate 43. Albany Bridge.

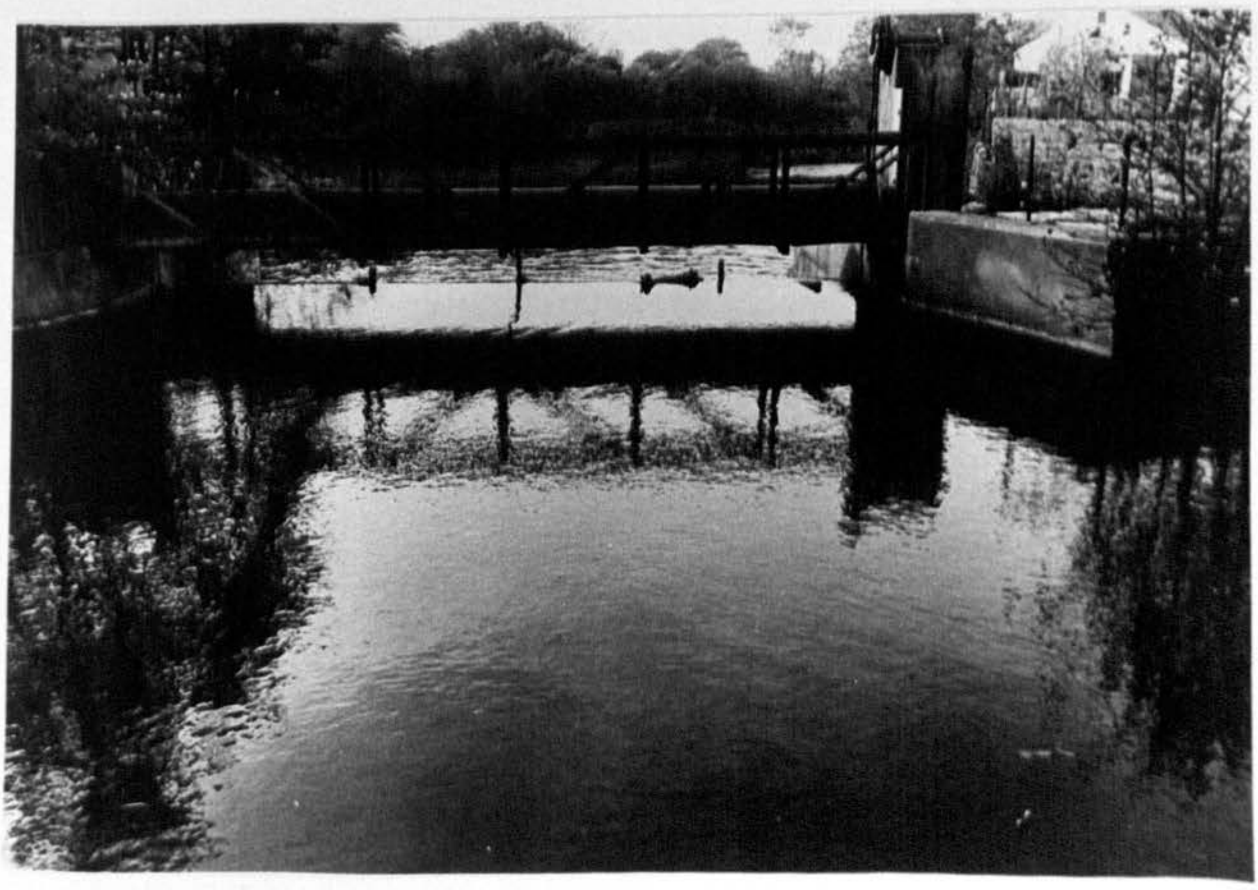


Plate 44. Automatic Tilting Gate at Royal Mills.

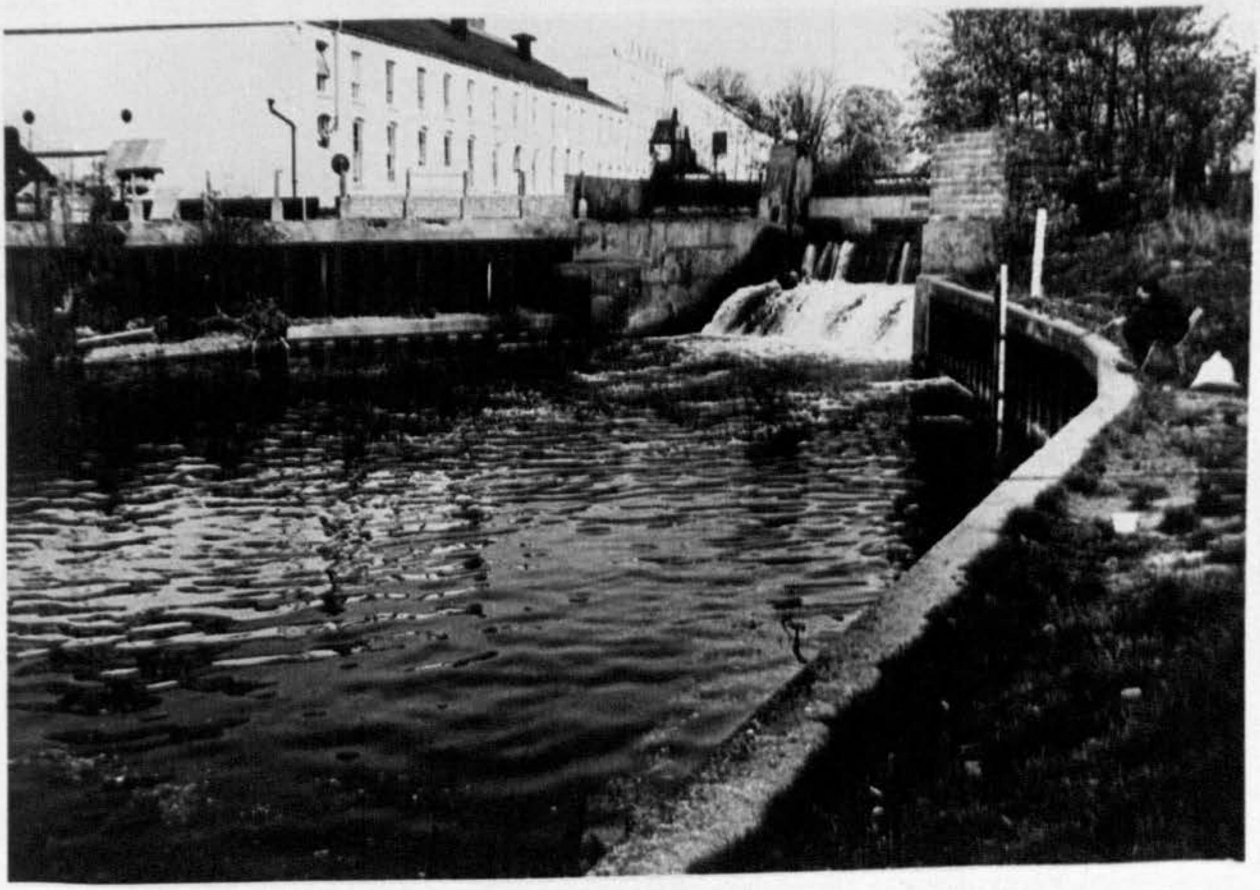


Plate 45. Site of Automatic Level Recorder at Royal Mills.

Plate 46. Wilderness Sluice Gates.

Plate 47. Zenith Weir at the Confluence of the River Mole and River Ember.

Plate 48. Confluence of the River Mole and River Thames opposite Hampton Court.