Working Paper 306

The generation of faecal and total coliform surges by streamflow manipulation in the absence of normal hydrometeorological stimuli.

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ABSTRACT

The response of *Escherichia coli* and total coliform concentration to increases in river discharge is investigated. Artificial hydrographs were generated on eight occasions between 21st October, 1979 and 3rd March, 1981 by releasing water from Thruscross Reservoir in North Yorkshire to be restored in Fewston Reservoir. The majority of the releases were made following rainless periods in order to isolate bacterial responses to change in river regime from those induced by rainfall on the land surface. In the absence of rainfall bacterial concentrations are shown to increase by over ten fold in response to stage increases. It is suggested that two stores of bacteria must exist on the catchment. The first a land store and the second a channel or near channel store. Modelling the movement from the land to the channel store must relate to hydrological processes whilst movement between stores in the channel, i.e. in the water, may be closely allied to sedimentary processes. Some consideration is given to bacterial levels in relation to EEC guidelines for contact recreation.

Introduction

In earlier papers (Kay and McDonald, 1978; Kay and McDonald, 1980a), the authors suggested that the time-dependent bacterial decay relations advocated by Gravel *et al.* (1969) and Zanoni (*et al.* (1978) were not readily applicable to field situations. A distance dependent decay relationship of the form

$$C_d = \alpha.10^{\lambda d} \qquad (1)$$

α = a constant

d = distance from mainstream input

λ = a distance dependent decay coefficient

provided a more accurate prediction of coliform concentration. However, such a single variable analysis produced significant relationships in only 59% of the cases studied. In an attempt to explain the residual variance, the authors examined the influence of a further twenty variables. The results were reported in McDonald and Kay (1981a) and indicated that short-term hydro-meteorological input was the major influence on bacterial concentration in the two reservoirs studied. Variations in bacterial concentration during the passage of eleven natural hydrographs on two streams was reported in Kay and McDonald (1980b) and McDonald and Kay (1981b). Increases in concentration in the order of 100 fold were frequently observed and in most cases such observations could be statistically supported. Such findings are in broad agreement with the findings of Davis *et al.* (1970), Thornton *et al.* (1980) and Kunkle (1970).

This paper reports on a series of experiments in which streamflow was manipulated, in the absence of normal hydrometeorological stimuli, by releasing water from a reservoir thus simulating a hydrograph event.

Study site

Figure 1 shows the study site. Artificial 'hydrographs' were generated by releasing water from Thruscross Reservoir into Fewston Reservoir via two manual 36" valves. Sampling sites are shown in Figure 2. Sampling site A lies 400 m down-stream of the dam face at Thruscross and has a catchment area of approximately 30 km^2. Sampling site B is 2500 m below the dam. Catchment area for sampling site B is approximately 35 km^2. Stream stage was recorded manually on each occasion at each site. Where necessary flow velocity was estimated with float and stopwatch.

The multiple tube Most Probable Number technique was utilised for total coliform (T.C.) and *E. coli* (E.C.) enumerations (H.M.S.O., 1969). Minerals Modified Glutamate Media was used for presumptive enumeration of total coliform. The presence of coliform was confirmed using lactose ricinoleate broth. The presence of *E. coli* was confirmed using lactose ricinoleate broth and peptone water. All incubation temperatures and times were exactly as instructed in H.M.S.O. (1969). Water samples for bacteriological analysis were collected in pre-sterilised 250 ml pyrex glass stoppered bottles. After aseptic collection samples were stored in an ice chest (with initial temperature 0^0C) and analysed in the laboratory within six hours of collection, as recommended in H.M.S.O. (1969). Hydrogen ion activity was measured in the laboratory immediately after the bacteriological analysis, using a PYE Unicam model 290 meter with automatic temperature compensation. The specific conductance of each sample was measured using L.T.H., PB/5 conductivity meter, with automatic temperature compensation to the reference temperature 25^0C (Edwards *et al.*, 1975). Turbidity was measured using a Hach model 2100A turbidimeter.

On all occasions sampling started before the start of the hydrograph. A minimum of three samples were taken during baseflow conditions. Sample frequency at this time being between 4 and 6 per hour. During the rising limb of the hydrograph sampling frequency increased to 1 sample per 2 to 3 minutes. Sample frequency was reduced on the falling limb and was continued until the river returned to its original baseflow levels *except* where this would have caused the recommended 6-hour maximum between sampling and analysis to be exceeded (H.M.S.O., 1969). The sampling format was chosen to yield maximum information in the light of the variations in the bacterial concentrations observed in McDonald and Kay (1981b).

Hypothesis, experiment and results

The initial hypothesis was that the increase in bacterial numbers during hydrographs (McDonald and Kay, 1981b) was caused by movement of bacteria from surface and near surface faecal sites by throughflow, pipeflow and overland flow during the rainstorm. Therefore, the generation of an artificial hydrograph during a dry period, using hypolimnetic water of low bacterial concentration (Kay and McDonald, 1980a), would result in no increase in bacterial numbers. Indeed, reduction in fluvial bacterial concentrations due to dilution effects might be expected. The hypothesised result is shown in Figure 3 below.

The first artificial release was made on 21st October, 1979 following several rainless days. The results in Figure 4 shows a marked response in bacterial concentration. Baseflow concentrations average 2 $\log_{10}$ T.C. per 100 ml while peak concentrations average 3 $\log_{10}$ T.C. per 100 ml. This result would suggest rejection of the initial hypothesis outlined in Figure 3. Figure 5 shows the results of a replicate artificial hydrograph generated on the 21st November, 1979. In this case, a double peaked hydrograph was generated on the assumption that any bacteria in unconnected channel edge pools would be unavailable for incorporation in the second pulse. Again, in the absence of normal hydrometeorological stimulae the background concentration of 2 $\log_{10}$ total coliform bacteria per 100 ml rises by a factor of 10 during the first flood wave to a value of almost 3 $\log_{10}$ TC per 100 ml and increases in the second pulse to 3.2 $\log_{10}$ TC per 100 ml. No marked decline in bacterial concentration was observed between the pulses. A third replicate (Figure 6) for 2nd July 1980 shows the same bacterial response to increased flow. Figures 7 and 8 are derived from a release on 9th July 1980 measured at sites A and B respectively on Figure 1. The stage hydrograph shows the attenuation of the peak during the travel down the catchment but despite the lowered peak, site B has a more marked response to increased flow, peaking at 3.5 $\log_{10}$ T.C. + E.C. per 100 ml as opposed to 2.85 $\log_{10}$ T.C. + E.C. per 100 ml at site A. both sites had baseflow concentrations of approximately the same value. Since concentration increased downstream, the peaks are not being accidentally created from a reservoir bacterial store. This is strongly supported by the Thruscross reservoir outflow concentrations reported in Kay and McDonald (1980a).

The results have been statistically analysed by the use of a non-parametric analysis of variance test, the Kruskall Wallis test. The results of the three simple releases 21st October, 1979, 2nd July, 1980 and 9th July, 1980 have been utilised to test the null hypothesis that there is no significant difference in bacterial concentration during baseflow and during the hydrograph. Calculated H from the formula:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \left(\frac{R_i^2}{n_i} \right) - 3(N-1) \qquad (2)$$

was 3.8404 which is significant at the 95% level. It should be noted that that the break point between base and generated flow was hydrologically defined thus given the evident delay in bacterial response some 'baseflow' bacterial values are included in the hydrograph. Using logarithmic

transformation of bacterial concentrations to provide a normally distributed sample (Velz, 1951) and testing the results using students t gives a value of 7.87 indicating hypothesis rejection at the 99.9% probability level.

In catchment management artificial releases are sometimes generated to provide water for recreation. Figure 9 shows the 'hydrograph' created for a day's slalom canoeing on 5th September, 1980. The bacterial response is once again clear with a peak of 10 to 30 times the baseflow concentration occurring during the rising limb of the hydrograph. The subsequent decline in bacterial concentration despite the maintenance of high flow regime has significant management and scientific implications. From a management viewpoint, the stimulation of high bacterial concentration which exceed he EEC (1976) guidelines for contact sports is a serious limitation on recreational water management. However, since continued high flow appears to flush out the available bacterial store, the simple management option is to allow a release to start prior to the utilisation of the water for contact sport so that at time of contact bacterial levels have subsided.

In terms of modelling fluvial bacterial dynamics, Figure 9 would suggest that the bacterial store in the river is finite for any specific flow level and can be depleted. A depletion process is supported by the results given in Figures 10 and 11. Here, an artificial pulse was generated (3rd March, 1981) immediately after a major natural hydrograph which could be expected to have flushed the available channel store of bacteria. The hydrograph record is given in Figure 12. In both cases bacterial concentration does not respond to the artificial pulse, indeed a limited dilution process is observed.

In this last case little relationship is found between bacterial concentration and turbidity (Figure 13). Indeed, peak turbidity values are less than half of those observed when the bacterial fluvial store has not been depleted. Figure 14 shows the relationship between Turbidity (NTU) and bacterial concentrations for an undepleted store pulse on 21st October, 1979.

Discussion

The results presented here suggest that at least two stores exist within the system whereby faecal indicator bacteria appear in catchment stream waters. The first store is on or near the surface of the land and will be influenced by slurry spreading, stocking density and other management considerations and by decay controlled largely by the micro habitat at the site. Bacteria from this store are transferred to a second store associated with the river channel. The processes which are involved in the transportation of bacteria between the two stores are unknown but it would seem likely to be associated with water transport, and so with the hillslope hydrological processes of overland flow, throughflow and groundwater flow which may also be affected by catchment management practices. The channel store could be sedimentary but high bacterial numbers associated with algae or with largely unconnected channel edge pools cannot be discounted.

A bacterial response similar to or associated with sediment might go some way to explain the results given in Figure 5. In that case the bacteria in suspension appeared to remain in suspension and to be increased on the following pulse. Hjulstrom's diagram in Figure 15 would indicate that bacteria could be entrained by the pulse and remain in suspension until much lower velocities were encountered; the second pulse would add further to the bacterial concentration. In addition, several authors have suggested a sediment bacterial store (Matson *et al.*, 1978; Grimes, 1974; Hendricks and Morrison, 1967; Van Donsel and Geldreich, 1971). These papers report both marine and freshwater habitats and none are conclusive about the mechanisms by which bacteria are stored and released. Possible explanations included simple deposition of bacterial clumps, adsorption to particular grain sizes, slower rates of death in sediment or, as suggested by Hendricks (1970) and Gerba and McLeod (1975), growth of *E. coli* population in sediment by metabolism of hexose and protein from an organic origin.

The second store is clearly finite but of unknown 'size' and both rates and mechanisms of depletion and replenishment remain to be identified. Models of bacterial concentrations must be related both to hill slope hydrology models for movement between stores and to fluvial models for store transfer in the river system.

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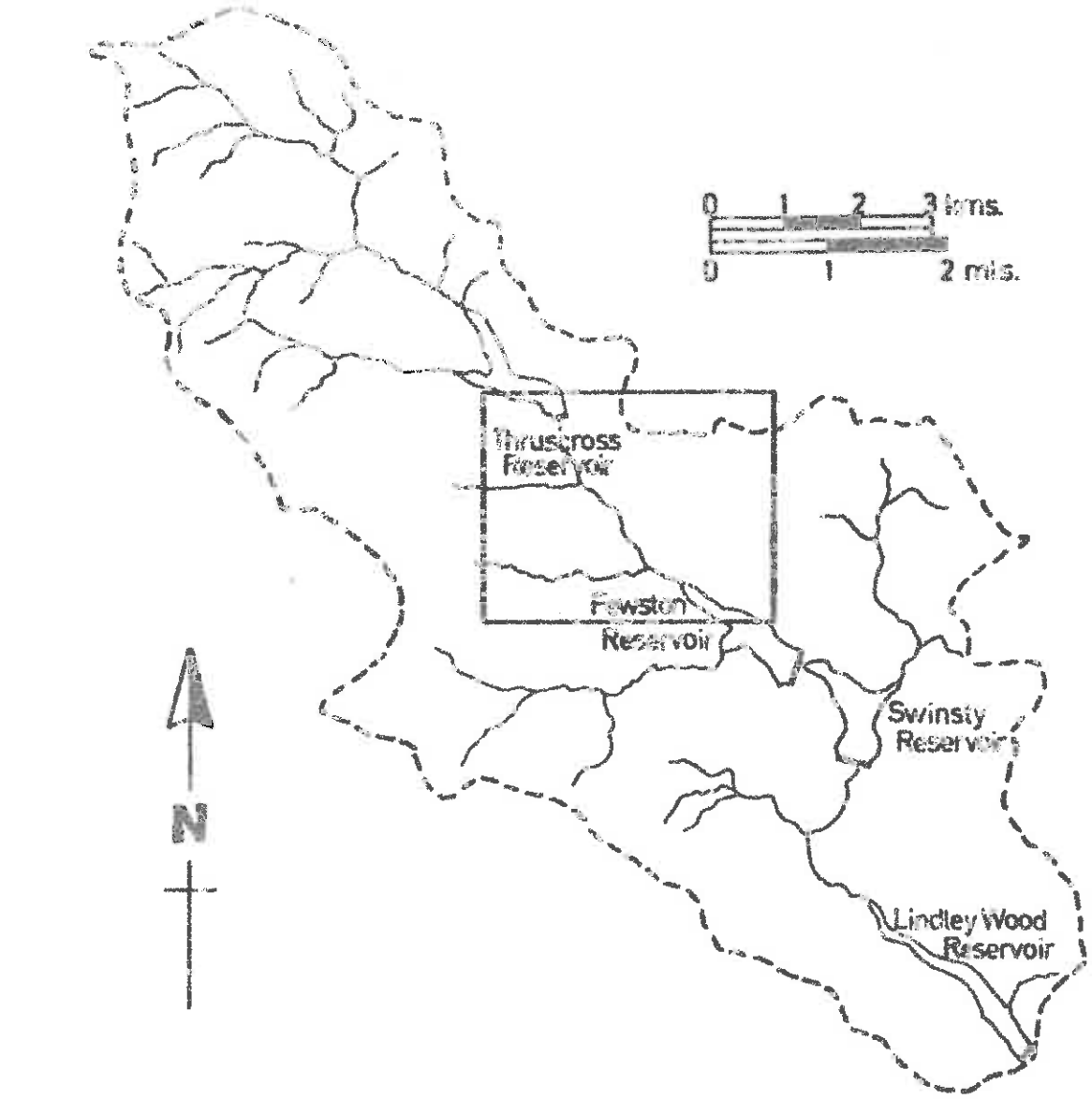
Figure 1


0 1 2 3 kms.
0 1 2 mls.
Thruscross Reservoir
Fewston Reservoir
Swinsty Reservoir
Lindley Wood Reservoir
N

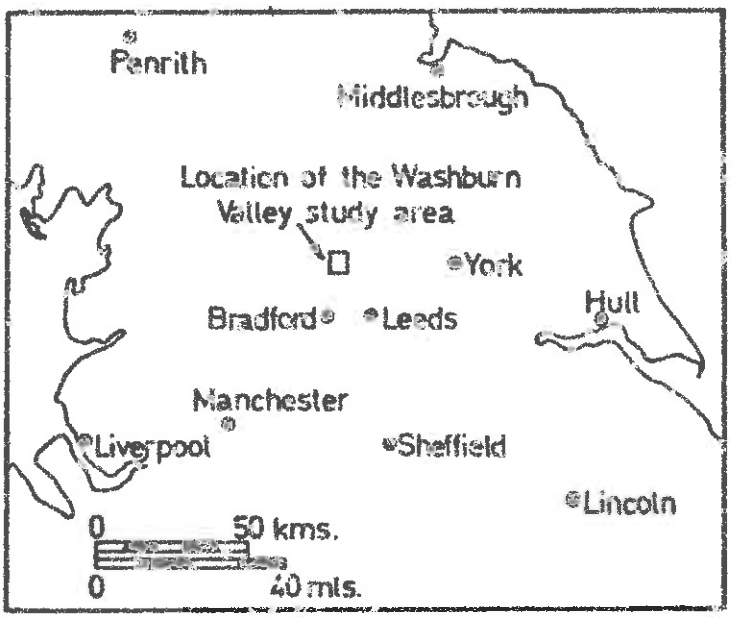
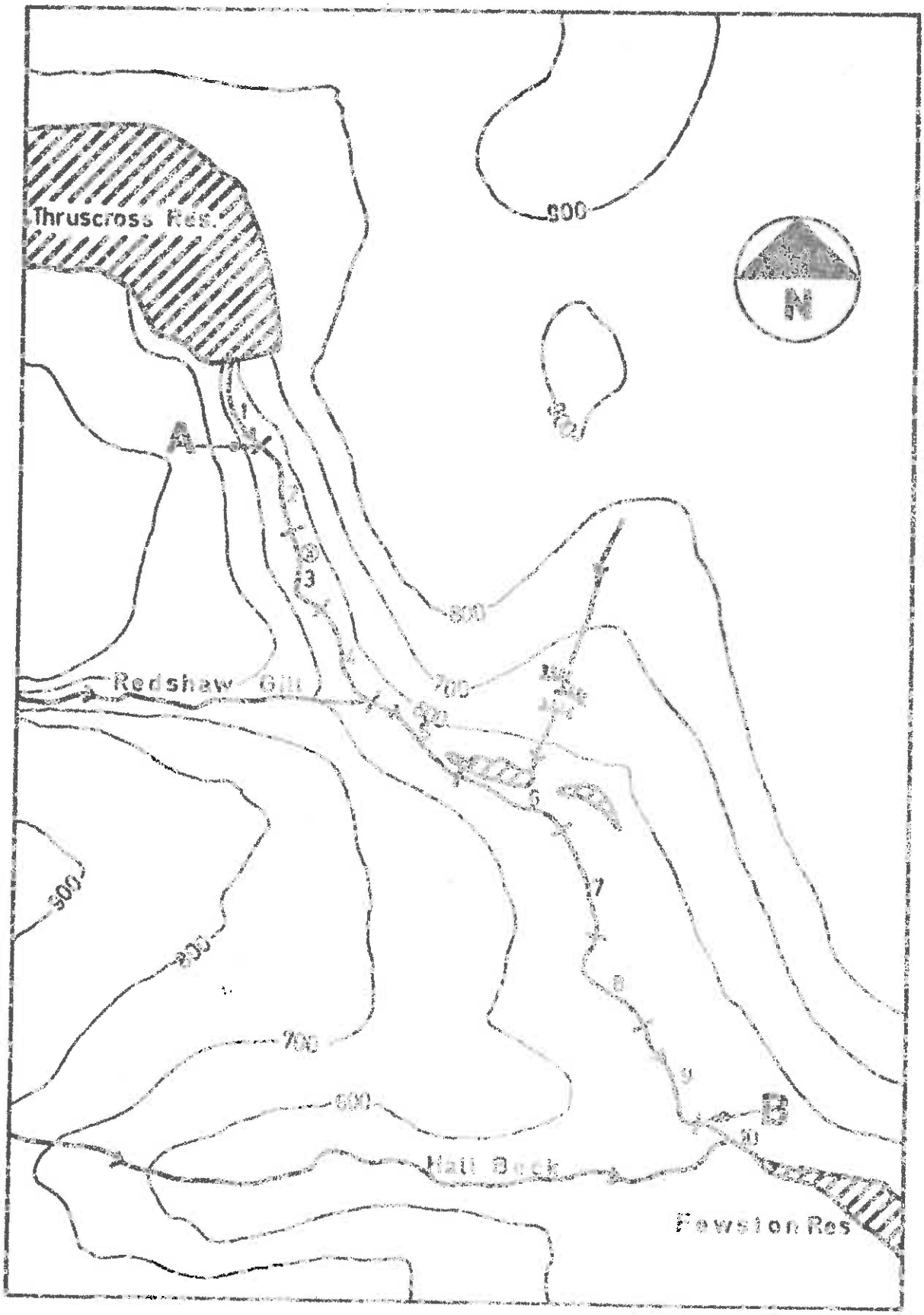

Penrith
Middlesbrough
Location of the Washburn Valley study area
York
Bradford
Leeds
Hull
Manchester
Liverpool
Sheffield
Lincoln
0 50 kms.
0 40 mls.

Fig 2 The study site: River Washburn between Thruscross and Fewston Reservoirs



⊗ = Site of stage recorder.

3 = Reach boundaries.

0 500m 1000m

Figure 3

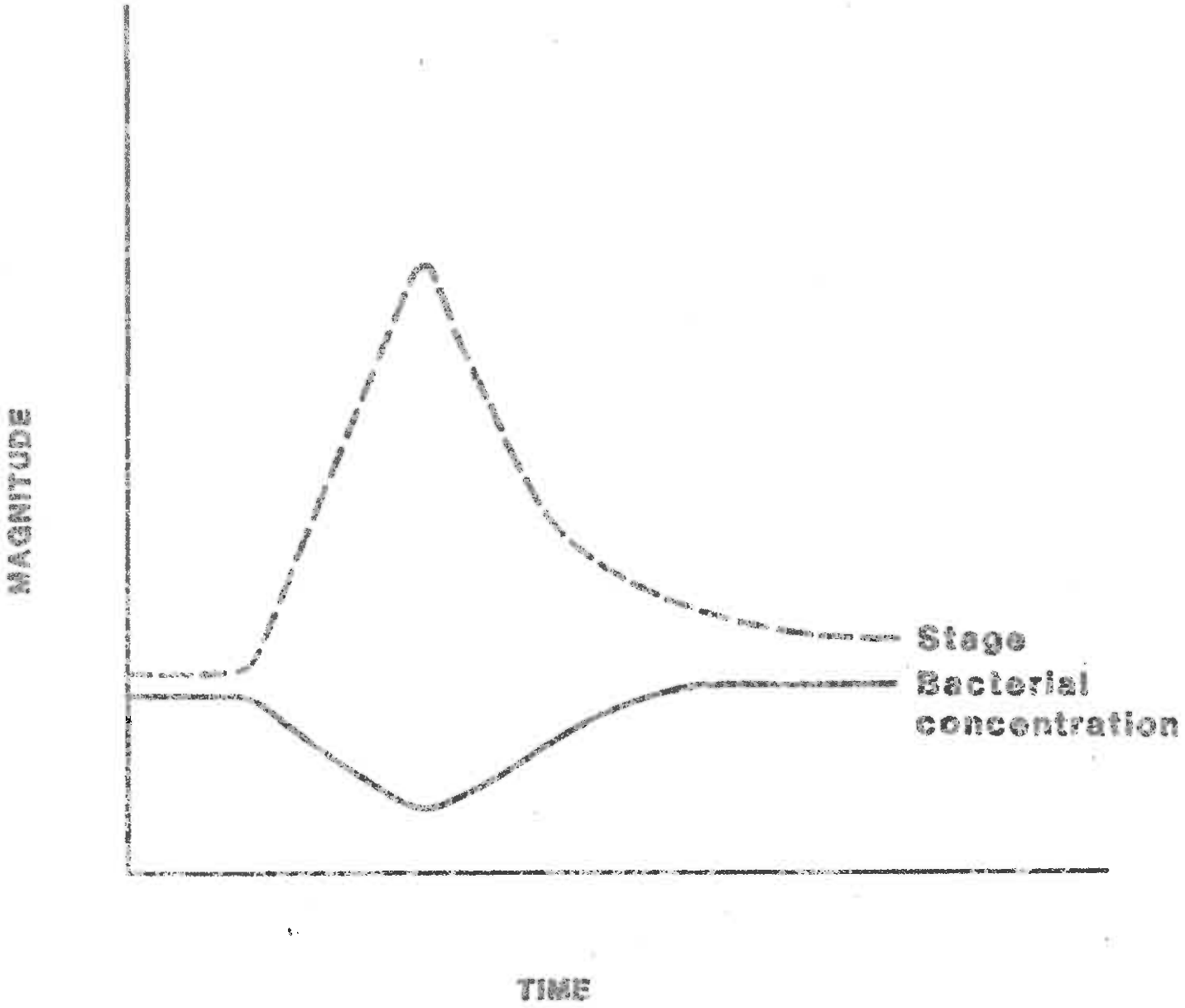


Figure 4

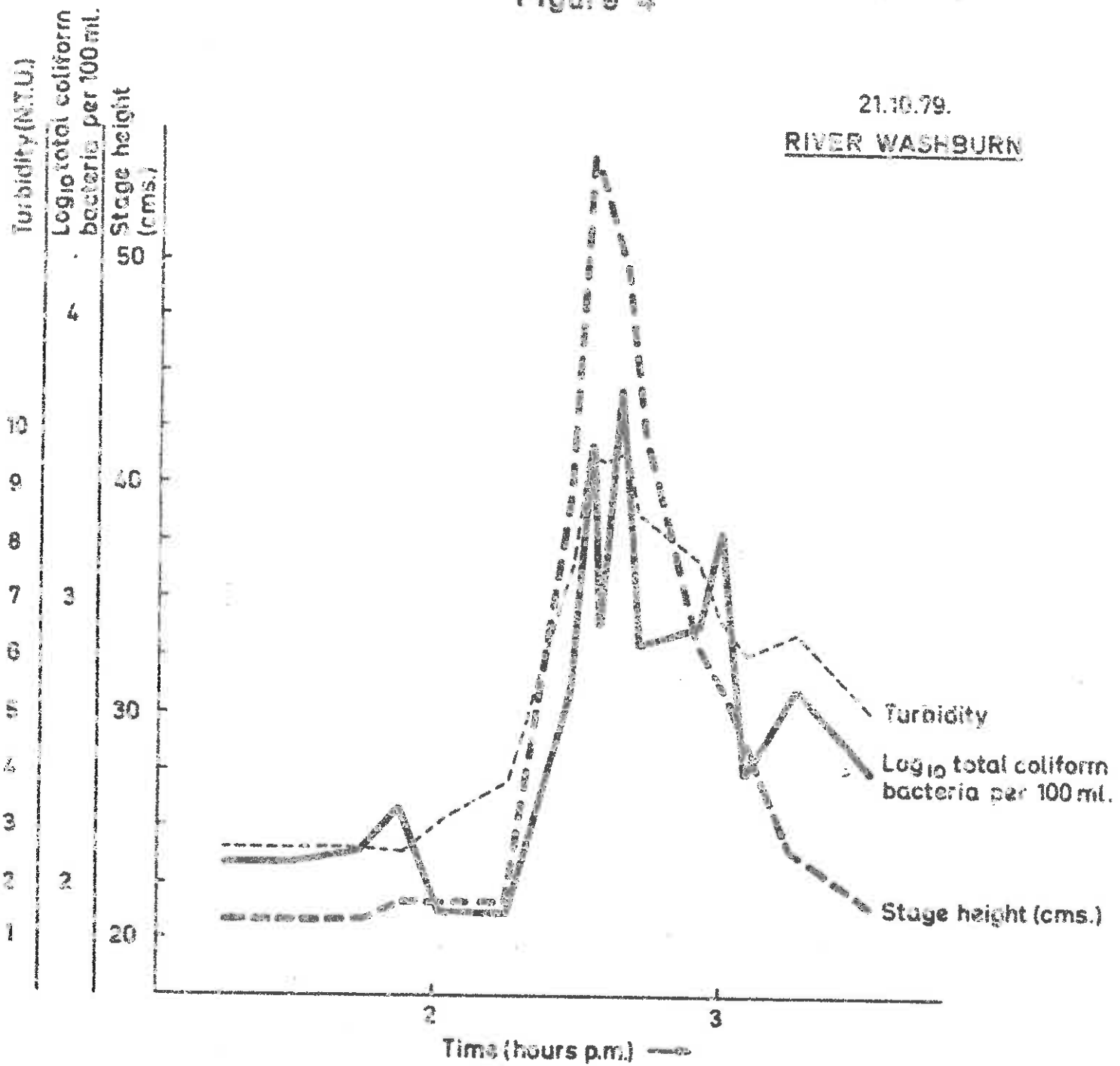

21.10.79.
RIVER WASHBURN
Turbidity (N.T.U.)
Log10 total coliform bacteria per 100 ml.
Stage height (cms.)
10
9
8
7
6
5
4
3
2
1
4
3
2
50
40
30
20
2
3
Time (hours p.m.)
Turbidity
Log10 total coliform bacteria per 100 ml.
Stage height (cms.)

Figure 6

21.11.79.

RIVER WASHBURN

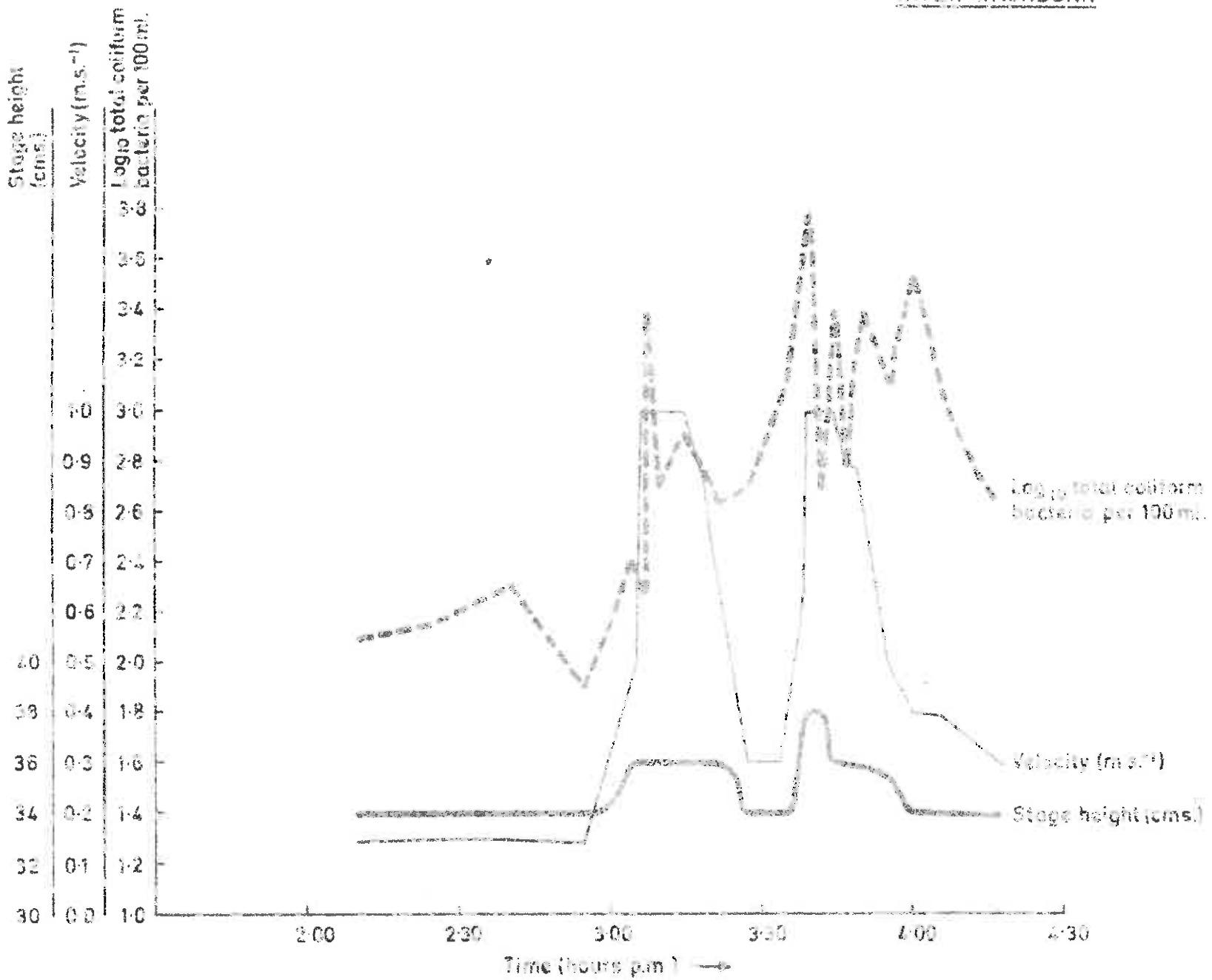


Figure 6

River Washburn 2.7.80.

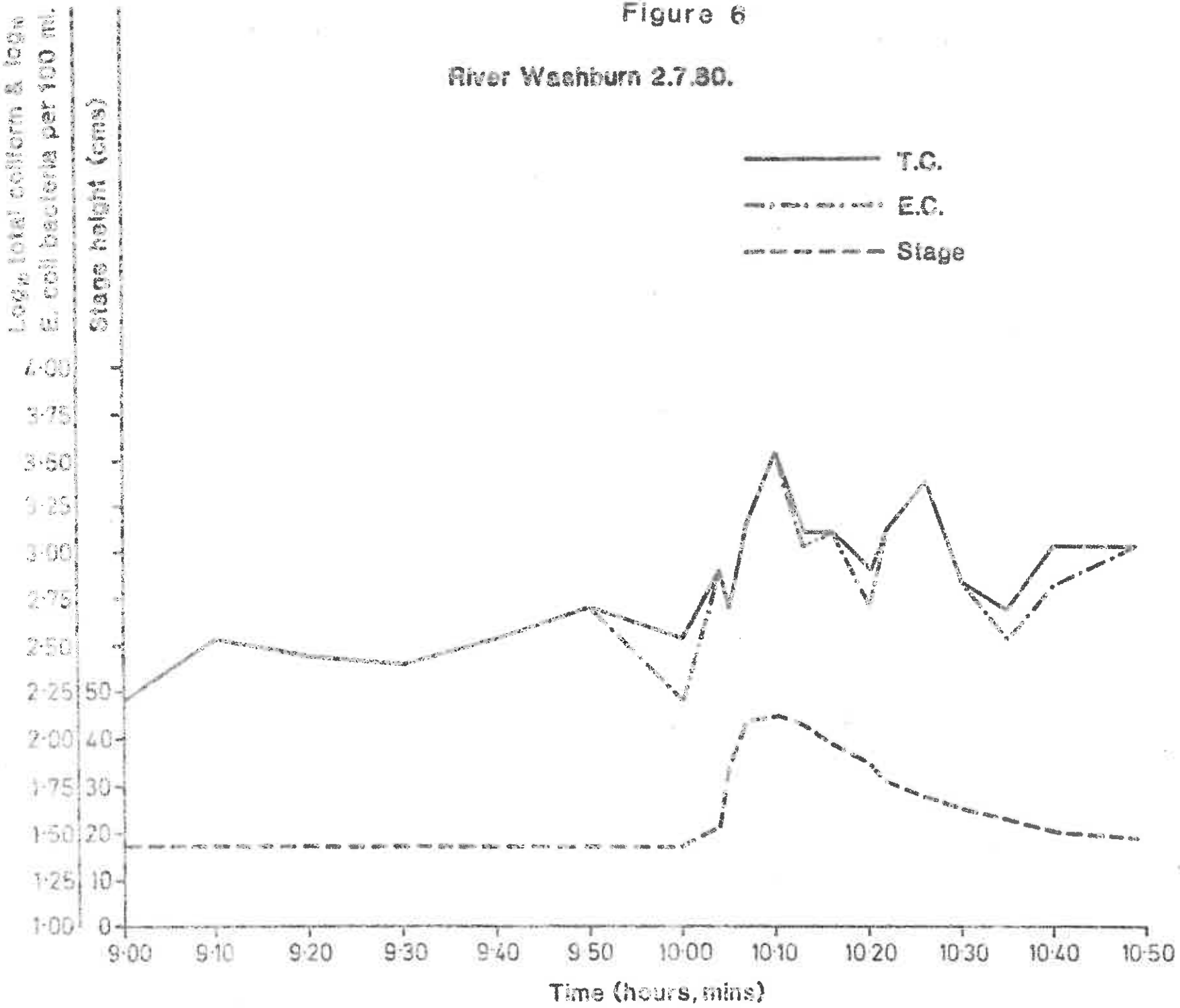


Figure 7

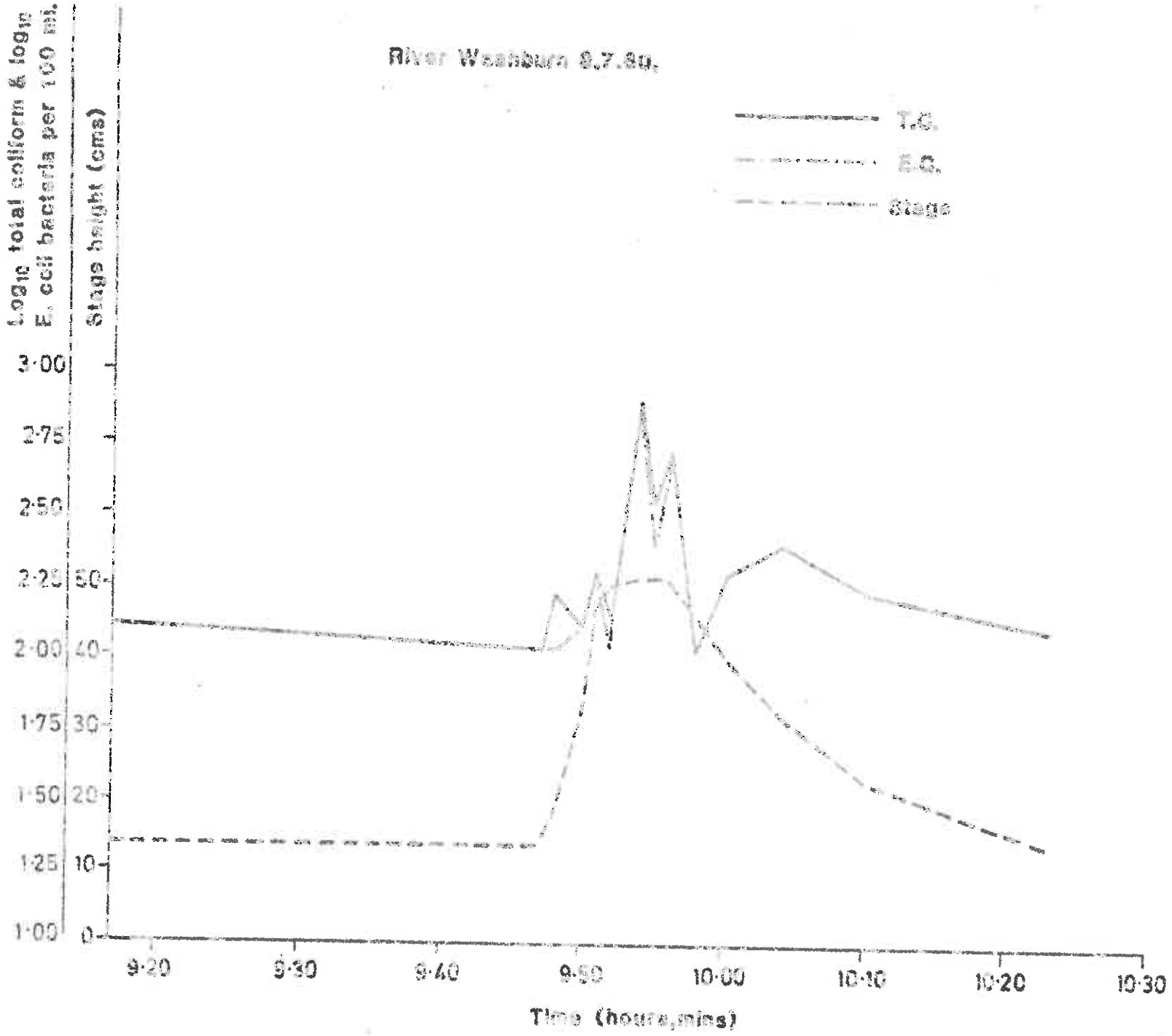
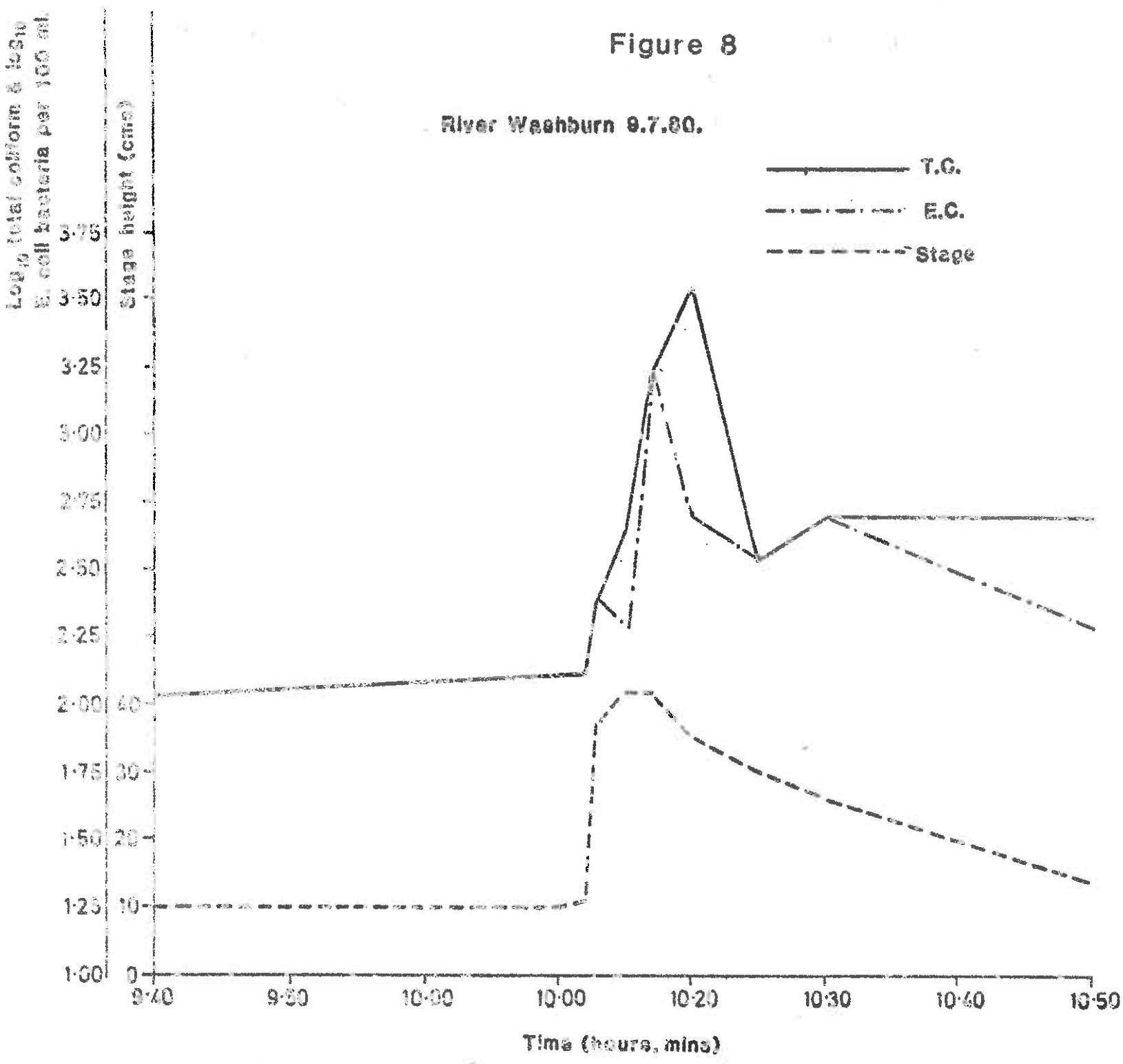

River Wesnburn 8.7.80.
T.C.
F.C.
Stage
Log10 total coliform & log10 E. coli bacteria per 100 ml.
Stage height (cms)
3·00
2·75
2·50
2·25
2·00
1·75
1·50
1·25
1·00
50
40
30
20
10
0
9·20
9·30
9·40
9·50
10·00
10·10
10·20
10·30
Time (hours,mins)

Figure 8


River Washburn 9.7.80.
T.C.
E.C.
Stage
Log10 total coliform & log10 E. coli bacteria per 100 ml
Stage height (cms)
3·75
3·50
3·25
3·00
2·75
2·50
2·25
2·00
1·75
1·50
1·25
1·00
40
30
20
10
0
9·40
9·50
10·00
10·10
10·20
10·30
10·40
10·50
Time (hours, mins)

River Washburn 6.7.80. Figure 9

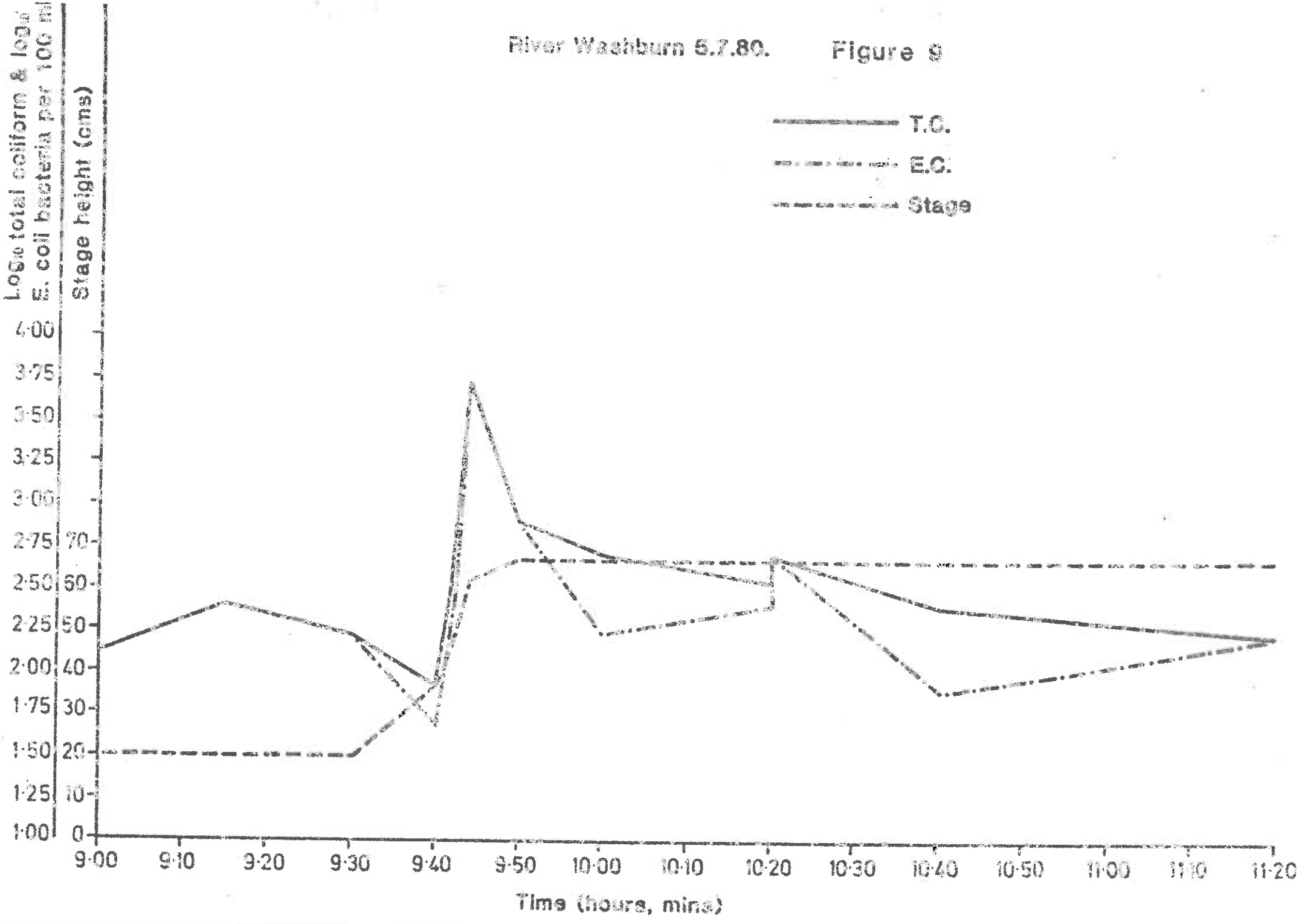


Figure 10

RIVER WASHBURN 3/3/81

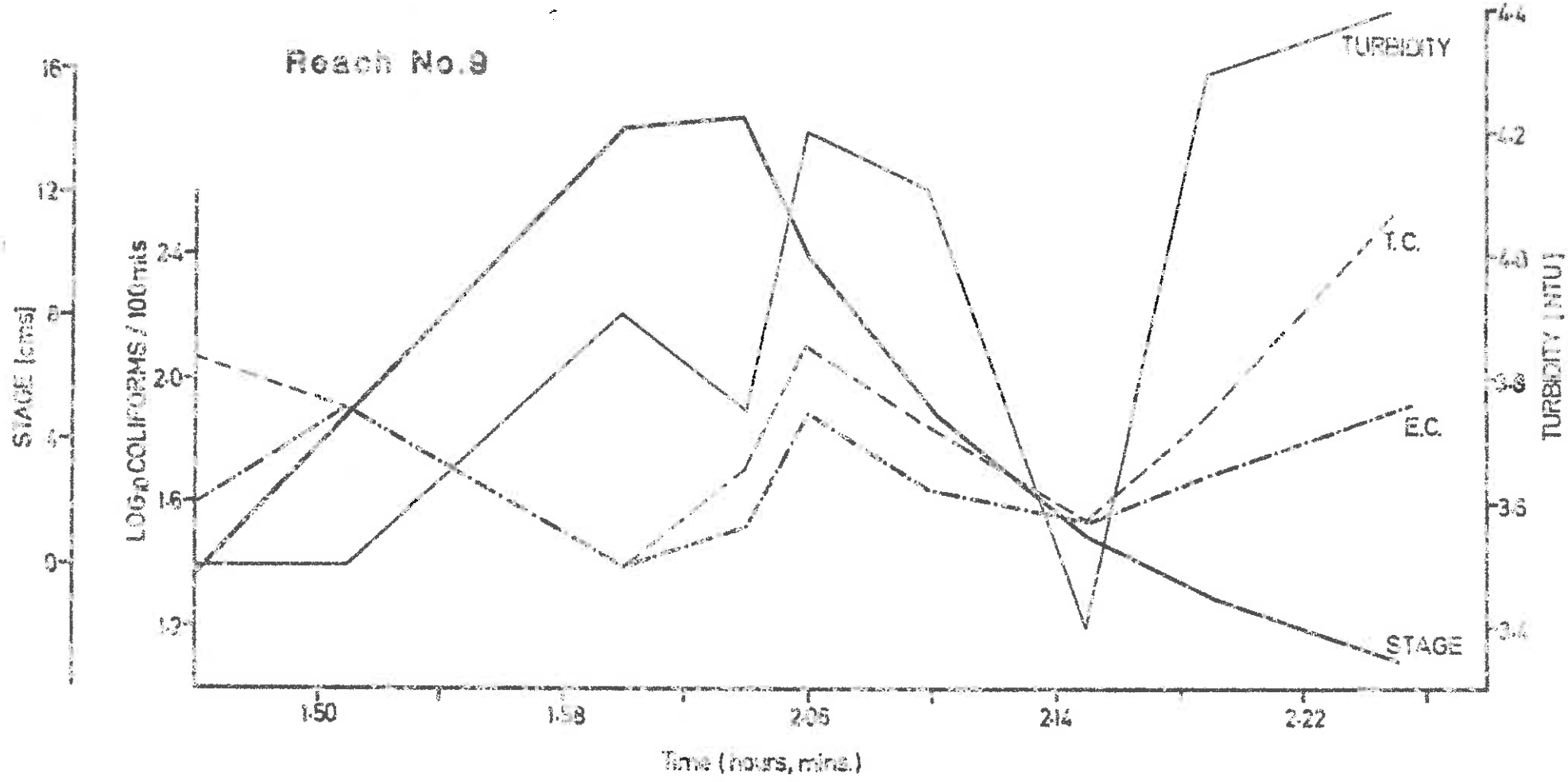


Figure 11

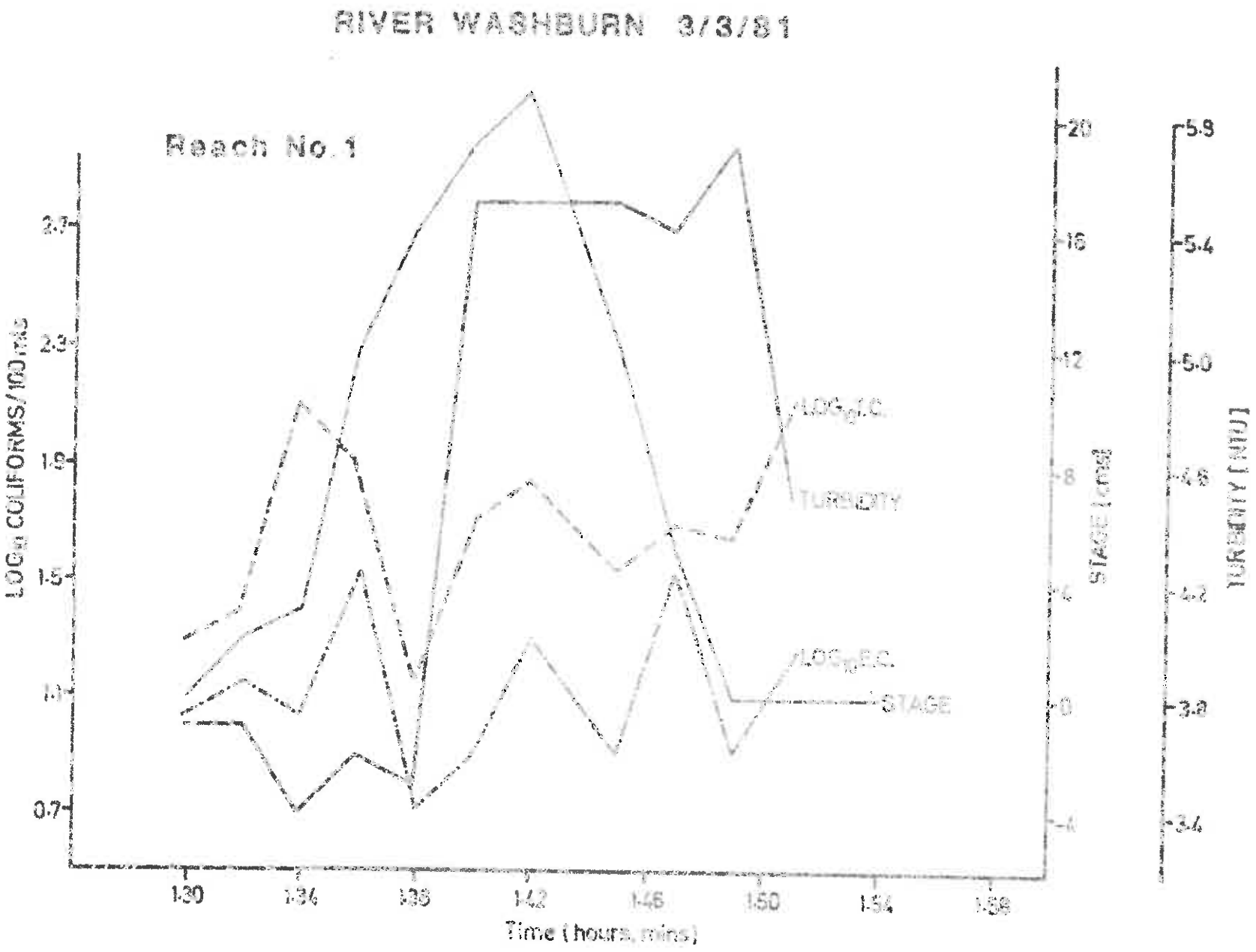

RIVER WASHBURN 3/3/81
Reach No. 1
LOG10 COLIFORMS/100 mls
2.7
2.3
1.9
1.5
1.1
0.7
20
16
12
8
4
0
-4
STAGE (cms)
5.8
5.4
5.0
4.6
4.2
3.8
3.4
TURBIDITY (NTU)
LOG10 F.C.
TURBIDITY
LOG10 F.S.
STAGE
1.30
1.34
1.38
1.42
1.46
1.50
1.54
1.58
Time (hours, mins)

Figure 12

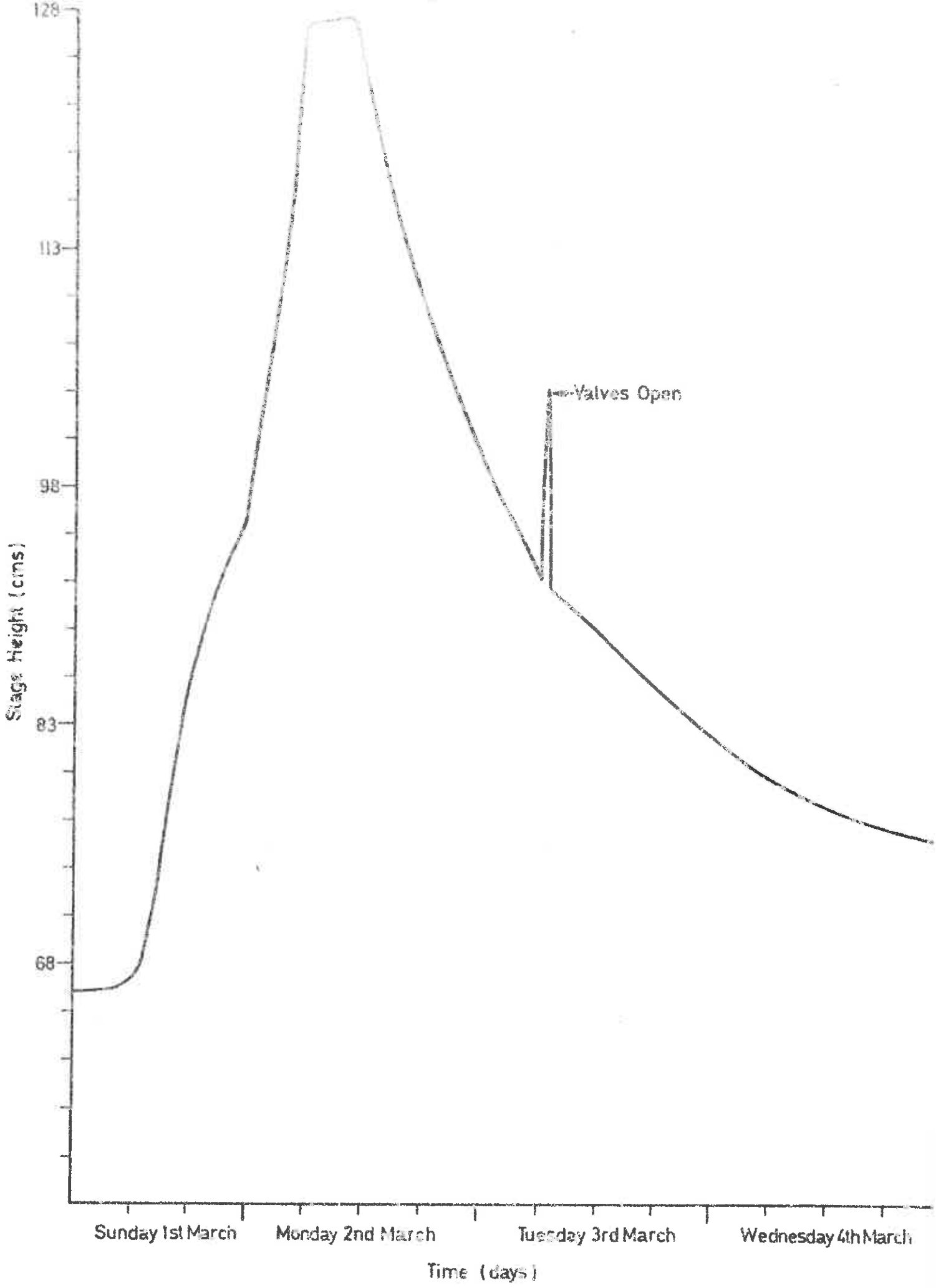

128
113
98
83
68
Stage Height (cms)
Valves Open
Sunday 1st March
Monday 2nd March
Tuesday 3rd March
Wednesday 4th March
Time (days)

Figure 13

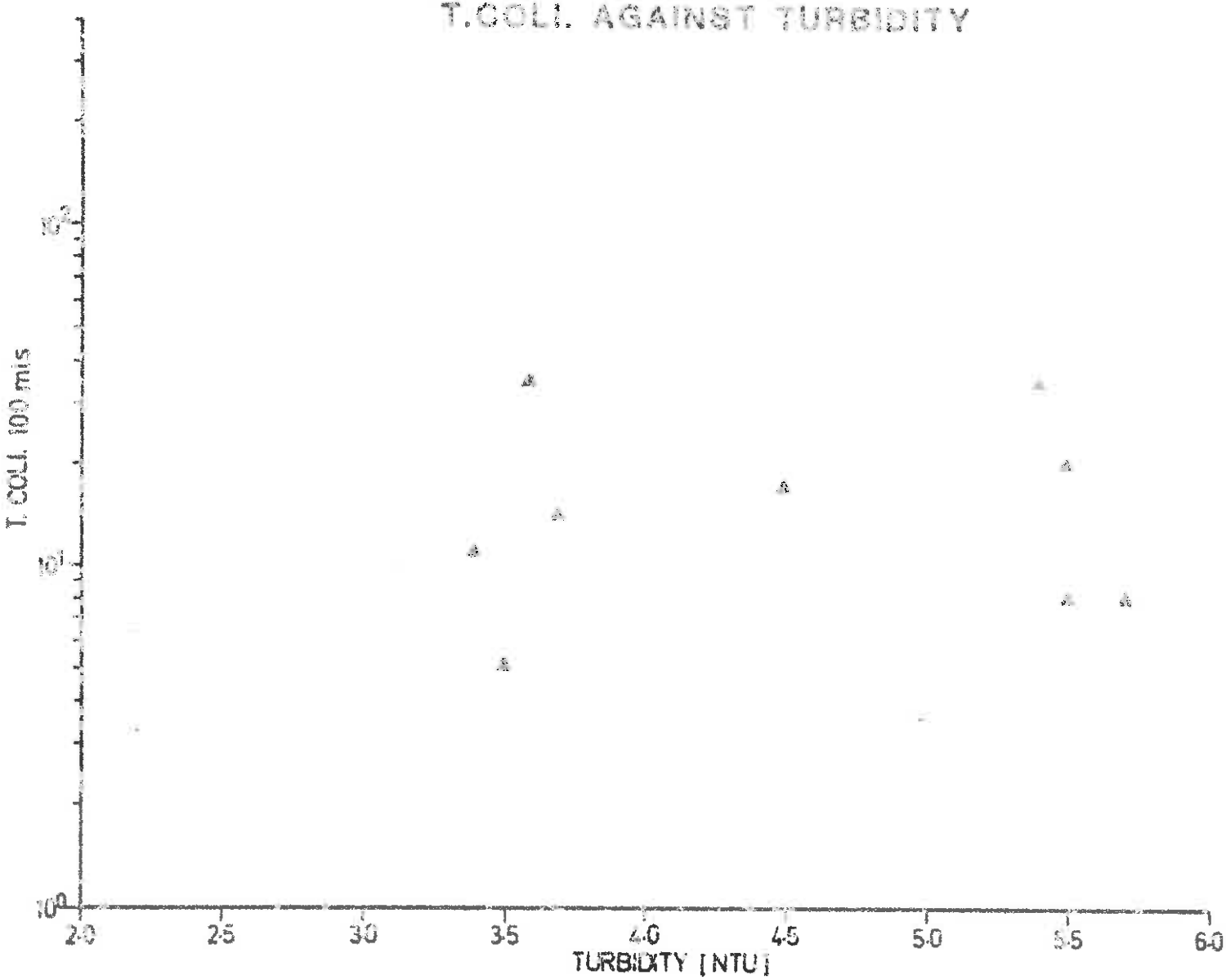

T.COLI. AGAINST TURBIDITY
T. COLI. (100 mls
10²
10¹
10⁰
2·0
2·5
3·0
3·5
4·0
4·5
5·0
5·5
6·0
TURBIDITY (NTU)

Figure 14

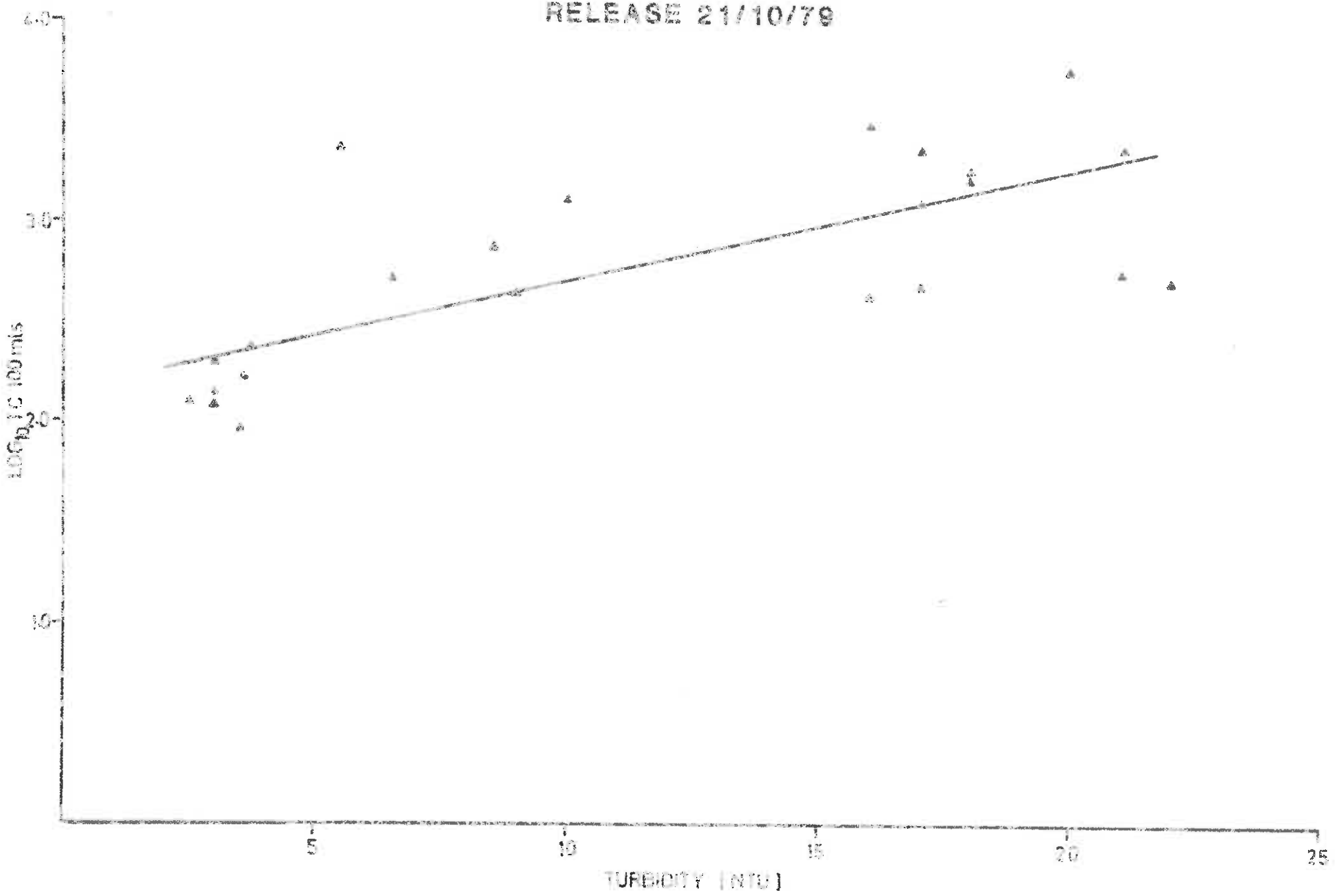


Figure 15