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LAKE ST. LUCIA ESTUARY DISPERSION STUDY

Radioactive Tracer Field Survey 19 - 25 October 1972

Introduction

This project was undertaken jointly between the Institute, the Atomic Energy Board and the Hydrological Research Unit of the University of the Witwatersrand. The latter unit under contract to the Natal Provincial Administration is engaged in an extensive study of the complete Lake St.Lucia hydrological and hydraulic system. The lake system, lying some 250 km north of Durban, is 45 km from North to South and 15 km from East to West. The average depth is 1 to 2m. The lake is linked to the sea by a 20km long estuary, 200 to 400m wide and 1 to 2m deep. Due to fluctuating amounts of incoming freshwater and sea water the salinity of the lake can vary from near freshwater to 25% above that of sea water. The fluctuation in salinity causes disruption in the ecological system of the lake and the associated wild life.

In seeking a solution to the problem the Hydrological Research Unit has developed a mathematical model of aspects of the lake system. Various radioactive tracer tests have been proposed to check and calibrate the parameters used in this mathematical model, in particular the dispersion coefficient in a tidally oscillating estuary. This report describes a radioactive tracer field survey of the estuary section.

Field Work

Tests of compatibility between colloidal gold-198 tracer and St. Lucia water were undertaken using atomic absorption spectrometry. These tests showed that losses of gold concentration over a 3 hour period reached 15% in clear estuary water and 59% in cloudy estuary water, thus excluding the use of this tracer. *

A total of 1 Ci bromine-82 made up in five equal ampoules was released at five points across the width of the estuary near the South end (Station 6) at low tide. For release two of the ampoules (containing dry powder $CaBr_2$) were crushed at ∿ 1m depth. The others were each first mixed into 5 litres of water which was then poured quickly into the river.

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* Subsequent tests at the AEB laboratories led to the choice of bromine-82 in the form of $CaBr_2$ as the tracer.

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Prior to the release of the tracer a background survey was undertaken at different stations along the estuary. At fixed measuring stations along the estuary sets of traverse measurements alternately at two different depths 0,5m and 1,0m, were taken continually as the tracer cloud passed. Transverse measurements were accomplished by travelling at a slow uniform speed across the width of the estuary in a 5m motor launch with the detector (5cm x 5cm NaI(T1) scintillator) mounted on a vertical pole which could be positioned at different depths against the side of the boat. Boat positions were determined by fixes on marker poles spaced at 20m intervals across the width of the estuary. Data were collected on paper chart and on magnetic tape.

Accumulated counts over a 15 sec period were also taken at selected fixed positions. Such "dwell mode" measurements were taken particularly on day two and three. During the tracer test, flow rate measurements at numerous points across a particular cross section were taken 24 hours per day. Tidal range records were also kept.

The tracer was released at 13.40 hrs. on Monday 23rd October, 1972. Sets of transverse measurements were done at three stations 8, 9 and 13a on the first day. On Tuesday and Wednesday "dwell" measurements were taken between station 6 and 20. Shortly after the release of the tracer a strong southerly wind started to blow for the next 36 hours. This caused a "set up" in the North South oriented lake system with the water level rising in the north and falling below mean sea level in the south. This resulted in a virtually continuous in-flow of sea water, i.e. the flow in the estuary was not tidally oscillating during the experiment. The tracer was therefore "lost" to the southern area of the lake where it was diluted in the larger volume of water to below the detectable limit.

On the second day of measurements it was noticed that radio frequency emission from the boat engine was producing a fluctuating count rate up to five times the background count rate in the detector system. Measurements of tracer concentration were already low on the 2nd day and were rendered virtually useless because of the high engine "noise". Subsequent readings were taken with the engine switched off.

Data Handling

The data on magnetic tape was processed to give graph plots of each traverse i.e. concentration versus width of the estuary and integral counts of each traverse.

Because of very low lateral mixing of tracer, the transverse measurements

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picked up five distinct slugs at station 8 and 9 and partially mixed peaks at station 13a (Gravel Pits). For analysis the most clearly defined peak (No. 4) was chosen and followed through the three stations. Each transverse measurement was integrated for this peak and background subtracted. These integrated values were than plotted versus time of measurement for each of the stations thus providing a time concentration curve. Fig. 1,2 and 3.

The time concentrations curves were analysed to yield a value of the longitudinal dispersion coefficient D_ℓ according to the methods of Fischer[1], Gardener[2] and Filip[3]. During the 1st half tidal cycle after release of tracer the estuary was assumed to be a uniform moving stream. The basic one-dimensional mass balance equation,

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial X} = D_\ell \frac{\partial^2 C}{\partial X^2} \qquad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

was used by the above authors to solve for D_ℓ. C is the tracer concentration, X is the distance along the river and t is time. U is the average flow velocity. The equations derived by these authors are valid if good mixing of the tracer has occurred i.e. if the tracer concentration in any particular spot in the river cross section is not much different from the average concentration values. Data collected up to the end of the first day indicated a lack of good mixing despite the plot of log $^1/C$ max versus log X (fig 4.) giving a straight line of slope $^1/_2$ (for station 9 and 13a) which is an indication of good mixing (ref. 2).

Gardener equation

$$D = \frac{U^3 N^2}{4R^2_{max}\Pi X} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where N is the net number of counts accumulated over the time concentration curve. R_{max} is the maximum count rate measured. The other symbols are as in equation 1.

Filip equation:

$$D = \frac{W^2 U^3}{11.1\ X} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where W is the width in seconds of the tracer time conc. curve at half height of the net count rate above background.

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Fischer equation:

$$D = \tfrac{1}{2}U^2 \frac{(\sigma^2_{t_2} - \sigma_{t_1}^{\ 2})}{\overline{t}_2 - \overline{t}_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

where subscripts 1 and 2 refer to two sequential measuring stations and σ is the statistical variance on the time concentration curve ($\sigma_t^{\ 2} = \frac{\Sigma Ci(ti - \overline{t})^2}{(\Sigma Ci) - 1}$ and $\overline{t}$ is the mean time of arrival of the tracer cloud at the station concerned.

In all the above equations as a first approximation the mean time of arrival $\overline{t}$ was taken to be the time of peak arrival t_{max} which is not quite correct. See Thackston ref 4. similarly $U = X/t_{max}$ is subject to inaccuracy.

Results

I. 1st half tidal cycle

Results of measurements in the 1st half tidal cycle after release of tracer are given in time concentration curves for Stations 8,9 and 13a. The paràmeters used in the calculation of D_ℓ are given in table 1.

In compiling the time concentration (T.C.) curves for individual pulses errors are introduced by contribution from adjacent pulses. In particular the TC curve for station 13a was compiled from "eye-ball" stripping of merged peaks. Further, in calculating the standard deviation σ for use in the Fisher equation the large "tail" contribution in TC curve 8 was replaced with a more gaussian fit shown as dotted line in fig. 1. Another source of error is the non uniform boat speed during each traverse and from traverse to traverse.

Results of the longitudinal dispersion coefficients D_ℓ calculations are given in table 2. The dispersion coefficient is fairly low for station 8 and 9 i.e. $< 2m^2/s$. At station 13a it has increased by a factor of 10 to 100 the latter being for Fishers method. The average speed (using time of peak arrival) between station 9 and 13a increased over the previous reach and since the equations are functions of the 2nd or 3rd power of the speed a small change in the latter produces a large change in the dispersion coefficient. Because of the onset of darkness measurements at station 13a were suspended resulting in a truncated TC curve.

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If a mean time of arrival was used and not t_{max} a slower speed and hence lower D_ℓ would result. e.g. assuming an extra 20 mins. between 9 and 13a would give a D_ℓ of 112 m^2/s for Fishers method instead of $187m^2/s$. The Fisher value for D_ℓ therefore should be considered as an upper limit.

An idea of the very small lateral mixing can be gauged from table 3. The most distinct pulses i.e. those showing the least lateral mixing were chosen for tabulation. Even after a distance of 8km the breadth of the pulse given by the full width at half maximum of a traverse at t_{max} was 30 meters. Taken as a function of estuary cross section this is a factor of 3 to 5 greater than at station 8.

II. Measurements from 18 to 26 hours after release

As was previously mentioned the flow was not tidally oscillating and the tracer was lost into the southern area of the lake. Very low concentrations were therefore encounted. These were made difficult to interpret because of th engine "noise" factor. These measurements are thus not tabulated but the following comments can be made:

1. The highest tracer reading after 19 hours was 24 ± 7 cps (corrected for background and decay, the natural background varied from 3 to 10 cps) found in midstream at the northern end of Potters channel. Readings at the edge of this channel were background. This highest reading confirmed flow of tracer into the lake. At 26 hours after release the reading at the same site was 8±7 c
2. Going down towards the estuary mouth the trend was to lower reading e.g. 3 cps at station 18, but a local high at station 14 of 20 cps was observed.
3. At station 13a 2 cps were measured. No tracer was observed lower than station 12.

III. Measurements taken 43 hours after release gave completely negative results.

IV. Dilution factor:

A rough estimate of the dilution factor after 20 hours elapsed time wa made. Assuming 95% of the tracer was in the slug bounded by 4σ seconds, the volume of the tracer cloud at 8 was estimated for a single pulse which contains one fifth of the total injected tracer. If this amount of tracer were mixed uniformly with this volume the count rate would be approximately 400 cps or 200 cps for the total activity. Taking an observed count rate of 10 cps some 20 h after release this gives a dilution factor of 200 from station 8. Observed co rates were mostly below 10 cps therefore this dilution factor is a minimum valu

CONCLUSIONS

The tracer test yielded approximate values of the longitudinal dispersion coefficient for the first 6 hour period. Because of adverse weather conditions the estuary system was not tidally oscillating and a dispersion coefficient over a longer time period could not be evaluated. Further because of the loss of tracer into the southern end of the lake and the problem of engine "noise" obscuring the tracer counts, only a rough estimate of dilution over the longer time period could be given.

Future tracer tests

Although weather conditions played a major role in frustrating the objects of the tracer test, the following improvements are suggested:

1. The tracer should be released on one pulse; good mixing can be checked after flow reversal.
2. The time of release should be before mid-day at low water to enable a full ½ tide cycle to be followed.
3. If mixing in the 1st tidal cycle is important, facilities for working at night should be considered.
4. The electronic equipment should be shielded from engine "noise".
5. To avoid truncation errors in TC curves the measuring stations shou be chosen to allow full passage of the tracer cloud before arrival at the next station.

Acknowledgements

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TABLE 1. Parameters used to calculate longitudinal dispersion

Station	Distance from release* X km	Peak time from release t_{max} sec	Full width at half max. W sec	Standard deviation σ sec	Ave. Speed from release U m/s	Ave. speed between station U m/s
8	1,47	4560	660	331	0,32	-
9	2,75	9300	1200	533	0,30	0,27
13a	8,07	15900	3300	2013	0,51	0,81

* From chainage values of 1973 survey

Release time 13.40 hours Monday 23rd October 1972

TABLE 2. Values of longitudinal dispersion D_ℓ (m^2/s)

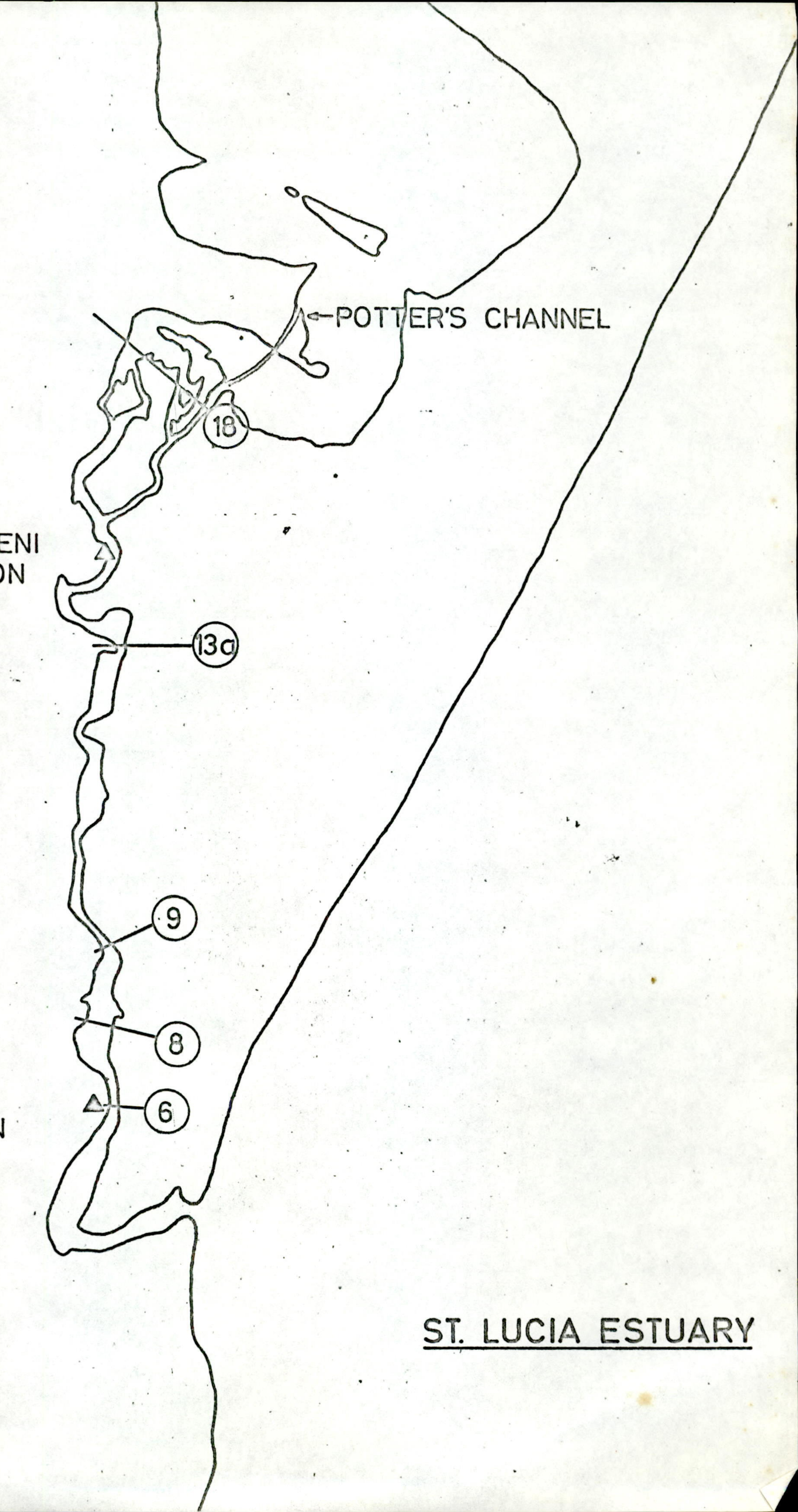
Station	Filip	Gardener	Fischer
8	0,89	1,90	-
9	1,22	1,19	1,35
13a	15,9	15,6	187,0

TABLE 3. Lateral dispersion of individual pulses

Station	Time of pulse	Tracking width W_t	Duration of tracking S	Full width at half max. of peak F	FWHM * $F \times \frac{Wr}{S} =$ L	Estuary cross † section A	Ratio $\frac{L}{A}$
		meters	sec	sec	meters	m^2	
8	14,57	260	176	10	14,8	340	0,04
8	14,46	260	165	15	23,6	340	0,07
9	16,09	80	51	7	10,9	200	0,06
9	16,14	80	57	10	14,0	200	0,07
13a	17,49	110	55	8	16,0	155	0,10
13a	18,05	110	55	15	30,0	155	0,19

* Assuming a constant boat speed

† Using cross sections surveyed on 23rd November 1972



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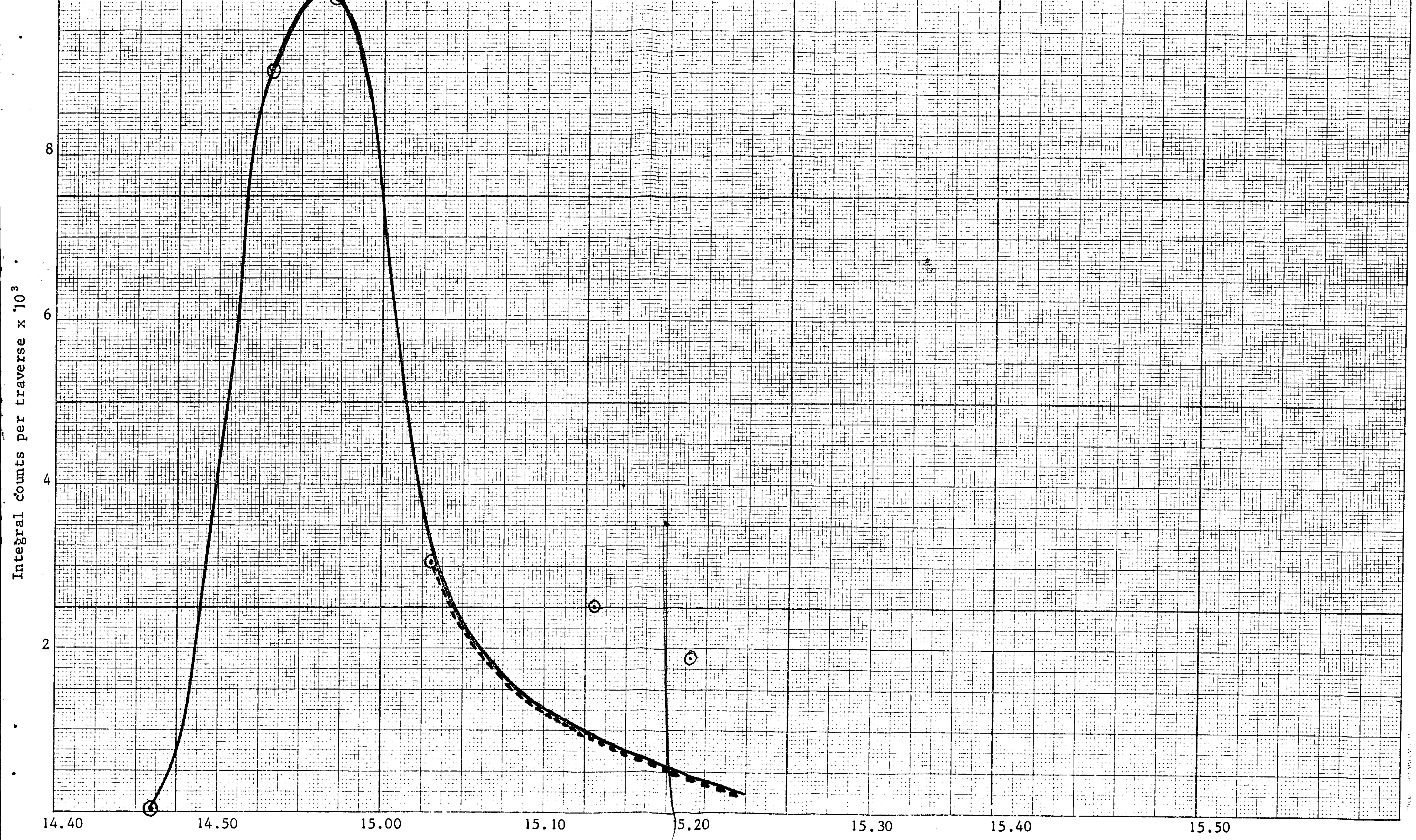

Fig. 1. Station 8 Time Concentration Curve

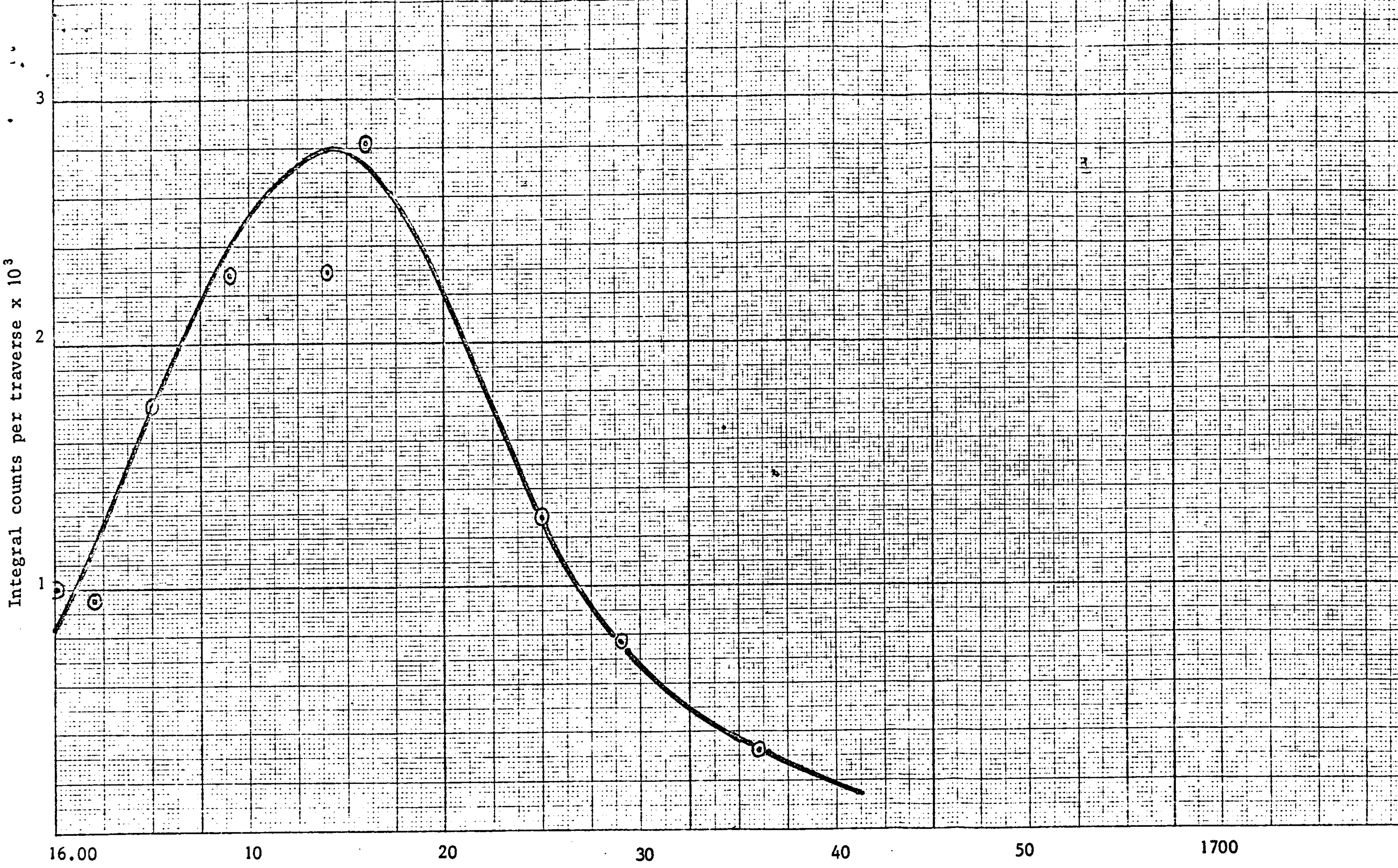

Fig. 2. Station 9 Time Concentration Curve

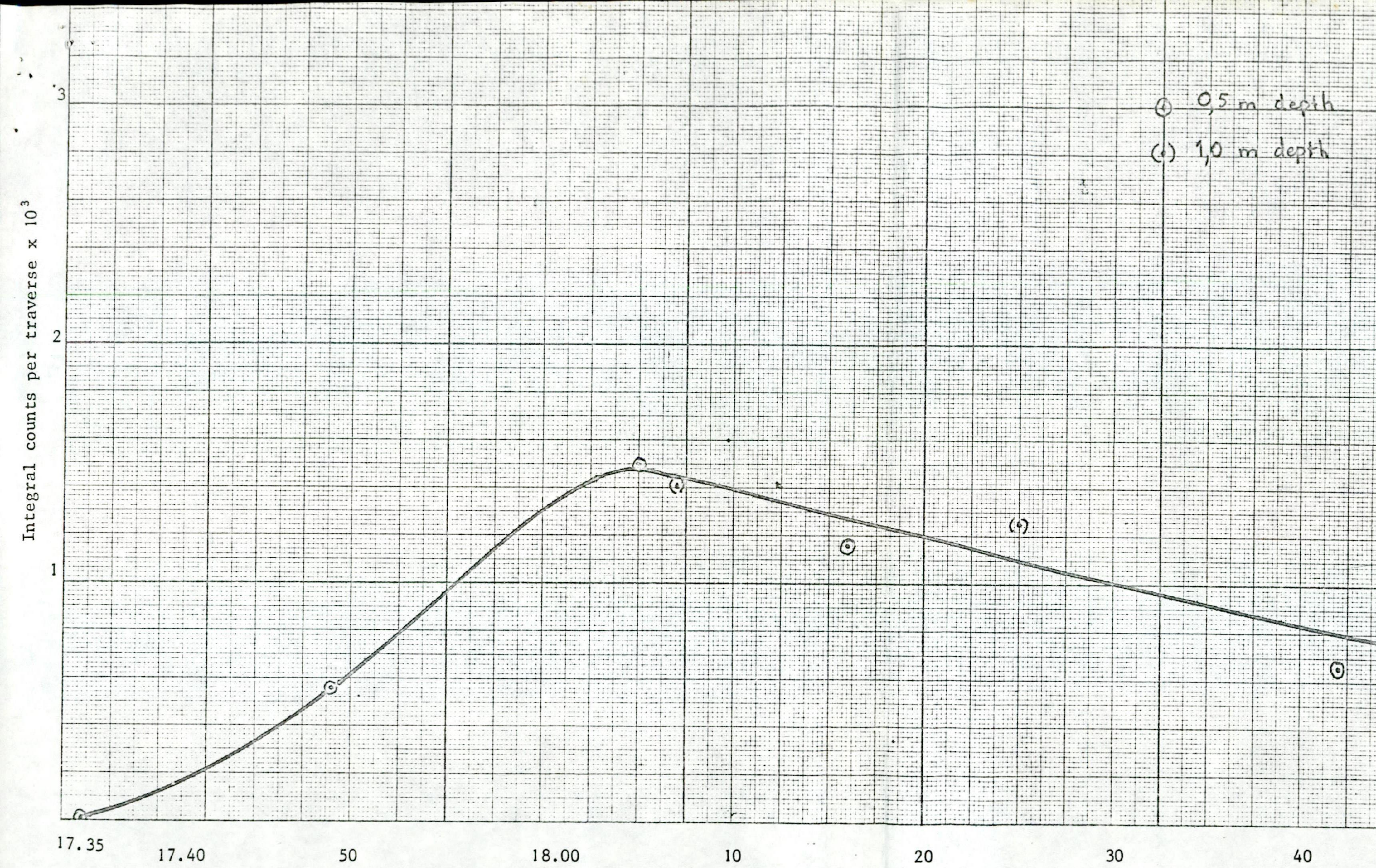

Fig. 3. Station 13a Time Concentration Curve