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MEASUREMENTS OF THE CONFIGURATION OF A BREAKUP JAM

by

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ABSTRACT

Detailed data on the transverse and longitudinal thickness variations of a breakup jam on the Thames River are reported herein. Measurements were made possible by a thaw-freeze sequence which permitted access to the jam surface. Such information is rare for breakup jams and only two similar, though less comprehensive, data sets are known to the writers.

The jam thickness varies widely in the transverse direction but exhibits no consistent trend which, in a crude sense, justifies the usual theoretical assumption of constant thickness across the stream. In the downstream direction, the thickness increases to a maximum at the toe of the jam; it decreases rapidly to zero downstream of the toe, i.e., where the broken ice is accumulated under intact sheet ice.

From water level measurements and cross-sectional surveys, hydraulic data for the flow under the jam are available. These may be combined with the thickness data to test various theoretical concepts.

MANAGEMENT PERSPECTIVE

Ice jams cause serious flooding. The documentation of case histories of ice jams is vital in the understanding of the underlying processes. This report provides nearly unique detailed data on an ice jam thickness and shape and will be used to improve our knowledge and in the development of mathematical models of jams. (Project 23: Flooding and Ice).

A/Chief
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SOMMAIRE

La présente étude renferme des données précises sur les variations de l'épaisseur le long de l'axe transversal et de l'axe longitudinal d'une embâcle sur la rivière Thames. On a pu prendre des mesures grâce à une série de gels et de dégels qui a permis de percer la surface de l'embâcle. Les informations de ce genre sur les embâcles sont rares; à la connaissance des auteurs, il n'existe que deux autres ensembles de données semblables encore que celles-ci soient moins exhaustives.

L'épaisseur de l'embâcle varie énormément le long de l'axe transversal et ne présente aucune tendance particulière ce qui, en quelque sorte, justifie l'hypothèse habituelle voulant que l'embâcle soit d'épaisseur uniforme d'une rive à l'autre. Le long de l'axe longitudinal, l'épaisseur augmente vers l'amont où elle atteint son maximum. Elle décroît rapidement vers l'aval et devient nulle au point où les pans de glace s'accumulent sous la nappe de surface qui n'est pas encore cassée.

Les données hydrauliques sur l'écoulement de l'eau sous l'embâcle ont été produites à partir des mesures de niveau d'eau et des relevés le long de sections du chenal. Ces données peuvent être étudiées à la lumière de celles sur l'épaisseur de l'embâcle pour vérifier diverses notions théoriques.

PERSPECTIVE GESTION

Les embâcles provoquent des inondations graves. La préparation d'études de cas d'embâcles est essentielle pour mieux connaître les mécanismes sous-jacents. La présente étude renferme des données exhaustives virtuellement uniques sur l'épaisseur et la forme d'une embâcle. Elle servira à améliorer nos connaissances et à élaborer des modèles mathématiques. (Projet n° 23: Inondations et glaces.)

Le chef intérimaire

Division de l'hydraulique

1.0 INTRODUCTION

A major component of the Hydraulic Division's ice jam research program is the annual documentation of ice regime and jamming in two southern Ontario streams, i.e., the lower Thames and the upper Grand. This is a long term effort, initiated in 1979 and aimed at both quantification of ice-related phenomena in the observation reaches and improvement of qualitative understanding as a guide to laboratory and theoretical research. The results of annual observations are normally presented in regular reports issued with one or two year's lag and include supplementary hydrometric data and interpretations.

On the other hand, this report is a special issue, intended for timely presentation of rare data gathered during the January 1986 breakup, regarding the configuration and physical dimensions of a jam that froze in place when cold weather resumed. Such information is normally not possible to obtain for breakup jams and the only other data sets of this kind known to the writers are those reported by Calkins (1978) and Wuebben and Stewart (1978), though their data are not as detailed as the present set. Lack of thickness measurements has proved a major obstacle in ice jam research especially with regard to documentation and testing of various theoretical concepts (e.g., see Beltaos 1983). The present data are now being analyzed and the results will be reported when the analysis is completed. It was recognized, however, that different interpretations of the data are possible, depending on point of view and mathematical model used. For this reason, it was decided to issue a data report as soon as possible, independently of analytical considerations.

Figure 1 is a plan of the lower Thames River from Middlemiss to the mouth of Lake St. Clair. The study reach normally extends from the mouth to Thamesville though an effort is made to also document interesting events that might occur above Thamesville.

2.0 BACKGROUND INFORMATION

By the morning of December 17, 1985, a complete ice cover had formed on the lower reaches of the Thames, as far upstream as Chatham. As usually happens, the cover continued advancing upstream owing to incoming slush pans and by early afternoon on December 17, the edge of the cover was already past Kent Bridge. It is estimated that passage by Thamesville occurred on the following day.

By mid-January of 1986, the ice cover had attained a thickness ranging from about 30 cm below Chatham to about 20 cm near Thamesville. Intense rainfall on January 17 and 18 caused the river stage to rise sharply. At Thamesville, the ice cover was set in motion on January 20 and small jams began to form. During the next two days more of the study reach was cleared of ice while jams became less frequent but longer. Between 1800 and 2000 on January 22, the final jam formed and was documented in the morning of January 23 (Fig. 2). By this time, the flow discharge was already beginning to decline (Figs. 3 and 4) and cold weather returned so that the breakup did not progress any farther. Various aspects of the jam are illustrated in photographs at the end of the report.

After January 23, winter conditions resumed and a solid ice layer formed on the surface of the jam. As soon as it was deemed safe, field crews were at the site to begin thickness measurements. The work proved to be slower than anticipated while the originally planned number of measurements was significantly increased when first results became available.

It was thought that the presence of the jam had the potential to cause problems during the spring breakup. Fortunately, the latter occurred under conditions of little runoff and significant thermal deterioration of the ice cover. This is the so-called "mature" type of breakup and causes no problems.

3.0 DATA COLLECTION

3.1 Water Level Profile of Jam

To obtain water surface elevations along ice jams, conventional topographic surveys are, as a rule, too slow because the jam may release or change configuration before the survey is completed. The method adopted to circumvent this difficulty is to photograph the water stage against identifiable objects near the river banks (e.g., see photos 4 and 5). These photographs are then used to locate and survey the jam levels when the river is clear of ice. The obvious lack of accuracy is partially compensated for by the possibility of taking numerous spot water levels over long river distances.

Table 1 summarizes the results of the photographic surveys and shows that errors are of the order of ten centimetres.

3.2 Thickness Surveys

Methods of Measurement:

Starting at the ice jam toe, measurement transects were placed upstream at 20 - 30 m intervals for the first 300 m, where the transect coincided with a TBM* at 32.31 km from the river mouth. Upstream from this position, the lines were placed at previously surveyed TBM's with the interval increasing from 0.75 km to approximately 3.0 km, up to a TBM at 42.00 km from the river mouth.

To maintain maximum safety, an assessment of the ice conditions was made at each transect prior to commencing the measurements. A diver's safety line was attached to one crew member who then proceeded on foot along the proposed transect to the opposite side of the river. While making this crossing, that crew member continually probed the ice ahead with an ice chisel to determine its

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* Temporary bench mark

safety and to visually detect any unstable conditions. During this procedure the other crew members attended the safety line on the river bank as anchor men and payed the line out as required. Once a safe path was determined, the safety line was detached from the observer, the shore end tied to some anchoring point and the line left stretched out across the river. The mobile crew member then returned to the starting point and while doing so, paced off the river width to establish an approximate bank to bank distance. It should be noted here that all crew members wore survival suits and maintained a vigilance on ice conditions throughout these surveys.

Actual measurement points along a transect were next established by dividing the river width into equal parts keeping the interval near 10 m. Extra points were frequently added closer to the bank. The distance between points was normally measured with a 30 m tape measure by two crew members, starting from the interface of water surface and shore at the left bank and continuing to the same interface on the right bank. As these points were measured they were identified by shovelling the snow away from an approximate 1 m^2 area at each site. This procedure made later ice thickness measurements easier and more accurate by preventing a slush buildup around the holes.

While the location of measuring points was being established and recorded, the third member started drilling access holes through the ice at those sites (see Photo 6). Drilling equipment consisted of 3 HP gasoline powered ice drills with 18 cm diameter, 1 m long augers. Two 1 m long extension bars were made up to bolt onto the auger to give a 3 m drilling depth capacity. The operation of this extra length equipment required a strong team effort to complete the drilling procedures.

As the drilling continued, one crewman commenced taking and recording the remaining observations. These observations included ice layer or multiple ice layer thickness, depth of water, distance from water surface to ice surface plus general information about the water column under the ice and ice surface conditions. The tool for measuring ice thickness, water depth and probing the water under the ice was made at the National Water Research Institute (NWRI). It consists of a set of ten 1 m long, 2 cm diameter aluminum tubes which can be easily joined together to form a measuring rod 1 m to 10 m in length. Each section is inscribed at 0.5 cm increments with every 5 cm mark being numbered as well. One section of the rod has a 1 cm thick, 5 cm diameter plate permanently fixed to its bottom end, while its top end and those of the other nine sections have identical joining sockets. This allows one to assemble the upper position of the rod in any order and still maintain direct reading configuration. The bottom plate is used as the indicator to identify the underside of the ice and the depth of water. To use this device for water depth measuring it was simply lowered vertically into the water until the bottom plate rested on the river bottom and the depth read directly from the rod at the water surface. To measure ice thickness the rod was lowered into the access hole with the edge of the bottom plate in contact with the side wall of the hole. When the plate slid below the underside of the ice cover, a slight jolt was felt. The rod was then pulled gently upward until the upper surface of the plate caught on the ice. The value read from the rod at the ice surface minus the 1 cm plate thickness gave the ice thickness (see Photo 7). At this point, the separation between the water surface and ice surface was also noted. Water column conditions such as ice layers, slush build up under the ice cover, water clarity and water velocity were also observed during this operation.

Stationary and in motion conditions were also recorded. These observations included surface roughness, depth and type of snow cover plus a general description of the ice. Photographic and VHS video records were also made to complete the observation procedure and provide a permanent visual display of conditions. Ice jam formation and collapsing, plus ice cracking, breaking up and piling along the shoreline were recorded in this manner.

Our crew of three collected a complete set of measurements at 160 access holes during a ten day period in February 1986. Of these sites, 123 were located along the 10 km length of a single jam, with 87 being positioned within the first 300 m upstream from the toe.

3.3 Difficulties Experienced

Difficulties encountered during this observation period were numerous and varied. A brief summary of some of these items is given here.

Safety of personnel, our first major problem involved protection against breaking through the ice cover, falling due to the jumbled condition of the ice field, frostbite and hypothermia. Teamwork plus the use of a safety line and survival suits provided considerable security against these hazards, except that of falling. To appreciate the difficulty of safe movement, one need only picture a 10 km long pressure ridge stretching from one river bank to the other in width, with ice slabs piled up to 3 m high. Serious injury was successfully avoided by pre-planning movements and then executing them carefully.

The second major problem was in drilling access holes and retrieving the equipment. Hazardous footing on the surface plus the jumbled configuration of ice throughout the jam thickness made it extremely hard to keep the holes vertical (see Photo 8). To compound the problem, loose and floating ice within and under the ice jam frequently trapped the auger. Retrieval sometimes required the efforts of all three crew members. Access to the work area, although generally good, did involve carrying all equipment up to a kilometer for some locations.

3.4 Possible Errors

The rugged conditions described introduced some possible errors.

Measured ice thickness at any individual point could have errors due to the location and/or the condition of the lower end of the access holes. Available equipment did not allow us to observe whether the ice auger breakthrough points were at peaks or hollows of the underside of the jam. We were also unable to tell whether or not the undersurface broke away clean or was shattered by the auger, creating a natural edge to measure from. Several thickness readings were taken around the sides of each hole to reduce this error potential. Similar conditions on the surface made measurement of the surface layer open to error also.

Another possible error was the specification of water surface width. The actual water's edge was hidden by inaccessible piled ice (see Photo 9). This necessitated estimation of these points for inclusion in profile data.

4.0 RESULTS

4.1 Ice Jam Thickness

The results of thickness measurements are presented in Figs. 5(a) to 5(p). Clearly evident is the intense variability of thickness across the channel but no consistent trends can be detected. This lack of trend justifies, in a crude sense, the "one-dimensional" assumption of uniform transverse thickness that is made in theoretical literature on ice jams. Figure 6 is a contour plot of the data in the area near the toe of the jam. Noteworthy is the fact that the accumulation of ice blocks does not abruptly end at the toe but persists for some distance under the sheet ice cover.

Table 2 summarizes average thicknesses across the channel at different locations. The average thickness shows a general tendency to increase in the downstream direction, reaching a maximum at the toe but decreases to nil within a relatively short distance beyond the toe. This decrease could be attributed to friction between the broken ice accumulation and the sheet ice cover, as explained by Beltaos and Wong (1986). The friction is likely generated by the effective upward stress produced by buoyancy effects. The configurations measured by Calkins (1978) and Wuebben and Stewart (1978) resemble the present one though their data do not extend beyond the toe area.

In his attempt to describe the hydraulic resistance of freeze up accumulations, Nezhikhovskiy (1964) introduced an absolute roughness parameter, ε, such that

$$\varepsilon = \left|\text{local thickness - average thickness}\right| \qquad (1)$$

and found that the average roughness, $\bar{\varepsilon}$ generally increased with increasing average thickness, $\bar{t}$. This finding led to approximate empirical relationships between Manning coefficient and t, for three types of freeze up accumulations. Reasoning that accumulations of solid ice blocks are the most likely to resemble breakup jams, Beltaos (1983) re-analyzed Nezhikhovskiy's applicable data set and deduced the following empirical relationship:

$$d_{i,84} = 1.43\,[1 - e^{-0.734(\bar{t} - 0.15)}] \qquad (2)$$

in which both $\bar{t}$ and $d_{i,84}$ are expressed in metres while $d_{i,84}$ = a measure of the jam's absolute roughness, equivalent to the 84-percentile particle size of channel beds. An approximation to $d_{i,84}$ is the quantity ε_{84} which can be calculated with the present data (using Eq. 1) via a frequency analysis on ε. Because relatively few individual measurements of thickness were performed in each section (Table 2) it was decided to lump together sections of comparable average thickness so as to increase respective sample sizes.

Calculated values of $\bar{\varepsilon}$ and ε_{84} are presented in Table 3. While a general increasing trend is evident, the group 1.47 - 1.53 m does not fit well with the rest. This is caused by the rather extreme variability of thicknesses across section 33.79 km (Fig. 5.c). If this section is excluded, the corresponding values of ε and ε_{84} will conform to those of the other groups, as indicated in Table 3. Figure 7 is a plot of ε_{84} versus $\bar{t}$ (assumed equal to $\bar{t}_s/0.92$). Equation 2 is also plotted for comparison. There seems to be general agreement between Eq. 2 and the present data, though the approach to a constant limiting roughness may occur at smaller values of $\bar{t}$ than indicated by Eq. 2. Given that Eq. 2 is a means for predicting f_i, the friction factor of the jam underside, which is influenced by the logarithm of $d_{i,84}$, relatively large errors in $d_{i,84}$ would translate to tolerable errors in f_i.

4.2 Profile of Jam

Using the data already described along with surveyed cross sectional geometry of the channel, it is possible to produce the diagram of Fig. 8, showing the longitudinal profile of the jam, as it would have been on January 23, 1986.

Implicit here is the assumption that the thickness of the jam did not change appreciably during January 23 to February 26, when the thickness measurements were completed. This assumption appears reasonable, owing to the decreasing discharge and resumed cold weather after January 23 so that minimal, if any, thickness changes by collapse or thermal erosion should occur. As a direct test of this assumption, Section 32.17 km was surveyed twice (February 4 and February 25). Fig 5(i) shows that the two sets of measurements are consistent with each other and reveal no significant changes.

Figure 9 is an enlarged version of Fig. 8 near the toe area and illustrates the relatively sharp gradients of thickness that prevail near the toe.

4.3 Discharge

Measurements of discharge are not available for the period of the January '86 breakup. The Thamesville hydrograph of Fig. 3 is based on such related data as water levels, weather conditions, rainfall, flows at upstream gauges and the like. For the Thamesville gauge, flow estimates of this kind are usually reliable owing mainly to the presence of upstream gauges where ice effects are often minimal during breakup periods at and below Thamesville. The Chatham hydrograph in Figure 3 is a mere translation in time of the Thamesville hydrograph and assumes a travel interval of about 12 hours while neglecting any tributary inflows or flow attenuation effects.

The estimated flow discharge under the January 23 jam is 290 m^2/s. The corresponding ice effect at Thamesville, where open-water conditions prevailed at that time, is about 0.4 m which appears plausible in view of the distance and slope involved.

4.4 Hydraulic Characteristics

With the above described information it is possible to compute hydraulic parameters at various locations within the jam reach (Table 4) and plot their longitudinal variation (Fig. 10). It may be noted that least depths and maximum velocities occur at the toe of the jam where not only the jam is thickest but also the overall water depth is least (see Fig. 8).

5.0 SUMMARY

The configuration and spatial thickness variation of breakup jams is difficult to measure owing to the usually hazardous access conditions. Safe access is made possible, however, when a breakup jam freezes in place due to resumed cold weather. Such opportunities are infrequent and to date the only pertinent data sets have been those of Calkins (1978) and Wuebben and Stewart (1978).

Detailed data on a January 1986 jam that formed in the Thames River near Chatham have been reported herein along with descriptions of measurement procedures and difficulties encountered.

A striking though not entirely unexpected finding was the large variability of jam thickness across and along the stream. Lateral variations exhibited no consistent trend. On the other hand, the thickness had an obvious tendency to increase in the downstream direction. Near the toe, the average thickness increased from 1.5 to about 3.0 m within a river distance of only 200 m. However, downstream of the edge of the intact sheet ice cover that held the jam, the thickness decreased rapidly, vanishing within 80 m.

The longitudinal profile of the jam, as it would have been on January 23, 1986, was reconstructed from the above data as well as from water level surveys and cross-sectional data. The profile shows least depths and largest slopes and velocities near the toe of the jam, as might have been expected.

Finally, the labour-intensive nature and slowness of the procedure employed to perform the thickness measurements, should be noted. Instrumentation for remote sensing of ice jam thicknesses is needed.

ACKNOWLEDGEMENTS

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REFERENCES

Beltaos, S. 1983. River Ice Jams: Theory, Case Studies and Applications. Journal of Hydraulic Engineering, ASCE, Vol. 19(10), pp. 1338-1359.

Beltaos, S. and J. Wong. 1986. Downstream Transition of River Ice Jams. Journal of Hydraulic Engineering, ASCE, Vol. 112, No. 2, pp. 91-110.

Calkins, D.J. 1978. Physical Measurements of River Ice Jams. Water Resources Research, Vol. 14, No. 4, pp. 693-695.

Nezhikhovskiy, R.A. 1964. Coefficients of Roughness of Bottom Surface on Slush-Ice Cover. Soviet hydrology, Washington, Am. Geoph. Union, pp. 127-150.

Wuebben, J.L. and D.M. Stewart. 1978. Physical Measurements of Ice Jams - 1976-77 Field Season. U.S. Army CRREL, Special Report 78-3, Hanover, N.H.

Table 1. Water levels in jammed reach, a.m. January 23, 1986, as obtained by photographic documentation.

Location (km from river mouth)	Geodetic Elevation of Water Level (m)	Average Elevation (m)
31.90	177.367 177.307	177.34
32.19	177.659 177.622	177.64
32.31	178.044*	177.91
32.50	178.022 178.027	178.02
32.70	178.469 178.489	178.48
33.00	178.629	178.63
33.05	178.403 178.412	178.41
33.34	178.811 178.792	178.80
33.48	178.634 178.663	178.65
33.49	178.700 178.680	178.69
35.20	179.470 179.374 179.354	179.40
35.80	179.245 179.246 179.392	179.29
37.30	179.589 179.596	179.59
38.00	179.606	179.61
39.18	179.764 179.801	179.78
39.19	179.835	179.84
40.18	179.923	179.92
40.19	179.919	179.92
41.60	180.210 180.215	180.21
42.00	180.078 180.077	180.08
42.65	180.134	180.13
48.65	180.386 180.369	180.38

* Elevation of top of ice. Estimated water level elevation = 177.911 m, using measured thickness of jam and flotation condition (this is the number shown in third column).

Note: Elevations are also known for nearby gauge sites, i.e., 177.36 m at 30.72 km and 178.91 m at 33.79 km.

Table 2. Average ice jam thicknesses, as measured in February 1986

Location (km from river mouth)	Date of Measurement	$\bar{t}_s$* (m)	Number of Verticals Across
32.02	26 Feb.	N.A.	sheet ice
32.04	26 Feb.	0.68	8
32.06	26 Feb.	1.82	8
32.08	26 Feb.	1.77	7
32.10(toe)	24 Feb.	2.57	6
32.12	24 Feb.	2.38	6
32.14	25 Feb.	2.73	6
32.17	4&25 Feb.	2.46	12
32.20	25 Feb.	1.73	6
32.23	26 Feb.	1.86	7
32.26	3&4 Feb.	2.72	6
32.31	11 Feb.	1.53	7
33.09	11 Feb.	1.47	6
33.79	4 Feb.	1.48	9
35.82	12 Feb.	0.97	8
39.19	12 Feb.	0.47	6

*t_s = distance of jam underside from water level

Table 3. Roughness measures $\bar{\varepsilon}$ and ε_{84}.

Range of $\bar{t}_s$ (m)	Value of $\bar{\varepsilon}$ (m)	Value of ε_{84} (m)	Number of Measurements in Sample
0.47	0.15	0.35	6
0.68-0.97	0.31	0.58	16
1.47-1.53	0.71	1.23	22
	(0.56)*	(0.86)*	(13)*
1.73-1.86	0.56	1.05	28
2.38-2.73	0.55	0.99	36

* Not including Section 33.79 km

Table 4. Characteristics of flow in study reach, January 23, 1986

Location (km from river mouth)	Flow Area (m^2)	Width at Bottom Ice Surface (m)	Average Flow depth (m)	Average Velocity (m/s)
31.02	381	84.0	4.54	0.76
31.42	345	79.2	4.36	0.84
32.00	399	91.1	4.38	0.73
32.10	252	75.2	3.35	1.15
32.20	284	76.0	3.74	1.02
32.31	432	93.9	4.60	0.67
32.55	385	99.2	3.88	0.75
32.74	346	78.8	4.39	0.84
33.09	381	79.0	4.82	0.76
33.49	394	82.3	4.79	0.74
33.79	330	71.0	4.65	0.88
34.32	356	75.7	4.64	0.81
34.99	399	75.1	5.31	0.73
35.03	423	94.3	4.49	0.69
35.82	561	93.4	6.01	0.52
36.32	430	84.0	5.12	0.67
36.67	413	79.5	5.20	0.70
37.53	412	76.1	5.41	0.70
38.56	566	75.0	7.55	0.51
39.19	515	87.8	5.87	0.56
40.18	582	103.5	5.62	0.50
40.69	465	88.0	5.28	0.62
41.59	494	82.0	6.02	0.59
42.00	503	87.2	5.77	0.58
42.40	430	72.0	5.97	0.67
42.77	435	74.5	5.84	0.67

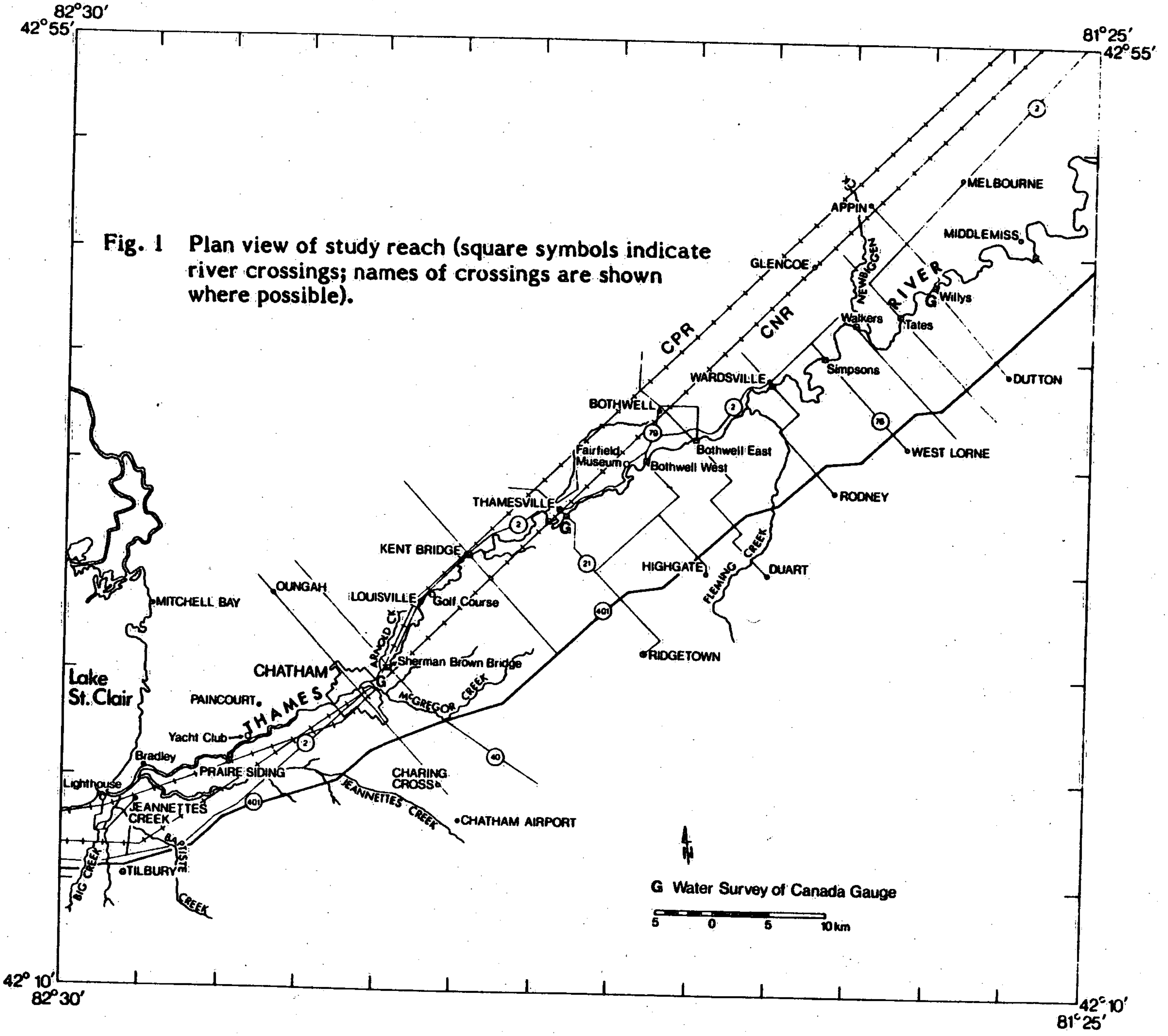


Fig. 1 Plan view of study reach (square symbols indicate river crossings; names of crossings are shown where possible).

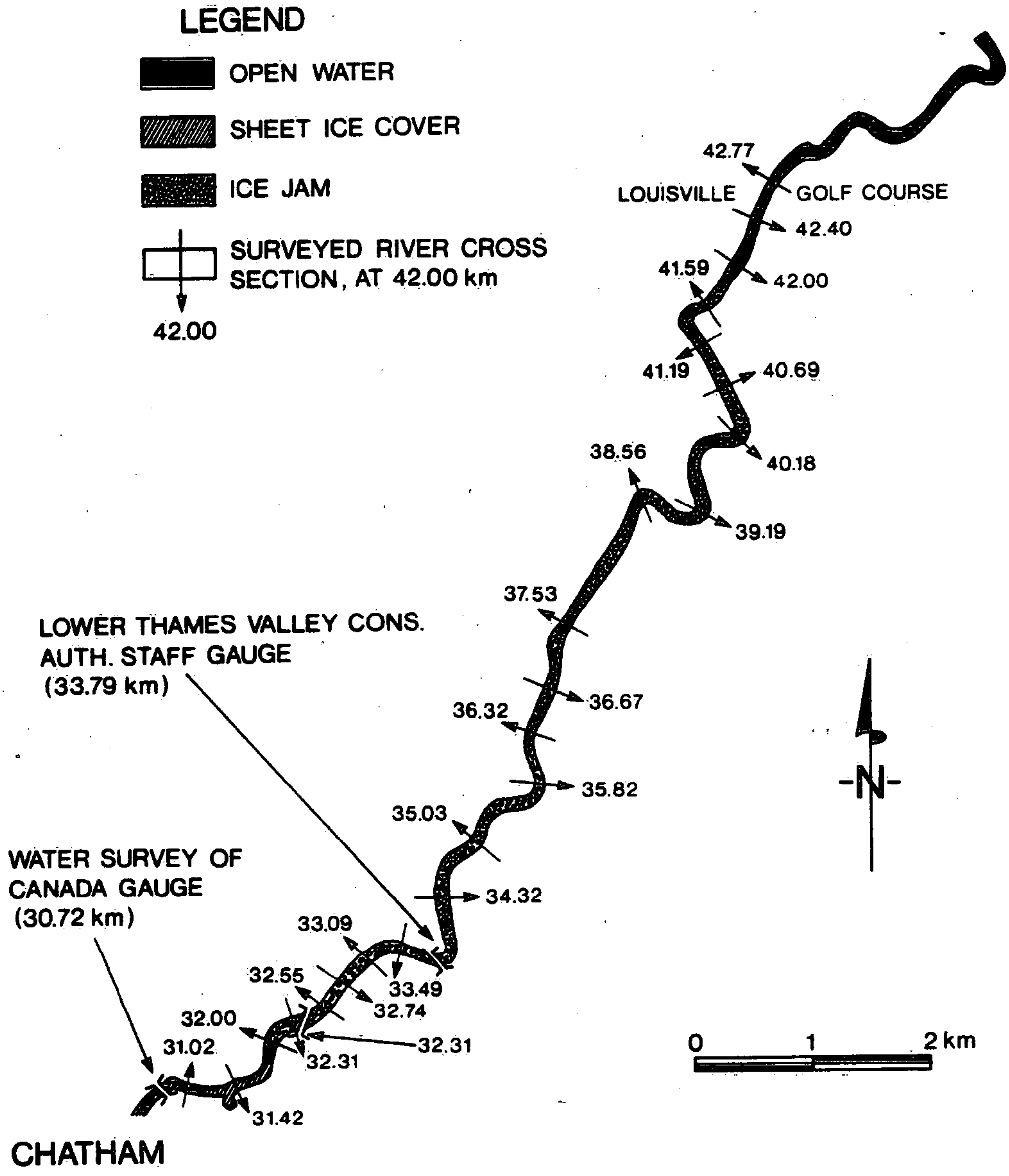
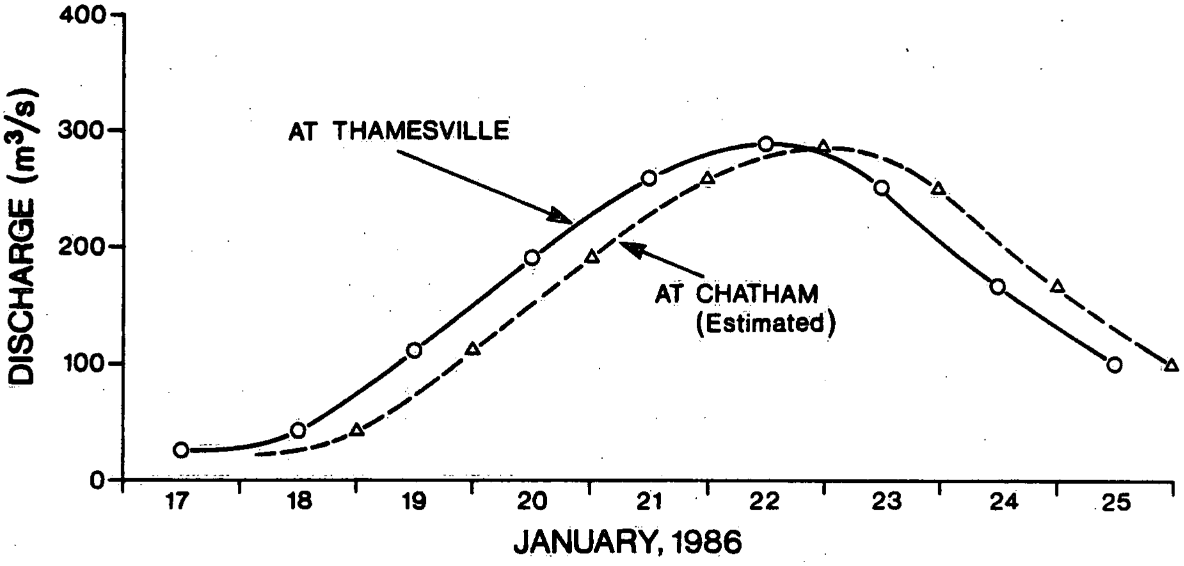


Fig. 2. Ice conditions in Thames River above Chatham, in the morning of Jan. 23, 1986.

Fig. 3. Discharge hydrographs during January breakup. (Water Survey of Canada, Guelph, Provisional Data)



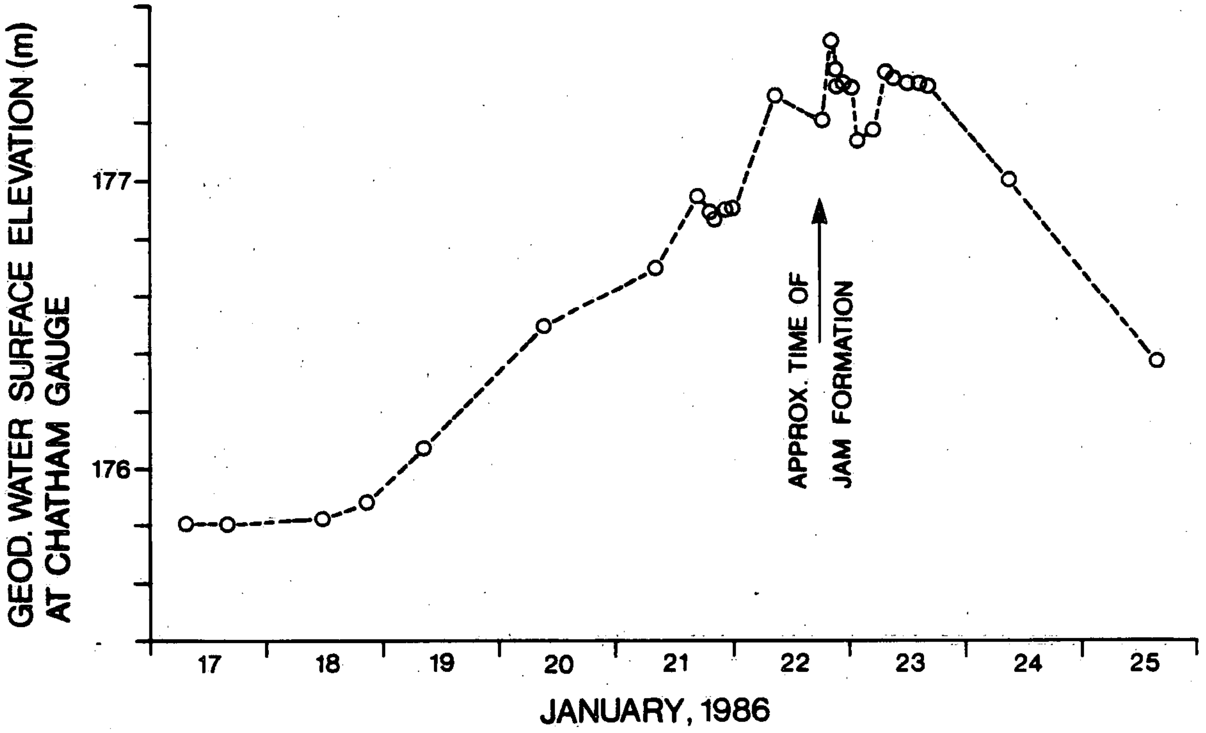
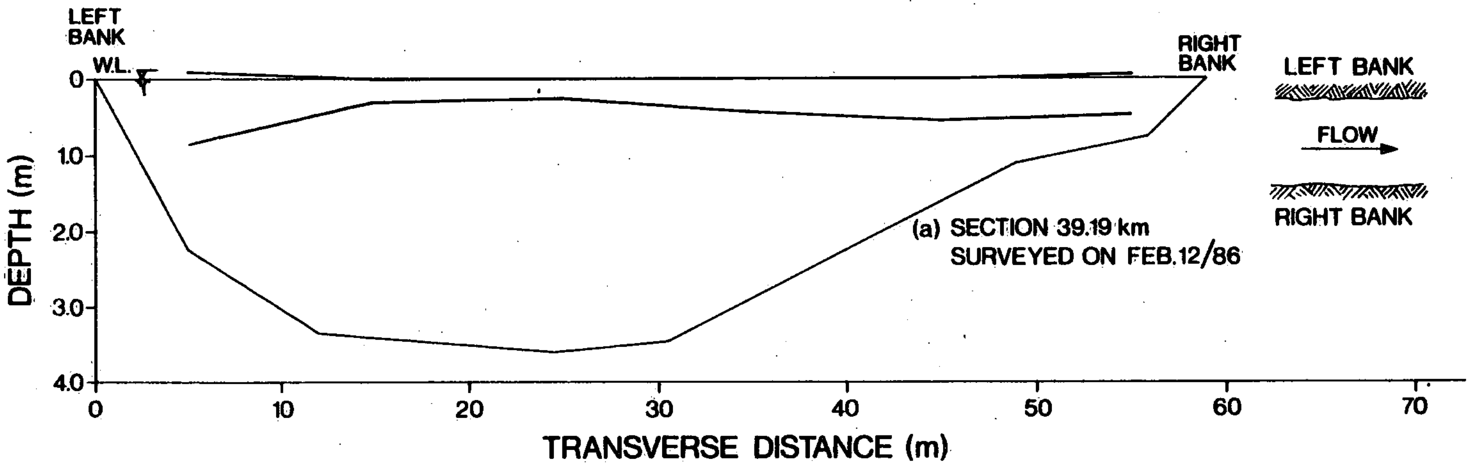


Fig. 4. Stage hydrograph during January breakup at Chatham gauge.



Figs. 5(a) to 5(p). Transverse distribution of ice jam thickness.

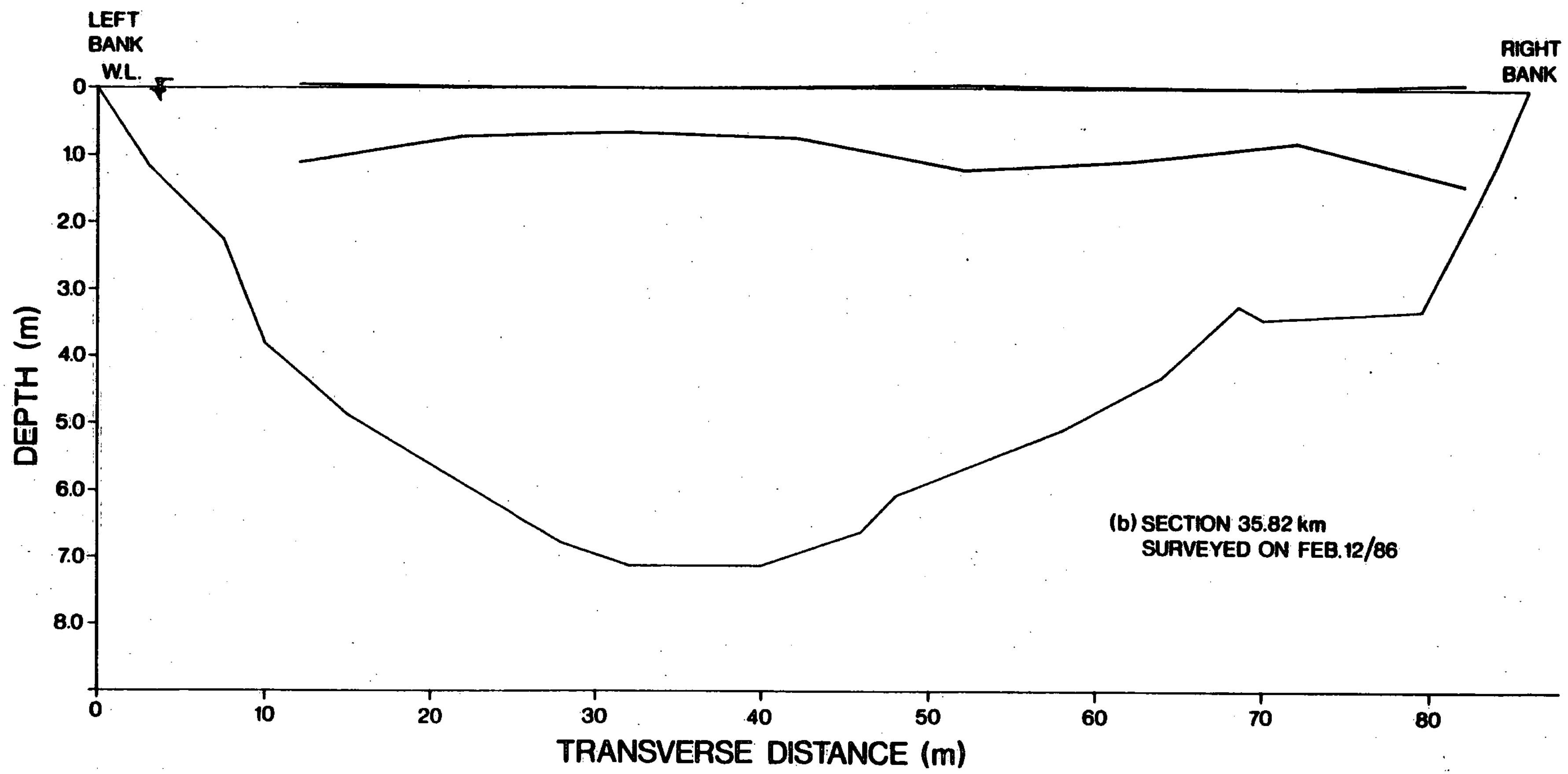
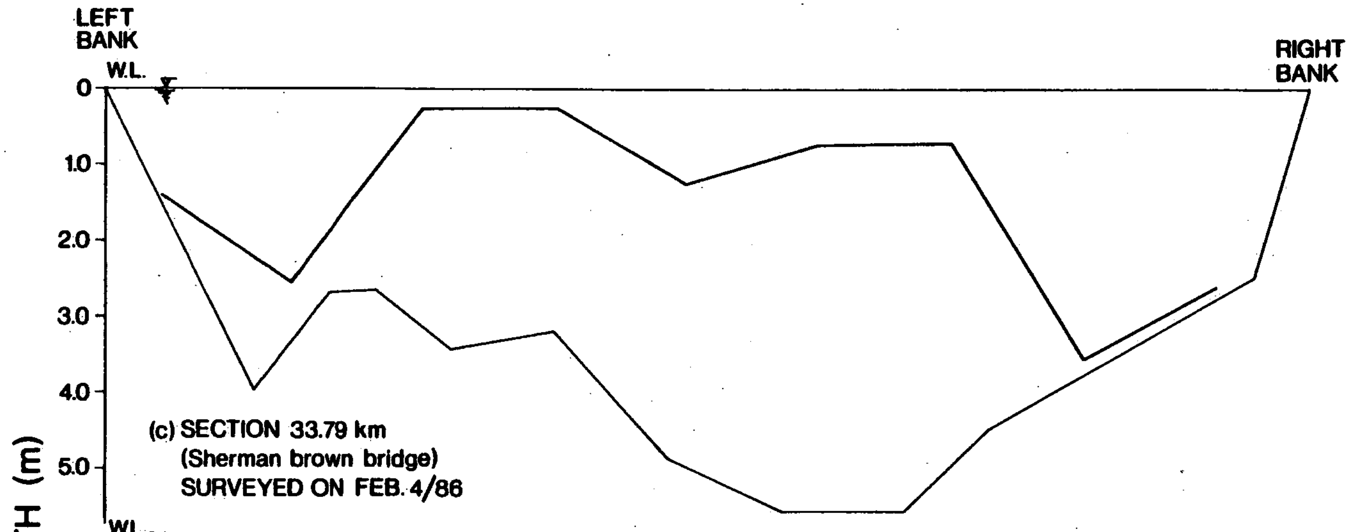


Fig. 5(b). (continued)

Fig. 5(c). (continued)



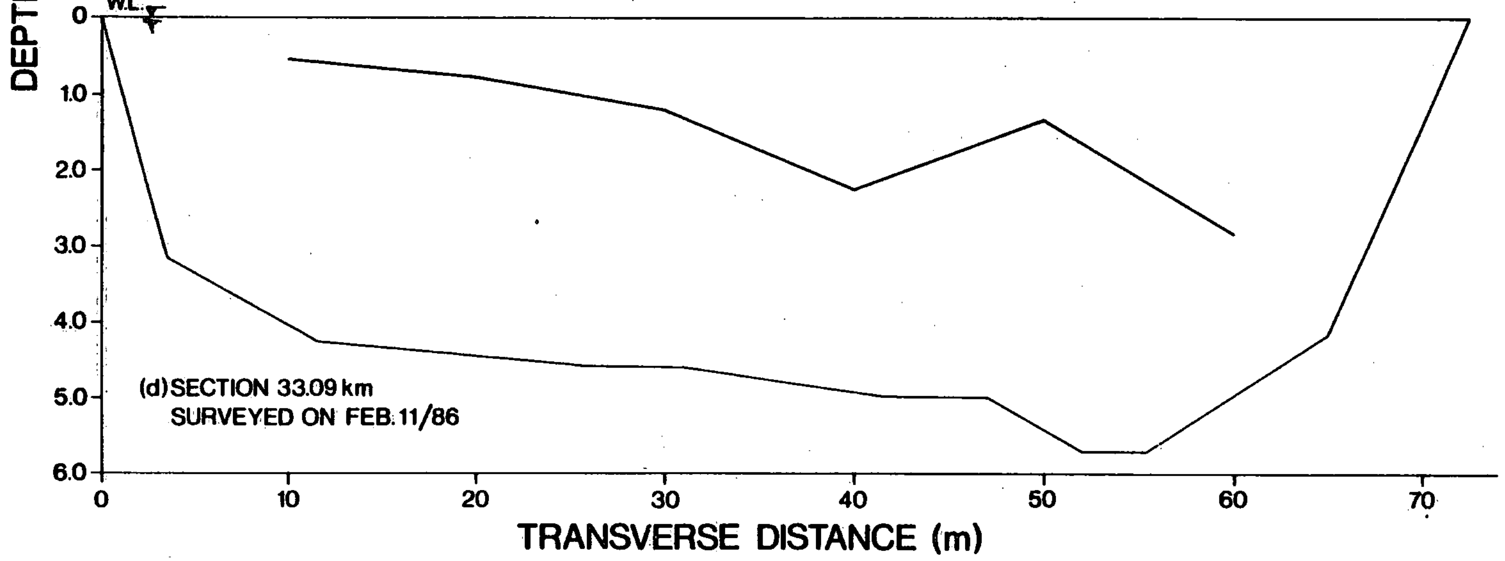
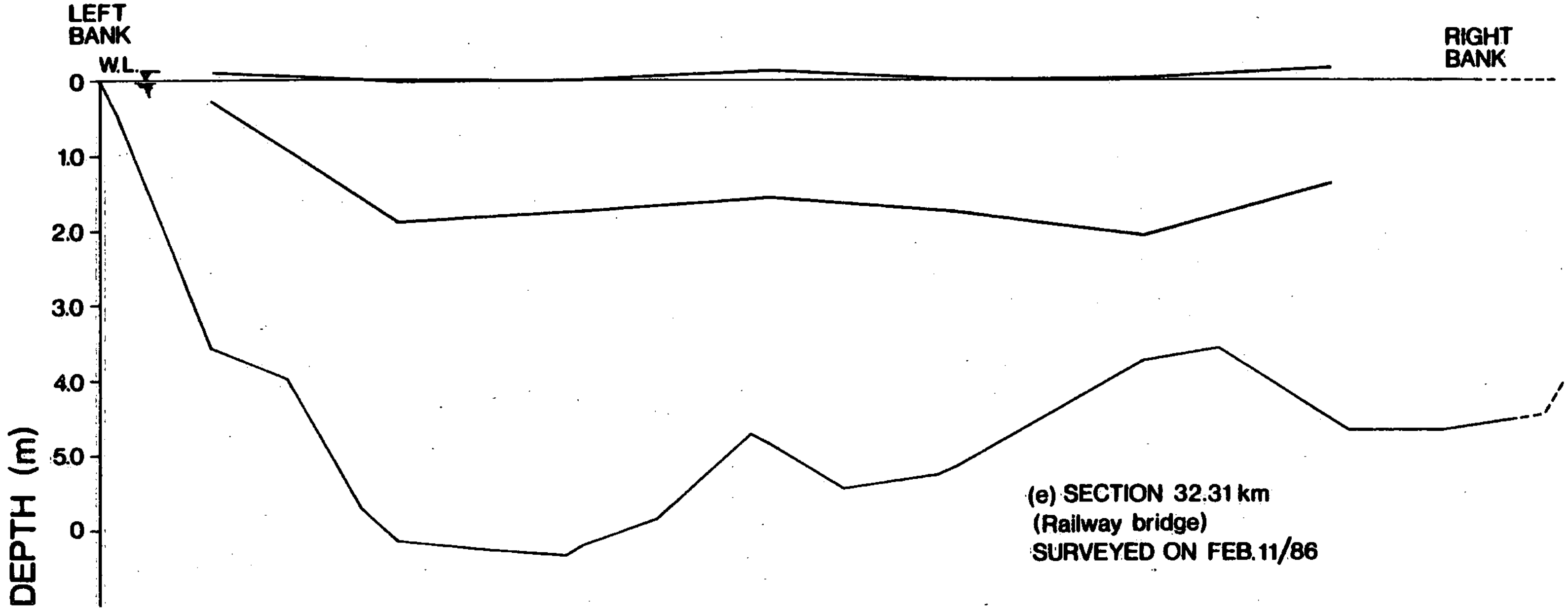


Fig. 5(d). (continued)

Fig. 5(e). (continued)



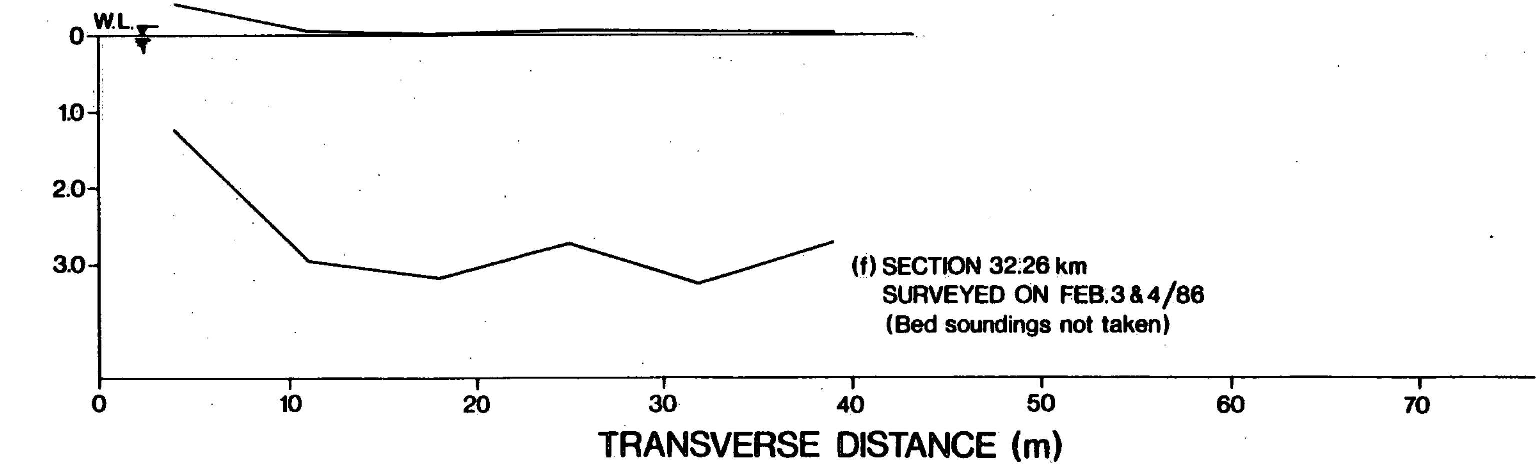
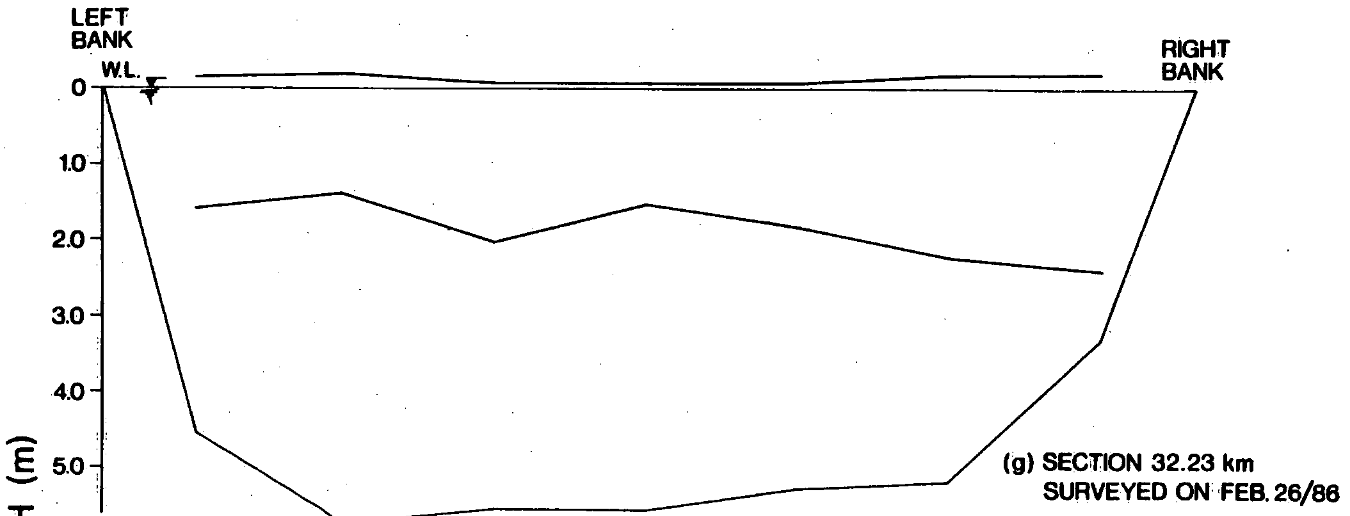


Fig. 5(f). (continued)

Fig. 5(g). (continued)



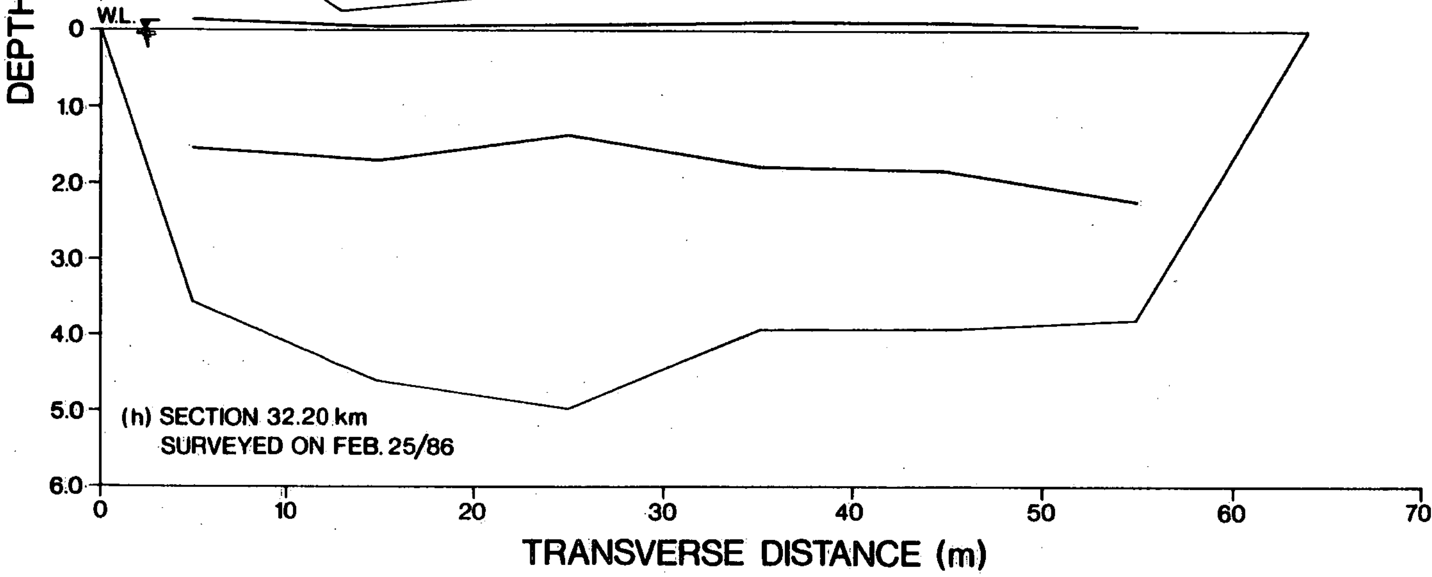
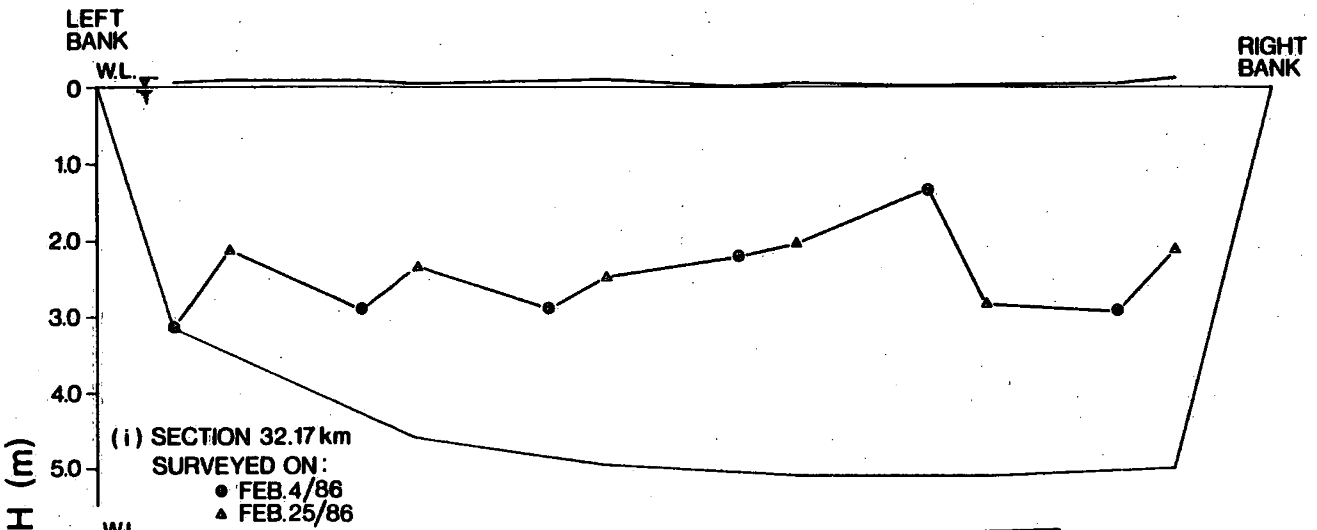


Fig. 5(h). (continued)

Fig. 5(i). (continued)



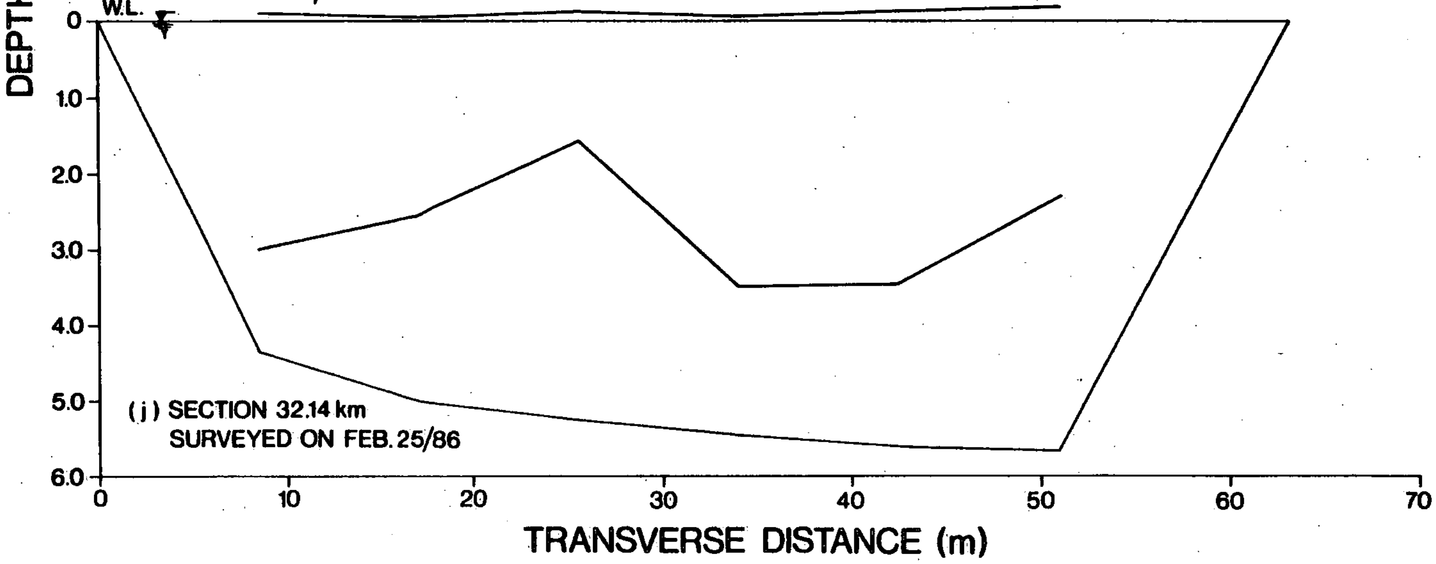
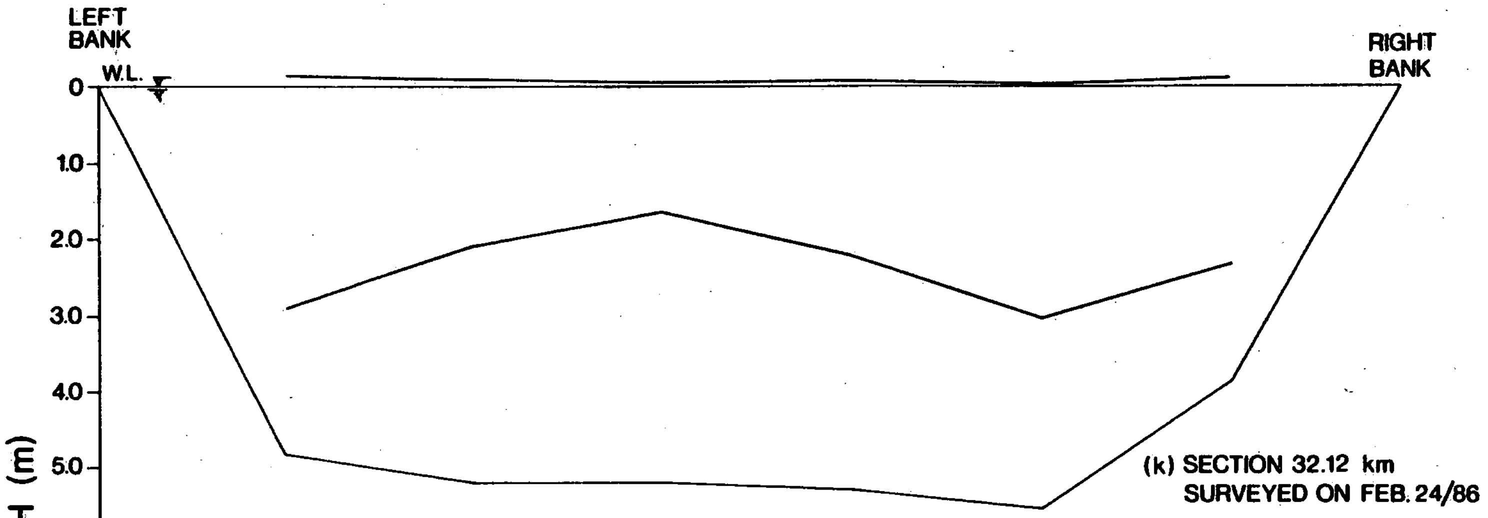


Fig. 5(j). (continued)

Fig. 5(k). (continued)



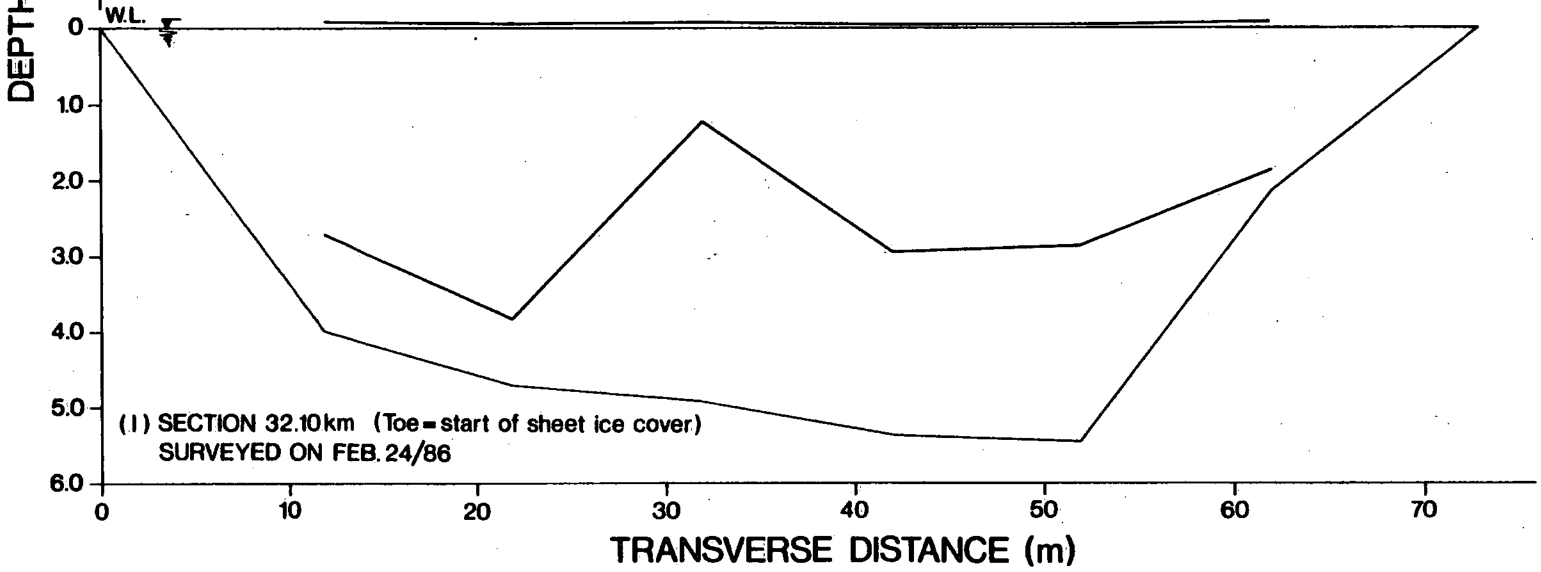
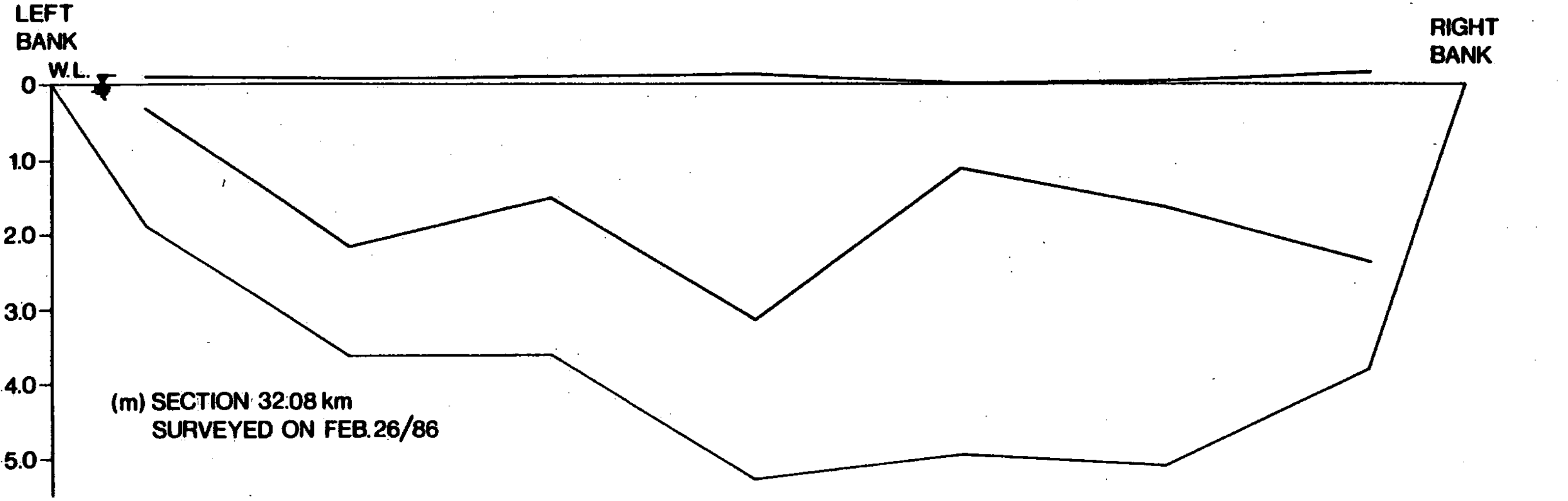


Fig. 5(l). (continued)

Fig. 5(m). (continued)



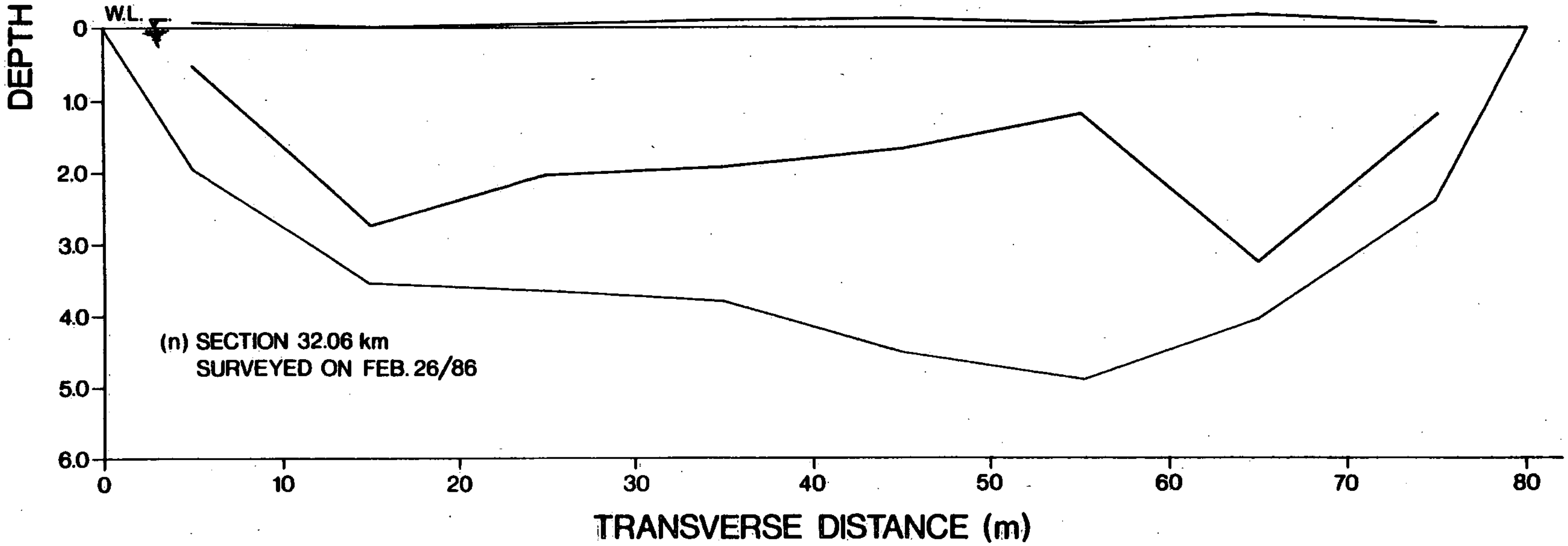
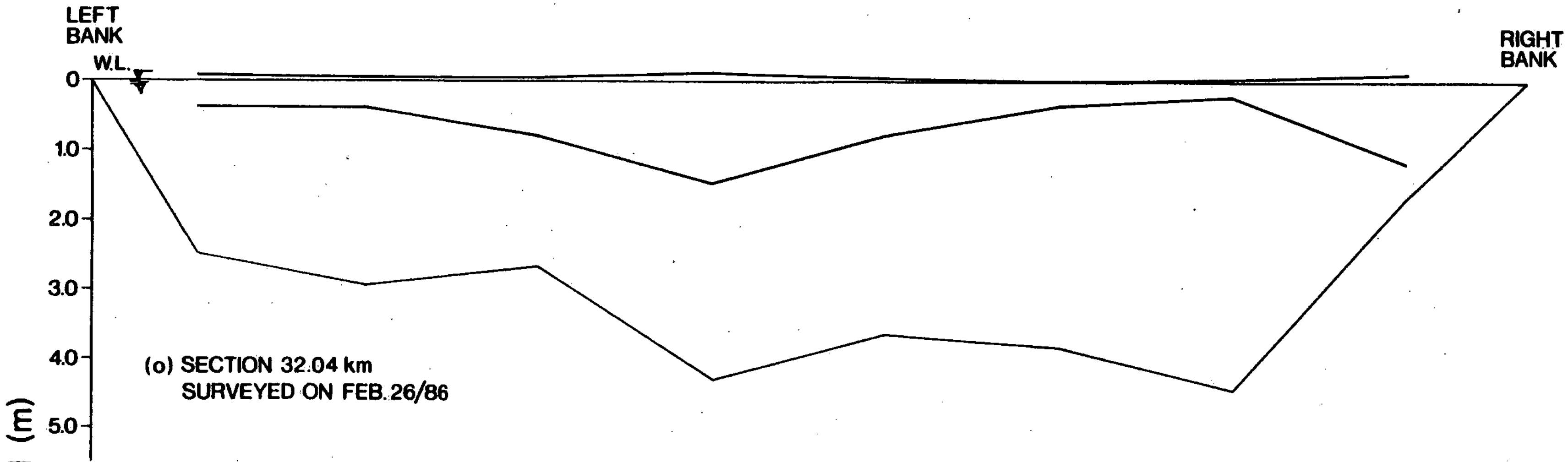


Fig. 5(n). (continued)

Fig. 5(o). (continued)



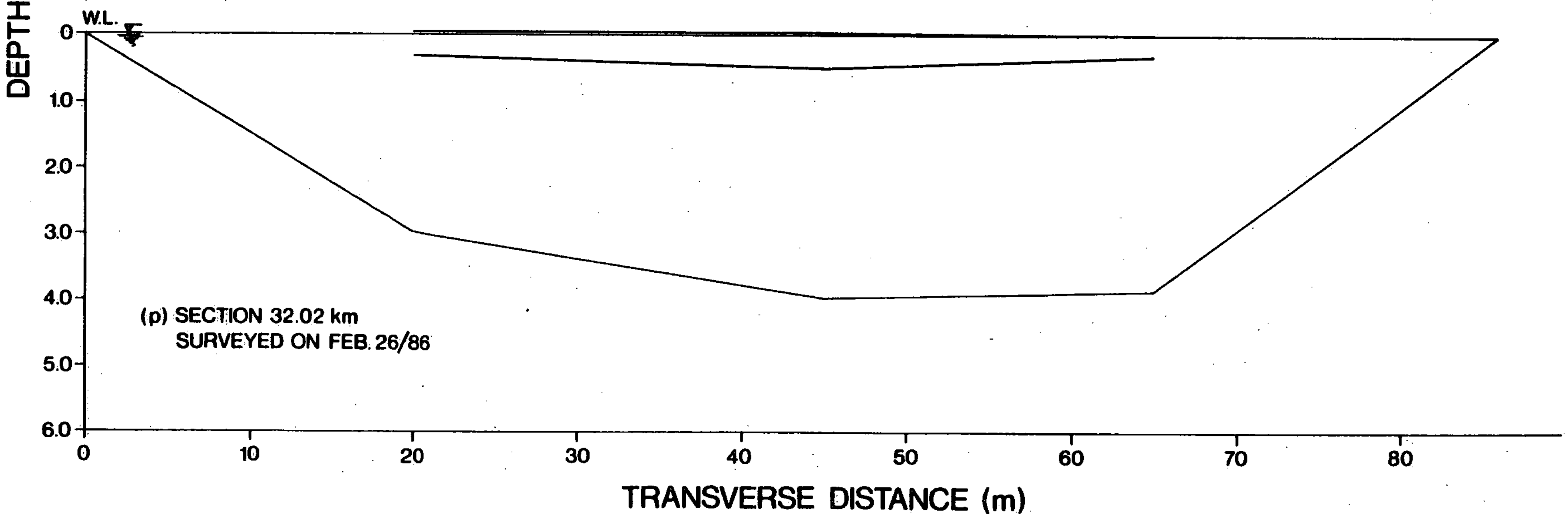
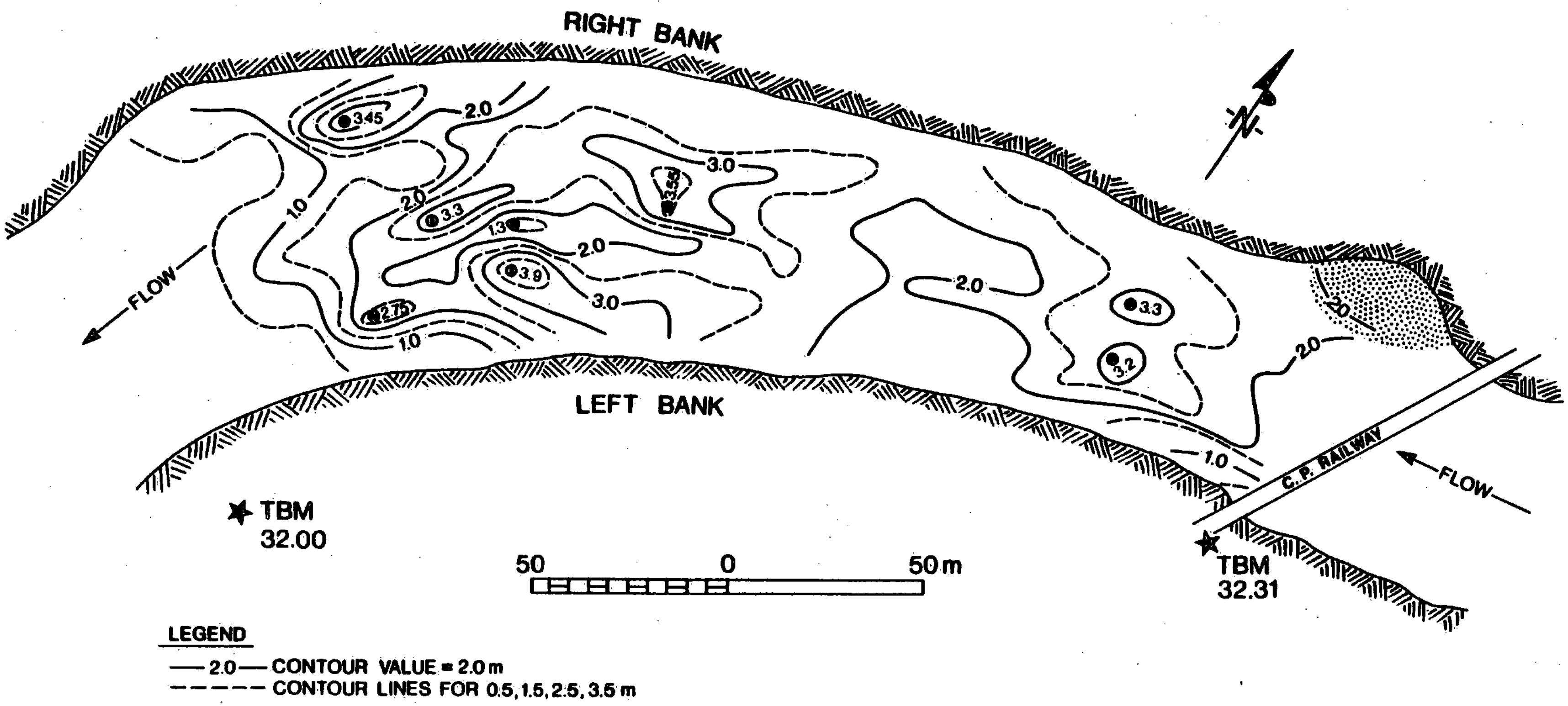


Fig. 5(p). (conclusion)

Fig. 6. Contour-line plot of ice jam thickness in the vicinity of the toe.



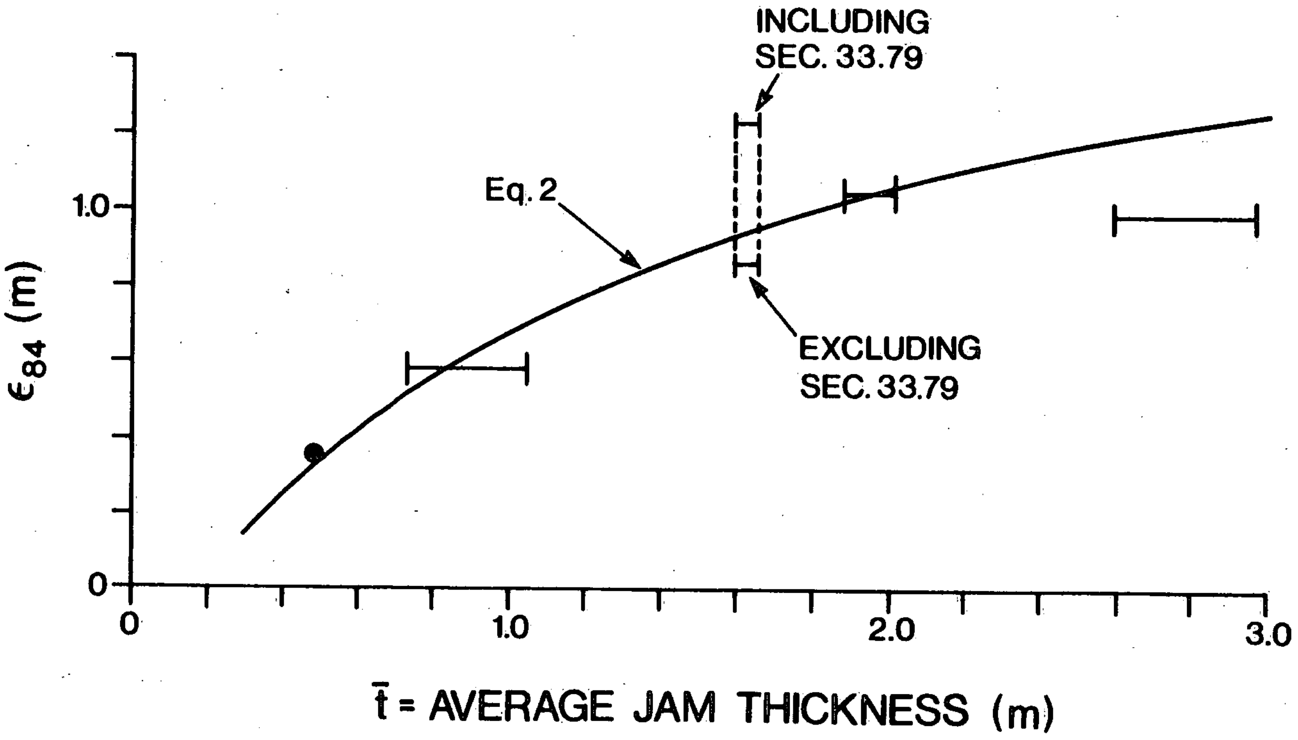


Fig. 7. Variation of ϵ_{84} with $\bar{t}$ and comparison with previous results.

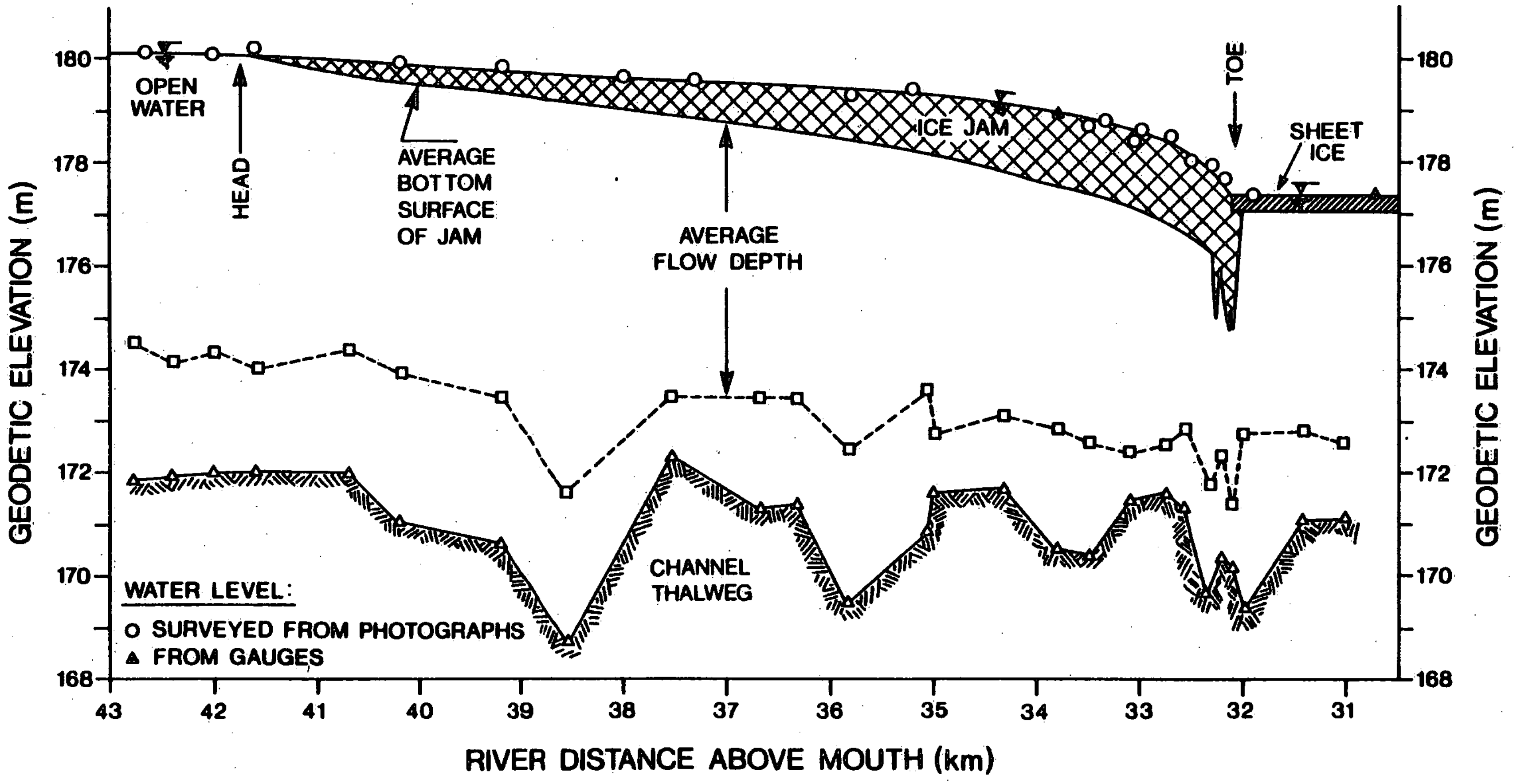


Fig. 8. Longitudinal profile of ice jam.

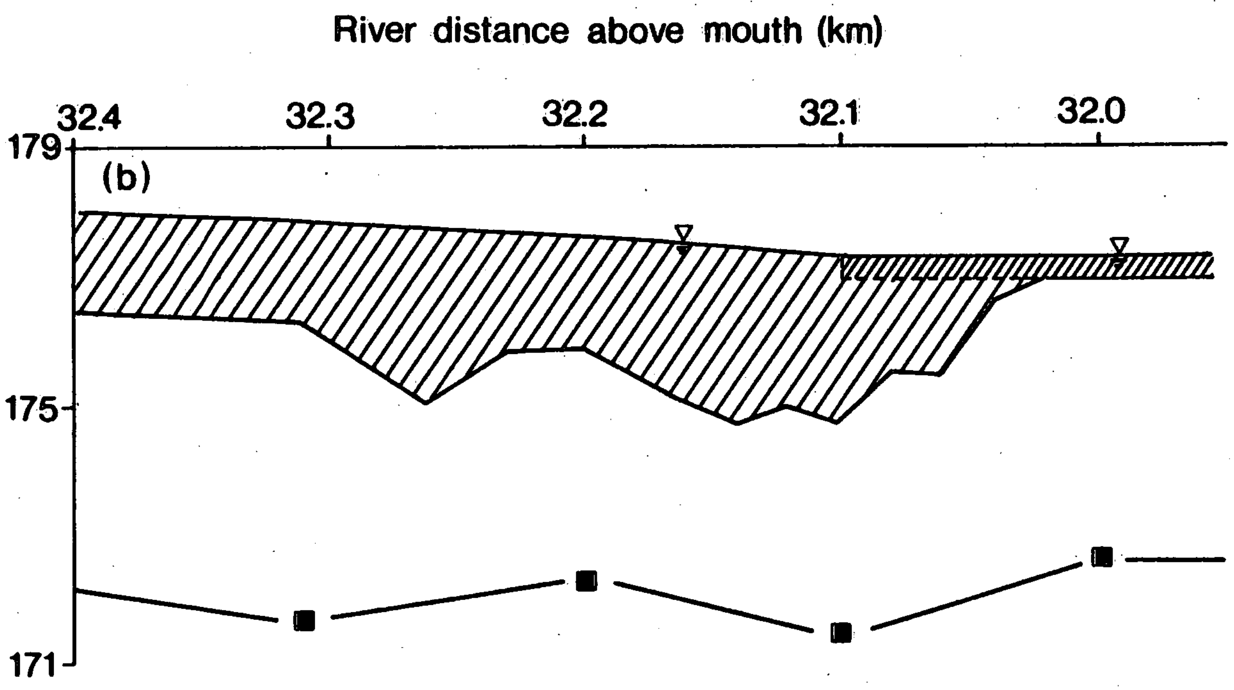


Fig. 9. Longitudinal profile of jam in the vicinity of the toe.

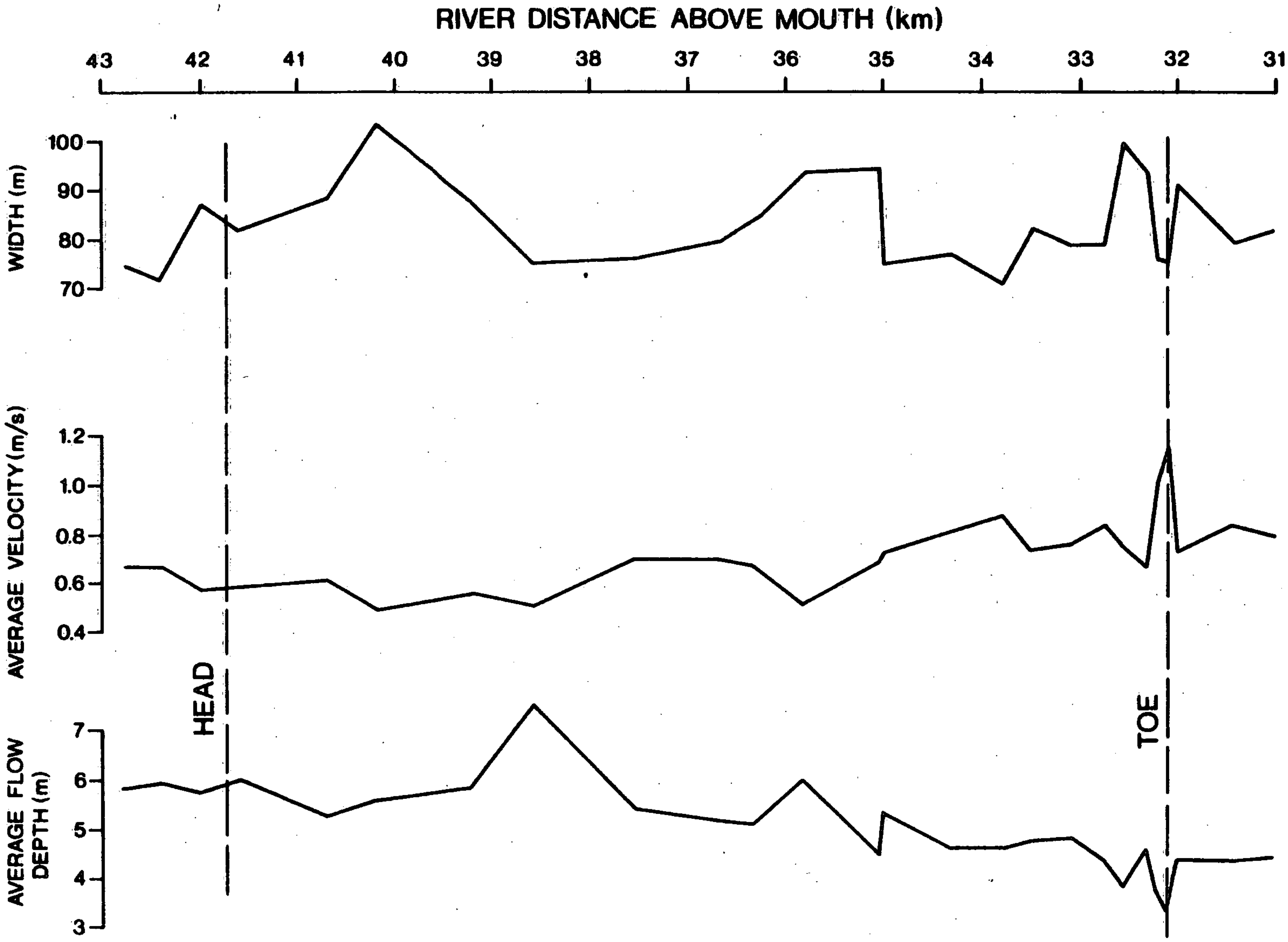


Fig. 10. Longitudinal variations of width, velocity and flow depth in the jammed reach.

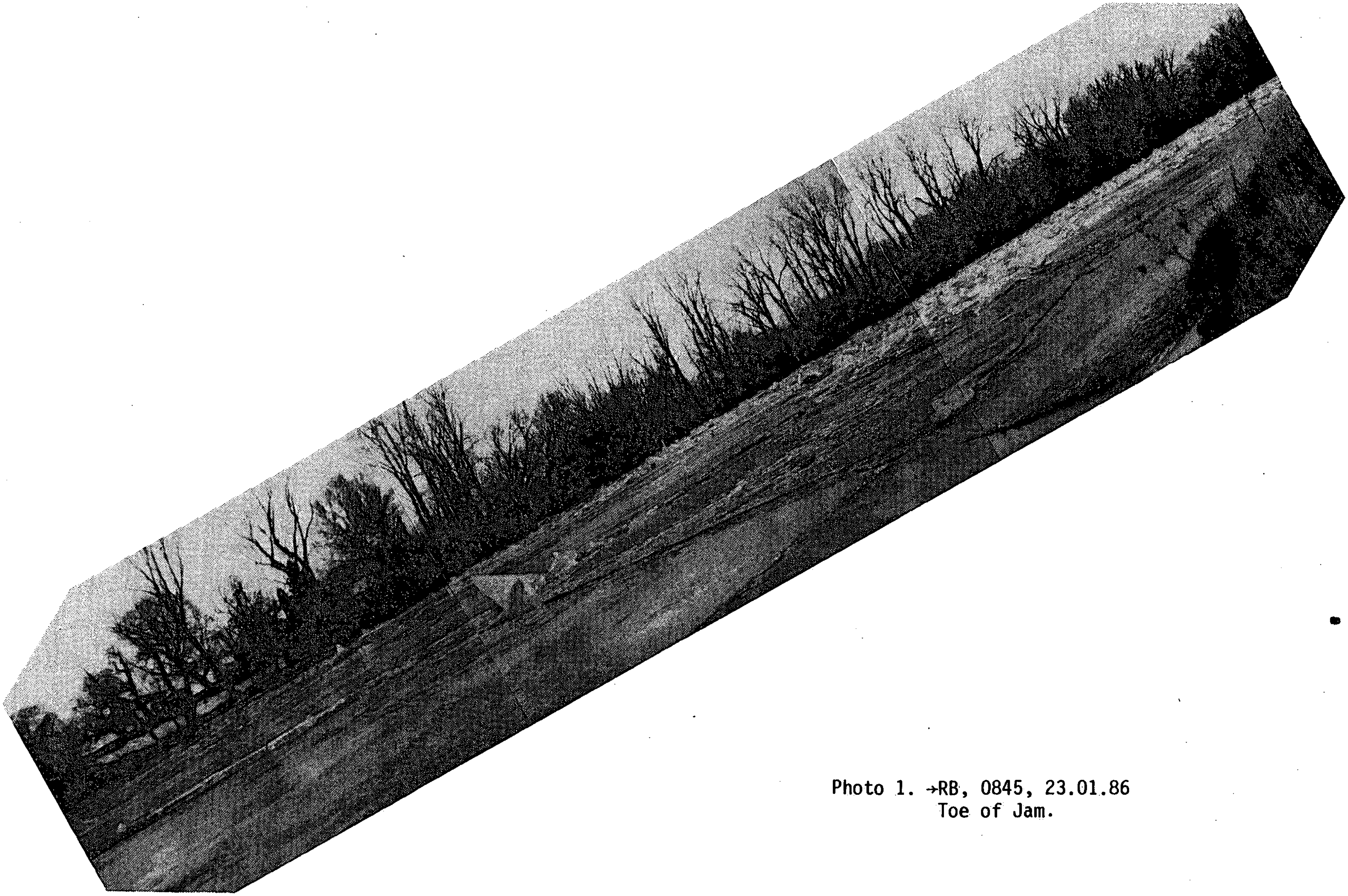


Photo 1. →RB, 0845, 23.01.86
Toe of Jam.

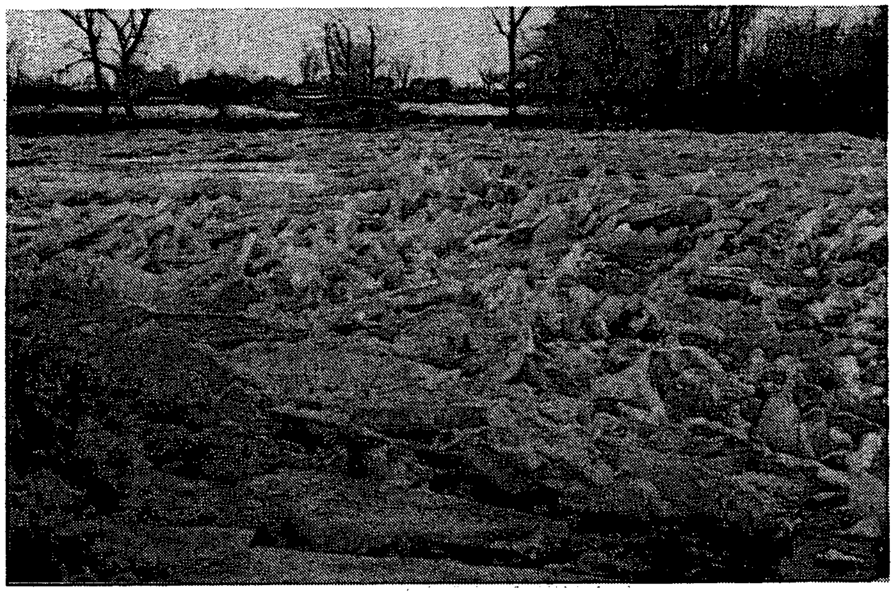


Photo 2. →d/s, 0840, 23.01.86
Surface appearance of
jam near toe.

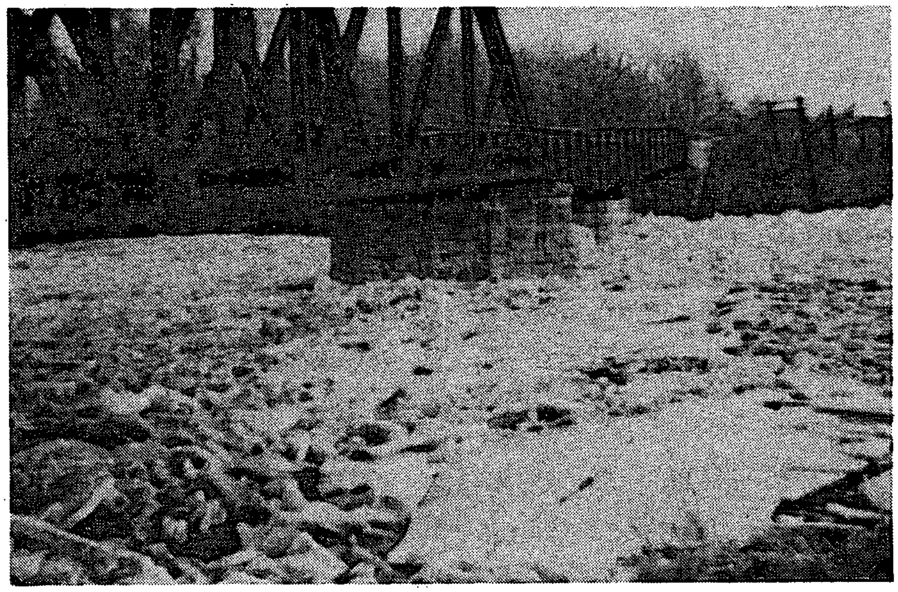
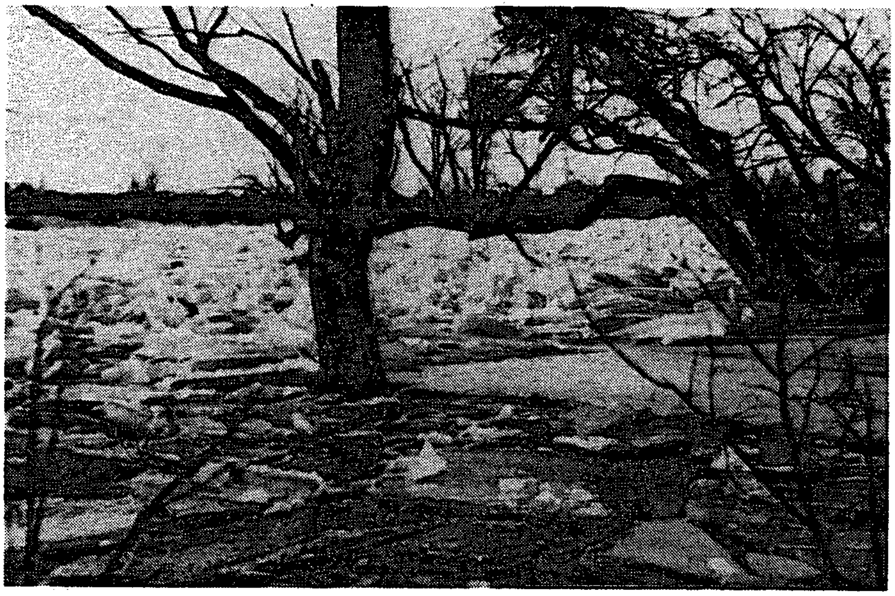


Photo 3. →RB, 0830, 23.01.86
View of jam at CP Railway
Crossing (32.31 km).



Photos 4 & 5. Examples of photos used to survey ice jam water levels. Upper photo: →LB at mouth of Arnold Creek; lower photo: →LB, 300 m d/s Sherman Brown Bridge.

Photo 6. Drilling access hole for thickness measurement, February 1986.

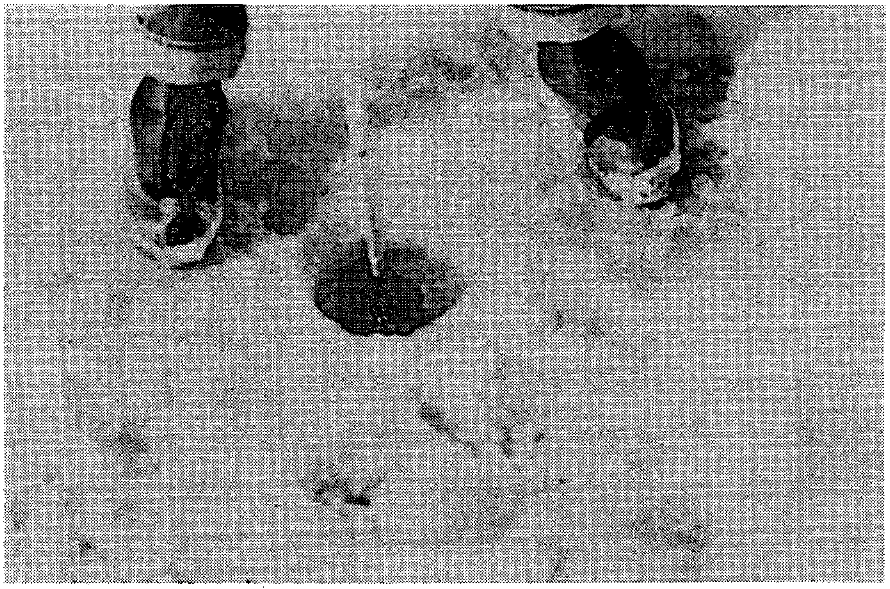


Photo 7. Measuring the thickness of the jam. February 1986.

Photo 8. Preparing to drill near
CP Railway Crossing.
February 1986.

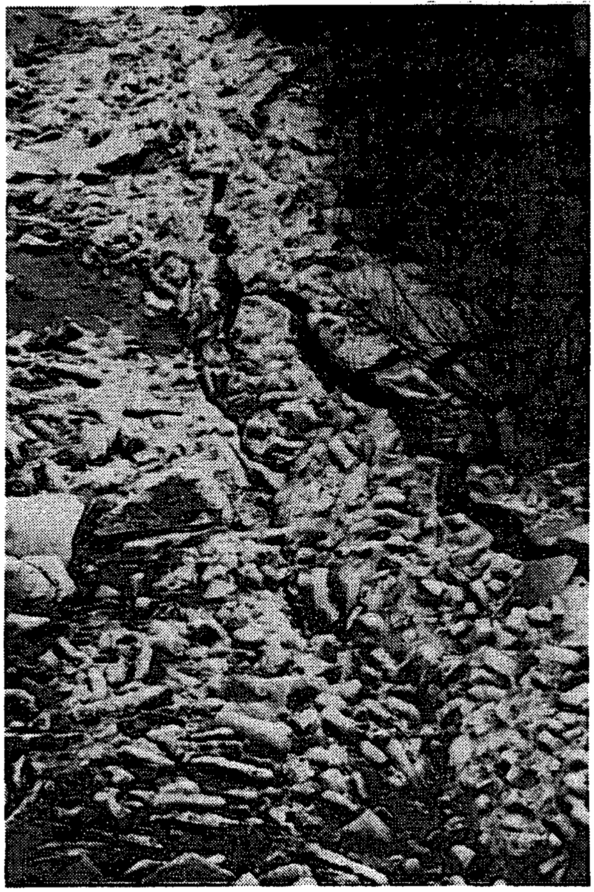


Photo 9. Ice pile on right bank,
formed by decrease in water
level. February 1986.