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**ICE FREEZE-UP AND BREAKUP IN
THE UPPER GRAND RIVER:
1982-83 OBSERVATIONS**

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ABSTRACT

The third year's ice observations on the Upper Grand River are described and interpreted. The winter was mild, and a "mature" breakup was observed. Breakup initiation data for the Marsville gauge site are consistent with earlier findings on other rivers. However, this is not the case for the other two gauges, Upper Belwood and West Montrose. A possible cause of this discrepancy is the different manner of ice breakup and removal at these locations. Data from the freeze up process at Upper Belwood and West Montrose are analyzed and compared with the theory of equilibrium floating ice jams. The results are consistent with earlier findings on breakup jams but more data are needed before conclusions can be made.

SOMMAIRE

Dans le présent rapport sont présentées et interprétées les données de la troisième année d'observation glaciologique dans la partie supérieure de la rivière Grand. L'hiver a été doux et on a pu observer une débâcle "mature". Les données sur le début de la débâcle à la station de jaugeage de Marsville concordent avec les résultats antérieurs obtenus pour d'autres cours d'eau. Cependant, il n'en va pas de même pour les sites de jaugeage de Upper Belwood et West Montrose. On pourrait expliquer cette incompatibilité par les différences entre les processus de débâcle et d'élimination des glaces à ces endroits. On a analysé les données sur le processus d'englacement à Upper Belwood et West Montrose et on les a comparées à la théorie des embâcles flottants à l'équilibre. Les résultats sont compatibles avec des données préliminaires concernant les embâcles, au moment de la débâcle mais il est nécessaire d'obtenir davantage de données pour tirer des conclusions.

MANAGEMENT PERSPECTIVE

This report presents the results of a continuing field observation program on ice jams. These data are used to verify/modify existing theories and models, and will help to develop methods to forecast, control and prevent ice jams and associated flooding.

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PERSPECTIVE-GESTION

Ce rapport présente les résultats d'un programme continu d'observations des embâcles sur le terrain. Ces données sont utilisées pour vérifier ou modifier les théories et les modèles qui existent à l'heure actuelle et permettront de concevoir d'autres méthodes de prévision, de contrôle et de prévention des embâcles et des inondations qui y sont associées.

Le chef intérimaire
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1.0 INTRODUCTION

The Grand River Study is part of a long-term field research program initiated in 1979. The objective of the program is to improve methodologies for deterministic and statistical solutions to problems related to flooding. Specific goals are:

- To develop an index for forecasting the time of breakup.
- To identify channel features that are conducive to ice jamming and assess associated frequencies.
- To provide a data base for statistical analysis of peak breakup stages and develop a methodology to transpose the results to sites where little or no historical information exists.
- To obtain quantitative data for testing and improving existing theories.
- To improve qualitative understanding as a means of guiding laboratory and theoretical research.

At the present time, observations are carried out in two reaches, one on the Lower Thames River from Thamesville to the mouth; the other on the Upper Grand River from Leggatt to West Montrose (see Figure 1). The two study reaches have different characteristics. The Lower Thames River has a fairly uniform slope of approximately 0.2 m/km, and carries an average discharge of 55.2 m³/s at Thamesville. The study reach on the Upper Grand River has a wide range of slopes and may be divided into five sections with average slopes ranging from 0.73 m/km (at Lake Belwood) to 8.20 m/km (at Elora Gorge) (see Figure 2). The Grand River study reach has an average discharge of 7.70 m³/s at Marsville.

Observations of the freeze-up and breakup in the Lower Thames River 1979-1983, have been documented in previous reports (Beltaos, 1981, 1983, 1984). Results from the first two seasons (1980-81, 1981-82) on the Upper Grand River have also been reported (Wong & Beltaos, 1983). The present report gives the results of the 1982-83

season on the Grand River and contains the following: a description of the study reach; summaries of freeze-up and breakup observations; and analysis and interpretation of the recorded data. During freeze-up a large buildup of slush at West Montrose caused the water level to rise 1.7 m in 26 hours, flooding the houses on the left bank. The winter was mild and the breakup was "mature" and uneventful.

2.0 DESCRIPTION OF STUDY REACH

The Grand River study reach is 62 km long with its upstream boundary at Leggatt and its downstream boundary at West Montrose (see Figure 1). The downstream boundary is not a strict one and observations have been carried out as far downstream as Winterbourne. Leggatt, the upstream boundary, is assigned a chainage of 0.00 km and all distances downstream are measured along the river from this point. Table 1 contains a list of the more important points along the study reach and their respective chainages, as measured on 1:50,000 topographic maps.

Figure 2 is an approximate water surface profile of the study reach. Water surface elevations have been obtained from a series of 1:50,000 topographic maps at the intersections of elevation contours with the stream boundaries. Straight lines have been drawn between points representing successive contour intersections. River crossings and gauge locations are also shown in Figure 2.

The study reach may be divided into five sections as shown in Figure 2. The divisions are based on the average slopes and the ice regimes in the sections. The sections are listed below and their average slopes and lengths are summarized in Table 2.

- I Leggatt to Upper Belwood.
- II Lake Belwood.
- III Shand Dam to Elora.
- IV Elora Gorge.
- V Inverhaugh to West Montrose.

Ice related problems have been known to occur in only two of the five sections: section I and section V. Section I, which includes Grand Valley, Waldemar and Marsville, is 25 km long and has an average slope of 1.44 m/km. Section V, which includes Inverhaugh and West Montrose, is 13 km long and has an average slope of 1.96 m/km.

Lake Belwood (section II) freezes up early in the winter and acts as a control against spring flooding. The Shand Dam is regulated during the winter months so that the storage in the lake is reduced. This enables the lake to accept the increased flow of water and ice delivered by section I during the spring runoff. The ice is held in the lake and is not allowed to move downstream into sections III and IV. The dam is also capable of controlling, to some extent, the discharge from the lake as in the case of the 1981 West Montrose flooding.

Sections III and IV are extremely steep with average slopes of 3.61 m/km and 8.20 m/km, respectively. This length of river usually stays free of ice during the winter months. There are three weirs in Fergus and Elora, at 40.37 km, 45.75 km and 46.42 km. Short lengths of ice (~1 km) form behind the weirs but the ice usually melts in place and does not cause any problems.

There are three Water Survey of Canada (WSC) gauges and six Grand River Conservation Authority (GRCA) gauges within the study area. Locations of the gauges are noted in Figure 2 and Table 1. River characteristics for the three WSC gauges are summarized in Table 3 for the period 1970 to 1979. At Marsville, the minimum and maximum recorded daily discharges are 0.03 m³/s (July 1979) and 306 m³/s (April 1975). The ten-year average discharge is 7.70 m³/s. At this flow, the average open water width, depth and velocity in the vicinity of this site are calculated as 38.0 m, 0.63 m and 0.56 m/s based on nearby hydrometric surveys. The average river slope is approximately 2.31 m/km and the Manning coefficient of the river bed, n_b , is 0.052 at Q (discharge) = 7.70 m³/s.

3.0 SUMMARY OF FREEZE-UP AND BREAKUP OBSERVATIONS

3.1 Freeze-Up 1982/83

In December and early January, the temperature fell below 0°C and ice began to form in the study reach. The ice, however, was removed on January 10 and 11 when the mean daily temperature rose above 0°C and approximately 9 mm of rain fell in the watershed. The warm spell is documented in Figures 3(a) and 3(b) where the temperature and precipitation data at Elora and Grand Valley are plotted for January, February and March, 1983.

The cold weather returned on January 12 and freeze-up observations were carried out between January 12 and January 21. Daily accounts of the freeze-up process are summarized below.

January 12

Mean temperature =	-11.3°C at Grand Valley; -10.3°C at Elora
Snow	= none
Discharge	= 16.6 m ³ /s near Marsville; 23.3 m ³ /s at West Montrose

On this date, the water level in the river was still high because of the increased discharge from the recent rainfall. The river at most observation points was open with some border ice along its banks and with slush flowing.

At 1451 h, the leading edge (the upstream end) of an ice cover was observed 650 m downstream of the Upper Belwood bridge. A portion of the incoming slush submerged upon arriving at the leading edge, while the rest of the incoming slush gathered on the water surface causing the leading edge to move upstream until a shove occurred and the cover thickened. This process was repeated as the leading edge moved upstream. Photo A1 shows the texture of the ice cover near the leading edge.

In Section III of the study reach, ice covers with open patches were observed at the weirs in Fergus and Elora.

January 13

Mean temperature = -9.5°C at Grand Valley; -8.0°C at Elora
Snow = none
Discharge = $9.9 \text{ m}^3/\text{s}$ near Marsville; $21.3 \text{ m}^3/\text{s}$
at West Montrose

The ice cover at Upper Belwood moved further upstream and by 1000 h, the leading edge was $\approx 250 \text{ m}$ d/s of the bridge. The rate of the ice cover progression, Rate_{ic} from its last observed location to its present location is approximately equal to 0.02 km/h .

Slush continued to flow in all parts of the river and border ice continued to grow along the banks.

January 16

Mean temperature = -11.0°C at Grand Valley; -11.1°C at Elora
Snow = none on January 16 but 5.4 cm fell on
January 14 and 15 at Grand Valley; none on
January 16 but 5.0 cm fell on January 14
and 15 at Elora
Discharge = $5.2 \text{ m}^3/\text{s}$ near Marsville; $19.0 \text{ m}^3/\text{s}$
at West Montrose

By 1100 h, the ice at Upper Belwood progressed past the bridge and beyond the bend 350 m u/s of the bridge (Photo A2 and A3). $\text{Rate}_{ic} \approx .008 \text{ km/h}$. By comparing the Rate_{ic} values, it is seen that the ice cover progressed at a slower rate as it moved towards and past the Upper Belwood bridge. The slower rate was probably due to the river bed profile. The steep section upstream the bridge followed by a deeper,

less-steep section downstream of the bridge may have promoted a thicker slush accumulation just downstream of the bridge (possibly a hanging dam formation).

Other factors which may account for the lower $Rate_{ic}$ are warmer temperatures between January 13 and 16 (Figures 3(a) and 3(b)) and a decrease in the discharge. Both factors would cause a reduction in frazil slush production. The water level variation with time during the freeze-up in Figure 4 shows that the average daily gauge reading on this date was $H_f = 1.45$ m (Elev. = 427.80 m). By 1423 h, the leading edge was ≈ 700 u/s of the bridge. $Rate_{ic} \approx 0.10$ km/h. The ice cover progressed at a faster rate after passing the Upper Belwood bridge.

By 1210 h, ice cover had formed at the weir in Grand Valley and extended past the Amaranth St. bridge. At 1315 h, the river was still open along Hwy. 25 north of Grand Valley.

January 17

Mean temperature = -13.8°C at Grand Valley; -14.4°C at Elora
Snow = none
Discharge = $4.8 \text{ m}^3/\text{s}$ near Marsville; $18.7 \text{ m}^3/\text{s}$
at West Montrose

By 1014 h, the ice cover that originated from Upper Belwood had moved beyond the 2nd crossing below Marsville and was ≈ 400 m u/s of that bridge. $Rate_{ic} \approx 0.08$ km/h.

By 1200 h, the ice cover north of Grand Valley extended along Hwy. 25 and was just downstream of the 1st crossing above Grand Valley.

January 18

Mean temperature = -14.8°C at Grand Valley; -15.0°C at Elora
Snow = none
Discharge = $4.3 \text{ m}^3/\text{s}$ near Marsville; $16.0 \text{ m}^3/\text{s}$
at West Montrose

By 1000 h, the ice cover that originated from Upper Belwood had passed the 1st crossing below Marsville and was moving towards the Marsville gauge site.

At 1015 h, the river at Marsville gauge site was still open with slush flowing downstream and with some border ice at the side. Photo A4 shows the condition of the control section ≈ 250 m below the gauge. The Water Survey of Canada chart for this gauge in Figure 5 shows that the water level had been fairly constant over the past two days and that the approaching ice cover had not yet affected the level.

By 1120 h, the ice cover near Grand Valley had progressed to ≈ 75 m below the 2nd crossing above Grand Valley.

At 1145 h, the ice cover was ≈ 250 m d/s of the Marsville gauge site. $\text{Rate}_{ic} = .10$ km/h. The incoming slush collected at the leading edge of the ice cover and very quickly froze into place. Unlike the process at Upper Belwood, there was very little collapsing or shoving of the ice cover. At 1238 h, the leading edge was ≈ 50 m above the bridge and at 1313 h, the edge was ≈ 100 m above the bridge. $\text{Rate}_{ic} = .23$ km/h. Figure 5 shows the increase in the water level as the ice cover formed through the gauge site. The figure also notes the location of the leading edge at various times throughout the freeze-up. Photos A5, A6 and A7 show the texture of the ice surface, which was much smoother than the surface at Upper Belwood. The average daily gauge reading at Marsville was $H_f = 3.8$ m (Elev. = 437.228 m). After freeze-up, the water level then steadily decreased over the next several days.

At 1345 h, the ice cover north of Grand Valley had progressed to ≈ 50 m d/s of the 3rd crossing u/s of Grand Valley.

January 19

Mean temperature	=	-14.3°C at Grand Valley; -14.2°C at Elora
Snow	=	none
Discharge	=	3.9 m ³ /s near Marsville; 13.0 m ³ /s at West Montrose

In Section V of the study reach, an ice cover formed below Winterbourne and over the past days it advanced past Winterbourne and toward West Montrose. At 0930 h, the leading edge was located ≈ 900 d/s of the West Montrose covered bridge. A profile of the water surface was taken between 0930 h and 1033 h and this profile and two others taken at later times are presented in Figure 6.

By 1145 h, the ice cover north of Grand Valley had progressed beyond the 3rd crossing u/s of Grand Valley and the leading edge of this cover was ≈ 600 m d/s of the Leggatt Bridge.

By 1311 h, a new ice cover had initiated just d/s of the Irvine bridge (1st crossing u/s of Waldemar) and the cover extended upstream to ≈ 250 m d/s of the Quarry bridge (2nd crossing u/s of Waldemar). The smooth texture of the cover is shown in Photo A8 and A9.

At 1450 h, the leading edge of the ice cover was still located ≈ 900 m d/s of the West Montrose bridge. By this time, the water level at the bridge began to rise. A water surface profile was taken between 1515 h and 1600 h (Figure 6). The freeze-up process was similar to that observed at Upper Belwood. Some incoming slush submerged at the leading edge while the rest gathered behind the edge. The slush accumulation slowly extended upstream until the newly formed cover collapsed or shoved reducing its length and, at the same time, increasing its thickness. This action is reflected in the Water Survey of Canada gauge chart in Figure 7. The water level rose quickly until 1608 h when the gauge reading was 11.91 m (Elev. = 320.35 m). The collapse of the ice cover then caused a sharp decline in the water level, thereby creating a spike on the gauge chart. A number of these spikes may be observed throughout the freeze-up period.

January 20

Mean temperature	=	-12.5°C at Grand Valley; -14.5°C at Elora
Snow	=	none
Discharge	=	3.6 m ³ /s near Marsville; 10.0 m ³ /s at West Montrose

At West Montrose, the water level continued to rise overnight as the leading edge approached the gauge (located just downstream of the bridge). At 0940 h, the leading edge was just downstream of the bridge and the gauge was 12.95 m (Elev. = 321.38 m) and rising. $Rate_{ic} = 0.05$ km/h.

At 0958 h, the leading edge was at the wooden bridge. The condition of the ice cover at and downstream of the bridge is shown in Photo A10 and A11.

Incoming slush continued to collect at the leading edge while the river remained open upstream of the bridge. Another water surface profile was taken between 0958 h and 1104 h (Figure 6).

At 1115 h, the leading edge was just upstream of the bridge while the gauge continued to record an increase in the water level. At 1142 h, the edge was between the wooden bridge and Hwy. 86 when another shove occurred. The water level at the gauge continued to rise after that even though the leading edge was ≈ 200 m u/s of the bridge. The continued increase in the water level may be due to the submergence of the incoming floes at the leading edge and movement of the ice accumulation under the water surface.

At 1315 h, the ice cover originated from Lake Belwood was located ≈ 250 m d/s of Hwy. 9 bridge.

At 1325 h, the leading edge of the short ice cover originated from Irvine bridge was located ≈ 50 m u/s of the Quarry bridge. The ice cover here was fairly smooth.

At 1407 h, the leading edge of the ice cover started from the weir in Grand Valley remained ≈ 600 m d/s of the Leggatt bridge. The edge did not advance over the past day.

At 1528 h, the water level at West Montrose reached a maximum level of 13.30 m (Elev. = 321.74 m). The leading edge at this time was ≈ 450 m u/s of the wooden bridge and ≈ 400 m d/s of Hwy. 86 bridge. $Rate_{ic} = .08$ km/h. The slush accumulation shoved a great deal and the rough texture of the newly formed cover above the wooden bridge can be seen in Photos A11 and A12. The average daily gauge reading on this date was $H_f = 13.10$ m (Elev. = 321.54 m).

January 21

Mean temperature = -10.0°C at Grand Valley; -9.4°C at Elora
Snow = none
Discharge = $3.4 \text{ m}^3/\text{s}$ near Marsville; $7.0 \text{ m}^3/\text{s}$
at West Montrose

The water level at West Montrose had fallen overnight and at 1030 h, the gauge reading was 12.82 m (Elev. = 321.25). By this time, the ice cover had extended past Hwy. 86 and past the railway bridge. Ice conditions downstream and upstream of Hwy. 86 are shown in Photos A14 and A15. The ice surface seems to be smoother downstream of the bridge.

3.2 Winter 1982/83

It was not constantly cold between freeze-up and breakup and there were a number of days when the mean daily temperature rose above 0°C and when substantial amounts of rain fell. The meteorological data at Elora and Grand Valley in Figure 3(a) and 3(b) showed that warmer and wetter periods occurred between February 1 and February 3 and between February 15 and February 22. Between February 1 and February 3, 20.6 mm of rain fell in Grand Valley while 22.0 mm fell in Elora. The charts also showed that on February 22, 5.6 mm and 7.8 mm of rainfall were recorded in Grand Valley and Elora, respectively. A mid-winter visit on February 21 revealed that the ice had deteriorated but was still intact at all locations including West Montrose.

Because of these weather conditions, the ice growth throughout the study reach was poor, and by March 1 when the breakup observations commenced, the ice cover in general had deteriorated, and open areas and leads were present at a number of locations.

3.3 Breakup 1982/83

The meteorological charts in Figures 3(a) and 3(b) show that the mean daily temperature rose above 0°C on the last day in February and remained well above this mark until March 11. The warmer weather was accompanied by rainfall on March 3 and 4, and additional runoff accelerated the breakup process. Breakup observations began on March 1 and ended on March 5 when the ice was either in Lake Belwood or below West Montrose which is the downstream limit of the study reach.

The daily observations are summarized below.

March 1

Mean temperature	=	1.0°C at Grand Valley; 3.2°C at Elora
Rain	=	none
Discharge	=	3.5 m ³ /s near Marsville; 4.2 m ³ /s at West Montrose

At West Montrose, the ice cover was intact at 1029 h on February 21, and it extended to 1-2 km u/s of Hwy. 86. The river was open upstream of this point. The ice was gone by 1400 h on March 1 when the breakup observations began. As noted earlier, rain did fall between February 1 and February 3 and again between February 20 and February 22. Since the ice was present on February 21, it seems then that the removal of the ice took place between February 21 and February 22. The gauge chart in Figure 8 shows that the water level peaked at 12.06 m (Elev. = 320.499 m) at 0100 h on February 22, which represents an increase of only ≈0.40 m above the average gauge reading throughout the winter. The small change in the water level indicates that the ice moved downstream with very little difficulty.

At Upper Belwood, the ice cover was intact with an open lead ≈70 m long starting at the creek inlet located ≈300 m u/s of the bridge.

At the 1st crossing d/s of Marsille and the 2nd crossing d/s of Marsville, the ice cover was intact with a number of open areas.

At Marsville, the ice cover was intact above and at the gauge. The river was open below the control section located ≈ 250 m d/s of the bridge.

At Hwy. 9, the river was open upstream and under the bridge. Ice cover started 200 m d/s of the bridge and was continuous to the Marsville gauge.

At Waldemar, the river was open with some border ice along its banks.

At Irvine bridge, the ice cover which started just d/s of the bridge and extended to ≈ 50 m u/s of the Quarry bridge was intact.

At Boyne Creek, a 500 m long ice cover was located 200 m d/s and 300 m u/s of the creek inlet.

The ice cover which started at the weir in Grand Valley was intact. This cover extended pass the Amaranth St. bridge and around the bend ≈ 400 m u/s from the bridge.

In summary, there were four ice covered sections that were still intact. The main section originated from Lake Belwood to 200 m d/s of Hwy. 9. The cover was ≈ 8 km long. The other three shorter sections were at the following locations: from Irvine Bridge to ≈ 50 m u/s of the Quarry bridge (≈ 1.7 km long); at Boyne Creek (≈ 0.5 km long); and from the weir in Grand Valley to ≈ 400 m u/s of Amaranth St. (≈ 1 km long). Excluding the ice in Lake Belwood, about 20% of the study reach was still covered with intact ice on March 1.

March 2

Mean temperature	=	2.5°C at Grand Valley; 2.1°C at Elora
Rain	=	none
Discharge	=	7.4 m ³ /s near Marsville; 5.4 m ³ /s at West Montrose

The ice continued to deteriorate and the open areas increased in size and number. The overall condition of the river, however, remained the same.

At Upper Belwood, the open lead became larger and there was water over the ice in some places.

The ice which started in Grand Valley now extended to only 300 m u/s of the Amaranth St. bridge.

March 4

Mean temperature = 1.0°C at Grand Valley; 1.8°C at Elora
Rain = 5.2 mm on March 3 and 3.0 mm on March 4 at
Grand Valley; 1.2 mm on March 3 and 1.0 mm
on March 4 at Elora
Discharge = 17.0 m³/s near Marsville; 7.5 m³/s
at West Montrose

Rainfall began on the night of March 3 and continued throughout the day on March 4, accumulating a total of 8.2 mm at Grand Valley. The rainfall caused an increase in runoff which was noted in the daily discharge of 17.0 m³/s near Marsville.

At 0900 h, the river at Upper Belwood was open from the creek inlet to ~30 m d/s of the bridge. Photo B1 looking downstream shows the broken ice blocks gathered behind the ice cover which was still intact. Photo B2 looking upstream shows the open reach between the bridge and the inlet of the creek.

At 0930 h, the ice cover at Marsville was still intact. Photo B3 shows the condition of the ice from the bridge to the control section downstream. Below the control section, the river was open. Along the left bank ~150 m u/s of the bridge, there was an open area in the ice cover as shown in Photo B4. The Marsville gauge chart in Figure 9 indicates that the water level had been rising over the past few days, and at 0932 h, the reading was 4.10 m (Elev. = 437.48 m).

At 0949 h, breakup was initiated at H_B = 4.14 m (Elev. = 437.52 m). The ice sheet moved downstream breaking up into smaller pieces. Some ice moved past the control but then larger floes blocked

the section and held back the rest of the ice. The water level continued to rise until 1040 h at a level of 4.740 m (Elev. = 438.118 m) when the blockage was removed and the remaining ice moved downstream.

At Irvine bridge, a 150 m long piece of ice broke off the ice cover and was gone by 1042 h. The remaining ice sheet was intact upstream of the bridge.

At 1053 h, the ice cover that originated from the weir in Grand Valley extended to ~50 m d/s of the Amaranth St. bridge. By 1240 h, the entire ice cover was gone.

By 1110 h, a jam had formed at the 1st crossing d/s of Marsville. The toe was located just d/s of the bridge as shown in Photo B5 and the jam extended 350 m u/s of the bridge as shown in Photo B6. The thickness of the ice blocks ranged from 10 to 25 cm. Some more ice arrived at the head of the jam at 1323 h (possibly from Marsville) and again at 1337 h (possibly from Irvine bridge).

At 1630 h, pieces of ice at the toe of the jam were detached and washed downstream. The jam, however, did not release because it was held back by the bridge. A stage record taken just u/s of the bridge (Table C.3) indicates that this movement caused a drop of 0.43 m in the water level.

At 1550 h, the river at Upper Belwood was open upstream of the bridge and for ~75 m downstream.

At 1600 h, thermal erosion of the ice cover at the 2nd crossing d/s of Marsville resulted in some open areas and a narrow channel running past the bridge.

March 5

Mean temperature = 3.8°C at Grand Valley; 4.3°C at Elora

Rain = none

Discharge = 25.0 m³/s near Marsville; 10.0 m³/s
at West Montrose

By 0815 h, the jam at the 1st crossing d/s of Marsville had released. The river was open.

At 0830 h, the river was open at the 2nd crossing d/s of Marsville.

At 0825 h, the ice formed a jam downstream of the Upper Belwood bridge (Photo B7) with the head ≈ 75 m d/s of the bridge. The water level variation with time as the ice at the gauge eroded and as the jam formed downstream of the gauge is shown in Figure 10.

4.0 DATA INTERPRETATION AND ANALYSIS

4.1 Ice Bridging

Over the past five seasons (1981-85), it has been observed that ice bridging, i.e., the formation of ice cover across the entire width of the rivers occurs at a number of locations in the study reach. The points of ice bridging and the extent of ice growth in a typical winter are shown in Figures 11(a) and 11(b). Of the eight points, five are weirs where the surface velocity is slowed considerably and smooth plate ice is formed. Another location of ice bridging is at Lake Belwood, which usually freezes early in the winter. From the lake, the leading edge of the ice then progresses up the river towards Upper Belwood and Marsville. The other two points of ice bridging are at the bend just downstream of Irvine bridge and at the bend near the trailer park 2.5 km downstream of Leggatt. It is not obvious why a complete ice cover should form at these two points and this may be a topic for future observation and research because ice bridging is important in developing models to simulate the freeze-up process.

4.2 Freeze-Up Analysis

Daily accounts of the freeze-up process at three gauge sites (West Montrose, Upper Belwood, and Marsville) revealed that ice covers at West Montrose and Upper Belwood, were created by means of freeze up

ice jam (shoving) or hanging dam formation. At the third gauge site near Marsville, the ice cover formed on a cold day (avg. temp. = -15°C) and the leading edge moved upstream past the gauge at a fast rate ($\approx 0.23 \text{ km/h}$). No shoving was observed, and therefore, the cover was formed by juxtaposition or possibly frontal progression.

According to Michel (1984), all cases of ice cover formation can be presented in one universal diagram, where U , the average velocity under the cover, is plotted against h_i , the ice thickness. Michel plotted points from five sets of data from three large rivers and fitted two curves to these points (Figure 12). Curve 1 represented the best fit of cases of frontal progression, while Curve 2 represented the best fit of cases of shoving. Because the shoving process involves a number of factors other than U and h_i (Pariset et al. (1966), Beltaos (1983), Calkins (1983)), Curve 2 which was fitted to points from large rivers would not be applicable to the smaller Grand River. Therefore, this curve is not shown in Figure 12. The figure also shows that the range of the juxtaposition (or quasi-static) cases is just above Curve 1 in the low h_i range.

The data from the three gauge sites are analyzed for the expected range of ice thicknesses, and the results are plotted in Figure 12. The Marsville points are close to the juxtaposition range and to the frontal progression curve. The points for West Montrose and Upper Belwood are well below Curve 1 indicating that shoving or the formation of hanging dams occurred at these locations.

The conclusion from the above analysis is consistent with the field observations.

4.3 Freeze-Up Jams

According to the above discussion, the ice cover at West Montrose and Upper Belwood was formed by means of freeze-up jams where the ice/slush accumulations shoved and collapsed as the leading edge of the cover moved upstream. The data collected during this process can be

compared with the existing ice jam theory, which is based on the flow hydraulics and mechanics of a fragmented ice cover (Pariset et al. (1966), Uzuner and Kennedy (1976), Beltaos (1983)). A full analysis is not possible because the thickness of the newly formed ice cover is not available. However, a simplified analysis can be performed as follows.

Based on theory and field data, Beltaos (1983) has shown that the water depth, h_j , caused by a floating, equilibrium jam can be approximately determined from the following relationship

$$n \equiv h_j/WS = f(\xi) \quad (2)$$

in which W = channel width at the elevation of the bottom surface of the jam; S = channel slope. $h_j = h + s_i t$ = total water depth; h = depth of flow under the jam; t = jam thickness, and s_i = specific gravity of ice ≈ 0.92 . The parameter ξ is a dimensionless discharge defined by

$$\xi = (q^2/gS)^{1/3}/WS \quad (3)$$

in which $q = Q/W$; Q = discharge; and g = acceleration of gravity.

Figure 13 shows available data taken from various Canadian rivers, plotted in the form of Eq. 2. These data represent breakup conditions, i.e., jams comprising accumulations of solid ice blocks with prevailing air temperatures being positive or not much below freezing. On the other hand, freeze up jams consist mainly of frazil slush and may have different strength and hydraulic roughness characteristics. Therefore, the present data need not be consistent with those of Figure 13 but a comparison would be of interest.

Data pertaining to ice cover formation at West Montrose and Upper Belwood have been analyzed and are summarized in Table 4. In this table, the average values of S , W and h_j are evaluated from the observed water surface profile and surveyed cross-sections. The parameters n and ξ defined in Eq. 2 and Eq. 3 are then calculated. In

the case of Upper Belwood, the water surface profile was not measured during freeze up. The profile is estimated using the water surface elevation at the gauge and by assuming that the slope is equal to 0.00127 which is the open water slope measured in May, 1985. The resulting pairs of η and ξ are plotted in Figure 13 where they are seen to be consistent with the trend defined by the breakup jam data points. However, more data are needed before any conclusions can be drawn in this respect. The thickness of the freeze up accumulations should also be measured as soon as a sufficiently thick layer of solid ice develops at the water surface.

4.4 Initiation of Breakup

A preliminary conceptual model of breakup was developed by Beltaos (1981, 1983). In the model, the breakup process was assumed to take place in the following sequence; warmer temperatures and increased stage cause the ice to be freed from the banks; cracks form in the ice, and eventually, the river is covered by large separate ice sheets; with further increase in stage, the channel width increases until some of the ice sheets can "clear" the bends and other obstacles; the moving ice sheets break up and small ice jams are formed; the jams cause further increase in the stage which produces further dislodgements of other ice sheets and so on, until the entire reach is cleared of ice.

The model was applied to data from the Thames River and it was shown that, at a given site, the breakup initiation stage, H_B , depends on the maximum (daily average) freeze-up stage, H_F , as well as on the ice thickness at the time of breakup, h_i . The stage is usually associated with the time of formation of a complete ice cover across the stream and thus provides a measure of the ice cover width, W_F . Similarly, the stage H_B is a measure of the water surface width that is available for movement of the ice cover, W_B . Beltaos (1981, 1982a) argued that the ratio W_B/W_F should depend on h_i/W_F as well as on several other dimensionless parameters that reflect the driving force of

the water, ice strength and channel geometry. Because W usually varies as a power of Y (= average flow depth), the ratio W_B/W_F can be replaced by Y_B/Y_F . Considering also that ΔH (= stage in excess of stage at zero discharge) is a rough measure of Y , Y_B/Y_F can be approximately replaced by the more convenient parameter $\Delta H_B/\Delta H_F$.

The available data for the 1982-83 season are listed in Table 6. H_F and H_B were deduced from observation notes and from gauge records provided by Water Survey of Canada and by Grand River Conservation Authority. The ice thickness measurements listed in Table 5 enable ice growth patterns to be established for the three gauge sites. The ice thickness is related to the degree-days of frost after freeze-up and estimates of ice thicknesses at the time of breakup are listed in Table 6.

Figure 14 shows $\Delta H_B/\Delta H_F$ plotted against $100 h_i/W_F$ along with a data range applicable to the Thames River at Thamesville. It is seen that the data point for Marsville is in fair agreement with the Thames River data but those for West Montrose and Upper Belwood are not. The discrepancy may be due to breakup processes at the three sites being different from each other and different from those in the Thames River, as described next.

At Marsville, an ice sheet extending from the control section ≈ 250 m d/s of the gauge to at least 250 m u/s of the gauge was intact. The river was open below the control section, and broken ice accumulated upstream of the ice sheet. At 0949 h on March 4, the ice sheet shifted and broke into smaller pieces. Initiation occurred at this time and the gauge reading was $H_B = 4.14$ m (Elev. = 437.92 m). Some ice moved past the control but then larger floes re-blocked the section and held back the rest of the ice. The water level continued to rise until 1040 h at a level of 4.740 m (Elev. = 438.12 m) when blockage was removed and the remaining ice moved downstream.

At West Montrose, the river was cleared before the start of the 1982-83 breakup observations. However, observations from other years (1981-1985) provide enough information to suggest how breakup at

West Montrose usually occurs. The ice upstream of Hwy. 86 breaks up and the broken floes form an ice jam at the upstream edge of the unbroken ice cover. The jam then weakens the cover immediately downstream of the toe by exerting force on the cover or by promoting erosion of the ice. Eventually, the ice breaks up and the jam together with the newly broken ice move down. More cover may be broken when the jam arrives at the upstream edge, and the jam then moves further downstream. Eventually, the jam comes to rest on the unbroken ice cover and the process repeats itself until the river reach is cleared of ice. At West Montrose, the jams have a tendency to be held up a long time at the piers of the wooden bridge and at or near the control section at 62.01 km.

At Upper Belwood, the inflow from the creek ≈ 300 m u/s of the bridge caused the ice sheet to be eroded. By 1550 h on March 4, the ice was eroded from the creek to ≈ 75 m below the gauge. Technically, the ice was gone from the gauge site and breakup initiation had occurred. The gauge reading at this time was $H_g = 1.36$ m (Elev. = 427.71 m). By 0825 h on March 5, the ice upstream broke up and moved down forming a jam with the toe at the unbroken ice cover. At this time, the head of the jam was ≈ 75 m d/s of the bridge. The jam then moved downstream in the same sequence of events described in the above paragraph until the ice was transported into Lake Belwood.

From the accounts of breakup, it is clear that breakup initiation at Marsville is similar to the process assumed in the conceptual model. It is, therefore, not surprising that the agreement in Fig. 14 is fairly good. On the other hand, the ice sheets at West Montrose and Upper Belwood broke up in a different manner. The obstacles in the smaller river such as control section, bridge piers, narrow channels, etc., did not allow the ice sheet to move downstream in large pieces. Before the stage can rise sufficiently, the ice sheet is destroyed by intermittently advancing jams from upstream. This mechanism is related to the conditions of release of ice jams which, to date, remain unclear.

5.0 DISCUSSION AND SUMMARY

Observations of the 1982-83 ice season on the Upper Grand River have been described and partly interpreted in the previous sections.

Freeze up observations indicate that the ice cover at Marsville gauge site was formed by the process of juxtaposition. No shoving was observed at this location and the leading edge moved quickly through the reach producing a relatively thin ice cover. On the other hand, shoving was observed at Upper Belwood and at West Montrose, and the ice slush accumulations at the two gauge sites were thicker than what would be expected for jams formed by frontal progression. Data from these locations were then compared with the existing theory on equilibrium floating jams. The resulting data points are close to the trend defined by breakup jams but more data are needed before conclusions can be drawn. Jam thickness is an important variable that should be measured in detail in future work.

A preliminary conceptual model of breakup initiation was applied to the data from three gauge sites. The removal of the ice cover at the Marsville gauge is similar to the process assumed by the model, and the data from this location agree fairly well with the model. The data from West Montrose and Upper Belwood do not agree with the model, because the covers at these locations are removed by advancing ice jams from upstream. The conditions of release of ice jams and the destruction of the ice sheets are not clear and therefore a model of breakup initiation for these cases cannot be presented at this time.

Ice growth rate in the 1982-83 winter was low because of warm, wet spells during the winter period. By the beginning of breakup, the ice was deteriorated and the quantity of the ice coverage was less than that of a typical season. The breakup was "mature", and no major jam was observed.

6.0 CONCLUSIONS

Interpretation of the 1982-83 ice observations indicate the following:

- a) Ice growth was low in the study reach, and breakup was "mature" and uneventful.
- b) The existing model of breakup initiation does not apply to some sites along the Upper Grand River. The breakup and removal of the ice cover at these sites depend on thermal effects as well as on the mechanics of advancing ice jams.
- c) Three different ice formation processes occurred at the three gauge sites. Ice cover was formed at Marsville by the process of juxtaposition, while freeze up ice jams (or shoving) produced the cover below Upper Belwood. At West Montrose, the process involved was a combination of freeze up ice jam and hanging dam formation.
- d) Ice thickness measurements are needed in order to completely analyze the freeze-up ice jams at West Montrose and Upper Belwood. The measurements should be done shortly after the formation of the stable ice cover before erosion of the under-surface can change the thickness significantly.

7.0 ACKNOWLEDGEMENTS

Acknowledged with thanks is the valuable assistance provided by the Grand River Conservation Authority and the Water Survey of Canada; these organizations worked with our field crew in providing important field notes and reports on river conditions.

Messrs. W.J. Moody and F. Dunnett of the Hydraulics Division provided valuable assistance with both field work and data processing. Review comments by Dr. Y.L. Lau are appreciated.

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TABLES

TABLE 1.

Important Locations In Study Reach

<u>Description</u>	<u>Chainage (km) distance from Leggatt</u>
Leggatt bridge (GRCA gauge site)	0.00
3rd crossing u/s of Grand Valley	3.96
2nd crossing u/s of Grand Valley	4.64
1st crossing u/s of Grand Valley	7.39
Amaranth St. bridge; east end of Grand Valley	10.21
Dam in Grand Valley	10.88
Main St. bridge in Grand Valley	11.11
Mouth of Boyne Creek	12.55
2nd crossing u/s of Waldemar (Quarry bridge)	13.26
1st crossing u/s of Waldemar (Irvine bridge)	15.09
Mouth of Willow Brook	16.09
Canadian Pacific Railway bridge	16.14
Waldemar bridge (GRCA gauge site)	16.24
Hwy 9 bridge	17.46
Marsville bridge (WSC and GRCA gauge site)	19.84
1st crossing d/s of Marsville bridge	21.54
2nd crossing d/s of Marsville bridge	22.96
Upper Belwood bridge (GRCA gauge site)	24.75
Belwood bridge	29.57
Shand Dam (GRCA gauge site)	36.56
Shands Bridge (WSC gauge site)	37.71
Scotland St. bridge in Fergus	40.24
Mill Dam in Fergus	40.37
St. David St. (Hwy 6) bridge in Fergus	41.05
Tower St. bridge in Fergus	41.30
Canadian National Railway bridge	43.72
Dam in Elora	45.75
High St. bridge in Elora	46.26

TABLE 1. (continued)

<u>Description</u>	<u>Chainage (km) distance from Leggatt</u>
Dam in Elora	46.42
Mouth of Irvine Creek	46.69
Bridge in Elora	46.74
Elora Gorge Park bridge	49.18
Mouth of Carroll Creek	51.03
Mouth of Swan Creek	51.69
1st crossing d/s of Inverhaugh	53.33
2nd crossing d/s of Inverhaugh	56.26
Canadian Pacific Railway bridge	60.32
Hwy 86 bridge	60.87
West Montrose covered bridge (WSC and GRCA gauge site)	61.74
Winterbourne	65.22

TABLE 2.
Grand River Sections

Section	Location		Average Slope (m/km)
I	Leggatt to Upper Belwood	(0.00 to 26.01)	1.44
II	Lake Belwood	(26.01 to 36.56)	0.73
III	Shand Dam to Elora	(36.56 to 45.78)	3.61
IV	Elora Gorge	(45.78 to 49.18)	8.20
V	Inverhaugh to West Montrose	(49.18 to 61.74)	1.96

TABLE 3.

Minimum, Maximum and Average Flow (m³/s) (1970-79)*

Gauge Year	Grand River near Marsville Drainage Area = 694 km ²			Grand River below Shand Dam Drainage Area = 800 km ²			Grand River at West Montrose Drainage Area = 1,170 km ²		
	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.
1970	.201** Aug	6.60	161 Apr.	1.08 Jan.	7.77	98. Apr.	1.56 Jan.	12.2	120 Apr.
1971	.116 Oct.	5.99	194 Apr.	.946 Oct.	6.69	120 Apr.	2.36 Oct.	10.7	176 Apr.
1972	.057 Sep.	6.95	264 Apr.	2.11 Mar.	8.11	368 Apr.	3.51 Oct.	12.9	507 Apr.
1973	.099 Oct.	8.36	143 Mar.	1.64 Nov.	9.83	110 Mar.	3.34 Nov.	14.6	156 Mar.
1974	.170 Sep.	7.38	178 Apr.	1.84 Feb.	9.22	188 May	3.17 Dec.	13.6	379 May
1975	.314 Jun	7.12	306 Apr.	2.31 May	7.77	125 Apr.	3.54 Jan.	12.0	234 Apr.
1976	.255 Jun.	9.08	289 Mar.	1.67 Jan.	10.5	153 Mar.	2.49 Jan.	15.3	211 Mar.
1977	.136 Jun.	8.47	243 Mar.	1.27 Jan.	9.89	118 Mar.	1.50 Jan.	13.6	183 Mar.
1978	.459 Sep.	7.29	174 Apr.	1.56 Mar.	7.38	152 Apr.	2.29 Mar.	11.8	197 Apr.
1979	.031 Jul.	9.72	197 Apr.	1.84 Feb.	11.8	239 Apr.	1.54 Sep.	16.5	315 Apr.
Average		7.70			8.90			13.32	

* Data from Water Survey of Canada publication "Historical Streamflow Summary, Ontario, to 1979"

** Flowrates are in m³/s

TABLE 4.
Characteristics of Freeze-Up Ice Jam on Grand River Study Reach, 1982-83.

Ice Jam	Time/ Date	State of Jam	Gauge height (m)	Estimated Flowrate Q (m^3/s)	Average Width W (m)	Average Slope S (m/km)	Average Depth h_j (m)	η	ξ
West Montrose	1000 h 20 Jan 83	building	13.060	10.00	45.0 m	.00128	2.06	35.7	27.4
Upper Belwood	16 Jan 83	steady	1.45	8.00	54.2 m	.00150	1.45	17.8	14.0

TABLE 5.
Ice Thickness Data

Location	Date of Measurement	Average Ice Thickness (cm)	Range of Ice Thickness (cm)
(1980-81)			
Marsville*	Jan. 15	24.1	15-28
West Montrose*	Jan. 16	29.6	26-32
West Montrose*	Feb. 16	50.5	38-59
Near 1st crossing u/s of Grand Valley	Jan. 9-14	24.3	14-32
(1981-82)			
Marsville*	Feb. 3	28.0	5-41
West Montrose*	Jan. 22	32.0	12-60
West Montrose*	Feb. 11	43.0	28-50
Near 1st crossing u/s of Grand Valley	Jan. 13	34.0	23-51
Near Marsville	Jan. 13-19	22.0	9-43
Near Upper Belwood	Jan. 13-19	27.0	14-35
Near Hwy 86 crossing	Jan. 13-19	20.0	11-30
Near West Montrose	Jan. 13-19	24.0	9-40
(1982-83)			
Marsville	Feb. 14	28.5	25-34
West Montrose	Feb. 16	26.2	13-67

* From data provided by Water Survey of Canada, Guelph. At West Montrose, significant slush deposits under the solid ice cover were present; thicknesses apply to the slush free portion of the channel.

TABLE 6.

Selected Characteristics of 1982-83 Seasons

Location	H_F (m)	Date of H_F	Probable H_B (m)	Approx. time of H_B	Estimated h_i at time of H_B (cm)	H_{max} (m)	Time of H_{max}	Estimated discharge at H_{max} (m^3/s)
West Montrose	13.10	20 Jan 83	12.020	1640 h 20 Feb 83	24.7	12.030	1200 h 23 Feb 83	17
Upper Belwood	1.45	16 Jan 83	1.355	1550 h 4 Mar 83	28.9	2.025	1800 h 4 Mar 83	
Marsville	3.85	18 Jan 83	4.140	0948 h 4 Mar 83	27.5	4.665	1040 h 4 Mar 83	

Location	W_F (m)	H_O (m)	ΔH_F (m)	ΔH_B (m)	$\frac{\Delta H_B}{\Delta H_F}$	$\frac{100h_i}{W_F}$
West Montrose	57.8	11.09	2.01	0.93	0.46	0.41
Upper Belwood	63.3	0.13	1.32	1.23	0.98	0.46
Marsville	39.9	3.31	0.54	0.83	1.54	0.69

FIGURES

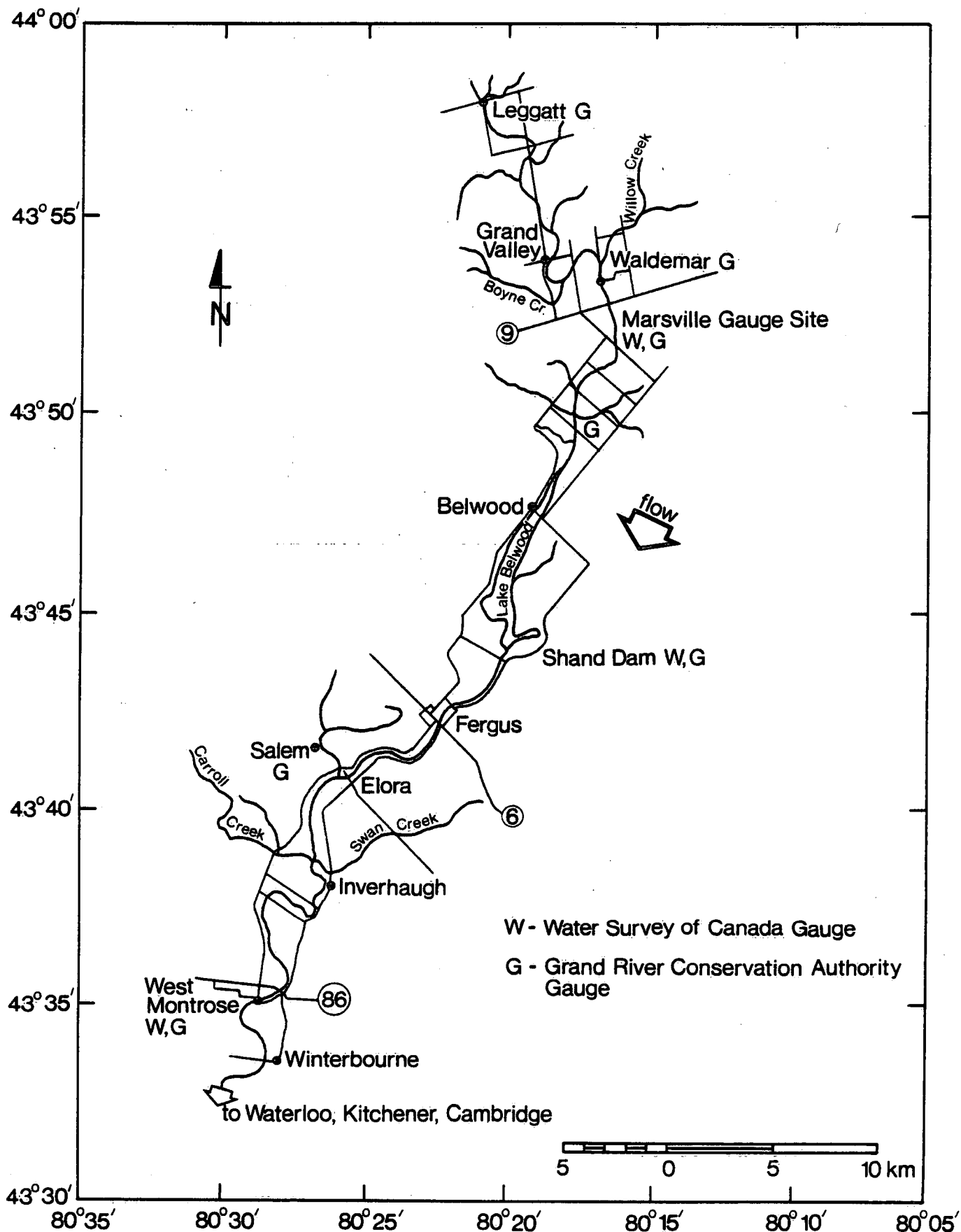


Figure 1 PLAN VIEW OF UPPER GRAND RIVER STUDY REACH

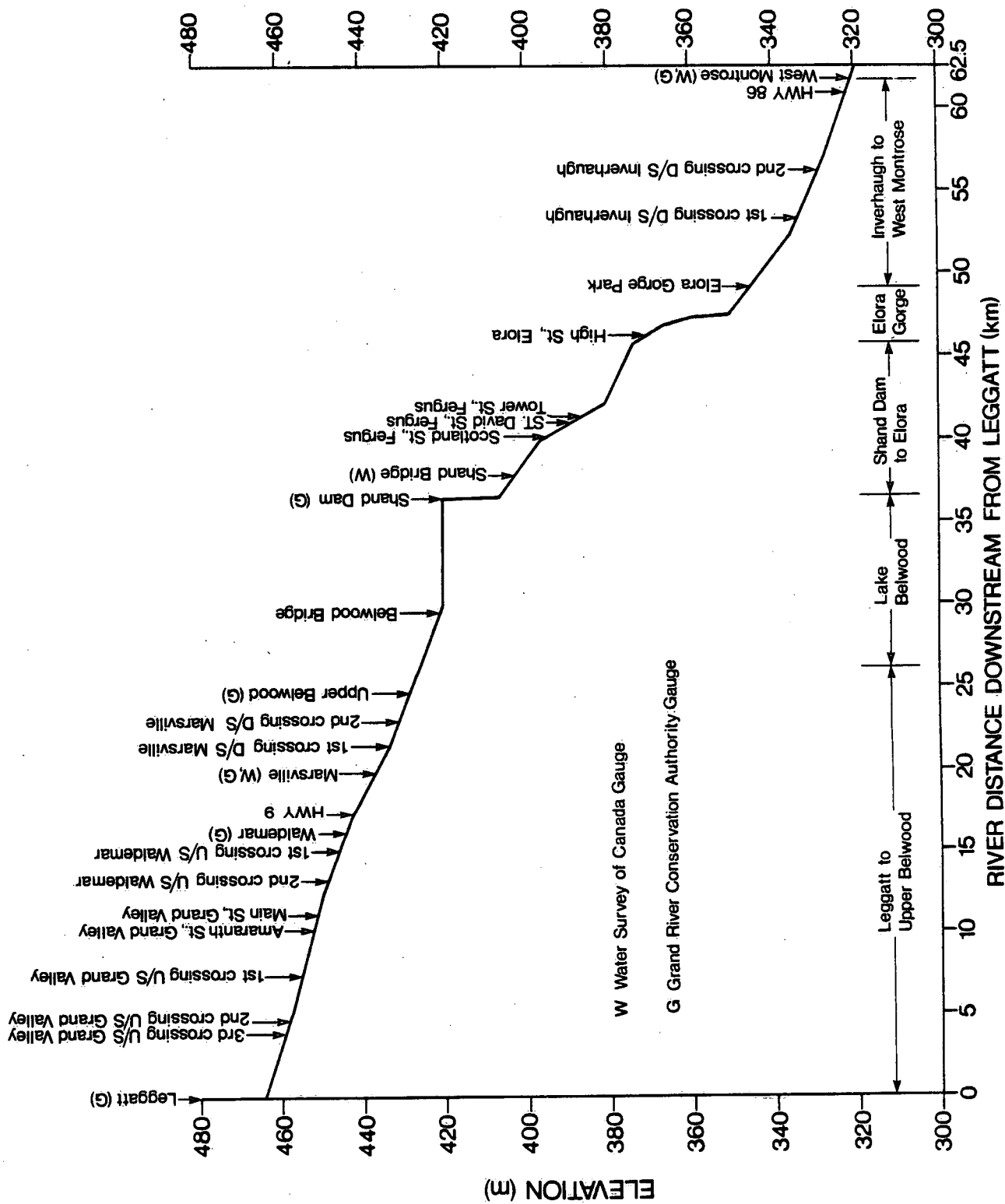


Figure 2 LONGITUDINAL PROFILE OF UPPER GRAND RIVER

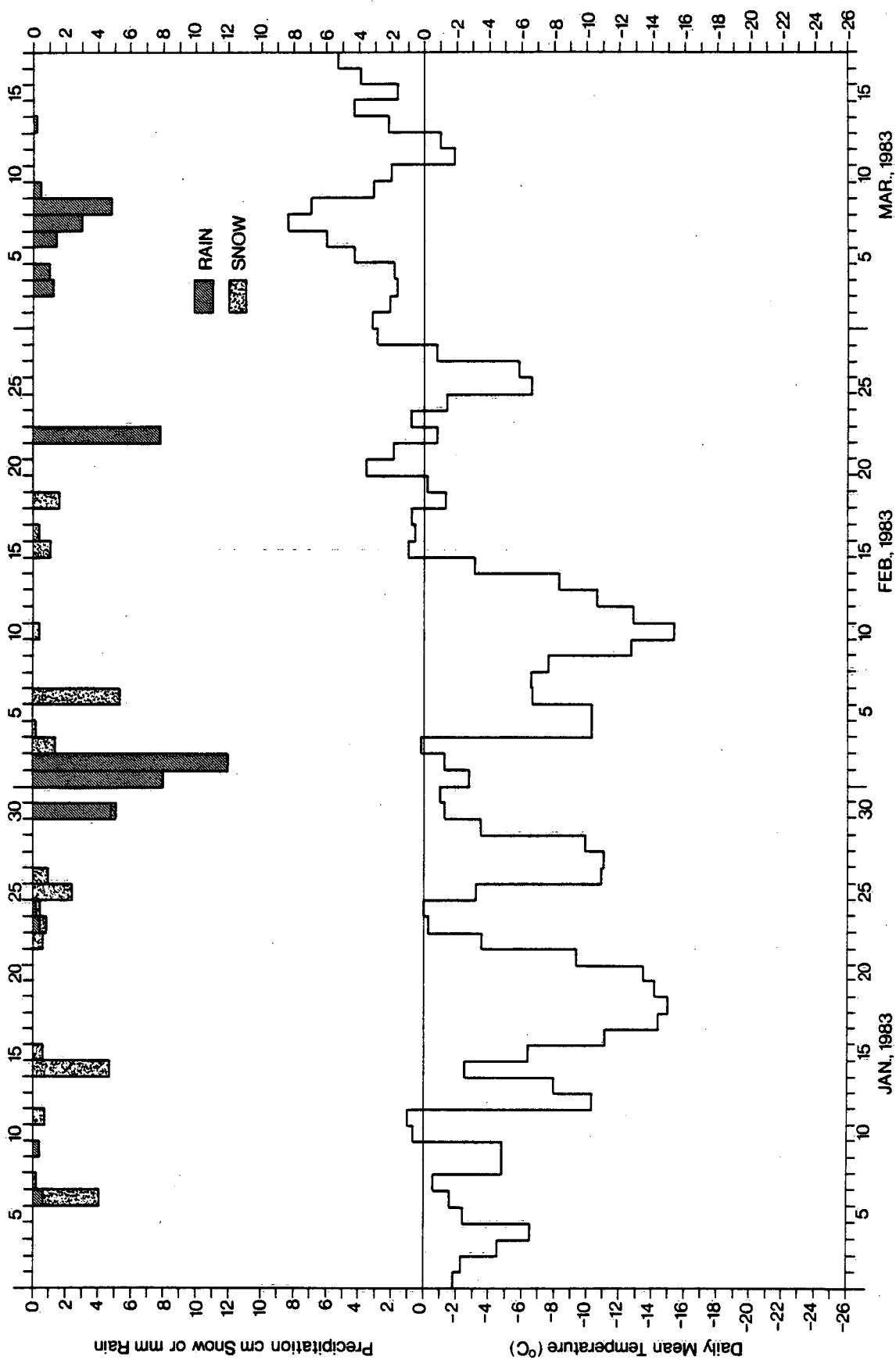


Figure 3a Daily Meteorological Data at Elora Station 1982-83

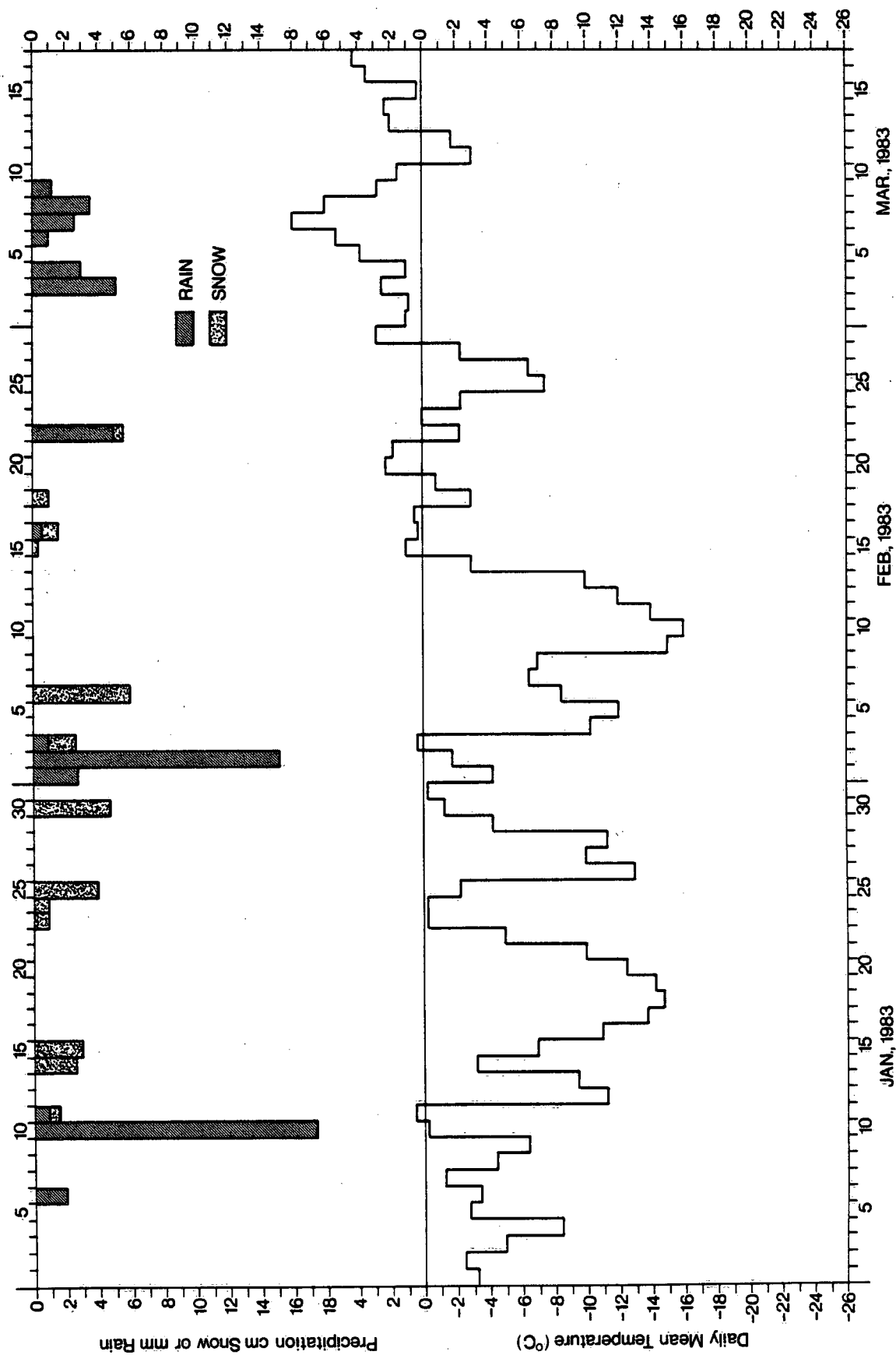


Figure 3b Daily Meteorological Data at Grand Valley WPCP Station 1982-83

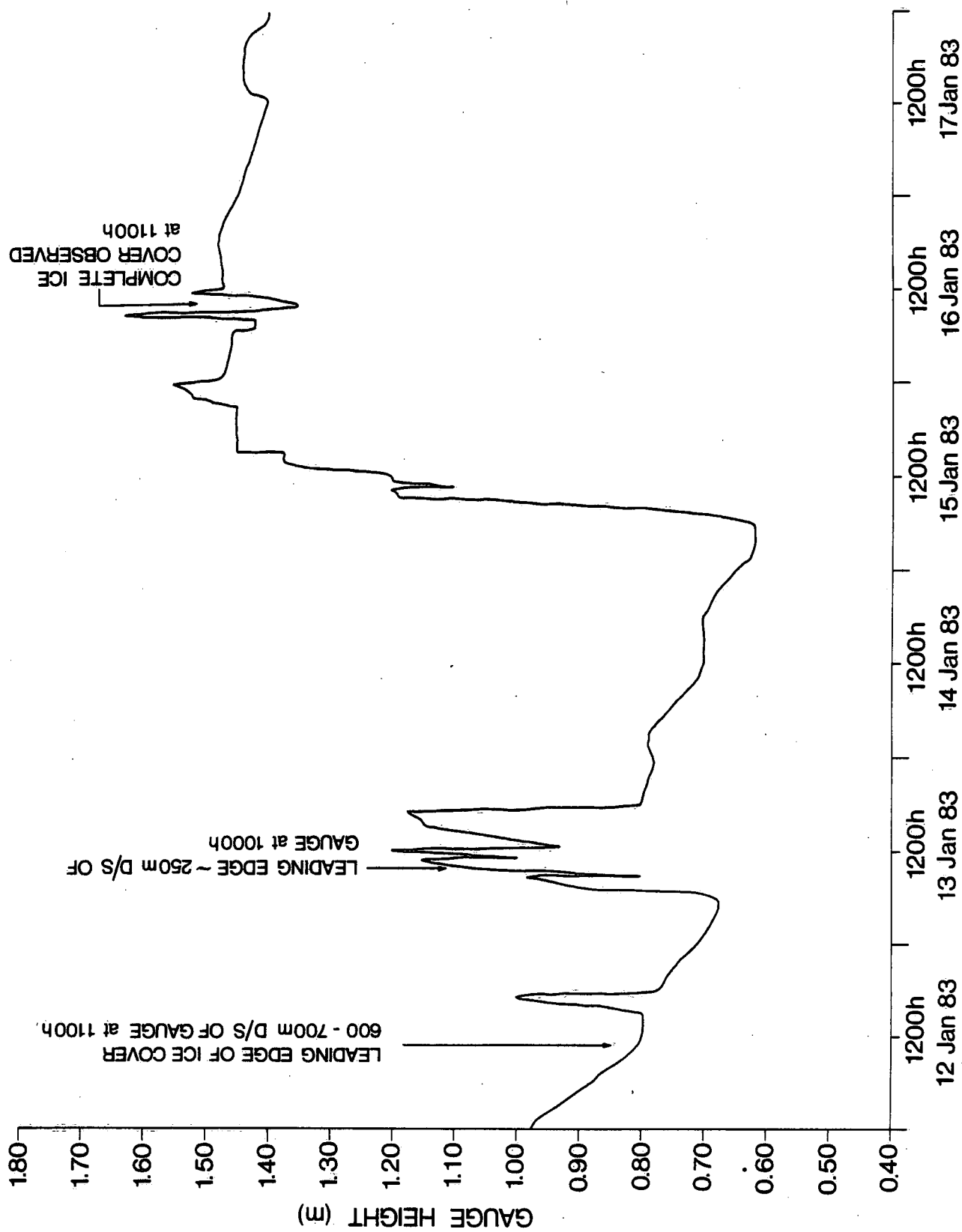


Fig.4 Water level variation with time at Upper Belwood. Freeze up 82-83. Jan 12-17, 1983.

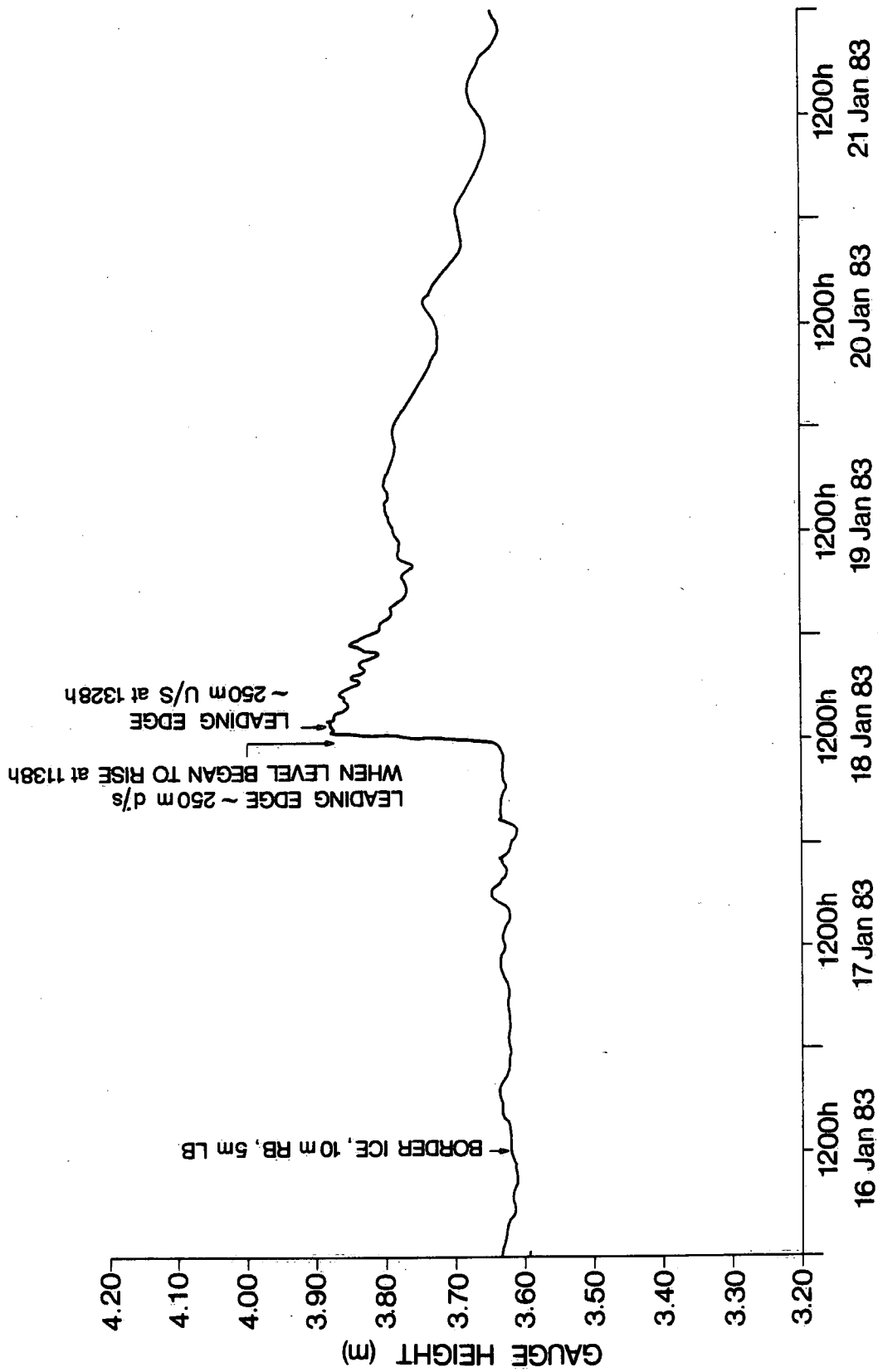


Fig. 5 Water level variations with time at Marsville. Freeze up 82-83. Jan 16 - 21, 1983.

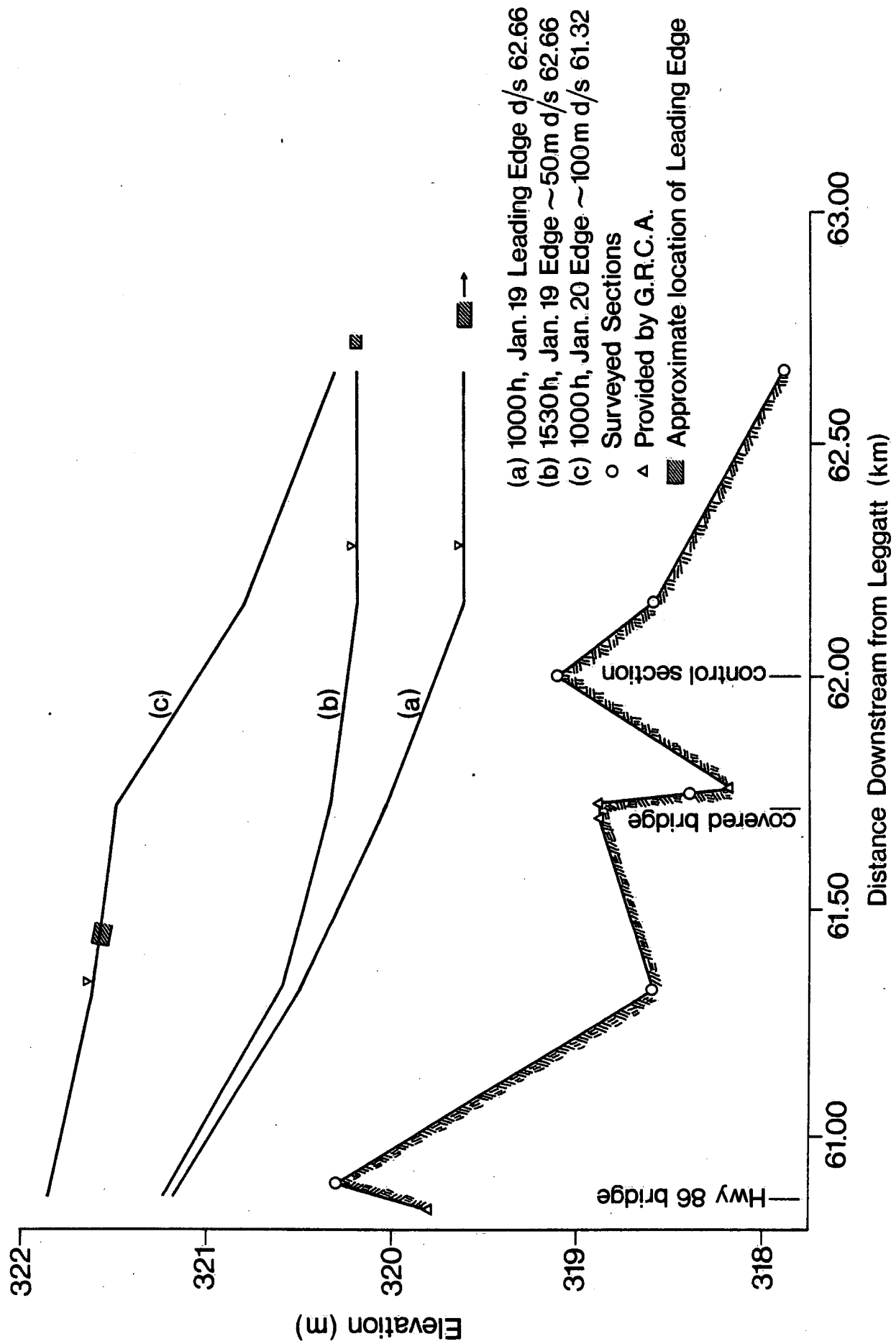


Figure 6 Bottom elevation and water level profiles during freeze up at West Montrose.

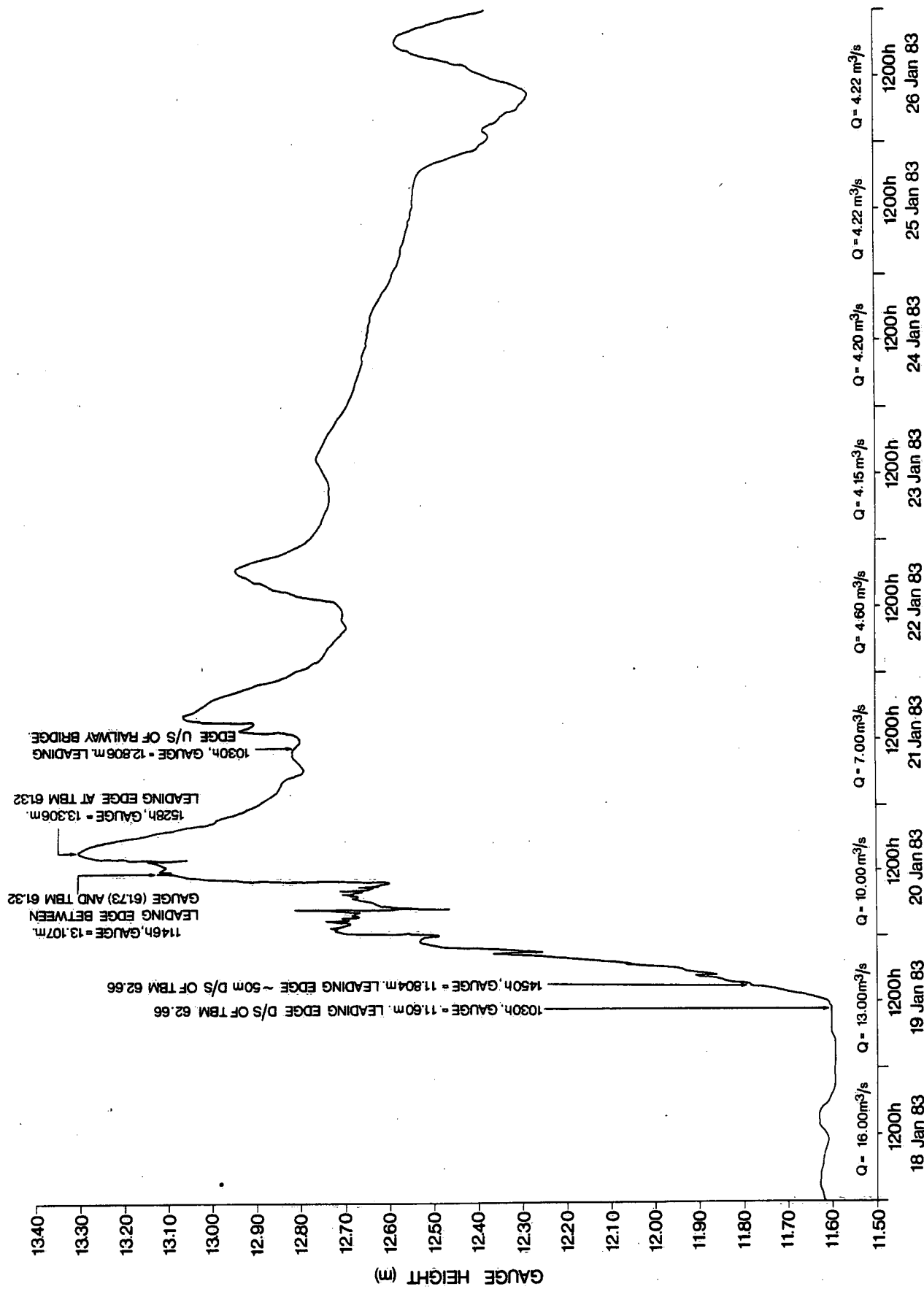


Fig.7 Water level variation with time at West Montrose. Freeze up 82-83. Jan 19 - 26, 1983.

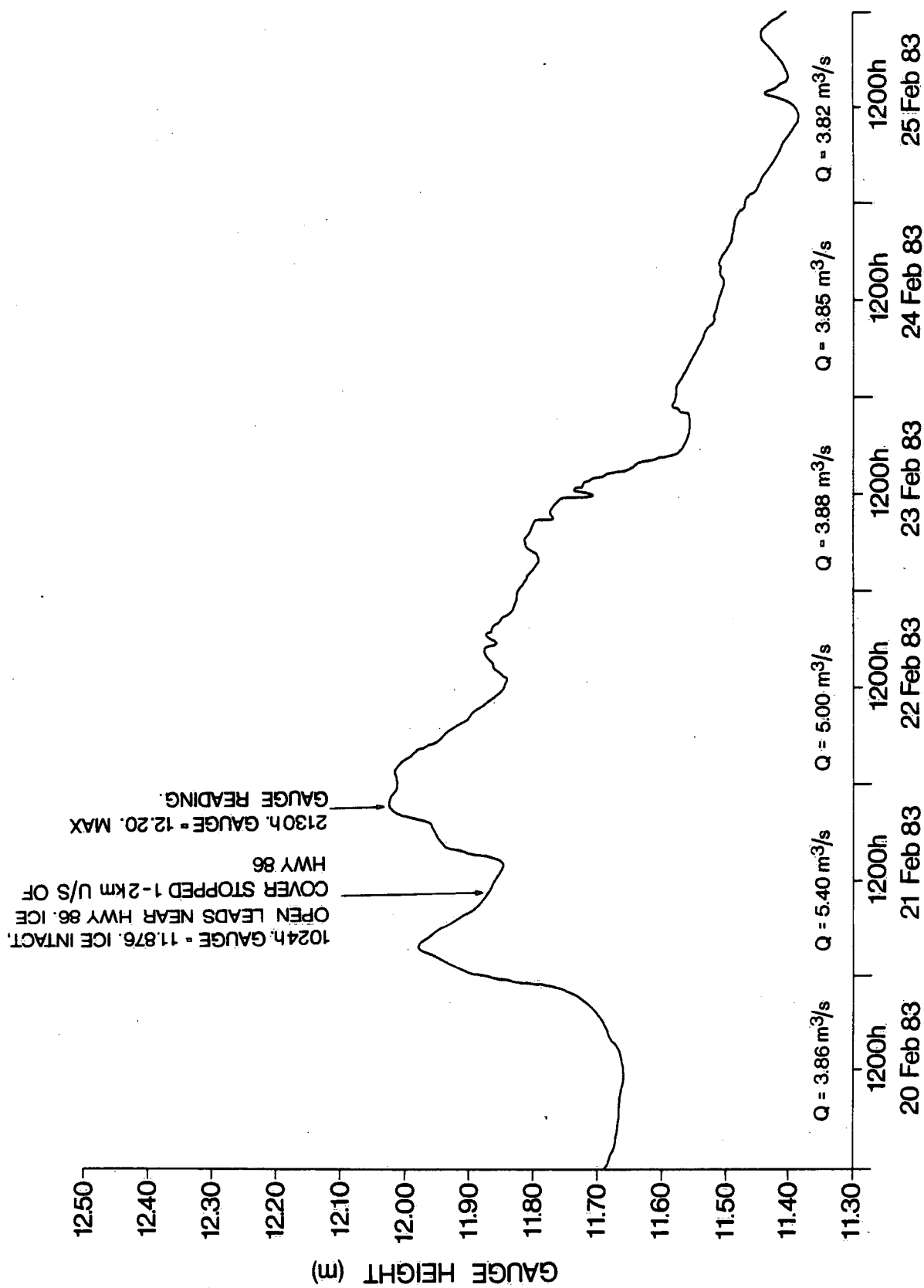


Fig.8 Water level variation with time at West Montrose. Breakup 82-83 .Feb 19-23, 1983.

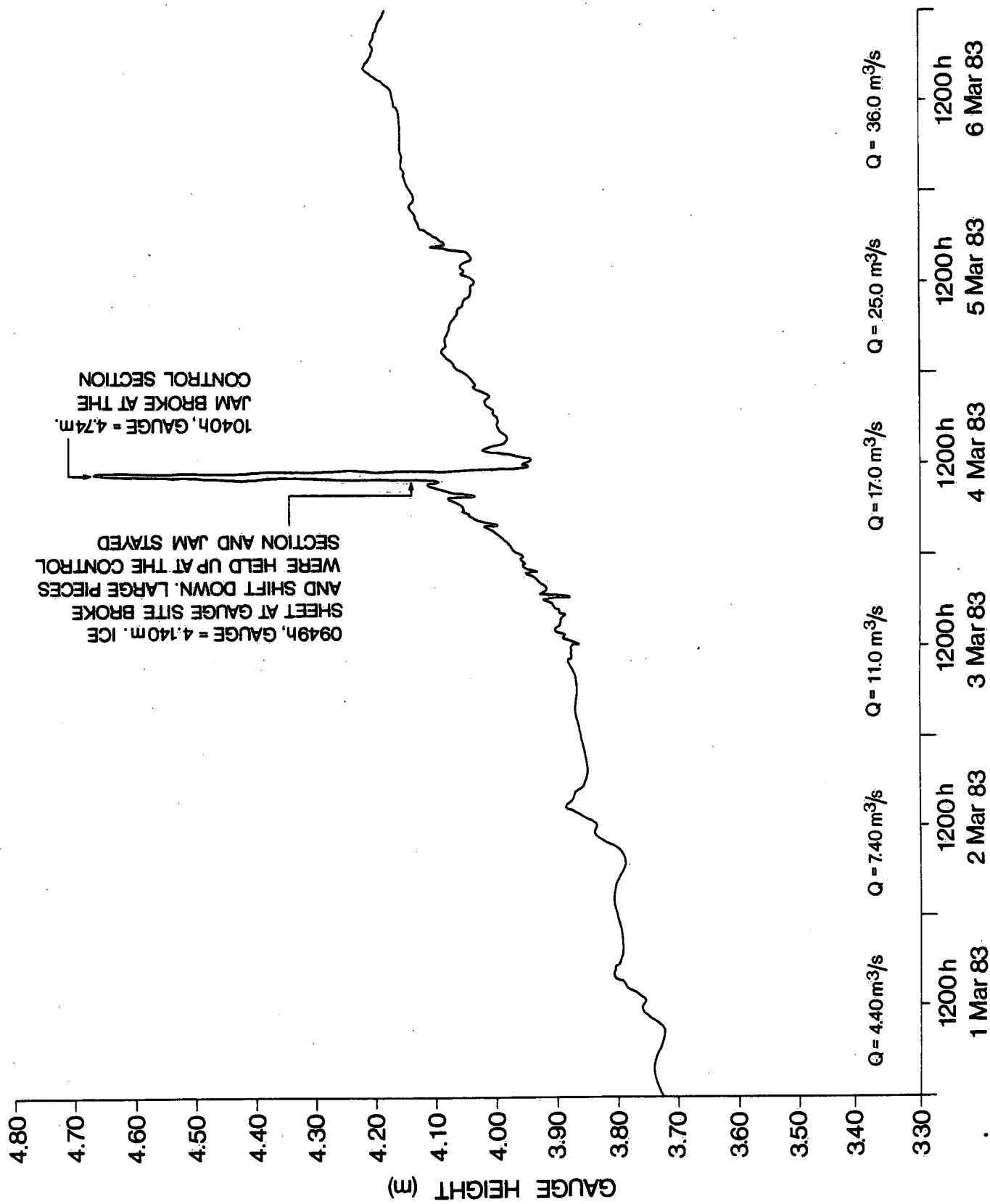


Fig.9 Water level variation with time at Nashville. Break up 82-83. Mar 1 - 6, 1983.

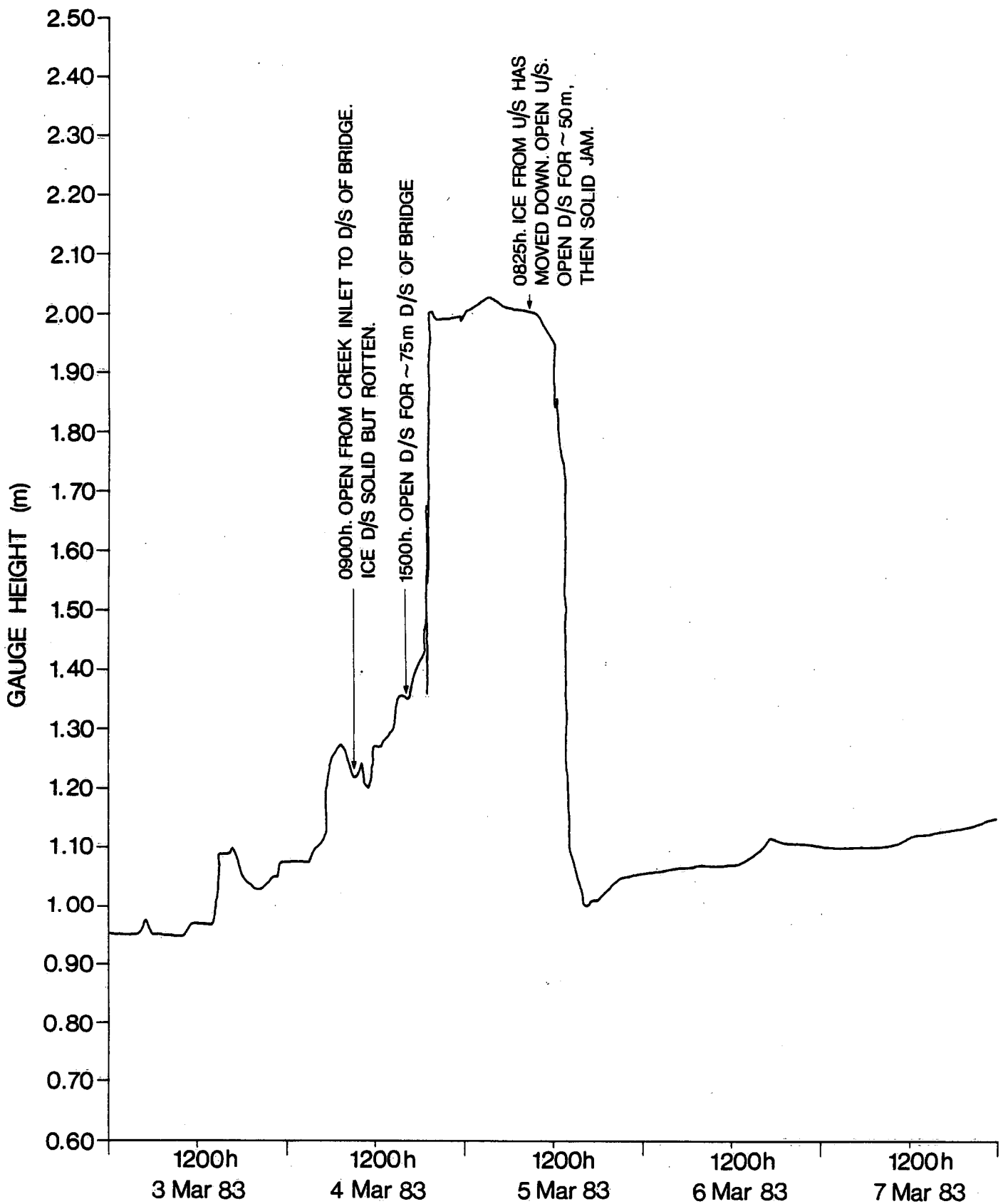


Fig.10 Water level variation with time at Upper Belwood. Breakup 82-83. Mar 3-7,1983.

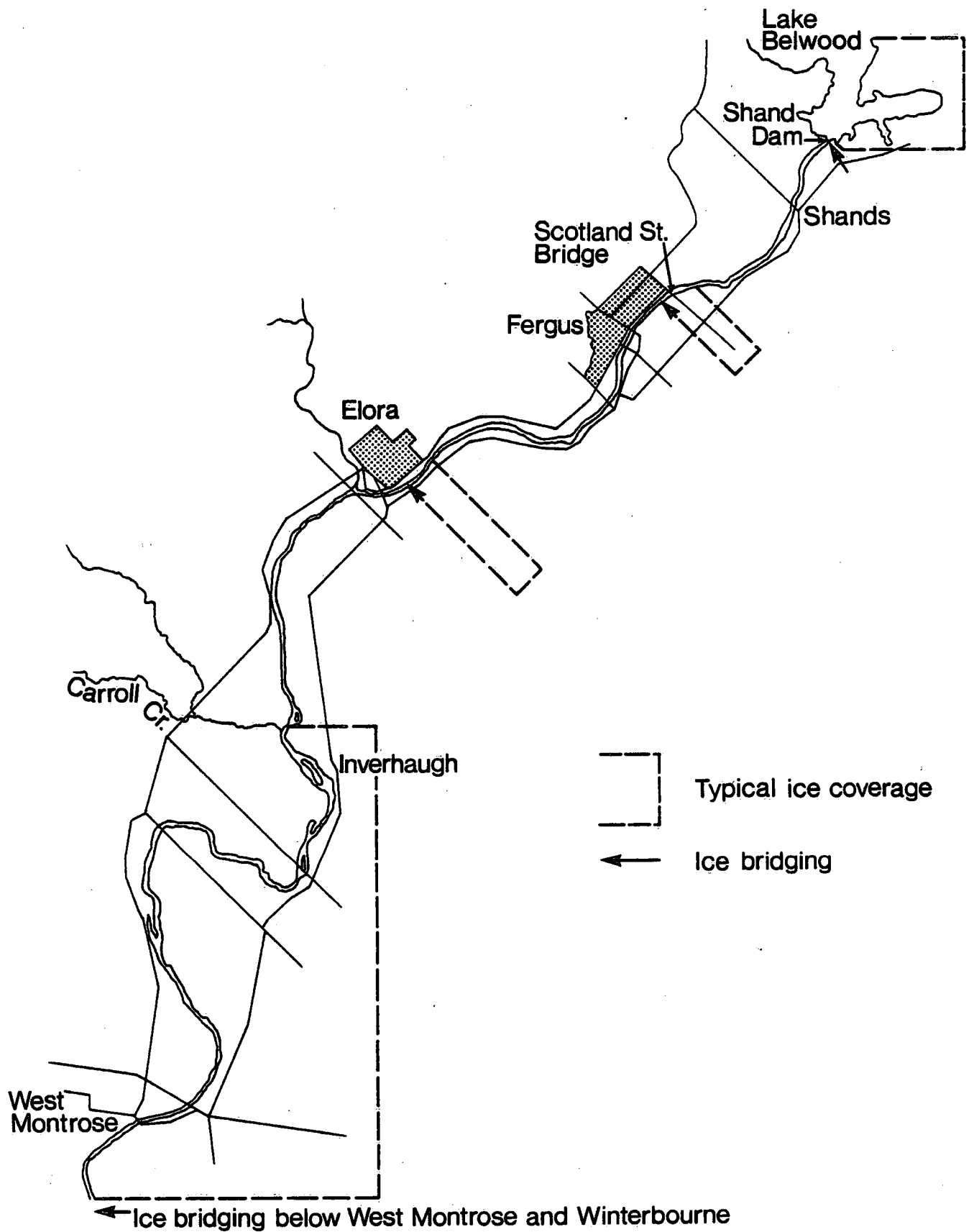


Figure 11a LOCATION OF ICE BRIDGING AND EXTENT OF TYPICAL ICE COVERAGE. LOWER HALF OF REACH.

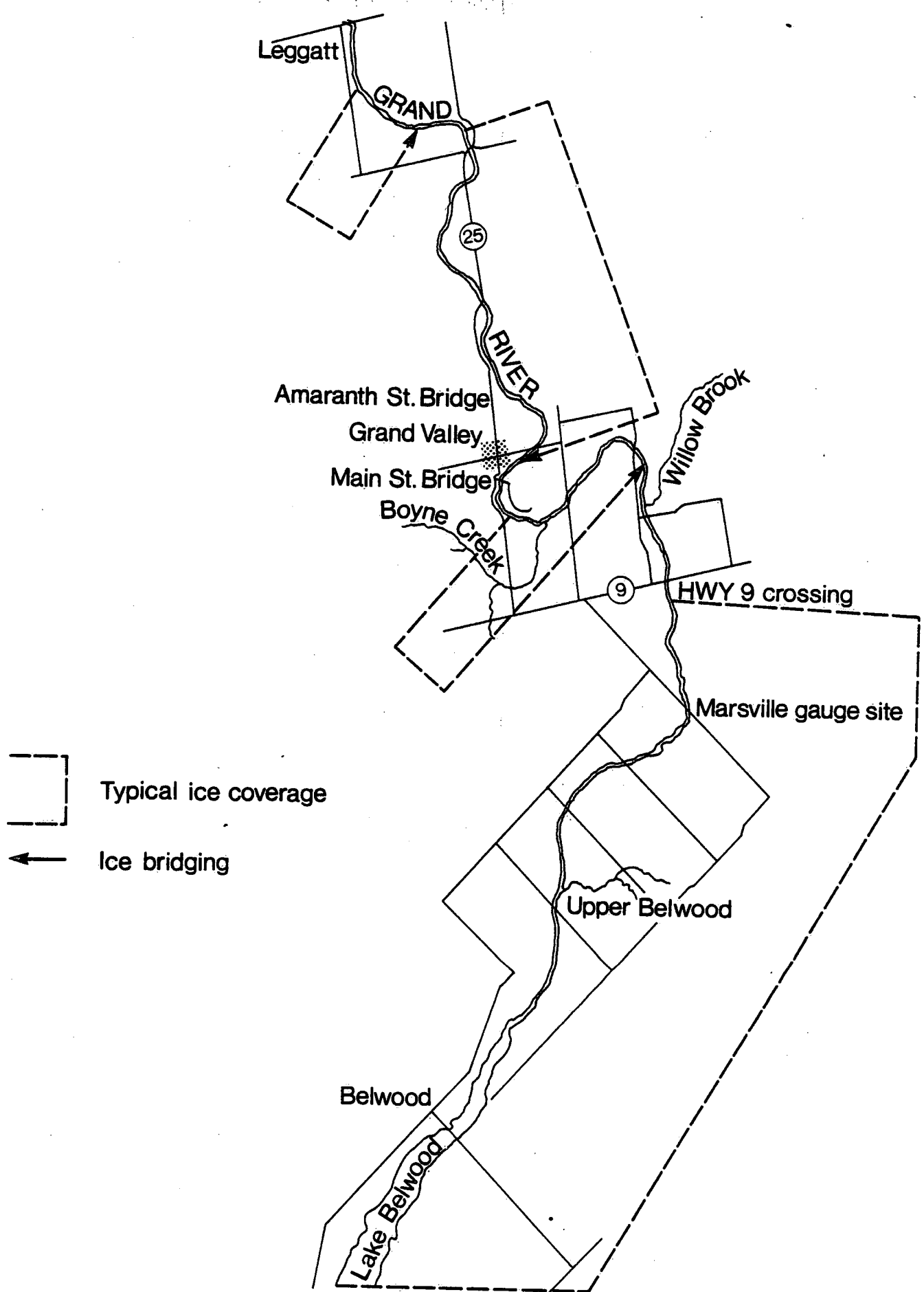


Figure 11b LOCATION OF ICE BRIDGING AND EXTENT OF TYPICAL ICE COVERAGE. UPPER HALF OF REACH.

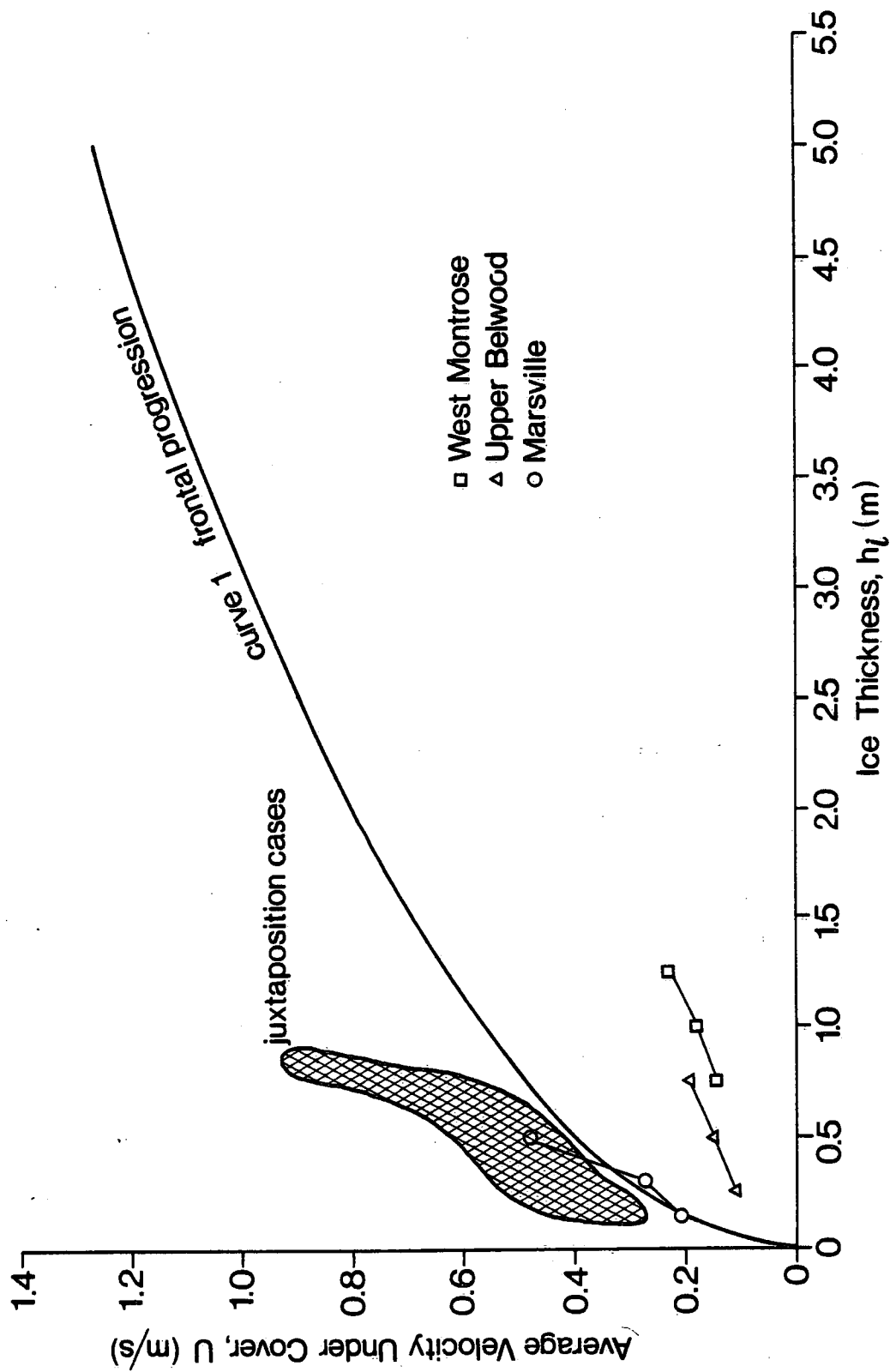


Figure 12 Universal representation of measured thickness of ice covers at time of formation. (Michel 1983)
 Curve represents best fit for data from these large rivers in five winter. Data points from Upper Grand River also included.

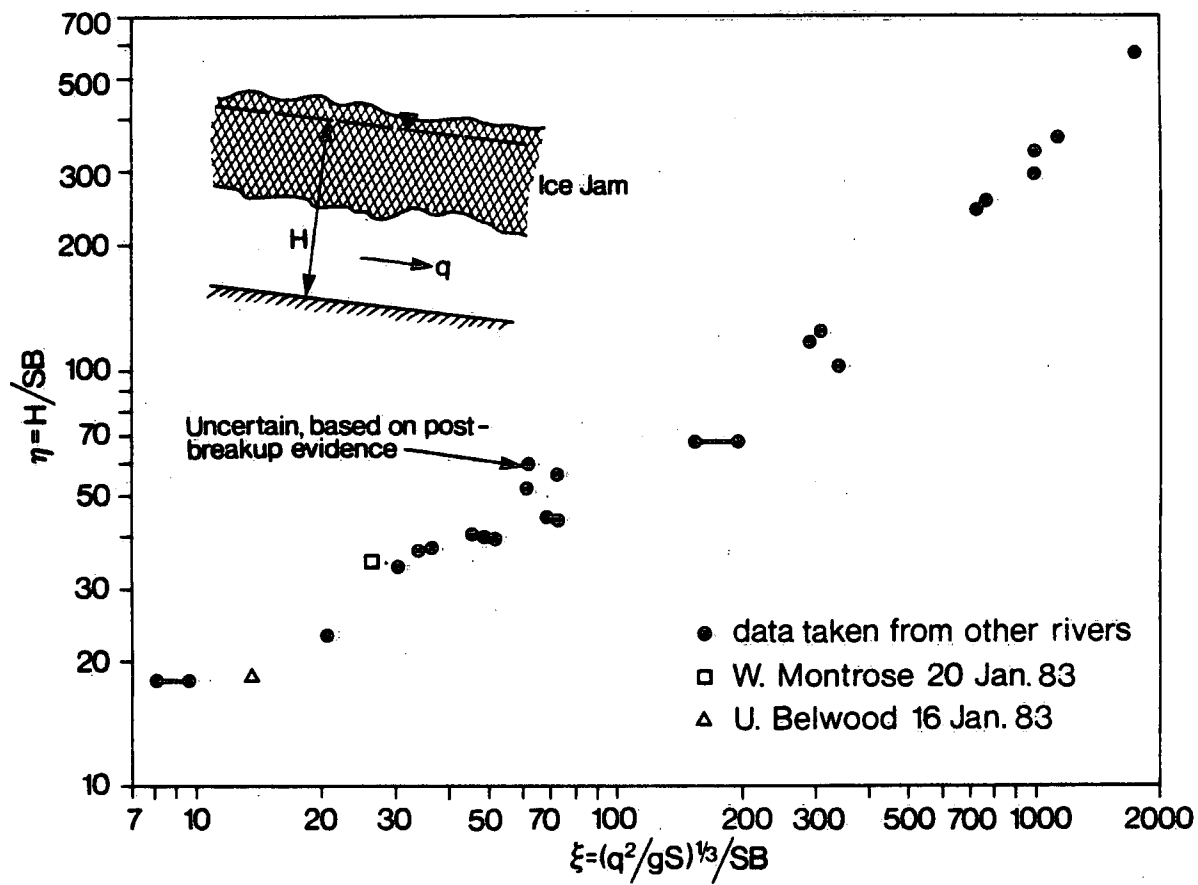


Figure 13 Dimensionless jam stage versus dimensionless discharge. Grand River data.

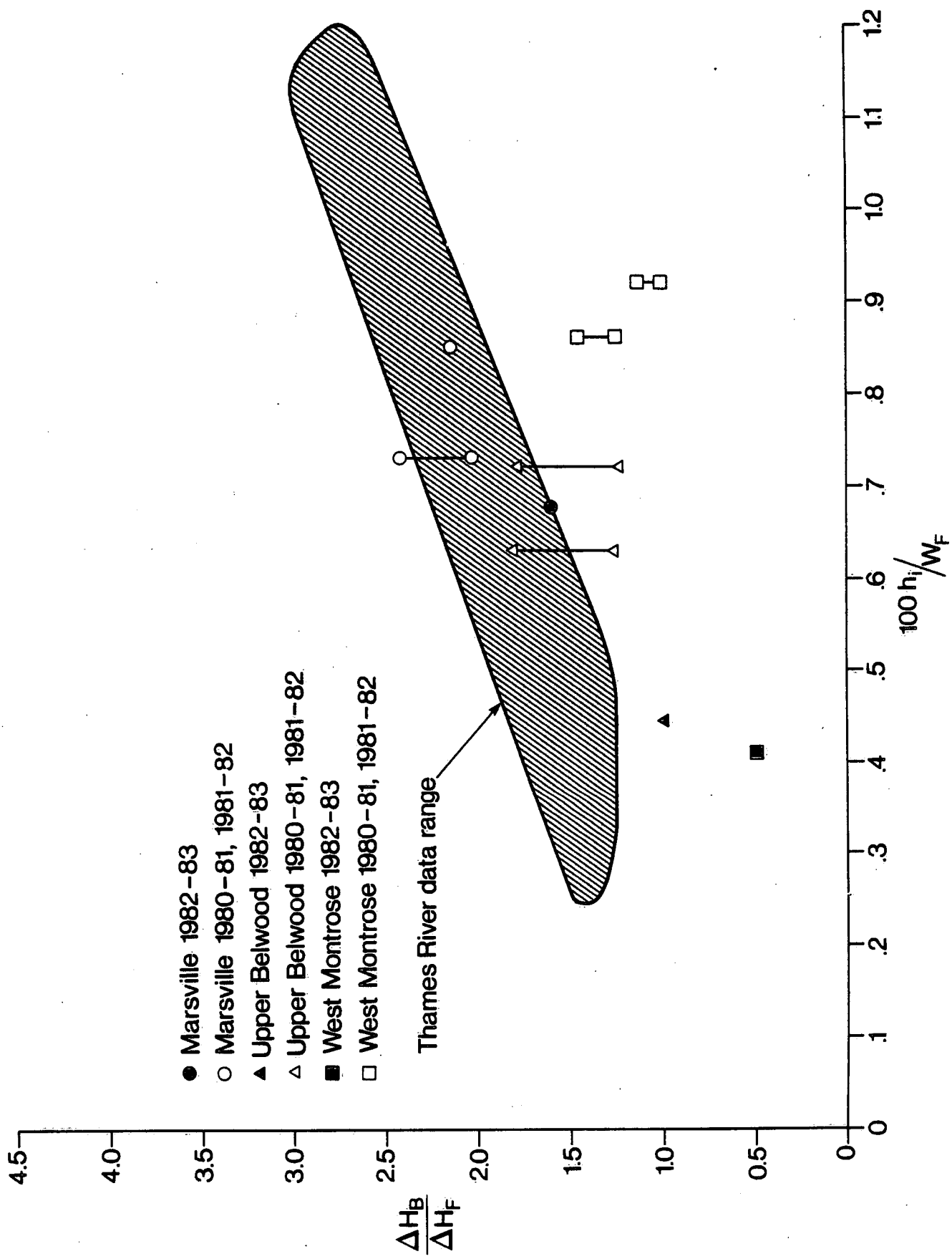


Figure 14 DIMENSIONLESS BREAKUP AND INITIATION STAGES VERSUS DIMENSIONLESS ICE THICKNESS. GRAND RIVER AT MARSVILLE, UPPER BELWOOD AND WEST MONTROSE.

APPENDICES

**APPENDIX A
PHOTOGRAPHS OF FREEZE UP
1982/83**



**A1. UPPER BELWOOD. 1415h,
Jan 12, 1983. Texture of ice accumulation
near leading edge.**



**A2. UPPER BELWOOD. 1100h,
Jan 16, 1983. Ice cover formation.
Looking d/s from bridge.**



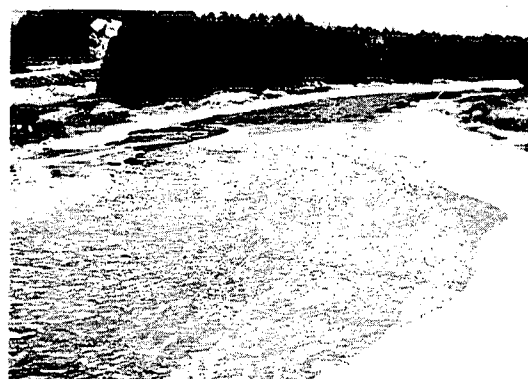
**A3. UPPER BELWOOD. 1100h,
Jan 16, 1983. Ice cover formation.
Looking u/s from bridge.**



**A4. MARSVILLE. 1015h, Jan 18,
1983. Control section d/s of bridge was
open.**

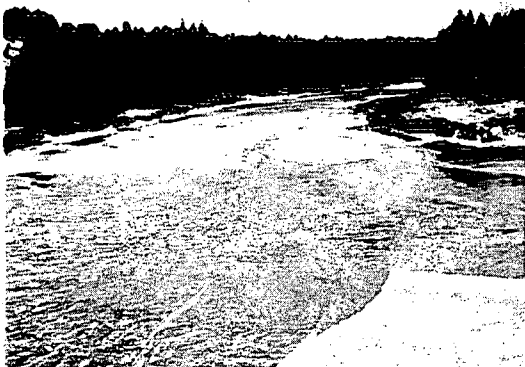


**A5. MARSVILLE. 1240h, Jan 18,
1983. Newly formed ice cover d/s of
bridge.**



**A6. MARSVILLE. 1240h, Jan 18,
1983. Newly formed ice cover u/s of
bridge.**

**APPENDIX A
PHOTOGRAPHS OF FREEZE UP
1982/83 CONTD.**



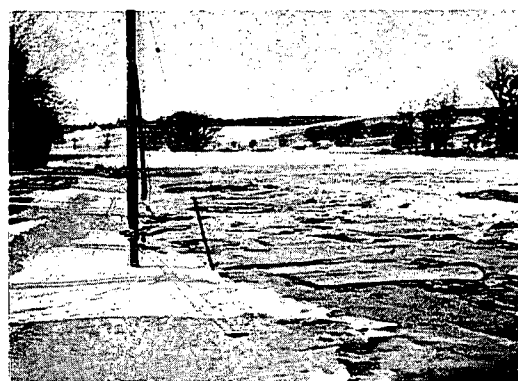
A7. MARSVILLE. 1316h, Jan 18, 1983. Newly formed ice cover u/s of bridge.



A8. IRVINE BRIDGE. 1311h, Jan 19, 1983. Smooth ice cover initiated just d/s of bridge.



A9. IRVINE BRIDGE. 1311h, Jan 19, 1983. Smooth ice cover u/s of bridge.



A10. WEST MONTROSE. 0958h, Jan 20, 1983. Slush/ice cover d/s of wooden bridge.



A11. WEST MONTROSE. 1000h, Jan 20, 1983. Slush/ice cover at wooden bridge.

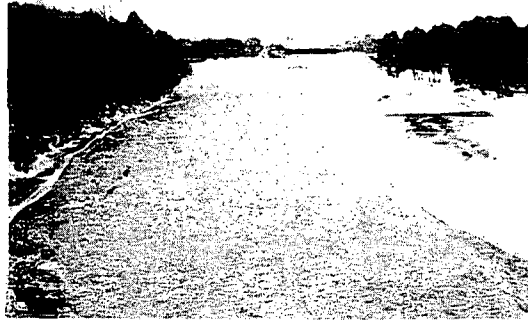


A12. WEST MONTROSE. 1530h, Jan 20, 1983. Rough slush/ice cover u/s of bridge. Looking u/s from LB.

**APPENDIX A
PHOTOGRAPHS OF FREEZE UP
1982/83 CONTD.**



**A13. WEST MONTROSE. 1530h,
Jan 20, 1983. Rough slush/ice cover u/s
of bridge. Looking u/s from RB.**



**A14. HWY 86. 1050h, Jan 21, 1983.
Looking d/s towards West Montrose.**



**A15. HWY 86. 1050h, Jan 21, 1983.
Looking u/s towards R/R bridge.**

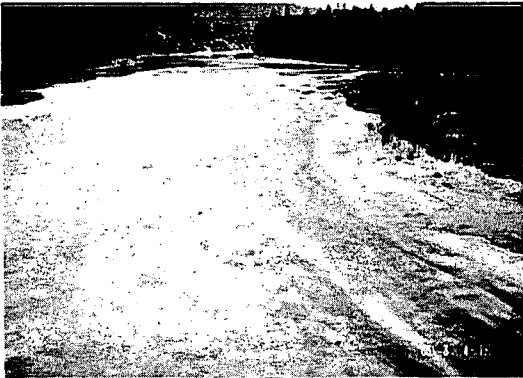
**APPENDIX B
PHOTOGRAPHS OF BREAKUP
1982/83**



B1. UPPER BELWOOD. 0900h, Mar 4, 1983. Looking d/s. Open to ~30m d/s.



B2. UPPER BELWOOD. 0900h, Mar 4, 1983. Looking u/s. Open to creek outlet.



B3. MARSVILLE. 0930h, Mar 4, 1983. Looking d/s. Open below control section.



B4. MARSVILLE. 0930h, Mar 4, 1983. Looking u/s. Open area along RB.



B5. 1st CROSSING D/S OF MARSVILLE. 1110h, Mar 3, 1983. Looking d/s at toe of jam.



B6. 1st CROSSING D/S OF MARSVILLE. 1110h, Mar 3, 1983. Looking u/s at jam.

**APPENDIX B
PHOTOGRAPHS OF BREAKUP
1982/83 CONTD.**



**B7. UPPER BELWOOD. 0825h, Mar 5,
1983. Looking d/s to head of jam.**

APPENDIX C

TABLE C1.

Water Levels and Ice Conditions at West Montrose

Date	Time	Gauge Reading (m)	Elevation (m)	Remarks
				<u>FREEZE-UP</u>
12 Jan	0915	11.737	320.176	Open. Frazil/slush flowing T = -10°C
13 Jan	1356	11.685	320.124	Some border ice. T = -1°C
16 Jan	0935	11.662	320.101	Winterbourne still open. T = -11°C
17 Jan	1525	11.658	320.097	T = -10.5°C
18 Jan	1305	11.630	320.069	Some border ice. Frazil/slush flowing by. Winterbourne was completely ice covered.
19 Jan	1030	11.601	320.040	Large areas of slush flowing by slowly. Leading edge 30 m d/s of TBM 62.66. Gauge starting to rise. T = -10°C Ice shoved. Leading edge 200 m d/s of TBM 62.66
	1450	11.804	320.243	
	1502	11.821	320.260	
	1602	11.904	320.343	
	1609			
20 Jan	0940	12.945	321.384	Leading edge just d/s of gauge. Gauge reading rose over 1 m since yesterday. Slush flowing pass gauge.
	0958	12.986	321.425	Leading edge u/s of covered bridge. Leading edge between covered bridge and Hwy 86. Ice began to shove at this time.
	1115	13.128	321.567	
	1142			
	1146	13.107	321.546	Leading edge ≈50 m d/s from TBM 61.32. Gauge seems to be levelling off.
	1201	13.111	321.550	
	1528	13.306	321.745	
21 Jan	1030	12,806	321.245	Completely ice covered at West Montrose. Ice cover past R/R bridge u/s of Hwy. 86 Gauge falling. T = -4°C.
21 Feb	1024	11.876	320.315	Condition same. No real change. Some open sections along banks u/s of West Montrose. No cracks in ice. Ice cover stop 1-2 km u/s of Hwy. 86.
				<u>BREAKUP</u>
1 Mar	1400	11.341	319.780	Ice all gone.

APPENDIX C

TABLE C2.

Water Levels and Ice Conditions at Upper Belwood

Date	Time	Tape Reading (m)	Elevation (m)	Remarks	
<u>FREEZE-UP</u>					
12 Jan	1100	5.37	427.19	Ice cover 600-700 m d/s of bridge. T = -10.6°C	
13 Jan	1354	5.37	427.19	Leading edge ~250 m d/s of bridge. T = -8.0°C.	
	1000	5.22	427.34		
16 Jan	1300	5.29	427.27	Condition same. Completely ice covered.	
	1109	4.81	427.75		
	1427	4.76	427.80		
17 Jan	1000	4.83	427.73	Solid ice except for two holes u/s of bridge.	
	1112	4.83	427.73		
	1340	4.81	427.75		
18 Jan	0957	4.86	427.70	Solid ice.	
19 Jan	1400	4.91	427.65		
20 Jan	1250	4.92	427.64		
24 Jan	1000	4.95	427.61		
28 Jan	1415	5.10	427.46		
4 Feb	0850	4.96	427.60		After rainfall, water from creek u/s along LB has been flowing over ice.
<u>BREAKUP</u>					
1 Mar	1000	5.35	427.21	Same few open spots u/s of bridge. Open spots larger. Water flowing onto ice d/s of bridge.	
2 Mar		5.31	427.25		
4 Mar	0900	4.96	427.60	River open from creek inlet to d/s of bridge. Ice solid but looking rotten. Open d/s for ~75 m d/s of bridge.	
	1153	4.89	427.67		
	1550	4.83	427.73		
	1732	4.78	427.78		
5 Mar	0825	4.22	428.34	Ice from upstream has moved down. Open u/s. Open d/s for ~75 m, then solid jam	
	1002	4.26	438.30		

APPENDIX C

TABLE C3.

Water Levels and Ice Conditions 1st Crossing d/s Marsville

Date	Time	Tape Reading (m)	Elevation (m)	Remarks
12 Jan	1108	6.875	433.65	<u>FREEZE-UP</u> Lots of slush flowing by. Solid ice cover. Very few open holes.
13 Jan	1022	7.065	433.46	
16 Jan	1130	7.235	433.29	
16 Jan	1328	7.25	433.28	
18 Jan	1009	6.59	433.94	
	1411	6.50	434.03	
19 Jan	1345	6.61	433.92	
20 Jan	1300	6.63	433.90	
24 Jan	1020	6.89	433.64	
28 Jan	1405	7.00	433.53	
4 Feb	0900	6.81	433.72	<u>BREAKUP</u> Some large holes u/s. Broken ice formed small jam near bridge. Ice d/s of bridge intact. Small jam 200 m u/s. Small jam at bridge. Jam extends 350-400 m u/s from bridge. Ice thickness 10-25 cm. Toe of jam broke off. Jam held up by bridge piers. Jam broke at approximately this time. Open.
1 Mar	1015	6.93	433.60	
2 Mar	0930	6.84	433.69	
4 Mar	0920	6.49	434.04	
	1026	6.57	433.96	
	1110	5.67	434.86	
	1123	5.68	434.85	
	1141	5.70	434.83	
	1200	5.71	434.82	
	1318	5.69	434.84	
	1432	5.65	434.88	
	1634	5.635	434.89	
	1640	6.21	434.32	
	1720	6.21	434.32	
	1830			
5 Mar	0815	6.51	434.02	

APPENDIX C

TABLE C4.

Water Levels and Ice Conditions at Marsville

Date	Time	Gauge Reading (m)	Elevation (m)	Remarks
				<u>FREEZE-UP</u>
12 Jan	1115	3.849	437.227	Some border ice. Lots of frazil/slush.
13 Jan	1030	3.725	437.103	Condition same. Control section clear.
16 Jan	1143	3.618	436.996	10 m of border ice on RB. 5 m of border ice on LB.
17 Jan	1033	3.631	437.009	Condition same. T = -12.5°C.
18 Jan	1138	3.686	437.064	Gauge rising. Leading edge of ice cover ≈250 m below gauge. T = -12°C. Cold and windy.
	1210	3.806	437.184	
	1232			Leading edge is at gauge site. No packing.
	1240	3.872	437.250	
	1316			Leading edge is ≈100 m above gauge.
	1328			Leading edge is ≈250 m above gauge.
	1330	3.875	437.253	Ice covered.
19 Jan	1340	3.791	437.169	Condition same, T = -10°C.
20 Jan	1300	3.735	437.113	T = 0°C
24 Jan	1030	3.630	437.008	
28 Jan	1400	3.653	437.031	
4 Feb	0912	3.853	437.231	After rainfall, open d/s of control section.
				<u>BREAKUP</u>
1 Mar	1021	3.737	437.115	Holes near control section. 100 m u/s of bridge is open.
	1138	3.758	437.136	
2 Mar	0945	3.819	437.197	Open d/s of control section.
	1235	3.838	437.216	
4 Mar	0932	4.104	437.482	Rained overnight. Gauge rising steadily. Ice jam behind ice sheet.
	0946	4.133	437.511	Ice thickness = 15-25 cm
	0949	4.140	437.518	Jam broke at gauge.
	0950	4.195	437.573	
	0952	4.338	437.716	
	0957	4.496	437.874	Large ice sheet jams at control section. Some flow getting around it along RB.

TABLE C4. Water Levels and Ice Conditions at Marsville (continued)

Date	Time	Gauge Reading (m)	Elevation (m)	Remarks
4 Mar	1000	4.513	437.891	Jam broke. Ice from upstream passing gauge. Ice still passing gauge.
	1005	4.572	437.950	
	1010	4.606	437.984	
	1020	4.638	438.016	
	1040	4.740	438.118	
	1105	3.955	437.333	
	1258	3.968	437.346	
	1323	4.016	437.394	
	1325	4.010	437.388	
	1444	3.983	437.361	
5 Mar	0300	4.090	437.468	Gauge falling slowly. Remaining ice along RB is \approx 13 to 25 cm thick.
	0848	4.056	437.434	
	0938	4.044	437.422	