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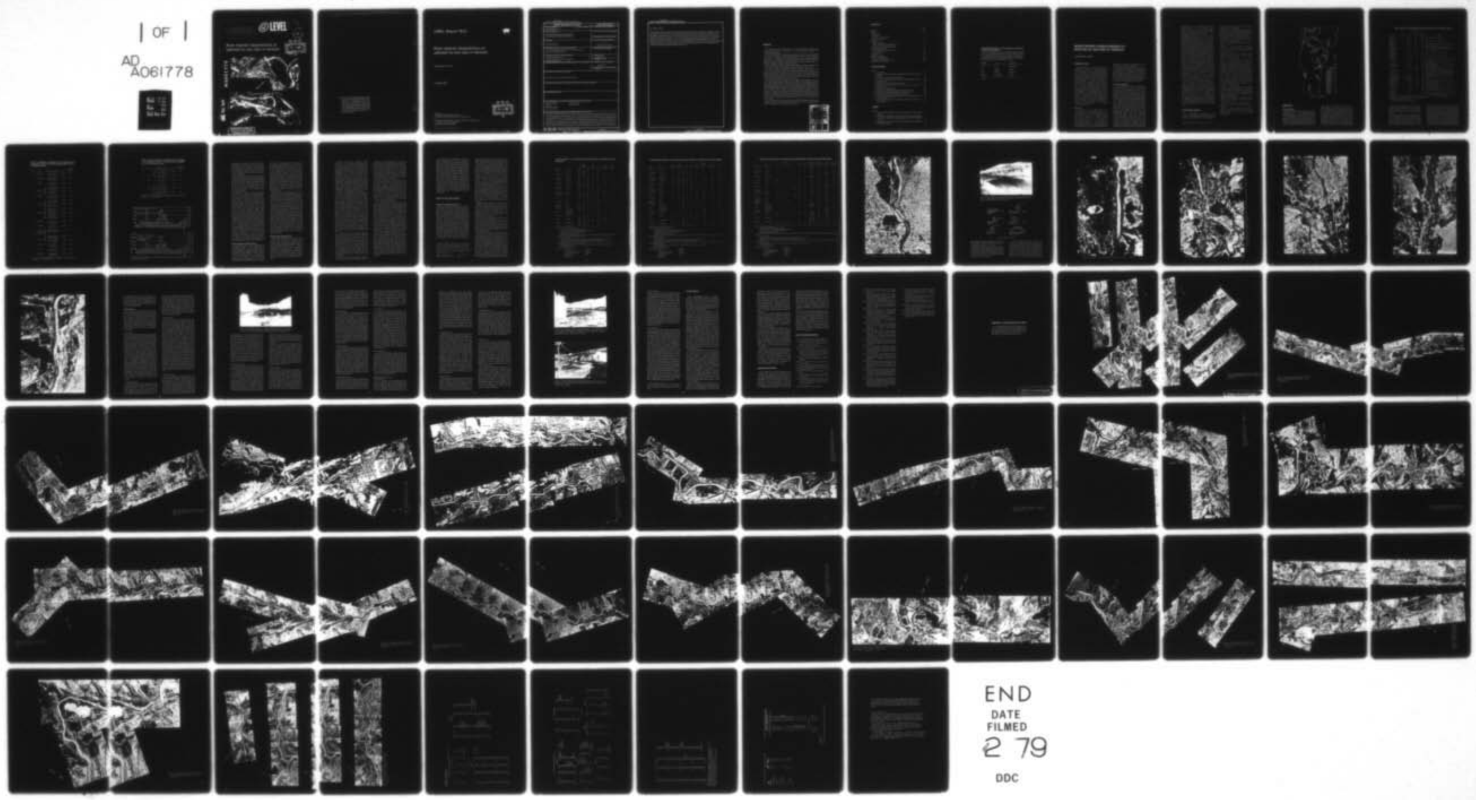

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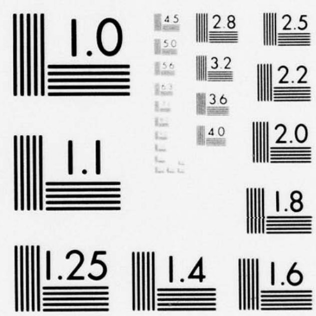

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U.S. ARMY CORPS OF ENGINEERS

REPORT 78-25

River channel characteristics at selected ice jam sites in Vermont

Cover: Ice jam on the Ottauquechee River in the same reach as shown in photomosaic 19 in Appendix A. Photographs shown here were taken on 30 January 1976 after water (black streaks) had flowed across the snow covered floodplain. Numbers show profile sites for detailed studies of ice and river characteristics being performed by D. Calkins and others.

CRREL Report 78-25

River channel characteristics at selected ice jam sites in Vermont

Lawrence W. Gatto

October 1978

Prepared for
EMERGENCY OPERATIONS CENTER
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
By
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The objectives of this investigation were to describe channel characteristics and geographic settings of ice jam sites from aerial photographic interpretation, to indicate which characteristics may be important in causing ice jams, and to suggest additional uses of aerial photographs. Aerial photographs were taken of 19 sites with a Zeiss RMK 15/23 aerial camera on 17, 19, and 21 April 1976. Uncontrolled photomosaics of each site were assembled and major river characteristics were delineated on the photomosaics. Characteristics described include: manmade structures, falls, rapids, changes in channel depths, channel islands, mid-channel shoals or bars, river bed material, river sinuosity, meanders, floodplain width, riparian vegetation, and types of development on the floodplain. River channel widths

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20. Abstract (cont'd)

were measured from the photographs along rivers where ground truth data were available for comparison. Lengths of channel riffles and pools were measured along the rivers where variations in river depths were evident on the photographs. Seventy-nine percent of the sites have some form of flow control structure which causes a pool with a backwater condition of low velocity. The low flow condition in the pool allows a solid ice cover to form which impedes ice movement and initiates ice jams. Aerial photographs provide a regional perspective for evaluating channel characteristics at an ice jam site and for analyzing the geographic setting at each site during ice-free conditions. Photographs taken after ice jams have formed are useful in monitoring ice jam formation, in analyzing ice characteristics, and in documenting ice jam breakup and movement.

PREFACE

This report was prepared by Lawrence W. Gatto, Research Geologist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The work was funded by the Emergency Operations Center, New England Division, Corps of Engineers, under Intra-Army Order 76-C-22, *Analysis of Potential Ice Jam Sites — Connecticut River at Windsor, Vermont*. Project planning and performance were conducted in cooperation with Darryl J. Calkins, Research Hydraulic Engineer, CRREL, under the CRREL Ice Engineering Program, *Fundamental Mechanics of Ice Jams*, CWIS No. 31332.

Darryl J. Calkins of CRREL and Major Robert Hando of the New England Division, Corps of Engineers, reviewed the technical content of this report.

The author expresses appreciation to Robert Wernecke, Roy Gaffney, Jeff Cueto, and Barry Cahoon of the Vermont Department of Water Resources for assistance with initial site selections; and to personnel from the Vermont Civil Defense Department for notification of ice jam occurrences during the 1975-1976 winter which verified that many of the sites selected in December 1974 from historical records remained as active ice jam sites.

The author also expresses appreciation to Thomas Marlar, CRREL, for acquisition of aerial photographs; to Robert Demars, CRREL, for photographic processing; to Eleanor Huke, CRREL, for assistance in preparing maps and photomosaics, in measuring channel characteristics from the photographs, in reducing data, and for helpful suggestions in preparing the report; to Harlan McKim, CRREL, Carolyn Merry, CRREL, Thomas Marlar, Tom Wilkinson, Buffalo District, Corps of Engineers, Guenther Frankenstein and Stephen DenHartog, CRREL, for critical comments and suggestions during report preparation; to Major Robert Hando, NED, for technical review of this report; and, especially, to Darryl Calkins for assistance and recommendations throughout the project and for technical review of this report.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
mile	1.6093	kilometer
degree	0.01745329	radian

*Exact

RIVER CHANNEL CHARACTERISTICS AT SELECTED ICE JAM SITES IN VERMONT

Lawrence W. Gatto

INTRODUCTION

Kennedy (1975) lists two requisites for the formation of an ice jam: 1) a large discharge of frazil or fragmented solid ice, and 2) an obstacle in the channel that impedes downstream passage of ice. Both Kennedy (1975) and Uzuner and Kennedy (1976) indicate that the types of channel obstacles (natural and manmade) are almost boundless, i.e., changes in width (e.g., bridge piers and abutments), changes in depth (e.g., sand bars), manmade surface obstacles (e.g., ice booms), and combinations of these. Sokolov and Gotlib (1975) also enumerate some locations along a river channel where ice jams can frequently occur: 1) transition zones where channel slopes change suddenly from steep to gentle, 2) reaches below rapids where flow velocity is retarded, 3) river confluences, 4) sharp bends where wide velocity distributions occur, 5) abrupt narrowings of channels, 6) shallows with islands, and 7) river reaches covered with stable ice.

Objectives

The objectives of this study were to: 1) describe and enumerate channel characteristics and geographic settings at selected ice jam sites in Vermont using aerial photographs taken during ice-free conditions, 2) indicate which characteristics may be factors in causing ice jams to form and which may aggravate the effects of jams at these sites, and 3) suggest some possible additional uses of aerial photographs in the analysis of ice jams and in the acquisition of other pertinent geologic and geomorphic information on ice jam site characteristics.

It was not an objective of this study to provide the capability of predicting where and when ice jams will occur or to explain ice jam mechanics. The feasibility of developing such a predictive index, and the analysis of ice jam mechanics are being addressed in an ongoing, long-term analysis of ice jams conducted by other CRREL investigators (Calkins, principal investigator).

Previous investigations

Aerial photographs have been used in analyzing several aspects of ice jams. Mollard (1973) described some geohydrologic features, e.g., channel sinuosity, channel patterns, qualitative stream bed gradients, channel lengths, valley lengths, stream channel material, and floodplain types, that can be observed and measured on aerial photographs. Joering (1968) and (Kudritskii et al. 1956) included channel width and roughness, drainage area, meander wavelength, stream and bank vegetation, lengths of shoals and pools in channel, and locations of rapids as identifiable and measurable on aerial photographs. Joering (1968) concluded that aerial photographic interpretation provides reliable reconnaissance-type data for hydrologic analysis and inventory. Kudritskii et al. (1956) also mentioned that stereo photographs are especially useful when some of these channel features are being measured. McKim et al. (1976) compared the utility of satellite and high-altitude aircraft photographs for analyzing many of the above features as well as general local topography, basin shape, drainage density, and stream network (i.e., channel patterns, stream ordering, and bifurcation ratios). They concluded that many of the channel and basin features are more evident in areas of high relief.

DenHartog (1977) used vertical aerial photographs to observe the location of shallow bars, bends, and constrictions at an ice jam site on the Pemigewasett River, near Plymouth, New Hampshire. He concluded that aerial photographs of a specific site must be taken when the site is with and without jams to aid in determining the causes of jams. MacKay et al. (1974) used aerial photographs for river surveillance of erosion on channel islands, beds, and banks, caused by ice moving in the river during breakup. In addition, they used the photographs to determine surface current velocities and to document the extent of flooding due to ice jams. Sherstone (1973) also used aerial photographs to measure surface water velocities and to characterize ice within an ice jam. Calkins (1977), using aerial photographs, measured the sizes of ice blocks in a jam along the longitudinal profile of the jam and found the sizes of the blocks decreased upstream. Gerard (1975) reported that aerial photographic reconnaissance can provide valuable information on the formation, characteristics, and consequences of ice jams, and on geomorphic characteristics of ice jam sites.

As part of an earlier CRREL investigation, "Analysis of potential ice jam sites, Connecticut River at Windsor, Vermont" (Calkins et al. 1976),photointerpretation techniques were used with ground truth data to begin evaluating the possibility of preparing an index of ice jamming potential that could be used to determine likely sites of ice jam occurrences along a river. Because of the success of this photointerpretation approach and of the other investigations just mentioned, a photointerpretation approach was used during the present study to describe the channel and local setting at selected ice jam sites.

GLOSSARY OF TERMS*

Bar — A ridge-like accumulation of sand, gravel, or other alluvial material formed in the channel, along the banks, or at the mouth of a stream where a decrease in velocity induces deposition (river bar, channel bar).

Bed material — The material of which the bed of a stream is composed; it may originally have been the material of suspended load or of bed load, or may in some cases be partly residual.

Confluence — A place of meeting of two or more streams; the point where a tributary joins the main stream; a fork (junction).

Falls — A waterfall or other precipitous descent of water.

Meander — One of a series of somewhat regular, sharp, freely developing, and sinuous curves, bends, loops, turns, or windings in the course of a stream.

Meander bar (point bar) — A deposit of sand and gravel located on the inside, and extending into the curve, of a meander.

Pool — 1) A small, quiet, and rather deep reach of a stream, as between two rapids or where there is very little current. 2) A small or large body of impounded water, artifically confined above a dam or the closed gates of a lock.

Rapids — A part of a stream where the current is moving with a greater swiftness than usual and where the water surface is broken by obstructions but without a sufficient break in slope to form a waterfall, as where the water descends over a series of small steps. It commonly results from a sudden steepening of the stream gradient, from the presence of a restricted channel, or from the unequal resistance of the successive rocks traversed by the stream.

Riffle — A natural shallows or other expanse of shallow bottom extending across a streambed over which the water flows swiftly and the water surface is broken in waves by obstructions wholly or partly submerged; a shallow rapids of comparatively little fall.

Riparian — Pertaining to or situated on the bank of a body of water, especially of a watercourse such as a river.

Shoal — A relatively shallow place in a stream, lake, sea, or other body of water; a shallows.

Sinuosity —Ratio of length of the channel or thalweg to the down-valley distance; channels with sinuosities of 1.5 or more are called meandering.

*Definitions from Glossary of Geology (Gary et al. 1972)

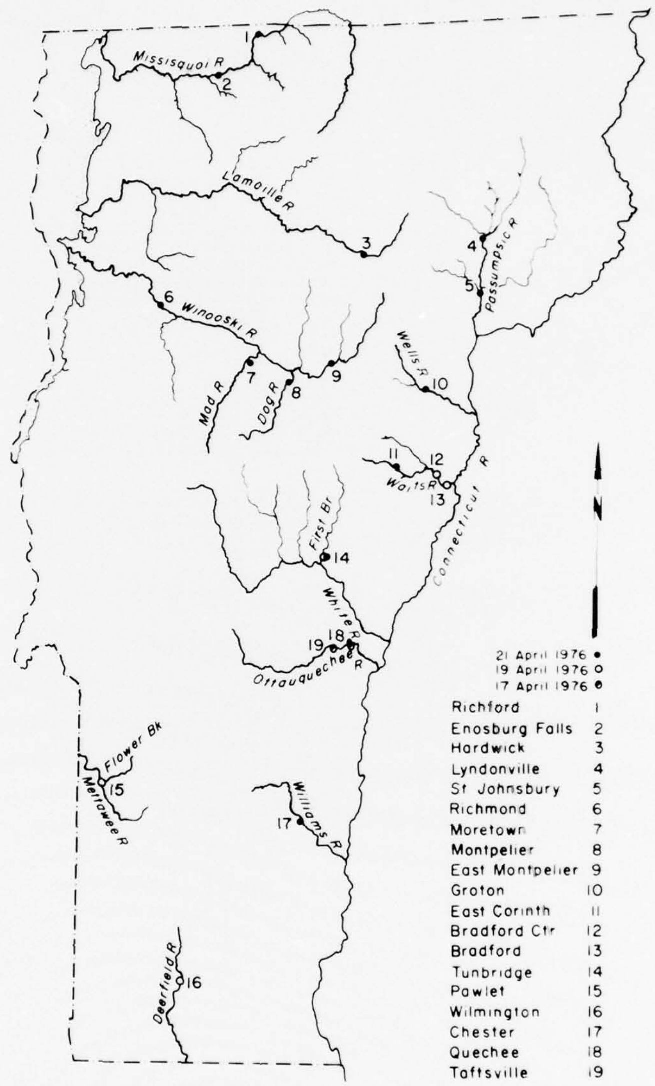

Figure 1. Ice jam sites.

APPROACH

Photo acquisition

Black and white (Plus-X 2402 film) aerial photographs (9 × 9 in.) were obtained from 19 sites in Vermont on 17, 19 and 21 April 1976 (Fig. 1). The photographs were taken with a Zeiss RMK 15/23 aerial camera. Aircraft altitude was adjusted above the mean ground elevation at each site to provide photographs with a nominal scale of 1:6000. Local terrain changes and aircraft altitude fluctuations caused the photographic scale variations shown in Table I. U.S. Geological Survey topographic maps (Table II) were used in planning the flight line orientation and mileage, appropriate aircraft altitudes, and sequence for photographing the sites. Uncontrolled photomosaics of each site were prepared with the black and white prints (photomosaics are shown in App. A). Points of interest and the limits of the river channel where ice jams usually occur were delineated. The

Table I. Data on aerial photographs acquired for analysis of ice jam sites in Vermont.

River/town	Site no.	Date	Altitude (msl) (ft)	Nominal scale*	Remarks
Missisquoi/ Richford	1	21 Apr 76	3580	1:6400	From East Richford to East Bershire
Missisquoi/ Enosburg Falls	2	21 Apr 76	3380	1:6100	From North Enosburg to South Franklin
Lamoille/ Hardwick	3	21 Apr 76	3780	1:5200	From Hardwick Lake upstream 2.5 straight line (SL) miles past Hardwick
Passumpsic, East/West Branch/ Lyndonville	4	21 Apr 76	3580	1:5800	From 1.2 SL miles downstream from Lyndonville to 1.5 SL miles upstream on the East and West Branches
Passumpsic/ St. Johnsbury	5	21 Apr 76	3580	1:5800	From St. Johnsbury Center to Passumpsic
Winooski/ Richmond	6	21 Apr 76	3280	1:6300	From Richmond 4.4 SL miles downstream
Mad/Moretown	7	21 Apr 76	†	1:6100	From confluence of Winooski and Mad Rivers up Mad R. 5.1 SL miles
Dog/Montpelier	8	21 Apr 76	†	1:6700	From 2 SL miles downstream from Riverton to 3.5 SL miles downstream
Winooski/ East Montpelier	9	21 Apr 76	†	1:5300	From Plainfield downstream 1 SL mile past confluence with Kingsbury Branch
Wells/Groton	10	21 Apr 76	3880	1:5300	From 1.3 SL miles upstream on the South Branch to 1.3 SL miles downstream of Groton
Tabor Branch, Waits/E. Corinth	11	21 Apr 76	3680	1:6800	From Topsham Four Corners on Tabor Branch to confluence with Waits R., upstream on Waits 2 SL miles and downstream 2.5 SL miles, from confluence
Waits/Bradford Center, Bradford	12 13	19 Apr 76	†	1:6200	From Bradford village to 1.4 SL miles upstream from Bradford Center
First Branch, White/Tunbridge	14	19 Apr 76 21 Apr 76**	3580	1:5400	From 0.8 SL miles south of Tunbridge to 3.2 SL miles north
Flower Brk. and Mettawee/Pawlet	15	19 Apr 76	3680	1:5700	From confluence of Mettawee R. and Flower Brk. up Flower Brk. 3.4 SL miles
Deerfield/ Wilmington	16	19 Apr 76	3580	1:4600	From 3.5 SL miles upstream from Wilmington to Harriman Reservoir
Williams/Chester	17	21 Apr 76	3580	1:5800	From 1 SL mile upstream from Gassetts to 2.5 SL miles downstream from Chester
Ottauquechee/ Quechee	18	17 Apr 76	†	1:5900	From upper Deweys Pond upstream 3.4 SL miles
Ottauquechee/ Taftsville	19	17 Apr 76	†	1:5900	From 0.5 SL miles downstream of Taftsville, upstream to 1 SL mile past West Woodstock

Note: Camera - Zeiss RMK 15/23 Metric, Film type - Plus-X 2402, Negative size (in.) - 9×9, Focal length (in.) — 6

*Rounded off from scale shown on photomosaics in Appendix A

†Information not determined or known

**Flown twice, weather on first day was marginal

scales shown on the photomosaics are for the original aerial photographs, not for the photomosaics themselves. The mosaics shown here have been reduced from much larger original mosaics.

Initially, the intent was to photograph the sites in September or October when river water levels are statistically low (Fig. 2) for this region to best observe the channel features. In addition, flows in the fall are comparable to the flows in February and March when ice jams generally begin to form; therefore, the water levels in the fall might be similar to those that are present when jams form. This would allow observation of the channel features that might be more important in initiating jams. Usually, ice jams form during or after a period of high flow and high water levels that release the cover of stable ice and start an ice run. Looking at the discharge trends for the 1941-1970 period (Fig. 2), it is apparent that the discharge statistically decreases from the November-December period

Table II. Topographic quadrangles used for planning aerial photographic missions, for determining photographic scale, and for analyzing each site.

Site no.	*Name*	*Topographic quadrangle**	*Scale*	*Quadrangle date*
1	Richford	Jay Peak, Vt N4445 - W7230/15	1:62,500	1953
2	Enosburg Falls	Enosburg Falls, Vt N4445 - W7245/15	1:62,500	1953
3	Hardwick	Hardwick, Vt N4430 - W7215/15	1:62,500	1951
4	Lyndonville	Lyndonville, Vt N4430 - W7200/15	1:62,500	1951
		Burke, Vt N4430 - W7145/15	1:62,500	1951
5	St. Johnsbury	St. Johnsbury, Vt-NH N4415 - W7200/15	1:62,500	1949
6	Richmond	Essex Junction, Vt N4422.5 - W7300/7.5	1:24,000	1972
		Richmond, Vt N4422.5 - W7252.5/7.5	1:24,000	1948
7	Moretown	Middlesex, Vt N4415 - W7237.5/7.5	1:24,000	1968
		Waterbury, Vt N4415 - W7245/7.5	1:24,000	1948
		Waitsfield, Vt N4407.5 - W7245/7.5	1:24,000	1970
8	Montpelier	Barre, Vt N4400 - W7230/15	1:62,500	1957
9	E. Montpelier	Plainfield, Vt N4415 - W7215/15	1:62,500	1953
10 11 12	Groton E. Corinth Bradford Center	Woodsville, Vt-NH N4400 - W7200/15	1:62,500	1935
13	Bradford	Woodsville, Vt-NH N4400 - W7200/15	1:62,500	1935
		Mt. Cube, NH-Vt N4345 - W7200/15	1:62,500	1931
14	Tunbridge	Strafford, Vt N4345 - W7215/15	1:62,500	1944
15	Pawlet	Pawlet, Vt N4315 - W7307.5/7.5	1:24,000	1967
16	Wilmington	Wilmington, Vt N4245 - W7245/15	1:62,500	1954

*Coordinates are for the southeast corner of quadrangle. /7.5 or /15 indicates the map series, i.e., 7.5- or 15-min series.

Table II (cont'd). Topographic quadrangles used for planning aerial photographic missions, for determining photographic scale, and for analyzing each site.

Site no.	Name	Topographic quadrangle*	Scale	Quadrangle date
17	Chester	Ludlow, Vt N4315 - W7230/15	1:62,500	1929
		Saxtons River, Vt N4300 - W7230/15	1:62,500	1957
18	Quechee	Quechee, Vt N4337.5 - W7222.5/7.5	1:24,000	1959
19	Taftsville	Quechee, Vt N4337.5 - W7222.5/7.5	1:24,000	1959
		Woodstock North, Vt N4337.5 - W7230/7.5	1:24,000	1966
		Woodstock South, Vt N4330 - W7230/7.5	1:24,000	1966

*Coordinates are for the southeast corner of quadrangle; /7.5 or /15 indicates the map series, i.e., 7.5- or 15-min series.

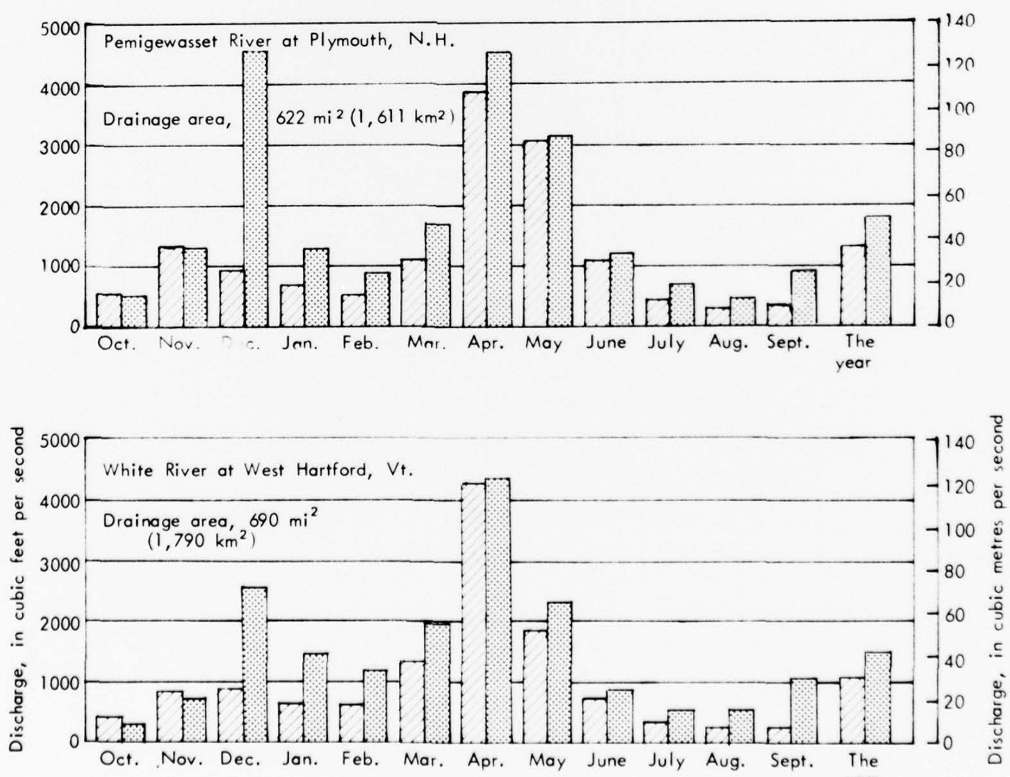

Figure 2. Median discharge at two long-term index gaging stations for period 1941-70 (U.S. Geological Survey 1974).

to February, then increases through March to April when it peaks and decreases to the August-September period. A stable ice cover generally forms during the decreasing discharge period from December through February; then this cover is broken and set in motion as discharge increases in March.

After considering that much of the channel might be obscured from view during the August-October period because of the tree canopy, and because of aircraft scheduling problems during this time, the aircraft mission was flown in April before leaf out and after the disappearance of ice from all the sites. Regional flows were variable from normal to above normal during this time (USGS 1976).

In retrospect, there are several reasons that the best time to acquire aerial photographs for this type of study would be in late October or early November. Based on the long-term flow data in Figure 2, flows at this time are comparable to those in February and March when jams usually begin to form. During the October-November period, the extents of riffles and pools could be easily observed and measured since water levels would be down. These features were apparent on the April photographs for only a few sites. In addition, most trees are bare at this time and would not obscure channel margins. Flying weather is usually good because atmospheric haze is low and cloud-free days are numerous. However, sun angle is decreasing during this period and shadows may mask portions of the channel margins that are bordered by trees. As DenHartog (1977) indicated, ideally aerial photographs should be taken twice: once when water levels are low and jams are absent to allow best observation of the channel so that possible obstructions to flow could be documented; and again, during increased flows after jams have formed to show where the ice was stopped and to suggest which obstruction may be the primary factor in initiating the jams.

Photo advantages and disadvantages

Although the utility of aerial photographs in geomorphic studies is well established, the following limitations or disadvantages inherent in the photographs should be considered before quantification of geomorphic features: 1) uncorrected horizontal distances are easily determined but vertical relief is more difficult to measure, and 2) photographic scale is variable and geometric or relief distortions are common. The effects of these limitations can be reduced by utilizing geometrically corrected and rectified photographs that lessen the measurement errors that result from distortions on uncorrected photographs. If corrected photographs are not available, however, it must be recognized that scale variations and geometric distortions tend to increase from the central to the peripheral portions of a photograph; therefore, measurements should be made in the middle portion of the photograph where distortions are minimal. Thus, whenever possible, measurements of river channel characteristics during this project were made in the middle third of the photograph to minimize the errors caused by these distortions.

In spite of these limitations there are several advantages in using aerial photographs: 1) a permanent record of river channel conditions existing at the time of photo acquisition is obtained; 2) more detail is available than on maps or charts of the same scale; 3) the effects of processes active and the features present at a site can be observed; and 4) some data can be more economically acquired from photographs than from extensive field surveys. However, data collected from photographs may not be as accurate as data acquired from field reconnaissance; therefore, the requirements and objectives of an investigation must be considered in determining whether photointerpretation techniques would be useful. This project was designed as a reconnaissance of ice jam sites to show the river channel features that characterize these sites and those that can be observed and measured using aerial photographs. This project was not intended to determine precise cross sections or hydraulic parameters that must be obtained from field surveys.

Features observed and measured

Initially the characteristics that were to be observed and measured were: channel width, channel shape or patterns, drainage patterns, channel slope, relative depths, generalized cross section (width and depth), riffle (i.e., shallows) and pool lengths, and manmade structures or modifications. However, after a preliminary evaluation of the photographs and a determination of the river characteristics likely to have a role in causing ice jams, the number of characteristics to be measured or described was reduced.

Drainage pattern (e.g., dendritic, trellis, parallel, etc.) was considered an unimportant factor in causing ice jams, and therefore it was not described during this study although aerial photographs could be used for that purpose. Although relative depths can be observed and generalized cross sections determined with aerial photographs, the accuracy of these determinations is too low to be useful in site characterization. Because river channel slope is important but not readily obtainable from aerial photographs, topographic quadrangles (Table II) were used to estimate the local average channel slope. Calkins (personal communication, 1976) stated that average river slope measured from quadrangles would be inadequate for use in the ice jam areas where backwaters are present.

Calkins et. al. (1976) have also indicated that sites in a stream channel where ice jams generally form are: 1) constrictions; 2) exposed rock outcrops and manmade structures (e.g., bridge piers); 3) long, low-velocity, deep water pools; and 4) shallow sections that cross portions of the channel where grounding of ice floes could begin. Calkins (personal communication, 1976) has also indicated that drainage area may indirectly influence ice jam formation at river confluences. The tributary river with a small drainage area might jam first because the peak flow and travel time would occur earlier than those for a river with a larger watershed having the same general shape and same geographic aspect (orientation). He has also reported that the drainage area for the smallest river on which he had observed a significant ice jam was approximately 30 square miles; the width of that river at the jam site was 50-70 ft [similar to the Tunbridge site (no. 14, Fig. 1); Table BID, App. B)].

To analyze the sites for the four conditions described by Calkins et al. (1976), the following channel features were observed, described, or measured: 1) meanders, since they can cause drastic changes in flow fields and can reduce the downstream flow of ice; 2) the presence of shoals or riffles, since ice can become grounded on the river bed at these locations; 3) the locations of pools, since in these low-velocity areas ice movement can slow, and a stable ice cover can form; 4) the presence of manmade structures and channel widths, since these factors can restrict flow.

Calkins (personal communciation, 1976) also stated that on small rivers manmade structures and natural river configuration can be very important factors in initiating ice jams; therefore, these small rivers would be measured in terms of drainage area or possibly widths. On larger rivers, channel configuration is less important and manmade structures can be the predominant factor in initiating the jams. A comparison of the drainage areas of the smaller and larger rivers may give a measure of the relative importance of these two river conditions.

Riparian vegetation was described, since it was felt that the presence of trees and brush may tend to increase the "holding capacity" of the shore. However, Calkins (personal communication, 1976) indicated that riparian vegetation probably does not influence the ice jam, except where trees are abundant; in this case, the trees could keep the ice in the channel and restrict the ice from spreading into the floodplain. The channel material was described since its size would influence the frictional resistance of the river bed to flow.

As an evaluation of the accuracy of the measurements of channel width, and riffle and pool lengths, made on the aerial photographs, the measurements were compared with those taken during ground surveys at a different time. This comparison was made at the Tunbridge (14) and the Quechee (18) (Fig. 1) sites, where field data were collected at 3 and 13 river cross sections, respectively. Photo measurements of channel widths were also made at the Hardwick (3), St. Johnsbury (5), Bradford (13), and Chester (17) sites. The lengths of riffles and pools were measured only at the Tunbridge and Bradford sites where they were most apparent. The above six sites were considered important by Vermont Department of Water Resources personnel because jams at these sites are usually severe.

Most of the widths measured on the photographs were within 10% of those measured by surveys. The differences result from several factors: 1) ground surveys were made in the summer, whereas the photographs were acquired in April when water levels were different; 2) locations where the widths were measured on the ground did not coincide precisely with photomeasurement locations; and 3) photo scales varied. In spite of these differences, the accuracy of photo measurements could be sufficient depending on the objectives of the reconnaissance.

In summary, the descriptions of the geographic settings for all 19 sites included: 1) upstream and downstream limits of the reaches where the ice jams usually form; 2) estimates of local channel slopes; 3) presence of major slope changes (i.e., falls, rapids); 4) channel widths, shapes, or patterns (plan view configuration, i.e., meandering, sinuous, braided, straight); 5) relative channel depths; 6) channel material that influences the frictional resistance to flow; 7) apparent water surface roughness (enhanced or obscured by sunglint*); 8) channel bottom variations when water penetration is sufficient; 9) riparian vegetation that may contribute to the restriction of ice flow when the river water level is higher than the normal channel; 10) floodplain characteristics; 11) manmade structures and modifications; and 12) possible major factors causing jams.

RESULTS AND DISCUSSION

Appearances of observed features

Figures 3-9 indicate how the features and conditions (Table III) observed at the various sites appeared on the original aerial photographs at full scale. Many of these features are shown in Figure 3. The other figures were selected to show the remaining features at different geographic settings. The dark, smooth appearance of the pool (1)† contrasts with the wavy lighter appearance of the riffle (2) (Fig. 3). Water depths are greater in the pools, but water velocities and surface roughness are generally less. The lighter appearance of the riffles results from a possible combination of increased bottom reflection and increased solar reflection due to water surface roughness. A large riffle (1 in Fig. 4) that extends across the Waits River is frequently the site of ice jams. Bed material here is coarse with exposed boulders (2) and cobbles (3). In Figure 3, channel islands (3), shoals or bars (4), and exposed rocks (5) obstruct flow and contribute to the ice jam potential of a particular river reach.

Following the measuring procedures suggested by Langbein and Leopold (1966) and Leopold and Maddock (1953), meanders (6 in Fig. 3) were classified into six groups (Fig. 5, Table III) based on the angle between 0° and 180° made by the river reaches on either side of the meander: A = 0° to 30°; B = >30° to 60°; C = >60° to 90°; D = >90° to 120°; E = >120° to 150°; F = >150° to 180°. The upstream meander in Figure 3 is class A; the two middle meanders are class B. Riparian trees and brush (7) may tend to impede the break-up and release of an ice jam. They may also reduce the areal extent of a jam by restricting lateral movement out of the river channel (Calkins, personal communication, 1976). Meander bars (8) were delineated because flowing ice may become grounded on them as the ice moves through a meander. The sunglint (9) is shown as a very light water surface that results from solar reflection from the water into the camera.

Bridge crossings where the channel has been narrowed or where bridge piers extend into the river are sites where jams can form. Usually piers can not be seen on the aerial photographs, but they (1) are evident at a bridge near the St. Johnsbury site (Fig. 6). An example of excessive sunglint that obscures all water detail is apparent at Point 2 in Figure 6.

Pools (2) (Fig. 7) upstream from dams, falls or other flow control structures are typical sites where jams form. Dams appear as distinct lines (1) across the river with white water just downstream. Rapids appear as patches of white water below the dam in this photograph. Sunglint obscures surface water detail on the west side of the photograph (Fig. 7).

In narrow, shallow rivers many features are less obvious. This is apparent on Figure 8, which shows the upper part of the Groton site. Rapids (1) are apparent upstream of and within the site. Sunglint obscures the rapids on the downstream end of the photograph. The appearance of a pool (2) is well illustrated in this figure. The pool contrasts well with the adjacent rapids and riffles. It appears to have a smooth surface and the dark tone is due to less bottom reflection because of greater depths and less sunglint because of a smoother water surface. Exposed rocks and associated rough water are apparent in the upstream end, but sunglint obscures them

*Sunglint is synonymous with hotspot or solar reflection. Hotspot is defined as the destruction of fine image detail on a portion of a wide-angle aerial photograph; it is caused by the absence of shadows and by halation near the prolongation of a line from the sun through the exposure station (Avery 1968, p. 317). (Copyright, Burgess Publishing Company, reprinted by permission.)

†Point designations and numbers ( ) refer to locations on the figure or photomosaic (App. A) of each site.

Table III. Summary of site specific features and conditions as observed from aerial photographs.

Site[1]	River	Channel width[2] (ft) Max	Min	Avg	Slope[3] (ft/mi)	Falls[4]	Flow control structure	Total bridges
Richford	Missisquoi	250 (P4)	80 (P5)	ND	13	NA	X	2
Enosburg Falls	Missisquoi	500 (P3)	160 (P5)	ND	ND	NA[5]	X[5]	1
Hardwick	Lamoille	115[6]	25	65	29	NA[5]	X[5]	5
Lyndonville	Passumpsic	200 (P2)	70	85 (P1)	5	NA	NA[7]	5
St Johnsbury	Passumpsic	A 160[6] B 485[6]	70 100	124 199	7 10	NA[5] X	NA[5] X	2 3
Richmond	Winooski	300	150	ND	2	NA	NA	4
Moretown	Mad	250	40	ND	16	X[5] (P3)	X	4
Montpelier	Dog	150	70	ND	7	NA	NA[7]	1
East Montpelier	Winooski	160 (P4)	50 (P5)	ND	12	NA	NA[7]	1
Groton	Wells	90	35	ND	73	X (P6)	X	6
East Corinth	Waits	110	30	ND	46	X (P4)	NA	1
Bradford Ctr Bradford	Waits Waits	250[6] (P5)	65 (P4)	107	24	NA[5]	X[5]	5
Tunbridge	First Branch, White	85 (P6)	40 (P5)	64	17	NA	X	0
Pawlet	Flower Brook and Mettawee	40	25	ND	54	X (P1)	X	2
Wilmington	Deerfield	90	30 (P3)	ND	5	NA[5]	X[5]	1
Chester	Williams	A 50[6] B 110[6]	20 25	34 56	24 20	NA NA	NA NA	2 2
Quechee	Ottauquechee	266[6] (P6)	100 (P5)	145	12	NA	X	1
Taftsville	Ottauquechee	220	55	ND	12	NA	X	4

Notes: 1 Site named after nearest town

2 Estimates, due to inherent photographic distortions

3 Estimated from 15 and 7.5-min topographic quadrangles (Table II)

4 Falls within study site unless otherwise indicated

5 Falls and/or dam downstream of site

6 Additional measurements in Table BI (App. B); some of the max and min values may not appear in Appendix if the measurement sites did not correspond to a 100-ft interval site

7 Not on photomosaic

8 Average sinuosity over the length of the site, sinuosity at various locations within the site would vary

9 From upstream end of Section 1 to downstream end of Section 3 shown on photomosaic

10 Meanders or bends: A = 0° to 30°, B = >30° to 60°, C = >60° to 90°, D = >90° to 120°, E = >120° to 150°, F = >150° to 180°, number refers to how many of a particular class

11 Number of tributaries at site large (≈5-10 ft wide at confluence) enough to contribute ice to main stream

12 See Table BII (App. B)

13 Entire site not on photomosaic

Abbreviations:

X, present	D, dense
NA, not apparent	M, moderate
P1, P2, etc., refer to locations on the appropriate photomosaic	S, sparse
	Pr, predominant
ND, not determined	N, No
P, patchy	Y, Yes
NP, not present	

Table III (cont'd). Summary of site specific features and conditions as observed from aerial photographs.

Site[1]	River	Piers observed	Rapids Above	Rapids In	Riffle	Pool	Channel islands	Mid-channel shoals or bars	Exposed rocks and bedrock	River sinuosity[8]
Richford	Missisquoi	N	NA	X (P3)	NA	X	X	X	NA	1.13
Enosburg Falls	Missisquoi	N	NA[7]	X (P2)	NA	X	X	X	NA	1.29
Hardwick	Lamoille	N	X	X	X	X	NA	X	X	1.09
Lyndonville	Passumpsic	Y, 1*	NA	NA	NA	X	X	X	NA	1.15
St. Johnsbury	Passumpsic	A N	NA	NA	X	X	X	NA	NA	1.06
		B N	X	NA	NA	X	X	X	NA	1.12
Richmond	Winooski	Y, 3*	NA	NA	X	X	X	X	NA	1.38
Moretown	Mad	N	NA	X	X	X (P4)	X	X	X	1.14
Montpelier	Dog	N	X	NA	X	X	X	X	NA	1.66
East Montpelier	Winooski	N	X	X	X	X	X	X (P1)	X	1.35
Groton	Wells	N	X	X	X	X	X	X	X	1.17
E. Corinth	Waits	N	X	X (P3)	X	X	NA	NA	X	1.05
Bradford Ctr / *Bradford*	Waits / Waits	N	X	X (P3)	X	X	X	X	X	1.11[13]
Tunbridge	First Branch, White		X	X (P4)	X	X	X	X	X	1.07
Pawlet	*Flower Brook* and Mettawee	N	X	X	X	X	X	X (P4)	X	1.26
Wilmington	Deerfield	N	X	X (P2)	X	X	X	X (P4)	X	1.06
Chester	Williams	A N	X	X	X	X (P2)	NA	X	X	1.11
		B N		NA	X	X	X	X	X	1.11
Quechee	Ottauquechee	Y	X	X (P3)	X	X	X	X (P4)	X (P3)	1.08
Taftsville	*Ottauquechee*	Y, 1*	X	X (P5)	X (P7)	X (P6)	X	X	X (P5)	1.17

*Number of bridges at which piers were observed.

Notes: 1. Site named after nearest town.

2. Estimates, due to inherent photographic distortions.

3. Estimated from 15 and 7.5-min topographic quadrangles (Table II).

4. Falls within study site unless otherwise indicated.

5. Falls and/or dam downstream of site.

6. Additional measurements in Table BI (App. B); some of the max and min values may not appear in Appendix if the measurement sites did not correspond to a 100-ft interval site.

7. Not on photomosaic.

8. Average sinuosity over the length of the site; sinuosity at various locations within the site would vary.

9. From upstream end of Section 1 to downstream end of Section 3 shown on photomosaic.

10. Meanders or bends. A = 0° to 30°, B = >30° to 60°, C = >60° to 90°, D = >90° to 120°, E = >120° to 150°, F = >150° to 180°; number refers to how many of a particular class.

11. Number of tributaries at site large (≈5-10 ft wide at confluence) enough to contribute ice to main stream.

12. See Table BII (App. B).

13. Entire site not on photomosaic.

Abbreviations:

X, present	D, dense
NA, not apparent	M, moderate
P1, P2, etc., refer to locations on the appropriate photomosaic	S, sparse
ND, not determined	Pr, predominant
P, patchy	N, No
NP, not present	Y, Yes

Table III (cont'd). Summary of site specific features and conditions as observed from aerial photographs.

Site[1]	River	Meanders[10] A	B	C	D	E	F	Total	Confluence[11]	Floodplain width (ft)	Riparian trees and brush	Bed material[12]	Floodplain development
Richford	Missisquoi	3	2	3				8	4	1700 → I (P8) (P3)	P-Pr	NA	S-M
Enosburg Falls	Missisquoi	3	7	3	1	1		15	8[13]	ND	P	NA	S
Hardwick	Lamoille	2	6	2				10	3	ND	P-Pr	Coarse (P4)	S-M
Lyndonville	Passumpsic	3	4	1	4	2	1	15	1	400 → 4000 (P3)	P-D	NA	S-M
St Johnsbury	Passumpsic	A 3	4	3	1			11	4	ND	P-S	NA	S-M
		B 6		2		2		10	2	ND	P-Pr	NA	M-S
Richmond	Winooski	6	3	1	1	2	1	14	11	ND	D-P	Coarse (P4)	S-M
Moretown	Mad	7	16	11	3	1	2 (P6)	40	6	ND	D-P	Coarse (P4)	S-M
Montpelier	Dog	3	1	4	1		1	10	1	1300	Pr-P	NA	S
East Montpelier	Winooski	2	5	5	1			13	1	ND	Pr-P	Coarse	S
Groton	Wells	6	10	4	2	1	3 (P4)	26	7	ND	P-Pr	Coarse	S
East Corinth	Waits	5	8	1				14	1	NA	Pr-P	Coarse	S
Bradford Ctr Bradford	Waits Waits	10	13	5	3 (P6)			31	8	ND	Pr-P	Coarse	M-S
Tunbridge	First Branch, White	4	10	5				19	2	300 → 900 (P9) (P7, 8)	P	Coarse	S
Pawlet	Flower Brook and Mettawee	5	7	1		1		14	1	ND	Pr	Coarse-medium	S-M
Wilmington	Deerfield	5	3	3				11	5	ND	Pr	Coarse	M-S
Chester	Williams	A 2	7	1				10	1	1100	P-Pr	Coarse	S
		B 4	3	2		1	1	11	4	1000 → 2000	Pr	Coarse	S
Quechee	Ottauquechee	4	6	3	1			14	7	200 → 1200 (P7) (P8)	P-Pr	Coarse	S
Taftsville	Ottauquechee	14	12	6	2	2		36	9	350 → 2500 (P9)	Pr-P	Coarse	S-D
		97	127	66	20	13	9	332	86				

Notes: 1. Site named after nearest town

2. Esitmates, due to inherent photographic distortions
3. Estimated from 15 and 7.5-min topographic quadrangles (Table II)
4. Falls within study site unless otherwise indicated
5. Falls and/or dam downstream of site
6. *Additional measurements in Table BI (App. B)*, some of the max and min values may not appear in Appendix if the measurement sites did not correspond to a 100-ft interval site
7. Not on photomosaic
8. Average sinuosity over the length of the site, sinuosity at various locations within the site would vary
9. From upstream end of Section 1 to downstream end of Section 3 shown on photomosaic
10. Meanders or bends: A = 0° to 30°, B = >30° to 60°, C = >60° to 90°, D = >90° to 120°, E = >120° to 150°, F = >150° to 180°, number refers to how many of a particular class
11. Number of tributaries at site large (≈5-10 ft wide at confluence) enough to contribute ice to main stream
12. See Table BII (App. B)
13. Entire site not on photomosaic

Abbreviations:

X, present	D, dense
NA, not apparent	M, moderate
P1, P2, etc., refer to locations on the appropriate photomosaic	S, sparse
ND, not determined	Pr, predominant
P, patchy	N, No
NP, not present	Y, Yes
	I, Indefinite

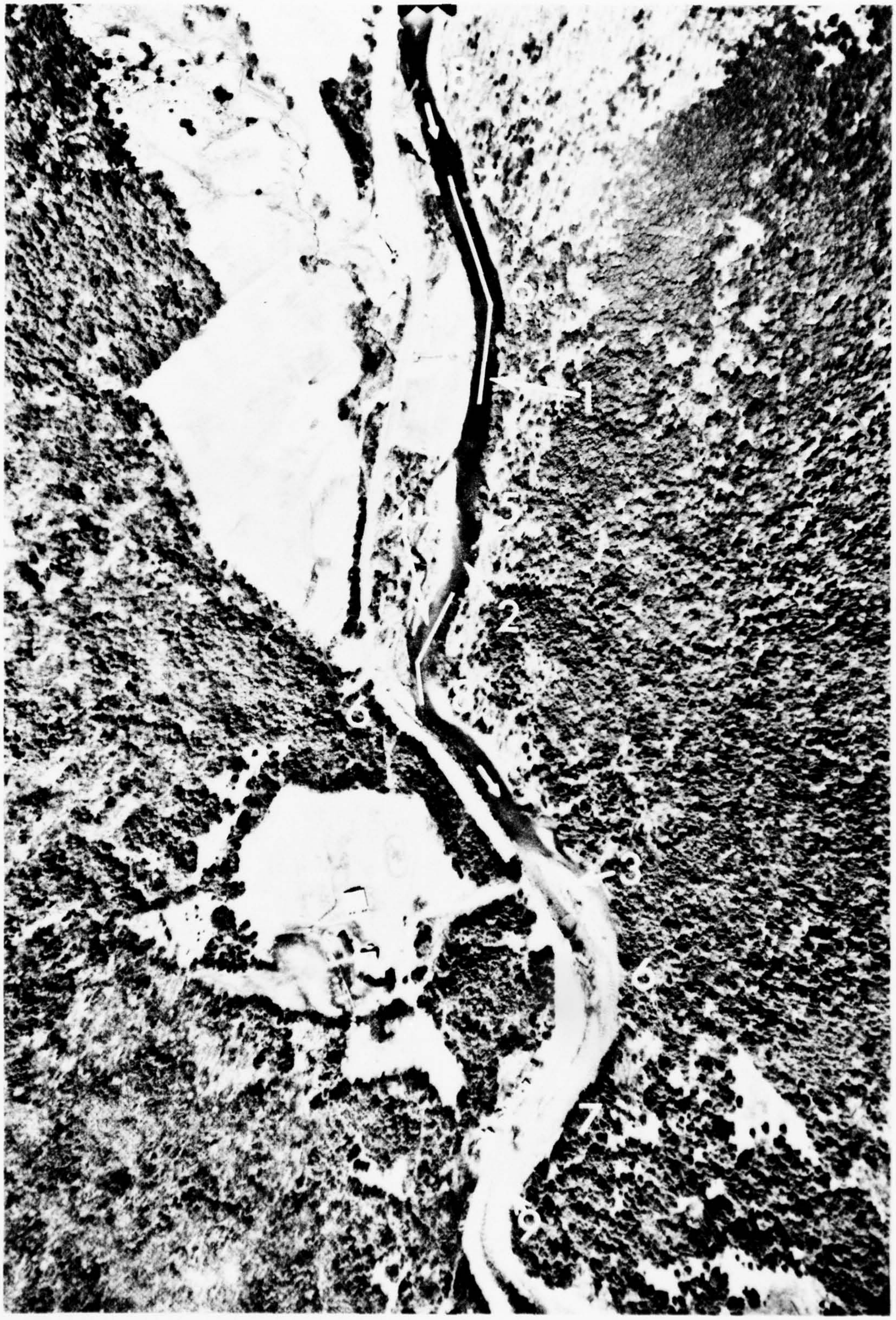

Figure 3. Waits River upstream from Bradford site. Scale: 1 in. = 519 ft (north is upstream).

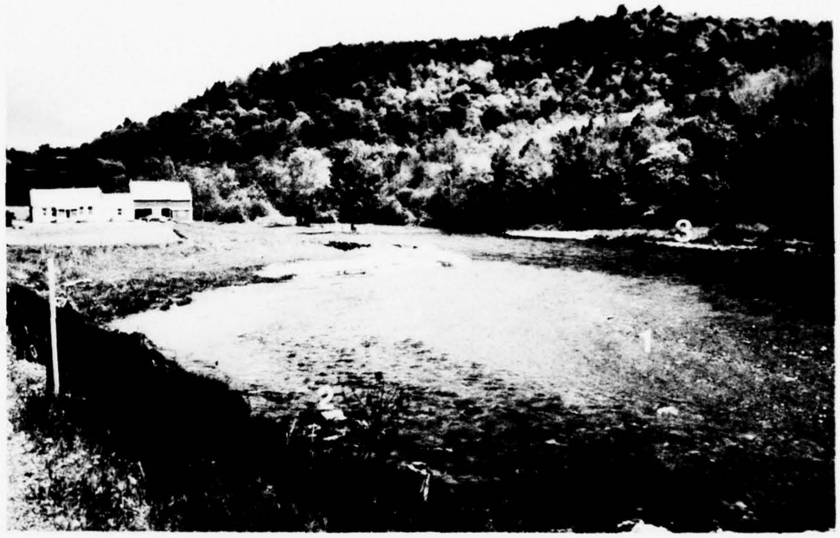

Figure 4. View upstream on Waits River from point 5 on photomosaic 12-13 (App. A). (Photo, courtesy of D. Calkins).

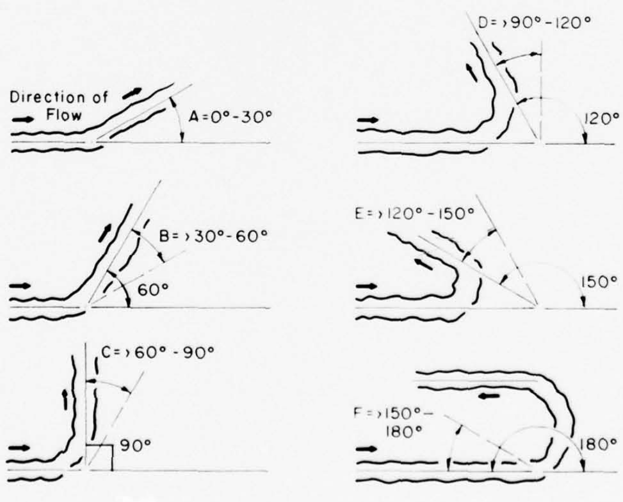

Figure 5. Meander classes.

downstream. The many exposed rocks and some large boulders along the channel suggest that the channel material is very coarse.

Rapids (1), a dam (2), and a dam pool (3) appear in Figure 9. The dam pool obscures much of the detail of channel roughness that is evident downstream from the dam, although shoals and riffles with surface waves are faintly observable at the light areas (4) in the water.

At the Wilmington site (Fig. 10) the appearance of a large confluence (1) is illustrated. Ice entering the main river from a tributary may add enough ice volume to the main channel to contribute to the formation of an ice jam. Within each site the number of major tributary confluences was counted (Table III). Small confluences (2) (Fig. 10) were not counted, since the amount of ice contributed to the main channel

Figure 6. Northern end of St. Johnsbury site, Reach A. Scale: 1 in. = 483 ft.

Figure 7. Winooski River, upstream from usual ice jam site shown on photomosaic 9. Features shown here are typical of those in the study site. Scale: 1 in. = 439 ft.

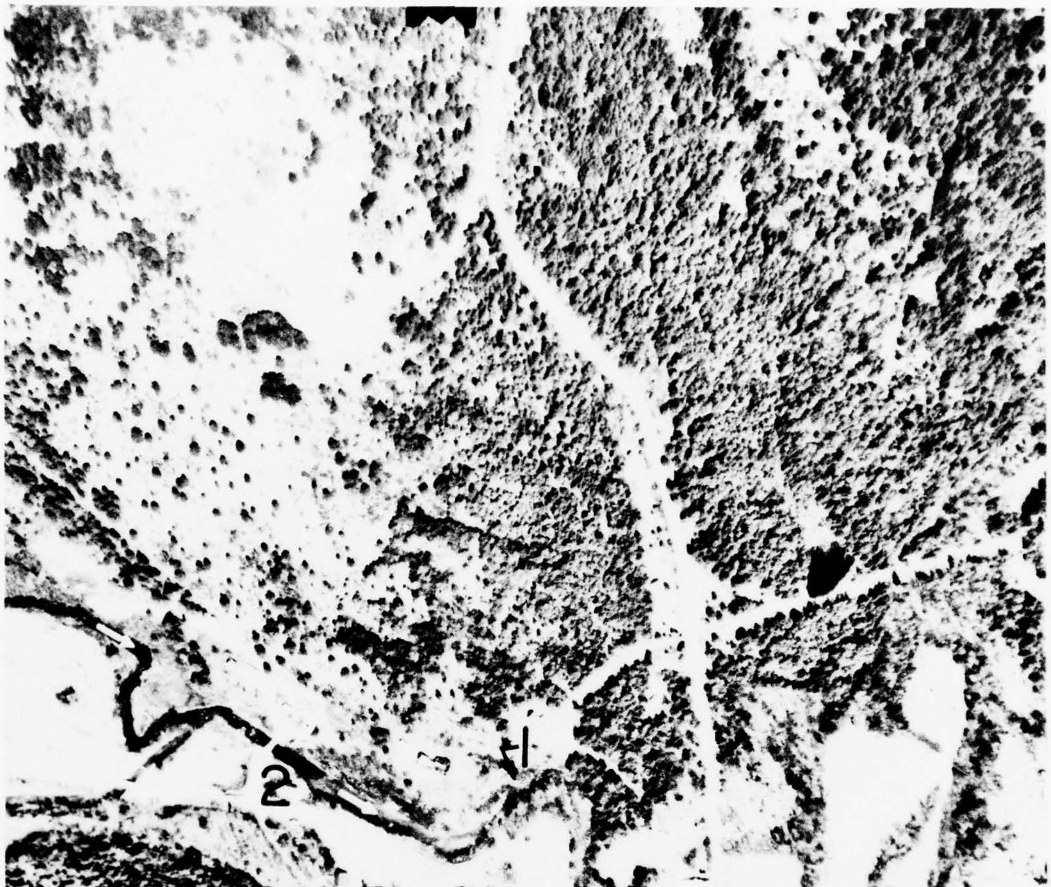

Figure 8. Groton site, photomosaic 10. Scale: 1 in. = 441 ft.

Figure 9. Tabor Branch of Waits River, upstream of the study site. Scale: 1 in. = 563 ft.

Figure 10. Downstream end of Wilmington site, photomosaic 16. Scale: 1 in. = 381 ft.

was probably insignificant. The coarse texture of the bed material is apparent as shown by the many exposed rocks in the channel and by the boulders (3) along the shore. Sunglint obscures the surface water detail on the downstream side of the photograph (Fig. 10).

Site descriptions

Most of the sites described have not been observed in the field with or without ice jams by the author and the upstream and downstream limits of sites as marked on the photomosaics were provided by personnel from the Vermont Department of Water Resources who have visited all the sites. Most of the information in Table III was obtained from aerial photographic interpretation, although data on channel slope were obtained from the USGS topographic quadrangles.

Richford (Site 1)

Because ice jams generally occur along the reach of the Missisquoi River through Richford, channel modifications have been made along this reach by the Corps of Engineers, New York District. These modifications included channel straightening near point 1 and construction of a diversion dam/weir (2). Riprap (9) is apparent along the channel where modifications were made. Pools are very faint (7) and shoals are generally not apparent except near the mid-channel bars or islands on the east side of the site. The river appears shallow (6) and deep (7) at the two sharp meanders. Riparian vegetation includes extensive areas of grass. Downstream of point 3 floodplain development is sparse; however, buildings are frequently found on the floodplain very near the channel upstream. Jams may form at this site because ice movement is slowed while passing through the first meander and because an ice cover forms on the pool downstream from the rapids (3). Morris and Aiken (1973) report that jams frequently occur here when ice accumulates behind a stable cover formed on pools and in slack water reaches.

Enosburg Falls (Site 2)

Jams occur from the power dam in Enosburg Falls upstream past North Enosburg (1). The upstream limit of this site is off the photomosaic. The river slope is gradual but is not estimated because contours on the topographic quadrangle (Table II) do not cross near this reach. Rapids (2) occur on the eastern end, and pools are extensive. Channel widths are variable, approximately 500 ft at point 3, 350 ft at point 4, 160 ft at point 5, and are widest near mid-channel islands and bars. Most of the channel is bordered by grass with scattered trees and brush. The floodplain appears to be wide, but its boundaries are not readily discernible. A power dam is the downstream limit of this site, and the low velocity pool behind the dam probably causes the formation of jams.

Hardwick (Site 3)

Ice jams typically occur along the Lamoille River from Hardwick to Hardwick Lake. The channel slope is generally uniform, and riffles and exposed mid-channel rocks are common (Fig. 11). The pool behind the Hardwick Lake dam (1) apparently extends approximately 350 ft east of the bridge (2) where the rough surface water and riffles end. A pool is present at the eastern end near the bridge (3). The channel material appears coarse (near point 4), and is granules to cobbles (Fig. 11, Table BII, App. B). The coarse material appears to be used as riprap along the channel near the bridge at point 2. Riparian vegetation is predominantly grass and brush along the upper portion, and trees and brush along the lower portion. The floodplain is not well defined on the photographs and the channel appears to be incised, although Calkins (personal communication, 1976) stated that the channel is not incised. A large meander bar is present on the sharp meander at the eastern end of the reach; but bars are not apparent on the other more gradual meanders. A stable ice cover that forms on the lake is a primary factor in initiating ice jams here. Frankenstein and Calkins (personal communication, 1976) point out that frazil ice from the upstream rapids and the railroad bridge piers may also be important factors.

Lyndonville (Site 4)

Ice jams usually occur along the Passumpsic River north of Lyndonville. The water surface appears smooth and the water appears deep throughout the reach. Small mid-channel bars are apparent and Frankenstein (personal communication, 1976) has observed a mid-channel bar in this reach. Meander bars are absent or small. Trees and brush occur in patches along the southern and northern portions, and border the entire central portion of the channel. The

Figure 11. Channel at Hardwick site looking downstream. Riffle (1), channel rocks (2), coarse channel material (3). (Photo, courtesy of S. DenHartog).

floodplain width is variable, 400 ft near point (3) and nearly 4000 ft at the southern end across the north side of Lyndonville. Five bridges cross the river, three near meanders; bridge piers are visible at the middle bridge only. It is likely that the combined effects of a mild gradient and sharp meanders that restrict passage of flowing ice initiate local jamming. Calkins (personal communication, 1976) feels that the slope change along this reach is the major factor. However, indicators of this change are not apparent on the photomosaics; this points out the need for field verification and ground-truth data collection surveys as an integral part of further investigations using photointerpretation techniques.

St. Johnsbury (Site 5)

Ice jams frequently occur in two reaches of the Passumpsic River near St. Johnsbury: Reach A, from St. Johnsbury Center (1) to the north end of St. Johnsbury (2); and Reach B, from the dam just north of the confluence of the Moose (5) and Passumpsic Rivers to the first dam downstream from St. Johnsbury. The northern end of Reach A, near St. Johnsbury Center, appears to be shallower than the southern end. Sunglint (3) on the southern portion of each photograph in the photomosaic enhances water surface roughness features and shows that the roughness decreases to the south along the reach. Water is too deep for indications of depth changes to be apparent, although scattered small riffles are faintly apparent. The floodplain is narrow except near St. Johnsbury Center and south to the large flat (4), and channel widths vary from 70 to 160 ft (Table BI, App. B).

Indications of changes in relative depth along Reach B are apparent only around the island near the mouth of Sleepers River (6). The floodplain appears to be wider and the channel shape more variable along this reach. Channel widths along Reach B (Table BI, App. B) are greater and more variable, and five major channel constrictions (7) occur. Previous studies (U.S. Army Corps of Engineers 1972) indicated the primary factors causing ice jams in these reaches to be the bridge piers, the pool from the dam, and the channel constrictions.

Richmond (Site 6)

The ice jam site extends from the bridge in Richmond downstream 4.5 miles to the railroad bridge. The smooth appearance of the water surface suggests that the water is generally deep and that riffles are not prominent. The channel is widest generally near bars or islands. Trees and brush border this reach, except along the west bank north of the interstate bridges (5) where grass borders the channel. Grassy patches also border the reach at a few small areas elsewhere. Meander bars (1) have formed on two of the meanders. The floodplain is usually wide, except at location (2), where the river flows in a narrow channel with no floodplain. Developments on the floodplain are farms, a trailer park (3), and the town of Richmond. Piers for three of the four bridges that cross this reach are apparent, but the piers were not built in the river channel. The factors that most likely initiate jams are the railroad bridge piers, meanders and mid-channel islands or bars.

Moretown (Site 7)

Jams generally occur from approximately 0.6 miles upstream from the dam (1) to 1 mile upstream from Moretown (2). Sunglint (5) obscures the water surface in several locations on the downstream end of the reach. The channel widths are variable; where bedrock is exposed (7) the river channel is narrower than where the bedrock is not exposed. Along the southern side trees and brush occur on the lower third of the reach, and are patchy elsewhere. Along the northern side, grass and brush border most of the channel, and trees or patches of trees are scattered. At the upstream end of the channel, the floodplain is approximately 1600 ft wide; at the eastern end, it is absent. The likely causes of jamming are the dam (1) pool and the shallow channel.

Montpelier (Site 8)

The site along the Dog River is approximately 1.5 miles southwest of Montpelier. The channel slope appears to be uniform, and riffles are more prominent than pools. There appears to be riprap just east of point 2 on the outside of the sharp meander. The channel widths are variable (70 ft at point 1, 100 ft at 2, 150 ft at 3); they are generally widest near mid-channel bars, and narrowest along meanders. The sharp meanders, mid-channel bars and associated shallows probably cause the ice jams. Calkins (personal communication, 1976) suggested that the local change in slope and the confluence with the Winooski River (north end of photomosaic) may also be important factors.

East Montpelier (Site 9)

This site is located between Plainfield and East Montpelier on the Winooski River. The channel slope appears uniform. Water appears shallow near the bars (2) and along the eastern part of the reach where riffles are common; along the western portion of the reach, it appears deeper since pools are predominant. The channel widths are variable: 125 ft at point 3, 160 ft at point 4, 50 ft at point 5, 75 ft at point 6, and widest near mid-channel bars. Sharp meanders occur at the western end of the reach and the floodplain is widest at this end. A small downstream dam, mid-channel bars and the meanders probably restrict ice flow enough to be the major factors initiating jams.

Groton (Site 10)

Ice jams form along the Wells River from Groton (1) upstream approximately 2 miles along the South Branch (2). From the upstream end to the confluence of the river with the North Branch (3), the channel slope is steep, depths are usually shallow, riffles are predominant and long, pools are scattered and short, and the floodplain is generally narrow. Below the confluence, the floodplain is wider, and the slope is more gentle, although still steep. Bedrock is exposed at point 7. Channel widths are variable: 35 ft at point 8, 90 ft at point 9, and 70 ft at point 10. Important factors in causing ice jams are probably reduced channel slope (45 ft/mi) between the most downstream bridge and the third bridge, shoaling (5) near Groton, and the most downstream meander. Calkins (personal communication, 1976) said that the most significant factor is the reduced channel slope in the floodplain and possibly frazil ice formation in the steep reaches.

East Corinth (Site 11)

Ice jams typically occur at the confluence of the Waits River and Tabor Branch (1) near East Corinth (2). The channel is steepest along the Tabor Branch, and it is shallow. Pools along the Waits River portion are usually small and not too deep. The channel widths along the Tabor Branch vary from approximately 30 to 50 ft, and widths increase to 75 to 110 ft along the Waits River. Ice jams have formed along the Waits River at the bridge (5) near the confluence and have caused ice flowing down the Tabor Branch to stabilize and back up the Tabor.

Bradford Center (Site 12) and Bradford (Site 13)

Site 12 extends from the upstream limit (shown on photomosaic) to Bradford Center (1). Site 13 extends from point 2 to the downstream limit. In some years jams occur along the entire reach, but generally are limited to these locations. For purposes of this discussion, sites 12 and 13 are considered as one. The relative depths are more apparent here than along many of the other sites; therefore, the lengths of the pools and riffles were measured (Table BIII, App. B). The riffle lengths varied from 190 to 1625 ft; pools varied from 110 to 825 ft. The channel widths were measured in three reaches: within the site, upstream, and downstream (Table BI, App. B). Vegetation consists primarily of trees and brush with scattered patches of grass and brush. The floodplain is very narrow or absent. Development through this area is concentrated at Bradford Center and scattered along the downstream channel. The primary factors that initiate jamming are low flows that occur along wide areas with shallow depths (Fig. 4), and restricted flows that result from mid-channel obstructions (i.e., islands and bars). Morris (1973) reports that ice bumpers have been suggested for reducing the effects of jams at this site.

Tunbridge (Site 14)

Jams generally occur along the First Branch of the White River from below the Fairgrounds just south of Tunbridge (1) upstream to North Tunbridge (3). The lengths of the riffles and pools were measured (Table BIII, App. B), since relative depths are apparent. The average riffle length is 950 ft; the average pool length is 960 ft. The longest riffles and pools occur along the southern portion of the river. The channel widths (Table BI, App. B) vary from 40 ft at point 5 to 85 ft at point 6. Ground surveys indicated that the channel bottom material is variable, from granules to boulders. Trees and brush are predominant here, and grass is patchy. The floodplain widths are variable and wider in the upper portions of the reach. The most likely factor causing jams along this reach is the pool behind the dam (2). Because the pool develops a stable ice cover, river ice accumulates, but, as DenHartog (personal communication, 1976) pointed out, this is not always true for all jams that form at this site.

Pawlet (Site 15)

Jams frequently form east of Pawlet upstream from the dam (1). The channel slope is steep and appears uniform. The channel depths appear variable, with shallow pools (2) and riffles (3); the riffles are common. The channel widths vary from 25 to 40 ft. Most of the upstream part of the channel is bordered by trees and brush; near the dam, grass borders the north side of the reach. Bars (4) are common in the pool behind the dam (1); a few are scattered upstream. Exposed rocks upstream suggest cobbly to bouldery channel material, whereas the bars near the dam appear finer grained. The floodplain is narrow and the brook appears to be incised. The primary factor in causing ice jams is probably the dam pool.

Wilmington (Site 16)

Jams usually start to form in the upper end of Harriman Reservoir (1) where flowing river ice is stopped by the stable ice cover that forms on the reservoir. The jams can extend a mile upstream through Wilmington. The channel widths vary from approximately 30 ft at point 3 to 90 ft at the western end of the channel. The channel appears incised with no apparent floodplain, and the pools are small. The bottom material of the channel appears cobbly to bouldery upstream from the bridge and at the bars (4). The major factor initiating jams is the ice buildup behind the stable ice cover on Harriman Reservoir.

Chester (Site 17)

There are two reaches along the Williams River near Chester where ice jams typically occur: Reach A is 1.5 miles north of North Chester (point 1 on Reach B), and Reach B extends from Chester 1.3 straight line miles downstream. Along Reach A, one pool (2) is apparent; the remainder of the reach is a riffle. Exposed rocks are common and rapids are small. Channel widths (Table BI, App. B) vary from 20 to 50 ft. The floodplain is wide (about 1100 ft) and marshy (3) on the west central side. The meanders and the meander bars at the southern end, and the shallow water, may be the primary factors that initiate the ice jams.

The channel along Reach B appears to be deeper than that along Reach A and has several mid-channel bars and large, well developed meander bars. Channel widths vary from 25 to 110 ft. Although riffles and shallow pools are apparent, most of the channel is shallow. Channel bottom material appears coarse [note the exposed boulders and the coarse appearance (4)]. The floodplain width varies from 2000 ft at the south end to 1000 ft in the middle. The mid-channel bars and bridge may be the controlling factors causing ice jamming.

Figure 12. View upstream on the Ottauquechee River from upstream point 3 on photomosaic 18. Rapids in foreground and center are shown on photomosaic. (Photo, courtesy of D. Calkins).

Figure 13. View upstream on the Ottauquechee River from point 5 on photomosaic 18. Note riffle in center and coarse material on the bar. (Photo, courtesy of D. Calkins).

Quechee (Site 18)

Jams occur from the dam (1) in Quechee (2) to a location two miles upstream. Shoals are aligned longitudinally along the channel and the deeper water occurs on either side of them. Small pools are common, and although riffles are not prominent, they do occur (Fig. 12). Channel widths vary from 100 ft at point 5 (Fig. 13), to 266 ft at point 6. Usually the widest sections of the channel are adjacent to mid-channel bars or islands. Trees and brush border the upper third of the channel, while grass and brush with patches of trees border the lower two thirds. Calkins (1976, Fig. 4d) describes an ice jam below the foot and golf cart bridge and states that the pool behind the Quechee Dam is the major factor in causing the jam because it prohibits ice movement by developing a stable ice cover that backs up upstream river ice.

Taftsville (Site 19)

Jams have occurred at various locations along the Ottauquechee River from the dam (1) in Taftsville (2) (section A on photomosaic) through Woodstock (3) to West Woodstock (4) (Section C).* Depths appear shallow along most of the reach in this area; pools (6) are less numerous and not as long as riffles (7). Sunglint (8) is minimal and occurs on only a few photographs. The channel widths are variable, mid-channel bars or islands are common, and meander bars occur at most of the meanders. The channel appears incised along Section A. Dense trees and brush are predominant along Section A and the lower half of Section B. Along upper Section B, dense patches of trees and brush are sparser and grass is more common than in section A. Trees and brush are sparse along the north side in Section C, but dense along the south. The floodplain is prominent (350 ft wide) upstream from location 9. Across the large meander, the floodplain is 2500 ft wide, but it narrows to approximately 1000 ft in West Woodstock. Bridge piers are evident at the upstream bridge (10) in Woodstock. The most likely cause of ice jams in Section A and the lower portion of Section B is the dam pool in Taftsville. Farther upstream, the shallow water, bridge piers, mid-channel and meander bars, and the meanders may initiate jams.

*Sections A and B on the photomosaic join at the arrows 1 and 2 in the middle of Section A, and on the lower right of Section B. Sections B and C overlap, point D is common to both.

CONCLUSIONS

Aerial photographs provide a regional perspective for evaluating the channel characteristics at an ice jam site and for analyzing the geographic setting at each site. The regional perspective can be very useful in selecting locations along the river where ground surveys and cross sections might be made for further evaluation of the river characteristics.

The utility of aerial photographs in the analysis of ice jams and ice jam sites is clear. Photographs of ice-free conditions are useful in estimating channel widths, and riffle and pool lengths; in identifying channel obstructions, shape, bottom materials, and floodplain characteristics; in surveying for locations of cross sections; and in providing a regional perspective to evaluate channel characteristics upstream, through, and downstream from an ice jam site. Photographs taken after ice jams have formed are useful in identifying the formation stage of ice cover growth, in analyzing the size, shape, and distribution of the ice blocks that form the jam; and in documenting ice jam breakup and movement. Aerial photographs should be taken during ice-free conditions when the river discharge is similar to that during ice jam formation, when trees are bare or nearly so, and when haze is generally minimal to provide maximum photographic clarity.

In detailed investigations of the characteristics of ice jam sites or of ice jams, the results of the interpretation of the aerial photographs should be verified by conducting ground surveys. Ground surveys should also be performed, particularly for site analysis, to determine the presence of bridge piers, the size of bed material not always apparent on aerial photographs, and the slope of the channel along its longitudinal profile. In-depth analysis of ice jams must also include the compilation and synthesis of 1) historical information regarding frequency, severity, and resulting flood damage and channel erosion, including description of previous jams (i.e., time jam formed, flooding, movement and breakup) from local people; and 2) data from aerial photographs taken during ice and ice-free conditions.

Calkins (1976) points out that generally no single factor is responsible for initiating ice jams. However, one condition does repeatedly show up in the aerial photographs: a flow control structure. In the 19 sites evaluated, at least 15 (79%) have a flow control structure of some type within the site or downstream from it. This implies that a pool with a backwater condition of low velocity exists and that a solid ice cover forms on the pool. This solid ice cover often impedes the transport of ice downstream from the fast flowing reaches; consequently the jams form behind these pools. The structure might be a small power dam, a flow control weir, a bridge pier, or a natural constriction that creates the backwater.

There are sites with no structures, however, where ice jams occur; the conditions responsible for initiating the jams at such sites are unclear. Generally, in these locations jams form at sharp meanders in floodplains, where there is a natural channel restriction or widening, or a significant change in water surface slope, usually from a steep to a mild condition.

Many of the conditions suspected to be factors causing jams at the sites studied could be changed in such a fashion that the jams would not form or that, if they did form, they would be less severe and their effects less of a problem than at present. However, any modifications, such as straightening the channels, changing the shapes of channel cross sections, increasing their depths, etc., would alter the character of the river regimes and the environmental settings at the locations.

Hando (personal communication, 1977) indicated that this aspect of environmental alteration is extremely important to local people near the ice jam sites and throughout Vermont. The "Vermont as Vermont" consideration of alternatives for reducing the effects of ice jams would have to be addressed before any channel or structure modifications performed to alleviate the problem of future ice jams.

ADDITIONAL STUDIES

Future studies using aerial photographs could enumerate the characteristics of selected ice jam sites in New Hampshire and Maine in a fashion similar to that of the present study and give a weighted value of these characteristics based on the results to date of the studies of ice jam mechanics. This would provide a permanent photographic record of the important sites with an accompanying evaluation of the channel characteristics that play a dominant role in causing ice jams. Such a record might be useful to those evaluating possible approaches to removing jams after the channels are obscured by ice. Wilkinson (personal communication, 1977) indicated that these studies of natural and artificial means of jam breakup and of the success of ice jam removal operations, including appropriate techniques, limiting factors, etc., would be helpful to Corps of Engineers field offices.

A long-term investigation addressing the processes of ice jam formation, the hydraulics of the river at an ice jam site, and the mechanics of ice jam formation on the Ottauquechee River is currently underway.* Wilkinson (personal communication, 1977) pointed out that such an investigation is needed and that results from it would be very useful. The ultimate objective of that study is to determine whether the location and the time of an ice jam can be predicted. This is not presently possible.

SELECTED BIBLIOGRAPHY

Avery, T.E. (1968) *Interpretation of aerial photographs.* Minneapolis, Minnesota: Burgess Publishing Company.

Calkins, D.J. (1976) Observations of mid-winter ice jams — White, Ottauquechee, and Connecticut Rivers, 1976. CRREL Technical Note (unpublished).

Calkins, D.J. (1976) Personal communication. Research Hydraulic Engineer, CRREL.

Calkins, D.J., M.S. Hutton and T.L. Marlar (1976) Analysis of potential ice jam sites on the Connecticut River at Windsor, Vermont. CRREL Report 76-31, submitted to the Emergency Operations Center, New England Division, Corps of Engineers. AD A031572.

Calkins, D.J. (1977) Ice jam measurements and undercover roughness calculations. CRREL Technical Note (unpublished).

DenHartog, S.L. (1976) Personal communication, Research Geologist, CRREL.

DenHartog, S.L. (1977) Aerial photointerpretation of a small ice jam. CRREL Special Report SR 77-32. AD A045870.

Frankenstein, G. (1976) Personal communication. Ice Engineering Branch, CRREL.

Frankenstein, G. and D.J. Calkins (1976) Personal communication.

Gary, M., R. McAfee, Jr., and C.L. Wolf (Editors) (1972) Glossary of geology. American Geological Institute, Washington, D.C.

Gerard, R. (1975) Preliminary observations of spring ice jams in Alberta. *Proceedings of the Third International Symposium on Ice Problems, 18-21 August 1975*, Hanover, New Hampshire, p. 261-274.

*Darryl Calkins, CRREL, principal investigator

Hando, R. (1977) Personal communication. Chief, Emergency Operations Center, Corps of Engineers, New England Division.

Joering, E.A. (1968) Interpreting hydrologic characteristics of streams from airphotos. Appendix G. In *Alaskan Stream and Basin Characteristics Pertinent to Military Mobility*. Contract report prepared for the U.S. Army Tank Automotive Command by CRREL, p. G-1 to G-17.

Kennedy, J.F. (1975) Ice jam mechanics. *Proceedings of Third International Symposium on Ice Problems, 18-21 August 1975*, Hanover, New Hampshire, International Association of Hydraulic Research, Committee on Ice Problems, p. 143-163.

Kudritskii, D.M., I.V. Popov and E.A. Romanova (1956) Hydrographic interpretation of aerial photographs. Report TT 64-11094, published for U.S. Department of Commerce and National Science Foundation by the Israel Program for Scientific Translations.

Langbein, W.B. and L.B. Leopold (1966) River meanders — Theory of minimum variance. U.S. Geological Survey Professional Paper 422-H. U.S. Government Printing Office, Washington, D.C.

Leopold, L.B. and T. Maddock, Jr. (1953) The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional Paper 252. U.S. Government Printing Office, Washington, D.C.

MacKay, D.K., D.A. Sherstone and K.C. Arnold (1974) Channel ice effects and surface water velocities from aerial photography of Mackenzie River break-up. Environmental-Social Committee, Northern Pipelines, Canadian Task Force on Northern Oil Development, Report 74-12, July, p. 73-107.

McKim, H.L., L.W. Gatto, C.J. Merry and R.K. Haugen (1976) *Skylab imagery: Application to reservoir management in New England*. CRREL Special Report 76-7. AD A030329.

Mollard, F.S. (1973) Airphoto interpretation of fluvial features. *Proceedings of the Ninth Canadian Hydrology Symposium, Fluvial Processes and Sedimentation*. University of Alberta, Edmonton, Alberta, 8-9 May 1973, p. 341-380.

Morris, F.A. (1973) Ice jam investigations, 28 February-2 March 1973, upper Connecticut River Basin, New Hampshire and Vermont. U.S. Army Engineers, New England Division, Emergency Operations Center Report no. 2.

Morris, F.A. and J.M. Aiken (1973) Ice jam investigations, 7-10 February 1973, upper Connecticut River Basin, White River Junction area. U.S. Army Engineers, New England Division, Emergency Operations Center Report No. 1.

Sherstone, D.A. (1973) Remote sensing techniques applied to current velocity measurements and river ice jamming. *Proceedings of the Ninth Canadian Hydrology Symposium, Fluvial Processes and Sedimentation*, University of Alberta, Edmonton, Alberta, 8-9 May 1973, p. 403-419.

Sokolov, I.N. and Y.L. Gotlib (1975) Ice jam control upstream and downstream from hydro power plants. *Proceedings of Third International Symposium on Ice Problems, 18-21 August 1975*, Hanover, New Hampshire, International Association of Hydraulic Research, Committee on Ice Problems, p. 175-178.

U.S. Army Corps of Engineers, New England Division (1972) Flood plain information, Passumpsic and Moose Rivers. Report prepared for Town of St. Johnsbury, December, 25 p.

U.S. Geological Survey (1974) Water resources data for Massachusetts, New Hampshire, Rhode Island, Vermont. Part 1, Surface water records.

U.S. Geological Survey (1976) Water resources review for April 1976, Streamflow and groundwater conditions, 14 p.

Uzuner, M.S. and J.F. Kennedy (1976) Theoretical model of river ice jams. *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers*, vol. 102, no. HY9, p. 1365-1383.

Wentworth, C.K. (1922) A field study of the shapes of river pebbles. U.S. Geological Survey Bulletin 730-C, p. 114.

Wilkinson, T. (1977) Personal communication. Chief, Foundations and Materials Branch, Corps of Engineers, Buffalo District.

APPENDIX A: PHOTOMOSAICS OF SITES

The original photomosaics used in this work were from 2 to 5 times the size of the reproductions in this Appendix. Each caption contains the scale of the original photomosaic and the amount each photomosaic was reduced for publication.


A
A
5
1
2
8
B
A
A

Figure A1. Missisquoi River, Richford, Vermont, 21 April 1976. Original scale 1 in. = 532 ft; ¼ original size.

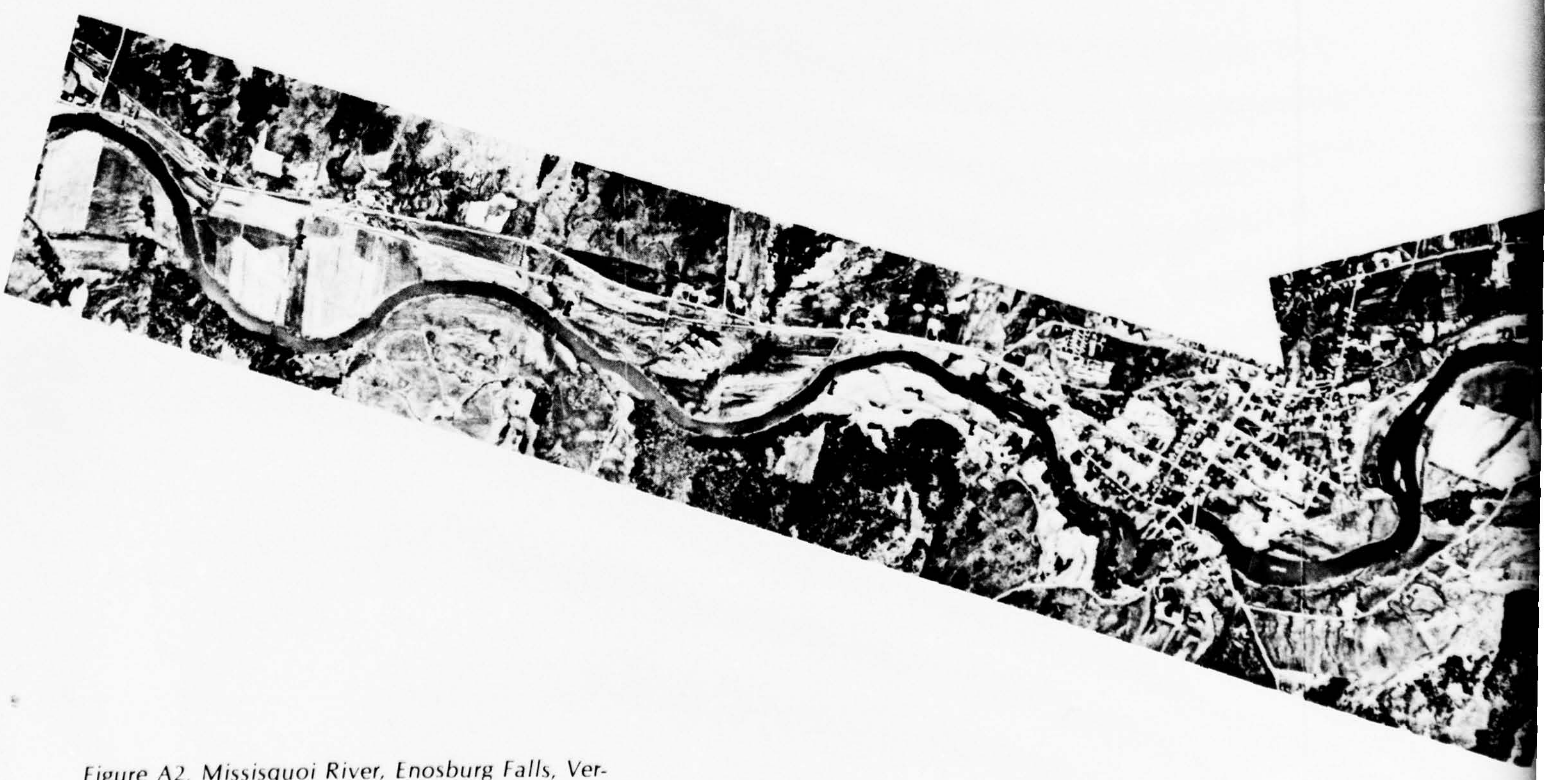

Figure A2. Missisquoi River, Enosburg Falls, Vermont, 21 April 1976. Original scale 1 in. = 511 ft; 1/5 original size.


5
4


2
3
4

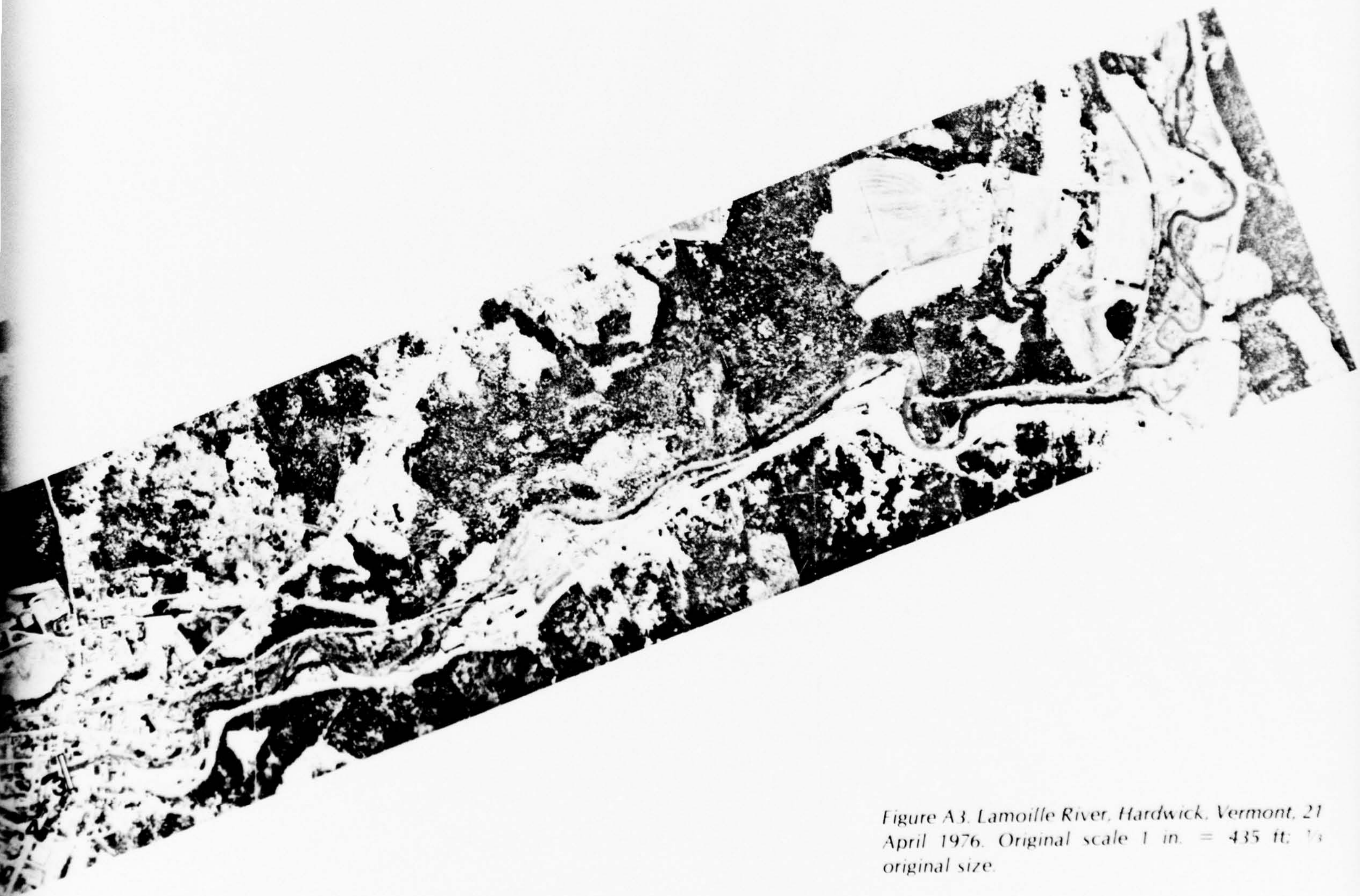

Figure A3. Lamoille River, Hardwick, Vermont, 21 April 1976. Original scale 1 in. = 435 ft; 1/3 original size.

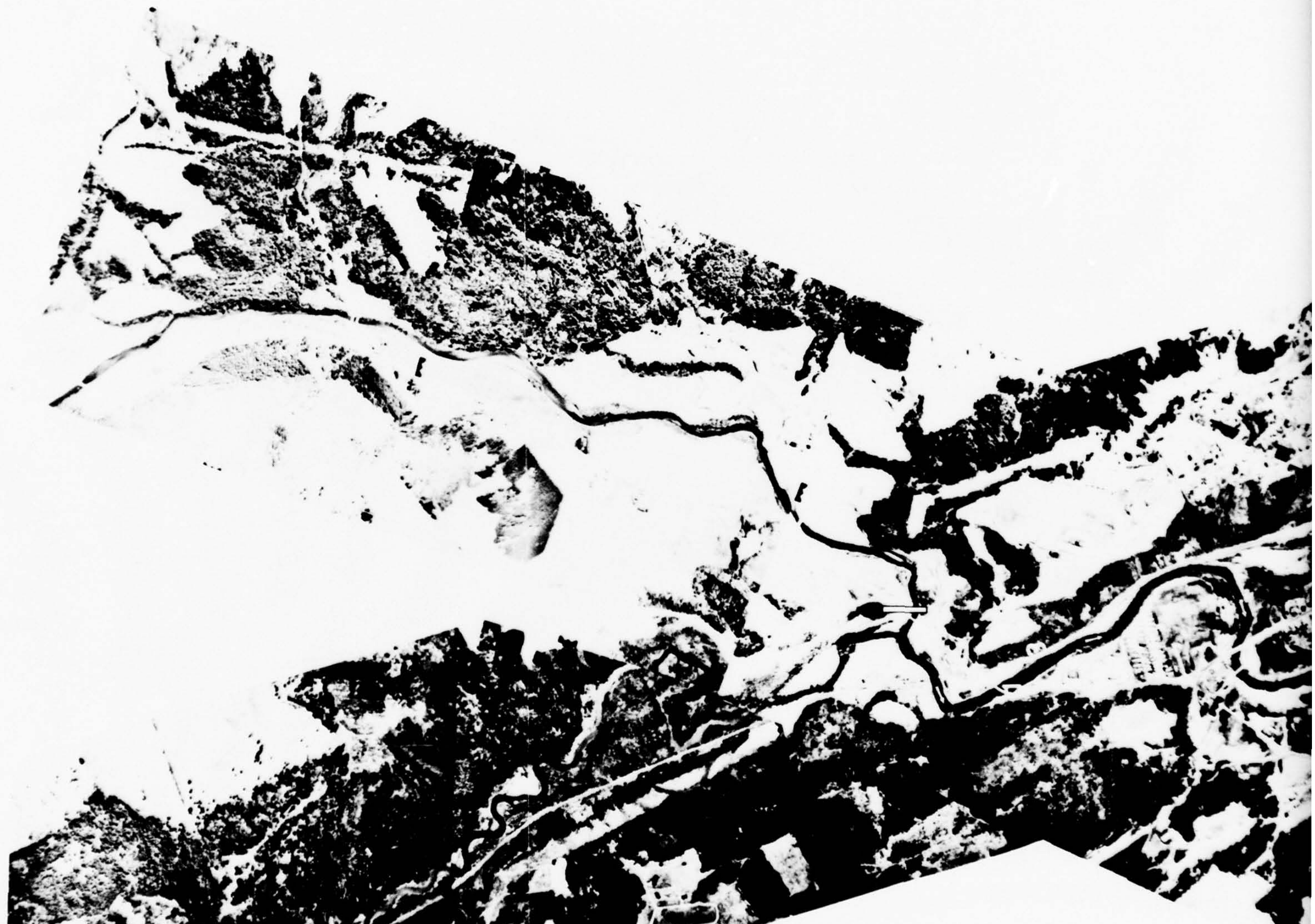

Figure A4. Passumpsic River, Lyndonville, Vermont, 21 April 1976. Original scale 1 in. = 480 ft; 1/3 original size.


A
A
B


A


Figure A5. Passumpsic River, St. Johnsbury, Vermont, 21 April 1976. Original scale 1 in. = 483 ft; ¾ original size.

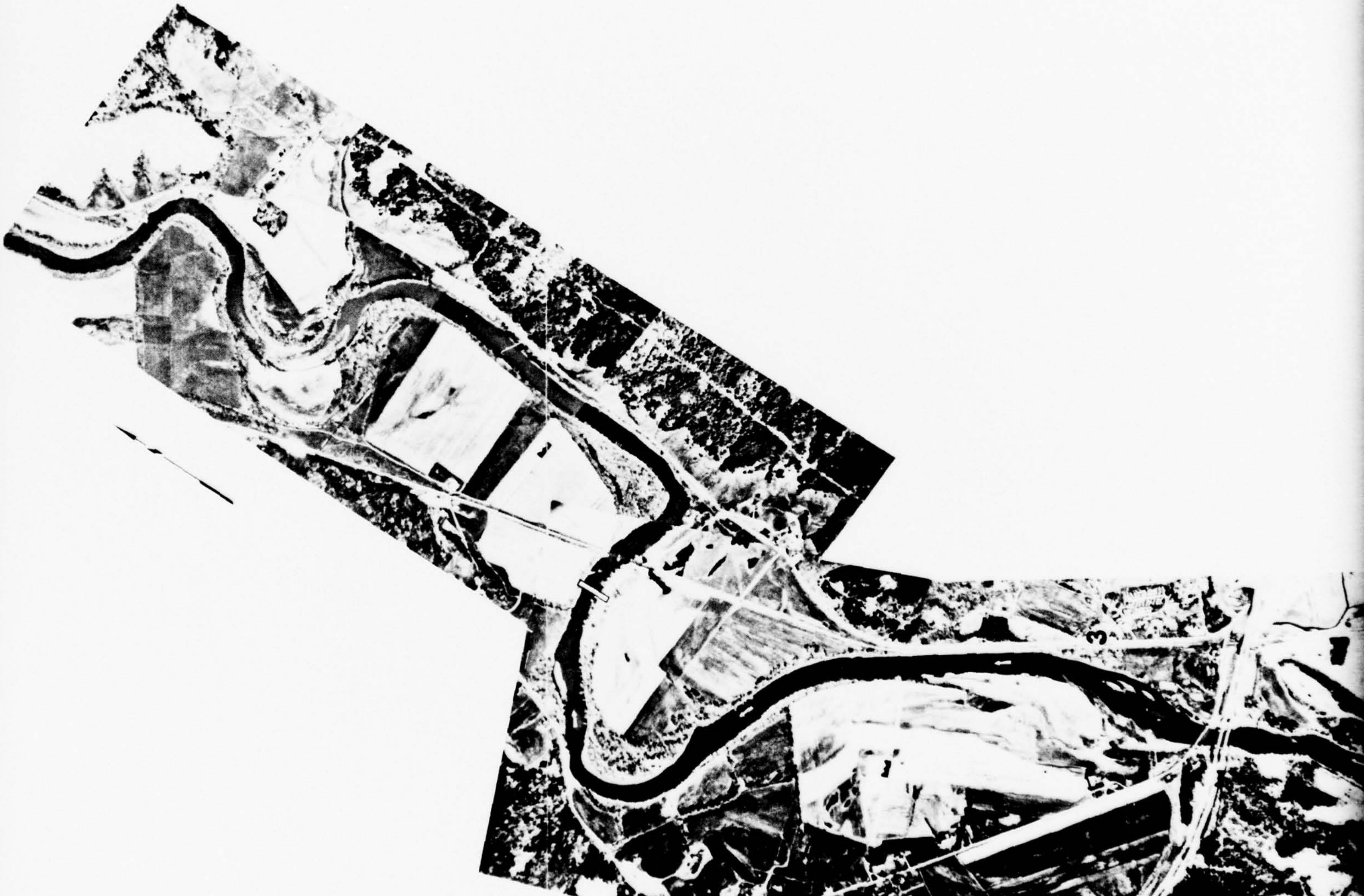

Figure A6. Winooski River, Richmond, Vermont, 21 April 1976. Original scale 1 in. = 521 ft; ¼ original size.


4
2
4

Figure A7. Mad River, Moretown, Vermont, 21 April 1976. Original scale 1 in. = 505 ft; $^{2}/_{4}$ original size.

2
3
N

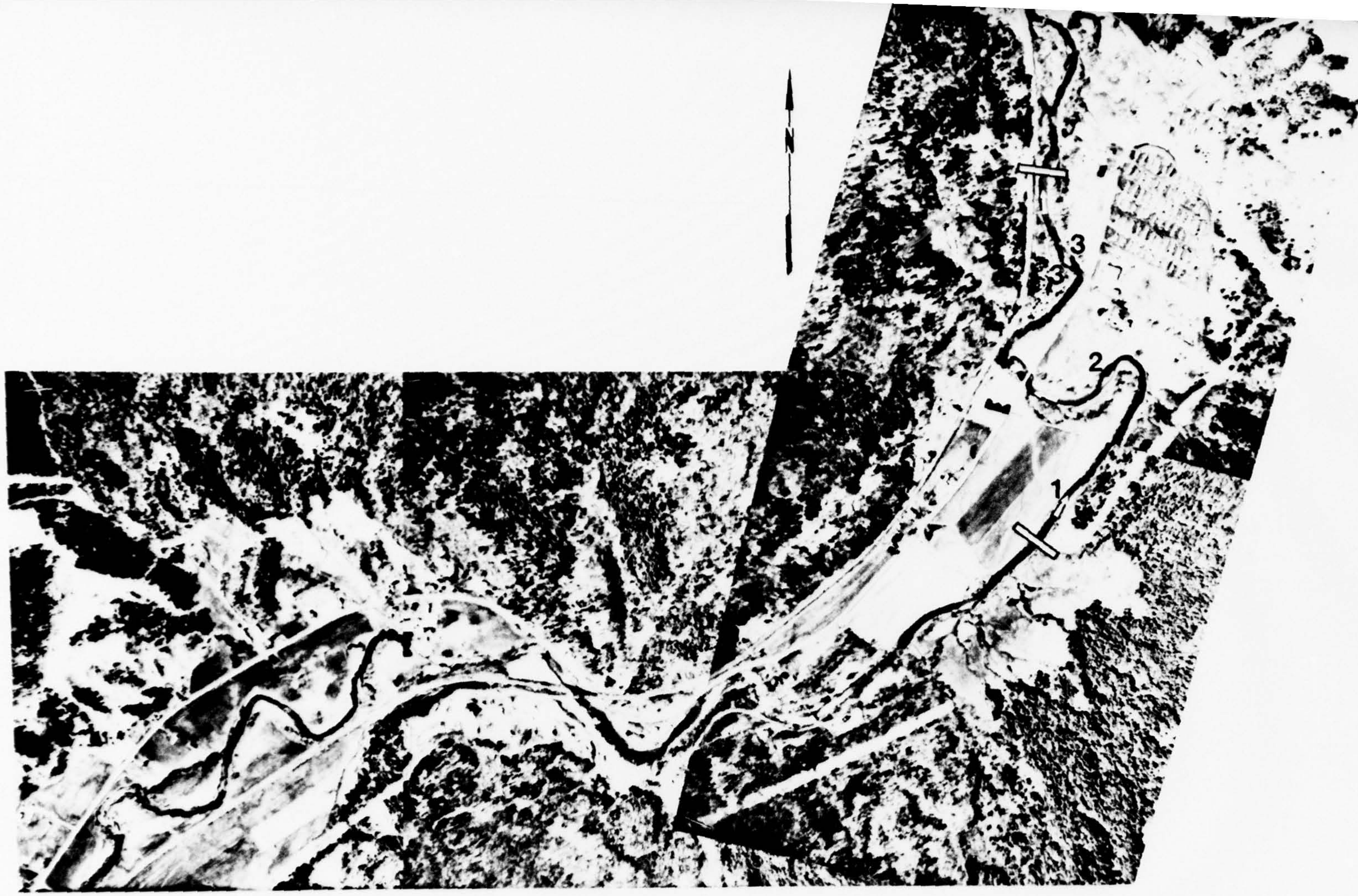

Figure A8. Dog River, Montpelier, Vermont, 21 April 1976. Original scale 1 in. = 556 ft; $^{2}/_{5}$ original size.


3
2
5
6
2
1

Figure A9. Winooski River, East Montpelier, Vermont, 21 April 1976. Original scale 1 in. = 439 ft; ½ original size.

Figure A10. Wells River, Groton, Vermont, 21 April 1976. Original scale 1 in. = 441 ft; ⅓ original size.

2


3

Figure A11. Waits River, East Corinth, Vermont, 21 April 1976. Original scale 1 in. = 563 ft; ¼ original size.

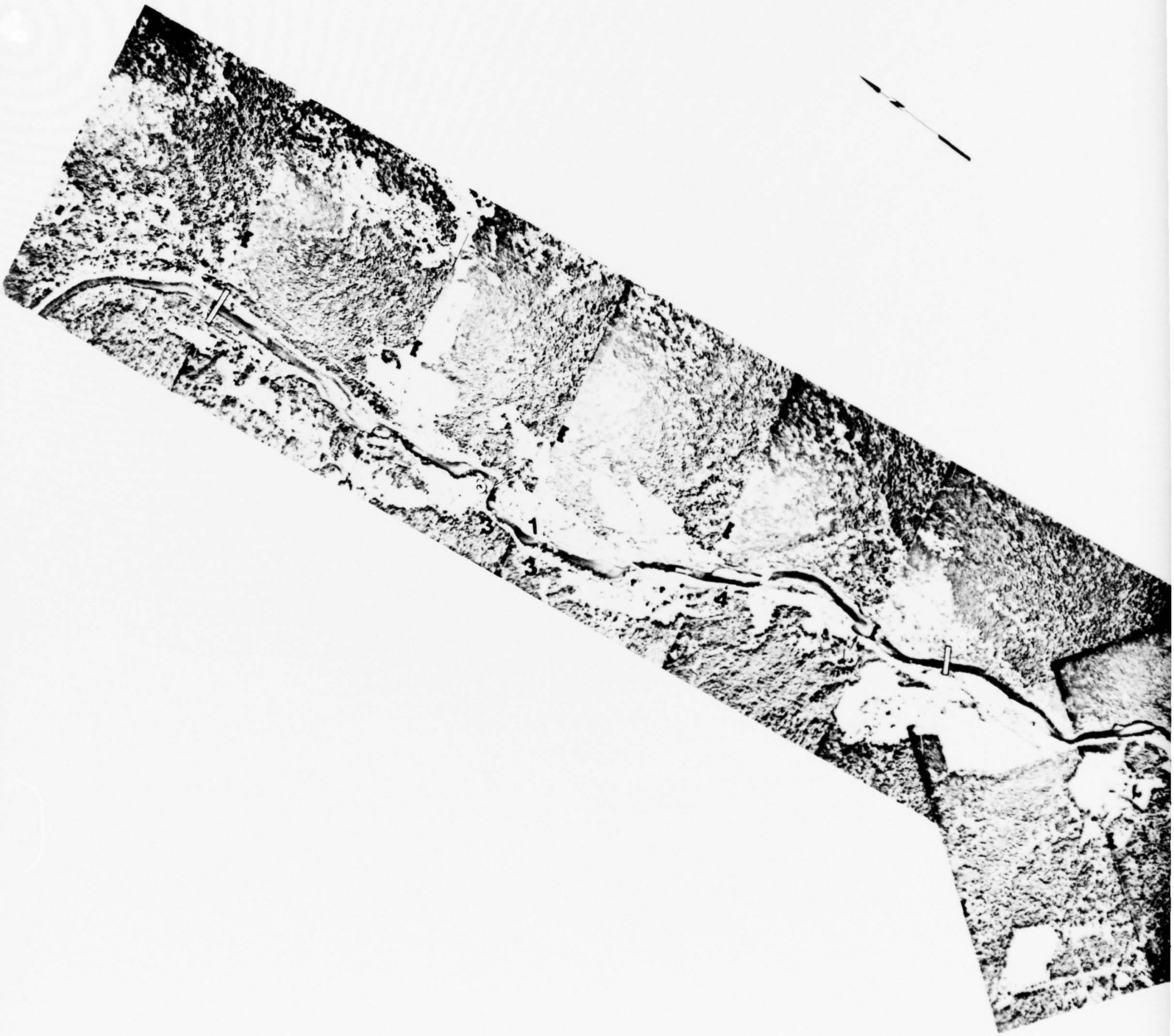

Figure A12-13. Waits River, Bradford, Vermont, 19 April 1976. Original scale 1 in. = 519 ft; ¼ original size.

2

Figure A14. White River, First Branch, Tunbridge, Vermont, 19 April 1976. Original scale 1 in. = 450 ft; ⅓ original size.

2

Figure A15. Flower Brook, Mettawee River, Pawlet, Vermont, 19 April 1976. Original scale 1 in. = 473 ft; ½ original size.

Figure A16. Deerfield River, Wilmington, Vermont, 19 April 1976. Original scale 1 in. = 381 ft; $^{2}/_{3}$ original size.


A
B
A'

Figure A17. Williams River, Chester, Vermont, 21 April 1976. Original scale 1 in. = 487 ft; ⅓ original size.


5
4
6
3
8

Figure A18. Ottauquechee River, Quechee, Vermont, 17 April 1976. Original scale 1 in. = 492 ft; ½ original size.

A

B

C

Figure A19. Ottauquechee River, Taftsville, Vermont, 17 April 1976. Original scale 1 in. = 492 ft; ⅓ original size.

APPENDIX B: CHANNEL DATA

Table BI. Channel widths (ft) at approximately 100-ft intervals measured on aerial photographs*.

IA. Hardwick site.

1)† 40 (UE)	11) 45	21) 55	31) 75	41) 70
50	50	55	80	80
25	55	60	80	90
40	50	40	80	90
25	45	60	80	90
55	45	70	95	80
70	50	65	80	90
55	50	65	85	115
70	50	80	50	49) 100 (DE)
10) 45	20) 55	30) 75	40) 70	

IB. St. Johnsbury site.

Reach A

1) 90 (UE)	31) 110	61) 135	91) 115	121) 100
95	130	120	120	70
100	140	120	125	95
120	120	130	110	124) 125 (DE)
115	130	130	140	
110	135	130	130	
110	120	150	120	
120	115	120	100	
125	120	140	115	
10) 110	40) 125	70) 155	100) 115	
110	120	160	120	
100	120	155	125	
160	130	120	135	
55+25 (I)	120	115	140	
135	115	100	125	
130	110	125	140	
130	105	150	160	
120	115	145	160	
110	120	145	140	
20) 100	50) 140	80) 130	110) 100	
95	150	145	130	
95	135	130	140	
85	135	135	145	
100	130	145	150	
130	130	140	145	
100	130	145	145	
120	130	135	135	
120	145	100	140	
130	145	95	125	
30) 135	60) 145	90) 95	120) 115	

IB. (continued)

Reach B

1) 285 (UE)**	31) 190	61) 125	91) 185
225	210	140	195
210	185	170	170
190	175	230	150
190	160	255	190
195	160	290	225
175	130+30 (I)	330	220
200	120+35 (I)	340	220
160	140+30 (I)	305	215
10) 160	40) 135+40 (I)	70) 250	100) 235
175	150	200	240
200	185	175	250
215	185	150	250
205	200	160	275
130	210	195	230
100	240	210	106-111) River channel off mosaic
155	220	195	150
155	215	155	113) 155 (DE)
380	235	205	
20) 260	50) 175+70 (I)	80) 185	
270	150+90+55 (I)	200	
260	280+40 (I)	150	
235	400+60 (I)	140	
235	315+65+65 (I)	135	
220	420+65 (I)	170	
200	320+65 (I)	180	
165	230	190	
130	185	195	
200	150	180	
30) 170	60) 150	90) 195	

IC. Bradford Center and Bradford site.

Reach 1[††]

1) 100 (UE)	16) 115	31) 135	46) 15+160 (I)	61) 95
105	130	135	10+20+40+30 (I)	70
95	120	125	80+20 (I)	63) 95 (DE)
100	130	115	100	Average = 115
105	120	110	80	
110	115	100	100	
100	110	125	105	
110	120	45+85 (I)	110	
90	120	45+105 (I)	110	
95	125	50+95 (I)	115	
100	125	45+65 (I)	120	
95	125	50+85 (I)	130	
105	155	110	70+7[illegible] (I)	
110	140	95	60+55 (I)	
15) 115	30) 130	45) 110	60) 115	

Reach 2[††]

1) 70 (UE)	11) 105	21) 50+190 (I)	31) 105	41) 125
65	110	55+165 (I)	100	10+105 (I)
70	110	35+110 (I)	100	15+95 (I)
80	90	90+15 (I)	100	10+100 (I)
75	85+10 (I)	130+10 (I)	100	20+75 (I)
70	20+110 (I)	110	105	10+20+90 (I)
115	15+110 (I)	90	110	10+20+95 (I)
100	50+95 (I)	90	85	120
85	35+110 (I)	70	85	90
10) 100	20) 225	30) 100	49) 95	50) 70 (DE)
				Average = 110

Reach 3[††]

1) 100 (UE)	11) 100	21) 60	31) 90
70	80	60	105
65	90	65	80
90	85	80	70
105	105	70	100
105	90	95	135
95	100	105	110
90	100	95	95
90	65	105	100
10) 100	20) 50	30) 110	40) 150 (DE)
			Average = 91

ID. Tunbridge site.

1) 80 (UE)	21) 80	41) 50	61) 80
60	45	40	75
50	50	50	40+10 (I)
55	75	55	40+10 (I)
65	60	50	35+25 (I)
60	55	65	65
70	60	45	75
70	45	45	80
65	60	50	50
10) 65	30) 70	50) 65	70) 65
65	70	60	80
60	80	65	80
70	75	50	80
80	70	50	74) 70 (DE)
80	30+25 (I)	55	
75	70	70	
70	65	70	
70	55	75	
75	50	65	
20) 75	40) 60	60) 85	

IE. Chester site.

Reach A

1) 30(UE)	21) 25	41) 40
20	20	50
35	30	40
35	30	40
35	35	40
40	35	40
30	35	47) 45 (DE)
30	40	
25	35	
10) 30	30) 35	
30	30	
40	35	
50	25	
30	25	
30	35	
35	35	
35	30	
40	45	
35	30	
20) 30	40) 20	

Reach B

1) 65(UE)	21) 35	41) 50	61) 65
45	75	50	80
50	40	45	75
40	75	45	80
45	85	60	70
45	65	60	60
35	55	50	65
35	25	50	60
35	30	70	65
10) 35	30) 55	50) 60	70) 45
30	55	40	50
40	50	40	40
40	75	65	50
35	100	75	45
30+30(I)	45+35(I)	65	50
65	45+45(I)	80	65
35+25(I)	30+30(I)	55+30(I)	77) 75 (DE)
25+25(I)	40	55+30(I)	
45	45	90	
20) 35	40) 55	60) 55	

IF. Quechee site.

1)	148 (UE)	41)	160	81)	131	121)	115
	156		156		115		148
	156		152		107		168
	152		148		107		221
	152		135		107		229
	143		127		98		254
	119		119		98		270
	131		119		107		123+107 (I)
	115		131		102		107+70 (I)
	127	50)	131	90)	107	130)	98+82 (I)
10)	135		131		98		107+90 (I)
	139		152		111		213
	148		98		115		197
	131		90		82		188
	119		107		98		156
	135		131		107		156
	139		111		123		180
	152		111		115		205
	172		123		107		213
	176	60)	135	100)	98	140)	57+156 (I)
20)	164		131		115		16+164 (I)
	164		139		127		45+143 (I)
	164		135		139		250
	143		148		98+16 (I)		250
	131		168		107+25 (I)		246
	127		98		139		213
	119		115		115		197
	115		123		107		184
	123		107		115		168
	119	70)	115	110)	98	150)	148
30)	131		131		107		148
	131		143		90		152
	119		148		135		160
	115		160		148		168
	123		171		148		164
	123		160		156		168
	139		143		164		168
	139		139		139	158)	152 (DE)
	148		156		135		
	156	80)	152	120)	127		
40)	156						

*UE, upstream end. DE, downstream end. I, channel divided by mid-channel bar or island; widths are measured across each channel section.

†Numbers in end parentheses refer to numbers of sites measured.

**At confluence of Moose and Passumpsic Rivers.

††Reaches are between the numbered arrows shown on photomosaic.

Table BII. Wentworth (1922) size classes (modified).

Name		Size range (mm)	Size range (in.)
Boulder	Coarse	>256	>10.07
Cobble	Coarse	256 64	10.07 2.51
Pebble	Coarse	64 4	2.51 0.15
Granule	Medium	4 2	0.15 0.07
Sand	Medium	2 0.06	0.07 0.002
Silt	Fine	0.06 0.004	0.002 0.0001
Clay	Fine	<0.004	<0.0001

Table BIII. Lengths of riffles and pools measured on aerial photographs along the main portions of channels (ft)*

IIIA. Bradford Center and Bradford site.

R^1	170	R^9	275
P^1	100	P^9	375
R^2	300	R^{10}	400
P^2	550	P^{10}	460
R^3	450	R^{11}	900
P^3	150	P^{11}	575 675 } I
R^4	240	R^{12}	875 750 } I
P^4	210	P^{12}	350
R^5	190	R^{13}	1625
P^5	160	P^{13}	1425
R^6	310	R^{14}	775
P^6	800 575 } I	P^{14}	460
R^7	900 1025 } I	R^{15}	2225
P^7	825 800 } I	P^{15}	820
R^8	600 700 } I	R^{16}	3125
P^8	110	P^{16}	375

IIIB. Tunbridge site

$R^1 = 260$	$R^3 = 2550$
$P^1 = 310$	$P^3 = 2295$
$R^2 = 280$	$R^4 = 715$
$P^2 = 360$	$P^4 = 900$

*R = Riffles

P = Pools

NOTE: Superscripts represent numbers of respective riffles and pools.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Gatto, Lawrence W.

River channel characteristics at selected ice jam sites in Vermont / by Lawrence W. Gatto. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1978.

iii, 60 p., illus., 27 cm. (CRREL Report 78-25.)

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Bibliography: p. 26.

1. Ice jams. 2. Remote sensing. 3. River characteristics. I. United States. Army. Corps of Engineers. II. Series: U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H. CRREL Report 78-25.