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AN ESTIMATE OF THE DISCHARGE OF THE ST. FRANCIS RIVER.

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April, 1903.

The Summer School of Surveying of McGill University was located in September, 1902, at the Village of Upper Melbourne, near Richmond, Quebec, and on the St. Francis River. One part of the work undertaken by the students was a determination of the discharge of the river by means of current meters. This paper contains a summary of the methods employed and of the results obtained.

THE RIVER AND ITS DRAINAGE AREA.

The St. Francis River has its source in and flows through that hilly portion of the Eastern Townships in the Counties of Compton, Wolfe and Richmond, of which Sherbrooke is the commercial centre. The main drainage area, as shown by the map, is considerably greater in breadth than in length. One main branch of the river rises in Lake Memphremagog and connecting lakes, and the other is fed from Lake St. Francis and its tributary streams. These two main branches, the Magog and the St. Francis, come together at Sherbrooke, and continue to the St. Lawrence as the River St. Francis. From the Lake Memphremagog source to the Lake St. Francis source the distance is about ninety-five miles, and from Richmond to the New Hampshire boundary from fifty to fifty-six miles; these boundaries including a watershed with a total area of about 3,080 square miles.

The country drained by the St. Francis is hilly, and many of the streams have a rapid fall. Numerous heights above sea-level, taken from White's "Altitudes on Canada," are marked on the map, and are sufficient illustration of this feature. On these streams and rivers the water is impounded by dams, whence power is obtained to run saw and grist mills. At Sherbrooke there is a noteworthy example of this, for there the Magog River drops about one hundred feet within the city limits. The Magog, Coaticook, Salmon and other rivers are likewise used for power purposes. There are numerous small ponds and lakes in this area which act as storage reservoirs, and assist materially in maintaining a satisfactory flow during the dry months.

Table 1 gives the total rainfall and snowfall during the year 1902 at the Richmond Station, and the averages for this and certain other stations in the district. The records from which these data are derived are somewhat incomplete and unsatisfactory. It is most unfortunate that the Dominion Government does not place sufficient funds at the disposal of the Meteorological Service as to enable it to secure observers at more numerous stations and to ensure that the observations that are taken will be complete and without any such omissions as those that appear in the Richmond record for 1902. The members of the Can. Soc. of C.E., who are directly interested in hydraulic work, might note that nearly all the meteorological data upon which they rely are obtained for the Government by volunteer observers, and that the department would probably welcome any offers of similar assistance, and be prepared to supply necessary instruments.

Along the north-western margin of the watershed lies the "Stoke Mountain" range, which can be traced from the shore of Lake Memphremagog, north-east, past the city of Sherbrooke, where it is well exposed, and thence to Lake St. Francis. East of Lakes Weedon and Aylmer, it forms a ridge with an elevation of from 500 feet to 600 feet above the level of these lakes. The rocks are

Table of Rain and Snowfall in inches in the vicinity of the St. Francis watershed.

(Data supplied by the Meteorological Office, Toronto.)

Place.	County.	Date.		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept	Oct	Nov.	Dec	Total.	
Richmond ..	Richmond .	1902.	Rain ..	..	0.0	0.70	2.50	5.47	..	..	..	2.98	4.33	1.90	0.0	..	
			Snow ..	..	18.0	8.0	3.6	3.0	..	..	..	..	..	5.0	15.0	..	
Richmond ..	Richmond .	Average ..	Rain ..	0.54	0.38	0.67	1.72	3.35	4.08	4.03	3.96	3.28	2.77	2.23	0.39	30.42 }	40.85
			Snow ..	26.0	23.0	21.2	5.1	0.4	..	..	..	..	1.1	8.0	18.0	104.3 }	
Cranbourne .	Dorchester .	Average ..	Rain ..	0.65	0.49	0.73	0.97	3.20	4.49	5.49	4.33	4.09	3.11	1.65	1.17	30.37 }	47.75
			Snow .	37.5	28.6	29.6	18.3	2.2	..	..	..	0.8	8.7	23.4	29.7	173.8 }	
Danville ..	Richmond .	Average ..	Rain ..	0.55	0.25	0.34	1.05	3.32	3.83	5.27	3.96	4.34	3.41	1.97	0.93	29.22 }	37.[illegible]
			Snow ..	13.4	18.1	20.2	7.1	0.4	..	..	..	..	1.1	11.2	16.1	87.6 }	
Barnston ..	Stanstead .	Average .	Rain .	0.68	0.93	0.63	1.25	3.62	4.38	4.38	3.31	3.96	3.01	2.11	1.06	29.32 }	40.77
			Snow ..	25.1	20.5	23.5	12.5	0.1	..	..	..	..	0.2	9.0	23.6	114.5 }	

Average for district 41.84 inches per year.

for the most part metamorphic, and probably consist of old and highly altered volcanic.

Just west of this central crystalline belt is a series of rocks, presenting a considerable variety of character, embracing slates of various colours—purple, black, green and grey sandstones—often so highly quartzose as to form hard quartzite-quartziferous schists and conglomerates. These are usually regarded as of Cambrian formation. A narrow belt of somewhat similar rocks appears south-east of the crystalline belt.

Flanking these are rocks referred to as of the Cambro-Silurian age. On the west they are fossiliferous limestones and associated graphite and calcareous shales. To the east of the ridge, and probably underlying the whole of the central and eastern part of the area, are a series of ochre-spotted slates and sandstones. These latter, although much obscured by a covering of drift, are apparently partly crumpled, or possibly have formed overturned synclinal basins, in which apparently calcareous beds appear; the slates and sandstones possibly representing denuded crests of small anticlinals. The writer wishes to acknowledge his indebtedness to Mr. A. W. G. Wilson for the geological facts above given.

The gauging of the river and the subsequent reductions form part of the regular surveying school course, and the writer, as one of the demonstrators appointed for the school, was in immediate charge of the fieldwork under the direct instructions of Professors McLeod and Kerry. He is indebted to them for information as to the methods of reductions, and for general advice and assistance in the preparation of this paper.

The work of the survey included—

(1) Regular readings of the height of the river.

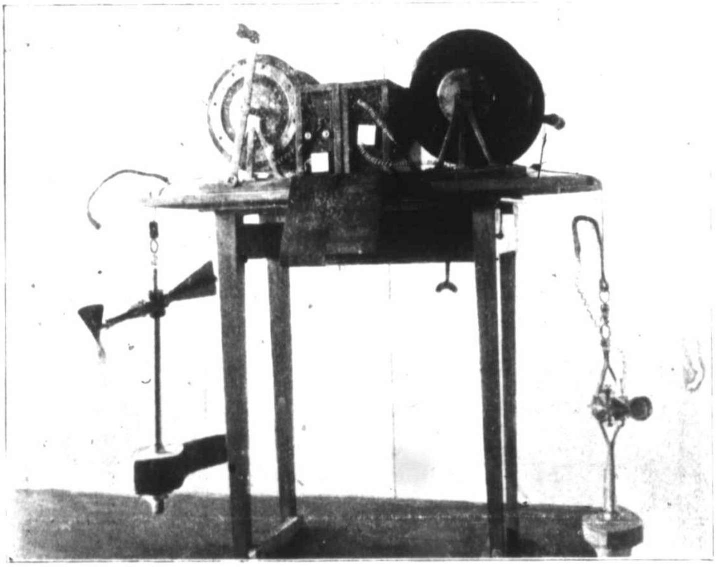
(2) A sounding survey for the river channel for a distance of about ¾ of a mile.

(3) A determination of the flow of the river as given by the current meters.

(4) Rating the current meter.

EQUIPMENT.

The special equipment consisted of two current meters (see Figure A), one of the Amsler and the other of the Price type. The Amsler meter consists of two propeller blades mounted on a hori-



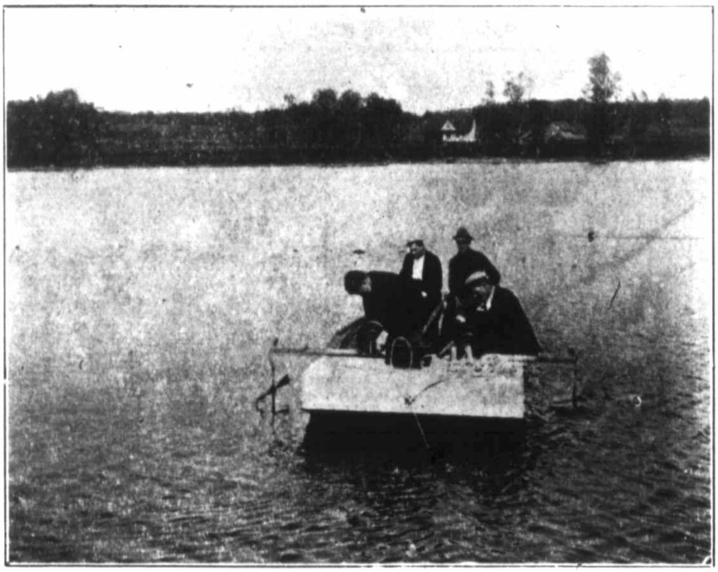


FIGURE "A"

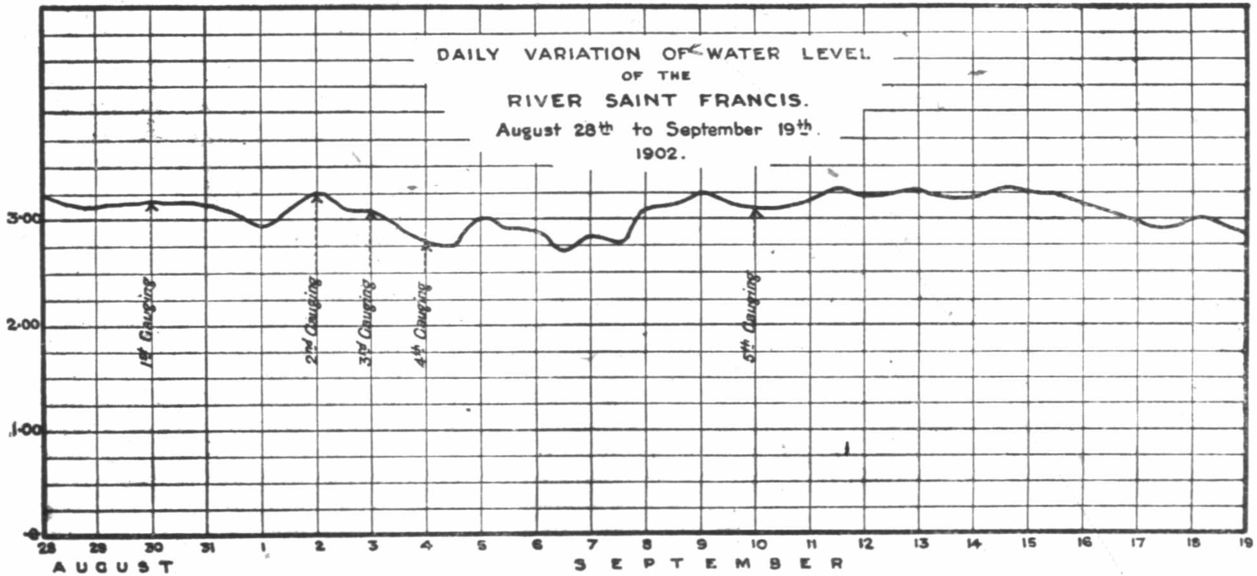

DAILY VARIATION OF WATER LEVEL
OF THE
RIVER SAINT FRANCIS.
August 28th to September 19th.
1902.
3·00
2·00
1·00
0
1st Gauging
2nd Gauging
3rd Gauging
4th Gauging
5th Gauging
28 29 30 31
AUGUST
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
SEPTEMBER

FIGURE 1.

zontal axis, running on roller bearings. A worm on this axis drives a wheel, on which there are projecting studs, and these studs striking against a spring lever complete the electric circuit; contact is made at every tenth revolution. The Price meter has five cup vanes mounted on a vertical axis, the upper end of which is cam shaped, and makes contact at every revolution by rubbing against a spring. Both meters are fitted with rudder tails, and when suspended are free to move into any position under the action of the current.

A wooden scow was built on the spot, and was about eighteen feet long, six feet wide, and drew three or four inches of water when loaded. The ends were each decked in to provide platforms from which to work the meters and anchors. The two meters were suspended over opposite sides of the scow (see plate), on the end of a wire cable, having an outside and an inside metallic conductor, insulated from one another by rubber and cotton covering. The cable was wound on wooden reels mounted on strong metal frames. The cables and reels were of special design, and were made for this work in the college shops. Both meters were supported by brass frames in electrical contact with the outside conductors of the cable. The frames were held in a vertical position by means of heavy lead weights, fastened to their lower ends. The length of wire reeled off in one revolution of the drum was 2.2 feet, and a spring stop, working in holes bored into a brass ring attached to the reel, provided means of holding the drum at any point when reeling out or in. The meter was let down until the axis of the instrument was in the surface of the water. It was then lowered, and the number of turns of the drum or fractions of turns recorded. It was in this way possible to keep an exact record of the distance below the surface at which the meter was working. Readings were taken at the surface and at vertical intervals corresponding to one revolution of the drum. The electric current was provided by a battery of three dry cells, the circuit passing through the outer casing of the cable, through the brass frame and the instrument, back by the inner cable and the frame of the drum. An ordinary small size "buzzer" was placed in the circuit to record the contacts in the meter.

A record of the height of the river from day to day was kept by observation on a gauge placed alongside the mooring wharf, and securely bolted thereto. The readings were taken at 8 a.m. and 6 p.m., and are graphically represented in Figure 1. The height of

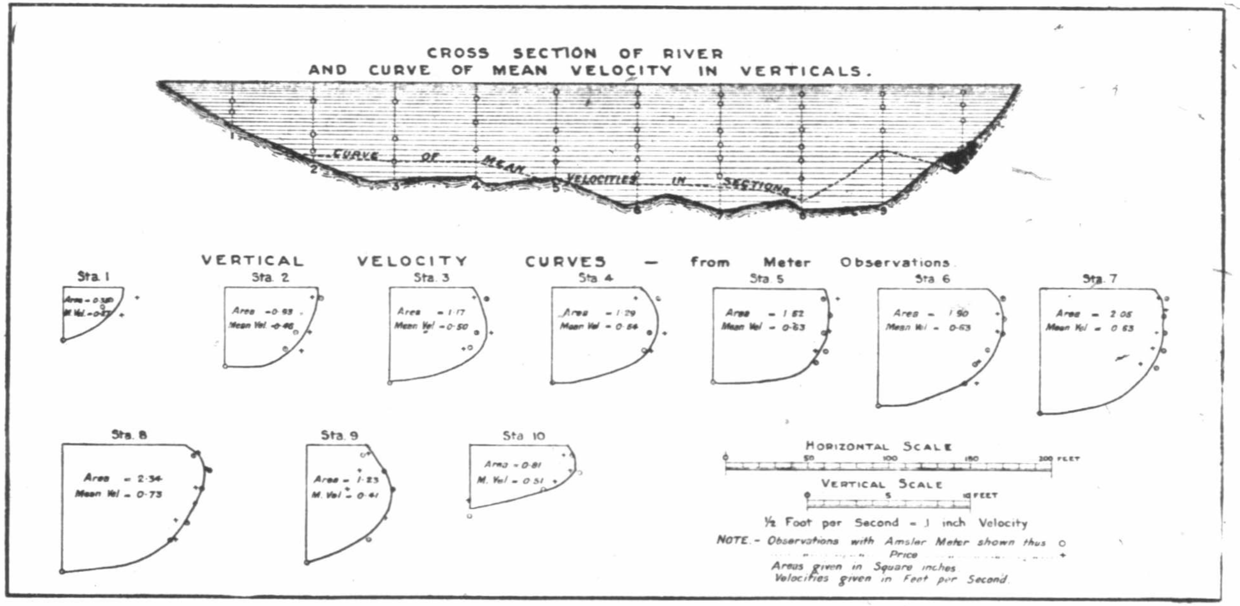

CROSS SECTION OF RIVER
AND CURVE OF MEAN VELOCITY IN VERTICALS.
CURVE OF MEAN VELOCITIES IN SECTION
VERTICAL VELOCITY CURVES — from Meter Observations.
Sta. 1
Sta. 2
Area = 0.93
Mean Vel. = 0.46
Sta. 3
Area = 1.17
Mean Vel = 0.50
Sta. 4
Area = 1.29
Mean Vel = 0.54
Sta. 5
Area = 1.82
Mean Vel = 0.63
Sta. 6
Area = 1.90
Mean Vel = 0.63
Sta. 7
Area = 2.05
Mean Vel = 0.63
Sta. 8
Area = 2.34
Mean Vel = 0.73
Sta. 9
Area = 1.23
M. Vel = 0.41
Sta. 10
Area = 0.81
M. Vel = 0.51
HORIZONTAL SCALE
0 50 100 150 200 FEET
VERTICAL SCALE
0 5 10 FEET
½ Foot per Second = .1 inch Velocity
NOTE.- Observations with Amsler Meter shown thus ○
Price +
Areas given in Square inches
Velocities given in Feet per Second.

FIGURE 2.

the gauge relatively to a bench-mark on a birch tree close to the camp wash-house was taken by levelling, the zero of the gauge being 11.98 feet below the bench-mark.

The sounding survey of the river showed that the upper half of the reach was free from obstacles or irregularities of any serious nature, and the smallest and otherwise most suitable section in it, at right angles to the direction of the current, was selected for the gauging section. This section was run in from the survey, and it was decided to take meter readings on it at ten points, as equally spaced as possible. A cross section of this section is shown on the accompanying Figure 2.

On shore, at one end of the section, two upright poles were aligned about fifty feet apart. Two transits were set up, one at each of the stations from which the setting-out angles were to be read. Another pole was firmly fixed on the boat midway between the two meters. The boat was then rowed upstream slowly, and with a little judicious poling the upright on the boat was gradually brought into line by one of the transits which was set for that particular station, and with the uprights on shore. The anchors by which the boat was held in position were then thrown overboard, one directly upstream and one directly down. By paying out one or other of the ropes which held them, the position of the boat could be altered at will. To take up a new position, the lower anchor was hauled in, the boat brought up stream by means of the upstream line, then poled sideways into its new position as it drifted down.

The operation of metering required five men in all. Two were stationed on shore with the transits, two were necessary to record the number of revolutions made by the meters, and the fifth called the time and assisted in moving the boat. The instruments were let down to the required depth, and five runs, each of a minute's duration, were taken at each depth, the mean of these five being used in the subsequent reductions.

It was necessary to rate the meters, or in other words, to obtain the number of electrical contacts which corresponded to different velocities in feet per second. The nearest still water was at the dam of the Richmond County Electric Company's plant, about four miles from the camp, on the Salmon River. Arrangements to let down the water in the pool, so that there would be no flow over the dam during the rating, were very kindly made by Mr. J. W. Harkom, M. Can. Soc. C.E., the manager of the Company. The method was as follows: An ordinary inch pine board about six

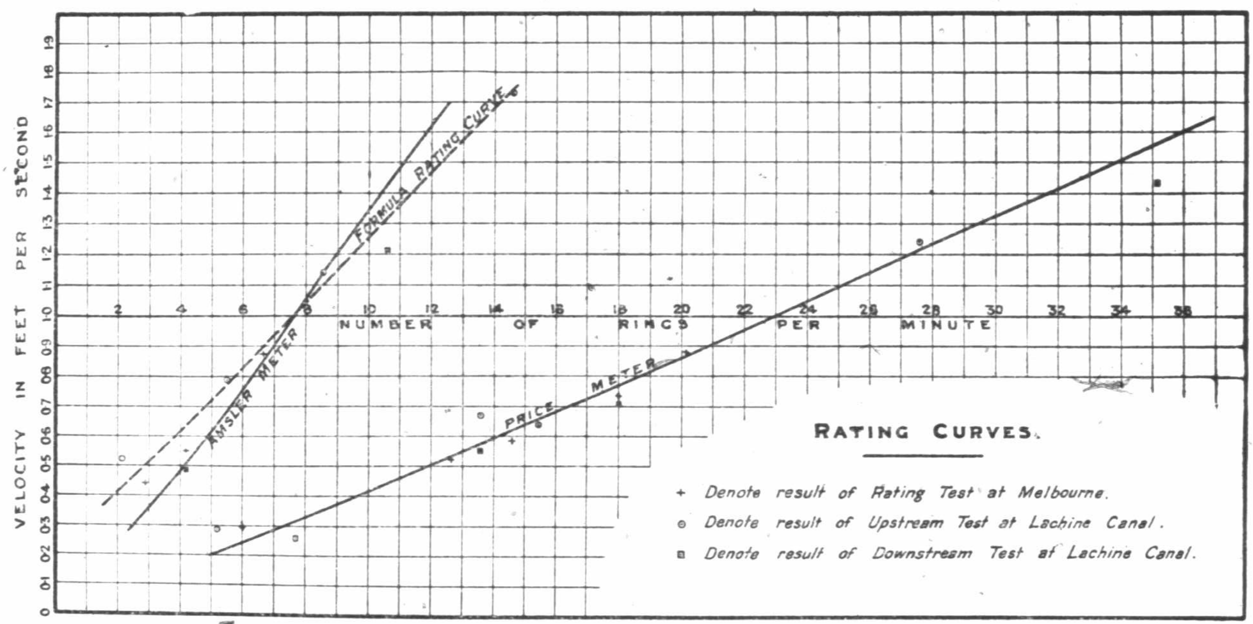

VELOCITY IN FEET PER SECOND
0 0·1 0·2 0·3 0·4 0·5 0·6 0·7 0·8 0·9 1·0 1·1 1·2 1·3 1·4 1·5 1·6 1·7 1·8 1·9
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
NUMBER OF RINGS PER MINUTE
AMSLER METER
FORMULA RATING CURVE
PRICE METER
RATING CURVES.
+ Denote result of Rating Test at Melbourne.
⊙ Denote result of Upstream Test at Lachine Canal.
▫ Denote result of Downstream Test at Lachine Canal.

FIGURE 3.

feet long and one foot wide, with pointed ends and with a perpendicular arm about three feet long and two inches wide, fastened to the centre, was used as a float. The meters could be attached to the arm, and were then suspended in the same manner as when attached to the brass frames used in gauging, being practically free to set themselves to the impulses of the current against the rudder. The batteries and buzzers were carried at the top of the float. The float was attached to one end of a strong cord wound on one of the cable drums. Another cord was attached to the other end of the float for guiding purposes. The float, with meter attached, was then moved in one direction through a distance measured by the number of turns of the drum, and the number of rings of the buzzers counted. The water in the pool being still, it was not necessary to make observation in the reverse direction, although this was sometimes done. With very little practice, the float could be kept moving at a constant speed. The number of turns of the drum and the number of rings were taken at different speeds.

The conditions and time available here were not altogether favourable to an exact determination, and the ratings were continued, after the school broke up, in one of the still water basins of the Lachine Canal.

The results of these ratings are shown plotted on Figure 3. The curves were drawn graphically, as it was considered that the number of readings obtained did not justify the determination of a rating equation by the method of least squares. The second rating curve for the Amsler meter was plotted by ordinates calculated by the formula given by the makers at the time of purchase. As the instrument has been in use some time, and several changes have been made in its construction, the curve from the actual readings was adopted.

Curves were plotted for the ten stations with the depth in feet and velocity in feet per second as ordinates. The values obtained by both meters for the velocity at each station were plotted, and an average curve drawn through the point. The areas bounded by these curves were then measured by planimeter, and this area, when divided by the depth, gave the mean velocity in a vertical section at the several stations.

The cross section of the gauging section was obtained by plotting the sounding taken in the preliminary survey, together with those taken during the metering.

It was assumed that the mean velocity at different points in the cross section would vary, for a very short distance, almost directly with the depth at the point; and the known mean velocities at the ten points were therefore plotted to suitable scale with the water surface in the cross sections at datum line; a curve drawn through the points thus obtained, and roughly parallel to the bottom of the river, was adopted as the mean velocity curve, the ordinates to which at each point would give the mean velocity of the river at the point.

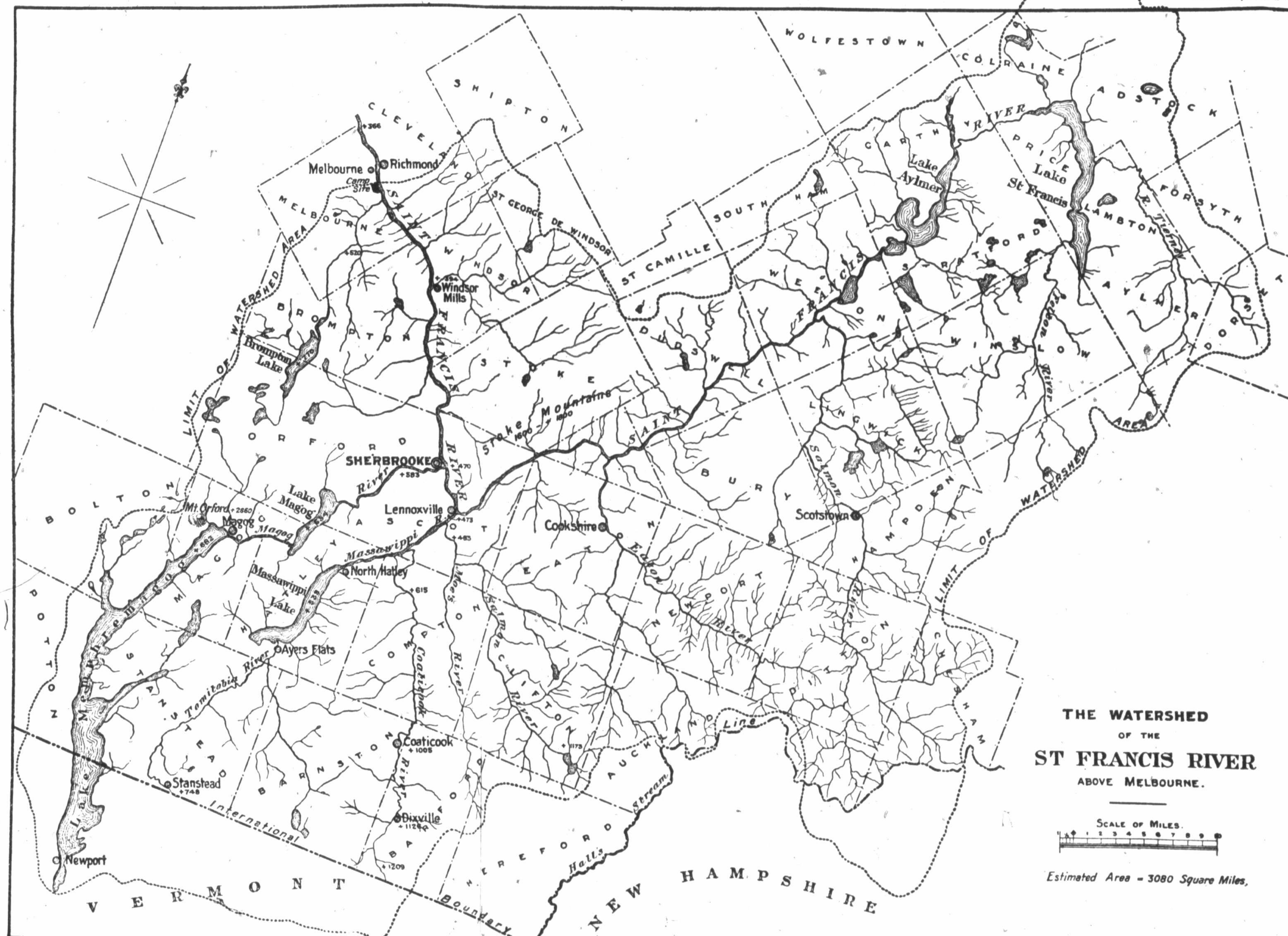
The discharge was calculated by dividing the cross sections into narrow sections, the mean depths and velocities for which were obtained by scaling from the plotted curves and then multiplying the widths, depths and velocities together.

While on the survey, five separate parties made complete meter gaugings of the river, and their results are given in the following table. The weather prevailing while the work was in progress is also recorded for each measurement:—

Date 1902	Discharge in cu. ft. per second.	Ht. of River.	Weather Conditions.
Aug. 30...	1819	A.M. P.M. 3.18 Mean 3.18	Cloudy, moderate breeze up stream. A wet period had just preceded this day.
Sept. 2..	1648	3.25 to 3.10 Mean 3.17	Fair, with a stiff breeze from N.W. up the river; river surface choppy. Rained heavily the preceding day.
Sept. 3..	1614	3.10 to 2.90 Mean 3.00	
Sept. 4..	1513	2.80 to 2.75 Mean 2.77	Cloudy; heavy rain night of 3rd; showery in forenoon light breeze in afternoon.
Sept. 10..	1719	3.10 to 3.10 Mean 3.10	Moderate breeze from N.W. up stream.

Each calculated discharge is the average of the individual calculations of the students who made the field observations, a working party being usually four in number. It is interesting to note that the rain did not affect the level of the river for some time after it fell; and that the discharge and the recorded height of the river vary quite accordantly.

The average discharge for all the measurements is 1,663 cubic feet per second, and corresponds to a gauge height of 3.0 feet.


THE WATERSHED
OF THE
ST FRANCIS RIVER
ABOVE MELBOURNE.
SCALE OF MILES.
Estimated Area = 3080 Square Miles,
Melbourne
Richmond
Camp Site
Windsor Mills
SHERBROOKE
Lennoxville
Magog
Mt Orford +2860
Lake Magog
North Hatley
Massawippi Lake
Ayers Flats
Coaticook +1005
Dixville
Stanstead
Newport
Cookshire
Scotstown
Lake Aylmer
Lake St Francis
Stoke Mountains
CLEVELAND
SHIPTON
MELBOURNE
ST GEORGE DE WINDSOR
WINDSOR
BROMPTON
Brompton Lake
STOKE
ORFORD
BOLTON
POTTON
STANSTEAD
BARNSTON
BARFORD
HEREFORD
COMPTON
ASCOT
EATON
CLIFTON
NEWPORT
AUCKLAND
DITTON
CHESHAM
HAMPDEN
BURY
LINGWICK
DUDSWELL
WESTON
STRATFORD
WINSLOW
SOUTH HAM
ST CAMILLE
WOLFESTOWN
GARTHBY
COLRAINE
ADSTOCK
PRICE
LAMBTON
FORSYTH
AYLMER
DORSET
LIMIT OF WATERSHED AREA
SAINT FRANCIS RIVER
Magog River
Massawippi
Tomifobia River
Coaticook River
Moe's River
Salmon River
Eaton River
Salmon River
Halls Stream
Line
International Boundary
VERMONT
NEW HAMPSHIRE