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I.K. Tsanis, H. Biberhofer, and
C.R. Murthy

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Scientific Liaison Officer
C.R. Murthy
Lakes Research Branch
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario

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I.K. Tsanis [1], H. Biberhofer [2] and C. R. Murthy [3]

[1] Department of Civil Engineering
McMaster University

[2] Water Quality Branch - Ontario Region
Inland Waters Directorate
Canada Centre for Inland Waters

[3] Lakes Research Branch
National Water Research Institute
Canada Centre for Inland Waters

Abstract

As part of a major research study on developing strategies for a long-term water quality monitoring program in the Cornwall/Massena section of the St. Lawrence River, physical data were analyzed to determine the hydraulic flow characteristics of this area. During the summer of 1989, a moving boat flow measurement system, surface drifters and moored current meters were used to determine the flow distribution in the Cornwall/Massena area located downstream from the Saunders Hydroelectric Power Dam. Two methods were used to evaluate mean cross sectional current velocities and the flow around the Cornwall and St. Regis Islands. Logarithmic profiles were fitted to the horizontal velocity data in the vertical. Mean velocities were calculated along with the bottom shear stresses and the equivalent bottom roughness heights. The cross sectional variability of the bottom roughness height was used with the Manning formula to determine the horizontal velocity distribution. The flow rates were calculated based on the velocity profiles and the moving boat measurement system. The total flow around the Cornwall island is divided into 65.5% through the south channel and 34.5% through the north channel while 34.3% of the total flow is through the channel between Cornwall and St. Regis Islands.

INTRODUCTION

Knowledge of the hydraulic characteristics of the St. Lawrence River in Cornwall-Massena area is very important for water quality monitoring. For example, determination of the flow distribution around the Cornwall Island is vital for assessing the loadings of the contaminants in this area. To address this problem current meters, ship-tracked surface drifters and the moving boat flow system were used to provide information on the direction, velocity and volume of water through the various channels.

Since the opening of the St. Lawrence Seaway, field data on river current flow patterns and current velocities has been periodically recorded (St. Lawrence Seaway Authority, 1989). The St. Lawrence River flow rate is routinely measured hourly at the Moses-Saunders Power Plant control facilities at Cornwall, Ontario (International St. Lawrence River Board of Control). The outflow in the St. Lawrence River may range between 5,660 m^3/s and 9905 m^3/s depending on the water levels and other associated hydraulic factors. The river is subject to changing current patterns and velocities primarily because of the fluctuating range of outflows moving downriver, off Lake Ontario.

The monitoring of the water levels is performed by the St. Lawrence Committee on River Gauging (Ontario Hydro, Environment Canada, 1986-89). Four water level gauges are within the Cornwall-Massena area: (a) Saunders Tailwater (datum = 47.20), (b) Pollys Gut (datum = 46.60), (c) Cornwall (datum = 46.33) and (d) Summertown (datum = 46.15). The map indicating the location of the water level stations and the water levels with respect to the datum for the last four years in these four stations are given in Figures 1a and 1b.

The flow downstream from the Moses Saunders Power Dam is complicated with two thirds of the total flow through Polly's Gut (see Figure 2). A spur dike and a training dike at Polly's Gut were constructed to reduce turbulent eddies in the approach to the lock and align the flow with the navigation channel (International St. Lawrence River Board of Control, 1982).

Figure 3 shows a map of the area of interest indicating the locations where the flow measurements were undertaken. The cross sections (water level with respect to the IGCC datum) were calculated from the field sheets 8317-8319 (Canadian Hydrographic Service). In a technical report by the Canadian Hydrographic Service the water levels were correlated linearly with the total flow for navigation purposes but no flow balance was attempted (Richards, B., 1986).

In this report, flow data from moored current meters, moving boat profiling measurements and surface drifters are analyzed. Two methods are used for evaluating mean cross sectional currents and the flow distribution in the North and South channels around Cornwall and St. Regis Islands. Previous chemical monitoring across the river in this area showed a strong horizontal heterogeneity. These results are very useful for designing and siting any future chemical monitoring stations in this area.

THEORETICAL BACKGROUND

Velocity Profiles in Turbulent Flow

The currents in the Cornwall-Massena area are high (3-6 knots) and the bottom in the Cornwall-Massena area was strewn with rocks 50 cm and less in diameter. Since the flow is turbulent and the bottom rough, a logarithmic velocity profile in the rough turbulent regime is a good approximation. The equation appropriate for this profile is given by Yalin, 1972:

$$\frac{U(z)}{U_*} = 2.5 \ln \left[30.1 \frac{z}{k_s} \right] \tag{1}$$

where k_s is the equivalent bottom roughness height, U_* the shear velocity, h is the water depth at the current meter location and U(z) is the velocity at a distance z from the bottom. The average velocity is given by the following equation:

$$\frac{U_{ca}}{U_*} = 2.5 \ln \left[11.0 \frac{h}{k_s} \right] \tag{2}$$

where U_{ca} is the average velocity at the cross sectional compartment (where the velocity was measured) and corresponds to the velocity at a depth z=0.36 h. The Manning's coefficient n is equivalent to wall-roughness height to the one-sixth power (White, 1979) in SI units

$$n = 0.0382\ k_s^{1/6} \tag{3}$$

There is a factor of 15 variation in roughness from a smooth glass channel (n=0.01) to a tree-lined floodplain (n=0.15). There is a large scatter in channel resistance due to variations in slope, cross section, bank configuration, and vegetation, especially in natural channels.

The Manning's formula for uniform-flow velocity in wide channels such the river cross sections under consideration in SI units is

$$U_{av} = \frac{1}{n}\ h^{2/3}\ S_o^{1/2} \tag{4}$$

An accurate estimate of the total discharge can be made by dividing the cross section into compartments and by using the following equation (Shen & Ackermann, 1980):

$$Q_T = \sum_{i=1}^{N} U_{ci}\ \Delta A_i \tag{5}$$

where i = index for compartments, N = total number of compartments, U_{ci} = the average velocity in the ith compartment, ΔA_i = $h_{ci}\,\Delta x_i$ the area of the ith compartment, h_{ci} = average depth of the i compartment and Δx_i = the horizontal distance between adjoining compartments.

The average velocity in any compartment of the composite area is calculated by using the Manning equation (4) (Ven Te Chow, 1959) assuming that the Manning equation is applied individually for each compartment.

$$U_{ci} = U_{ca}\ (\frac{h_{ci}}{h_{ca}})^{2/3}\ \frac{n_{ca}}{n_{ci}} \tag{6}$$

where n_{ci} = the Manning's roughness coefficient for the ith compartment, h_{ca} = average depth of the current meter compartment and n_{ca} = the Manning's roughness coefficient of the current meter compartment. The above approach is widely used in the instances, when the velocity data is limited. The velocity distribution can be synthesized from the depth data via Eq. (6)) (Krishnappan & Lau, 1982).

PHYSICAL EXPERIMENTS

(a) Current Meters

Three "Neil-Brown" current meter moorings were deployed at the north and south channels of the Cornwall Island for a period of approximately six months (May 2 - October 14 1989). The current meters were installed on bottom-mounted frames approximately one meter from the bottom.The current meter data was translated and written on a digital tape in a standard NWRI format. Hourly and monthly averages, variance of the velocity signals, and spectral analysis (Penicka, 1978, Mooers, 1973 and Calman, 1978) of the velocity time series were performed.

The results of these moorings had been subject of close examination and much conjecture. Post-field checking of the current meters themselves show that they were returned from the mooring site in operating condition. However, anomalies in the readings taken by these current meters lead to the following conclusions:

(a) Mooring 89-07C-003A009 was found by divers laying on it's side and was decided that the data was considered invalid for the entire period.

(b) Mooring 89-07C-02A009 looked reasonable until August 2 1989. The rest of the data was rejected as contaminated.

(c) Mooring 89-07C-001A010 was edited in two files: May 1-21, 1989 and July 8-17, 1989 (File No. 89-07B-001A010).

The mean currents and directions for the above periods are given in Table 1. The power spectra indicate energy peak around 24 hrs reflecting the diurnal flow regulation at the Power dam. A typical spectral plot is given in Figure 3.

The mean currents were quite small, of the order of 20-40 cm/sec (being closed to the rough bottom and in the wake of the bottom anomaly). Six hourly mean current speed and directions showed some deviations from the principal axes unacceptable for river flow situations. For these reasons it was decided not to use the current meter results in the flow calculations. Nevertheless, the experience gained is quite valuable for planning future studies in the area, particularly the use of moored current meters in fast flowing currents.

(b) Ship-tracked Surface Drifters

A drifter consists of a float and a sail ($2 \times 2\ m^2$) set at an adjustable distance below the water surface. The sail has a larger exposed area than the float to the current to minimize wind effects. In the present experiments the plate was in 1.5 m from the water surface. The drifter velocity vector at the current meter cross section can be calculated by linearly interpolating the velocities and directions of the drifter as it approaches and passes through the cross section. The velocities perpendicular to the cross section are calculated and the velocity at the current meter cross section is derived by interpolation (Tsanis and Murthy, 1989). The average velocity of the drifter compartment is approximately equal to the surface velocity divided by 1-1.20 (the range is due to three dimensionality of the flow and wind influence).

The velocities of the individual drifters were calculated from the distance travelled and travel time for thirteen drifters. The time of release with the appropriate time lag was used to determine the total flow rate from the Power Dam at that instance. The released drifters crossed the cross sections designated in Fig. 4 at a particular depth and with a particular velocity. This depth and drifter velocity is used to calculate the flow rates through the section following the procedure by Tsanis and Murthy, 1989.

The variability of up to 30% in the flow rate estimates in the different cross sections was observed (depth variability, bends, secondary flow etc.) in the study area. The above variability leads us to conclude that although the drifters give good information on the velocity and an overall rough estimate of the flow, they cannot be used alone for accurate flow calculations. Additional information such as horizontal velocity distribution in vertical is needed.

(c) Moving Boat Profiling System

The moving boat measurement system is a completely automated system for stream flow measurement used by Water Survey of Canada. The current measurements are made by traversing river perpendicular to the current while recording the channel geometry and the combined river and boat velocity. The average velocity, width and depth of different cross sectional compartments are calculated and combined to produce compartmental discharges. The total river discharge is produced by summing the compartmental discharges after correcting for width and mean velocity.

An Ottmeter measures combined boat and river velocity. The measurement processor counts the number of pulses per second corresponding to this velocity and computes the river velocity. An electronic compass is used to determine the resulting angle between the current meter and a reference line and is used to determine the sine and cosine values for determining the river velocity and the compartmental width. The depth data is provided by a digital depth sounder. Additional information on the theory, system components and measurement procedure can be found in Hydrometric Manual - Automated Moving Boat Measurement System.

The flow rate was calculated in seven cross-sections (see Fig. 3) along with two or three vertical velocity profiles taken in each cross section. Logarithmic velocity profiles according to Eq. (1) were fitted to field data and provided the necessary shear velocity u_* and bottom roughness height k_s. Eq. (2) was used to provide the mean vertical velocity U_{ca} of the measured location. Eq. (3) was used to calculate the Manning's coefficient.

The cross sections were divided up to twenty compartments and the depths and areas of compartments were calculated. The Manning's coefficient at two or three locations where the velocity was measured in each cross section was variable. Linear interpolation yielded appropriate values of Manning's coefficient in the different compartments. The value n was increased by 20% between the location close to the shore and the shore in case of a sloping bottom. Using the Eqs. (6) and (5) the compartmental velocities can be calculated as well as the total flow rate through the cross sections. A sensitivity analysis was conducted by calculating the flow rate (a) by assuming there is no variability of n across the section and (b) based on one vertical velocity profile. In the case of symmetrical cross section velocity profiles the variability was of the order of 10% while in the cases of asymmetrical cross sectional velocity profiles (river bends) the variability was up to 25%. Detailed calculations of the flow rates from different methods are given in Appendix A.

Appendix B provides a summary table of the flow rate estimates based on the moving boat measurement system, conventional drifters and vertical velocity profiles together with the corresponding total flows from the Power Dam. The flow distribution (in percentage of the total flow) around Cornwall and St. Regis islands based on the above measurement techniques are:

	Cornwall Island	
	North Channel	South Channel
Moving Boat System	34.8%	65.2%
Velocity Profiles	34.4%	65.6%
Drifters	31.9%	68.1%

Flow between Cornwall South Channel and St. Regis Island

Moving Boat System	34.00%
Velocity Profiles	34.47%

Flow between North Shore and Pilon Island

Moving Boat System	7.26%
Velocity Profiles	6.45%
Drifters	7.40%

CONCLUSIONS

Analysis of field data collected in the Cornwall-Massena area during the summer of 1989 yield a better understanding of the complicated hydraulic characteristics of this area. Logarithmic profiles for fully turbulent flow fitted to the velocity data reveal a strong cross-sectional variation of the bottom roughness height. This variation in the roughness after interpolation was taken into account when evaluating the cross sectional average velocity.

The flow in the Cornwall-Massena area is unsteady due to daily flow regulations into the Power Dam. The unsteady nature of the flow was taken into account in the flow rate calculations by interpolating water levels and discharges.

The flow distribution in the channels around the Cornwall and St. Regis Islands was determined. The flow around Cornwall Island is 65.5% through the south channel and 34.5% through the north channel. The flow between Cornwall and St. Regis Islands is 53% of the south channel flow while the flow between the north shore and Pilon Island is 7% of the total flow.

RECOMMENDATIONS

(1) The moored current meters are unsuitable for use in rivers with fast moving currents such as in the St. Lawrence River at Cornwall-Massena area. The best flow measurements can be accomplished by using the moving boat profiling system and mechanical (Price) flow meters.

(2) In order to obtain detailed and accurate flow rate estimates a number of conventional drifters should be released simultaneously in both the north and south channels at varying distances from the shore. In addition, a number of vertical velocity profiles at varying distances from the shore should be measured in order to provide adequate information for the proper calculation of the cross sectional average velocity.

(3) Detailed chemical monitoring should be continued in both south and north channel cross sections of Cornwall and St. Regis islands, at different distances from shore to resolve the strong crosswise concentrations gradients.

(4) With a view to establish a permanent long term water quality monitoring station in the Cornwall/Massena section of the St. Lawrence River, it is recommended that the on site physical and chemical monitoring studies should be continued in both south and north channel cross sections of Cornwall and St. Regis islands.

(5) Application of 2-D advection - diffusion models to major Point Sources in this area may also assist in the determination of chemical loadings as well as in the selection and siting of long term water quality monitoring stations.

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REFERENCES

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TABLE 1

Current Meters

	Latitude	Longitude	Current Speed (cm/s)	Direction degrees
89-07C-001A010	45-01-14	74-41-16	20.2	72.5
89-07C-001B010	45-01-14	74-41-16	38.3	80.5
89-07C-002A009	45-00-28	74-39-12	24.7	71.9

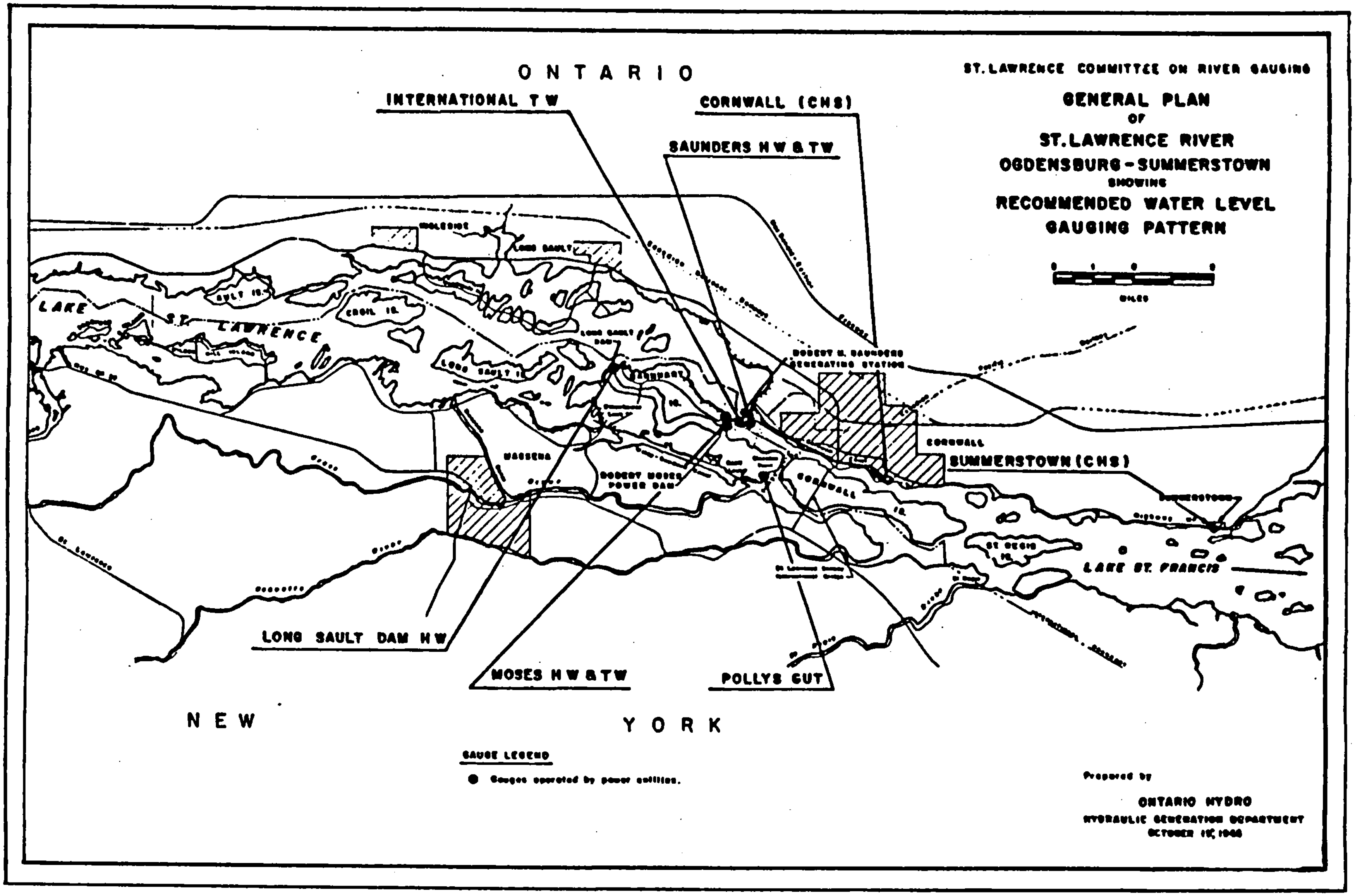
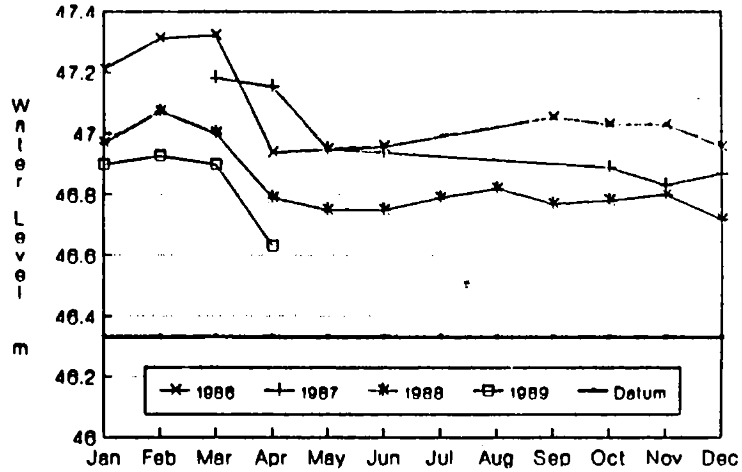
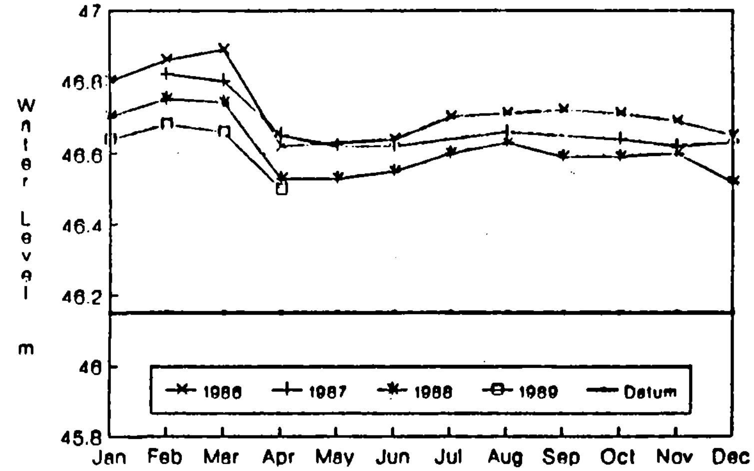


Fig. 1 Location of water level gauges in the St. Lawrence River in Saunders Hydroelectric Power Plant Area

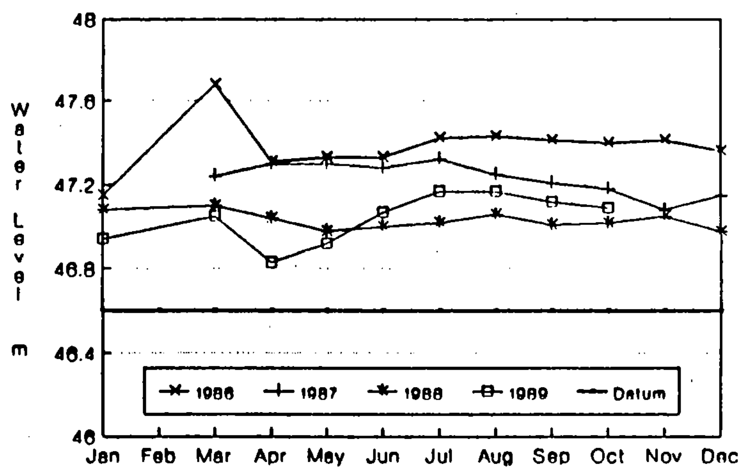
Mean Water Levels 1986-1989
St. Lawrence at Cornwall Canal



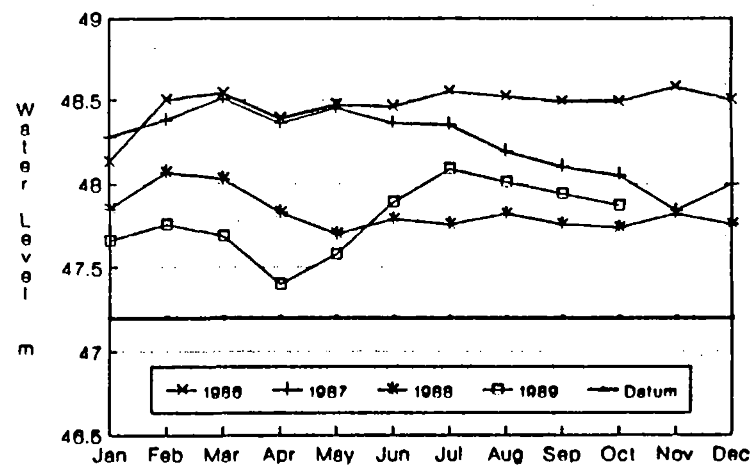
Mean Water Levels 1986-1989
St. Lawrence at Summerstown



Mean Water Levels 1986 - 1989
St. Lawrence at Pollys Gut



Mean Water Levels 1986 - 1989
St. Lawrence at Saunders Tallwater



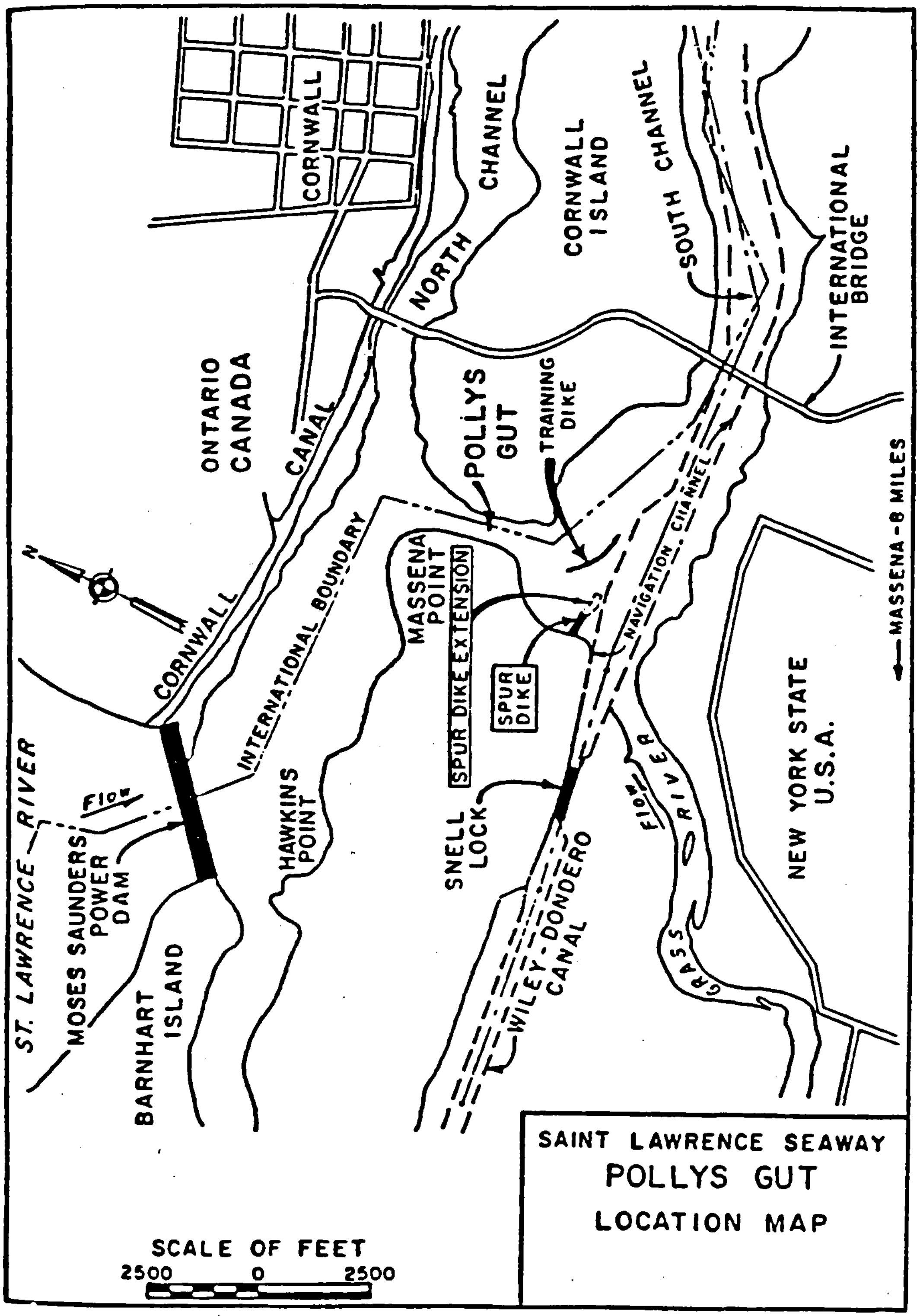


Fig. 2 Map of the St. Lawrence Seaway at Pollys Gut

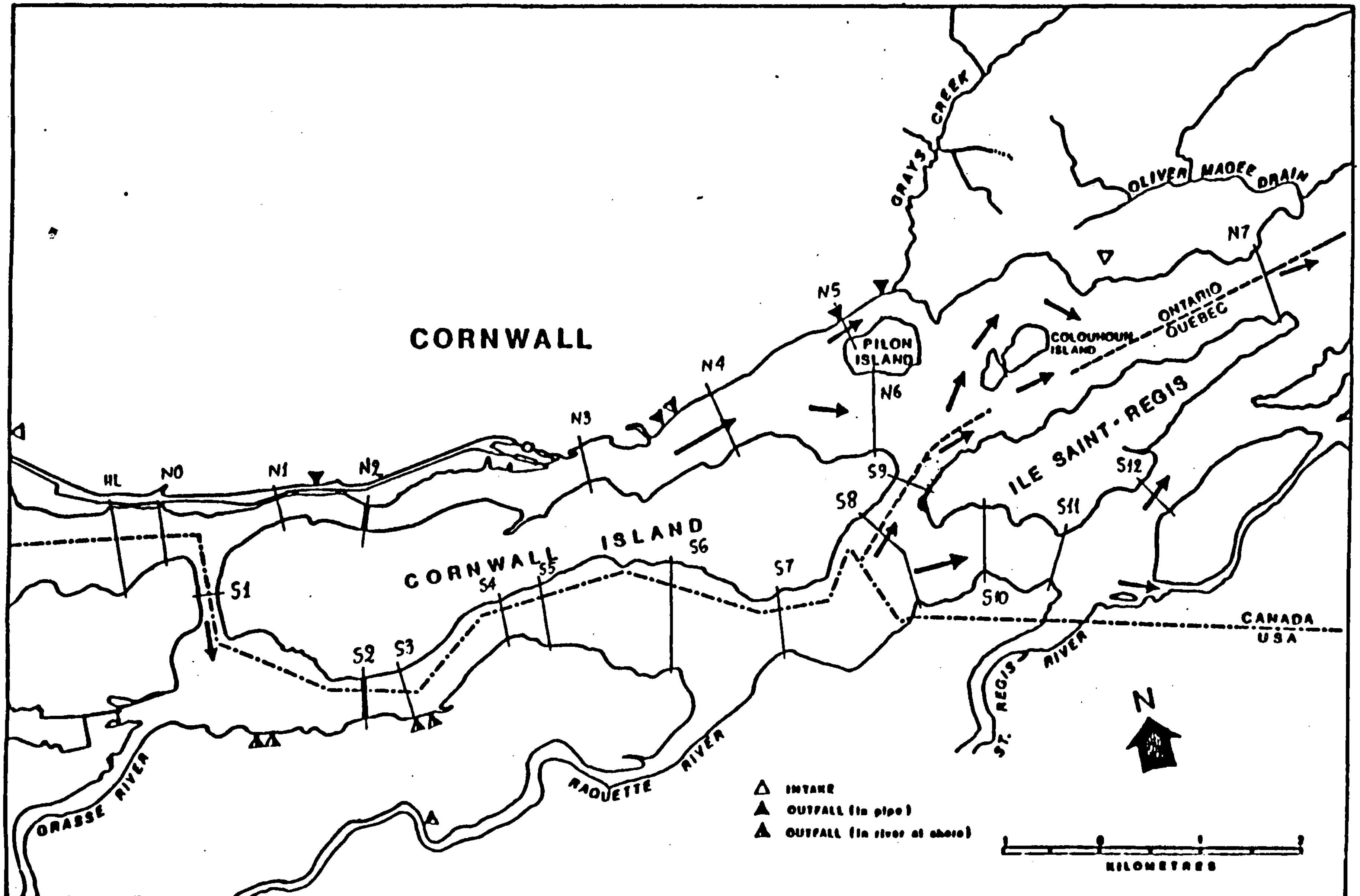
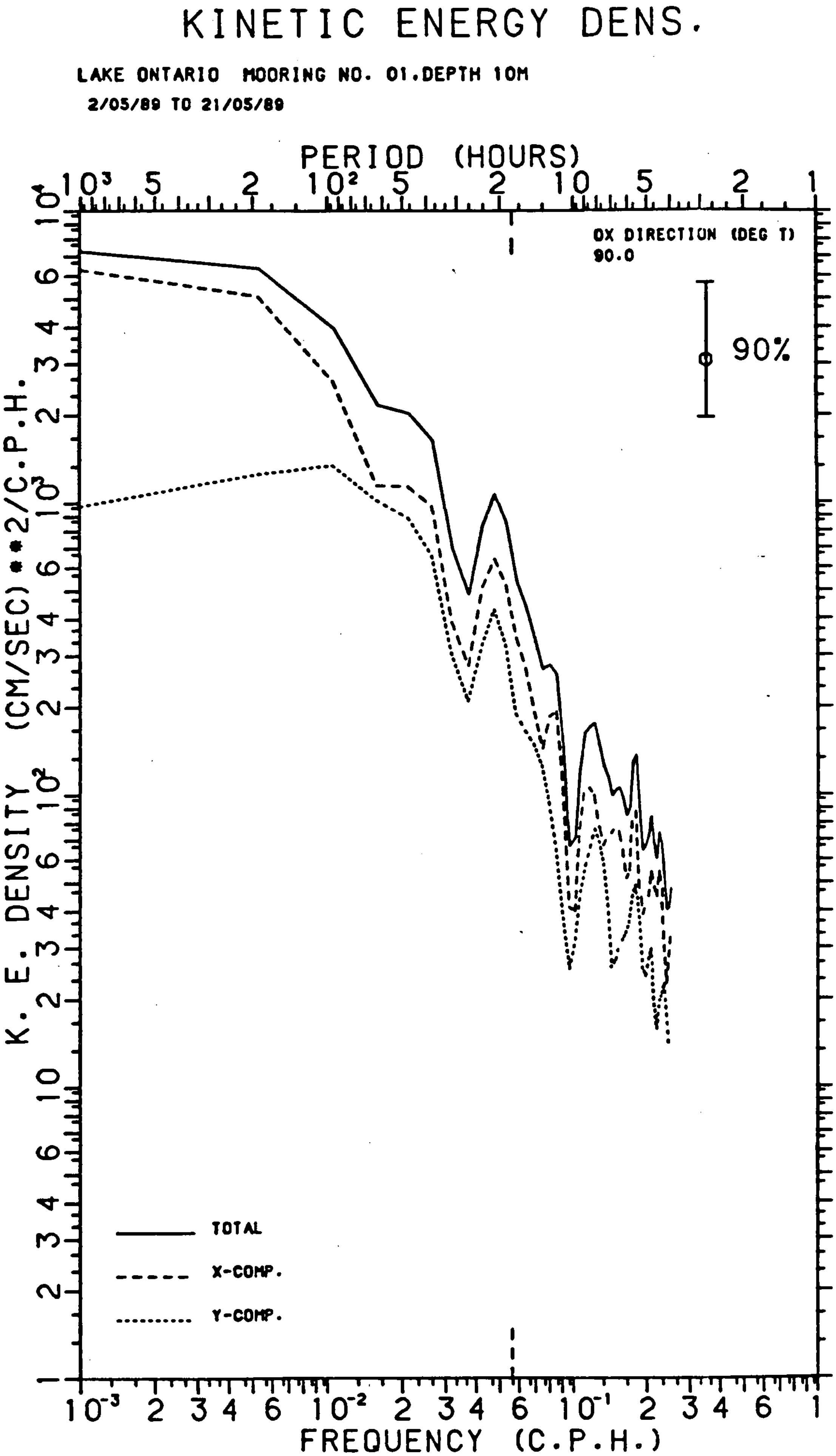

CORNWALL
CORNWALL ISLAND
ILE SAINT-REGIS
PILON ISLAND
COLQUHOUN ISLAND
ONTARIO
QUEBEC
CANADA
USA
GRAYS CREEK
OLIVER MAGEE DRAIN
GRASSE RIVER
RAQUETTE RIVER
ST. REGIS RIVER
HL
N0
N1
N2
N3
N4
N5
N6
N7
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
N
INTAKE
OUTFALL (in pipe)
OUTFALL (in river at shore)
KILOMETRES

Fig 3


KINETIC ENERGY DENS.
LAKE ONTARIO MOORING NO. 01.DEPTH 10M
2/05/89 TO 21/05/89
PERIOD (HOURS)
DX DIRECTION (DEG T)
90.0
90%
K. E. DENSITY (CM/SEC)**2/C.P.H.
TOTAL
X-COMP.
Y-COMP.
FREQUENCY (C.P.H.)

F084

APPENDIX A

Flow Rates: Lagrangian Drifters and Moving Boat Profiling System

CONVENTIONAL DRIFTERS

Drifter #1 — 13-Sept.'89

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S2	13.2	1.367	3962-4754	3955
S3	10.2	1.367	5988-7185	5082
S4	10.2	1.692	5662-6794	4185
S5	14.0	1.142	5361-6433	6673
S6	4.7	0.732	5676-6811	7088

Drifter #2

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S7	6.8	1.068	5490-6588	5126

Drifter #3

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S2	14.8	1.367	4209-5043	3955
S3	10.1	1.367	6909-8291	5082
S4	10.1	1.692	3759-4510	4185
S5	13.0	1.142	5563-6675	6673
S6	5.7	0.732	6075-7290	7088

Drifter #4 — 14-Sept.'89

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S2	14.8	1.358	3647-4376	3955
S3	10.4	1.358	5798-6957	5082
S4	10.0	1.410	4781-5737	4185
S5	7.5	1.316	9366	6673

Drifter #5

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S4	10.1	0.907	3055-3666	4185
S5	13.1	0.564	2768-3321	6673

Drifter #6

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S2	10.0	0.830	2895-3474	3955
S3	10.3	0.830	3612-4334	5082
S4	10.0	1.210	5073-6087	4185
S5	13.1	1.030	4100-4920	6673
S6	10.1	0.783	3645-4374	7088
S7	5.0	0.812	5124-6149	5126

CONVENTIONAL DRIFTERS

Drifter #7 — 14-Sept.'89

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
N4	11.8	0.627	2342-2810	5051

Drifter #8

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
N2	4.1	2.350	2115-2538	1069
N3	9.6	0.940	2006-2407	2683
N4	11.4	0.672	2554-3065	5051
N5	10.0	0.514	479-575	1283

Drifter #9 — 11-Oct.'89

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S2	5.0	0.940	5210-6252	3955
S3	10.8	0.714	3011-3613	5082
S4	10.0	1.215	4120-4944	4185
S5	13.2	1.153	5629-6755	6673
S6	10.1	0.796	3706-4447	7088
S7	6.0	0.586	3274-3929	5126

Drifter #10

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
N4	11.6	0.394	1480	5051

Drifter #11

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S2	10.1	1.170	4054-4865	3955
S3	10.0	1.170	5193-6232	5082
S4	10.2	1.207	4040-4848	4185
S5	11.9	1.191	6231-7477	6673

Drifter #12 — 12-Oct.'89

Crossection	Depth (m)	Velocity (m/s)	Total Q (cms)	XS-AREA (mE2)
S2	14.6	1.730	4689-5627	3955
S3	11.2	0.982	4042-4850	5082
S4	10.1	1.151	3877-4652	4185
S5	13.1	1.061	5206-6247	6673
S6	9.8	1.029	4889-5869	7088

13th of September, South Channel, Drifters 1, 2 & 3.

13-Sep-89

(South Channel, Drifter #1)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
15:35:00	0				
15:51:30	1354	990	1354	1.367	7477
15:59:00	2115	450	762	1.692	
16:06:00	2595	420	480	1.142	
16:18:00	3441	720	846	1.175	
16:27:00	3836	540	395	0.731	7404

13-Sep-89

(South Channel, Drifter #2)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
16:38:00	0				
16:54:00	959	960	959	0.999	7404
17:05:00	1664	660	705	1.068	
17:13:00	2087	480	423	0.881	7415

13-Sep-89

(South Channel, Drifter #3)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
17:32:00	0				
17:41:00	846	540	846	1.567	
17:50:00	1382	540	536	0.992	7415
17:58:00	1918	480	536	1.116	
18:08:00	2595	600	677	1.128	
18:18:00	3328	600	733	1.222	7410
18:37:00	4344	1140	1015	0.891	

14th of September, South Channel, Drifters 4, 5 & 6.

14-Sep-89

(South Channel, Drifter #4)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
09:53:00	0				
10:02:00	733	540	733	1.358	7476
10:08:00	1297	360	564	1.567	
10:18:00	2144	600	846	1.410	
10:23:00	2539	300	395	1.316	7420

14-Sep-89

(South Channel, Drifter #5)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
10:38:00	0				
10:46:00	564	480	564	1.175	7420
10:53:00	1072	560	508	0.907	
11:13:00	1749	1200	677	0.564	7440

14-Sep-89

(South Channel, Drifter #6)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
11:45:00	0				
12:02:00	846	1020	846	0.830	7440
12:13:00	1467	660	621	0.940	
12:20:00	1974	420	508	1.209	
12:30:00	2595	600	621	1.034	
12:42:00	3300	720	705	0.979	7440
12:54:00	3864	720	564	0.783	
13:02:00	4428	480	564	1.175	
13:20:00	4936	1080	508	0.470	
13:33:00	5569	780	633	0.812	7408

14th of September, North Channel, Drifters 7 & 8.

14-Sep-89
(North Channel, Drifter #7)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
15:34:00	0				
15:53:00	508	1140	508	0.445	7408
15:56:00	621	180	113	0.627	
16:08:00	1128	720	508	0.705	
16:42:00	1692	2040	564	0.277	7430

14-Sep-89
(North Channel, Drifter #8)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
17:06:00	0				
17:11:00	705	300	705	2.350	7440
17:22:00	1523	660	818	1.239	
17:25:00	1749	180	226	1.253	
17:33:00	2200	480	451	0.940	
17:45:00	2877	720	677	0.940	
17:54:00	3413	540	536	0.992	
18:02:00	3836	480	423	0.881	
18:07:00	4118	300	282	0.940	
18:14:00	4400	420	282	0.672	
18:41:00	5303	1620	903	0.557	7400

11th of October, South and North Channel, Drifters 9 & 10.

11-Oct-89

(South Channel, Drifter #9)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
13:51:00	0				
13:59:30	480	510	480	0.941	7401
14:05:30	737	360	257	0.714	
14:13:10	1228	460	491	1.067	
14:19:45	1708	395	480	1.215	
14:29:45	2400	600	692	1.153	
14:40:45	3003	660	603	0.914	
14:52:15	3360	690	357	0.517	
14:56:00	3539	225	179	0.796	7431
15:15:15	4443	1155	904	0.783	
15:20:00	4610	285	167	0.586	
15:28:30	5023	510	413	0.810	
15:37:00	5146	510	123	0.241	

11-Oct-89

(North Channel, Drifter #10)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
15:53:00	0				
16:01:01	145	481	145	0.301	7461
16:09:30	346	509	201	0.395	
17:09:30	1763	3600	1417	0.394	7450
17:21:06	2121	696	358	0.514	
18:00:00					7434

12th of October, South and North Channel, Drifters 11, 12 & 13.

12-Oct-89

(South Channel, Drifter #11)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu. m/s)
15:43:00	0				
15:53:30	737	630	737	1.170	
15:59:30	1172	360	435	1.208	7376
16:06:45	1697	435	525	1.207	
16:14:15	2233	450	536	1.191	
16:29:00	3025	885	792	0.895	
16:30:00	0			stopped	
[16:34:00	45	240	45	-]	

12-Oct-89

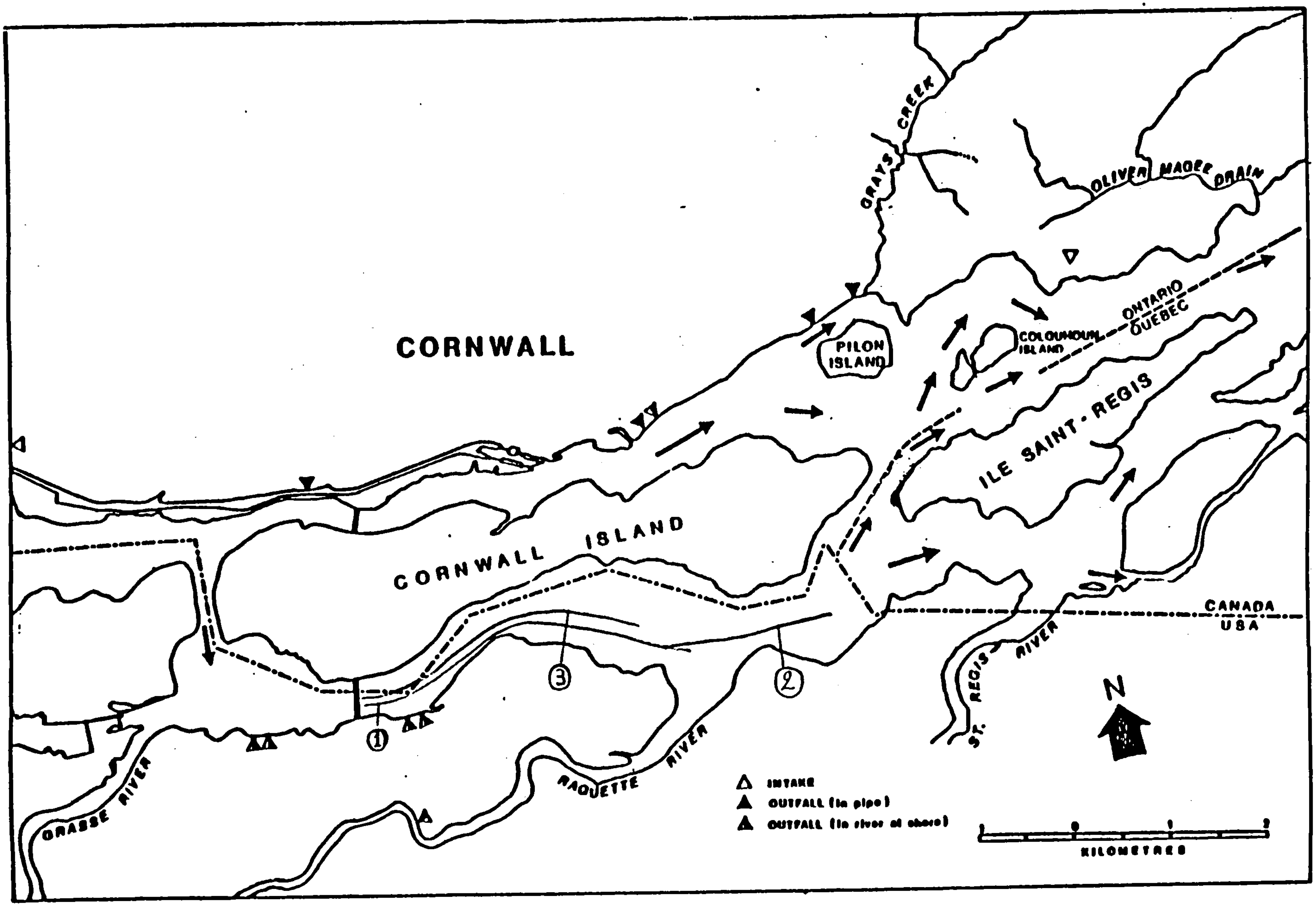
(South Channel, Drifter #12)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
16:45:00					
16:49:45	493	285	493	1.730	
16:54:30	773	285	280	0.982	
17:02:00	1266	450	493	1.096	7373
17:08:30	1715	390	449	1.151	
17:18:00	2320	570	605	1.061	
17:28:30	2993	630	673	1.068	
17:40:00	3262	690	269	0.390	
17:44:00	3509	240	247	1.029	
18:00:00					7322

12-Oct.-89

(North Channel, Drifter #13)

Time (sec.)	Displacement (meters)	dt (sec.)	ds (meters)	Velocity (m/s)	Total Flow (cu.m/s)
14:11:00					7205
14:20:45	301	585	301	0.515	
14:26:30	401	345	100	0.290	
14:44:00	781	1050	380	0.362	
14:48:00	859	240	78	0.325	
14:56:00	926	480	67	0.140	7350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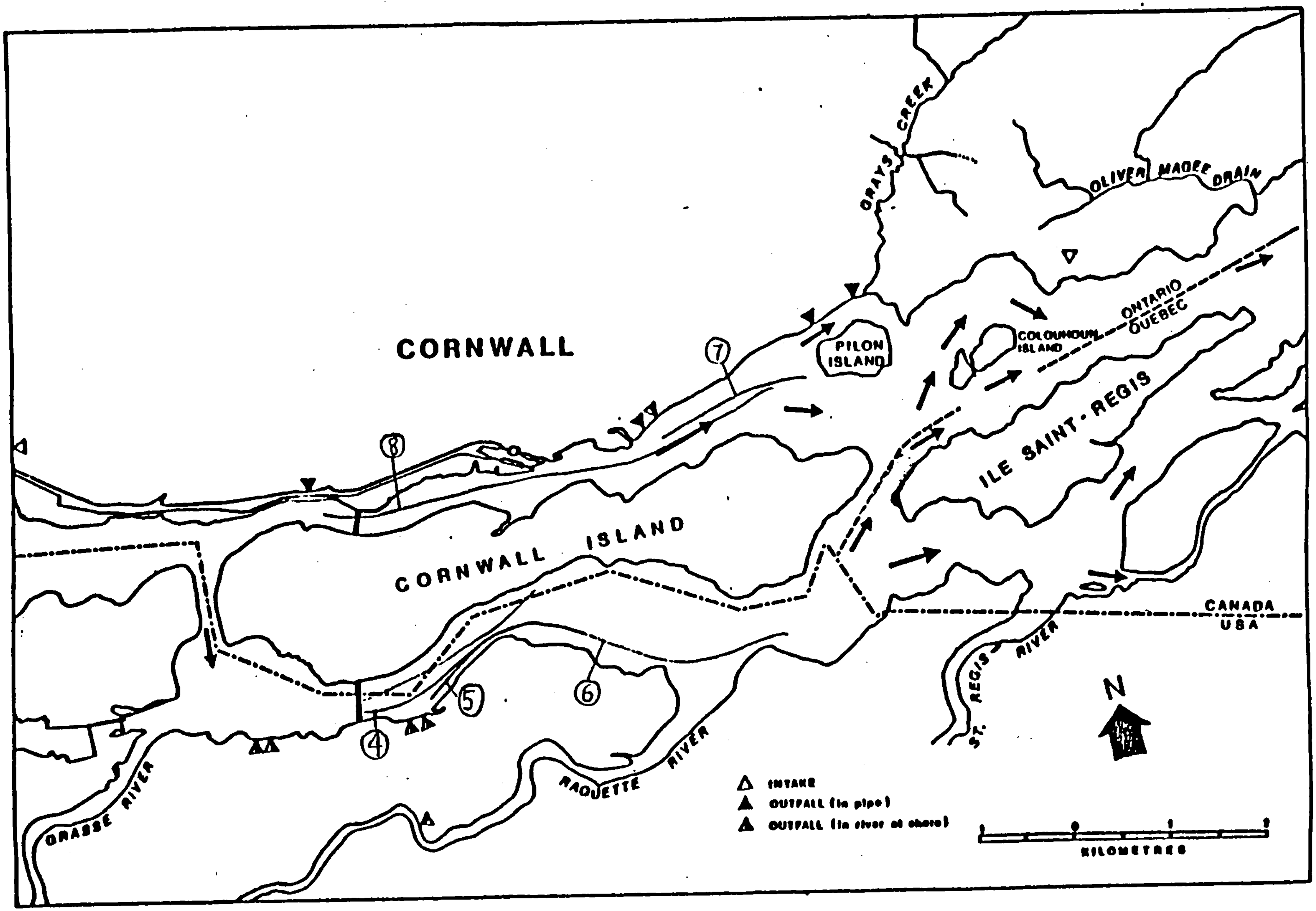
CORNWALL ISLAND
PILON ISLAND
COLQUHOUN ISLAND
ILE SAINT-REGIS
GRAYS CREEK
OLIVER MAGEE DRAIN
ONTARIO
QUEBEC
CANADA
USA
GRASSE RIVER
RAQUETTE RIVER
ST. REGIS RIVER
1
2
3
N
INTAKE
OUTFALL (in pipe)
OUTFALL (in river at shore)
KILOMETRES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CANADA
USA
ST. REGIS RIVER
RAQUETTE RIVER
GRASSE RIVER
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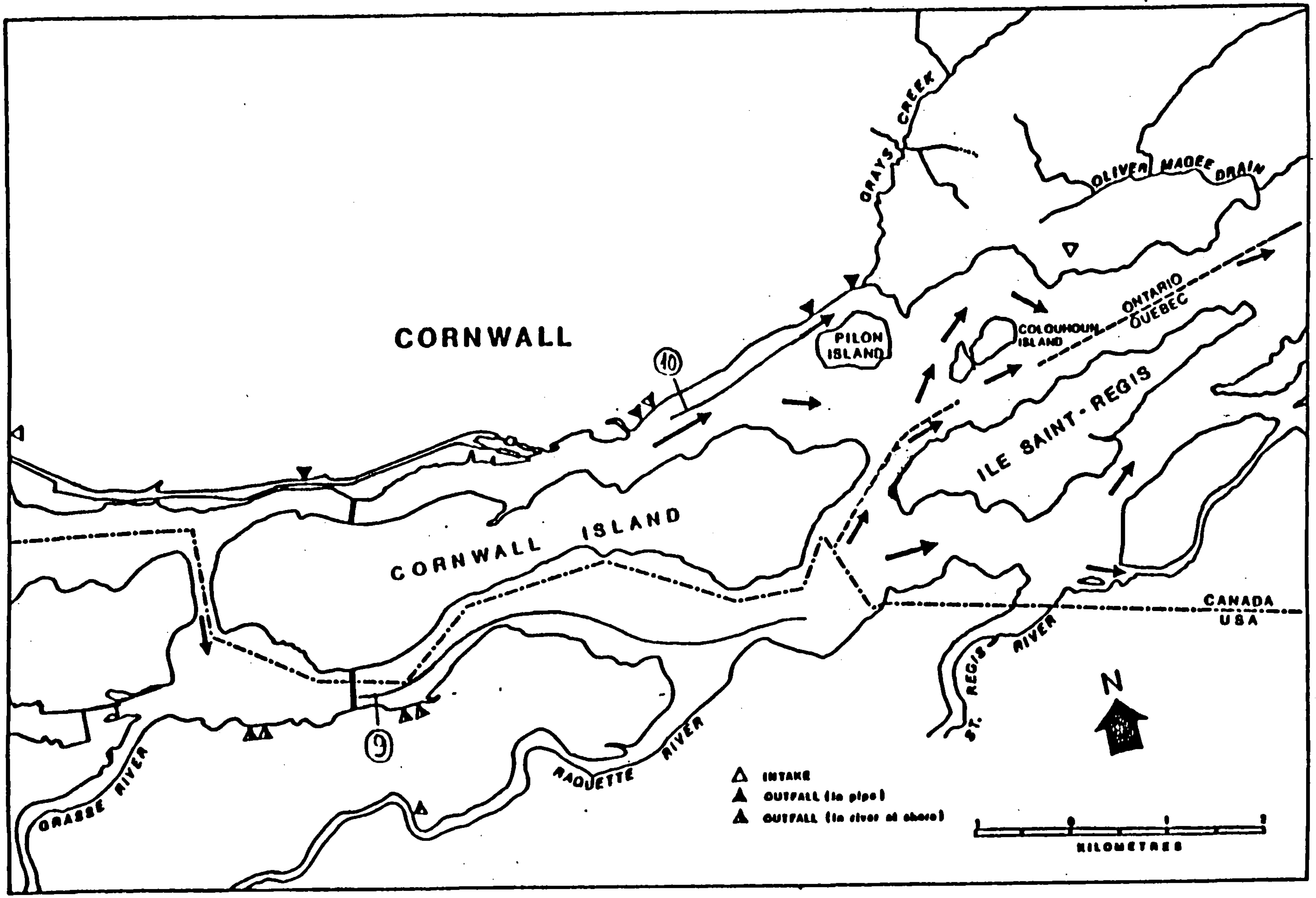
6
INTAKE
OUTFALL (in pipe)
OUTFALL (in river at shore)
KILOMETRES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ONTARIO
QUEBEC
CANADA
USA
GRASSE RIVER
RAQUETTE RIVER
ST. REGIS RIVER
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INTAKE
OUTFALL (in pipe)
OUTFALL (in river at shore)
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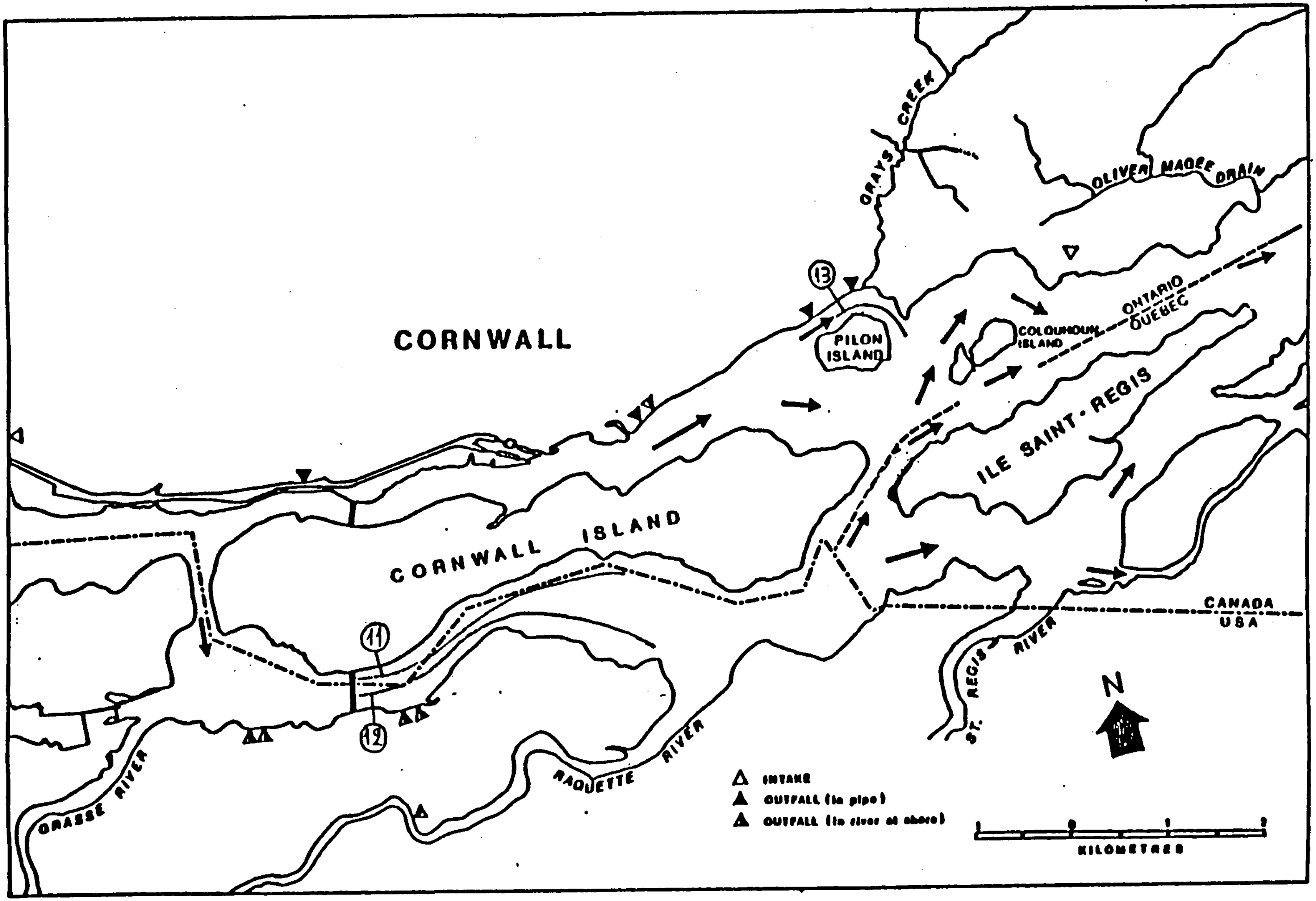
KILOMETRES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ONTARIO
QUEBEC
CANADA
USA
GRASSE RIVER
RAQUETTE RIVER
ST. REGIS RIVER
N
13
11
12
INTAKE
OUTFALL (in pipe)
OUTFALL (in river at shore)
1
0
1
2
KILOMETRES

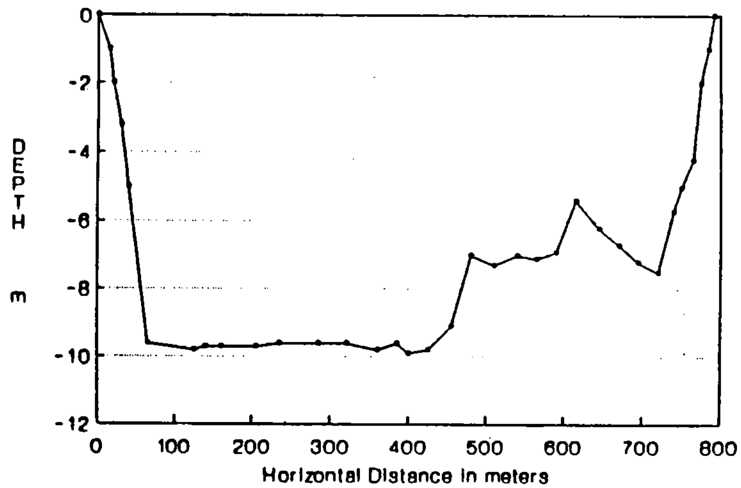
MOVING BOAT PROFILING SYSTEM

Flow Rate Measurement

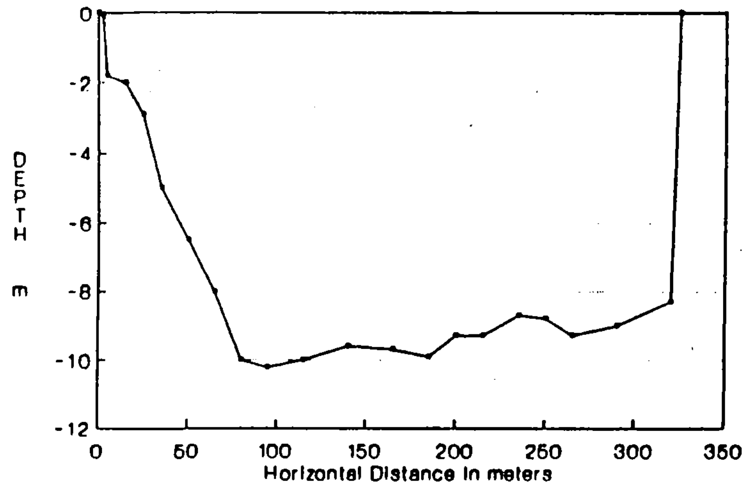
Code	Date	Start Time	Finish Time	Lag Time (mins)	Discharge (cms)	Total Flow (cms)
HL	891013	09:55	11:05	20	6856	6600
N3	891011	14:59	16:11	90	2554	7415
N5	891013	16:08	16:53	180	503	6800
N7	891014	08:55	11:23	200	4882	6640
S4	891012	08:54	09:52	80	4722	7315
S6	891012	13:30	14:23	100	1616	7142
S9	891013	13:21	14:27	130	2335	6590

Name Key

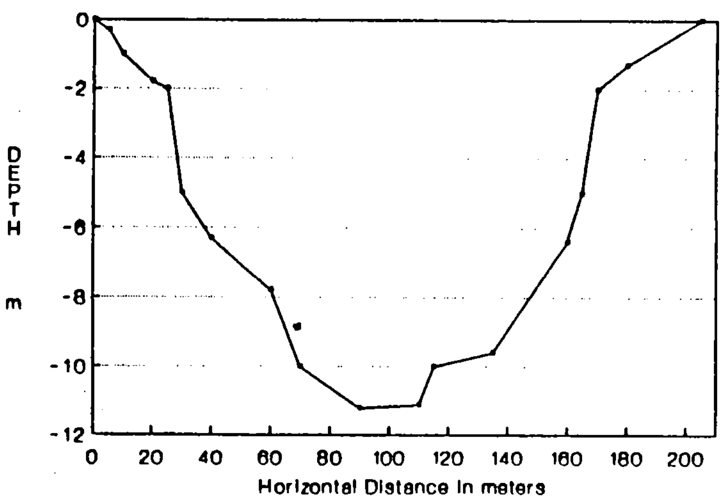
Code		
HL	Hydro Dam	-Source of Total Flow
N3	Corner of Cornwall Warf	-North Channel
N5	Pilon Is. & North Shore	-North Channel
N7	Stonehouse Point	-North Channel
S4	Raquette Point	-South Channel
S6	South Shore to Shoal	-South Channel
S9	St. Regis to Cornwall Is.	-Crossover into Ontario



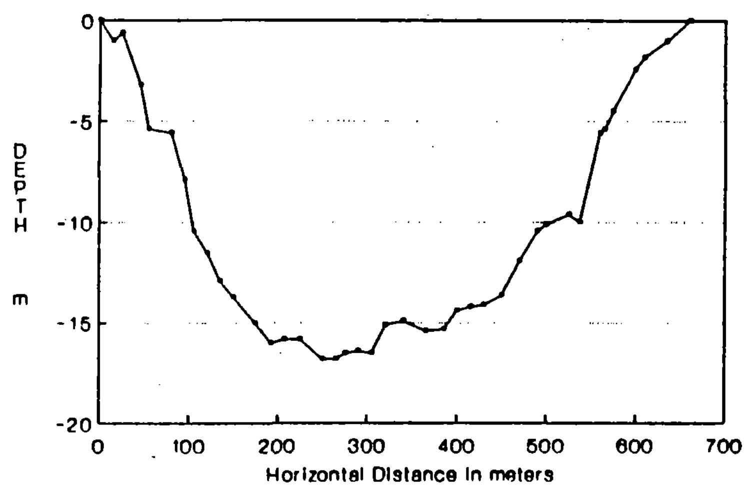
HL, Area = 6162 mE2, AvgDepth = 7.6 m



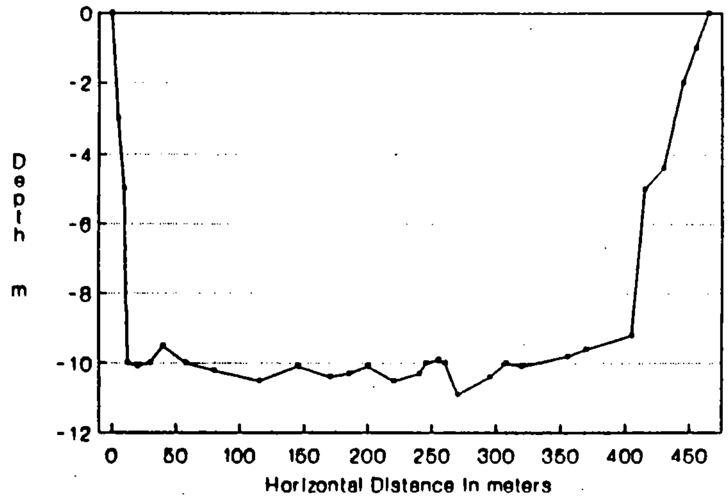
N3, Area = 2683 mE2, AvgDepth = 8.3 m.



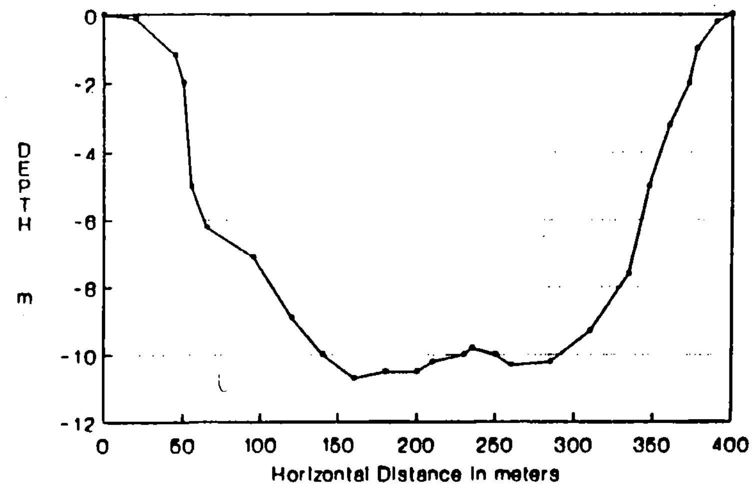
N6, Area = 1294 mE2, AvgDepth: 6.3 m



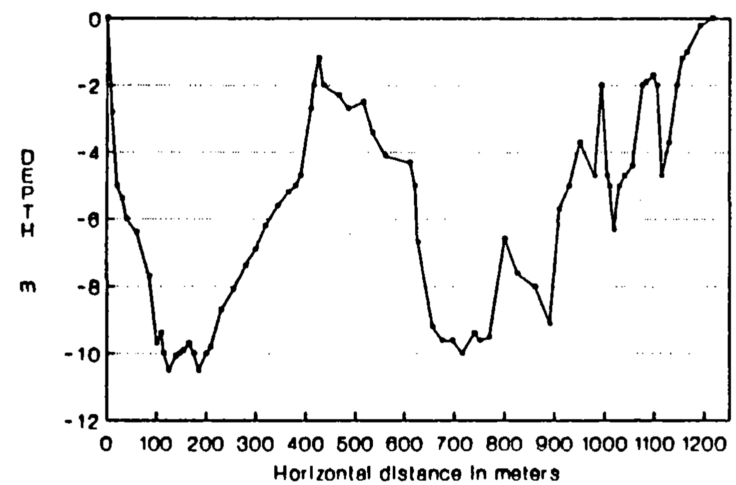
N7-AREA = 6944 mE2, AvgDepth = 10.6 m



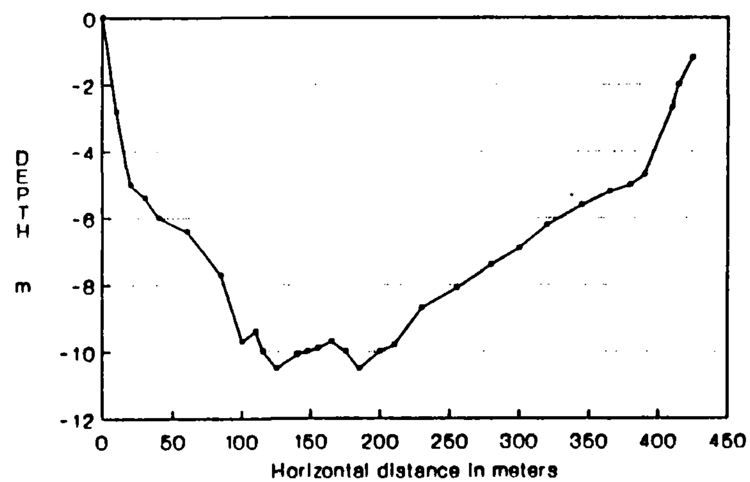
S4, Area = 4185 mE2, AvgDepth = 9.0 m



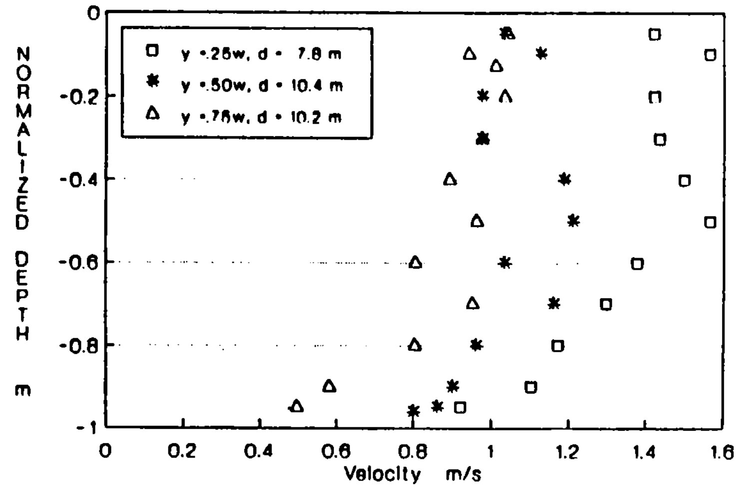
S9, AREA = 2792 mE2, AvgDepth=7.0 m



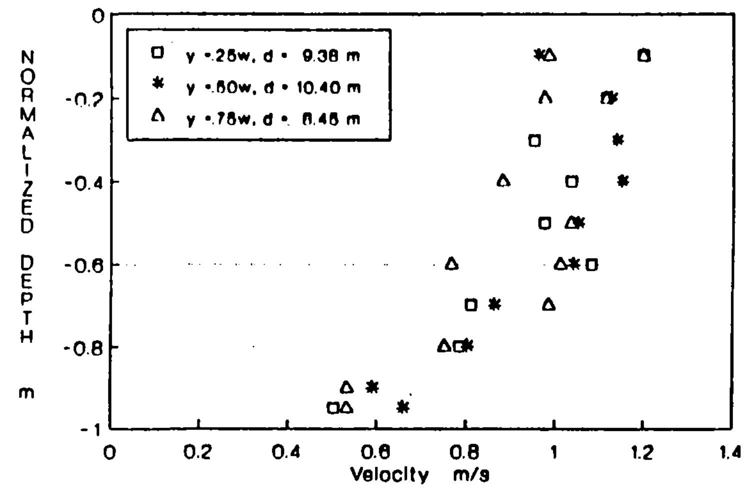
S6, AREA = 7088 mE2, AvgDepth=5.8 m



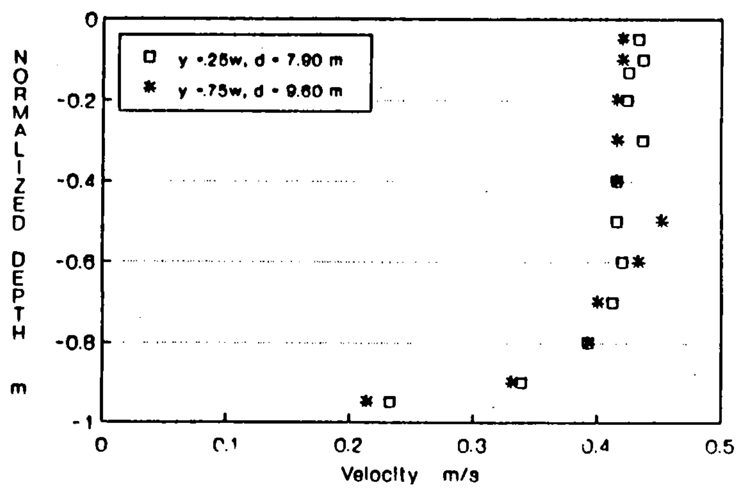
S6a, AREA = 3203 mE2, AvgDepth=7.5 m



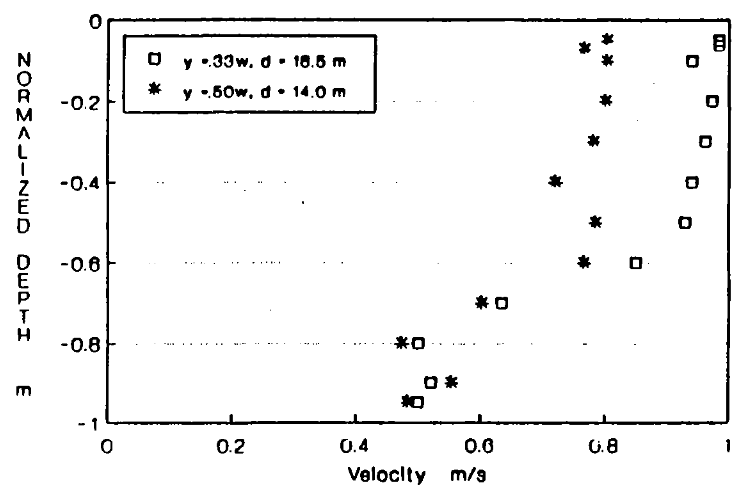
HL-Near Moses-Saunders Power Dam



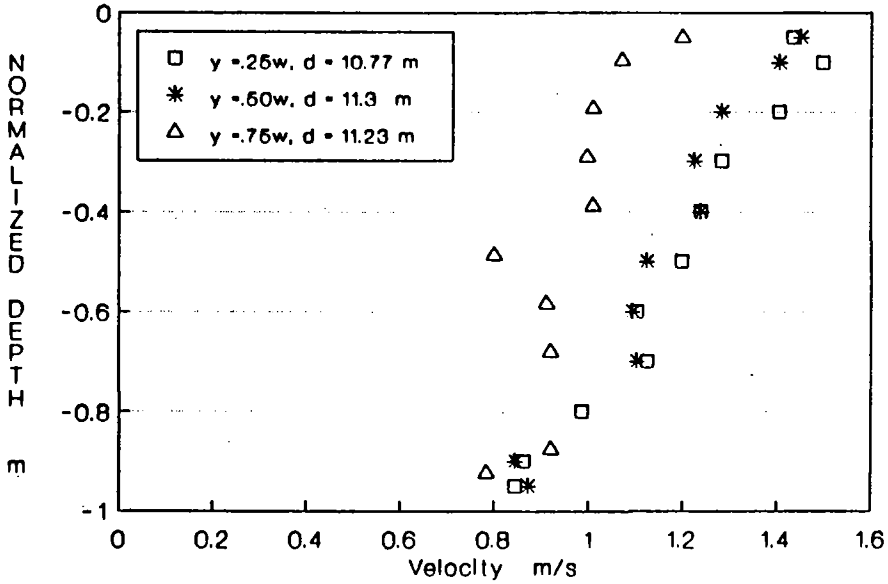
N3-Cornwall Is. to Mainland



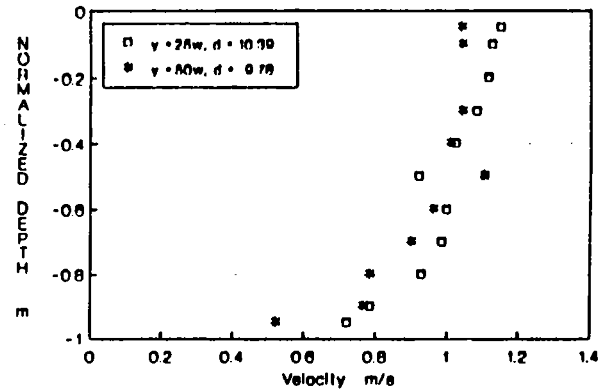
N5-Pilon Is. to Mainland



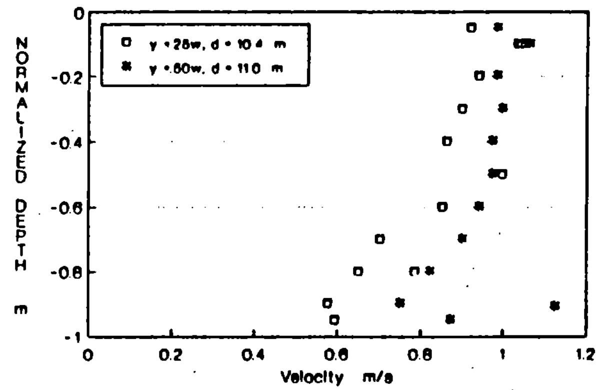
N7-St. Regis Is. to Mainland



S4-Mainland to Cornwall Is.



S6-From Mainland to Central Cornwall Is.



S9-St. Regis Is. to Cornwall Is.

Vertical Velocity Profile Calculations

Q (cms)	Crossection	Depths (m)	u*	ks	Um	n
	N3-1/4L	8.45	0.0876	1.343105	0.9279	0.0401
7[illegible]00 to	N3-1/2L	10.4	0.076	0.752603	0.9546	0.0364
7471	N3-3/4L	9.38	0.0724	0.877753	0.8628	0.0374
	S4-1/4L	11.23	0.09	0.644030	1.1826	0.0355
7142	S4-1/2L	11.3	0.0732	0.221543	1.1584	0.0297
	S4-3/4L	10.77	0.0368	0.003579	0.9574	0.0149
(7195)						
7[illegible]05 to	S6-1/4L	9.78	0.0672	0.472921	0.9117	0.0337
7350	S6-1/2L	10.39	0.0552	0.087105	0.9907	0.0254
	HL-1/4L	10.2	0.0788	0.124645	1.3400	0.0270
6590.6	HL-1/2L	10.4	0.02872	0.000061	1.0372	0.0076
	HL-3/4L	7.8	0.07	0.629476	0.8601	0.0354
6607.5	S9-1/3L	10.4	0.0556	0.293485	0.8291	0.0311
	S9-2/3L	11	0.03132	0.000827	0.9313	0.0117
6996.9	N5-1/4L	7.9	0.02288	0.087229	0.3949	0.0254
	N5-1/2L	9.6	0.02412	0.184289	0.3830	0.0288
6787	N7-1/3L	16.5	0.078	3.186750	0.7882	0.0463
	N7-2/3L	14	0.0504	0.628078	0.6933	0.0354

u* = shear velocity
Ks = bottom roughness height
Um = vertical mean velocity

APPENDIX B

Comparison of Flow Rate Calculations

Comparison of Flow Rate Calculation Methods

Conventional Drifter Velocity Calculation

Drifter#	HL	N3	N5	N7	S4	S6	S9
1					5662	2909	
3					3759	3236	
4					4781		
5					3055		
6					5073	2180	
8		2006	479				
9					4120	2263	
11					4040		
12					3877	2861	
Total Flow		7420	7420		7315	7142	

Moving Boat Profiling System

Boat #	HL	N3	N5	N7	S4	S6	S9
1	6856	2554	503	4882	4722	1616	2335
Total Flow	6600	7415	6800	6640	7315	7142	6590

Comparison of Flow Rate Calculation Methods

Method	HL	N3	N5	N7	S4	S6	S9
1	6625	2507	481	4561	4579	2672	2284
2	6555	2511	510	4664	4676	2669	2352
3				4703		2594	2241
4				4615		2707	2425
5	6765	2766	578		4928		
6		2478	492		4807		
7	5193	2399			4102		
Total Flow	6590	7435	6997	6787	7142	7200	6608

Method Key

1 Vertical Velocity Profiles with Variable n.

2 Vertical Velocity Profiles with Constant n.

3 Vertical Velocity Profiles-Uca @ 1/3

4 Vertical Velocity Profiles-Uca @ 2/3

5 Vertical Velocity Profiles-Uca @ 1/4

6 Vertical Velocity Profiles-Uca @ 1/2

7 Vertical Velocity Profiles-Uca @ 3/4