APPENDIX A

DISCHARGE MEASUREMENT REDUCTION
U.S. ARMY CORPS OF ENGINEERS, DETROIT DISTRICT

PROGRAM 4316
(772F3026)

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1. Introduction.

The following text, in part, is adapted from "Discharge Measurement Procedures on the Great Lakes Connecting Channels and the International Section of the St. Lawrence River", published by the River Flows Subcommittee of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, dated October 1991. This document should be referenced for more detailed information.

Program 4316 for automated discharge computations was developed and implemented in 1967 by the U.S. Lake Survey District. It was adopted for use in the Great Lakes Area by the Coordinating Committee in the same year, and with the exception of minor modifications, has been used to compute most discharge measurements since that time. The program is a comprehensive and versatile data reduction tool, which accepts as input, point meter revolution data, meter rating data, directional coefficients, panel configurations and stage height data. The program performs all calculations required for the determination of panel areas, mean vertical velocities, mean panel velocities, panel discharges and total discharge at the section.

2. Data Input.

Prior to making measurements at a site, the velocity meters are rated to determine the coefficients needed to convert meter revolutions to velocities. These coefficients, along with meter identification, are part of the input to the program. At the conclusion of a metering session, or the metering season, the meters are again rated to ensure their accuracy.

Prior to making discharge measurements, the hydraulic section is surveyed to determine the bottom profile of the cross section and the direction of flow through various points along the section. From these surveys, hydrographic information is derived about the section and used as input to the discharge computation program. The general input data needed for a series of measurements includes: name of the river, name of the section, number of panels in the section, direction-of-flow coefficients for each panel, the area of each panel and the water level to which these are referenced, the width of each panel (feet), the position of the metering point within each panel (in feet from shore) and the position of each panel boundary (in feet from shore).

During an actual discharge measurement, the data collected are recorded on Form NCL-3a, "Discharge Measurement Field Notes" (Figure A-1). The data recorded include: the name of the section, measurement number, date, panel number, starting time for each panel measured, water level at the section gage, length of each meter reading in seconds, meter identification, depth of each reading and number of revolutions per reading for each meter. These data, along with the general data discussed in the previous paragraph, are entered in a formatted computer file and processed on a digital computer using Program 4316. A sample input file is shown on Figure A-2.

3. Method of Computation.

For each measurement, the program first converts the meter revolution counts to velocities, using the appropriate meter rating equations. From the computed velocities at each tenth depth, the average velocity in the vertical for each panel is then determined. The velocity-depth algorithm used in the program to compute the mean vertical velocities was developed by F.H. Quinn ("Vertical Velocity Distribution in Large Natural Channels", two unpublished reports, March, 1969 and February, 1984), based on the Prandtl and von Karman boundary layer theory. A logarithmic distribution is fitted to the point velocity data, as a function of depth, by the method of least squares. The depth function is:

$$f(d) = 1 - d^{1/2} - \ln(1 - d^{1/2})$$

where d is the ratio of the depth of the velocity observation measured from the water surface, to the total depth. Thus the adjusted or fitted velocity at any depth d is:

$$v = A\, f(d) + B$$

where v is the fitted velocity at depth d, and A and B are regression coefficients.

It was found that the residuals were minimized by breaking the curve at the 0.3 depth and performing separate regressions on each segment. The mean velocity is then equal to the sum of the areas under the two curves determined by integration as follows:

$$\bar{v} = 1/3\ Au + 3/2\ Al + 0.3\ Bu + 0.7\ Bl$$

where $\bar{v}$ is the mean vertical velocity and Au and Bu, and Al and Bl are regression coefficients for the upper and lower segments, respectively.

The transverse velocity routine in Program 4316 fits a parabolic curve through the mean vertical velocities across the section, taking the points three at a time and assuming zero velocity at the stream banks. The area under the curve in each panel, computed by integrating between panel boundaries, divided by the panel width is the mean panel velocity. Transverse coefficients are computed and printed on the output listings for measurement analysis, but do not enter into the computations.

The mean panel velocity is multiplied by the panel area, adjusted for variation in stage, and by the directional coefficient for the panel to determine the panel discharge normal to the section. The individual panel discharges are summed to obtain the total section discharge.

4. Output.

The output (documentation) from this program generally consists of six pages of summary tables and information. A detailed listing of intermediate calculations is also an option of the program. A sample output is shown on Figures A-3 to A-8 and is described below.

The first output page (Figure A-3) lists the input file data, along with descriptive titles, and the date and time the program was run. Messages follow the input data, indicating status of switches within the program, and displaying warning messages generated by data checking routines.

The second output page (Figure A-4) displays Table 1, a summary of the current meter rating equations and identification codes and numbers.

Table 2, a listing of water levels encountered during the discharge measurements, is generally not printed out, as the data on the table are considered redundant to the user; the water levels of interest are shown in the second column on Figure A-8.

Table 3 (Figure A-5), which summarizes the general data for each panel of the cross section, is printed on the third page of the output. Panel number, width, area (computed using a reference elevation) and directional coefficient are listed for each panel in the section.

The fourth output page (Figure A-6) summarizes the locations of the panel metering points and panel boundaries, referenced from the edge of the water in feet.

The point velocities, computed for each tenth depth for each panel in the section, using the appropriate meter rating equations, are displayed on the fifth page (Figure A-7). There are three lines of output for each panel. Each line of output includes: a single letter designation of the measurement section, the measurement number, the day, month and year of the measurement, the panel number and the starting time of the measurement. This information is followed by the meter code, then the velocity for the first to third tenth depth settings on the first line, fourth through sixth tenth depths settings on the second line, and seventh through ninth tenth depth settings on the third line.

The final results of the data reduction for one measurement are summarized in a table on the sixth page of output (Figure A-8). For each panel this table presents: the section gage elevation (feet, IGLD 1955), the panel area (square feet), the mean vertical

velocity (feet per second), the transverse curve panel area (square feet per second), the transverse coefficient, the directional coefficient, the mean panel velocity (feet per second) and the panel discharge (cubic feet per second). Lastly, the total section discharge (cubic feet per second) is given at the bottom of the table.

Program 4316 for reducing discharge measurements is almost 30 years old, yet remains valid in the 1990s. It is capable of accepting water level information in the new datum, IGLD 1985, and it is currently being revised to receive and compute data in metric units. The program is resident at both the Detroit District, Corps of Engineers, and the Monitoring and Systems Branch, Environment Canada-Ontario Region.

FORM NCL-3A
1975

DISCHARGE MEASUREMENT FIELD NOTES
U.S. ARMY CORPS OF ENGINEERS
GREAT LAKES HYDRAULIC & HYDROLOGY BRANCH

SHEET ___ OF ___

_____ RIVER _____ SECTION

SECTION IDENTIFICATION								MEAS NO		DATE DAY		MONTH		YEAR		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

REVOLUTIONS

PANEL NO.	E.S.T. HRS. MINS.	SECTION GAGE	NO. OF SECS.	METER ID. 1 2 3 4	METER 1 .1	METER 1 .2	METER 1 .3	METER 2 .4	METER 2 .5	METER 2 .6	METER 3 .7	METER 3 .8	METER 3 .9	METER 4 .4	METER 4 .4	METER 4 .4
18 19	20 21 22 23	24 25 26 27 28 29	30 31 32	33 34 35 36	37 38 39	40 41 42	43 44 45	46 47 48	49 50 51	52 53 54	55 56 57	58 59 60	61 62 63	64 65 66	67 68 69	70 71 72
01																
02																
03																
04																
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21																
22																
23																
24																
25																

REMARKS

Figure A-1

```
S                                ST. MARYS RIVER                                  RIVER   01
   15                          LOWER RAPIDS SECTION                               SECTION 02
                                 GATES 9-10 OPEN                                  DESCRIPT03
1 1                                                                               SWITCH  04
 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000DIR COEF05
 1000                                                                             DIR COEF06
  242  220  240  244  265  279  270  255  264  284  294  279  270  254AREA     07
  429                                                  57987                       AREA     08
   30   30   30   30   30   30   30   30   30   30   30   30   30   30WIDTH    09
   48                                                                             WIDTH    10
                                                                                  PAN PT   11
    0   15   45   75  105  135  165  195  225  255  285  315  345  375X        12
  405  444  468                                                                   X        13
    0   30   60   90  120  150  180  210  240  270  300  330  360  390Z        14
  420  468                                                                        Z        15
                                                                                  ELEV     16
                                                                                  MEA      17
                                                                                  MEA      18
                                                                                  MEA      19
R       27      2181        3
P       26      2200       - 3
D       19      2090       30
H       21      2176       - 3

SMLR    0125JUL89011259579.86 60RDPH130111108 85 84 62 47 70 49105 99 92
SMLR    0125JUL89021307579.89 60RDPH109108116118102 96 93 81 75 97100108
SMLR    0125JUL89031313579.91 60RDPH130130127117118112 93 93 87119120116
SMLR    0125JUL89041320579.88 60RDPH127137119120109 91102 87 75111126113
SMLR    0125JUL89051325579.83 60RDPH119106107 97 85 86 75 61 65 97 93 98
SMLR    0125JUL89061331579.79 60RDPH112111 96109 96 84 88 72 82 97101 92
SMLR    0125JUL89071337579.82 60RDPH 90 81113 87 80106 71 59 96 82 79108
SMLR    0125JUL89081342579.85 60RDPH 90 82 88 83 74 78 78 63 69 79 77 83
SMLR    0125JUL89091348579.85 60RDPH 89 90 91 86 80 83 74 62 66 82 83 85
SMLR    0125JUL89101354579.82 60RDPH 97 93 77 88 84 73 78 66 64 91 86 74
SMLR    0125JUL89111359579.80 60RDPH 64 76 82 72 72 73 51 61 66 55 69 78
SMLR    0125JUL89121405579.78 60RDPH 65 64 66 67 56 63 57 48 55 60 62 63
SMLR    0125JUL89131411579.77 60RDPH 60 62 59 55 52 55 51 44 46 55 60 58
SMLR    0125JUL89141416579.76 60RDPH 63 68 60 62 62 60 57 56 53 60 66 60
SMLR    0125JUL89151422579.77 60RDPH 71 62 74 60 53 60 51 47 56 64 61 74
SMLR    0225JUL89011439579.81 60RDPH117116104 88 87 57 52 67 51 83 96 88
SMLR    0225JUL89021444579.82 60RDPH130130122115111 97 96 81 87111122111
SMLR    0225JUL89031449579.83 60RDPH134129130118116101 97 88 83118117122
SMLR    0225JUL89041454579.84 60RDPH121130124109120 96100 97 78112115117
SMLR    0225JUL89051459579.86 60RDPH122112116 96101 90 97 66 79 96 96107
SMLR    0225JUL89061504579.86 60RDPH117108103106113103 93 83 91106 95 98
SMLR    0225JUL89071510579.86 60RDPH106105106 92 82 95 68 64 78 96 99102
SMLR    0225JUL89081514579.86 60RDPH 81 92107 80 86 97 64 75 89 73 87103
SMLR    0225JUL89091519579.88 60RDPH 94 98 84 85 83 66 65 73 64 81 89 79
SMLR    0225JUL89101524579.90 60RDPH 90 87 95 70 77 89 63 67 78 77 82 91
SMLR    0225JUL89111529579.92 60RDPH 85 65 86 77 64 78 70 55 73 79 61 80
SMLR    0225JUL89121534579.91 60RDPH 56 59 60 54 58 54 47 55 47 55 55 54
SMLR    0225JUL89131539579.90 60RDPH 55 68 52 50 68 55 44 62 51 51 67 51
SMLR    0225JUL89141544579.89 60RDPH 55 56 51 50 51 44 44 48 42 51 54 49
SMLR    0225JUL89151550579.90 60RDPH 67 53 59 63 59 50 52 44 44 63 50 54
```

SAMPLE PROGRAM INPUT

Figure A-2

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

ST. MARYS RIVER

LOWER RAPIDS SECTION

GATES 9-10 OPEN

12 JUN 1990 1047
INPUT PARAMETERS

```
S                          ST. MARYS RIVER                                  RIVER     1
  15                     LOWER RAPIDS SECTION                               SECTION   2
                           GATES 9-10 OPEN                                  DESCRIPT  3
1010000000000000000000000000000000000                                       SWITCH    4
 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000DIR COEF 5
 1000    0    0    0    0    0    0    0    0    0    0                    DIR COEF  6
  242  220  240  244  265  279  270  255  264  284  294  279  270  254AREA      7
  429    0    0    0    0    0    0    0    0    0    057987              AREA      8
   30   30   30   30   30   30   30   30   30   30   30   30   30   30WIDTH     9
   48    0    0    0    0    0    0    0    0    0    0                    WIDTH     10
    0    0                                                                  PAN PT    11
        0.       15.       45.       75.      105.      135.      165.
      195.      225.      255.      285.      315.      345.      375.X        12
      405.      444.      468.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.          X        13
        0.       30.       60.       90.      120.      150.      180.
      210.      240.      270.      300.      330.      360.      390.Z        14
      420.      468.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.          Z        15
    0    0    0    0                                                       ELEV      16
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0MEA      17
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0MEA      18
    0    0    0    0    0    0    0    0    0    0    0    0    1    MEA      19
                  SW  1 ON
                  SW  3 ON

        WARNING   METER CODE            D
        INTERSEPT LARGE                  30
```

Figure A-3

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

ST. MARYS RIVER

LOWER RAPIDS SECTION

GATES 9-10 OPEN

12 JUN 1990 1047

TABLE 1 - CURRENT METER RATING EQUATIONS

CODE	NUMBER	EQUATION
R	27	VELOCITY = 2.181 REV. + 0.03
P	26	VELOCITY = 2.200 REV. + -0.03
D	19	VELOCITY = 2.090 REV. + 0.30
H	21	VELOCITY = 2.176 REV. + -0.03

Figure A-4

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

ST. MARYS RIVER

LOWER RAPIDS SECTION

GATES 9-10 OPEN

12 JUN 1990 1047

TABLE 3

PANEL NUMBER	PANEL WIDTH FEET	PANEL AREA SQ FEET	DIRECTIONAL COEF
1	30	242	1.000
2	30	220	1.000
3	30	240	1.000
4	30	244	1.000
5	30	265	1.000
6	30	279	1.000
7	30	270	1.000
8	30	255	1.000
9	30	264	1.000
10	30	284	1.000
11	30	294	1.000
12	30	279	1.000
13	30	270	1.000
14	30	254	1.000
15	48	429	1.000

PANEL AREA REFERENCE ELEVATION 579.87

Figure A-5

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

ST. MARYS RIVER

LOWER RAPIDS SECTION

GATES 9-10 OPEN

12 JUN 1990 1047

TABLE 4

PANEL	X AND Z LOCATION	DISTANCE IN FEET FROM EDGE OF WATER TO PANEL POINT X	PANEL EDGE Z
	1	0.	0.
1	2	15.	30.
2	3	45.	60.
3	4	75.	90.
4	5	105.	120.
5	6	135.	150.
6	7	165.	180.
7	8	195.	210.
8	9	225.	240.
9	10	255.	270.
10	11	285.	300.
11	12	315.	330.
12	13	345.	360.
13	14	375.	390.
14	15	405.	420.
15	16	444.	468.
	17	468.	0.

Figure A-6

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026
ST. MARYS RIVER
LOWER RAPIDS SECTION
GATES 9-10 OPEN
12 JUN 1990 1047

VERTICAL VELOCITY

S	1	25	7	1989	1	1259	1	R	4.47	2	R	4.05	3	R	4.24
S	1	25	7	1989	1	1259	4	D	3.08	5	D	3.22	6	D	2.61
S	1	25	7	1989	1	1259	7	P	1.59	8	P	2.53	9	P	1.89
S	1	25	7	1989	2	1307	1	R	4.18	2	R	4.02	3	R	4.00
S	1	25	7	1989	2	1307	4	D	4.61	5	D	3.91	6	D	3.45
S	1	25	7	1989	2	1307	7	P	3.54	8	P	2.99	9	P	2.56
S	1	25	7	1989	3	1313	1	R	4.73	2	R	4.69	3	R	4.74
S	1	25	7	1989	3	1313	4	D	4.35	5	D	4.35	6	D	4.28
S	1	25	7	1989	3	1313	7	P	3.36	8	P	3.33	9	P	3.22
S	1	25	7	1989	4	1320	1	R	4.88	2	R	4.64	3	R	4.49
S	1	25	7	1989	4	1320	4	D	4.69	5	D	3.81	6	D	3.57
S	1	25	7	1989	4	1320	7	P	3.90	8	P	2.92	9	P	2.81
S	1	25	7	1989	5	1325	1	R	4.31	2	R	4.01	3	R	3.84
S	1	25	7	1989	5	1325	4	D	3.64	5	D	3.35	6	D	3.23
S	1	25	7	1989	5	1325	7	P	2.69	8	P	2.28	9	P	2.31
S	1	25	7	1989	6	1331	1	R	4.08	2	R	3.89	3	R	3.69
S	1	25	7	1989	6	1331	4	D	4.08	5	D	3.50	6	D	3.37
S	1	25	7	1989	6	1331	7	P	3.18	8	P	2.50	9	P	3.13
S	1	25	7	1989	7	1337	1	R	3.60	2	R	3.37	3	R	3.44
S	1	25	7	1989	7	1337	4	D	3.61	5	D	3.46	6	D	3.36
S	1	25	7	1989	7	1337	7	P	2.82	8	P	2.42	9	P	2.89
S	1	25	7	1989	8	1342	1	R	3.33	2	R	3.11	3	R	3.10
S	1	25	7	1989	8	1342	4	D	3.21	5	D	2.96	6	D	2.91
S	1	25	7	1989	8	1342	7	P	2.85	8	P	2.36	9	P	2.40
S	1	25	7	1989	9	1348	1	R	3.32	2	R	3.31	3	R	3.27
S	1	25	7	1989	9	1348	4	D	3.34	5	D	3.10	6	D	3.13
S	1	25	7	1989	9	1348	7	P	2.73	8	P	2.25	9	P	2.34
S	1	25	7	1989	10	1354	1	R	3.27	2	R	3.32	3	R	3.19
S	1	25	7	1989	10	1354	4	D	3.11	5	D	3.15	6	D	3.17
S	1	25	7	1989	10	1354	7	P	2.60	8	P	2.32	9	P	2.62
S	1	25	7	1989	11	1359	1	R	2.88	2	R	2.72	3	R	2.60
S	1	25	7	1989	11	1359	4	D	3.37	5	D	2.75	6	D	2.49
S	1	25	7	1989	11	1359	7	P	2.26	8	P	2.15	9	P	2.06
S	1	25	7	1989	12	1405	1	R	2.45	2	R	2.34	3	R	2.37
S	1	25	7	1989	12	1405	4	D	2.70	5	D	2.24	6	D	2.45
S	1	25	7	1989	12	1405	7	P	2.11	8	P	1.72	9	P	1.94
S	1	25	7	1989	13	1411	1	R	2.31	2	R	2.19	3	R	2.16
S	1	25	7	1989	13	1411	4	D	2.31	5	D	2.04	6	D	2.20
S	1	25	7	1989	13	1411	7	P	1.93	8	P	1.52	9	P	1.65
S	1	25	7	1989	14	1416	1	R	2.40	2	R	2.35	3	R	2.28
S	1	25	7	1989	14	1416	4	D	2.53	5	D	2.33	6	D	2.46
S	1	25	7	1989	14	1416	7	P	2.13	8	P	1.90	9	P	1.98
S	1	25	7	1989	15	1422	1	R	2.71	2	R	2.48	3	R	2.44
S	1	25	7	1989	15	1422	4	D	2.47	5	D	2.31	6	D	2.17
S	1	25	7	1989	15	1422	7	P	1.91	8	P	1.84	9	P	1.81

Figure A-7

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

ST. MARYS RIVER

LOWER RAPIDS SECTION

GATES 9-10 OPEN

12 JUN 1990 1047

MEASUREMENT NUMBER 1
25 JUL 1989

PANEL NO	SECTION GAGE	PANEL AREA	MEAN VERT VEL 9 DEPTHS	TRANSVERSE CURVE PANEL AREA	MEAN PANEL VELOCITY	TRAN COEF	DIR COEF	MEAN PANEL VEL	PANEL DISCHARGE
1	579.86	242	3.02	81	2.71	0.899	1.000	2.71	656
2	579.89	221	3.56	107	3.56	0.999	1.000	3.56	787
3	579.91	241	4.02	120	3.99	0.994	1.000	3.99	962
4	579.88	244	3.86	115	3.84	0.995	1.000	3.84	937
5	579.83	264	3.22	98	3.26	1.011	1.000	3.26	861
6	579.79	277	3.44	103	3.42	0.994	1.000	3.42	947
7	579.82	268	3.16	95	3.16	1.000	1.000	3.16	847
8	579.85	254	2.86	86	2.87	1.005	1.000	2.87	729
9	579.85	263	2.89	87	2.89	1.000	1.000	2.89	760
10	579.82	282	2.92	87	2.90	0.994	1.000	2.90	818
11	579.80	292	2.51	75	2.51	1.002	1.000	2.51	733
12	579.78	276	2.20	66	2.20	1.002	1.000	2.20	607
13	579.77	267	1.99	60	2.01	1.009	1.000	2.01	537
14	579.76	251	2.22	66	2.21	0.996	1.000	2.21	555
15	579.77	424	2.20	92	1.92	0.874	1.000	1.92	814
								TOTAL	11550

Figure A-8