STRATFORD/AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT

PHYSICAL CHARACTERISTICS OF THE AVON RIVER

Technical Report S-2

Prepared by:

A. Bacchus, Technologist
Water Resources Branch
Ontario Ministry of the Environment

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Enquiries with respect to this report should be directed to

Ontario Ministry of the Environment
985 Adelaide Street South
London, Ontario N6E 1V3
(519) 681-3600

PREFACE

This report is one of a series of technical reports resulting from work undertaken as part of the Stratford-Avon River Environmental Management Project (S.A.R.E.M.P.).

This two year project was initiated in April 1980, at the request of the City of Stratford. The S.A.R.E.M.P. is funded entirely by the Ontario Ministry of the Environment. The purpose of the project is to provide a comprehensive water quality management strategy for the Avon River basin. In order to accomplish this considerable investigation, monitoring and analysis has taken place. The outcome of these investigations and field demonstrations will be a documented strategy and implementation mechanisms considered to be most effective in resolving the water quality problems now facing residents of the basin. The project is assessing urban, rural and in-stream management mechanisms for improving water quality.

This report results directly from the aforementioned investigations. It is meant to be technical in nature and not a statement of policy or program direction. Observations and conclusions are those of the author and do not necessarily reflect the attitudes or philosophy of all agencies and individuals affiliated with the project. In certain cases, the results presented are interim in nature and should not be taken as definitive until such time as additional support data are collected.

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ABSTRACT

As part of the Stratford-Avon River Environmental Management Project, the River Systems Unit of the Ontario Ministry of the Environment carried out surveys during the summers of 1980 and 1981 to collect data on the physical characteristics of the Avon River. Data from these surveys are to be used in the development of a mathematical model to predict water quality changes under different management scenarios. Standard methods for measuring channel geometry, time of travel and streamflow were used. Results indicate that riffle-to-pool distance varied from 325 m to 550 m; average depth between reaches was consistent, ranging from 0.17m to 0.35m; and average width varied from 11.82 m to 20.31 m. Streamflow was observed to range from 0.04 m^3/sec to 63.7 m^3/sec at Station 10 during the period 1965-1979. Time of travel ranged from 4 to 10 hours depending on the reach, with total time of travel for the river downstream of Stratford varying from 26 hrs to 74 hrs, depending on flow. Reductions in flow observed between two downstream stations were attributed to anomalies in the operation of the Stratford WPCP. Substrate type was homogeneous throughout the river below Stratford although aquatic plant communities varied from reach to reach.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

In 1979, the Ministry of the Environment released a report which concluded that the existing poor water quality in the Avon River was a result of both urban and rural waste inputs. The major water quality problems in the river below the Stratford WPCP include the presence of compounds such as chlorine and ammonia in the river that are potentially toxic to fish, and excessive growths of algae and aquatic plants which at times choke the river and upset the normal oxygen balance essential to support aquatic life. These algal growths are attributed to an enrichment of river water resulting from large inputs of nutrients from municipal and agricultural sources.

This report presents data on the physical characteristics of the Avon River. These data will be used in the development of a mathematical model of the river to predict water quality changes under different management scenarios.

2. DESCRIPTION OF RIVER BASIN

The following description of the Avon River Basin has been taken directly from the June 1979 report, "Impact of Waste Inputs on the Quality of the Avon River", published by the Water Resources Assessment Unit, Technical Support Section, Southwestern Region:

> "The Avon River watershed is located in the Upper Thames River Basin in Perth County. The City of Stratford is the only large municipality in the watershed, having a 1978 population of 26,500, and is situated at the centre of the drainage basin (Figure 1). The mean annual precipitation at Stratford is 991 millimeters (39 inches).
>
> The Avon River watershed drains an area of 166 square kilometers (km^2) which is equivalent to 64 square miles (sq. mi.). Rocks and cobble make up the stream bed downstream from Stratford and a clay-silt stream bottom prevails immediately upstream from Stratford.
>
> The upper Avon River watershed (upstream from Brocksden) is in the Waterloo Hills minor physiographic region. The surface material is composed of sandy hills, some of which are ridges of sandy till while others are kames or kame moraines, with outwash sands occupying the intervening hollows. The watershed downstream from Brocksden is located on the Stratford till plain. The lower basin is in a broad clay plain and the main channel follows a narrow spillway along its entire route."

The study area described in this report is divided into the 'Main Channel' and the 'Experimental Channel' and extends from Lake Victoria downstream to Station 13 near the mouth of the Avon River (Figure 1). The main channel encompasses Lake Victoria and the downstream stretch between Station 6 and Station 13 (8 Reaches). The experimental channel, which is used as a pilot-scale representation of the main channel, is located near the mouth of the Avon River and is 384 meters long (see Figure 2 for location). The flow in the experimental channel is approximately one third of the total capacity of the river.

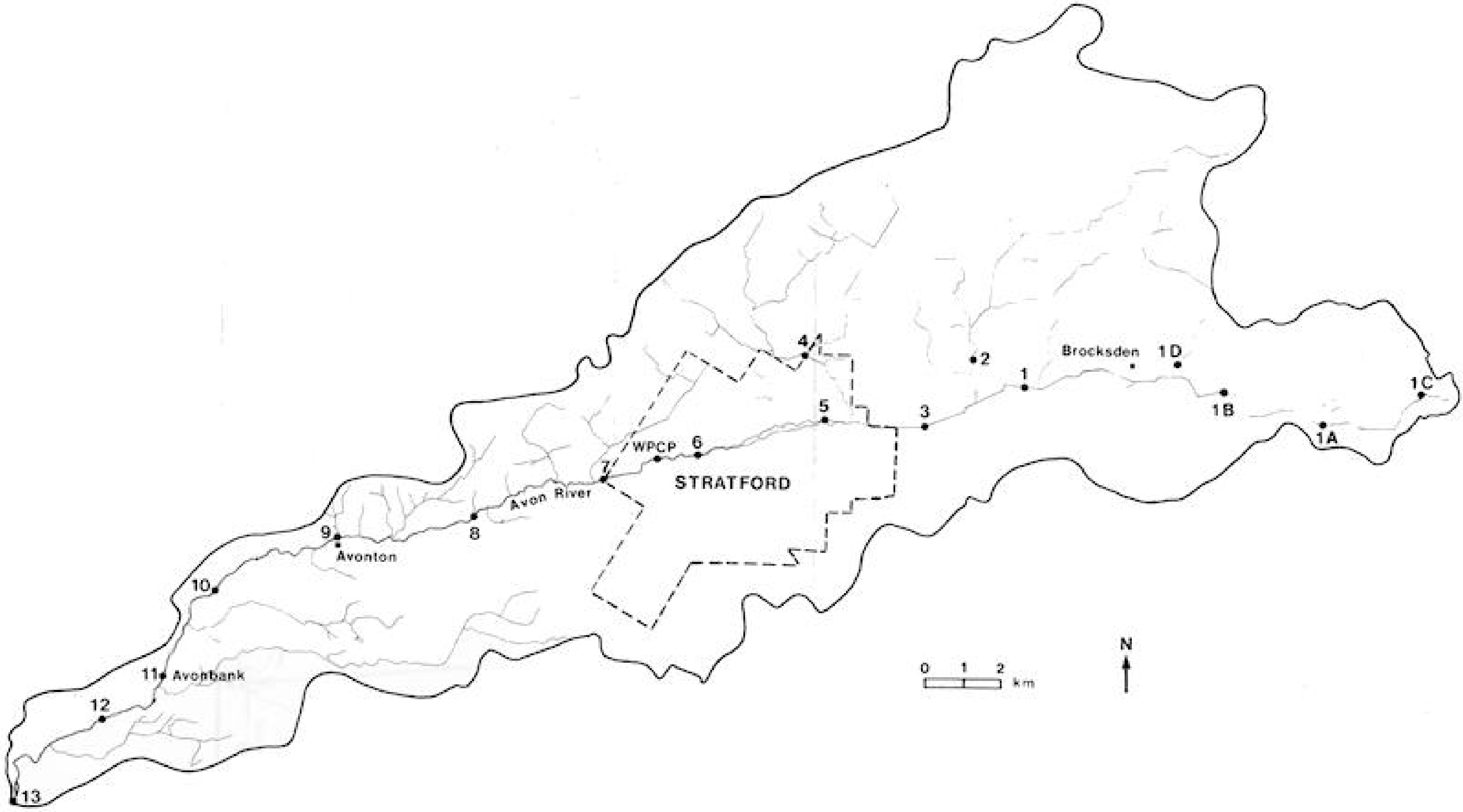

Figure 1. Monitoring Stations in the Avon River watershed

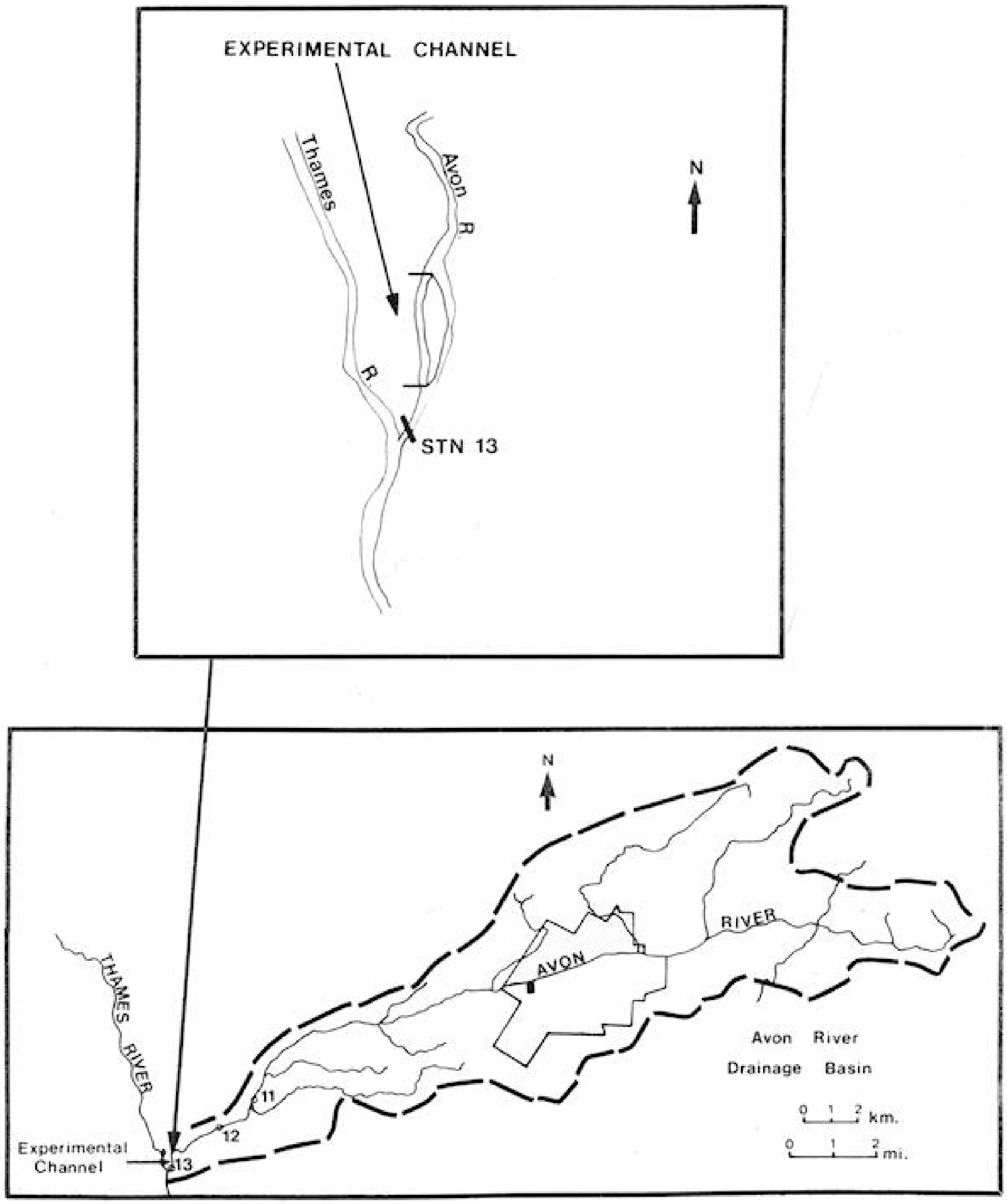

FIGURE 2. Location Of The Experimental Channel

3. METHODS

Details of the various methodologies employed are presented in Table 1.

The experimental channel was the first reach to be surveyed. It is 384 m long and took 3 man-days to survey. Two persons were required to measure longitudinal distance while another made measurements of depth and width. The distance between cross-sections varied from 6 m to 25.5 m.

The reach from the Stratford WPCP to the mouth of the river was the next section to be surveyed. This section is 17.9 km long and took 25 man-days to survey. There was significant variability in the river morphology between the WPCP and Station 10, and as a result, cross-section intervals varied from 32.5 to 359.0 m. From Station 10 to the mouth, a standard interval of 155 m was used for the survey.

After some preliminary modelling was carried out, it was decided to split reach 6-7 into two reaches: from Station 6 to the WPCP and from the WPCP to Station 7. This meant that additional cross-sectional data had to be collected between Station 6 and the WPCP. This work was carried out in May, 1981. The reach from Station 6 to the WPCP is 1000 m long and took 3 man-days to survey.

Most of the time-of-travel data were collected in 1980, but there were gaps in the data owing to occasional equipment malfunction. These gaps were filled in 1981 with the collection of additional data on the two new reaches.

Standard methods for measuring streamflow were used for all surveys.

METHODS

TABLE 1: DETAILS OF METHODS

Parameter	Dates Performed	Stations	Method
1. Channel Geometry	July 10/80 (experimental channel) Aug.11-15/80 (main channel between Stratford WPCP and Stn.13) May 27/81 (main channel between Stn. 6 and Stratford WPCP	140 cross-sections between the Stratford WPCP and the mouth of the Avon River and 22 in experimental channel.	A graduated rope, 160 metres long was used to measure longitudinal distances; a graduated rod and a tagline were used to measure depths and widths. Cross-section intervals were determined by changes in the stream morphology, i.e. significant changes in width, depth substrate type, etc.
2. Time of Travel	June 4-5/80 July 9-10/80, Aug 26-27/80, Oct 15-16/80, May 28/81, June 11,18,23/81 and July 9/81(main channel); July 17/80 and Sept. 24/80 (experimental channel).	Main Channel: Stations 6-13inclusive Experimental Channel: Stations 1,8,15 and 22	A slug of Rhodamine-WT dye(150-200 mL) was dumped at the head of each reach. Automatic samplers were then used at the end of each reach to collect water samples. Samplers were preset to start sampling at approximately one hour before the estimated time of travel. Samples were brought back to Toronto and analyzed for fluorescence (related to dye concentration).

TABLE 1: DETAILS OF METHODS - Cont'd

Parameter	Dates Performed	Stations	Method
			The difference between the time the dye was dumped and the time of the peak concentration of the dye cloud is taken as the time of travel for the reach. In the experimental channel, samples were collected manually since the time of travel between reaches were relatively short. Streamflow was also measured to relate the time of travel to flow.
3. Streamflow	Direct measurements were made on the same dates as the time of travel studies and also on Oct.14/81.	Stations 6 - 13	Streamflow was measured directly using flow meters and indirectly by monitoring continuously through manual or automatic measurement of water level and
	Indirect measurements were made at Stations 1 and 1D during the summer months of 1981; Station 7 during the summer months of 1980 and 1981; and at Station 10 from Oct. 1964 to present.	Stations 1, 1D, 7 and 10	conversion of water level to streamflow by means of a rating curve. The rating curve is developed by making direct measurements of streamflow through the range of water levels experienced at a station and then relating streamflow to waterlevel.

TABLE 1: DETAILS OF METHODS - Cont'd

Parameter	Dates Performed	Stations	Method
4. Slope			Slope was obtained by taking the difference in elevation from topographical maps from one station to the next, dividing the difference by the longitudinal distance between the two stations and multiplying the result by 100 to express the slope as a percentage.
5. Cross-Sections			A program was written in Fortran for plotting cross-sections and calculating cross-sectional areas and weighted average depths. Average depth, h_i, at a cross-section, i, weighted average top width, B, in a reach and weighted average depth, H, in a reach are calculated from the following 3 formulae respectively:

$$h_i = \frac{A}{w_i} = \frac{1}{w_i} \sum_{k=i}^{n} \left(\frac{d_{k-1} + d_k}{2} \right) (w_k - w_{k-1}) \qquad (1)$$

$$B = \frac{1}{2 x_m} \sum_{i=i}^{m} (h_{i-1} + h_i)(x_i - x_{i-1}) \qquad (2)$$

$$H = \frac{1}{4 B x_m} \sum_{i=i}^{m} (h_{i-1} + h_i)(w_i + w_{i+1})(x_i - x_{i-1}) \qquad (3)$$

where
- A = cross-sectional area
- w_i = top width at the cross-section, i
- n = number of verticals at the cross-section, i
- w_k = lateral distance from the left bank
- d_k = depth at a lateral distance, w_k
- B = weighted average top width of a reach
- m = number of cross-sections
- x_m = reach length
- x_i = longitudinal distance from the upstream end of the reach to a cross-section

4. RESULTS

4.1. Channel Geometry

Results from these surveys include substrate mapping, cross-sections, widths, areas and weighted average depths. A complete set of all 140 cross-sectional plots of the main channel and 22 in the experimental channel and substrate type are on file in the River Systems Unit, Water Resources Branch. A summary of the cross-sectional data is presented in Appendix A. Table 2 shows a summary of reach lengths, weighted average channel widths and weighted average stream depths during the survey period for the eight reaches on the main channel. Streamflow at Station 7 varied during the week of the survey from 0.13 to 1.32 m^3/sec. The reach from Station 6 to the WPCP was surveyed in May 1981 and the streamflow was 0.35 m^3/sec. Slopes are also included in Table 2 for the same reaches.

The results show that the riffle to pool distance varies from 325 m - 550 m. The average depth between reaches is fairly consistent ranging from 0.17 - 0.35 m. There are a few short deep sections that are not typical of the rest of the river; these are found mainly at bridges where excavation has taken place. The average stream width varies from 11.82 - 20.31 m. Time of travel during low flow varies from 4 hours at the first reach to 10 hours at reach 7 -8 for the same flow (0.015 m^3/sec). Substrate type is basically rocky and is the same throughout the study area; the only difference is the composition of rock sizes varying from cross-section to cross-section. Aquatic macrophyte communities vary from reach to reach. At the time of the survey, there was very little plant growth. The most common communities found were *Cladophora, Potamogeton pectinatus* and *Elodea canadensis*. Periphyton, algae and moss were more common in the first half of the study area.

TABLE 2: SUMMARY OF CHANNEL GEOMETRY FOR THE LOWER REACHES OF THE AVON RIVER

Reach	Reach Length (m)	Weighted Average Width (m)	Weighted Average Depth (m)	Slope (%)
Stn 6 - WPCP	1000	9.60	0.35	0.15
WPCP - Stn 7	1216	11.82	0.30	0.25
Stn 7 - Stn 8	3370	14.31	0.30	0.14
Stn 8 - Stn 9	2868	16.04	0.25	0.06
Stn 9 - Stn 10	3074	19.91	0.23	0.19
Stn 10 - Stn 11	2288	16.56	0.23	0.27
Stn 11 - Stn 12	1615	20.31	0.17	0.38
Stn 12 - Stn 13	3314	17.22	0.17	0.34

4.2. Streamflow - Time of Travel Relationships

The relationship between time of travel and flow was established for reaches between Station 6 and the mouth of the Avon River. Plots of these relationships are shown in Figure 3. Eight surveys were carried out under different flow conditions varying from 0.13 to 1.78 m^3/sec. Time of travel during low flow (0.15 m^3/sec) varies from 4 hours at the first reach to 10 hours at reach 7-8 for the same flow. The total time of travel from Station 6 to the mouth of the Avon varies from 26 hours at a flow of 1.0 m^3/sec to 74 hours at a flow of 0.15 m^3/sec. A summary of the flow rates and time of travel data for the main channel is presented in Table 3. Table 4 shows the hydraulic relationships and coefficients for each reach on the Avon River based on the time of travel data. (Note: The coefficients in the table are given in British units because the inputs for GRSM (Grand River Simulation Model) and DOMOD7 model are in British units).

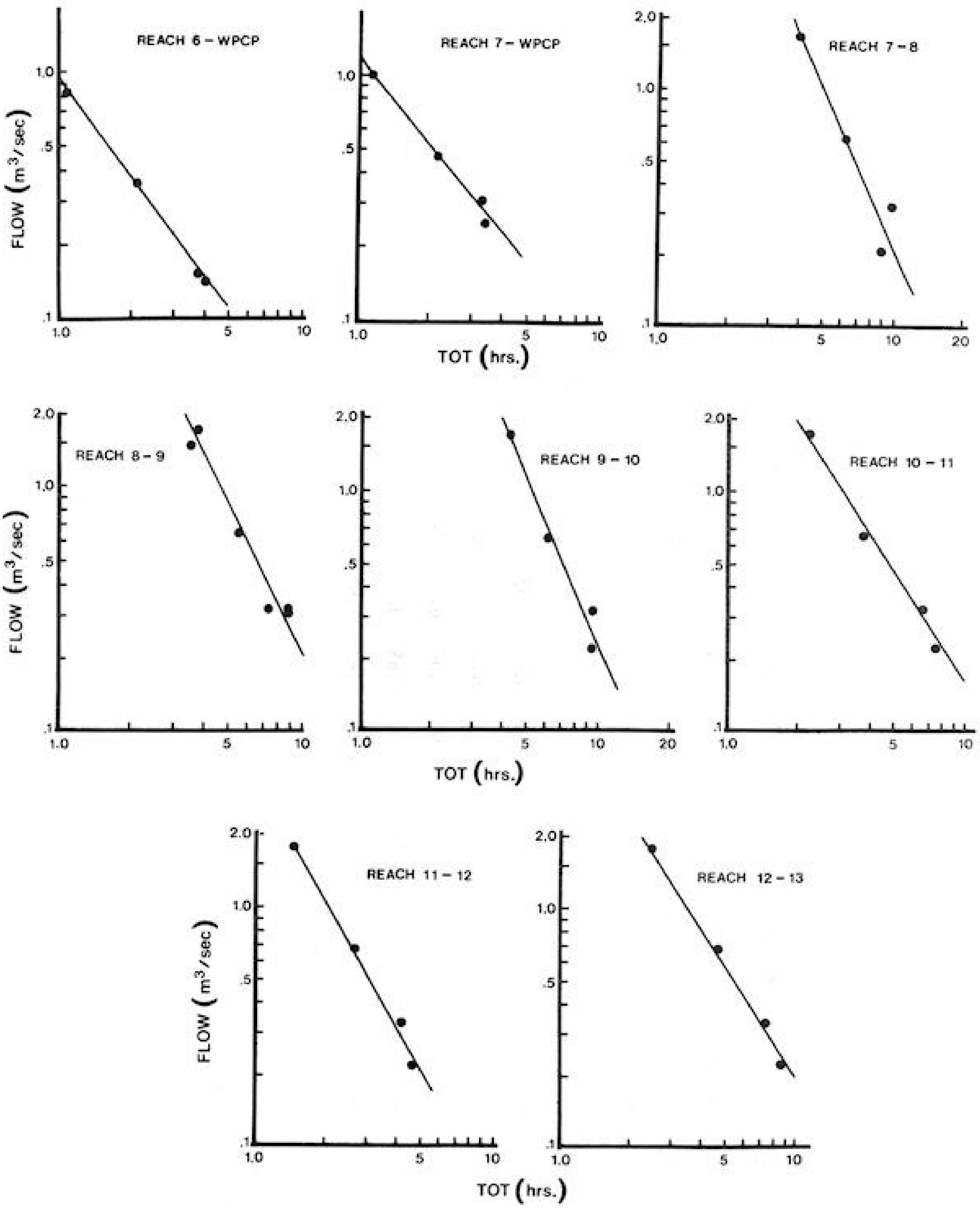

FIGURE 3: STREAMFLOW - TIME OF TRAVEL RELATIONSHIPS

TABLE 3: SUMMARY OF FLOW AND TIME OF TRAVEL FOR REACHES ON THE MAIN CHANNEL

Date	June 4-5/80		July 9-10/80		Aug 26-27/80		Oct 15/80		May 28/80		June 11/81		June 18/81		June 23/81	
Reach	FLOW (cms)*	TOT (Hrs)	FLOW (cms)*	TOT (Hrs)	FLOW (cms)*	TOT (Hrs)	FLOW (cms)*	TOT (Hrs)	FLOW (cms)*	TOT (Hrs)	FLOW (cms)*	TOT (Hrs)	FLOW (cms)*	TOT (Hrs)	FLOW (cms)*	TOT (Hrs)
Stn 6 - WPCP	-	-	-	-	-	-	-	-	0.35	2.15	0.15	3.78	0.14	4.03	0.83	1.40
WPCP - Stn 7	-	-	-	-	-	-	-	-	0.47	2.15	0.31	3.30	0.25	3.75	1.01	1.17
Stn 7 - Stn 8	1.67	3.93	0.32	9.72	0.21	8.83	0.62	6.22	-	-	-	-	-	-	-	-
Stn 8 - Stn 9	1.69	3.75	0.32	8.75	0.21	-	0.63	-	0.67	5.53	0.32	7.35	0.31	8.82	1.47	3.00
Stn 9 - Stn 10	1.70	4.25	0.32	9.50	0.22	9.50	0.64	6.12	-	-	-	-	-	-	-	-
Stn 10 - Stn 11	1.72	2.22	0.32	6.65	0.22	7.50	0.65	3.75	-	-	-	-	-	-	-	-
Stn 11 - Stn 12	1.76	1.45	0.33	4.17	0.22	4.67	0.67	2.62	-	-	-	-	-	-	-	-
Stn 12 - Stn 13	1.78	2.42	0.33	7.28	0.22	8.42	0.68	4.62	-	-	-	-	-	-	-	-

*Cubic Metres per Second

TABLE 4: HYDRAULIC RELATIONSHIPS & COEFFICIENTS* FOR THE LOWER REACHES OF THE AVON RIVER

Depth (ft) : $H = a\,Q^{d}$
Velocity (ft/sec): $V = b\,Q^{f}$
Width (ft): $W = c\,Q^{g}$
TOT (hr) : $T = b_{t}\,Q^{-f}$
Flow (cfs) $= Q$

Reach	a	b	b_t	c	d	f	g
6 - STP	0.558	0.088	13.348	20.356	0.135	0.727	0.138
STP - 7	0.605	0.066	23.129	25.054	0.020	0.842	0.138
7 - 8	0.264	0.125	24.499	30.334	0.416	0.446	0.138
8 - 9	0.300	0.098	27.341	34.011	0.362	0.500	0.138
9 - 10	0.213	0.111	25.322	42.218	0.419	0.443	0.138
10 - 11	0.407	0.070	29.965	35.116	0.221	0.641	0.138
11- 12	0.242	0.096	15.404	43.058	0.296	0.566	0.138
12 -13	0.308	0.089	33.995	36.499	0.216	0.646	0.138

* The coefficients a, b, b_t, c, d, f and g were developed by Leopold and Maddock for streamflow with d, f and g being dimensionless. For further information see, "Stream Water Quality Assessment Manual", Water Resources Branch, Ontario Ministry of the Environment, March 1980.

4.3. Streamflow

The Federal Government Gauging Station 02GD018 (Station 10) is a long-term gauging station and records are available from October 1964 to the present. Water level recorders at Stations 1 and 7 were installed and operated by staff of the Ministry of the Environment, London Office, during the summer months of 1980 and 1981. The water level recorder at Station (ID) was installed during May 1981. Records for all 4 stations are on file in the M.O.E., Southwestern Region Office in London. Streamflow varied from 0.04-63.7 m^3/sec at Station 10 for the period 1965-1979.

At Station 1, it varied from 0.05-0.27 m^3/sec for the period May-November 1980, and at Station 7 from 0.17-2.16 m^3/sec for the same period (May-November 1980). A special survey was carried out in October, 1981, to verify a hypothesis of exfiltration of flow between Stations 8 and 10. The results of the survey, presented in Table 5, show a significant loss or reduction in flow (0.04 m^3/sec) between Stations 8 and 9, and a small loss (0.01 m^3/sec) between 10 and 11. A possible explanation for the difference is presented in the discussion section. Other streamflow measurements were made on the dates mentioned above.

It is often of value to be able to estimate the probability of occurrence or the return period in years of particular events. The following data for the Avon River was taken from the Federal Gauging Station 02GD018 (Station 10).

The mean monthly streamflows and minimum monthly mean streamflows with 2 yr., 10 yr and 20 yr. return periods are shown in Table 6. The low flows (e.g. 20-year return flows) shown in this table are underestimates with regard to present and future conditions as the low flows in the Avon River are increasing yearly because of the increasing effluent discharge from the WPCP. Table 7 shows the percentage of time that the 1980 streamflow was less than or equal to a given level in the June-November period. These flows at the gauging station include flows from the Stratford WPCP.

TABLE 5: STREAMFLOWS AND TIMES OF TRAVEL FOR SPECIAL EXFILTRATION STUDY - OCTOBER 14, 1981

Station	Date	Time Period	Streamflow (m^3/sec)	Time of Travel (Hrs)
WPCP	Oct.14/81	11:45 -12:20	0.69	
7	Oct.14/81	13:00 -13:30	0.80	1.5
8	Oct.14/81	14:45 -15:15	0.82	5.5
9	Oct.14/81	15:25 -15:55	0.78	5.2
10	Oct.14/81	16:15 -16.40	0.84	5.7
11	Oct.14/81	17:00 -17:30	0.83	3.5
12	Oct.14/81	17:40 - 18:02	0.89	2.2

TABLE 6: SUMMARY OF 2-YR., 10-YR. AND 20-YR. RETURN PERIOD FLOWS FOR STATION 10.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean Monthly Flow, m^3/sec	1.95	2.49	5.47	4.39	1.42	0.79	0.54	0.48	0.65	0.91	2.41	1.95
Min. Monthly Mean Flow, m^3/sec 2 Yr. Return Period	1.59	2.10	5.38	4.76	0.91	0.74	0.45	0.45	0.44	0.57	1.70	2.10
Min. Monthly Mean Flow, m^3/sec 10 Yr. Return Period	0.57	0.51	2.69	1.22	0.68	0.45	0.31	0.30	0.20	0.22	0.65	0.65
Min. Monthly Mean Flow, m^3/sec 20 Yr. Return Period	0.51	0.40	2.10	1.13	0.62	0.42	0.28	0.28	0.19	0.22	0.45	0.40

Period of Record Used 1965-1977

* Note: Above flows include WPCP flows.

DRAINAGE AREA = 13,727 HECTARES

TABLE 7: CUMULATIVE FREQUENCY DISTRIBUTION OF DAILY MEAN FLOWS AT STATION 10 (JUNE THROUGH TO NOVEMBER, 1980)

Flow Range (m^3/sec)	# Days Flow Less Than or Equal to Flow Shown	% of Time Flow Less Than or Equal to Flow Shown
0.24	3	1.6
0.49	81	44.3
0.74	120	66.6
0.99	137	74.9
1.24	150	82.0
1.49	164	89.6
1.74	171	92.9
1.99	172	94.0
2.24	175	95.6
2.49	177	96.7
2.74	179	97.8
2.99	181	98.9
3.24	181	98.9
3.49	182	99.5
4.00	183	100

* NOTE: Above flows include WPCP flows.

The highest monthly average flows are measured in March with the lowest occurring in August. The Stratford WPCP discharges approximately 0.25 m^3/sec. From Table 7, it can be seen that there was a 1 to 1 or less dilution 44% of the time in June-November 1980 period; 2 to 1 or less dilution 22% of the time and only 2% of the time and only 2% of the time was there a dilution of 10 to 1 or greater.

In terms of the historical hydrologic record, the 1980 flows that are analyzed in Table 7 are relatively high. The minimum 30 day mean flow that occurred in the summer period (June to Sept) of 1980 was exceeded only 7 times from 1965 to 1980. Likewise the minimum 60 day mean flow was exceeded only 3 times over the same period. (Fortin & Seto, Statistical Analysis of Flow Data, File Report SAREMP, Nov 6, 1980).

Based on a statistical analysis of drought flows by Fortin and Seto, the mean 7-day drought flow at station 10 is 0.103 m^3 sec^{-1} for a 20-year return period and 0.132 m^3 sec^{-1} for a 10 year return period. After removing the influence of WPCP effluent flows, these 10 and 20 year 7-day drought flows are respectively 0.022 m^3 sec^{-1}. Their analysis of flood flow data indicates that a 10 year storm is 84 m^3 sec^{-1} and a 100 year storm is 137 m^3 sec^{-1}.

4.4 Slope of Streambed

The channel bed slope for each reach expressed in percentage is shown in Table 3 (See Page 14). Figure 4 shows a plot of stream bed elevations from Station 6 to the mouth of the Avon River. From these results, the slopes are seen to vary from 0.06% (Reach 8-9) to 0.38% (Reach 11-12).

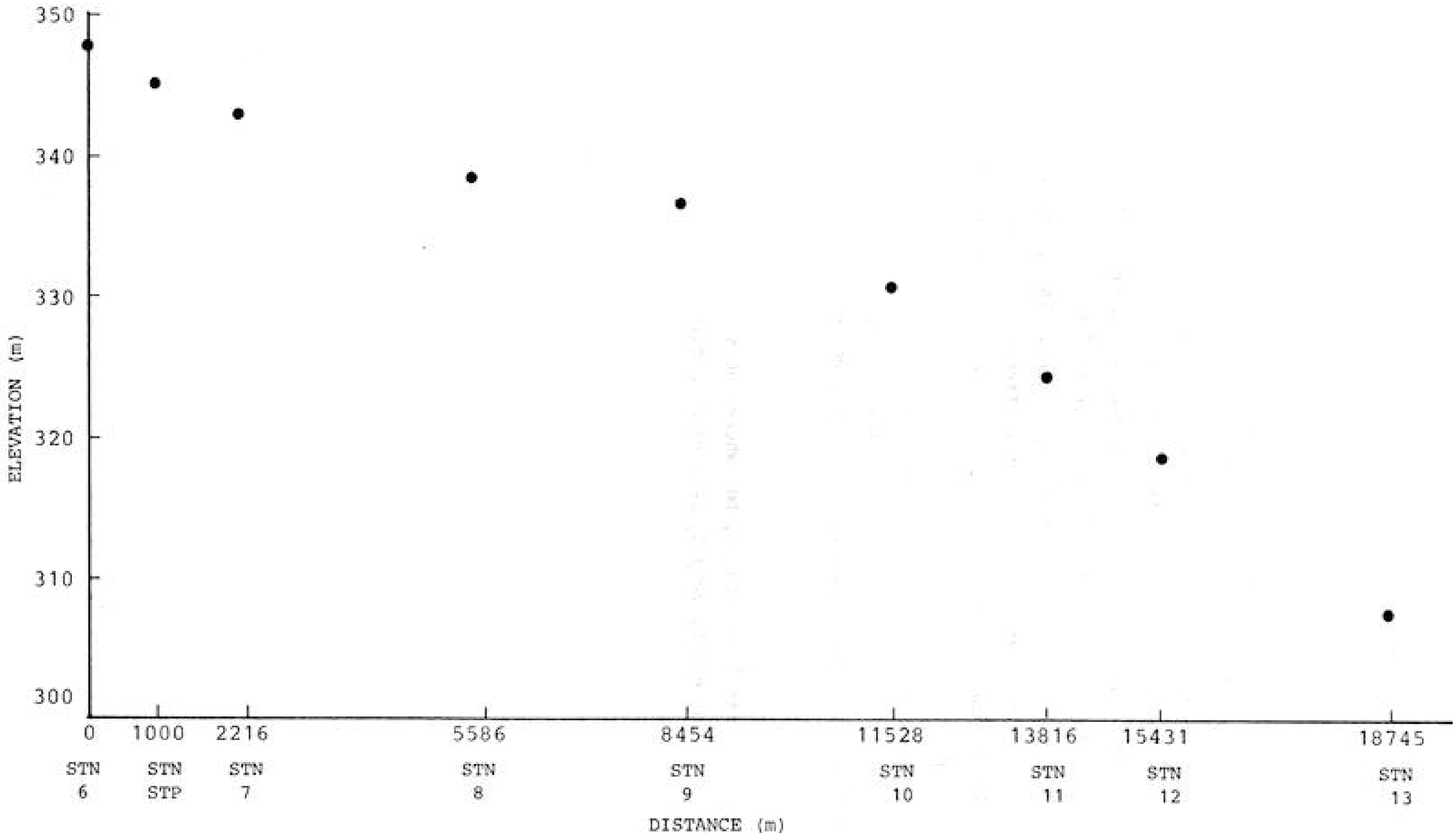

FIGURE 4: PLOT OF STREAMBED ELEVATIONS FOR STNS 6 - 13

5. DISCUSSION AND CONCLUSIONS

5.1. Channel Geometry

The Avon River has a typical U-shaped channel throughout the lower basin with many small rapids between the Stratford WPCP outfall and the mouth of the river. These rapids are beneficial in terms of natural aeration as they increase the effects of oxygen exchange by inhibiting the formation of diffusion-retarding boundary films at the air-water interface. Although the effects of the rapids were not monitored, the benefits could be significant. In the context of water quality improvement advantage can be taken of the natural drop in elevation of the stream-bed at rapids, to consider installation of small weirs (0.5 m), if such weirs are found to be effective oxygenators. However, access to these locations for construction purposes are very limited; farmers' lane-ways or open fields could be used in same cases.

Stream banks appear to be stable, but where the soil s were exposed, the banks were subject to varying degrees of erosion.

5.2. Streamflow

In the report 'Impact of Waste Inputs on the Quality of the Avon River', June 1979, published by Water Resources Assessment Unit, Technical Support Section, Southwestern Region, it was noted that there was loss in streamflow between Stations 8 and 10 and the question arose: Is there exfiltration occurring to the permeable substrate between these two stations? To address this question, a survey was carried out on October 14, 1981 to measure flows at every station successively between Stratford WPCP and Station 12. The results show a loss in flow of 0.04 m^3/sec between Stations 8 and 9, and a small loss of 0.01 m^3/sec between Stations 10 and 11. To explain the loss observed between these stations (see Table 5), it is necessary to look at the Stratford WPCP operation and the streamflow hydrograph for Station 7, shown in Figure 5. The changes in water levels caused by the WPCP operation are reflected by the hydrograph for Station 7. The sewage treatment plant discharges effluent at approximately 0.29 m^3/sec. As the filters become clogged, the effluent is used to backwash the filters and the backwash water is returned to the primary clarifiers. This operation takes approximately one half of an hour and when it is taking place, no effluent is discharged into the stream. Hence, there is a reduction or loss in flow entering the river during the filter backwash periods. Based on travel-time data, Figure 5 shows the specific plugs of water, A and B, that left Station 7 at different times and correspond to the same plugs that were measured at Stations 9 and 8 respectively during the flow measurement.

From the figure, it can be seen that plug B is at a higher flow than plug A, causing the flow at Station 8 to be higher than the flow at Station 9. The same logic could be applied to explain the small loss between Stations 10 & 11.

Another explanation for small losses could be water-taking by farmers and crop spraying companies. The author observed trucks taking water from the river at Station 7 on two occasions. On questioning the operator, it was learned that the truck had a capacity of 1000 gallons and on a good day, his company withdraws as much as 20,000 gallons from the river for crop-spraying.

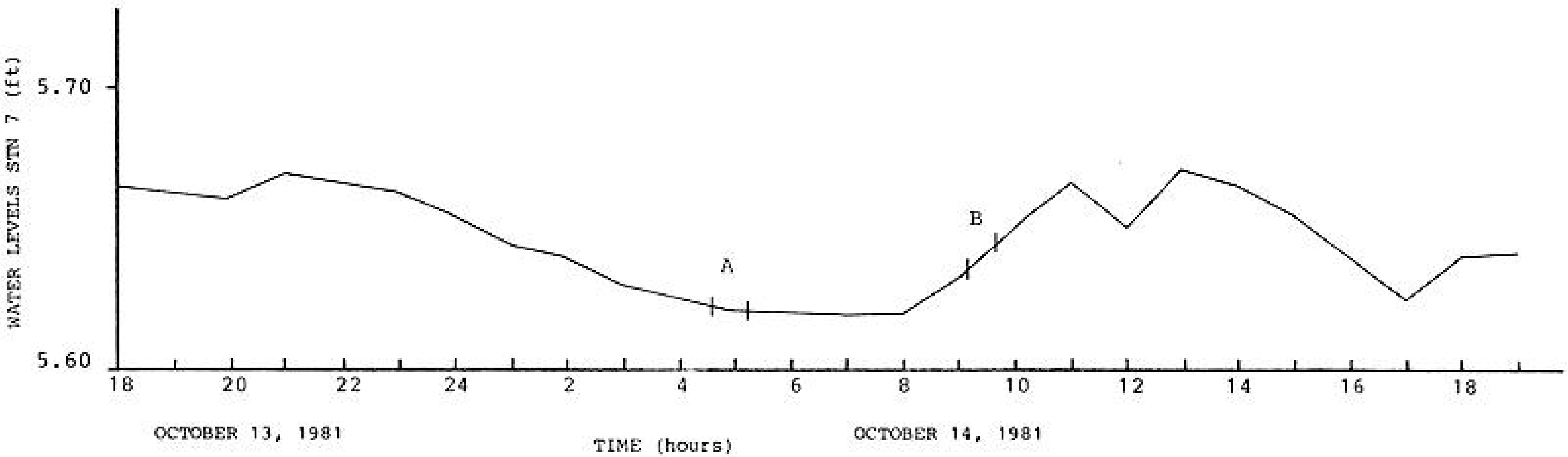

FIGURE 5: STREAM HYDROGRAPH AT STN 7

In general it is evident that WPCP effluent flows comprise a large portion of the total river flow during drought periods, with dilution ratios often exceeding 1:1. Effluent quality will therefore have a substantial impact on river water quality. A combination of shallow flows, nutrient enriched water, and a rocky substrate provide for luxuriant growth of nuisance aquatic plants.

5.3. Slope

Generally the Avon River bed is very flat, with slopes ranging from 0.06 to 0.38%. This flatness tends to produce sluggishness of flow especially under low flow conditions. If therefore, weirs are installed to improve water quality (increase DO concentration), they should only be small weirs (0.5 m head loss at localized areas where there are rapids. Any attempt to construct large weirs (i.e., larger than the natural drop in elevation found at rapids), might produce considerable impoundment upstream. There are special problems associated with the water quality of impounded water; these will not be dealt with in this report.

APPENDIX

A. SUMMARY OF CROSS-SECTIONAL DATA

A: SUMMARY OF CROSS-SECTIONAL DATA

Cross Section	Distance From WPCP (m)	Width (m)	Average Depth (cm)	Area (sq. m)
1 (WPCP)	0	12.30	46.42	5.71
2	75.0	15.00	34.27	5.14
3	114.0	12.10	29.18	3.53
4	243.0	13.10	37.29	4.89
5	288.0	9.10	32.08	2.92
6	320.0	11.50	22.28	2.56
7	442.0	15.50	18.21	2.82
8	598.0	9.30	10.52	1.91
9	654.0	4.00	19.87	0.80
10	778.0	14.00	25.50	3.57
11	1024.0	10.30	24.00	2.47
12 (Stn 7)	1216.0	13.70	72.40	9.92
13	1361.0	16.70	27.00	4.51
14	1511.0	13.00	18.54	2.41
15	1604.0	12.00	17.75	2.13
16	1699.0	12.00	27.50	3.30
17	1739.0	11.00	29.60	3.26
18	1862.0	16.50	42.35	6.99
19	1934.0	11.00	22.18	2.44
20	1997.0	13.10	47.86	6.27
21	2087.0	10.80	31.02	3.35
22	2160.0	12.20	26.56	3.24
23	2204.0	11.70	35.45	4.15
24	2303.0	15.90	16.91	2.69
25	2383.0	9.60	21.15	2.03
26	2435.0	13.00	23.15	3.01
27	2586.0	20.60	15.46	3.18
28	2697.0	15.80	28.63	4.52
29	2877.0	14.40	21.08	3.04
30	3021.0	15.50	39.77	6.17
31	3143.0	12.20	29.97	3.66
32	3237.0	9.60	23.56	2.26
33	3351.0	12.80	26.87	3.44
34	3510.0	20.50	26.22	5.38
35	3720.0	14.00	21.71	3.04
36	3820.0	12.80	46.81	5.99
37	3960.0	12.30	24.26	2.98

A: SUMMARY OF CROSS-SECTIONAL DATA - Cont'd

Cross Section	Distance From WPCP (m)	Width (m)	Average Depth (cm)	Area (sq.m)
38	4041.0	14.40	28.65	4.13
39	4136.0	10.10	25.86	2.61
40	4220.0	12.30	34.41	4.23
41	4371.0	21.20	34.68	7.35
42 (Stn 8)	4586.0	13.30	57.45	7.64
43	4749.0	16.00	21.56	3.45
44	5108.0	14.50	21.64	3.14
45	5355.0	24.50	31.19	7.64
46	5509.0	14.00	10.64	1.49
47	5619.0	13.40	28.93	3.88
48	5773.0	17.80	18.51	3.29
49	5910.0	12.80	26.84	3.44
50	5948.0	12.70	14.56	1.85
51	6205.0	20.20	33.54	6.78
52	6333.0	17.30	16.16	2.80
53	6580.0	11.00	20.18	2.22
54	6729.0	14.00	25.93	3.63
55	6942.0	19.30	40.09	7.74
56	7119.0	16.00	19.69	3.15
57	7209.0	17.00	12.35	2.10
58 (Stn 9)	7454.0	14.30	39.06	5.59
59	7567.0	12.00	24.58	2.95
60	7817.0	22.60	18.46	4.17
61	7950.0	18.30	17.28	3.16
62	8157.0	29.30	17.46	5.12
63	8466.0	19.30	17.30	3.34
64	8621.0	31.00	15.84	4.91
65	8821.0	18.00	22.44	4.04
66	8900.0	18.70	28.35	5.30
67	9123.0	17.10	38.79	6.63
68	9288.0	17.80	12.49	2.22
69	9449.0	16.20	22.59	3.66
70	9570.0	12.00	28.50	3.42
71	9845.0	19.70	13.51	2.66
72	10008.0	15.00	15.40	2.31
73	10273.0	27.20	28.82	7.84
74 (Stn 10)	10528.0	19.10	67.89	12.97

A: **SUMMARY OF CROSS-SECTIONAL DATA -** Cont'd

Cross Section	Distance From WPCP (m)	Width (m)	Average Depth (cm)	Area (sq.m)
75	10683.0	18.20	29.09	5.29
76	10838.0	23.00	18.43	4.24
77	10993.0	17.50	10.71	1.88
78	11148.0	23.30	20.11	4.68
79	11303.0	18.50	13.65	2.53
80	11458.0	14.80	14.80	2.19
81	11613.0	13.00	16.85	2.19
82	11768.0	13.40	13.07	1.75
83	11923.0	12.00	41.50	4.98
84	12078.0	17.40	27.67	4.81
85	12233.0	14.70	17.79	2.62
86	12388.0	12.80	15.78	2.02
87	12543.0	13.10	15.26	2.00
88	12631.0	17.60	34.39	6.05
89 (Stn11)	12816.0	17.70	32.35	5.73
90	12971.0	20.30	11.04	2.24
91	13126.0	18.30	15.65	2.86
92	13281.0	24.00	13.00	3.12
93	13436.0	12.40	15.17	1.88
94	13591.0	27.00	13.89	3.75
95	13746.0	16.00	12.31	1.97
96	13901.0	19.30	21.79	4.21
97	14056.0	17.60	15.68	2.76
98	14211.0	21.70	18.64	4.05
99	14366.0	14.00	21.29	2.98
100 (Stn12)	14586.0	13.00	19.54	2.54
101	14691.0	15.80	19.87	3.14
102	14846.0	14.40	17.43	2.51
103	15001.0	18.20	13.07	2.38
104	15156.0	21.10	12.88	2.72
105	15311.0	17.70	13.24	2.34
106	15466.0	19.20	30.69	5.89
107	15621.0	13.10	16.76	2.20
108	15776.0	25.50	8.10	2.07
109	15931.0	19.30	15.93	3.07
110	16086.0	17.70	30.45	5.39
111	16241.0	16.10	18.84	3.03

A: SUMMARY OF CROSS-SECTIONAL DATA - Cont' d

Cross Section	Distance From WPCP (m)	Width (m)	Average Depth (cm)	Area (sq.m)
112	16396.0	17.30	26.45	4.58
113	16551.0	13.20	22.48	2.97
114	16706.0	27.30	8.92	2.44
115	16861.0	12.70	18.18	2.31
116	17016.0	23.20	15.16	3.52
117	17171.0	14.00	17.29	2.42
118	17386.0	29.20	18.58	5.43
119	17481.0	7.40	12.03	0.89
120	17636.0	12.30	13.23	1.63
121	17785.0	9.10	12.48	1.14
122 (Stn13)	17845.0	22.40	15.00	3.36

A: SUMMARY OF CROSS-SECTIONAL DATA - Cont'd

Cross Section	Distance Above Stratford WPCP Outfall	Width (m)	Average Depth (cm)	Area (sq.m)
*123	1	13.00	54.65	7.11
124	66	9.79	21.82	2.13
125	116	9.75	17.99	1.75
126	196	12.50	23.32	2.92
127	246	12.00	69.52	8.34
128	311	9.50	15.45	1.47
129	365	7.00	37.32	2.61
130	445	7.00	20.21	1.42
131	545	10.00	40.75	4.08
132	620	7.75	44.44	3.44
133	670	9.00	36.25	3.26
134	720	16.50	21.14	3.44
135	750	8.00	50.37	4.03
136	800	6.50	25.69	1.67
137	835	8.00	44.34	3.55
138	915	6.00	45.00	2.70
139	966	10.20	37.90	3.67
140	993	23.50	31.30	7.36

* Cross-sections 123 - 140 were measured in May 1981.

STRATFORD-AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT
LIST OF TECHNICAL REPORTS

S-1 Impact of Stratford City Impoundments on Water Quality in the Avon River
S-2 Physical Characteristics of the Avon River
S-3 Water Quality Monitoring of the Avon River - 1980, 1981
S-4 Experimental Efforts to Inject Pure Oxygen into the Avon River
S-5 Experimental Efforts to Aerate the Avon River with Small In-stream Dams
S-6 Growth of Aquatic Plants in the Avon River
S-7 Alternative Methods of Reducing Aquatic Plant Growth in the Avon River
S-8 Dispersion of the Stratford Sewage Treatment Plant Effluent into the Avon River
S-9 Avon River In-stream Water Quality Modelling
S-10 Fisheries of the Avon River
S-11 Comparison of Avon River Water Quality During Wet and Dry Weather Conditions
S-12 Phosphorus Bioavailability of the Avon River
S-13 A Feasibility Study for Augmenting Avon River Flow by Ground Water
S-14 Experiments to Control Aquatic Plant Growth by Shading
S-15 Design of an Arboreal Shade Project to Control Aquatic Plant Growth

U-1 Urban Pollution Control Strategy for Stratford, Ontario - An Overview
U-2 Inflow/Infiltration Isolation Analysis
U-3 Characterization of Urban Dry Weather Loadings
U-4 Advanced Phosphorus Control at the Stratford WPCP
U-5 Municipal Experience in Inflow Control Through Removal of Household Roof Leaders
U-6 Analysis and Control of Wet Weather Sanitary Flows
U-7 Characterization and Control of Urban Runoff
U-8 Analysis of Disinfection Alternatives

R-1 Agricultural Impacts on the Avon River - An Overview
R-2 Earth Berms and Drop Inlet Structures
R-3 Demonstration of Improved Livestock and Manure Management Techniques in a Swine operation
R-4 Identification of Priority Management Areas in the Avon River
R-5 Occurrence and Control of Soil Erosion and Fluvial Sedimentation in Selected Basins of the Thames River Watershed
R-6 Open Drain Improvement
R-7 Grassed Waterway Demonstration Projects
R-8 The Controlled Access of Livestock to Open Water Courses
R-9 Physical Characteristics and Land Uses of the Avon River Drainage Basin
R-10 Strip cropping Demonstration Project
R-11 Water Quality Monitoring of Agricultural Diffuse Sources
R-12 Comparative Tillage Trials
R-13 Sediment Basin Demonstration Project
R-14 Evaluation of Tillage Demonstration Using Sediment Traps
R-15 Statistical Modelling of In-stream Phosphorus
R-16 Gully Erosion Control Demonstration Project
R-17 Institutional Framework for the Control of Diffuse Agricultural Sources of Water Pollution
R-18 Cropping-Income Impacts of Management Measures to Control Soil Loss
R-19 An Intensive Water Quality Survey of Stream Cattle Access Sites