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DETROIT RIVER FLOW CHARACTERISTICS AND THEIR APPLICATION TO CHEMICAL LOADING ESTIMATES[1]

F.H. Quinn
Great Lakes Environmental Research Laboratory, National Oceanic Atmospheric Administration, Ann Arbor, Michigan

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Abstract. Unsteady flow characteristics were analyzed at the Windmill Point, Fort Wayne, Wyandotte, and Fermi sections of the Detroit River using two hydraulic transient mathematical models. Both models consist of the complete one-dimensional equations of continuity and motion and were calibrated using discharge measurements taken during the 1963-1973 period. The models were used to generate hourly, daily, and monthly flows for the year 1968. A statistical analysis was made of these flows at the Fort Wayne and Fermi sections. The flows at the Fort Wayne section were found to be representative of the entire river on a monthly basis and on a daily basis under most conditions. Individual section flows are necessary for use on an hourly basis or under Lake Erie wind, tide and seiche conditions. Application of flows to computation of Detroit River chloride loadings shows entirely different loading phenomena for both base and peak loadings between the upper and lower river. It also illustrates the danger of computing yearly loadings based upon a limited number of samples for the lower river.

INTRODUCTION

This study of the Detroit River flow characteristics was undertaken to provide an aid for selecting appropriate flow time intervals for Detroit River chemical and biological loading studies. It also demonstrates the use of hydraulic transient models for water quality analysis. The Detroit River is important from a water resource standpoint as it furnishes approximately 80% of the total water supply to Lake Erie. In addition, the industrialized Detroit, Michigan - Windsor, Ontario area contributes various chemical and biological loadings which may also be transported to Lake Erie. Short-term river flow fluctuations are primarily induced by wind setups and seiches on Lakes St. Clair and Erie. These fluctuations are filtered out by the monthly time increments commonly used in water quantity studies. However, short-term fluctuations may impact water quality where loadings are computed with data obtained over a

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several hour period.

Two Detroit River hydraulic transient models are used to generate hourly, daily, and monthly flows at four river sections for the year 1968. These flows are analyzed statistically for both spatial and sectional variations. This analysis forms the basis for time increment selection. A water quality application is presented to illustrate the use of the model and the effects of flow-time intervals on chloride-loading computations.

FLOW COMPUTATION

The computed flow data consist of model-generated hourly, daily, and monthly flows for 1968 at the Windmill Point, Fort Wayne, Wyandotte, and Fermi River sections (Fig. 1). The water level data used to drive the models are average hourly, daily, and monthly elevations from the National Oceanic Atmospheric Administration (NOAA) water level gauges at Windmill Point, Fort Wayne, Wyandotte, and Fermi.

The mathematical models consist of the complete one-dimensional equations of continuity and motion. The equations are solved by the implicit method using the Newton-Raphson algorithm (Quinn and Wylie 1972). The primary model includes the reach of the river from Windmill Point to Wyandotte with an intermediate section at Fort Wayne. The second model is a branched model of the entire river from Windmill Point to the mouth which is represented by the Fermi water level gauge, with an intermediate section at Wyandotte. The latter model includes channels on either side of Grosse Ile. The models were calibrated using five sets of discharge measurements taken by the U.S. Army Corps of Engineers during the period 1963-1973.

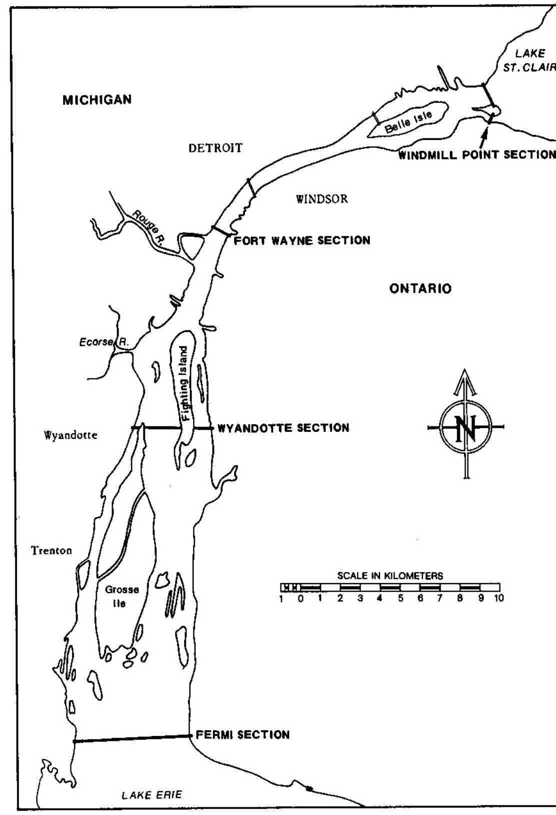

FIG. 1. Detroit River sections.

The inputs to the models are the water level elevations at the upstream and downstream ends of each model. The outputs are river flows at each section of the model along with a computed water level elevation at the intermediate section.

The model accuracy is primarily a function of the water surface elevation measurements and of the discharge data used for calibration. Analysis of the errors in the discharge measurements using a technique presented by Herschy (1970) indicates an error limit of about 2% at the one-standard deviation level. The limits of water-level-gauge accuracy contribute about 1.5% to the model error limit, resulting in an overall model error of about 2.5% at the one-standard deviation level. This error level applies only to the generated hourly flows as the discharge measurements are taken over an approximate 3-hour time period. For daily and monthly flows the model error should be limited to 1.5 to 2.0% at the one-standard deviation level.

SPATIAL FLOW VARIATION

Flow variation between specific reaches of the river, due primarily to changes in river storage between the four river sections was analyzed on a daily and monthly basis to assess the applicability of using one flow section to represent the entire river. The Fort Wayne section would be ideal for this purpose because it is used as a discharge measuring section in addition to being a long-term water level-gauge location. Quinn and Wylie (1972) have shown that large flow fluctuations can occur between all river sections on an hourly time basis. Thus, the flows at one river section cannot be used as representative of the entire river on an hourly basis. Analysis of average monthly flows indicates steady flow with no variation between the various sections. Thus the computed monthly flows at the Fort Wayne section represent the entire river.

For the daily flow analysis the river was divided into two reaches. In the upper river reach, between the Wyandotte and Windmill Point sections, 99% of the computed daily flow differences between the Windmill Point and intermediate Fort Wayne sections, and the Fort Wayne and Wyandotte sections, is less than 60 m^3/sec or approximately 1% of the flow. In the lower river reaches between the Wyandotte and Fermi sections approximately 84% of the daily flow differences are less than 60 m^3/sec and 99% of the differences are within 170 m^3/sec or approximately 3% of the flow. The higher differences in the lower reach result from Lake Erie wind effects. Effects resulting from 0.5 - 2 meter wind generated fluctuations in western Lake Erie water levels cause rapid changes in storage in the lower river. In addition, the Fermi gauge may not accurately represent the water level elevation at the river mouth during all wind tides and seiches, thus biasing the computations. As the spatial flow differences are less than the probable model errors, the daily computed flows at the Fort Wayne section can be used to represent the entire river except during Lake Erie wind tide and seiche conditions.

The one element lacking in the analysis of the 1968 data is the occurrence of a major wind-tide and seiches on Lake Erie. Therefore, the effects of a wind-tide and transient conditions upon the daily flow computations were analyzed using the wind-tide and resulting seiches of 27 October 1967. Table 1 shows pertinent flow data obtained by upper river model runs on both hourly and daily bases. Columns 3 and 4 show the large flow variations which can take place during a wind-tide. Of particular interest is the fact that the average daily flows computed from daily mean elevations is about 200 m^3/sec or approximately 4% higher than the average daily flows computed using the mean of the hourly flows. Therefore, particular care must be taken when computing daily flows from daily mean water level elevations during periods of wind-tides and seiches. However, the average daily flow at Fort Wayne can still be used to

TABLE 1. Detroit River flow analysis, wind-tide of 27 October, 1967

River section	Daily increments		Hourly increments	
	Ave. daily Flow (m^3/sec)	Ave. daily Flow* (m^3/sec)	Maximum Flow (m^3/sec)	Minimum Flow (m^3/sec)
Windmill Point	5749	5522	7250	3257
Fort Wayne	5749	5551	7137	3823
Wyandotte	5749	5607	7080	4020

*Mean of hourly flows.

represent the upper river.

SECTIONAL FLOW VARIATIONS

A statistical analysis of the variability between hourly and daily flows and between hourly and monthly flows was conducted for the Fort Wayne and Fermi sections of the river to serve as a decision making tool for the selection of flow time increments for various applications. The analysis consisted of computing standard deviations and maximum differences between hourly and daily flows and hourly and monthly flows for 1968 (Table 2). The maximum differences in December 1968 for the Fermi section are caused partially by missing gauge data. Comparison shows similar flow characteristics for the Fort Wayne and Fermi sections although the maximum differences tend to be greater at the Fermi section because of storage effects in the lower river, as explained earlier.

As would be expected, there is considerably less variation between the hourly and daily flows than between the hourly and monthly flows. This is particularly noticeable when examining the maximum differences.

APPLICATION

The effects of flow time intervals on chloride loading computations were analyzed using chloride concentration data provided by the Windsor Office of the International Joint Commission (IJC). The chloride loadings were computed for the Windmill Point, Fort Wayne, and Fermi River sections using Eq. 1.

$$L = \sum_{i=1}^{n} C_i \, Q \, F_i$$

where:

L is the total sample loading in Kg/day;

n is the number of panels sampled in the cross-section;

i is the individual panel number;

C is the measured panel chloride concentration in mg/l;

Q is the total river flow in m^3/sec; and

F is a conversion factor including the percentage of total river flow in the panel, to convert the loading to Kg/day.

The loading computations for the Fermi section are summarized in Table 3. A 3-hour chloride sampling interval was assumed for computing the loadings based on hourly flows. The computations show that yearly mean loadings

TABLE 2. Standard deviation and maximum differences in flows using absolute values for Year 1968.

	Mean flow	Flow analyses (m^3/sec)							
		Fort Wayne Section				Fermi Section			
	m^3/sec	Standard Hr-Mon[1]	Deviation Hr-Day[2]	Maximum Hr-Mon[1]	Difference Hr-Day[2]	Standard Hr-Mon[1]	Deviation Hr-Day[2]	Maximum Hr-Mon[1]	Difference Hr-Day[2]
January	5154	425	189	1501	708	566	283	2435	963
February	5466	510	227	1501	935	368	227	1444	935
March	5437	312	170	1048	850	340	227	1473	1416
April	5296	340	283	2181	1558	312	283	1444	1274
May	5296	312	227	1869	1076	312	255	1076	765
June	5437	312	227	963	991	368	283	1558	1501
July	5551	227	170	906	680	283	255	1303	1076
August	5522	227	198	878	651	283	283	1473	1218
September	5579	227	170	765	680	283	255	2775	2747
October	5692	255	198	1020	935	312	255	1303	1218
November	5621	340	283	1444	878	425	368	1529	1388
December	5834	425	283	1416	1529	595	453	1444	1812

[1] Hourly flows minus monthly flows.

[2] Hourly flows minus daily flows.

TABLE 3. Chloride loading at Fermi section for selected dates in 1968.

Sampling date	Flow rate (m^3/sec)			Chloride loading (Kg/day 10^4)		
	Hourly*	Daily	Monthly	Hourly	Daily	Monthly
April 8	5126	5267	5239	653	671	668
April 30	5324	5381	5239	952	962	937
May 7	5098	4956	5296	601	585	625
June 17	5268	5409	5409	588	604	604
July 22	5381	5494	5551	571	582	589
August 13	5239	5409	5551	768	793	814
August 19	5211	5409	5551	487	505	518
September 9	5324	5409	5579	565	574	592
September 30	5494	5834	5579	634	673	644
October 7	5239	5777	5692	596	657	647
October 28	6117	5919	5692	749	725	697
Mean				651	666	667

*Based on mean 3-hour flow during given measurement time.

TABLE 4. Loading computation differences due to time intervals, expressed as a percentage of hourly interval loading.

Section	Average absolute difference		Maximum absolute difference	
	Daily-Hourly	Monthly-Hourly	Daily-Hourly	Monthly-Hourly
Fermi	3.6	4.4	10.3	8.7
Fort Wayne	0.9	1.9	2.8	5.1
Windmill Point	2.1	3.6	4.2	14.1

computed from all three flow intervals, hourly, daily, or monthly, yield similar results. Thus, any of the flow intervals will suffice for computing yearly average loadings.

The effects of flow-interval selection are more pronounced when computing short-term loadings based upon individual chloride samples. Results summarized in Table 4 show variations of up to 4% on an average basis, considering all eleven chloride samples, and variations up to 14% for individual samples. A significant improvement is shown in the use of daily over monthly flow rates, although hourly flow rates still yield the most accurate results.

The individual chloride sample loadings computed on a daily flow interval are plotted on Fig. 2 for all three sections. The figure shows entirely different loading phenomena between the upper and lower river for both base and peak loadings. It also points out the danger of computing yearly loadings based upon a small number of samples for the lower river.

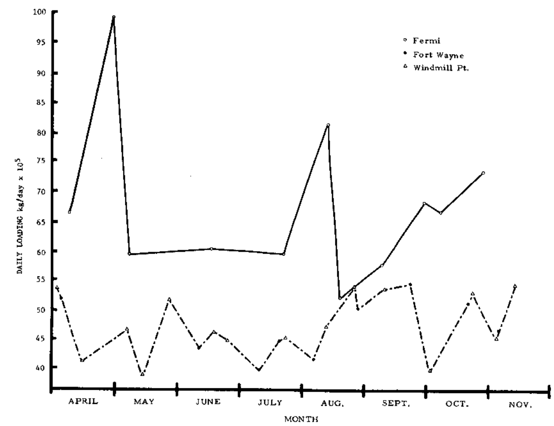

FIG. 2. Chloride loadings.

CONCLUSIONS

The model-generated flows for the Fort Wayne section are representative of the entire river on a monthly basis, and under most conditions, on a daily basis. Flows computed at the chloride sampling sections are required for computations done on an hourly basis or under Lake Erie wind, tide and seiche conditions.

Selection of an hourly, daily, or monthly flow-time interval depends on the time increment and on the accuracy necessary for the flow application. In the case of chloride loading computations, where samples are taken over an approximately 3-hour time period, daily flow intervals will usually suffice. This is particularly true when exact sampling times are not known. Daily, hourly, and monthly flow intervals were found to be equally suited for computing mean annual loadings. However, much short term detail was lost when monthly flows were applied to individual chloride sample concentrations to compute individual sample loadings.

Daily flows are adequate under most stable river conditions or when sampling times are unknown. Hourly flows should be used under Lake Erie wind-tide and seiche conditions or when exact sampling times are specified.

This paper also demonstrates for the first time the utility of using hydraulic transient models to compute chemical loadings in the connecting channels of the Great Lakes. This technique can be applied to other connecting channels, such as the St. Clair and Niagara Rivers, as additional transient models become available.

The use of hourly flow intervals can only be justified under the following criteria: one, when exact sampling times are known; or two, under Lake Erie wind-tide and seiche conditions.

REFERENCES

Herschey, R.W. 1970. The measurement of errors at flow measurement stations. *Hydrometry, Proc. of the Koblenz Symp.*, Sept. 1970. pp. 109-31, UNESCO.

Quinn, F.H. and Wylie, E.B. 1972. Transient analysis of the Detroit River by the implicit method. *Water Resources Res.*,5:1461-69.