CLEARWATER RIVER

TIME OF TRAVEL STUDY

APRIL , 1991

MINNESOTA DEPARTMENT
OF NATURAL RESOURCES
DIVISION OF WATERS
Surface Water Section

Acknowledgements:

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INTRODUCTION

Today in Minnesota there is a growing concern over the environment. Keeping pace with this environmental upsurge is an increased use and pressure to develop and utilize our natural resources. The Clearwater River is one of these limited natural resources. The Clearwater River which comprises 23 percent of the Red Lake watershed has many users and is becoming increasingly limitted in its ability to satisfy its users in respect to water supply and water quality. In order to examine the water supply and quality problems associated with the Clearwater River, the Department of Natural Resources (DNR), in cooperation with the Red Lake Watershed District (RLWD) and the University of Minnesota (Crookston), initiated a time of travel study in 1987.

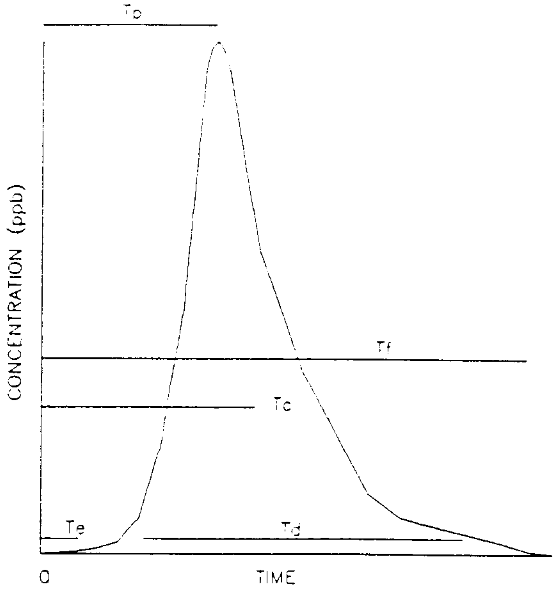
Time of travel studies are often performed to examine flow characteristics of a river in the event of a spill of a hazardous material upstream of a public water supply. Agencies in charge of protecting the public health need to know the amount of time they have before a contaminant reaches a water supply intake, the concentration of the contaminant, and the amount of time required for the pollutant to sufficiently disperse and move past an intake site.

The Clearwater River study was initiated to provide information on allocating water to various instream and out of stream uses, and to better understand the movement of contaminants at different flow levels in the river.

1.0. DYE TRACING AND TIME OF TRAVEL

Time of travel refers to the movement of water or waterborne materials from point to point in a stream for steady or gradually varied flow conditions (Hubbard et al. 1982). Because dye particles act similar to water particles dye can be used as a tracer to track the movement of water or water soluble particles in a stream. The injection of dye into a stream and the measurement of the time required for the dye cloud to pass a downstream point represents the time necessary for water to move through a stream segment at a known discharge. The dispersion rate of a dye cloud as it moves downstream is also used to assess the dispersion of water borne contaminants. (The downstream movement of water or dye can be represented by a time of concentration curve (Figure 1.1)).

Figure 1.1 Time of concentration curve



Where:

T_e = Time required for the arrival of the leading edge of a dye cloud at a sample point.

T_p = Time required for the arrival of the peak concentration of a dye cloud (also known as the time to peak)

T_c = Time required for the arrival of the centroid (center) of the dye cloud at a sample point.

T_f = Time required for the arrival of the trailing edge of a dye cloud.

T_d = Time required for the entire dye cloud to pass a given point or river reach and is equal to $T_f - T_e$

Time of travel is then defined as the time necessary for the dye cloud to pass between sampling points or travel a known length of river. Since time of travel is a function of discharge, the delivery time of a quantity of water can be predicted for locations along a known length of river.

The dispersion of a dye cloud is also a function of discharge. Knowing the dispersion rate of a dye cloud is useful in determining the concentration of water soluble contaminants along a river segment. The instantaneous injection of a known quanity of dye at a point and the quantity measured (or recovered) at a downstream location over time determines concentration of a substance in water at a known discharge.

A typical dye used in time of travel studies is Rhodamine WT. Rhodamine WT is a nonhazardous, odorless powder, dark red in color, that is usually mixed with water prior to use. (For the purpose of this study a 20% Rhodemine WT dye solution was used). Concentrations of this fluorescent dye are easily measured using a fluorometer. (Fluorometers measure the luminescence of a substance. The higher the fluorecence measured the higher the concentration of the substance.)

2.0. CLEARWATER RIVER WATERSHED CHARACTERISTICS

The Clearwater River is located in northwest Minnesota and is part of the Red Lake River Watershed. The Clearwater River watershed itself is 1396 square miles in size and is one of the 81 major watershed of the state (MnDNR, Office of Planning, 1981). This watershed includes portions of Beltrami, Clearwater, Mahnomen, Pennington, Polk, and Red Lake Counties. From its headwaters at Lower Long Lake near Ebro, to the confluence with the Red Lake River at Red Lake Falls, the river is 150 miles in length. It has over 30 tributary streams, rivers and ditches making up a stream network over 1700 miles in length.

The surficial geology of the watershed is composed primarily of ground moraines, stagnation moraines, and drumlins in the headwater region to Clearwater Lake. At Clearwater Lake, the undulating to hilly terrain changes as the river flows into the lake bottom of glacial lake Agassiz; a level featureless plain composed of lake modified tills, sand, gravel and small peat formations.

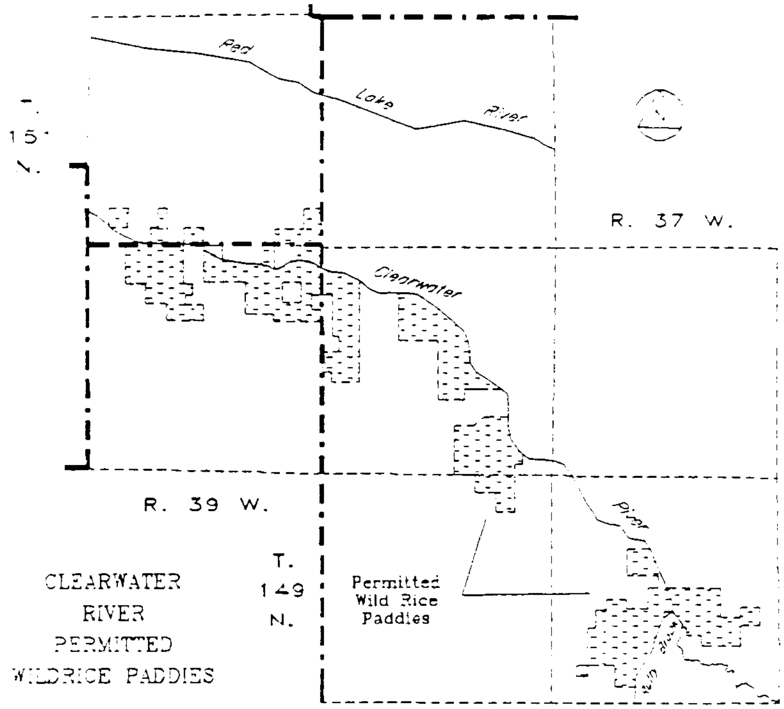
Soils in the area are light colored, well drained sandy loams and sand silts in the headwater areas to Clearwater Lake. A large portion of the watershed however, is composed of humic soils of silt, loam, peat and clay developed from lake modified tills. The transition to organic and silt-clay soils occurs at the fringe of the glacial lake plain. These soils are poorly drained and dark in color (U.S. Dept. of Ag. 1969, and U.S.Dept. of Ag. 1984).

In the 1950's, sections of the river were straightened and channelized by the U.S. Army Corps of Engnineers as part of a plan to reduce flooding in the Red Lake River watershed. Approximately 47 miles of river, beginning at the mouth of Ruffy Brook, were modified to provide capacity for floods of ten-year frequency (MnDNR Bulletin 10, 1959).

3.0 WILD RICE INDUSTRY

The major industry in the Clearwater River watershed is agriculture of which wild rice production is a large component. Nearly half of all Minnesota's commercial wild rice is produced along a 25 mile stretch of the Clearwater River between Clearwater Lake and the city of Plummer (Figure 3.1).

Figure 3.1 Wild rice paddies along the Clearwater River currently under permit.



Wild rice production began along this reach of river in 1968 with a small 50 acre operation. By 1973 more than 6000 acres of wild rice paddies were in production, and in 1981 the number had increased to 11,000 acres. Currently there are 14,498 acres of wild rice paddies in the watershed (MnDNR Water Appropriation Index, 1990).

Commercial wild rice operations require the flooding of paddies with up to eighteen inches of water in early spring or late fall. The spring flooding of the rice paddies typically begins in mid-March or early-April depending on the timing of spring runoff. This water cover must be maintained through the growing season which extends into midsummer (late July). A total of 30 inches of water is usually required to saturate the subsoil and maintain a constant water level throughout the growing season.

In the Clearwater River watershed, 99.5 percent of the water required for commercial wild ricing is provided by the Clearwater River and its tributaries. In some years the spring runoff flows of the Clearwater are not sufficient to supply all the ricing operations with water and still provide flows for instream flow requirements and other downstream users. The combined water appropriation of the wild rice operations is over 400 cubic feet per second (cfs). In times of low flow, because these operations have the capability of pumping the river dry water shortages and conflicts occur, therefore the timing of spring runoff and the allocation of water from the river is extremely important.

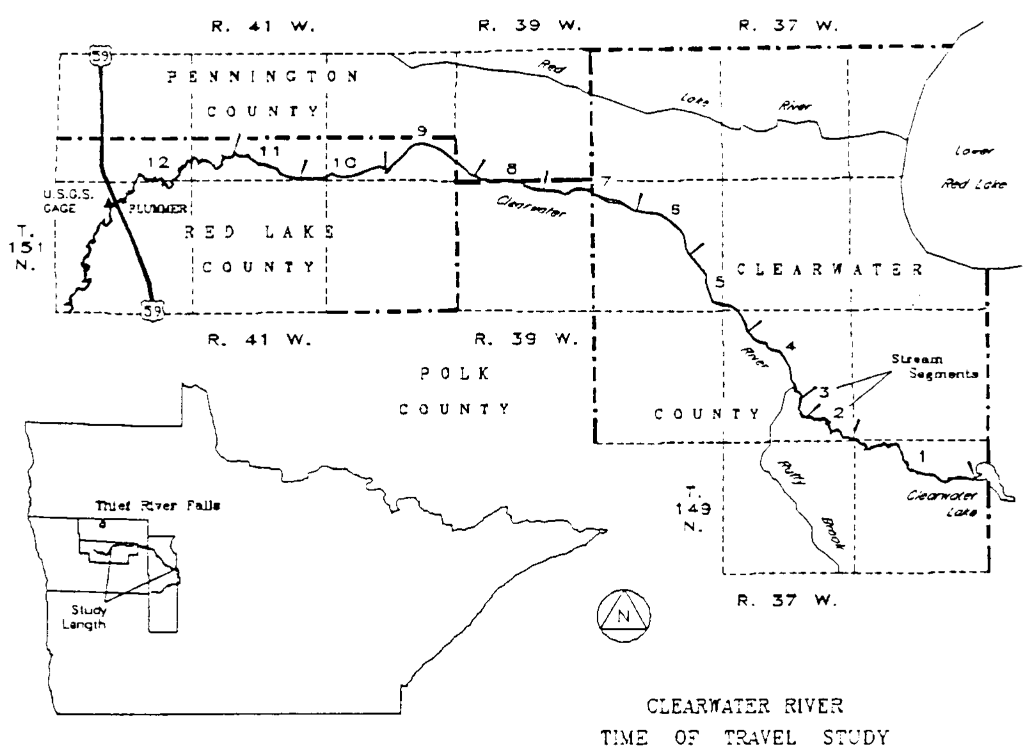
During the growing season the paddies are treated with a variety of chemical pesticides and fertilizers. In mid to late summer the paddies are drawn down for harvest by draining the paddy water back into the Clearwater River. The pesticides and fertilizers contained in the paddy water may impact the river water quality, and is a concern to downstream users.

4.0 STUDY DESIGN AND METHODOLOGY

The Clearwater River time of travel study was intially designed following the United States Geological Survey (U.S.G.S) guidelines for a low level time of travel and dispersion study (Hubbard et al. 1982).

The focus of the study was the heavily appropriated 69.4 mile stretch of river from Clearwater Lake (T.149N., R.37W., S.12) to the U.S.G.S. stream gaging station (U.S.G.S #05078000) near Plummer (T.151N., R.42W., S.4). Topographic maps and air photos were examined to determine the hydraulic and channel characteristics that may affect travel time. Detention areas such as backwaters and large pools were noted because they can negatively influence the dye travel time and concentration. Channel geometry, channel pattern, slope variations, diversions, impoundments, tributaries, river access points, and river miles were also marked on topgraphic maps. The study reach was then divided into 12 study segments based on these criteria (Figure 4.1).

Figure 4.1 Clearwater River Time of Travel Study location.



Following U.S.G.S. guidelines, a quantity of dye is injected at the upstream end of the study reach. The dye cloud is then sampled at specific location as it dispersed and traveled downstream. For the purposes of this study, dye was injected at the upstream end of all 12 study segments. A single dye injection was not practical for a number of reasons:

1. The wild rice growers along the study segment may be approriating water during the first measurement period. The possibility of losing dye at pumping sites required short subreaches with individual dye injections.

2. The Red Lake watershed district is interested in the delivery time of water supplies to appropriators. Because velocity is not uniform along the entire river reach, several subreaches enable better estimates of flow travel time from appropriator to appropriator .

3. The time of travel for flow from Clearwater Lake to Plummer was estimated at 108 hours at the low flow discharge (36 cfs). A single dye injection at this flow level was considered a constraint.

4.1 Estimates Of Velocity, Travel Time and Dye Quantities

Sampling schedule design and estimates of dye quantities, requires estimates of average channel velocity, depth, width and segment length.

Existing U.S.G.S streamflow gaging records along with previous discharge measurements made by the DNR and the RLWD were used to estimate velocities in the study reaches. Estimates of mean channel width, and depth for each study segment were determined from U.S.G.S, DNR and RLWD discharge cross-sections, topographic maps, and air photos.

The following equations were used to estimate the arrival time, and duration of the dye cloud:

Equation 4.1

$$T_p(est) = 1.47 * L/v$$

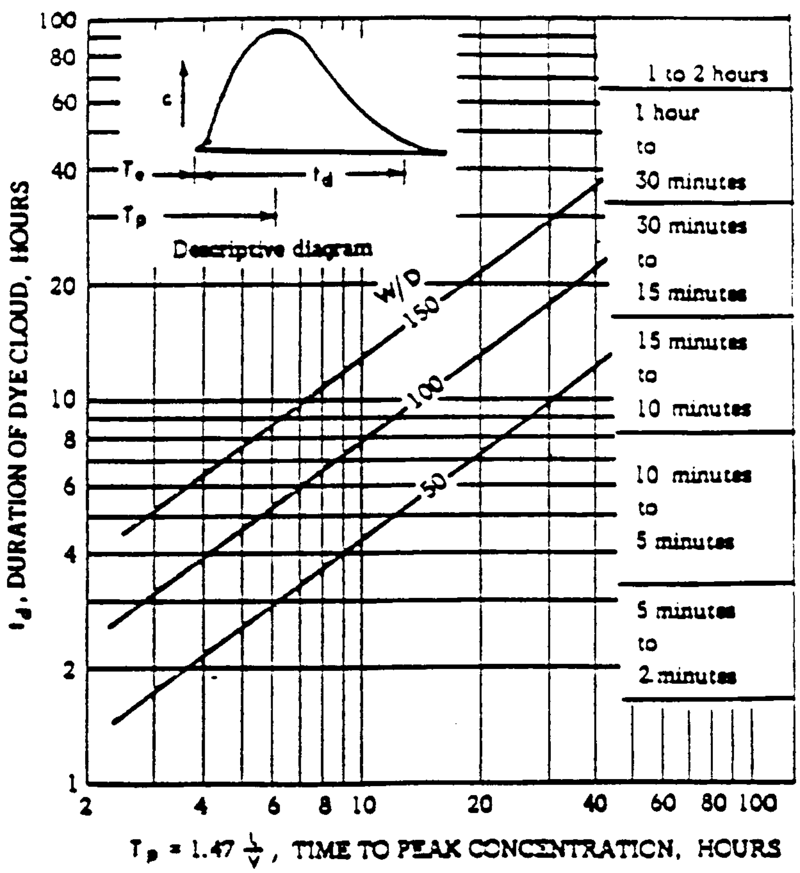
Where:

$T_p(est)$ = Estimated time to peak concentration

L = Length of river segment

v = Estimated mean velocity for the river segment at 36 and 300 cfs

Figure 4.2 Dye cloud duration estimation chart (from Hubbard et. al. 1982)



In order to know when to begin sampling an estimate of the arrival time for the leading edge ($T_e$est) of the dye is necessary and is given by:

Equation 4.2

$$T_e(est) = T_p(est) - (t_d / 2)$$

(this assumes the dye cloud is symmetrical in shape)

An estimate of the elapsed time to the trailing edge of the dye cloud T_f(est) is given by:

Equation 4.3

$$T_f(est) = T_e(est) + t_d$$

The following tables contain the estimated average velocity, dye quanity, and arrival and duration times for each of the twelve study segments.

Discharge = 300cfs

REACH	Length (mi.)	V est. (ft/sec)	Te est. (hrs)	Tp est. (hrs)	Td est. (hrs)	Est. Volume of dye (g.)
1	8.2	2.5	4	4.82	1.75	2450
2	8.9	2.5	4.31	5.23	1.85	2630
3	3.9	1.86	2.53	3.08	1.1	1591
4	4.1	2	2.46	3	1.1	1591
5	5	2.1	2.93	3.5	1.15	1818
6	3.8	2.1	2.14	2.66	1.05	1409
7	4.4	2.1	2.58	3.08	1	1591
8	3.3	2.1	1.89	2.31	0.85	1227
9	5.4	3.5	1.85	2.27	0.85	1227
10	4.1	3.5	1.36	1.72	0.72	909
11	3.8	3.5	1.25	1.6	0.7	863
12	14.6	1.6	12.2	14.2	4	6727

Discharge = 36cfs

REACH	Length (mi.)	V est. (ft/sec)	Te est. (hrs)	Tp est. (hrs)	Td est. (hrs)	Est. Volume of dye (g.)
1	8.2	0.85	11.38	14.18	5.6	907
2	8.9	0.85	12.4	15.4	6	952
3	3.9	0.85	5.19	6.73	3.1	454
4	4.1	1	4.7	6.17	3	408
5	5	1	5.65	7.35	3.4	454
6	3.8	1	4.23	5.6	2.75	363
7	4.4	1	4.92	6.47	3.1	431
8	3.3	1	3.6	4.85	2.5	349
9	5.4	1	6.04	7.94	3.6	499
10	4.1	1	4.58	6.03	2.9	397
11	3.8	1	4.23	5.6	2.75	374
12	14.6	1.1	15.9	19.5	7.2	1200

The quanity of dye required to accurately measure travel time and concentration for discharges of 36 cfs and 300 cfs were estimated to obtain a desired peak concentration of 10 part per billion (ppb).

Sampling design was set up in the following manner:

1. A discharge measurement was made at the injection point and sampling location for each segment prior to injection and sampling.

2. Dye was then injected at the top of a study reach and the time of injection and quantity of dye was recorded.

3. Automatic samplers located at the bottom of each study segment were set to begin sampling based on estimates of arrival time for the dye cloud.

4. Collected samples were marked, and relative dye concentrations were measured on site.

5.0 RESULTS

Flows declined rapidly during the high flow data collection, therefore a discharge of 300 cfs was not attained. Over the two day period an average discharge of 234 cfs was measured at the U.S.G.S. gage at Plummer. Discharges of 234 and 36 cfs roughly correspond to the 20 and 90 percent annual exceedence discharges.

Tables 5.1a and 5.1b summarize the results of the high and low flow studies. The total travel time from Clearwater Lake to Plummer at 234 and 36 cfs is 69.4 and 122.2 hours respectively. Total travel time is derived by summing the individual study reach centroid travel times.

Four families of graphs were produced to describe the flow characterstics throughout the study segment:

1. General timing and dye distribution curves (Figure 5.1). (See appendix A for individual study reach response curves.) In some instances the leading edge or tail of the dye cloud was not well defined during sampling and had to be estimated.

2. Travel time-distance relationships for the high and low flow conditions (Figure 5.2a and 5.2b).

3. Traveltime for peak concentrations through each study reach (Figure 5.3) based on discharge measurements made within each reach. (See appendix B for individual reache peak-travel time relationships).

4. Average velocity vs. discharge relationships for all sites over the range of flows between 36 and 234 cfs (Figure 5.4, see appendix C for all the study sites.). Table 5.2 describes the average velocity through the study segments derived from the arrival time of the peak concentration.

These graphs represent a few ways of presenting time of travel data and are not all inclusive. Tables 5.1a and 5.1b contain the data neecssary for other graphic representations. Please refer to Hubbard, 1982 for other examples of graphical presentation.

CLEARWATER RIVER TRAVEL TIME STUDY
LEADING EDGE, PEAK, CENTROID, TRAILING EDGE

TABLE 5.1A

DATA COLLECTED 5-11 TO 5-14-87

INDEX GAGE DISCHARGE: 36 cfs *

REACH	REACH LENGTH (mi.)	CUMULATIVE RCH. LGTH. (mi.)	QUANITY OF DYE (g)	LEADING EDGE (HR.) REACH	LEADING EDGE (HR.) CUMULATIVE	PEAK (HR.) REACH	PEAK (HR.) CUMULATIVE	CENTROID (HR.) REACH	CENTROID (HR.) CUMULATIVE	TRAILING EDGE(HR.) REACH	TRAILING EDGE(HR.) CUMULATIVE	MEASURED DISCHARGE IN REACH (cfs)	PEAK CONC. (PBB)	TIME PASSAGE OF CLOUD (HRS.) REACH	TIME PASSAGE OF CLOUD (HRS.) CUMULATIVE
1	8.2	8.2	710.8	10.92	10.92	13.42	13.42	14.01	14.01	22.5	22.5	44	12.2	11.58	11.58
2	8.8	17	7775	11.3	22.22	13.3	26.72	13.4	27.41	19.7	42.2	44	15	8.4	19.98
3	3.9	20.9	472.8	3.7	25.92	4.2	30.92	4.43	31.84	5.9	48.1	-	21.8	2.2	22.18
4	4.1	25	416.2	5.08	31	5.58	36.5	5.91	37.75	8.5	56.6	-	20.5	3.42	25.6
5	5	30	469.3	5.92	36.92	6.92	43.42	7.29	45.04	9.7	66.3	-	23.5	3.78	29.38
6	3.8	33.8	259.1	4.17	41.09	4.67	48.09	4.91	49.95	6.9	73.2	-	12.6	2.73	32.11
7	4.4	38.2	445.3	5.8	46.89	6.38	54.47	6.58	56.53	10.5	83.7	-	20.5	4.7	36.81
8	3.3	41.5	330.5	4.83	51.72	5.33	59.8	5.71	62.24	9	92.7	-	12.1	4.17	40.98
9	5.4	46.9	494.5	8.5	60.22	10.5	70.3	10.75	72.99	16.6	109.3	-	12.1	8.1	49.08
10	4.1	51	500.8	5.98	66.2	6.88	77.18	7.38	80.37	11.5	120.8	35	14.6	5.52	54.6
11	3.8	54.8	495.3	4.37	70.57	4.87	82.05	5.36	85.73	9.2	130	36.6	19.4	4.83	59.43
12	14.6	69.4	1018.3	29.58	100.15	35.08	117.13	36.42	122.15	50.9	180.9	36	7.3	21.32	80.75

* : FOUR DAY AVERAGE AT PLUMMER GAGE

TABLE 5.1B

DATA COLLECTED 6-26 TO 6-27-90

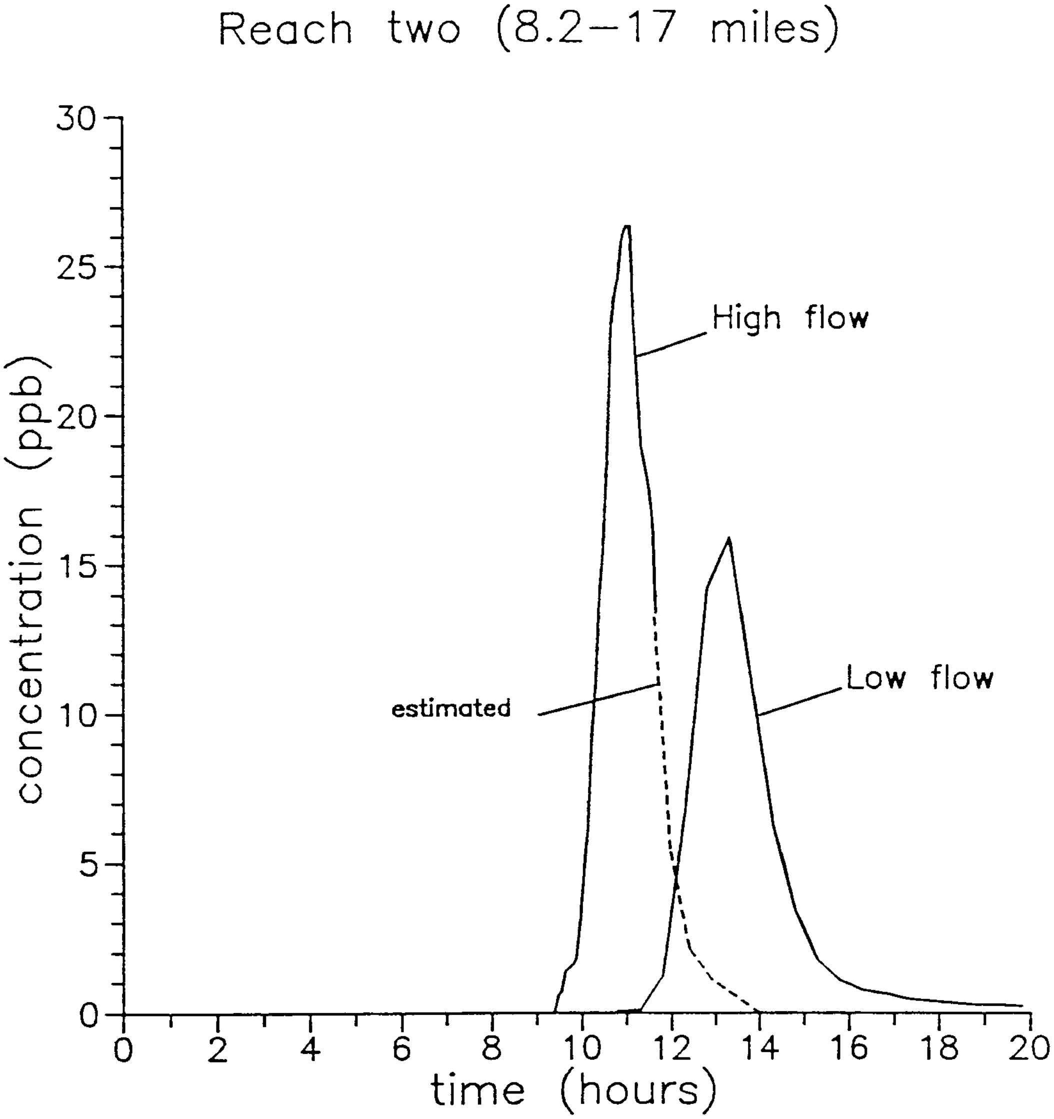
INDEX GAGE DISCHARGE: 234 cfs *

REACH	REACH LENGTH (mi.)	CUMULATIVE RCH. LGTH. (mi.)	QUANITY OF DYE (g)	LEADING EDGE (HR.) REACH	LEADING EDGE (HR.) CUMULATIVE	PEAK (HR.) REACH	PEAK (HR.) CUMULATIVE	CENTROID (HR.) REACH	CENTROID (HR.) CUMULATIVE	TRAILING EDGE(HR.) + REACH	TRAILING EDGE(HR.) + CUMULATIVE	MEASURED DISCHARGE IN REACH (cfs)	PEAK CONC. (PBB)	TIME PASSAGE OF CLOUD (HRS.) REACH	TIME PASSAGE OF CLOUD (HRS.) CUMULATIVE
1	8.2	8.2	2123.3	8.11	8.11	9.53	9.53	9.61	9.61	11.9	11.9	97	22.98	3.79	3.79
2	8.8	17	2170.6	9.47	17.58	11.01	20.54	11	20.61	12.4	24.3	110	26.3	2.93	6.72
3	3.9	20.9	1482.3	3.33	20.91	4.17	24.71	4.26	24.87	5.3	29.6	121	34.08	1.97	8.69
4	4.1	25	1523	2.92	23.83	3.5	28.21	3.6	28.47	4.17	33.8	196	32.6	1.25	9.94
5	5	30	1812.4	3.35	27.18	3.77	31.98	3.84	32.31	4.4	38.2	196	83.16	1.05	10.99
6	3.8	33.8	1367.4	2.82	30	3.23	35.21	3.32	35.63	3.9	42.1	204	69.66	1.08	12.07
7	4.4	38.2	1464.3	2.67	32.67	3.34	38.55	3.39	39.02	4.28	46.4	204	16.16	1.61	13.68
8	3.3	41.5	1025.7	2.64	35.31	3.3	41.85	3.42	42.44	4.2	50.6	237	35.79	1.56	15.24
9	5.4	46.9	1237.5	4.4	39.71	5	46.85	5.11	47.55	5.95	56.5	237	10.25	1.55	16.79
10	4.1	51	905.7	3.18	42.89	3.47	50.32	3.63	51.18	4.43	60.9	244	9.6	1.25	18.04
11	3.8	54.8	469.2	2.8	45.69	3.13	53.45	3.22	54.4	3.8	64.7	244	30.39	1	19.04
12	14.6	69.4	4485.8	13.35	59.04	14.85	68.3	14.98	69.38	16.85	81.6	234 *	15.65	3.5	22.54

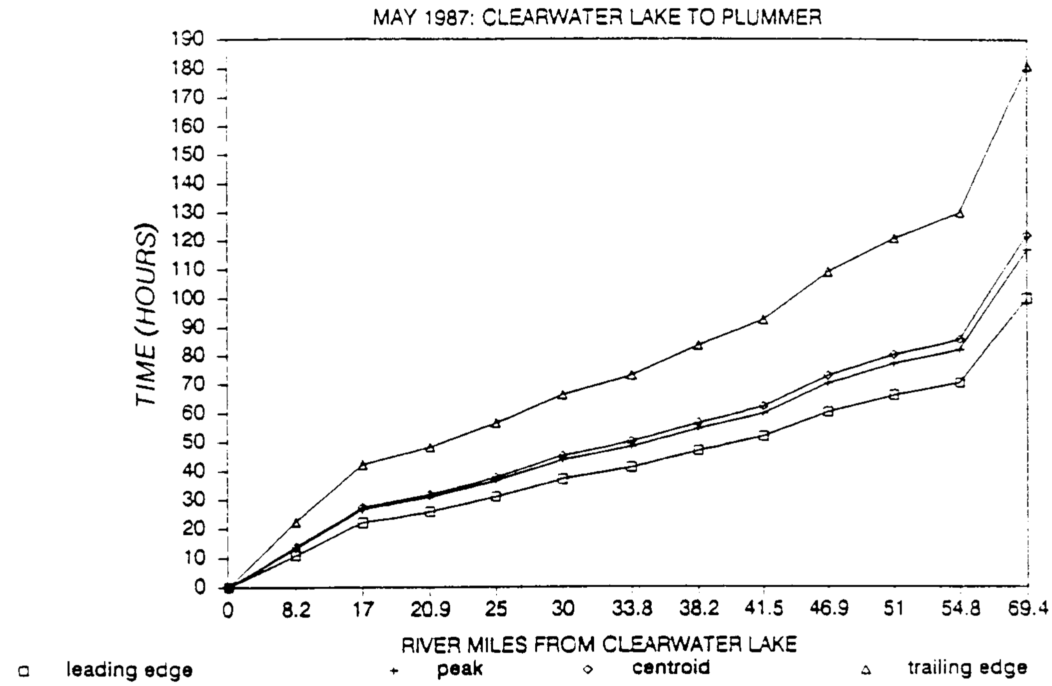
+ : BASED ON 10% OF PEAK CONC. STANDARD

* : TWO DAY AVERAGE AT PLUMMER GAGE

Figure 5.1 Study reach response to dye injections for the high and low flow conditions.



Figures 5.2a Travel-time distance relationships for the low flow condition (36cfs).



Figures 5.2b Travel-time distance relationships for the high flow condition (234cfs).

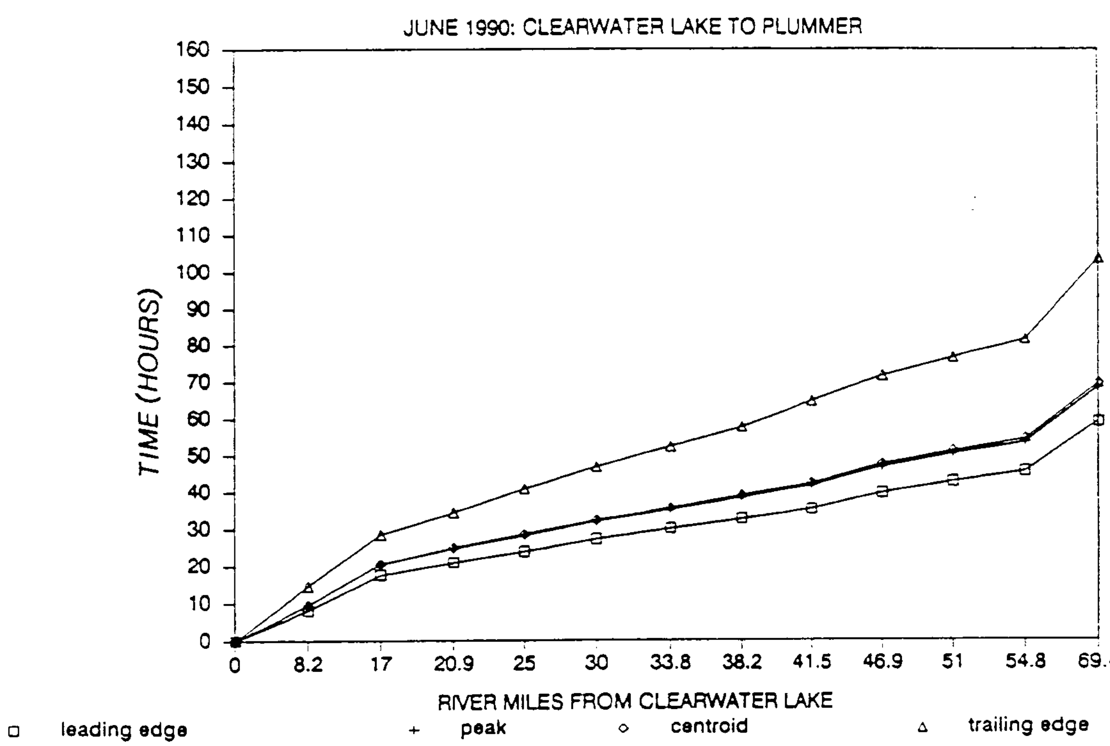


Figure 5.3

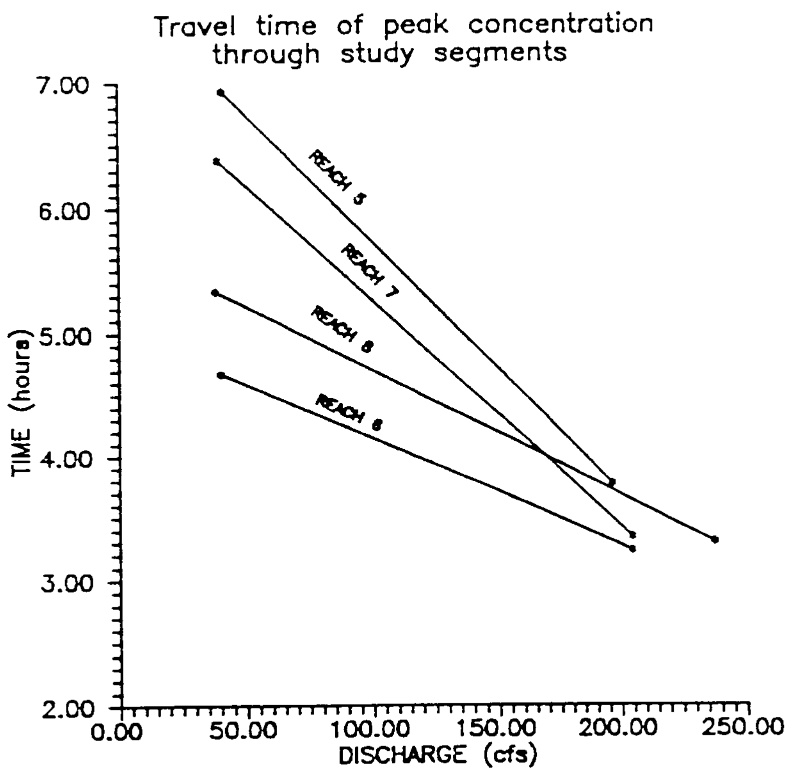


Figure 5.4

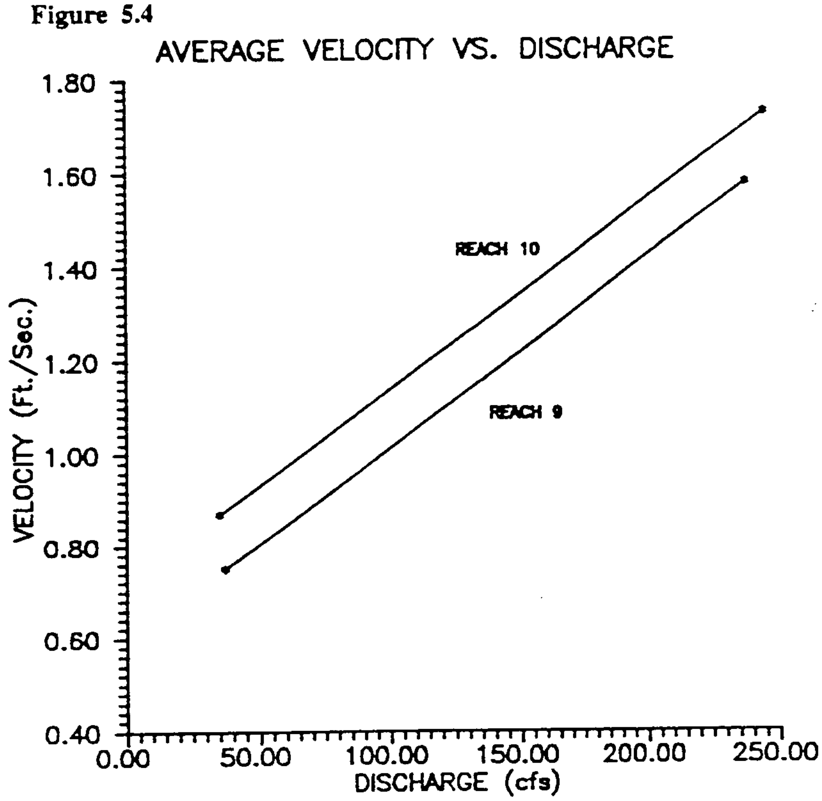


Table 5.2 Average velocity to discharge developed from time to peak for high flow (234 cfs), and low flow (36 cfs) dye tracings.

REACH	RCH. LGTH. (Mi.)	TIME TO PEAK (HOURS)		VELOCITY (MPH)		VELOCITY (FT/SEC)	
		HIGH FLOW	LOW FLOW	HIGH FLOW	LOW FLOW	HIGH FLOW	LOW FLOW
1	8.2	9.53	13.42	0.86	0.61	1.26	0.90
2	8.8	11.01	13.30	0.80	0.66	1.17	0.97
3	3.9	4.17	4.20	0.94	0.93	1.37	1.36
4	4.1	3.50	5.58	1.17	0.73	1.72	1.08
5	5.0	3.77	6.92	1.33	0.72	1.95	1.06
6	3.8	3.23	4.67	1.18	0.81	1.73	1.19
7	4.4	3.34	6.38	1.32	0.69	1.93	1.01
8	3.3	3.30	5.33	1.00	0.62	1.47	0.91
9	5.4	5.00	10.50	1.08	0.51	1.58	0.75
10	4.1	3.47	6.88	1.18	0.60	1.73	0.87
11	3.8	3.13	4.87	1.21	0.78	1.78	1.14
12	14.6	14.85	35.08	0.98	0.42	1.44	0.61

In general all of the natural channel segments (reaches 1, 2, 11, and 12) showed similar flow characteristics. The channelized reaches also showed similar relationships. Straight line interpletation between the two measured flows for any of the before mentioned descriptors (i.e. centroid peak, average velocity etc.) will yield acceptable results. This can be attributed to the uniform channel characteristics of the study reach. One should be cautious however, in any extrapolation beyond the measured flows.

6.0 CONCLUSIONS

The Clearwater River time of travel study was initiated in 1987 in order to better define the timing of flows through a 69 mile segment of the river with high user conflict. Originally the study plan followed U.S.G.S. guidelines for a low level time of travel study. In the latter part of 1989 water quality concerns in the Red Lake River watershed intensified, and resulted in the commencement of water quality investigations. Some of the agencies involved in the Clearwater time of travel study were also involved in the water quality research. The increased concern over water quality resulted in a higher level of data collection in the latter part of the time of travel study to better define water quality issues.

The Clearwater River time of travel investigation, in its current form, achieved its primary objective: Improved definition of the timing of flows on the river from Clearwater Lake to the town of Plummer for a wide range of flows (20 to 90 percent annual exceedence discharges). Due to existing low water conditions in the region the study was unable to examine a flow above 300 cfs. Further definition of time of travel above this level would enhance the existing work and improve our understanding of the river. In order to examine the dispersion rate of contaminants when addressing water quality issues, additional information would be needed at the low flow level (36 cfs) and also at any higher flow to be studied in the future.

If the reader has any questions related to this study or would like to discuss specific applications of the results, please contact Greg Kruse (612) 297-2402, or Dave Leuthe (612) 297-3886.

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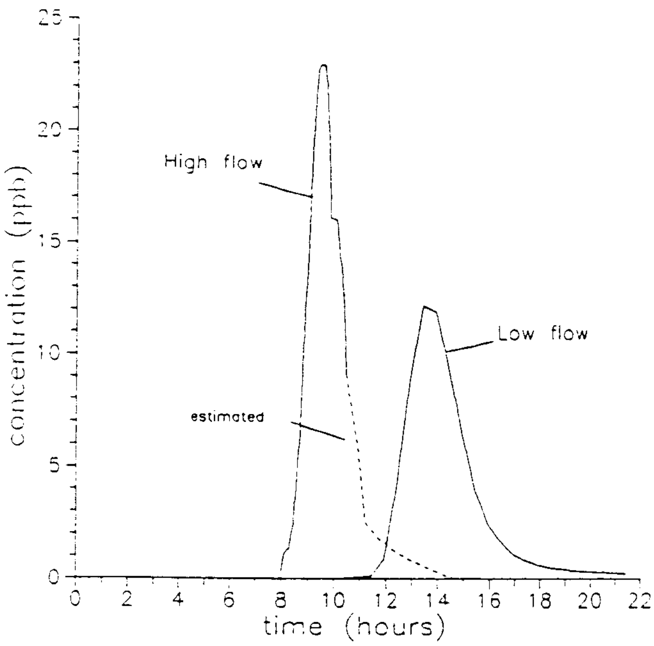
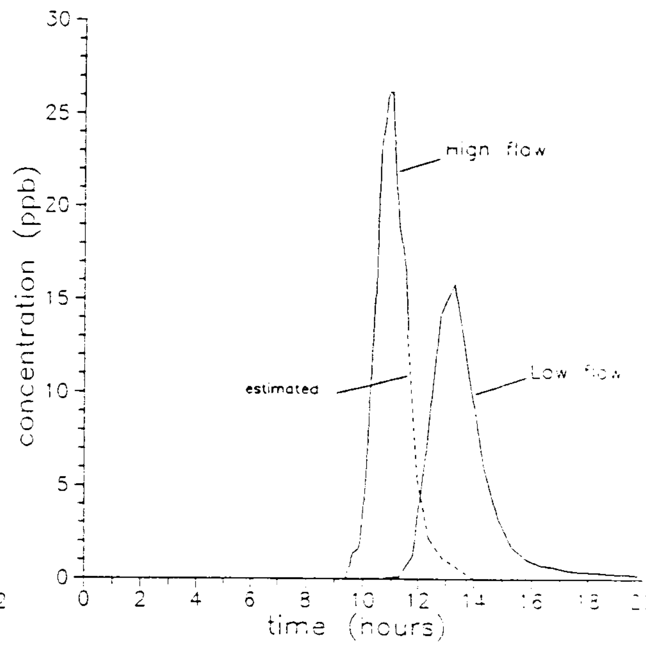
APPENDIX A

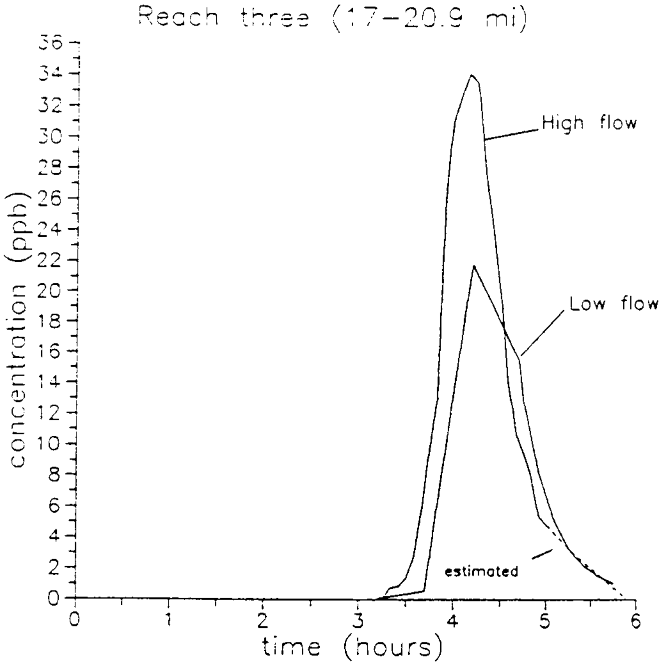
Reach one (0–8.2 miles)



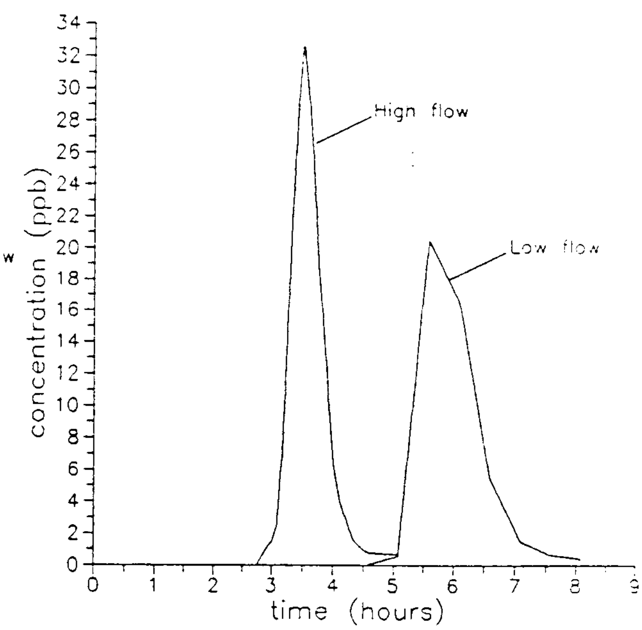
Reach two (8.2–17 miles)

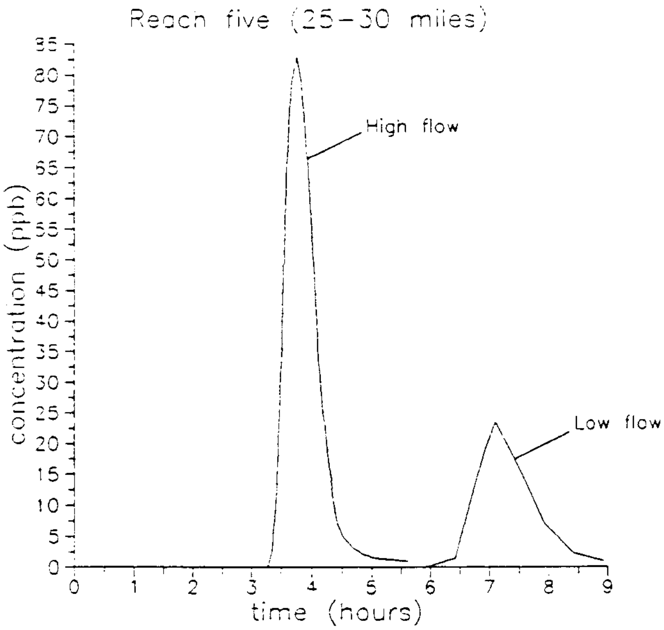


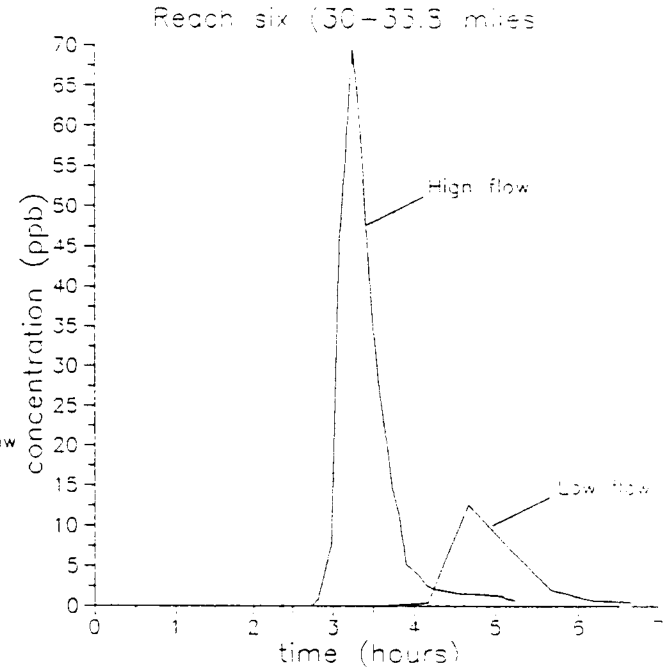
Reach three (17–20.9 mi)

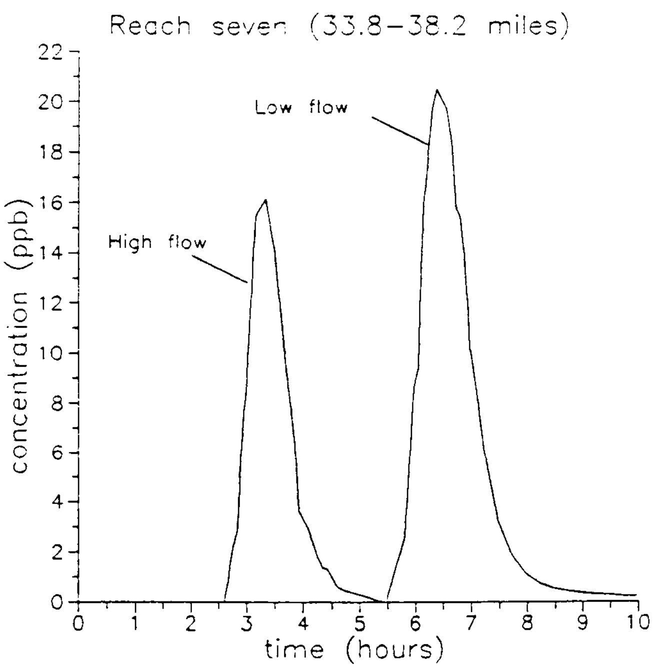


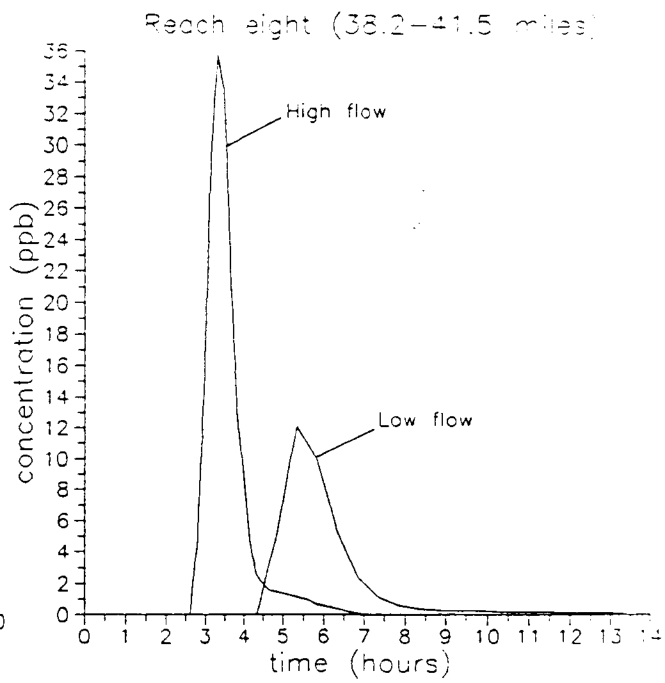
Reach four (20.9–25 miles)

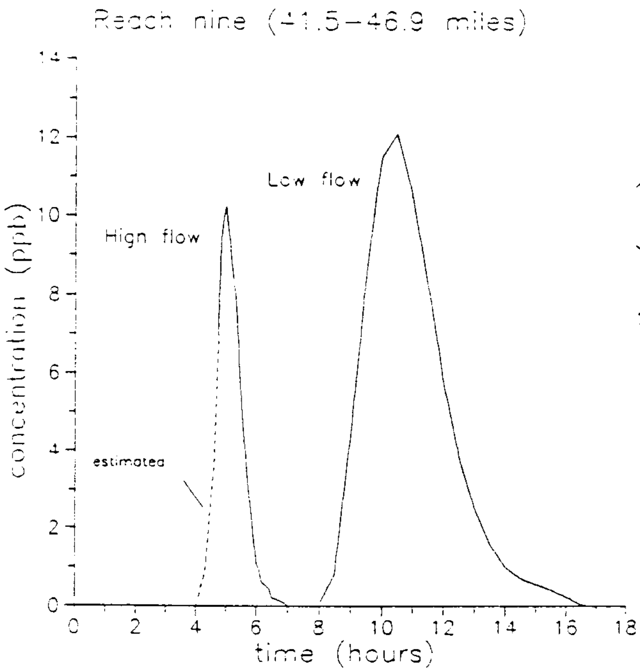


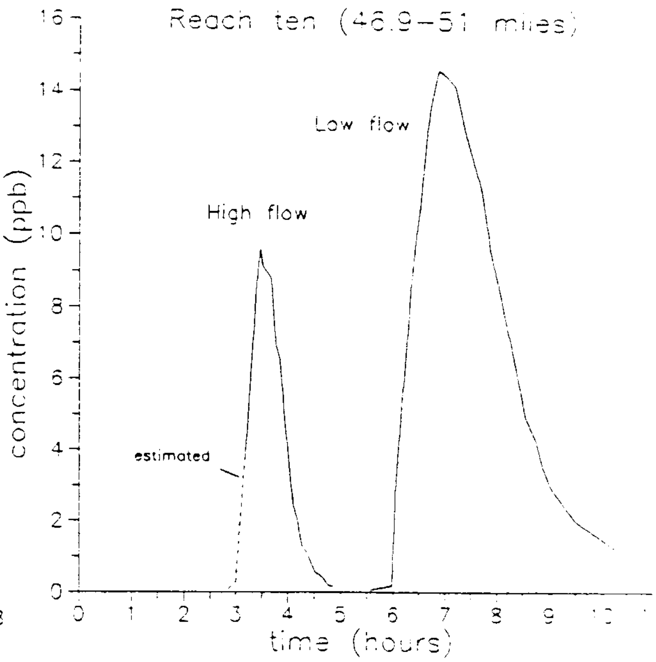

Reach five (25–30 miles)
concentration (ppb)
time (hours)
High flow
Low flow

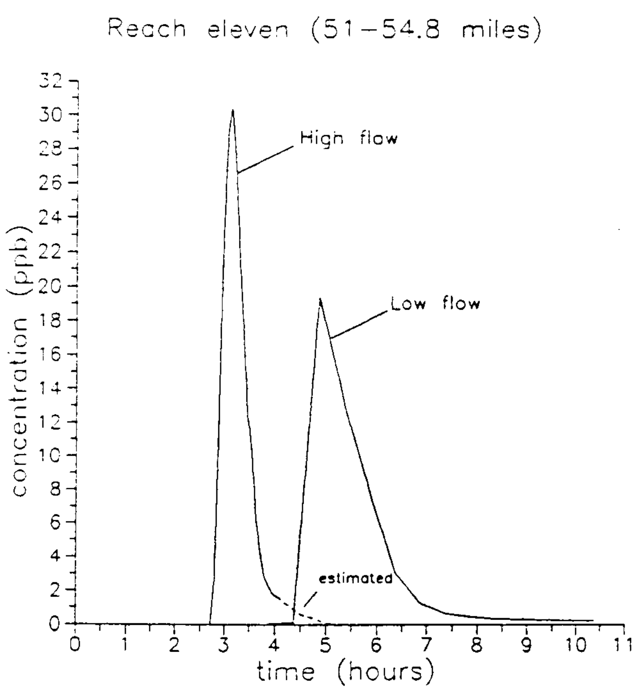

Reach six
concentration (ppb)
time (hours)
High flow
Low flow

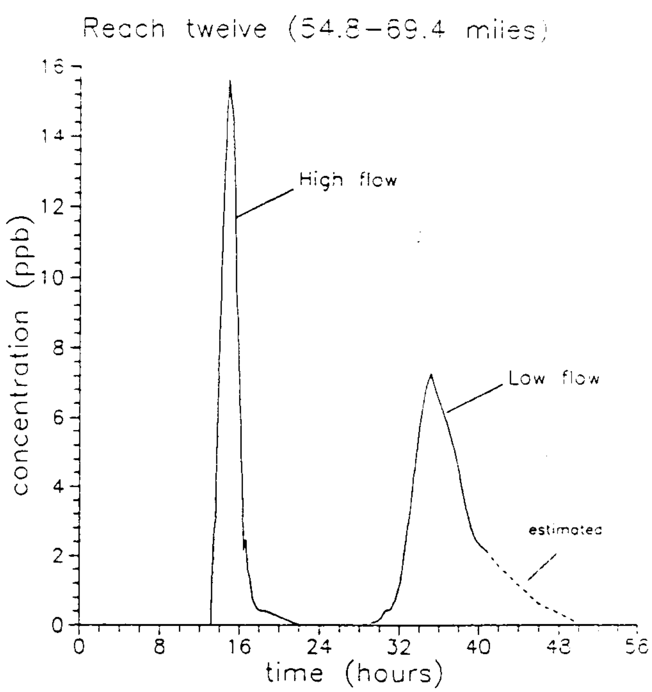

Reach seven (33.8–38.2 miles)
concentration (ppb)
time (hours)
Low flow
High flow


Reach eight (38.2–41.5 miles)
concentration (ppb)
time (hours)
High flow
Low flow

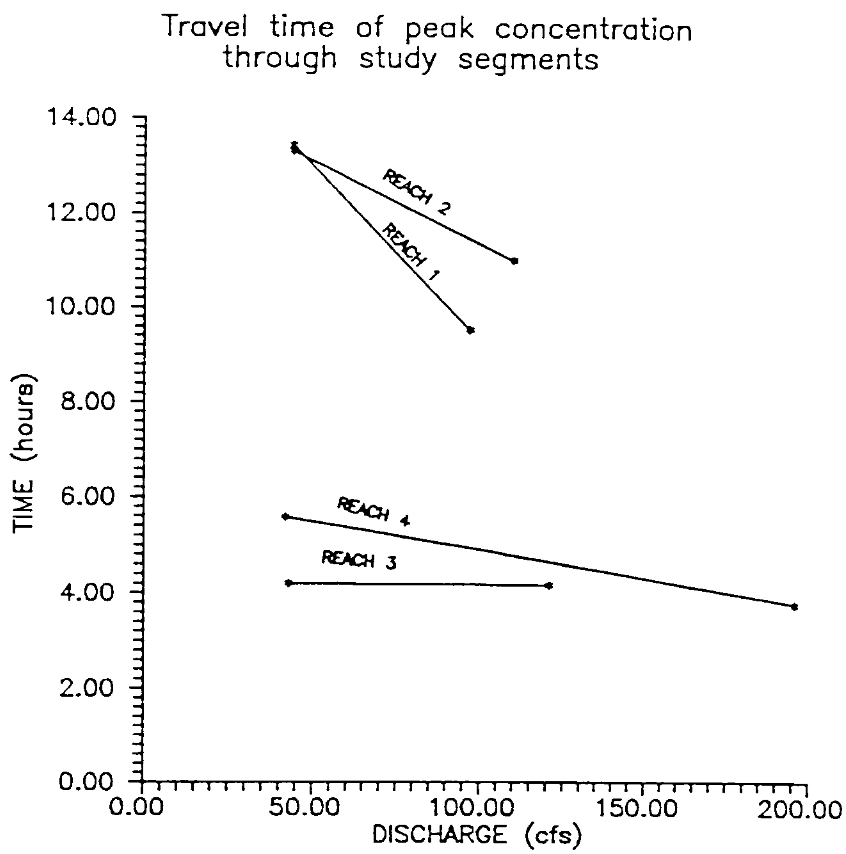

Reach nine (41.5–46.9 miles)
High flow
Low flow
estimated
concentration (ppb)
time (hours)

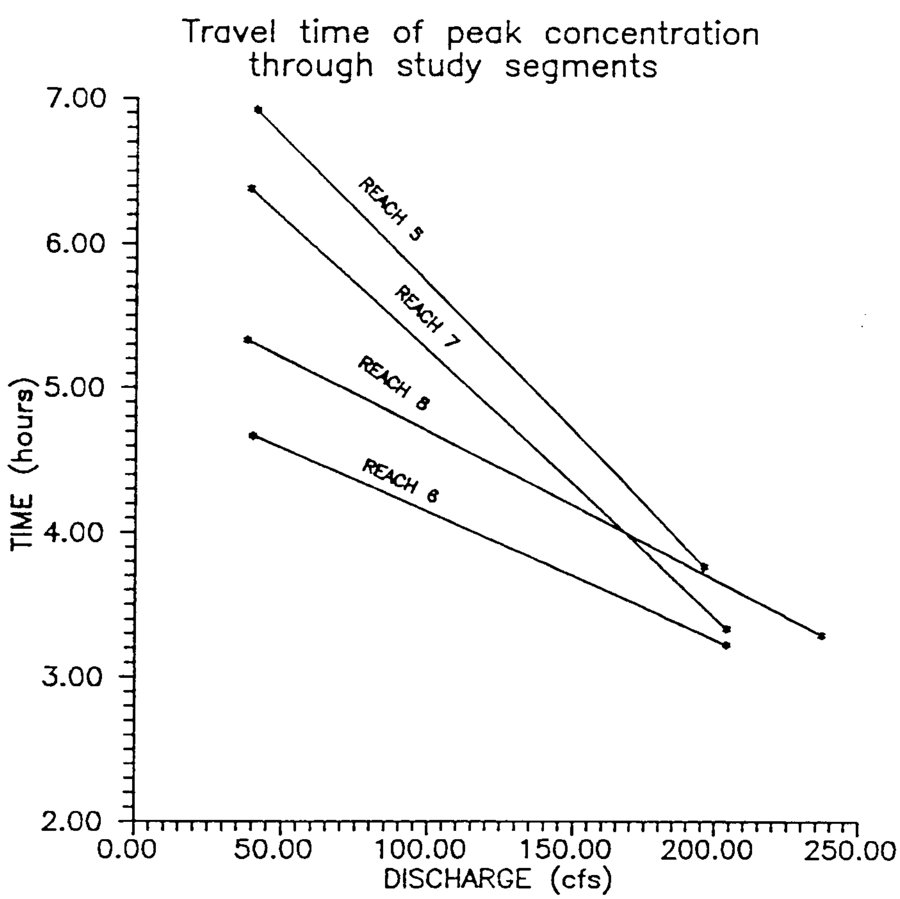

Reach ten (46.9–51 miles)
Low flow
High flow
estimated
concentration (ppb)
time (hours)

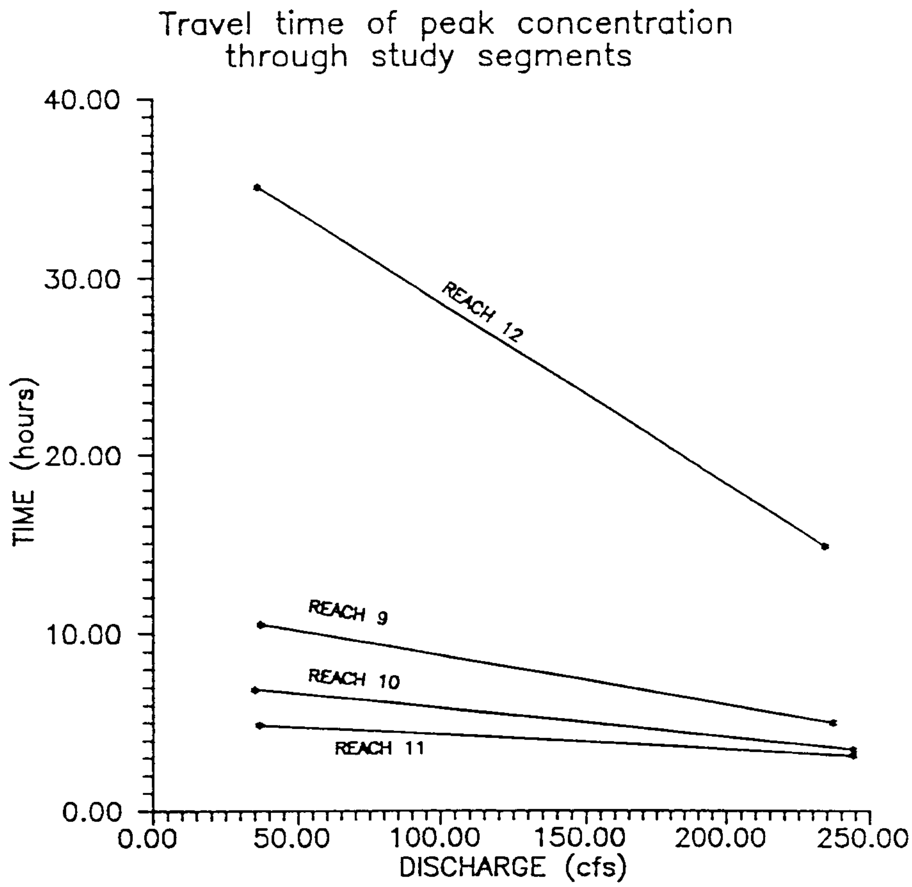

Reach eleven (51–54.8 miles)
High flow
Low flow
estimated
concentration (ppb)
time (hours)


Reach twelve (54.8–69.4 miles)
High flow
Low flow
estimated
concentration (ppb)
time (hours)

APPENDIX B

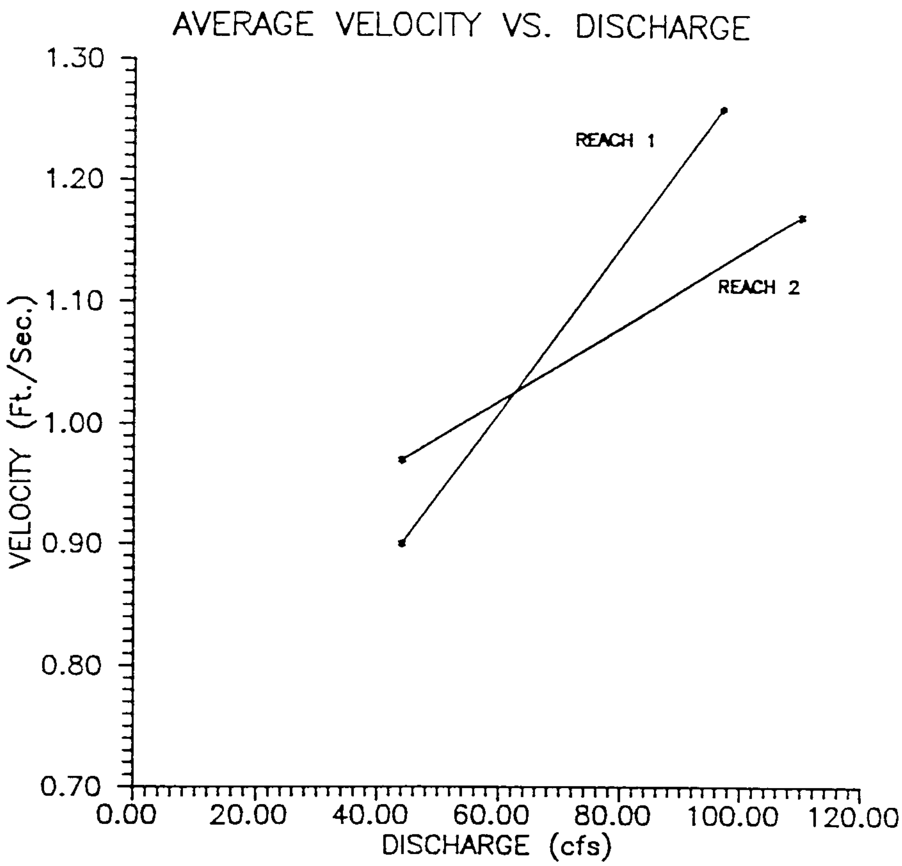

Travel time of peak concentration
through study segments
TIME (hours)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
DISCHARGE (cfs)
0.00
50.00
100.00
150.00
200.00
REACH 1
REACH 2
REACH 3
REACH 4

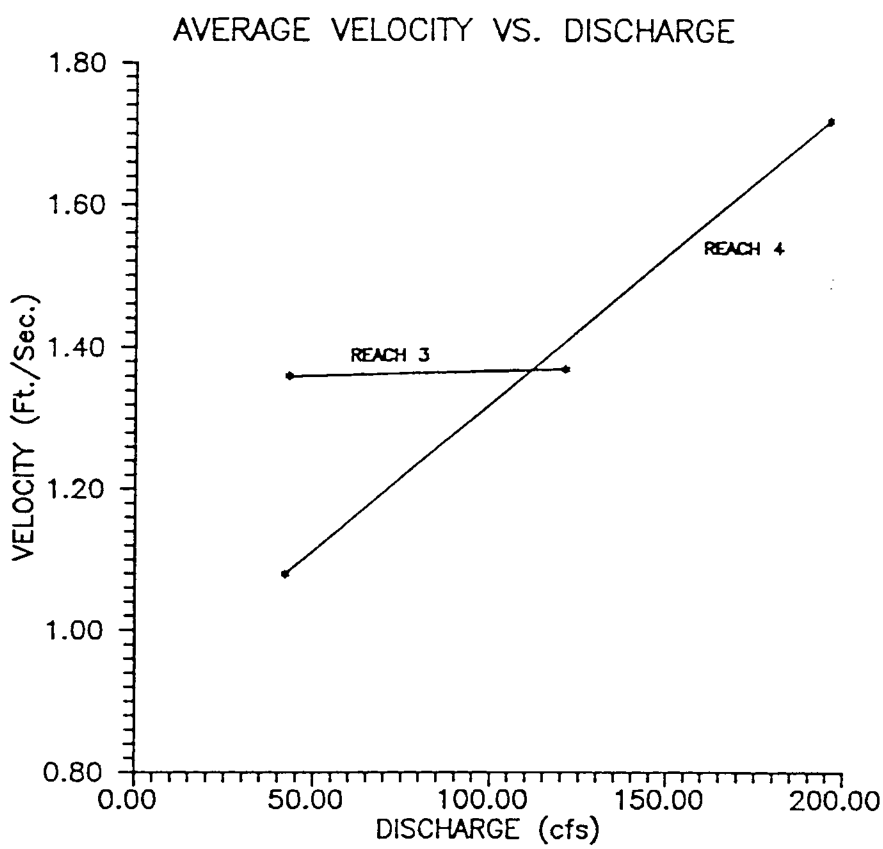

Travel time of peak concentration
through study segments
TIME (hours)
7.00
6.00
5.00
4.00
3.00
2.00
DISCHARGE (cfs)
0.00
50.00
100.00
150.00
200.00
250.00
REACH 5
REACH 7
REACH 8
REACH 6

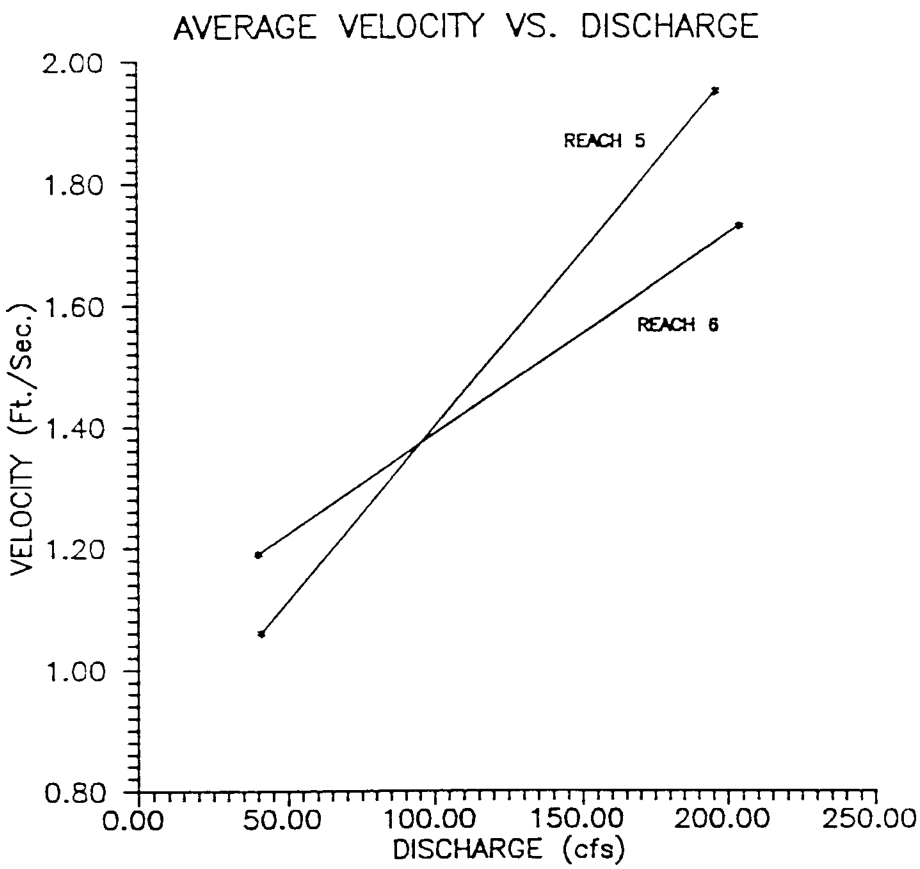


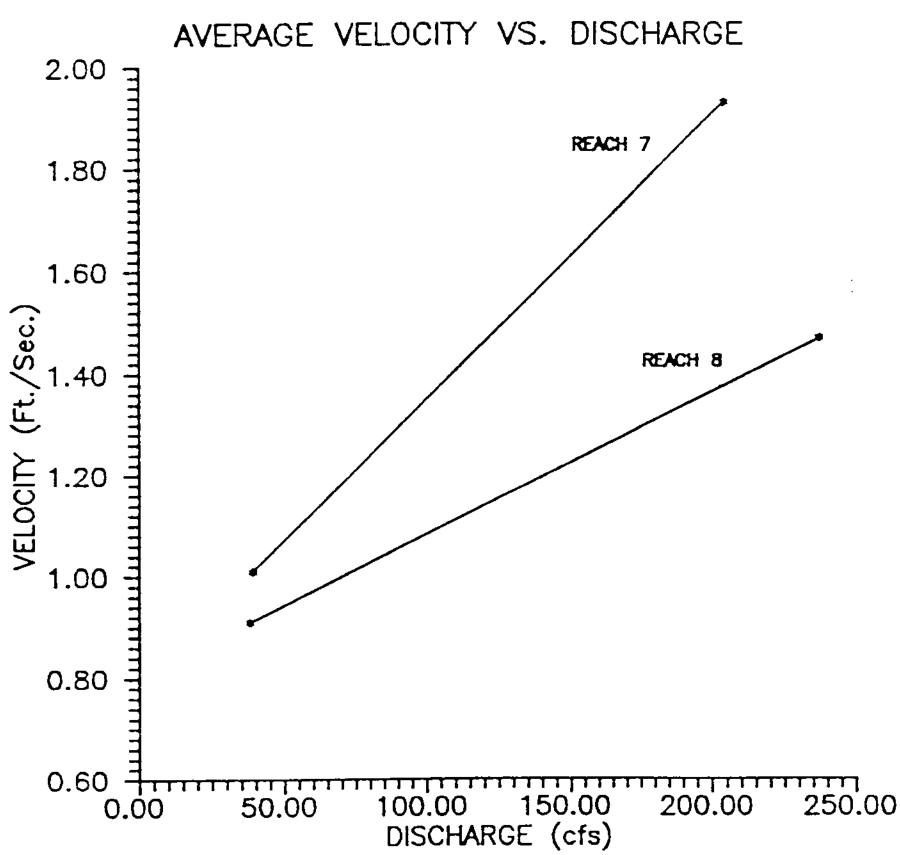
Note: The velocity and discharge relationships have been derived for actual discharge measured within the individual study segments and are not based on the index gage at Plummer.

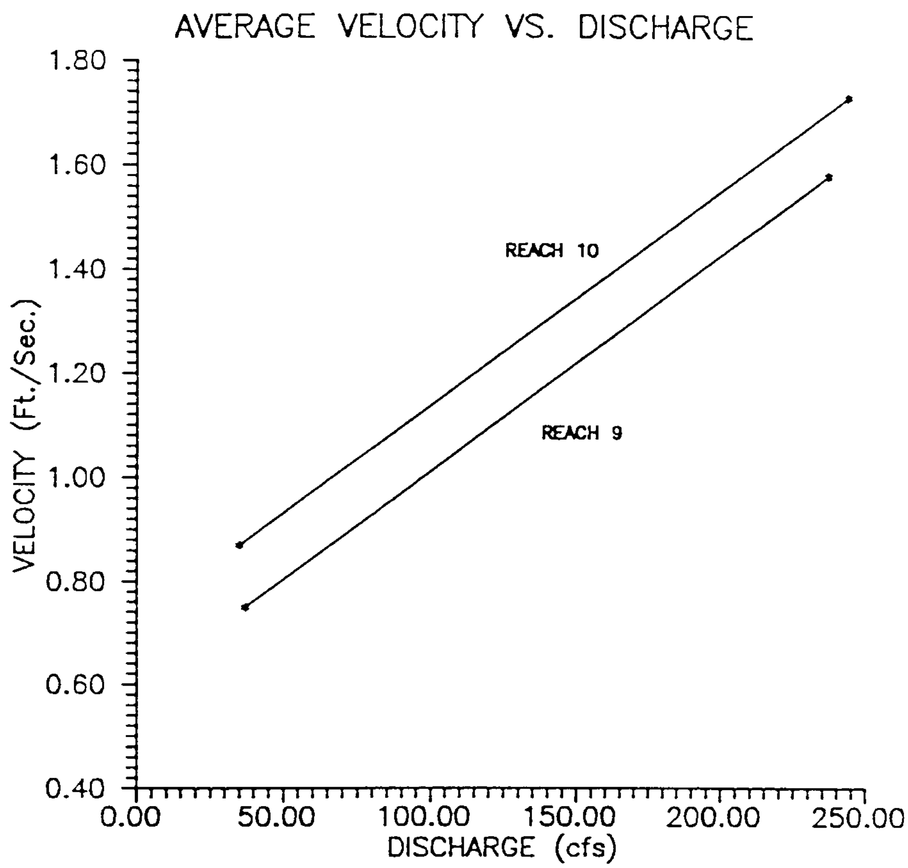
APPENDIX C

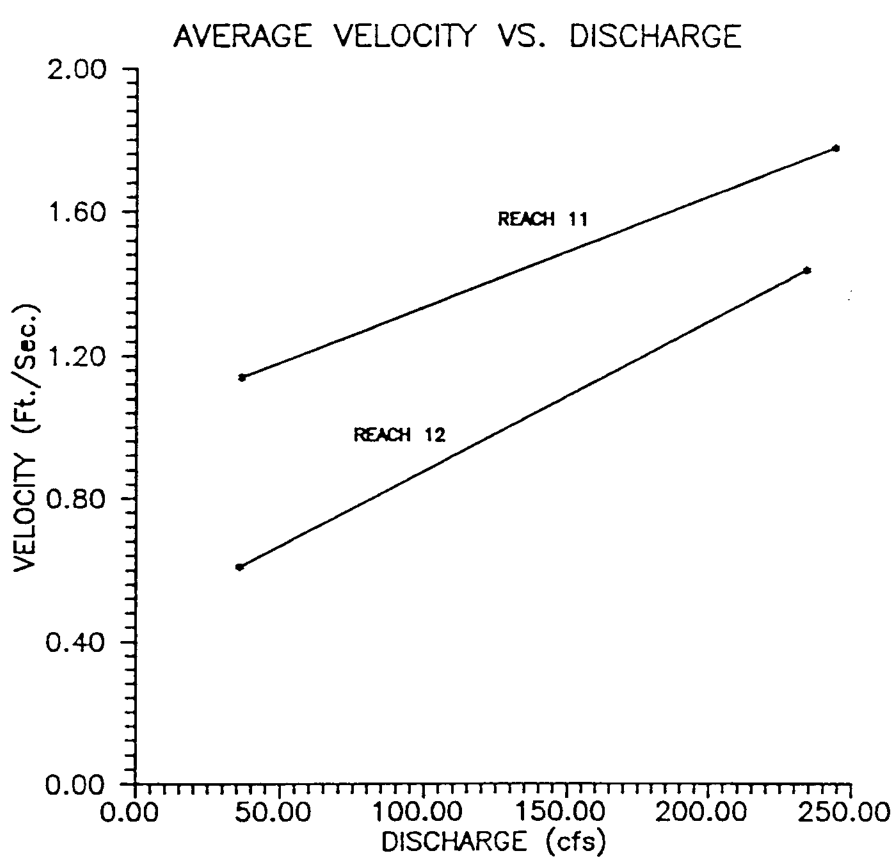

AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.00
20.00
40.00
60.00
80.00
100.00
120.00
DISCHARGE (cfs)
REACH 1
REACH 2


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
1.80
1.60
1.40
1.20
1.00
0.80
0.00
50.00
100.00
150.00
200.00
DISCHARGE (cfs)
REACH 3
REACH 4


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
DISCHARGE (cfs)
REACH 5
REACH 6
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.00
50.00
100.00
150.00
200.00
250.00


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
DISCHARGE (cfs)
REACH 7
REACH 8
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.00
50.00
100.00
150.00
200.00
250.00


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
REACH 10
REACH 9
0.00
50.00
100.00
150.00
200.00
250.00
DISCHARGE (cfs)


AVERAGE VELOCITY VS. DISCHARGE
VELOCITY (Ft./Sec.)
2.00
1.60
1.20
0.80
0.40
0.00
REACH 11
REACH 12
0.00
50.00
100.00
150.00
200.00
250.00
DISCHARGE (cfs)

Note: The velocity vs. discharge relationships have been derived for actual discharge meausred within the individual study segments and are not based on the index gage at Plummer.