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16. Abstract

This report covers the initial 15 months of effort to review the literature, select a prototype site, compare the performance of several automatic sampling devices, and install a prototype sampling site on I-5 north of Seattle.

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PREFACE

This report summarizes the initial 15-month effort of the Runoff Water Quality project to identify how, where and when to sample storm runoff from highways. The contents of this report reflect the chronological development of the first year's activity from site selection to field observation.

Separate reports have been prepared to describe specific tasks. Other reports in this series include:

Review of the Literature on Water Quality Impacts of
Highway Operations and Maintenance; December, 1977.

Task D: Effects of Velocity and Nutrient Alterations on
Stream Primary Producers and Associated Organisms; November, 1978

Background Conditions in the Lower Pilchuck River Prior to
SR 2 Construction (1977-78); March, 1979.

SELECTION OF MONITORING SITES

Planning for highway runoff monitoring began with visits to each District Office during the Summer of 1977 to explain the goals of the research project and explore potential sites for sampling stations. Discussions with district personnel were aimed at identifying general highway monitoring sites offering a variety of traffic, roadway-type, geographic and climatic conditions. In addition, contacts in each district were asked to suggest existing highways providing the opportunity to study runoff water quality problems of a specialized nature, as well as planned construction which would impact local streams or lakes during construction and/or operations. The latter group of sites would be considered for baseline studies of pre-existing water quality conditions, followed up by monitoring of the impact for comparison.

As the process advanced toward selecting the first long-term, fully-equipped highway runoff monitoring site to be placed in the Seattle area near the University, District 1 was requested to assist further in expanding the list of candidate sites to insure the choice of a station most suitable for initiating monitoring. Table I lists all sites identified by the districts, either during the initial screening or in the subsequent contact with District 1, to serve the various purposes of the project.

The list of suggested sites was evaluated according to a number of criteria to make tentative selections for further planning of the statewide monitoring program (including the site's ability to represent each of the state's distinct climatic regions, to furnish a range of traffic volumes and to provide various types of traffic). Considered in the latter category were freeway and arterial road types, as well as highways in urban, agricultural and natural areas. Another primary characteristic favoring the selection of a site for general runoff monitoring was the degree of segregation of highway drainage from any

TABLE I

POTENTIAL MONITORING SITES IDENTIFIED BY DISTRICT PERSONNEL

District	Site Location	Purpose
1	SR 2 at Pilchuck River, near Snohomish	Special study - effects of channel change
	I-90 at Echo Lake	Special study - grease and oil trap performance
	SR 92 at Stevens Lake	Runoff quality with light traffic
	SR 527 at Silver Lake	Runoff quality with medium traffic
	SR 509 at Miller Creek	Baseline study
	I-5 at Allison Street drain to Lake Union	Runoff quality with heavy traffic
	I-5 at N.E. 158th Street	Runoff quality with heavy traffic
	SR 520 at Portage Bay	Runoff quality with heavy traffic
	I-5 south of Kingdome	Runoff quality with heavy traffic
	SR 509 northbound north of S. 112th Street	Runoff quality with medium traffic
	I-405 at Kirkland grease trap	Runoff quality with heavy traffic
	I-405 elevated section at Renton	Runoff quality with heavy traffic
	I-5 southbound north of Boeing Field	Runoff quality with heavy traffic
	I-5 at Eastlake Avenue	Runoff quality with heavy traffic
2	Business SR 2 at Columbia River Bridge, southern portion of Wenatchee	Runoff quality from arterial with medium traffic
	location not fixed	Special study - comparison of washed and unwashed sand for winter maintenance
	location not fixed	Special study - impact of roadside ditch maintenance on runoff quality

Table 1 (continued)

District	Site Location	Purpose
3	Port Angeles area	Special study - logging debris
	SR 16 at China Lake	Baseline study
	SR 3 at Trident base	Baseline study
3/4	SR 101 in Gray's Harbor/Raymond area	Special study - sawdust fill leachate and herbicide usage
4	I-5 at Columbia River Bridge, Vancouver	Runoff quality with heavy traffic
	I-205 at Columbia River, east of Vancouver	Runoff quality with light traffic
	SR 500 at Burnt Creek	Baseline study
	I-5 at Salmon Creek	Special study - runoff from highway accidents
5	I-90 at Snoqualmie Pass	Runoff quality in wet, high mountain area
	I-82 at Wide Hollow Creek, Union Gap	Baseline study
	I-82 at Yakima River Bridge, Prosser	Baseline study
	Undesignated freeway site in Tri-Cities area	Runoff quality in agricultural area
6	I-90 at Latah Creek	Runoff quality with heavy traffic
	Parkway Street at Spokane River	Runoff quality from arterial with medium traffic
	North Division Street, Spokane	Runoff quality from arterial with heavy traffic

other source. Also considered in the evaluation were such characteristics as:

- Type of road surface (concrete, asphalt)
- Contribution to runoff from portion of right-of-way outside traffic lanes
- General site topography (level, upgrade, downgrade, cut, fill)
- Extraneous air pollution contributions to contaminants in highway runoff
- Type of drainage system (closed, lined open channel, unlined open channel)
- Maintenance practices (vegetation control, sweeping, washing, de-icing)
- Availability of electric power
- Security and convenience
- Slope of drainage (avoidance of supercritical flow)

Tentative monitoring site selections resulting from the review are listed in Table II. The first portion of the table summarizes the attributes of the choices for long-term runoff sampling. Below that are presented the selections for special studies and baseline water quality investigations.

Table II demonstrates that long-term site selections will represent the full range of climatic conditions and traffic volumes represented across the state. These choices are expected to produce a data set suitable for firmly establishing the roles of traffic volume, precipitation and other climatic factors in determining the concentrations and loadings of contaminants in highway runoff. In regard to traffic, selection of sites on paralleling highways I-5 and I-205, which have substantially different volumes, would be especially revealing. Tentative selections do favor freeways over arterials and rural roads and urban over nonurban areas. These choices reflect both the usual occurrence of problem areas and the expected type and site of future construction, the planning for which will use the results of the research program.

Long-term sites will be monitored for periods of two or more years to establish general relationships among contaminant concentrations and loadings

TABLE II

TENTATIVE MONITORING SITE SELECTIONS FOR HIGHWAY RUNOFF WATER QUALITY RESEARCH PROGRAM

Long-Term Runoff Sampling Sites

Location	District	Climate	Traffic Volume	Road Type	Surrounding Area
I-5 at N.E. 158th Street, Seattle	1	wet, lowland	heavy	freeway	urban
I-5 at Columbia River Bridge, Vancouver	4	wet, lowland	heavy	freeway	urban
I-205 at Columbia River	4	wet, lowland	light	freeway	urban
I-90 at Snoqualmie Pass	5	wet, high mountain	medium	freeway	natural
Tri-Cities area	5	dry	light	freeway	agricultural
North Division Street, Spokane	6	semi-dry, spring snow-melt	heavy	arterial	urban

Special Problem Sites

Location	District	Problem
I-90 at Echo Lake	1	Grease and oil trap performance
Proposed SR 2 near Snohomish	1	Pilchuck River channel change
Port Angeles area	3	Logging debris
SR 101 in Gray's Harbor/Raymond area	3/4	Sawdust fill leachate, herbicides

Baseline Receiving Water Quality Sampling Sites

Proposed Highway	Receiving Water	District
SR 509, Burien	Miller Creek	1
SR 2 Euclid Avenue, Wenatchee	Columbia River	2
SR 16	China Lake	3
SR 3 at Trident base	Hood Canal	3
SR 500	Burnt Creek	4
I-82 at Union Gap	Wide Hollow Creek	5

and precipitation, traffic and drainage basin surface area. Monitoring at the special problem sites will proceed for a shorter period, until a consistent pattern of behavior emerges. In the case of the baseline stations, projected receiving waters will be sampled and analyzed on a regular schedule for at least one year preceding and following construction, as well as during the construction phase. Fulfilling these tentative plans, of course, depends upon the compatibility of construction and research project schedules.

PRELIMINARY SR 520 MONITORING PROGRAM

The literature review conducted for the research project (Horner _et al_., 1977) revealed a considerable amount of inconsistency in reported concentrations and loadings of highway contaminants. Moreover, previous highway runoff monitoring programs demonstrated no consistency in field methods or means of expressing loadings. Furthermore, none of the studies reviewed were performed under climatic conditions characteristic of major regions in Washington. For all of these reasons, it was decided to accelerate the schedule to initiate a preliminary sampling effort within the current project's first year and to outfit the first long-term station at the beginning of the second year.

Objectives set for the preliminary study were the following:

1. To gain experience in anticipating runoff-producing storms, collecting samples manually and preserving and analyzing samples.
2. To compare the efficacy of characterizing runoff by means of a series of samples drawn directly from drains (discrete) versus sampling from a composite collection vessel.
3. To investigate various methods of expressing the loadings of contaminants and to gain some understanding of the relative importance of surface area, traffic volume and precipitation characteristics in determining loading.
4. To test the performance of automatic samplers during the latter part of the program, when such equipment would be available.

The site of the preliminary study was the same location employed by Sylvester and DeWalle (1972) in their earlier highway runoff study, at SR 520 on the east shore of Portage Bay in Seattle. This site was selected because of its convenience to the University and a National Weather Service meteorological station, as well as the accessibility of the drains and their adaptability to the objectives outlined.

Site Description

The study area encompassed both east- and westbound lanes of SR 520 at an elevated section on the Portage Bay Bridge approach. A median barrier divides the two east- and two westbound lanes, which drain separately through gratings at the road surface to small collection boxes and four-inch diameter vertical steel downspouts. These spouts discharge onto SR 520 right-of-way beneath the bridge adjacent to the National Marine Fisheries Service (NMFS) research station. The specific drains sampled were chosen in preference to others to the west, on the bridge itself, or to the east because of their accessibility and minimization of on- or off-ramp surface. Drain 1 serves two westbound lanes plus a portion of an on-ramp totaling 43 ft wide x 100 ft long, or 4300 ft^2. Drain 2 serves two east-bound lanes totaling 29 ft wide x 100 ft long, or 2900 ft^2. Both lanes have minimal shoulder and median area and are entirely paved. Each downspout was fitted with plastic hose to conduct the flow to covered, reconditioned 55 gallon oil drums placed beneath the drains on the NMFS parking lot.

Paving material at this site is concrete. The roadway has minimal slope (< 1 percent), but the on-ramp slopes are a few percent. An expansion joint exists within the 100 ft section sampled, causing loss of some portion of the runoff from the collection system. Additional potential losses were traffic spay over the side barriers and drainage downslope into an adjacent collection box. On the other hand, flow could have been supplemented by drainage from a section upslope. No study was conducted to define the exact drainage patterns, but runoff coefficients were estimated as described in the next section.

SR 520 is a limited access urban freeway connecting Seattle with its eastern suburbs via the Evergreen Point Bridge crossing Lake Washington. It is heavily traveled by commuting private cars and local buses, as well as some truck traffic. Thus, westbound lanes have a daily traffic peak in the morning hours and eastbound lanes in the late afternoon. Morning westbound traffic normally moves steadily at 40-50 mph, but afternoon rush hour eastbound traffic backs up from the bridge toll booths and usually moves very slowly in a stop-and-go fashion.

During the period of the preliminary study (January 1 - May 31, 1978), the roadway was swept by the City of Seattle every 10 - 14 days. Sand was applied in small quantities occasionally during the winter months. Otherwise, no maintenance was performed during the study.

Weather data were provided by the National Weather Service Portage Bay station, located within NMFS property approximately 150 ft from the runoff sampling site. Hourly precipitation records are maintained by this station. The Washington State Department of Transportation supplied exact traffic counts at 15 or 60 minute intervals. From recorders less than one-half mile to the west near the I-5 junction. These recorders accurately represented traffic flow through the sampled section, with the exception of including the small volume of eastbound traffic which exists at Montlake Boulevard prior to the site.

Sample Collection and Analytical Procedures

For the first half of the program both drains were sampled on the same schedule. After it had been established that runoff in the two drains was very similar, only the westbound lanes were sampled to permit concentration on other tasks. Westbound lanes were selected because they avoided the problem of very slowly moving rush hour traffic, which was judged to be more serious than including on-ramp vehicles. Three types of samples were drawn during the preliminary program. Most common was discrete sampling, in which one-liter portions of highway runoff were collected directly from the drains in plastic bottles. In this situation the flexible hoses were disconnected from the oil drums. A discrete sample was typically collected every 5-10 minutes during the first hour of a storm, every 15-20 minutes during the second and third hours and every 30-60 minutes thereafter.

Composites, a second type of sample, were drawn from the drums after the contents were thoroughly mixed with a stick. Composite sampling was performed at the beginning of storms when runoff began to collect before the technician reached the monitoring station. In addition, several composite samples were drawn for comparison with total contaminant accumulations estimated from a series of discrete samples collected during the same runoff period. Drums were prepared for composite sampling by emptying the previous contents and thoroughly washing with a hose attached to the city water supply.

The third means of sampling at SR 520 involved operating ISCO Model 1680 and Manning Model 4050 automatic samplers side-by-side for performance comparison. For this purpose the samplers were set up to take a simultaneous series of composite samples from the same oil drum collector. At the SR 520 site this operation had to be attended by a technician, who set the sampler timers when runoff began and stirred the drum just prior to sample removal. With automatic samplers available for only the final month of the first year program, data from this phase were limited, and will be reported in the year 2 report.

In the discrete sampling mode, flow rate was measured at least once during the period between samples. Flow rate was determined by measuring the level rise in the oil drums with a meter stick over an interval timed by a stop watch. Measurement of the cross-sectional area of the drums permitted conversion of the timed level rise to units of volume per unit time. When composite samples were collected, total flow volume was determined from the measured level rise in an initially empty drum. Runoff coefficients expressing actual runoff as a percentage of that expected were estimated for eastbound and westbound lanes. Estimates were made on the basis of eight comparisons of precipitation volume on the measured areas to total collected runoff.

Runoff samples were analyzed for pH and specific conductivity onsite immediately after collection. The pH was measured by a Leeds and Northrup Model 7417 pH meter. A Barnstead Model PM-70cB meter was employed to measure specific conductivity.

The remainder of each sample was preserved with concentrated sulfuric acid to $pH < 2$ and transported to the laboratory for performance of additional analyses within seven days of sampling. In the laboratory turbidity was determined in Formazin Turbidity Units (FTU) by means of a Hach Model 2100 turbidimeter. Total and volatile suspended solids (TSS and VSS) were measured by the gravimetric procedures in Standard Methods (American Public Health Association, 1975). Chemical oxygen demand (COD) was determined using the dichromate reflux procedure, also in Standard Methods. All quantities were measured throughout the program, except for VSS, which was not analyzed in the first month.

Contaminant levels were expressed in terms of various loadings, as well as in concentrations as measured. A loading represents the long-term burden created by intermittent discharge of a contaminant to the receiving water. It is generally expressed on the basis of time and traffic, roadway and/or meteorological conditions. Concentration is of shorter-term significance to biota, determining the acute effects of isolated runoff events. In particular, the usually elevated concentration prevailing in the "first flush," within the first 1-3 hours of storms, represents the most severe acute threat to organisms.

Selection of loading expressions for TSS, VSS and COD was guided by experience reported in the literature and summarized by Horner et al., (1977). The following loadings were estimated from those data representing full storms and were subsequently evaluated for their applicability to the objectives of the research program:

mg contaminant/m^2 road surface - dry day
lb contaminant/mile roadway - dry day
lb contaminant/acre road surface - inch rain
lb contaminant/vehicle - mile roadway
mg contaminant/m^2 road surface - vehicle - mm rain

The first four expressions appear in the literature, and the fifth combines major factors which might influence the total weight of contaminant discharged.

The basic loading estimate in mg/m^2-dry day was made using the following equation:

$$\text{mg/m}^2 - \text{dry day} = \sum_{\text{time}} \frac{(\text{mg/l})(\text{l runoff/min})(\text{min of runoff})}{(\text{m}^2 \text{ surface area})(\text{runoff coefficient})(\text{dry days})}$$

In applying this equation, flow rates and concentrations measured at approximately the same time were matched and assumed to hold in a time interval bracketing the sample. The summation was performed over the entire storm. The number of dry days preceding the onset of the storm was determined from hourly precipitation records. To restate the basic loading in other forms, use was made of standard conversion factors, the precipitation total measured during the respective storms, and the average daily traffic during the preceding dry periods. Conversion from the areal basis (m^2) to length of roadway (mile) was based on a mile of eastbound and westbound lanes of the dimensions measured at the monitoring site.

Experimental Results

Appendix A provides in raw form all the data representing complete storms collected during the five months of the preliminary program. The text of the report will summarize these data and emphasize the results of estimating loadings and comparing the various sampling methods.

Runoff coefficients were estimated for the separately drained east- and westbound lanes as described in the previous section. This effort involved eight independent comparisons between received and expected runoff from storms in January, 1978, at the beginning of the sampling program. The means of ratios of actual runoff to total precipitation striking the drained surface at each downspout were adopted as runoff coefficients for further analyses, as follows:

Table III. Estimated Runoff Coefficients at SR 520
Highway Runoff Drains

Drain	Lanes	Mean $\frac{\text{Runoff Received}}{\text{Total Precipitation Volume}}$	Coefficient of Variation*
1	Westbound	0.426	19.5%
2	Eastbound	0.712	26.7%

$$\text{*Coefficient of variation} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$$

As shown by the fairly low coefficients of variation, results were rather consistent. The presence of the on-ramp in the drainage basin of the westbound lanes apparently disrupted the drainage pattern such that a smaller proportion of precipitation flowed to the drain than in the eastbound lanes.

In summary of the contaminant concentration data presented in Appendix A, Table IV lists the maximum and minimum values recorded at any time in the program for the six constituents measured. Excepting pH, maximums were always measured during the early first flush period and minimums after at least three hours of precipitation. Maximums also tended to occur in the spring late in the sampling program, while minimums were usually recorded during the winter. Page 20 discusses possible explanations for this observation. The pH fluctuated within a narrow range in an irregular pattern.

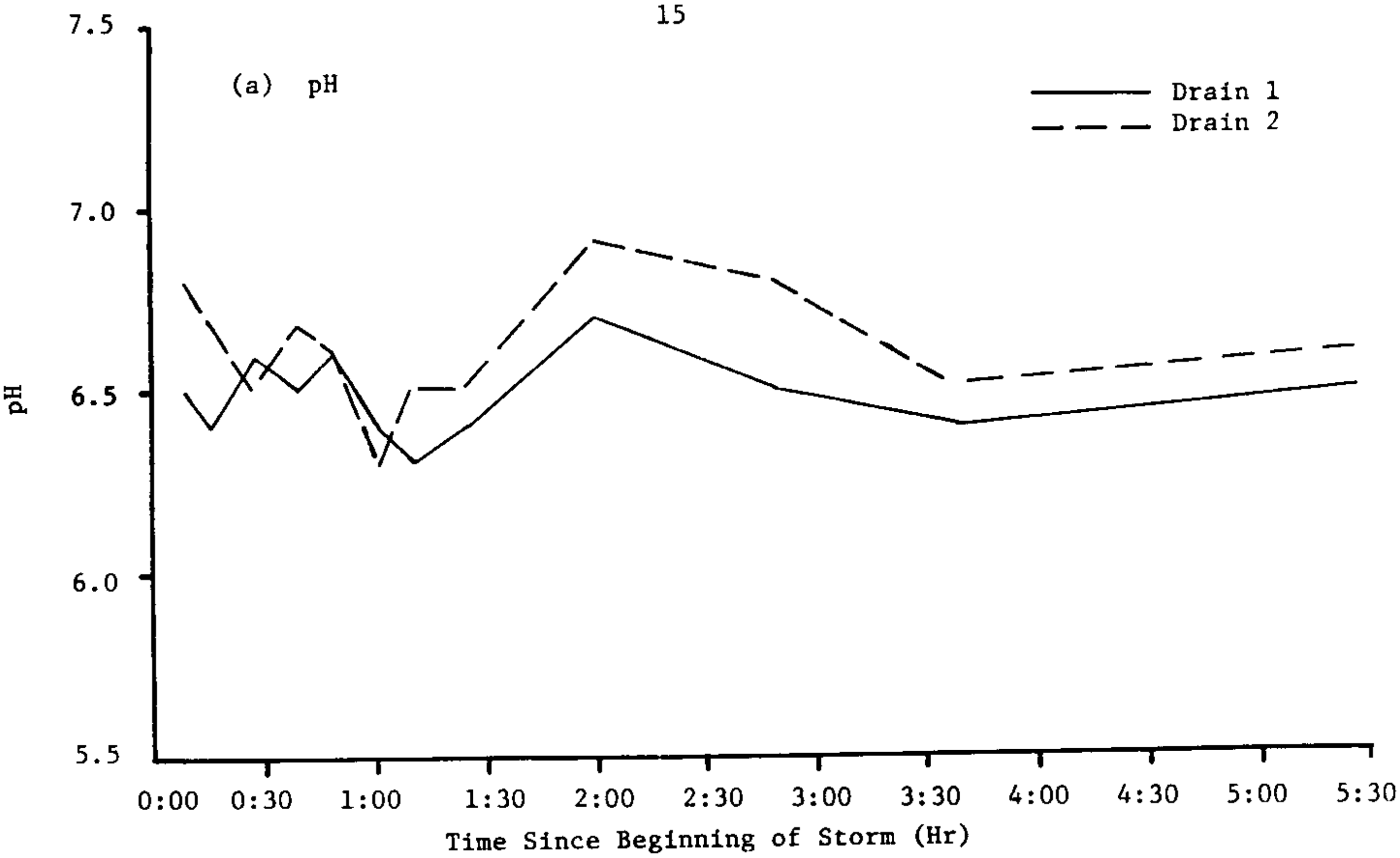
Table IV: Maximum and Minimum Values Recorded During Preliminary SR 520 Monitoring Program, January 1 - May 31, 1978

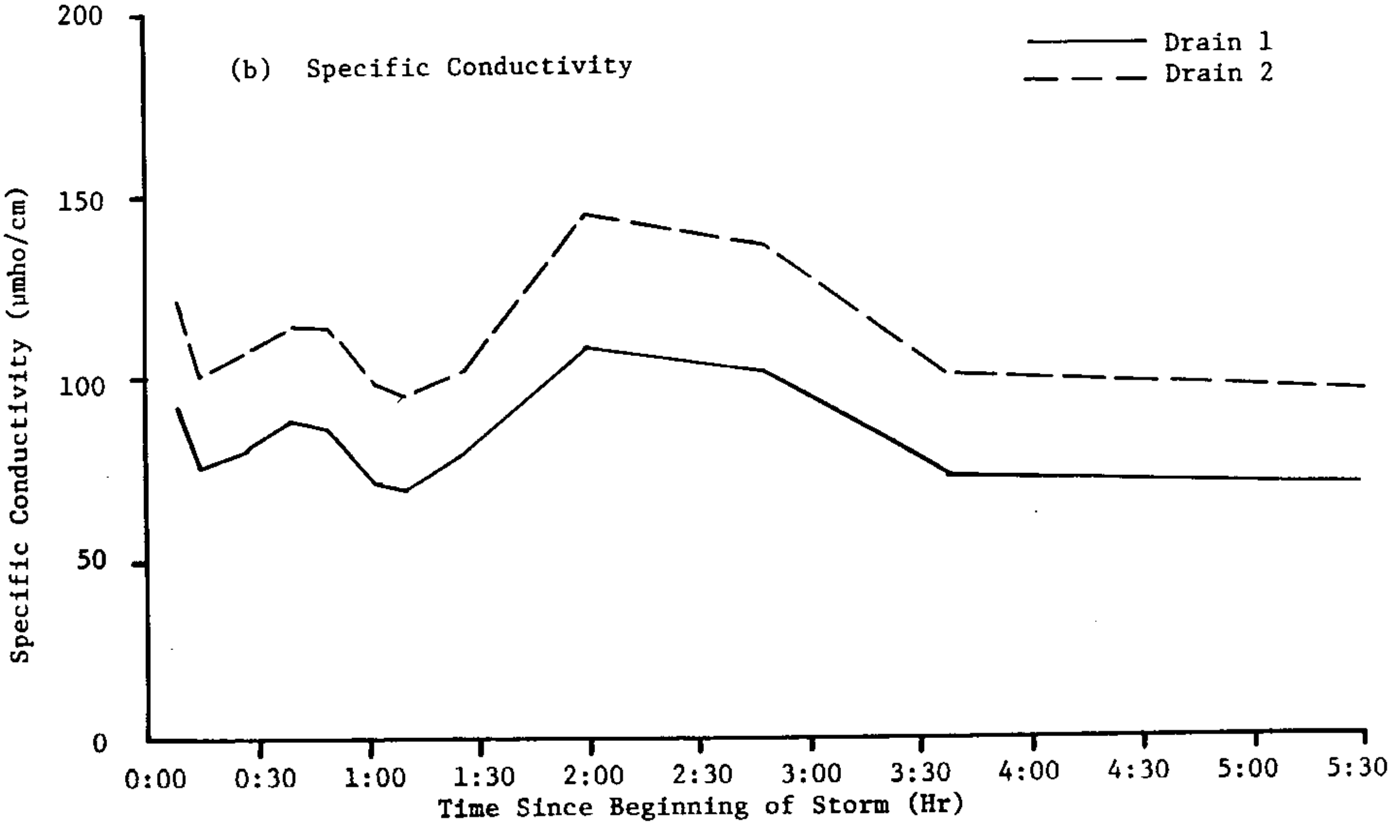
Constituent	Unit	Maximum Value	Maximum Date	Minimum Value	Minimum Date
pH	-	7.3	2/05	6.3	2/25
Specific conductivity	µmho/cm	578	4/26	44	2/09
Turbidity	FTU	270	5/09	21	2/09
Total suspended solids	mg/l	3064	4/17	4	1/09
Volatile suspended solids	mg/l	620	4/26	8	2/09
COD	mg/l	963	4/26	32	1/07

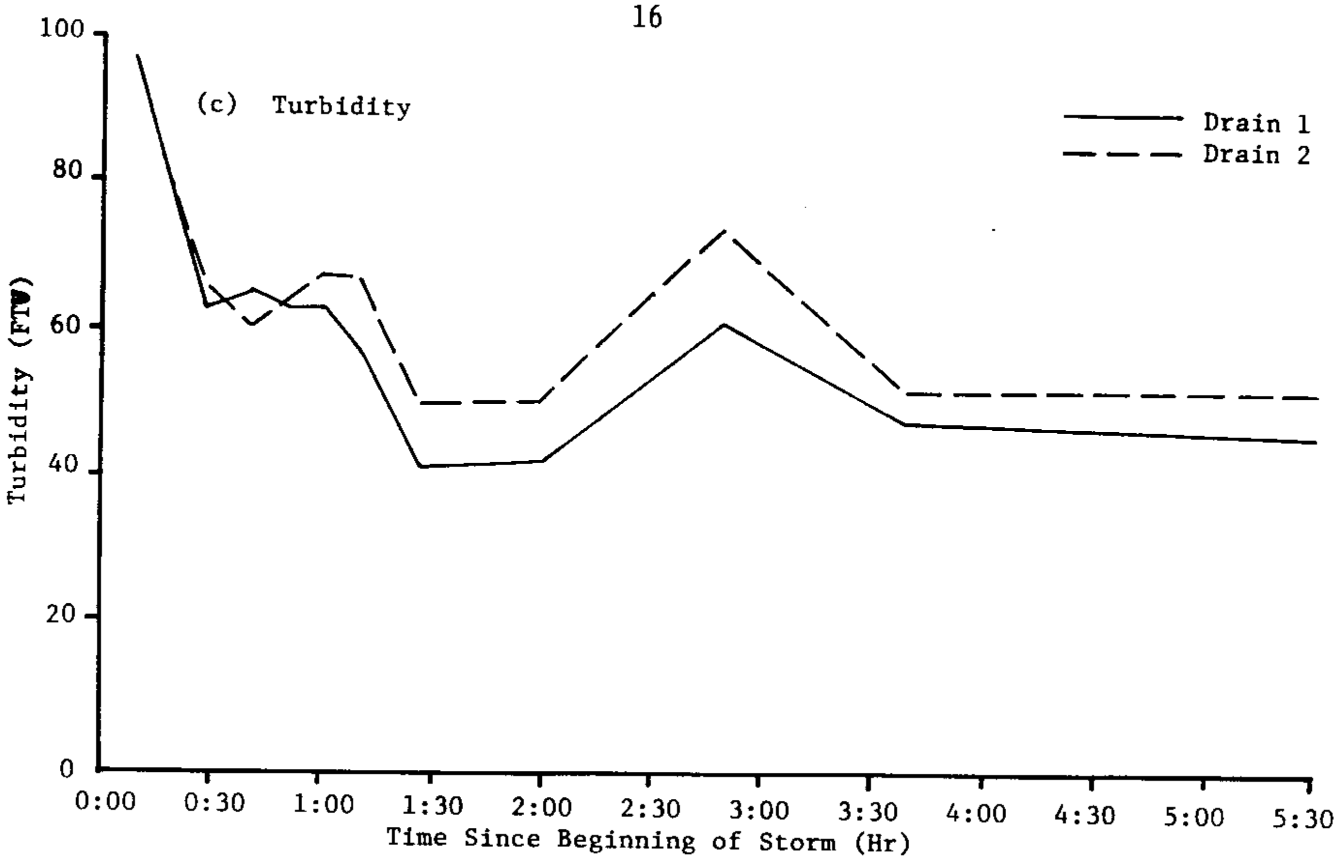
More specifically illustrating patterns of time variation of contaminant levels are the graphs in Figure 1. These plots, sometimes called pollutographs, show measured runoff constituent levels over a five and one-half hour storm on February 25, 1978. The behavior of the curves is typical of that observed throughout the program. Following the pollutographs is a plot of hourly rainfall for the same storm (Figure 2).

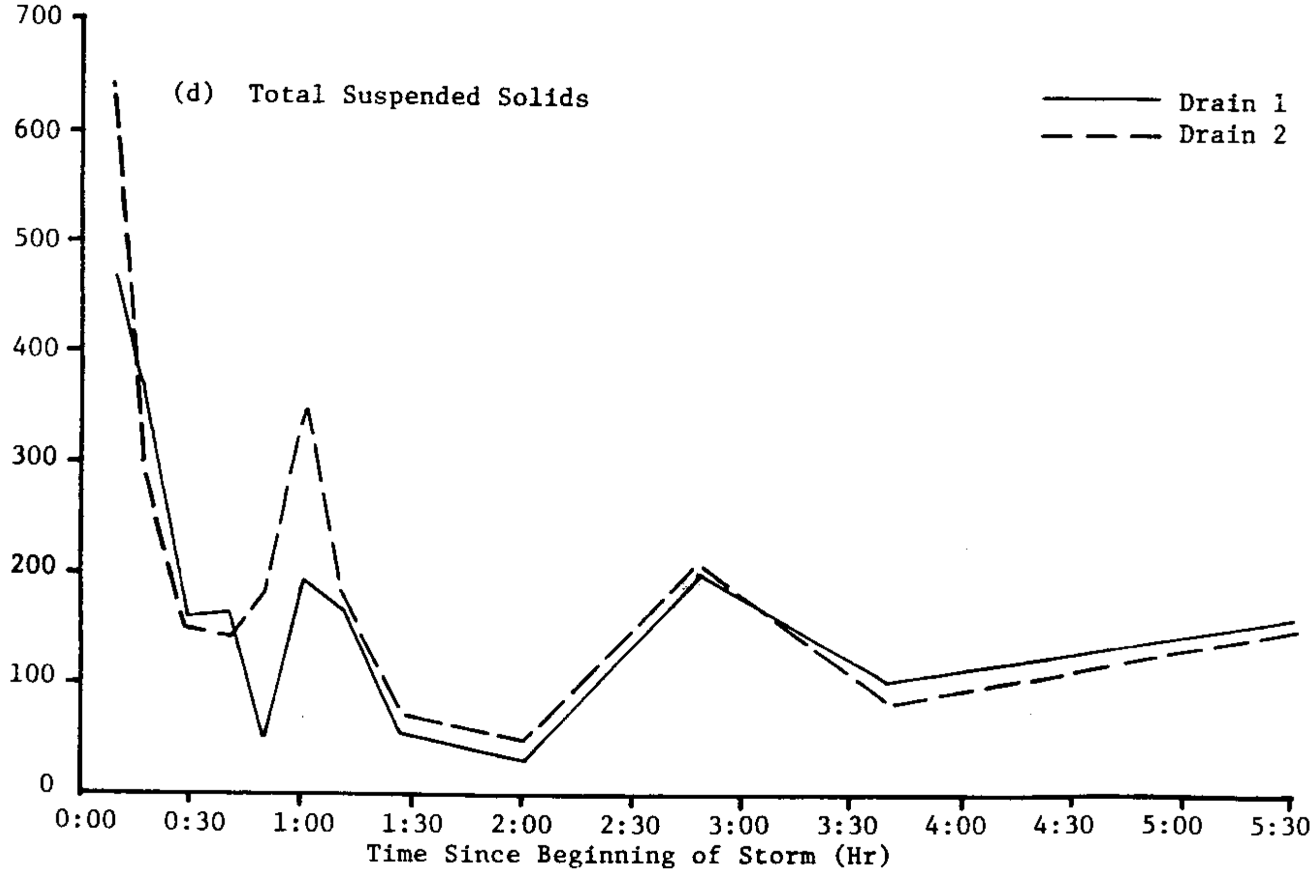
As demonstrated by the turbidity, TSS, VSS and COD plots, pollutant concentrations generally decreased from high initial values to a considerably reduced level within the first 30-60 minutes of a storm. The concentration then oscillated about the reduced level for the remainder of the storm.

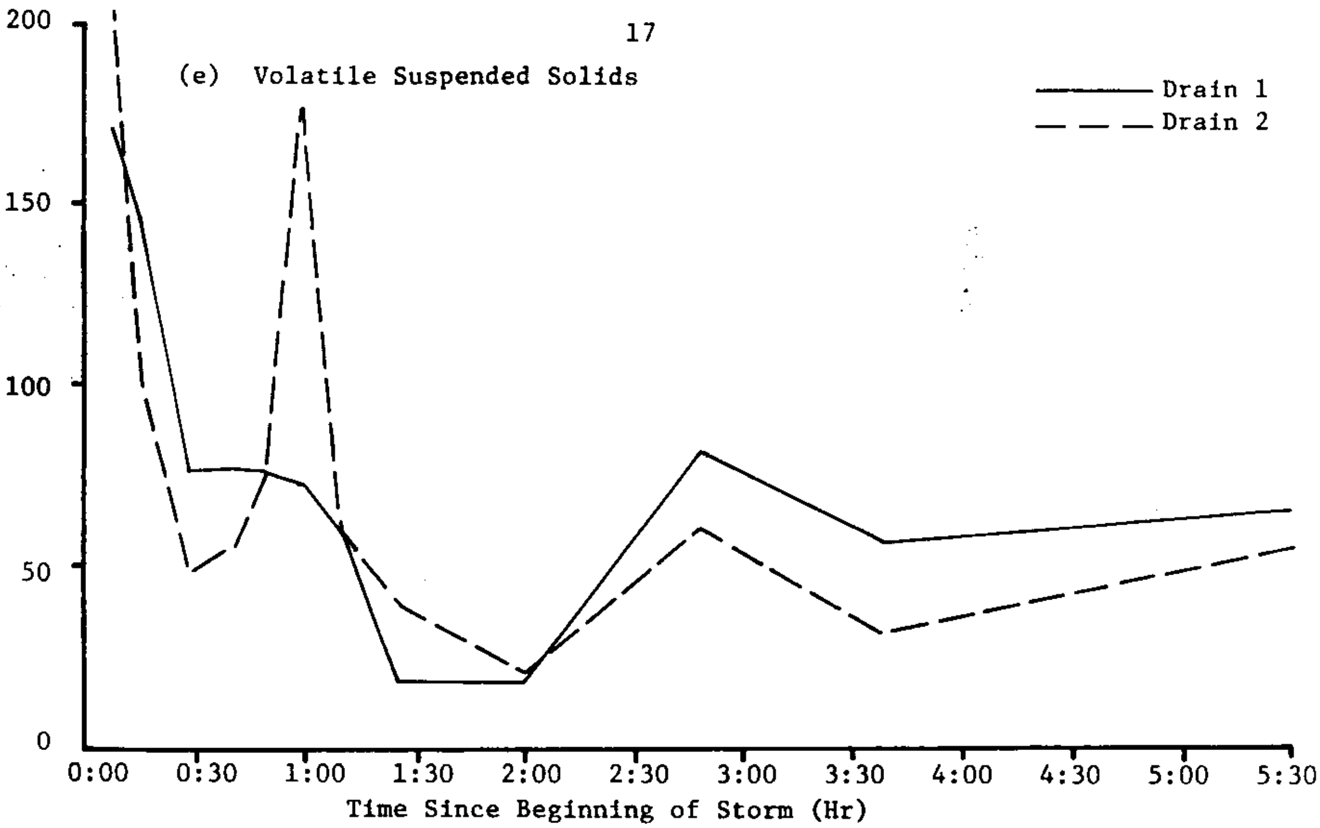
Figure 1: Typical Plots of Contaminant Levels Versus Time
(For Storm of February 25, 1978)


(a) pH
Drain 1
Drain 2
pH
7.5
7.0
6.5
6.0
5.5
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
Time Since Beginning of Storm (Hr)

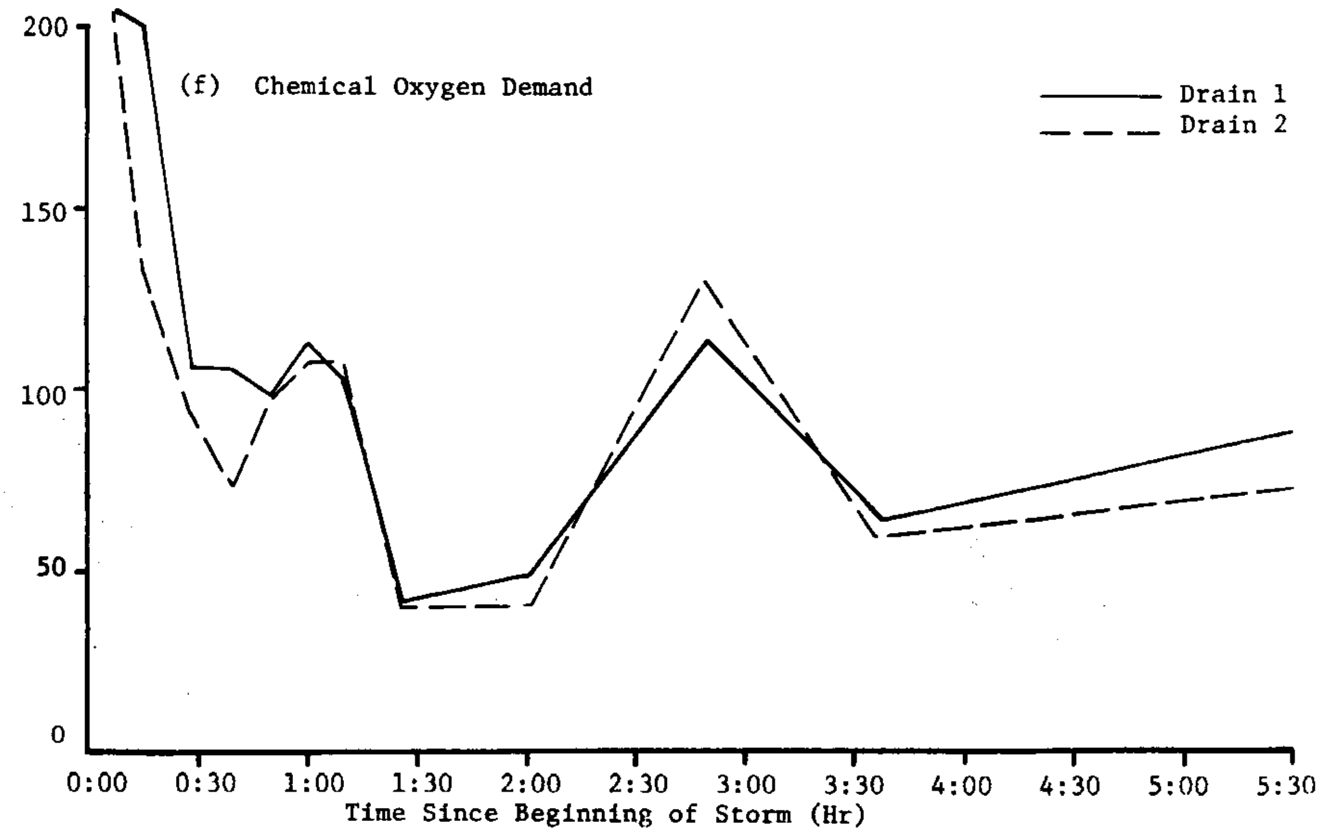

(b) Specific Conductivity
Drain 1
Drain 2
Specific Conductivity (μmho/cm)
200
150
100
50
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
Time Since Beginning of Storm (Hr)


(c) Turbidity
Drain 1
Drain 2
Turbidity (FTU)
100
80
60
40
20
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
Time Since Beginning of Storm (Hr)

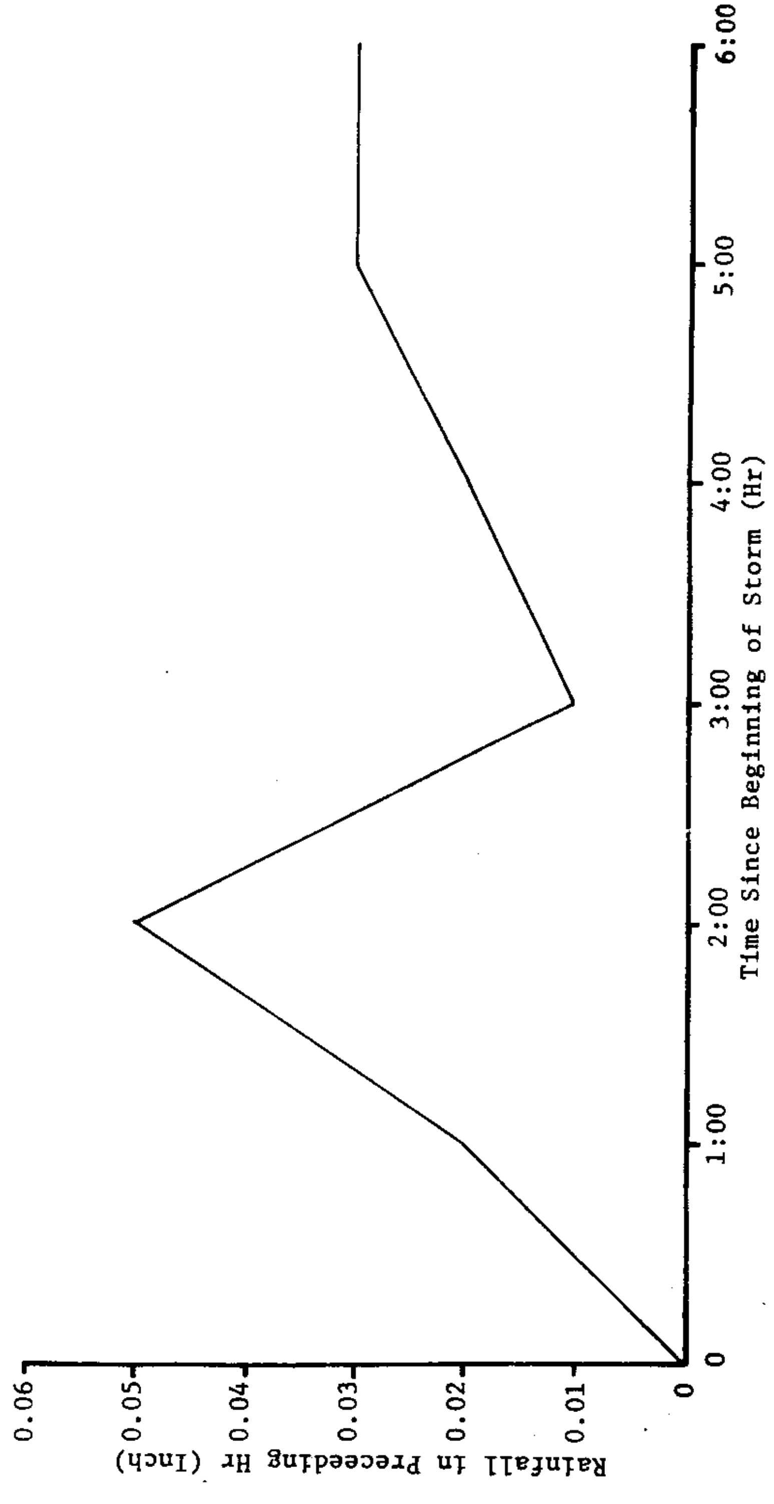

(d) Total Suspended Solids
Drain 1
Drain 2
700
600
500
400
300
200
100
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
Time Since Beginning of Storm (Hr)



(e) Volatile Suspended Solids



(f) Chemical Oxygen Demand


Rainfall in Preceeding Hr (Inch)
0.06
0.05
0.04
0.03
0.02
0.01
0
0
1:00
2:00
3:00
4:00
5:00
6:00
Time Since Beginning of Storm (Hr)

At first the amplitude of oscillation might approach the initial concentration, as in the case of VSS for Drain 2. After the first 30-90 minutes of precipitation, however, only small oscillations were observed.

An important trend observed on all pollutographs plotted during the program was the marked tendency for the curves graphed simultaneously for the two independent drains to vary in a very similar manner. Moreover, there was no clear tendency for concentrations to be greater in drainage from one set of traffic lanes than that from the other. The two sets of lanes transport approximately the same traffic volumes, but the traffic moves more steadily in the westbound lanes throughout the day. Apparently, these differences in traffic movement were unimportant in controlling the contaminant level in runoff and the manner in which runoff occurred. Runoff water quality depended much more on the precipitation pattern.

It may be noted here that pH fluctuated irregularly among slightly acidic values. This behavior was the general rule, although slightly alkaline readings were not unusual. In this case, specific conductivity did not exhibit a maximum at the beginning of the storm. Such a maximum was the more common, although not universal, occurrence. It may also be noted that the turbidity, TSS, VSS and COD curves exhibit very similar shapes. This behavior might be expected, considering the relationships existing among these measures of contamination. Turbidity is an expression of the light-scattering ability of particles in the flow, and TSS is the concentration of all such particles. The VSS represents the organic portion of the total suspended solids, and COD expresses the amount of organic materials oxidizable rapidly under the severe conditions of the test or over an extended time period under natural conditions.

To further investigate relationships between various measures of contamination in highway runoff, statistical correlation analyses were performed on several pairs of variables which have been noted to perform similarly. All available readings were entered in the calculations. Table V presents the results of these analyses.

All variable pairs are positively and significantly correlated, but correlations are not sufficiently strong to seriously consider formulating linear regression equations permitting the estimation of one quantity knowing another. Such equations developed from these data would have confidence bands wider than desirable for practical predictive applications. The lack of very high correlations probably reflects differences in the character of the runoff at different times and basic nonlinearity in the relationships. For example, COD may depend more greatly on dissolved rather than particulate organics on one occasion compared to another. Also, light-scattering ability (turbidity) does not seem to be directly related to TSS in highway runoff. The limited results available imply that qualitative judgments concerning the general character of the runoff may be made from knowledge of one or two constituents, but accurate quantitative statements require specific measurement of each quantity of interest. This preliminary conclusion will be reevaluated after the collection of more data.

Table V: Correlations Between Concentrations of Pairs of Constituents of SR 520 Runoff

Variables	Correlation Coefficient	No. Observations
TSS - Turbidity	0.520	188
VSS - TSS	0.812	134
COD - VSS	0.581	134

Pollutant loadings were estimated for TSS, VSS and COD for each complete storm monitored according to the procedure outlined in the previous section. Tables VI - X summarize these estimates, their means, coefficients of variation, and values derived from the literature by Horner et al., (1977). General inspection of the SR 520 loadings reveals that their means were considerably higher than those reported in or derived from the literature. Furthermore, the loadings generally increased through the experimental period; and the degree of variance was such that standard deviations exceeded the means in every case.

The general loading increase in the spring over the winter period followed the tendency also apparent in the concentrations. According to both the data and visual observations on the roadway, material accumulated over the course of the experiments. Consultation with city personnel responsible for sweeping the highway revealed no reduction in cleaning. In fact, less sand was needed as temperatures warmed. The build-up may have been caused by a combination of greater deposition and less effective washing of the road surface by the less frequent spring rains. It was noted that increased construction activity in the Seattle area in the spring generally increased the amount of soil deposited on local streets by erosion or construction vehicles. Apparently, the lighter spring runoff did not remove contaminants as fast as they were deposited, in spite of the high concentrations and loadings, allowing the build-up to occur.

The magnitudes of individual loadings and their variations appear to depend on factors inherent in the methods of calculation, in addition to concentrations. It is notable that very high values cannot be explained by an equivalent elevation in concentration. This fact, coupled with the observation that loadings vary in a similar manner for each constituent and each drain, is evidence that the patterns are largely created by the methods of estimation, rather than actual

Table VI: Estimated Loadings in Mg/M^2 - Dry Day

Storm Date	TSS		VSS		COD	
	Drain 1	Drain 2	Drain 1	Drain 2	Drain 1	Drain 2
1/7-1/8	4966	5260			6663	10,421
1/09	168	334			297	432
1/19	65	28			38	34
1/20	43	68			77	74
1/25	190	154			116	105
2/05	191	208	22	33	68	84
2/09	1092	1292	174	172	638	594
2/14	570	437	130	90	292	238
2/25	4176	5130	1752	1880	2503	2587
4/14	1764		268		604	
4/17	2372		366		286	
4/21	1435		297		398	
4/26-4/27	1011		231		427	
5/9	491		60		197	
Mean	1367		421		1811	
CV(1)	129.4%		149.2%		210.4%	
Reported (2)	155		-		82	

Notes: (1) Coefficient of variation
(2) From Horner et al., (1977)

Drain 1 -- Westbound Lanes
Drain 2 -- Eastbound Lanes

Table VII: Estimated Loadings in Lb/Mile - Dry Day

Storm Date	TSS		VSS		COD	
	Drain 1	Drain 2	Drain 1	Drain 2	Drain 1	Drain 2
1/7 - 1/8	803	850			1077	1685
1/09	27	54			48	70
1/19	11	5			6	5
1/20	7	11			12	12
1/25	31	25			19	17
2/05	31	34	4	5	11	14
2/09	177	209	28	28	103	96
2/14	92	71	21	15	47	39
2/25	676	831	284	305	405	419
4/14	286		43		98	
4/17	384		59		46	
4/21	232		48		64	
4/26 - 4/27	164		37		69	
5/09	79		10		32	
Mean	221		68		191	
CV(1)	129.5%		149.8%		210.4%	
Reported (2)	10.8 - 34.7		2.8 - 88.0		5.8 - 63.4	

Notes: (1) Coefficient of Variation

(2) From Horner *et al.*, (1977)

Drain 1 -- Westbound Lanes

Drain 2 -- Eastbound Lanes

Table VIII: Estimated Loadings in Lb/Acre - Inch Rain

Storm Date	TSS		VSS		COD	
	Drain 1	Drain 2	Drain 1	Drain 2	Drain 1	Drain 2
1/7-1/8	9	10			13	20
1/09	6	12			11	16
1/19	46	20			27	24
1/20	7	12			13	13
1/25	47	38			29	26
2/05	67	73	8	12	24	30
2/09	61	73	10	10	36	33
2/14	81	62	19	13	42	34
2/25	13	17	6	6	8	8
4/14	159		24		55	
4/17	300		46		36	
4/21	746		154		207	
4/26-4/27	312		71		132	
5/09	112		14		45	
Mean	99		30		38	
CV(1)	165.6%		138.7%		117.4%	
Reported (2)	5.6-31.0		-		2.6-22.0	

Notes: (1) Coefficient of Variation
(2) From Horner _et al_., (1977)

Drain 1 -- Westbound Lanes
Drain 2 -- Eastbound Lanes

Table IX: Estimated Loadings in Lb/Vehicle - Mile

	TSS		VSS		COD	
Storm Date	Drain 1	Drain 2	Drain 1	Drain 2	Drain 1	Drain 2
1/7-1/8	2.8×10^{-2}	3.6×10^{-2}			3.8×10^{-2}	7.2×10^{-2}
1/09	1.6×10^{-3}	1.7×10^{-3}			2.8×10^{-3}	2.2×10^{-3}
1/19	3.2×10^{-4}	1.4×10^{-4}			1.7×10^{-4}	1.4×10^{-4}
1/20	1.9×10^{-4}	2.6×10^{-4}			3.3×10^{-4}	4.3×10^{-4}
1/25	1.1×10^{-3}	9.0×10^{-4}			6.4×10^{-4}	6.1×10^{-4}
2/05	1.1×10^{-3}	1.0×10^{-3}	1.3×10^{-4}	1.6×10^{-4}	3.9×10^{-4}	4.2×10^{-4}
2/09	4.2×10^{-3}	4.5×10^{-3}	6.6×10^{-4}	6.0×10^{-4}	2.4×10^{-3}	2.1×10^{-3}
2/14	3.1×10^{-3}	2.4×10^{-3}	7.1×10^{-4}	4.9×10^{-4}	1.6×10^{-3}	1.3×10^{-3}
2/25	2.2×10^{-2}	2.4×10^{-2}	9.2×10^{-3}	8.6×10^{-3}	1.3×10^{-2}	1.2×10^{-2}
4/14	4.6×10^{-3}		6.8×10^{-4}		1.6×10^{-3}	
4/17	1.4×10^{-2}		2.9×10^{-3}		1.7×10^{-3}	
4/21	6.8×10^{-3}		1.4×10^{-3}		1.9×10^{-3}	
4/26-4/27	5.6×10^{-3}		1.3×10^{-3}		2.4×10^{-3}	
5/09	2.4×10^{-3}		2.9×10^{-4}		9.4×10^{-4}	
Mean	7.2×10^{-3}		8.5×10^{-3}		6.9×10^{-3}	
CV(1)	142.2%		307.4%		237.0%	
Reported (2)	$2.2 \times 10^{-4} - 1.7 \times 10^{-3}$		$6.1 \times 10^{-5} - 4.3 \times 10^{-4}$		$6.4 \times 10^{-5} - 1.2 \times 10^{-3}$	

Notes: (1) Coefficient of Variation

(2) From Horner *et al.* (1977)

Drain 1 -- Westbound Lanes

Drain 2 -- Eastbound Lanes

Table X: Estimated Loadings in Mg/M^2 - Vehicle - Mm Rain

Storm Date	TSS Drain 1	TSS Drain 2	VSS Drain 1	VSS Drain 2	COD Drain 1	COD Drain 2
1/7-1/8	1.1×10^{-2}	1.4×10^{-2}			1.5×10^{-2}	2.9×10^{-2}
1/09	2.7×10^{-3}	3.0×10^{-3}			4.8×10^{-3}	3.8×10^{-3}
1/19	1.6×10^{-3}	1.1×10^{-3}			1.4×10^{-3}	1.3×10^{-3}
1/20	9.3×10^{-4}	1.3×10^{-3}			1.7×10^{-3}	1.4×10^{-3}
1/25	1.8×10^{-3}	1.6×10^{-3}			1.1×10^{-3}	1.1×10^{-3}
2/05	3.8×10^{-3}	3.6×10^{-3}	4.4×10^{-4}	5.7×10^{-4}	1.3×10^{-3}	1.5×10^{-3}
2/09	1.0×10^{-2}	1.1×10^{-2}	1.6×10^{-3}	1.5×10^{-3}	5.9×10^{-3}	5.1×10^{-3}
2/14	2.3×10^{-3}	1.7×10^{-3}	5.2×10^{-4}	3.6×10^{-4}	1.2×10^{-3}	9.5×10^{-4}
2/25	1.5×10^{-2}	1.6×10^{-2}	6.2×10^{-3}	5.8×10^{-3}	8.9×10^{-3}	8.0×10^{-3}
4/14	1.6×10^{-2}		2.4×10^{-3}		5.4×10^{-3}	
4/17	7.0×10^{-2}		1.1×10^{-2}		1.3×10^{-2}	
4/21	5.5×10^{-2}		1.1×10^{-2}		1.5×10^{-2}	
4/26-4/27	1.4×10^{-2}		3.1×10^{-3}		5.7×10^{-3}	
5/09	3.0×10^{-3}		3.7×10^{-4}		1.2×10^{-3}	
Mean	1.1×10^{-2}		3.5×10^{-3}		5.8×10^{-3}	
CV(1)	156.5%		110.8%		116.5%	

Note: (1) Coefficient of Variation

Drain 1 -- Westbound Lanes
Drain 2 -- Eastbound Lanes

concentrations or any errors in sampling or analysis. Obviously, this situation in which contaminant loadings are dictated more by systematic factors than reality indicates that methods have not been sufficiently refined for use in the remainder of the research program. This subject will receive further attention in the following section.

To further investigate the degree of dependence of loading estimates on factors entering into their calculation, associations were explored by means of simple correlation analyses on the TSS data from Drain 1 samples. Correlation coefficients were computed for the association between each loading expression and the following factors: approximate TSS concentration one hour after the beginning of the storm, dry days preceding the storm, precipitation quantity, average daily traffic (ADT) in the dry period. Table XI presents the resulting correlation coefficients.

Table XI: Simple Correlations Betweeen TSS Loading Expressions and Environmental Factors

	Factor	Correlation Coefficient
mg/m^2 - dry day and Lb/mile - dry day	1 Hr Concentration	- 0.061
	Dry Days	- 0.549*
	Amt. rain	0.247
	ADT	0.021
Lb/acre - inch rain	1 Hr Concentration	0.593*
	Dry Days	0.054
	Amt. rain	- 0.347
	ADT	0.79
Lb/vehicle - mile	1 Hr Concentration	- 0.139
	Dry Days	- 0.510*
	Amt. rain	0.306
	ADT	- 0.043
mg/m^2 - vehicle - mm rain	1 Hr Concentration	0.265
	Dry Days	- 0.100
	Amt. Rain	- 0.301
	ADT	- 0.016

*Statistically significant at $P < 0.05$. Number of observations = 14.

The most striking result of the correlation analyses is that loadings expressed as mg/m^2 - dry day, Lb/mile - dry day and Lb/vehicle - mile, are significantly and negatively correlated with dry days. The use of the unit dry period in computing loadings of these types conveys the mistaken impression that loading increases inversely with the length of the dry period. It must then be concluded that loading expressions in the form weight/unit surface area - dry day and weight/vehicle/distance traveled are inappropriate for use in analyzing storm runoff in the winter-spring period in Western Washington. At this time very brief dry periods improperly bias loading computations of the type noted. The data do not permit making any general statement concerning the applicability of these loading expressions, save to recommend that their usefulness be evaluated in other climates and seasons later in the research program before the adoption of any expression.

It is notable that a recent report of work on urban runoff in Portland, Oregon by Miller and McKenzie (1978) also questions the applicability of the dry period as a basis for expressing contaminant burden in the marine lowlands of the Pacific Northwest. Shown by Marsalek (1976) to be the most significant variable in determining the quality of Toronto, Ontario, urban runoff, dry period length is commonly used as a basis elsewhere.

It might be expected that concentration, dry days and ADT should all positively affect loading. Among the expressions tested, only Lb/acre - inch rain complies with that expectation. The negative correlation with rainfall might reflect that precipitation at the beginning of storms, a relatively small proportion, is responsible for a disproportionate amount of material removal. Data are available only for relatively light rains ($\leqslant$ 0.36 inch total) however; and a conclusive judgement on this point cannot yet be made. This expression, or a variant of it, should be subjected to further evaluation.

This insignificant role of traffic volume in every case is counter to the experience of Shaheen (1975). Preliminary data reported by Gupta et al. (1977), however, are inconclusive in establishing the direct role of traffic in establishing loading in Lb/acre - inch rain. SR 520, of course, represents a heavily traveled freeway with day-to-day fluctuations less important than the continuously large traffic volume. Uncertainties concerning the roles of traffic and other factors existing in the literature and the results of this research to date require that special attention be directed to resolving these questions during the remainder of the study.

One of the objectives of the preliminary SR 520 study was to compare the efficacy of discrete versus composite sampling. Demonstration of reasonable agreement between the two methods would permit wider use of the more economical composite technique to amass a large amount of data that could be interpreted to provide total contaminant loadings over extended time periods. Limited discrete sampling efforts, more consumptive of manpower, equipment and laboratory resources, would be employed to establish maximum concentrations and pollutograph patterns. To accomplish this comparison, total weights of TSS, VSS and COD were estimated on three separate occasions from a series of discrete samples and a composite formed from the same runoff. The estimates were made according to:

$$\text{Discrete: Weight} = \sum_{\text{time}} (\text{Concentration})(\text{Flow rate})(\text{Time})$$

$$\text{Composite: Weight} = (\text{Concentration})(\text{Collected volume})$$

Table XII presents the results.

Success in duplicating estimates is mixed. The two comparisons involving data collected during the latter portions of storms are in notably greater agreement than the one comparison utilizing first-flush data. The greater

Table XII: Total Contaminant Weights Estimated from Discrete and Composite Samples

Storm Date	Period in Storm	Contaminant	Weight From Discrete (mg)	Weight From Composite (mg)	Percent Difference
4/14	~2-4 Hr	TSS	1.08×10^5	1.13×10^5	4.4
		VSS	2.54×10^4	2.37×10^4	6.7
		COD	5.42×10^4	5.56×10^4	2.5
5/09	~0-2 HR	TSS	1.11×10^5	3.15×10^5	64.8
		VSS	1.89×10^4	4.68×10^4	59.6
		COD	8.19×10^4	1.06×10^5	39.6
5/09	~2-4 HR	TSS	1.12×10^5	8.20×10^4	26.8
		VSS	1.79×10^4	1.60×10^4	10.6
		COD	5.30×10^4	3.69×10^4	30.4
Mean		TSS			32.0
		VSS			25.6
		COD			24.2

stability of contaminant levels after the initial period may explain this difference. The level of agreement is great enough to encourage additional evaluation of the two techniques at the I-5 permanent monitoring station. Perhaps more important is the realization that compositing has the potential to be the more accurate method of yielding total pollutant loadings, since this technique integrates contaminant mass flow over full storms. Obtaining satisfactory composites assumes that sufficient storage volume can be provided or a reliable means of flow-splitting devised and that the collected runoff is thoroughly mixed prior to sampling.

A further objective of the preliminary sampling program was an investigation of the precision of discrete and composite sampling and the laboratory analyses performed on the samples. To serve this purpose replicate discrete and composite samples were drawn and analyzed on several occasions. Discrete samples were collected in succession within a short time interval. Table XIII summarizes results.

The data demonstrated that sampling and analytical procedures yielded very precise measurements of pH, specific conductivity and turbidity in all cases (coefficient of variation $\lesssim$ 3.3%). Dispersion of TSS, VSS and COD values was greater in certain instances, particularly for TSS and VSS in the discrete sampling mode. This observation implies a substantial moment-to-moment variation in the concentrations of particulate matter in highway runoff. In consequence, establishing maximum concentrations and pollutograph patterns of suspended solids would require frequent sampling, especially in the early portion of storms. The results supply evidence that composite sampling would be the more reliable means of developing estimates of total contaminant loads, at least in the case of particulates. COD measurements in discrete samples were markedly more precise than TSS and VSS, tentatively suggesting that the COD in SR 520 runoff depended more on dissolved oxidizable substances present in more constant concentrations than suspended materials.

A final activity pursued under the preliminary program was a comparative study of ISCO and Manning automatic samples. Each drew a series of 16 simultaneous samples spaced at seven minute intervals from a drum into which SR 520 runoff was draining. Four such samples were collected on May 4, and the remaining 12 were drawn on May 9. Samples were analyzed as usual. Results are presented in Table XIV.

Table XIII: Results of Replicating Discrete and Composite SR 520 Runoff Samples

Date	Type Sample	Number Replicates	Constituent	Unit	Mean	Coefficient of Variation
4/14	Discrete	5	pH	-	6.7	1.1%
			Specific conductivity	μmho/cm	91	0.5%
			Turbidity	FTU	35	3.3%
			TSS	mg/l	71	32.9%
			VSS	mg/l	26	39.2%
			COD	mg/l	96	6.2%
5/09	Discrete	5	pH	-	6.5	0.6%
			Specific conductivity	μmho/cm	105	0.9%
			Turbidity	FTU	184	1.2%
			TSS	mg/l	561	6.8%
			VSS	mg/l	118	6.3%
			COD	mg/l	277	10.6%
5/09	Discrete	2	pH	-	6.6	0.5%
			Specific conductivity	μmho/cm	105	0.9%
			Turbidity	FTU	184	1.2%
			TSS	mg/l	375	17.4%
			VSS	mg/l	40	32.0%
			COD	mg/l	148	2.3%
4/14	Composite	5	pH	-	6.5	0.3%
			Specific conductivity	μmho/cm	149	0.4%
			Turbidity	FTU	100	1.1%
			TSS	mg/l	561	6.8%
			VSS	mg/l	118	6.3%
			COD	mg/l	277	10.6%
5/09	Composite	2	pH	-	6.6	0.5%
			Specific conductivity	μmho/cm	243	0.3%
			Turbidity	FTU	170	0.0%
			TSS	mg/l	1056	3.3%
			VSS	mg/l	236	9.9%
			COD	mg/l	532	10.6%
5/09	Composite	2	pH	-	6.8	0.5%
			Specific conductivity	μmho/cm	126	0.6%
			Turbidity	FTU	183	1.9%
			TSS	mg/l	469	1.7%
			VSS	mg/l	92	3.8%
			COD	mg/l	211	0.0%

Table XIV: Results Obtained from Simultaneous Sampling by ISCO and Manning Automatic Samplers

Date	Sample Number	pH		Specific Conductivity (μmho/cm)		Turbidity (FTU)		TSS (mg/l)		VSS (mg/l)		COD (mg/l)	
		I	M	I	M	I	M	I	M	I	M	I	M
5/4	1	7.0	6.9	151	155	51	50	109	71	53	15	120	118
	2	6.9	6.9	154	154	50	52	115	67	53	19	132	114
	3	6.9	6.9	154	157	98	81	433	201	100	26	264	157
	4	6.9	6.9	152	155	102	72	388	163	77	27	196	145
5/9	5	6.6	6.6	417	420	150	150	2643	2524	313	344	956	898
	6	6.7	6.6	334	340	180	160	1846	1838	267	267	924	858
	7	6.7	6.6	289	294	180	140	1430	1581	241	349	648	882
	8	6.7	6.7	249	257	190	150	1249	1355	203	226	552	886
	9	6.7	6.7	243	246	190	180	1013	922	149	122	592	588
	10	6.7	6.6	142	146	175	180	392	448	61	57	264	255
	11	6.8	6.7	110	110	180	170	651	448	97	69	360	267
	12	6.7	6.7	106	109	190	190	637	574	101	73	300	247
	13	6.6	6.7	109	111	210	210	487	584	71	85	312	274
	14	6.7	6.6	111	117	210	210	595	589	86	74	272	259
	15	6.7	6.8	112	122	200	205	695	517	104	66	296	231
	16	618	617	117	121	205	205	565	523	89	63	256	310

Note * (1) I -- ISCO Model 1680; M -- Manning Model 4050

The data demonstrate that the results of automatic sampling programs are somewhat dependent on the equipment employed. Mean percentage differences for 16 simultaneous determinations of the various constituents by each sampling method follow:

pH	0.8%
Specific conductivity	2.4%
Turbidity	7.7%
TSS	27.2%
VSS	31.4%
COD	16.5%

As in the discrete versus composite and replication studies, suspended solids results are the hardest to duplicate by independent techniques.

Another important result of this exercise is illustrated by Table XV. Here it is shown that readings in samples collected by the ISCO device were rather consistently higher than those in Manning samples where the quantity depended at least partially on particulates. This observation is counter to prior expectations, given that the Manning sampler features a vortex-action metering chamber drain specifically designed to increase the proportion of suspended solids captured. The ISCO device, which delivers the sample horizontally through a distribution tray, has been criticized for loss of solids during distribution to the correct sample bottle. Data are not sufficient nor of the proper type to evaluate conclusively whether later ISCO samples were artificially supplemented by solids lost in the system during earlier samples. It appears, however, that ISCO readings exceeded Manning as often in the earlier portions as in the latter portions of the May 4 and May 9 experiments. Since specific conductivity differences were small, it is not considered to be particularly significant that samples collected by the Manning sampler registered consistently higher values of this constitutent, which depends only on dissolved inorganics.

Table XV: Comparison of Magnitudes of Readings Obtained from ISCO and Manning Samples

Constituent	Number of Cases ISCO Higher (1)	Number of Cases Manning Higher (1)
Specific conductivity	0	14
Turbidity	8	3
TSS	12	4
VSS	11	4
COD	13	3

Note: (1) The remainder of 16 determinations were equal.

It must be emphasized that this study was not sufficiently comprehensive to finalize any conclusions about the performance of the two samplers purchased for the project. This report is meant to raise issues that should be resolved through the course of the full program. Side-by-side comparisons should continue during the next phase of the research in a variety of situations. Tests should involve discrete samples collected from a runoff stream, as well as further composites, and should be conducted on storms of varying intensities.

Further Implications of SR 520 Results

It is beneficial at this point to recap the major conclusions suggested by results presented in the previous section and then more generally consider certain of their implications for the research work to come. In summary, it has been demonstrated that:

1. The first-flush period of notably elevated concentrations lasts for approximately 30-60 minutes. During this time, concentrations can fluctuate substantially. For the remainder of the storm, much smaller oscillations about a reduced level are the rule.

2. Concentrations can vary seasonally to a marked degree.

3. Turbidity, TSS, VSS and COD concentrations vary in a similar manner, but the associations are not strong enough to predict one from another.

4. SR 520 contaminant loadings expressed in several forms exceeded those reported in or derived from the literature. It was shown that these results are due more to the calculation methods than the quality of the runoff.

5. Estimating loading storm-by-storm in weight/unit surface area-dry day and weight/vehicle/distance traveled are definitely inappropriate in a climate such as that existing during SR 520 experiments. An expression based on weight/unit surface area/unit quantity of precipitation may be more useful.

6. Day-to-day differences in traffic volume do not appear to have a significant role in determining runoff quality and pollutant loadings on a heavily traveled urban freeway.

7. Establishing the total quantity of contaminants running off a highway in a period with the use of composite samples is a promising technique if a workable means of obtaining composites can be devised.

8. A small amount of data indicates that ISCO and Manning automatic water samplers may exhibit substantially different performance, especially where particulates are concerned.

The most important lesson of the preliminary program concerns the use of various loading expressions to quantify the contaminant burden on receiving waters in terms of factors considered to be responsible for determining the level. Results demonstrated that the choice of an expression should be regionally based and its applicability verified by extensive data, rather than blindly selected from the literature. In Western Washington the considerable variability of loadings estimated from individual winter storm data suggests that pollutant burdens should instead be established over a longer time period. Thus, a prudent direction for future research is the derivation of a means with which to express weight of a contaminant contributed by highway runoff per annum or seasonal period per unit of some or all of the following factors: surface area, precipitation quantity, traffic volume.

When a large data base becomes available, it might be warranted to apply more sophisticated methods of statistical analysis than those employed here to select the most crucial variables and determine their patterns of activity. For example, multiple correlation techniques permit holding variables constant except those two whose association is under investigation. Such a method would produce a clearer picture of the role of variables entering the denominator of loading expressions, such as dry days, than the simple correlations used here.

Confident knowledge of loadings expressed as recommended, along with maximum concentrations and pollutograph patterns, would stand to realistically represent the impact of highway runoff on receiving waters. The research could then conclude with an informed analysis of the effects of such levels of contamination on the biota inhabiting receiving waters or human consumers of affected potable supplies. At that point it would be possible to properly prepare environmental impact assessments of highway projects, the ultimate goal of the research.

It should be noted in connection with contaminant loading expressions that SR 520 results do not necessarily have any specific applicability to Eastern Washington or to the Western Washington dry season. In these situations, extended dry periods frequently followed by shorter, more intense storms than those monitored at SR 520 may require different means of data analysis to correctly represent pollutant burden. The lesson of the preliminary study is a more general one: the means should be tailored to the situation at hand and fully verified by data.

The view of highway runoff provided by the SR 520 study, that contaminant concentrations and loadings vary substantially over time and some long-term expression of loading is required, essentially dictates the character of succeeding research efforts. Sampling must be directed at profiling each storm over a considerable time period to provide confident estimates of annual or seasonal loadings. The large number of runoff events in Western Washington would pose difficulties in logistics and elevate costs to the extent that an adequate program of discrete sampling may be infeasible. It is thus fortunate that estimating total contaminant quantities from composites would also permit the establishment of more stations statewide than otherwise possible, better covering the ranges of the various climatic and traffic conditions.

At the same time a need exists to better document maximum concentrations of the various runoff constituents and their temporal patterns. For this purpose a well-conceived discrete sampling program is also necessary. Such a program should be conducted selectively at stations representing each of the state's climatic regions, different seasons and varying levels and types of traffic. Discrete sampling should concentrate almost exclusively on the first two hours of runoff. This phase of the research might utilize a small number of automatic samplers to conduct a series of short-term studies at sites maintained over long periods for composite sampling. Once repetition indicated that the essential pattern of concentration variation for the given set of conditions had been discovered, the sampler would be moved to a new site. With such a program of long-term composite and short-term discrete sampling, the goals of the research project would be achieved in a cost-effective manner.

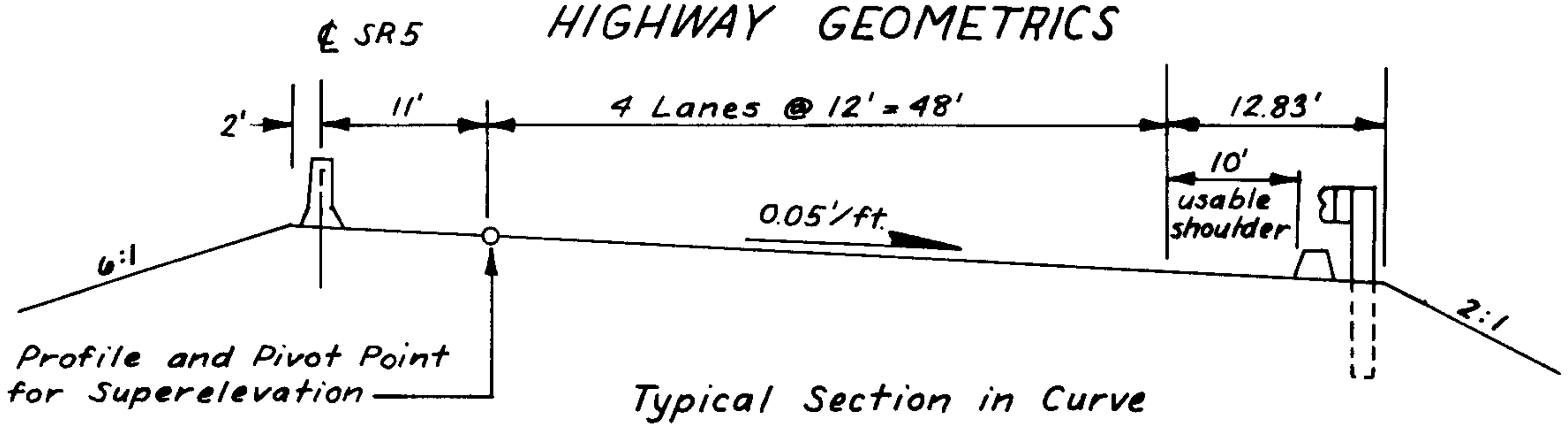
DESCRIPTION OF INTERSTATE-5, SEATTLE, MONITORING STATION

The first fully-equipped, long-term highway runoff monitoring site was installed on Interstate-5 just north of the Seattle city limits. The station monitors drainage from approximately 1000 ft. of the four northbound lanes plus median and shoulder extending north from NE 158th Street. This location presents an opportunity to conduct a well-controlled monitoring program on a heavily traveled highway unaffected by extraneous drainage and conveniently situated with respect to the University. Not only will the station provide for all data collection needs regarding heavily-trafficked highways in a climate typical of the Puget Sound Region, but it will also serve as a prototype at which training will be given those responsible for tending other long-term sites statewide.

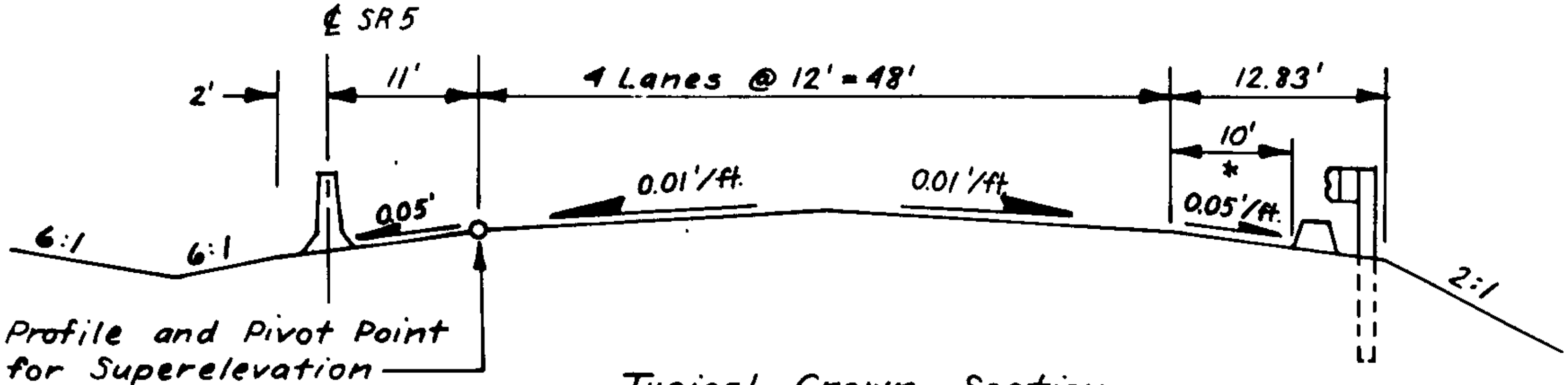
General Site Description

The site in question lies on a 1.1 percent upgrade. Encompassing a wide-radius curve, the four northbound lanes are sloped toward the shoulder, in contrast to sections in the same vicinity which are crowned. Figure 3 shows typical sections of the monitoring site. The drainage system receives runoff from a 36 ft. width of roadway, 23 ft. of median and 12 ft.-10 inch of shoulder. Prior to site modifications, drainage was directed into two Type 1 collection boxes (see Figure 4) by a curb which begins 516 ft. upslope from the first collection box. Side slopes are two percent north of the first box and 5-6 percent in the transition zone between boxes. Collection boxes drain individually through Armco galvanized pipe to a ditch at the base of the fill within the highway right-of-way. Drainage from southbound lanes is thoroughly segregated from this collection system, and the site receives no runoff from elsewhere in the right-of-way or the surrounding area.

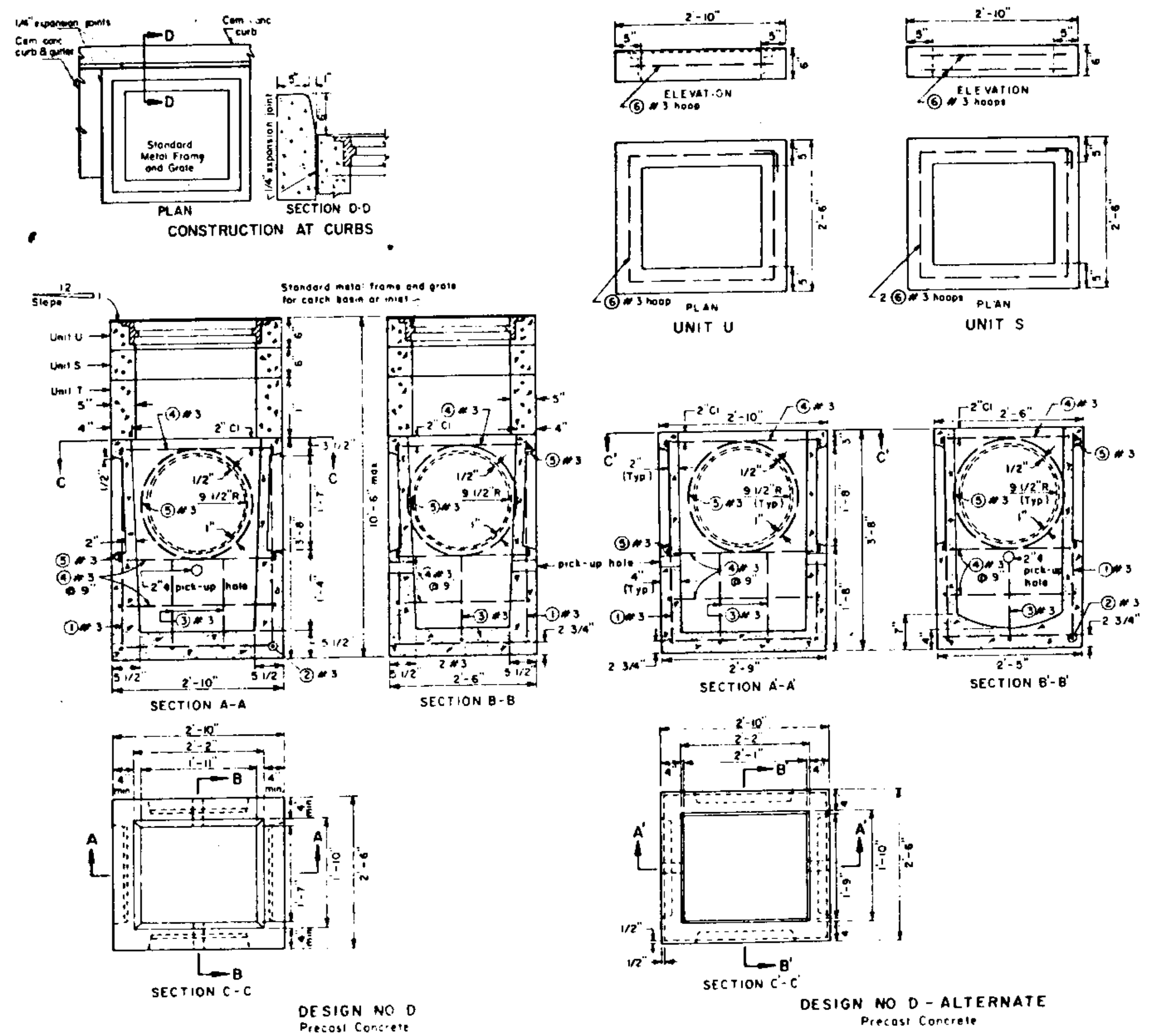
FIGURE 3. SR 5 WATER QUALITY MONITOR SITE HIGHWAY GEOMETRICS



Typical Section in Curve



Typical Crown Section
*usable shoulder



NOTES

The Contractor shall have the option of furnishing Design No. D as an alternate to Design Nos. A & B as shown on Standard Plan B-1, insofar as permitted by the height limits indicated or unless specified otherwise.

All precast concrete shall be class AX

All reinforcing steel shall be Grade 40 or Grade 60 (ASTM A-615) and shall have 1 1/2" clear cover unless otherwise noted

The grade line of the top inside of any inlet pipe shall meet the center line of the catch basin at a point no lower than the grade line of the top inside of the outlet pipe

The flow line of the outlet pipe must be 1'-5" minimum above bottom of the catch basin

Cutouts for pipes as required will be made by the Contractor to the lines and grades given by the Engineer

Design D shall be placed on a firm, level foundation. The pick up holes shall be grouted full after the catch basin has been placed

As many units S and T as needed may be used to obtain the necessary height, however a minimum of one unit S or T shall always be used immediately beneath unit U

Units S, T, and U shall be grouted in place to the satisfaction of the Engineer

Curb or curb and gutter will be measured without deducting for length of catch basin

The metal frame and grate shall be set to a slope to conform to the particular drainage problem. The frame may be placed with the flange down if approved by the Engineer

The standard metal frame and grate shall be furnished and installed as indicated hereon

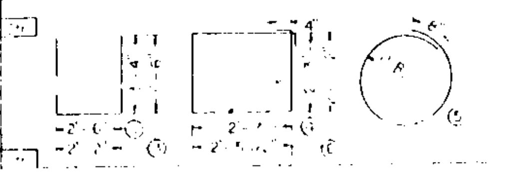
Figure 4: CATCH BASIN TYPE 2

BAR LIST

All dimensions are out to out

MARK	LOCATION	NO	SIZE	LENGTH
1	Bottom slab and walls	2	3	9-[illegible]
2	Bottom slab	2	3	2-[illegible]
3	Bottom slab and walls	3	3	5-[illegible]
4	Wall horizontal	3	3	[illegible]
5	Wall	4	3	[illegible]
6	Unit S	2	3	[illegible]
6	Unit T	3	3	2'-[illegible]
[illegible]	Unit [illegible]		3	[illegible]
7	Unit T	4	3	[illegible]

BENDING DIAGRAM



DATE	REVISION	BY	BRIDGE	APP'D
10-5-79	Revised Construction at Curb Detail Added Design D Alternate for base unit & note for min. grade	GW TG		

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
OLYMPIA, WASHINGTON
W. A. BULLEY, SECRETARY

A. D. Andrews
DESIGN ENGINEER

BRIDGE ENGINEER

APPROVED October 5, 1979

STANDARD PLAN B-1a

Site Preparation and Modifications

Several modifications were necessary to improve the reliability of estimates of the drainage area and working conditions at the site. This work was performed by Washington State Department of Transportation District 1 Maintenance staff.

As the 1032 ft. section described above would receive some runoff from the portion of the grade above the curbing, a third collection box and side drain was installed near the beginning of the curbed section to eliminate this extra contribution. To increase the length of highway sampled, the first existing drain was closed, thus directing all runoff to the second drain, where the sampling station was located. To permit controlled flow measurement and sampling, the existing drainage pipe was replaced by a short pipe draining at a small slope angle to an open section where a flume was installed.

Because of the sloping bank, a rubble and gravel pad approximately eight feet square was put in place to contain the sampling shelter and provide working room. A gravel path wide enough for a vehicle was extended from the shelter area to a new access gate installed in the fence delimiting the right-of-way at NE 158th Street and 1st Avenue NE.

To serve the site with electric power, a pole and service were installed near the fence. Overhead wires were extended to a second pole, located near the shelter, on which was mounted a circuit breaker box. An underground conduit carried wiring into the shelter. Seattle City Light connected the service to a nearby secondary.

Traffic counts are available to the project from an automated counting system installed between the freeway exits where the monitoring site is located under another Department of Transportation contract. The truck and bus percentages of the total count may be obtained by using a factor derived from a manual vehicular classification count routinely performed by the Department.

Site preparation work was completed by May 31, 1978. Following is an itemized account if its cost (Klasell and Johnson Memorandum, June 12, 1978):

Table XVI: Itemized Cost of I-5 Monitoring Site Preparation

Material (1)	
Access gate, posts, hardware	$ 206.58
Type 1 collection box	90.49
Type 1 collection box frame and grate	197.21
20 ft. of 8 inch metal drain pipe	41.53
Subtotal	818.81
Equipment Charges	
Pickup and drilling for service poles	86.41
Vehicles	271.84
Subtotal	358.25
Manpower (2)	
Preparation of site	852.10
Electrical service personnel	200.00
Subtotal	1052.10
TOTAL	$ 2249.16

Notes: (1) Used electric service from District 1 maintenance saved approximately $700.
(2) Total 105 man-hours required.

Monitoring Equipment

Prior to selection of flow monitoring, sampling and auxillary equipment, a thorough review was undertaken to evaluate marketed devices of the types required. The review consisted of contacting regional agencies experienced in storm runoff monitoring and requesting demonstrations by equipment vendors. The first phase of the review was documented by a memorandum by

Horner (1977a), contained in Appendix B. The second phase was reported by a portion of another memorandum by Horner (1977b), to be found in Appendix C. The text of this report will summarize the operation and costs of equipment selected for use at the I-5 site.

As the primary device for flow measurement, an H-flume was purchased from Plasti-Fab, Inc., because of its ability to provide accurate registration of level over a wide range of flow rates (Robinson and Wright, 1977). An ISCO Model 1700 bubble-type flow meter was chosen for flow measurement. The instrument senses resistance to a pressurized air bubble, released at the base of the flume, due to the existing head of water and converts the reading to flow rate according to calibration. It totalizes flow and signals a companion digital printer which registers the total both on a preset time schedule and at any time a sample is collected. A mercury switch was installed in the flume and connected to the flow meter to activate it when runoff begins. The meter, in turn, signals the water sampler to begin operation according to its preset schedule.

Both ISCO Model 1680 and Manning Model 4050 automatic water samples were purchased to permit comparison of their performance in various services. On the basis of these tests, one sampler will be selected for use at other automated stations. The spare sampler will be available for use in special studies best suited to its capabilities. Both samplers may be set to take flow-proportional samples as signaled by the flow meter or to sample according to a preprogrammed time schedule. Multiplex arrangements in each case permit the collection of multiple samples on each discrete sampling occasion or compositing a set number of samples in each bottle. The ISCO device has the capability of collecting four bottles per sample or four samples per bottle, and the Manning instrument has a greater capability of ten bottles per sample or ten samples per bottle.

Results of the SR 520 preliminary monitoring program showed that composite sampling would be a workable method of establishing total storm loadings of contaminants. Being more economical, and perhaps more accurate for this purpose, compositing would be preferred to discrete sampling. To provide the capability of obtaining composites of entire storms, a flow-splitting device was designed and built for the I-5 station.

Auxillary equipment was purchased and placed at the site to monitor meteorological conditions and background air pollution. A Weather Measure Model P501-1E tipping bucket rain gauge and event recorder registers every 0.01 inch of precipitation on a seven-day strip chart. A record of wind speed and direction is provided by a Weather Measure Model W123 recording wind system. Monthly dustfall is monitored by means of three dustfall buckets spotted around the sampling site.

The flow meter samplers and auxillary equipment requiring 12 volt DC electric power are connected to an automotive battery which is, in turn, connected to a regulating charger served by the AC power supply. The battery is charged intermittently as needed and provides emergency power in the event of loss of regular service.

To house equipment, a surplus double-walled aluminum shelter approximately 5 x 5 x 5 ft. was obtained from the US Geological Survey Tacoma Warehouse for the cost of transportation.

To provide a record which might be useful in planning future monitoring stations, Table XVII lists costs incurred in equipping the I-5 site.

Table XVII: Itemized Cost of Equipping I-5 Monitoring Station

Item	Specifications	Cost
Flow meter, digital printer, automatic activation	ISCO Model 1700	$ 2,628
Automatic water sampler	ISCO Model 1680 plus multiplexer	1,405
	Manning Model 4050	1,805
Sampler auxillaries	Base and sample bottle compartment for Manning	100
	1 liter metering chamber for Manning	50
Automotive battery and regulating charger	Standard	55
Flume	Plasti-Fab size 1.5 H-Flume with stilling well, bubble tube cavity and inlet channel	650
Tipping bucket rain guage and event recorder	Weather Measure P501-IE	467
Recording Wind System	Weather Measure W123	747
Dustfall bucket with bird ring	Precision Scientific No. 63080 and 63081 (3 ea. $104)	312
Transportation of housing to site	Tacoma-UW (for preparation) UW-site @ $17/hr plus gasoline	170
Flow-splitter and composite tank		500
	TOTAL	$ 8,889

In addition to hardware costs listed in the table, an estimated $2000 was expended in technician wages to install equipment and put the station in working order. Costs for site preparation, equipment and installation labor thus totaled $13,138. With the experience gained at I-5, this cost could be considerably reduced at any comparable site established in the near future.

Schedule

Following completion of site preparation in May, 1978, equipment that had been received was installed at the site. Equipment deliveries were completed by July 31, 1978, and installation and initial test runs by August 31, 1978. The early Fall period was used to develop station operating procedures and experiment with alternative means of splitting flow and compositing samples. Normal operations commenced in November. It is anticipated that data collection will proceed at this site for the duration of the research project. In addition to regular data collection aimed at establishing loadings and maximum concentrations and pollutograph patterns of the various contaminants, special studies will also be conducted to further compare discrete and composite sampling and the performance of the two types of automatic samplers. Results of these efforts will be issued in subsequent reports.

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APPENDIX

APPENDIX A: Raw Data, Preliminary SR-520 Monitoring Program.

Month	Day	Drain	Hour	Minute	Flow Rate* (GPM)	pH	Specific Conductivity (μmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks**
1	7	1	10	32	.17			40	6		98	
1	7	1	10	58	.17			35	14		71	
1	7	1	11	27	.50			52	156			
1	7	1	11	48	1.18			44	59		39	
1	7	1	12	16	1.09			36	60		32	
1	7	1	12	35	.44			38	98		43	
1	7	2	10	28	.27			37	14			
1	7	2	11	00	.27			48	51		67	
1	7	2	11	32	.70			57	26		83	
1	7	2	11	52	1.42			51	87		51	
1	7	2	12	10	.78			35	76		67	
1	7	2	12	31	.78			42	83		47	
1	7	1	22	10	.32			43	26		49	Complete storm:
1	7	1	23	15	.32			38	70		57	Dry days = 0.13
1	7	2	22	15	.38			59	82		65	Rainfall = 0.61 inch
1	7	2	23	20	.32			42	79		78	ADT = 16,840 westbound
1	8	1	12	51	.22			27	20		57	15,920 eastbound
1	8	1	14	30	9.5*			34	18		69	
1	8	1	23	52	25.2*			41	33		94	
1	8	2	12	54	.28			30	17		102	
1	8	2	14	32	12.9*			43	16		73	
1	8	2	23	54	30.6*			53	38		114	

* Signifies composite sample. In this case total flow (gal) is reported.

** Complete storm data were used in loading estimates. ADT is average daily traffic in the dry period preceding the storm.

APPENDIX A - Cont'd

Month	Day	Drain	Hour	Minute	Flow Rate* (GPM)	pH	Specific Conductivity (μmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks**
1	9	1	16	45	23.1*			16	25		106	Complete storm:
1	9	1	19	05	14.6*		177	63	19		118	Dry days = 0.58
1	9	1	20	52	33.7*		130	51	90		71	Rainfall = 0.14 inch
1	9	1	23	18	17.7*		134	35	31		71	ADT = 17,345 westbound
1	9	2	16	48	29.9*		214	76	151		164	31,667 eastbound
1	9	2	19	08	19.7*		198	75	97		139	
1	9	2	20	40	35.7*		167	79	89		109	
1	9	2	23	23	19.7*		156	48	4		50	
1	13	1	12	47	.01	6.7	482	45	120		238	
1	13	1	15	00	16.3*	6.8	250	150	740		246	
1	13	1	15	45	.45	6.8	160	120	944		258	
1	13	2	12	57	.02	6.8	433	53	145		231	
1	13	2	15	00	20.4*	6.7	265	130	222		211	
1	13	2	15	47	.54	6.8	215	130	296		250	
1	13	2	16	19	1.49	7.0	86	120	421		245	
1	13	2	16	52	.60	7.0	86	110	249		152	
1	13	1	16	18	1.13	6.9	82	110	1101		226	
1	13	1	16	50	.54	6.9	108	130	395		191	
1	19	1	10	30	34.3*	6.9		54	204		120	Complete storm: Dry days = 2.38
1	19	2	10	30	38.6*	7.1		55	86		105	Rainfall = 0.03 inch ADT = 34,925 westbound 34,632 eastbound
1	20	1	11	45	29.6*	6.8	282	33	64		113	Complete storm Dry days = 0.96
1	20	2	11	45	30.3*	7.0	324	43	107		117	Rainfall = 0.05 ADT = 36,255 westbound 42,758 eastbound

Month	Day	Drain	Hour	Minute	Flow Rate* (GPM)	pH	Specific Conductivity (µmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks**
1	25	1	10	50	25.5*	6.7	271	120	635		323	Complete storm:
1	25	1	11	15	.60	7.1	116	160	243		238	Dry days = 3.88
1	25	1	11	40	.67	7.3	105	130	256		138	Rainfall = 0.14 inch
1	25	1	12	05	.73	6.7	100	140	304		178	ADT = 29,583 westbound
1	25	1	12	32	.74	6.7	79	78	225		108	27,771 eastbound
1	25	1	12	55	.61	6.7	82	100	303		178	
1	25	1	14	09	.06	6.7	144	100	93		66	
1	25	2	10	50	25.5*	6.6	311	110	263		268	
1	25	2	11	15	.61	7.0	208	120	180		242	
1	25	2	11	40	.78	7.1	134	110	165		156	
1	25	2	12	07	.94	6.7	123	120	412		182	
1	25	2	12	33	.80	6.8	101	91	282		108	
1	25	2	12	57	.54	6.8	101	84	196		140	
1	25	2	14	12	.06	6.8	181	120	91		105	
2	5	1	13	25	.14	6.9	484	130	1844	136	331	Complete storm:
2	5	1	13	50	.19	7.1	357	100	372	36	207	Dry days = 2.75
2	5	1	14	18	.23	7.1	218	90	143	9	124	Rainfall = 0.07 inch
2	5	1	14	50	.30	7.3	163	145	864	87	191	ADT = 28,713 westbound
2	5	1	15	19	.45	7.2	109	110	366	70	171	32,702 eastbound
2	5	1	15	50	.42	7.2	117	87	290	35	103	
2	5	1	16	22	.15	7.2	145	62	169	15	99	
2	5	1	16	53	.11	7.3	153	50	96	18	107	
2	5	2	13	28	.14	7.0	431	120	521	46	223	
2	5	2	13	55	.26	7.1	352	80	288	40	227	
2	5	2	14	21	.29	7.2	244	95	359	88	187	
2	5	2	14	51	.36	7.0	184	120	482	75	175	
2	5	2	15	20	.44	7.2	142	105	483	80	299	
2	5	2	15	52	.44	7.3	131	90	716	100	115	
2	5	2	16	25	.16	7.3	158	63	113	22	75	
2	5	2	16	50	.10	7.3	174	50	85	21	123	

Month	Day	Drain	Hour	Minute	Flow Rate* (GPM)	pH	Specific Conductivity (µmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks**
2	9	1	00	50	39.4*	6.7	110	96	311	48	170	Complete storm:
2	9	1	00	52	2.27	6.8	77	125	716	101	292	Dry days = 0.63
2	9	1	01	05	2.29	6.7	53	40	97	11	96	Rainfall = 0.10 inch
2	9	1	01	24	1.44	6.9	44	29	74	21	64	ADT = 42,492 westbound
2	9	1	01	43	.79	6.8	53	21	28	16	36	46,143 eastbound
2	9	1	02	05	.65	6.9	57	22	43	14	44	
2	9	1	02	33	1.65	6.9	43	30	82	8	56	
2	9	2	00	51	30.6*	6.8	66	94	291	51	217	
2	9	2	00	53	2.04	6.9	52	105	600	106	221	
2	9	2	01	06	1.97	6.9	64	74	360	36	124	
2	9	2	01	25	1.40	6.9	53	43	186	28	80	
2	9	2	01	44	.68	6.8	64	28	148	9	52	
2	9	2	02	06	.52	6.8	66	31	95	19	52	
2	9	2	02	34	1.32	6.9	52	45	200	5	80	
2	14	1	15	50	8.8*	6.9	409	130	1057	124	392	Complete storm:
2	14	1	15	59	.46	6.8	234	105	671	139	375	Dry days = 5.29
2	14	1	16	21	.86	7.0	160	110	608	103	335	Rainfall = 0.33 inch
2	14	1	16	35	1.02	6.8	136	110	454	99	306	ADT = 29,932 westbound
2	14	1	16	48	1.77	6.8	114	95	424	93	245	29,907 eastbound
2	14	1	17	17	2.17	6.6	70	78	319	75	175	
2	14	1	17	40	2.48	6.8	59	82	430	99	192	
2	14	1	18	10	2.03	6.4	53	105	559	109	248	
2	14	1	18	33	1.66	6.6	63	72	222	84	132	
2	14	1	19	22	1.29	6.9	58	42	103	48	88	Replicates
2	14	1	19	22	1.29	6.9	59	52	87	43	68	
2	14	2	15	50	8.8*	7.2	451	150	577	106	371	
2	14	2	15	55	.66	6.8	289	145	449	113	314	

APPENDIX A - Cont'd

Month	Day	Drain	Hour	Minute	Flow Rate* (GPM)	pH	Specific Conductivity (μmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks**
2	14	2	16	17	.91	6.9	221	120	495	113	298	
2	14	2	16	32	1.06	6.9	146	118	408	113	241	
2	14	2	16	44	1.65	6.9	132	130	526	86	241	
2	14	2	17	10	2.02	7.2	94	120	504	78	232	
2	14	2	17	38	2.29	6.9	74	84	199	47	144	
2	14	2	18	08	2.03	7.3	72	73	288	55	128	
2	14	2	18	34	1.81	6.7	83	64	195	49	120	
2	14	2	19	23	1.63	6.9	78	35	233	56	104	Replicates
2	14	2	19	23	1.63	7.0	80	43	78	43	88	
2	25	1	14	05	1.05	6.5	92	98	465	171	204	Complete storm:
2	25	1	14	18	1.00	6.4	76	83	376	146	200	Dry days = 0.13
2	25	1	14	28	.83	6.6	81	63	157	76	106	Rainfall = 0.36 inch
2	25	1	14	39	.60	6.5	88	65	165	77	106	ADT = 30,706 westbound
2	25	1	14	49	.50	6.6	86	63	48	23	98	35,412 eastbound
2	25	1	14	59	.70	6.4	71	63	194	72	114	
2	25	1	15	11	.80	6.3	69	57	169	60	102	
2	25	1	15	27	.63	6.4	79	41	52	19	41	
2	25	1	15	59	.29	6.7	108	42	30	19	49	
2	25	1	16	51	.31	6.5	101	61	201	81	114	
2	25	1	17	39	.41	6.4	73	48	103	56	64	
2	25	1	19	31	.38	6.5	70	46	161	65	88	
2	25	2	14	05	1.42	6.8	121	96	641	203	204	
2	25	2	14	19	1.22	6.7	101	82	307	104	135	
2	25	2	14	29	.99	6.5	107	66	152	48	94	
2	25	2	14	40	.66	6.7	114	61	142	55	73	
2	25	2	14	50	.60	6.6	113	64	189	76	98	
2	25	2	15	00	.80	6.3	99	68	347	177	110	

Month	Day	Drain	Hour	Minute	Flow Rate* (GPM)	pH	Specific Conductivity (μmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks**
2	25	2	15	10	.96	6.5	95	67	184	60	106	
2	25	2	15	25	.75	6.5	102	50	75	41	41	
2	25	2	16	00	.41	6.9	145	51	47	21	41	
2	25	2	16	52	.40	6.8	136	74	204	60	131	
2	25	2	17	40	.51	6.5	100	52	83	32	60	
2	25	2	19	30	.51	6.6	95	52	143	54	72	
4	14	1	10	15	15.6*	6.9	307	97	460	79	232	Complete storm:
4	14	1	14	35	2.7*	6.4	307	125	1651	255	483	Dry days = 0.71
4	14	1	14	37	.87	6.4	266	120	922	136	386	Rainfall = 0.07 inch
4	14	1	14	44	.87	6.4	172	98	507	112	278	ADT = 62,915 westbound
4	14	1	14	52	.47	6.5	161	95	441	109	251	
4	14	1	15	02	.65	6.5	146	110	609	128	328	
4	14	1	15	12	.95	6.5	109	105	673	129	301	
4	14	1	15	22	1.50	6.5	111	87	313	101	174	
4	14	1	15	32	.75	6.5	117	78	233	85	278	
4	14	1	15	32	53.0*	6.5	149	99	544	114	255	Replicates
4	14	1	15	32	53.0*	6.5	149	100	591	124	251	
4	14	1	15	32	53.0*	6.5	148	100	518	110	284	
4	14	1	15	32	53.0*	6.5	149	102	611	128	272	
4	14	1	15	32	53.0*	6.5	148	100	542	116	324	
4	14	1	15	42	.68	6.5	130	54	116	48	104	
4	14	1	15	55	.68	6.7	151	52	96	52	108	
4	17	1	10	43	.11	6.7	244	100	3064	328	828	Complete storm:
4	17	1	10	50	.34	6.8	205	115	629	91	216	Dry days = 0.71
4	17	1	10	57	.24	6.9	184	125	430	54	208	Rainfall = 0.05 inch
4	17	1	15	12	1.36	6.8	116	100	597	129	320	ADT = 26,704 westbound
4	17	1	15	22	.41	6.8	133	95	313	73	200	
4	17	1	15	32	.34	6.9	160	98	220	53	180	

APPENDIX A - Cont'd

Month	Day	Drain	Hour	Minute	Flow Rate* (GPM)	pH	Specific Conductivity (µmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks**
4	21	1	17	15	18.4*			90	1244	430	589	Complete storm:
4	21	1	17	15	3.50			61	378	84	237	Dry days = 1.75 Rainfall = 0.03 inch
4	21	1	17	30	3.50			59	183	65	205	ADT = 34,320 westbound
4	26	1	08	40	6.8*	6.5	578	100	2216	620	963	Complete storm
4	26	1	22	35	44.9*	6.6	304	88	540	152	316	Dry days = 3.46
4	26	1	22	40	.09	6.6	180	61	121	35	138	Rainfall = 0.10 inch
4	26	1	22	55	.09	6.6	178	57	44	11	126	ADT = 29,286 westbound
4	26	1	23	10	.41	6.6	134	77	263	84	215	
4	26	1	23	25	.71	6.6	119	43	113	33	118	
4	26	1	23	40	.45	6.5	120	30	70	18	73	
4	26	1	23	55	.32	6.7	121	30	76	17	81	
4	27	1	00	10	.45	6.7	106	43	145	39	150	
4	27	1	00	25	.82	6.7	91	34	81	32	89	Replicates
4	27	1	00	25	.82	6.6	91	33	49	28	99	
4	27	1	00	25	.82	6.8	91	35	105	30	103	
4	27	1	00	25	.82	6.7	91	36	50	8	91	
4	27	1	00	25	.82	6.7	92	35	72	32	99	
5	09	1	09	45	.75	6.4	472	170	1760	183	608	Complete storm:
5	09	1	09	55	1.00	6.5	307	175	667	103	428	Dry days = 4.88
5	09	1	10	05	1.30	6.5	250	175	480	84	328	Rainfall = 0.19 inch
5	09	1	10	15	.85	6.6	221	130	228	19	260	ADT = 33,875 westbound Replicates
5	09	1	10	15	.85	6.5	225	135	284	19	264	
5	09	1	10	15	.85	6.6	225	130	290	24	260	
5	09	1	10	15	.85	6.6	225	135	292	24	260	
5	09	1	10	15	.85	6.5	226	130	266	26	260	
5	09	1	10	30	1.10	6.6	156	170	177	49	316	
5	09	1	10	45	1.17	6.7	156	140	301	61	180	

Month	Day	Drain	Hour	Minute	Flow Rate * (GPM)	pH	Specific Conductivity (µmho/cm)	Turbidity (FTU)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	Remarks
5	9	1	11	00	.43	6.7	162	150	314	63	176	
5	9	1	11	00	52.4*	6.6	243	170	1031	219	2010	Replicates
5	9	1	11	00	52.4*	6.7	242	170	1081	252	2000	
5	9	1	11	15	.70	6.6	123	155	357	86	227	
5	9	1	11	30	2.40	6.7	104	185	372	53	153	Replicates
5	9	1	11	30	2.40	6.5	105	185	434	44	145	
5	9	1	11	30	2.40	6.5	106	185	268	23	145	
5	9	1	11	30	2.40	6.6	106	185	380	30	149	
5	9	1	11	30	2.40	6.7	106	180	420	49	149	
5	9	1	11	45	.87	6.8	130	270	652	90	211	
5	9	1	12	15	.42	6.8	141	125	233	71	215	
5	9	1	12	45	.13	6.8	172	120	234	81	211	
5	9	1	12	45	46.2*	6.8	126	180	474	94	1040	Replicates
5	9	1	12	45	46.2*	6.9	125	185	463	89	1030	
5	9	1	13	15	.26	6.8	185	87	129	64	211	
5	9	1	14	22	.10	6.7	95	245	685	110	199	
5	9	1	14	40	2.50	6.7	86	83	147	52	109	

APPENDIX B

University of Washington Correspondence

INTERDEPARTMENTAL

DEPARTMENT OF CIVIL ENGINEERING
WATER AND AIR RESOURCES DIVISION

October 28, 1977

MEMO TO: Professors Mar
Burges
Ferguson
Welch
Spyridakis

FROM: Rich Horner

SUBJECT: USGS and METRO Experience with Flow Monitoring and Runoff Sampling

In the past several days I have visited the USGS/METRO urban runoff monitoring station in Enumclaw with Don Sturgill (METRO) and spoken with Ed Prych (USGS) and Paul Farley and Ed Cox (METRO) about their monitoring equipment and experiences.

The Enumclaw project encompasses monitoring of the runoff from a residential and an agricultural area, as well as the receiving Newaukum Creek near its source and at the mouth. Runoff monitoring stations are placed in ditches immediately downstream of culvert pipe discharges. The stations include equipment for recording flow and precipitation and sampling the runoff at set intervals. Equipment has been placed in housings which are mounted directly above the open ditches. Details on each aspect of the monitoring program follow as a basis for our discussions during the October 31 meeting.

Flow Measurement

USGS has the official responsibility for flow and precipitation monitoring and is employing its standard practice used in hundreds of stream gaging stations. This practice involves the use of a Fisher-Porter or Leopold and Stephens automatic digital stage recorder operated by a float in a stilling well. A weir has been installed for control purposes only (it is not calibrated for flow measurement). The stage recorder is calibrated for flow determination with the use of current meter and channel geometry measurements and Manning's formula. A staff gage has also been placed at the site for visual stage evaluation during visits. Fisher-Porter Model 1542 recorder lists for approximately $500 and the Leopold and Stephens model, which is considered better, for $625. With either instrument a timing device (approximately $100) and float tape ($32.50 for a 15 ft. tape) are also needed.

METRO has also installed their favorite flow monitoring equipment, ostensibly because it is more easily adapted to activating the water sampler but in reality, it seems, because they regard it as the most accurate method available. Their method employs the Arkon nitrogen bubbler flow recording system, which they have installed at a number of locations around the county. This device senses and records stage as a function of the head overlying a tube emitting nitrogen bubbles fed from a cylinder. In addition to accuracy, the distinct indication of peak stage is cited as an advantage of gas bubble instruments.

The Arkon device is manufactured in and distributed from England exclusively, which creates a long delivery time (6 months) and difficulty in obtaining parts and the copy-righted chart paper. The cost is approximately $1,700 including housing with paper costing $8 per roll. METRO regards the instrument's capabilities and general reliability as ample compensation for the delivery problems and relatively high cost.

Martig manufactures a nitrogen bubbler device competing with the Arkon with which METRO has had problems. Arkon is, in addition, the only field device recording on a strip chart (the others use less accurate circular charts). Martig costs approximately $1,200 and is American-made.

The nitrogen bubbler device can be easily installed to measure flow in pipes by passing the tube through an expansion screw in a drilled hole at a joint and bracketing it to the bottom. The tube is best installed a short distance away from the manhole interruption. Supercritical flows are a potential problem in areas of rapid slope. Such sections are best avoided but notching the bubbler tube outlet such that bubbles exit more smoothly may be a solution. Marsh-McBirney also makes a volumetric flow meter which is unaffected by supercritical flow. It senses velocity electromagnetically and depth by a bubble-type transducer and combines the measurements to read out flow directly on a circular chart. I will request prices on this device from the manufacturer.

METRO calibrates their Arkon recorders with the use of the Manning formula every 3-4 months. A computer program is available to relate flow and stage through an iteration on the Manning roughness coefficient. Other servicing includes winding the clock once each week, changing chart paper and changing the 80 cu.ft. nitrogen cylinders every 2-3 months.

Precipitation Gaging

USGS uses as a rain gage an ordinary galvanized bucket placed on the roof of the shelter as a float vessel for operation of the same type of stage recorder used for flow measurement. They favor this system because of their experience with the recorders. It also saves the cost of an event recorder, which must be provided when a tipping bucket device is used.

Water Sampling

METRO's responsibility in the program is the collection and analysis of water samples. They have selected Manning Model S-4040 Portable Discrete Sampler for the collection (brochure attached). It operates by pumping a sample into a filling chamber and then distributing it via tubing into sample bottles in a sequential manner. Manning is favored by METRO over its Sirco and ISCO competitors because of the following features:

- Vortex action in draining filling chamber which effectively washes down solids.

- Greater flexibility in setting sampling sequence, including up to three samples at each sampling occasion and the ability to composite several samples of equal size over several sampling intervals.

- The availability of a good wiring program permitting minor modifications to be done.

The Manning sampler will fill up to 24 sample bottles, with an interval adjustable from 3.7 to 60 minutes. The sampler itself will fit into a 55 gal. drain or a manhole, although a box to contain 24 sizable sample containers does not. It operates reliably on a 12 volt automobile battery, which retains its charge through several storms, perhaps excepting cold periods. The cost is approximately $1,700. The ISCO device costs about the same, and Sirco is slightly more expensive.

METRO has mounted the sampler on a wooden box which channels tubing into sample bottles contained in a drawer at the base of the box. The drawer is removable when all containers are filled for transport to the lab. A drawer containing empty bottles then replaces it. METRO has also modified the basic instrument to collect 1 liter, instead of 500 ml, samples by fashioning a new filling chamber from a glass reagent bottle. This modification also requires the replacement of one capacitor and costs less than $30 total.

Samplers are set to collect three 1 liter samples at each sampling occasion. METRO emphasizes the need for this amount of sample for their broad-based program, which includes oils, solids, BOD, heavy metals, nutrients and bacteriological analyses. In the concentrations existing, the extraction method (Standard Methods) for oil and grease requires 1 liter alone.

METRO recommends using flow to activate the sampler in a situation where stage increases rapidly, such as urban or highway runoff monitoring. Because of technical problems with flow activation, however, they are currently operating with precipitation activation using a home-made tipping bucket rain gage operating a mercury switch after 0.08 inch of rain is received.

The usual operating procedure is to sample at 15 minute intervals during the first few hours of a storm, at 30 minute intervals for the next several hours and thereafter, every 60 minutes until the stage falls off.

Housing and Security

Urban and agricultural runoff stations in Enumclaw are housed in approximately 4 ft. cube steel shelters obtained from the U.S. Atomic Energy Commission. USGS, Tacoma, has a number of such shelters. They are willing to give us enough for our entire statewide project in return for our removing the electronic equipment, for which they actually obtained the shelters. The estimated time for this job is one-half to one man-day per shelter. They are double-walled, quite sturdy and imposing in appearance. Disadvantages include some tendency to leak around the roof and some difficulty in putting holes in the floor because of structural work and the stainless steel bottom. Still, they will do the job, and the price is certainly right. Alternatives include mailboxes available from Winters Surplus and metal containers from Pacific Iron and Metal.

USGS and METRO both report few problems with security, other than in isolated areas where hunting is prevalent. Equipment housed much less securely than in Enumclaw has operated for the time required without disruption in Don Sturgill's four years experience.

Miscellaneous

METRO has arranged with the National Weather Service in Auburn to call personnel at any hour when radar shows a storm expected to deliver more than 0.4 inch precipitation over a several hour period. With this warning they have had several false alarms but have not lost any storms.

I have collected some literature on equipment from METRO and have requested much more from distributors. Within the next few days I will begin filing this in our library outside Steve's office in some organized fashion, which I will post.

Conclusions

I am impressed with the capability and apparent reliability of the system described. I particularly have few doubts that the Manning equipment is the way to go on our pilot studies of automated sampling. Potential delivery and parts problems with the Arkon flow monitor trouble me, but I believe the gas bubble system promises the best accuracy and adaptability to both open and closed culvert monitoring available. I do want to evaluate the Marsh-McBirney equipment but expect it to be expensive and perhaps not as widely proven. Recognizing that cost is a major consideration, I would emphasize the point that reliable water sampling and flow measurement is absolutely crucial and worthy of receiving the highest priority. We apparently can realize substantial savings in housing by taking some shelters off the hands of the USGS. Additional savings could be effected by accepting the cruder USGS system in the less critical area of precipitation gaging, rather than outfitting each site with a tipping bucket collector and event recorder, or dispensing with this measurement where a NWS station is fairly close to the site.

RH:lc
enc.

University of Washington Correspondence
INTERDEPARTMENTAL

DEPARTMENT OF CIVIL ENGINEERING
WATER AND AIR RESOURCES DIVISION

November 21, 1977

MEMO TO: Professors' Mar, Burges, Ferguson, Welch, Spyridakis

FROM: Rich Horner

SUBJECT: Review of Sampling and Flow Monitoring Equipment and Proposal for Initial Sampling Program on SR 520

A review of currently available automatic sampling and flow monitoring equipment was conducted by consulting manufacturers' representatives and users of the devices. Following is a summary of the results of this review.

<u>Portable Water Sampling Equipment</u>

There are three manufacturers of flexible, high quality portable automatic samplers. The attributes of their products are summarized in Table I. Differences exist mainly in the means by which the sample is drawn and metered and the adjustment of the sampling interval. The Manning equipment has the strong endorsement of METRO, while EPA Region X reports considerable successful experience with ISCO. Sirco's portable sampler is newer to the market and less extensively used at present, although the company is a veteran in the stationary sampling field.

The purchase decision apparently depends mostly on the position solids and organics will have in our monitoring program and the total volume required at each discrete sampling occasion. Unquestionably, Manning's 4050 instrument is superior to all others in sampling solids on a sequential schedule. ISCO's device has been regarded as inferior in this regard, but a higher-powered peristaltic pump in the improved version has somewhat alleviated the problem. The tray-type distribution system still tends to precipitate solids prior to entry into the sample bottle, thus leaving a residue contaminating the next sample collected. EPA studies using ISCO have been restricted to a composite collected in a central vessel rather than by means of the tray. ISCO also exposes the sample to more plastic (ABS) contact than other samplers, to the possible detriment of accuracy in monitoring the chlorinated hydrocarbons. EPA avoids such contamination by replacing the normal Tygon inlet tubing with teflon and again taking only a composite. This practice is in accord with studies of highway-generated organics appearing in the literature.

Table I: Attributes of Portable Water Sampling Equipment

	Sirco	ISCO	Manning
Model(s)	MK-VS7 + Multi-compositer and consecutive sample selector	1680 Sequential and Composite	4040 4050
Main Components	Vacuum pump. Electronics not solid state. Metering chamber and adjustable electrode. Solenoid controlled pinch valve.	Peristaltic pump. Sealed solid state controls. Multiplexer.	Vacuum pump. Sealed solid state controls. Metering chamber and fill sensor. Solenoid controlled pinch valve.
Sampling Capabilities	Continuously adjustable 3 min.-45 hr. or flow proportional. Compositing up to 10 per btl. Up to 10 btl/sampling occasion.	Continuously adjustable 1-999 min.(or 2-1998 min. with no cost option) or flow or time proportional. Compositing up to 4 per btl or 4 btl/sample.	Selection of 10 intervals from 3.7 min. to 24 hr. or flow or time proportional. Compositing up to 10 per btl. or 10 btl/sampling occasion.
Power Load	Medium	Light	Light
Modifications	1 liter metering chamber by Mfr. ($25)	No modification for > 650 ml/sample possible but 28 btl sample compartment standard.	1 liter metering chamber $285 by mfr. or $30 + time if done by us.
Advantages	Continuous sample interval adjustment. Ease of sample size modification.	Versatile programming features. Excellent sealing. Compatibility with flow meter.	4050-isokinetic sampling, vortex metering chamber drain for best movement of solids. Clear wiring diagram and instructions.
Potential Problems	Past reputation of poor compositing and poor service (Metro). Not as well sealed as others.	Solids dropped in filling tray and cross contaminate samples. Sample volume decreases as head increases. Much sample contact with plastic. Black case absorbing heat.	4040-Moisture causing pressure differential switch malfunction. Less flexibility in sample interval timing.
Costs (without battery)	$1900 Base + Compositer and Consecutive Sample selector. $25 for 1 liter metering chamber.	$1295 Base $110 Multiplexer	4040 - $1650 4050 - $1975 (incl. multiplexer and quartz clock timer). Note 1.

Table I: (Continued) Attributes of Portable Water Sampling Equipment

	Sirco	ISCO	Manning
GSA Contractor	No	Yes	Yes
Delivery	6-8 Weeks	2-4 Weeks	Immediate-45 days
Service	Now local. 2 week turnaround. Will advise on modifications without cost or warranty loss. Past reputation for poor service and expensive parts.	Basic parts local. Normally requires shipping to Nebraska.	Would do everything possible locally.

Note 1: $170 would be deducted if we provide sample bottles and a housing for them.

ISCO and Sirco have continuously adjustable discrete sampling interval selections, while Manning is limited to the ten positions of the rotary switch, with 3.7 minutes being the minimum. Manning and Sirco offer the greater flexibility in compositing and collecting multiple samples (10/btl or 10 btl/sampling occasion vs. ISCO's 4/btl or 4 btl/sample). For two former samplers have a 24 bottle collection chamber (in comparison to ISCO's 28 bottle chamber) and are fairly easily adaptable to collecting one liter samples. ISCO is limited to 500 mℓ volumes, or less where substantial lift is required. On a hypothetical sequential sampling schedule of drawing two liters every 7.5 minutes, the Manning and Sirco devices would thus collect for 90 minutes before sample containers must be replaced, while the ISCO sampler would require attention after 52.5 minutes. Collecting more than two liters per sampling occasion is impossible with ISCO; but, theoretically, up to 10 liters per sample could be drawn by the other instruments.

All factors considered, the Manning Model 4050 must be regarded as the most desirable sampler. ISCO has a certain appeal because of its flexible programming capabilities and compatibility with the rather attractive ISCO Model 1700 flow monitoring system. Unless the research is to be based on composite samples for organics and solids, with no need for large discrete sample volumes at all, however, the ISCO device cannot be recommended. Joining sampling and flow equipment from two different manufacturers is apparently a feasible arrangement.

Flow Monitoring Equipment

The choice of an instrument for flow measurement is less clear-cut than that of a sampler because of the lack of reported successful applications in supercritical flow. Instruments operating on four different fundamental principles were reviewed: gas bubblers (Arkon, ISCO), ultrasonic (Sirco, Manning), gas bubbler/electromagnetic velocity measurement (Marsh-McBirney) and conductivity (Manning). Attributes of the various devices are presented in Table II.

Those where limited supercritical experience is reported are the Arkon bubbler and the Marsh-McBirney instrument. METRO has modified the Arkon bubbler tube in high velocity service by notching it such that the bubble exits uniformly, rather than being torn away. In general, METRO contributes a most enthusiastic recommendation of the nearly trouble-free Arkon, enduring the extremely long delivery time. That recommendation is based on experience with approximately 10 instruments over a period of about five years. Marsh-McBirney has tested their device at velocities up to 15 ft/sec. They are unwilling to recommend its use at higher velocities without further tests because of the tendency for cavitation to develop around the electromagnetic sensor. The company has offered to lend us an instrument for a month (no earlier than January) for our test in supercritical flow, with a letter of request and return freight costs all that is required from us. This device definitely requires minimum 5-6 inch depth in high velocity flow. Its disadvantages are high instrument and battery cost and the circular chart, which is less accurately read than a strip chart.

Ultrasonic instruments have no theoretical problem with supercritical flow, but their installation would be difficult. All such devices have a "dead space," which must be maintained between the sender/receiver and the maximum water level, and require a hole in the pipe. Presumably, the sender/receiver would have to be retained at a spot somewhere above the pipe outer wall to insure maintenance of the dead space. Between the two ultrasonics, the Manning is more attractive because of its direct conversion of level to flow, although it is considerably more expensive than the Sirco.

The recently improved version of the Manning Dipper conductivity water surface sensor has been successfully used in sewers by METRO and EPA, although without specific experience in supercritical flow. EPA conducts flow-proportional sampling using the Dipper in combination with the ISCO sampler.

Devices of several types require information from the customer to program the conversion from level to flow. Included are the ISCO bubbler/coded disc converter, Manning UTC-2102 ultrasonic/electronic converter and Manning F-3000A Dipper conductivity/cam converter. This information should be provided in the form of a level-flow calibration performed by Pitot tube or current meter. Providing the geometry, roughness and slope for a Manning equation programming is an inferior method which is bound to lead to great inaccuracy. The manufacturers base accuracy quotations on a proper level-flow calibration. It is, of course, true that the same calibration must be performed at each sampling site to permit later manual or computer conversion of level data to flow when using instruments which do not make the conversion directly.

The ISCO Model 1700 bubbler has considerable appeal for several reasons. A digital printer, available as an option, would provide a record of the time at which flow measurement commenced and simplify data handling. The instrument is easily and cheaply adaptable to different sites, with the cost of each level-flow disc converter programmed to order being only $15. It is, in addition, compact and easily installed. On the negative side, power requirement is high, although manageable in intermittent operation; and uncertainty concerning the bubbler concept in supercritical flow remains.

Presently, the ISCO, Marsh-McBirney and Manning Dipper instruments appear to be the leading candidates for selection. It would be desirable to pursue an arrangement with each manufacturer similar to that offered by Marsh-McBirney, where we could conduct a short-term test under our most stringent supercritical flow condition. I will approach the ISCO and Manning representatives with that suggestion or attempt to borrow an instrument from one of their customers.

Precipitation Recording

Alternatives for precipitation recording are a tipping bucket collector with event recorder and a conventional stage recorder sensing water level in an ordinary galvanized bucket. Based on Weather Measure Corporation prices, a tipping bucket rain gage, event recorder with eight-day spring wound clock and cable would cost $440. A Leupold and Stevens Type F stage recorder with eight-day spring-driven clock costs $390. USGS recommends Leupold and Stevens, and I have found Weather Measure equipment reliable in the past. The choice here is not critical but depends on whether we wish to save a small amount with a stage recorder or spend the additional to acquire a completely assembled system.

Dust Monitoring

Envirex recommends locating three standard dustfall buckets at each sampling site to obtain a monthly composite indication of the contribution of non-highway airborne constituents. The buckets with bird rings cost $32.50 each (VWR), with a stand being extra if needed.

Station Housing

Portable samplers and flow meters are designed to be placed in manholes with the proper supports. Otherwise, housing alternatives remain the double-walled steel boxes available free from USGS or surplus mailboxes, as reported previously. The University could haul the steel boxes and set them in place for $17/hr. plus gasoline. Mailboxes are $25 each. Housing would be needed if the sampler is modified to collect one liter samples, as the collection chamber would likely not fit in a manhole. Precipitation monitoring equipment would also require housing. The fit would be very close in a mailbox with the sampler used as designed; modification for one liter samples may exceed the size of a mailbox. The heavy steel boxes could offer secure and spacious housing at any long-term site.

Proposal for Initial Sampling Program on SR520

I met with Steve Burges to evaluate the hydrologic aspects of the drainage sytem on SR520 and with John Ferguson to plan a first-stage sampling program. This program would begin prior to the delivery of automatic sampling and flow recording equipment and would serve to verify predicted flow characteristics,

APPENDIX C

Table II: Attributes of Flow Monitoring Equipment

	Arkon	ISCO	Sirco	Marsh-McBirney	Manning	Manning
Model(s)	--	1700	L30	250	UTC-2102	F-3000A Dipper
Principle	Bubbler-Nitrogen cylinder. Subsequent manual or computer conversion of level to flow	Bubbler-air compressor. Conversion of level to flow by coded function generator disc and photo-electric cell.	Ultrasonic sender/receiver. Subsequent manual or computer conversion of level to flow.	Bubbler (air compressor) + electromagnetic velocity sensing. Direct conversion to flow.	Ultrasonic sender/receiver. Conversion of level to flow directly by programmed electronic chip.	Conductivity water surface sensor. Conversion of level to flow directly by cam.
Recording	8-inch strip chart.	Totalizer. 4-inch strip chart or digital printer.	2 1/2-inch strip chart.	Totalizer. 7 day circular chart.	Totalizer. 2 1/2 inch strip chart.	7 day circular chart.
Power	Spring-wound clock (7 day).	AC or 12 V. DC.	AC, 12 V. DC or solar cell.	AC or 12 V. DC.	AC or 12 V. DC.	12 V. DC.
Supercritical Flow	See text.	No specific tests. See text.	No specific tests.	Tested up to 15 FPS. Need 5-6 in. depth minimum at high speed. See text.	No specific tests	No specific tests but theoretically applicable.
Advantages	Reliable operation. Accurate chart record.	Compatibility with sampler. Digital printer would show time flow began. Versatility of discs.	Lower power requirement.	Willing to lend for test. Potential for reliable supercritical service.	Versatility of chips.	Low power. Improved version has reputation for reliability (Metro). Easy installation.
Potential Problems (besides supercritical flow)	Long delivery time for instrument and charts.	High power requirement (manageable with intermittent operation).	Placement of sender/receiver (need hole in pipe and minimum 10 in. to water surface).	High power requirement (reduced with air cylinder). High cost. Circular chart less accurate. Possible sediment buildup around sensor.	High power requirement (manageable with intermittent operation). Placement of sender/receiver (26 in. min. to water surface and hole in pipe).	Cams harder to program than electronic level-flow converter. Circular chart less accurate.
Costs	Approx. $1700	$1595 meter. $895 digital printer (or $795 chart recorder). $137.50 level actuator switch. $15 each extra disc.	$1315 base price $100 DC power. $150 activation of sampler and recorder.	$3395 Base DC. $2795 Base AC. $275 Flow proportional sampling.	$1875 Base price. $90 heater chip. $100 each extra chip. $85 3 extra alarms.	$1470 24 in. base price. $1570, 48 in. base price. $145 flow proportional sampling. $280 level actuation with record of time totalizer (24 in.). $115 manhole bracket.
GSA Contractor	No.	Yes.	No.	Yes.	Yes.	Yes.
Delivery	6-9 months (England).	2-4 weeks.	5-8 weeks.	30-40 days.	60 days.	30 days.
Service	Factory service impossible but few breakdowns reported.	See ISCO, Table I.	See Sirco, Table I.	Local	See Manning, Table I.	See Manning, Table I.