EPA 907/9-74-005

WASTEWATER SAMPLING METHODOLOGIES AND FLOW MEASUREMENT TECHNIQUES

BY

U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION VII
SURVEILLANCE AND ANALYSIS DIVISION
TECHNICAL SUPPORT BRANCH
FIELD INVESTIGATIONS SECTION

DANIEL J. HARRIS
AND
WILLIAM J. KEFFER

JUNE 1974

EPA 907/9-74-005

WASTEWATER SAMPLING METHODOLOGIES

AND

FLOW MEASUREMENT TECHNIQUES

BY

U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION VII
SURVEILLANCE AND ANALYSIS DIVISION
TECHNICAL SUPPORT BRANCH
FIELD INVESTIGATIONS SECTION

DANIEL J. HARRIS
AND
WILLIAM J. KEFFER

JUNE 1974

DISCLAIMER

Mention of brand name of equipment does not constitute endorsement or recommendation of product by the Environmental Protection Agency. The information and findings presented in this paper are not to be construed as representing official equipment design or modification specifications.

ACKNOWLEDGEMENTS

The Environmental Protection Agency, Region VII Field Investigations Section wishes to acknowledge the cooperation of the cities of Kansas City, Kansas; Kansas City, Missouri; Lincoln, Nebraska; and Ashland, Nebraska, and Richards-Gebaur Air Force Base in allowing the section to conduct sampler comparison studies at their wastewater treatment facilities.

The section is also indebted to the Instrumentation Specialties Company of Lincoln, Nebraska; the N-Con Systems Company of New Rochelle, New York; and to Sirco Controls Company of Seattle, Washington, for loan of sampling equipment which was used in the sampler comparison studies.

TABLE OF CONTENTS

PAGE NO.

PAGE NO.

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The Environmental Protection Agency, Region VII, Field Investigations Section has been responding to an increasing number of requests for information resulting from its water/wastewater sampling activities and its experience with various commercial sampling and flow measurement devices. These requests have come from state environmental agencies, other EPA regions, engineering consulting firms, commercial laboratories, industries, universities, vocational schools, and individuals. It is the purpose of this report to consolidate and summarize the activities, experience, sampling methods, and field measurement techniques of the Field Investigations Section in order to provide a ready source of information for these interested parties.

During the past two years there has been a dramatic expansion in demand for wastewater chemistry data on point source discharges and a concurrent shift away from general purpose stream studies. In order to meet these needs and to provide data for enforcement efforts, compliance monitoring, water quality standards evaluations, and waste treatment facility operational assistance and performance evaluation, the Field Investigations Section has minimized efforts requiring manual methods of sample collection and has placed increasing reliance upon commercially available automatic wastewater sampling equipment.

Emphasis on point source sampling has been accompanied by a corresponding increase in the need for hydraulic discharge measurements for the purposes of making up flow-proportional samples, calculating pollutant loadings, and setting effluent limitations. With the hundreds of discharges sampled every year, the Field Investigations Section has been forced to resort to an ever expanding variety of flow measurement techniques as a result of the plethora of sampling site configurations encountered in its field surveys.

As the section gained familiarity and experience with various compositors and hydraulic measurement methods and with the accumulation of large volumes of water quality information, it became apparent that different sampling equipment and flow measurement techniques resulted in significant data dissimilarity. These discrepancies raised several questions regarding: (a) the reliability of various commercial sampling equipment, (b) the representativeness of samples collected by different automatic sampling equipment, (c) the variation in wastewater chemistry data which can be expected as a result of differences in performance of equipment and changes in manual collection methods, (d) the adequacy of discrete grab sample analysis for routine surveys and monitoring programs, (e) the necessity of flow-proportional sampling of raw municipal wastewaters, and (f) the precision of flow measurement methods.

During the past twelve months the Field Investigations Section has mounted several special sampling efforts and has extracted data from past and continuing surveys and has drawn upon the collective experience of the section's staff to gain insight into the preceding considerations. This report details the results of that twelve-month effort.

It is not the function of this report to serve as a substitute for the judgement of the professional in the field but rather to provide a basis for the development of sound sampling programs and to focus attention upon those sources of error and data variability which the section has gained knowledge of, often at considerable time and expense. It is the opinion of the Field Investigations staff that data quality control should start in the field instead of the laboratory.

As the experience of the section continues to grow, as new sampling situations are encountered, and as new equipment comes on the market and becomes available to the section for testing and evaluation, it is expected that this report will be revised and expanded.

II. STRUCTURE AND ACTIVITIES OF THE FIELD INVESTIGATIONS SECTION

The Field Investigations Section, which is located in the offices of the EPA, Region VII Laboratory*, consists of eight professional and subprofessional employees who are responsible for planning the field surveys and sample collection activities of the Surveillance and Analysis Division. This division, with its laboratory capability, provides the water quality information of the agency in the four-state region of Missouri, Nebraska, Kansas, and Iowa.

The Field Investigations professional staff includes two sanitary engineers (GS-13 and 11), one chemical engineer (GS-11), and one hydrologist (GS-9). The subprofessional staff consists of four engineering technicians in grades ranging from GS-3 to 6. The regional laboratory, with a staff of eight professional chemists (GS-7 to 13) and three microbiologists (GS-7, 9 and 12), is responsible for operating the mobile laboratories of the section during field surveys.

In areas outside the range in which analytical support can be provided by the regional laboratory, field sampling teams normally operate within a 161-km (100-mile) radius of a mobile laboratory which is generally set up at a wastewater treatment facility in a community within the area of interest. Because of logistics problems in some of the more sparsely populated areas of the region, it is frequently necessary to work field teams outside of

---

* 25 Funston Road, Kansas City, Kansas 66115

this 161-km (100-mile) radius. Ten to twenty-five percent of the total field activity may be conducted at distances up to 322 km (200 miles) from the laboratory base. Operating at these greater distances reduces the section capability by an estimated fifty percent and greatly increases the unit cost of sample collection.

Prior to mounting a survey the section makes every effort to ascertain and consolidate the various data needs of the agency and of the state in order to avoid duplication of effort and to minimize the number of laboratory set ups. It requires a minimum of one wk to ten days to prepare and stock a mobile laboratory; get it on site; have electricity, water, and phone installed; and then torn down and returned to Kansas City following completion of a survey. If possible, field activities in areas requiring mobile laboratory support are restricted to surveys of thirty days duration or longer.

Major field equipment currently available to the Field Investigations Section, in addition to analytical equipment permanently housed in the regional laboratory, are listed below with the approximate initial costs:

1	Mobile Laboratory	$15,000
1	Mobile Laboratory (on loan)	
7	GSA Vehicles (monthly operating cost)	800
5	Boats and Motors	5,000
50	Composite Sample Collectors (approximately $560 each)	28,000

Flow Recording and Measuring Equipment*	$ 6,600
Current meters	
Weirs	
Float recorders	
Conductance liquid level recorders	
Field Analysis Equipment	6,100
pH meters	
Conductivity meters	
Fluorometers	
Dissolved oxygen meters	
Sonar depth meters	
Portable Generators	1,200
Metal Detector	300

The section attempts to carefully review the locations to be sampled in order to limit sample collection and to reduce the analytical work load on the laboratory to the absolute min required to provide the necessary information. In the routine monitoring of municipal wastewater treatment facilities, the section normally utilizes unattended compositors to collect three 24-hr composites at all influent and effluent stations. Lagoon effluents are generally grab sampled due to the more uniform character of these discharges. Scheduling three days of sampling at each site allows the section some latitude in the event of compositor malfunction or missed dilutions in the laboratory. In the absence of any evidence

---

* See Chapter V

indicating a significant industrial waste problem, data collected on municipal wastewaters include:

Water temperature

Flow (instantaneous or continuous depending upon plant recorders and/or flow measurement devices)

pH

Specific conductance

Five-day biochemical oxygen demand

Chemical oxygen demand

Nonfilterable solids (Total suspended solids)

Ammonia nitrogen

Total kjeldahl nitrogen

Nitrite-nitrate nitrogen

Total phosphorus

Fecal coliform

Industrial wastewaters offer almost endless variety and it is difficult to generalize sampling efforts. Current industrial sampling has been oriented toward a 5-day work period at each plant with unattended mechanical time-composite sample collectors installed at each point of interest. Sample collection periods are generally 24 hr and samples are split with company personnel. Analytical requirements vary widely but generally include the same analyses as for municipal wastewaters plus several metal analyses and frequently oil and grease. Those industrial wastes which require use of the gas chromotography-mass spectrometer (GC-MS) for analyses require analytical times which are orders of magnitude greater than the time necessary for other determinations. A single sample for GC-MS analysis can demand as much as one man-month of professional analytical time.

Under favorable conditions a mobile laboratory field operation works best with a crew of seven people including: (a) two engineers, (b) two engineering technicians, (c) one chemist, (d) one microbiologist, and (e) one laboratory technician. Working entirely within a 161-km (100-mile) radius of the mobile laboratory this staff (which is rotated at 2-wk intervals) would be able to install compositors and collect approximately 100 samples per wk for field and laboratory analyses. Total time and cost for a 30-day field survey is estimated as follows:

<u>Engineers</u>

1 man-month office preparation

2 man-months field work

2 man-months data analyses and report writing

<u>Engineering Technicians</u>

2 man-months mobile laboratory and equipment repair and preparation

4 man-months field work

<u>Laboratory Personnel</u>

6 man-months mobile laboratory work

6 man-months regional laboratory analytical work

<u>Clerical</u>

2 man-months planning and report preparation

Costs

Salaries*	$23,500
Per Diem	7,300
Travel of Personnel	400
Government Bill of Ladings	400
Vehicles	1,000
Miscellaneous Equipment (Ice, batteries, containers, utilities, chemicals, etc.)	1,500
	$34,100

This results in an average cost per sample of $85.25 for survey work not requiring use of the GC-MS. The cost for estimating purposes should be raised to $100.00 per sample to cover management and other overhead.

* Salaries are multiplied by a factor of 1.2 to account for compensatory time allotted following the 10-to-12-hr, 7-day-a-week work schedule normally used in the field.

III. SAMPLER RELIABILITY, INSTALLATION, AND OPERATION

A. SAMPLER RELIABILITY

Within the past two yr the Field Investigations Section has purchased fifty commercial compositors of fifteen makes and models and, as a result of numerous surveys, has collectively accumulated approximately 90,000 hr of field operational experience with the units on municipal and industrial raw and treated wastewaters under summer and winter conditions. This experience has pointed out design weaknesses, operational difficulties, and maintenance problems and has given the section an understanding of the capabilities and limitations of each sampler.

A previous evaluation (1) of commercially available samplers reported little in the way of field operational information. It is believed that this summary of on-site experience with these instruments will be of value to others in the water pollution control field in selecting compositors for specific applications and in avoiding some of those operational problems encountered by the Field Investigations Section.

1. SAMPLER INVENTORY

Table I is an inventory of fourteen various makes and models of commercially available compositors which the Field Investigations Section has used routinely on field sampling efforts or has gained some experience with, courtesy of the manufacturer. The section also has two additional compositors which were either special order or were made in the laboratory; however, as these are nonstandard,

TABLE I

INVENTORY OF AUTOMATIC WASTEWATER SAMPLERS

Sampler	Cost	Power Supply	Type Of Sample	Type Of Pump	Intake Tube ID mm(a)	Liquid Intake Velocity cm/sec(b)	Purge Cycle
Sigmamotor WA-2	450	AC	Time	Peristaltic	3.17	7.9	No
Sigmamotor WD-2	650	AC-DC	Time	Peristaltic	3.17	7.9	No
Brailsford EV-1	583	AC-DC	Time or Flow	Vacuum Pump	4.76	0.45	No
Brailsford DU-1	325	DC	Time or Flow	Piston	4.76	0.45	No
Brailsford EP-1	300	DC	Time	Piston	4.76	0.45	No
Hants Mark 3B	595	Manual Vacuum	Time	Manual Vacuum	6.35	75(d)	No
ISCO 1391-X	995	AC-DC	Time or Flow	Peristaltic	6.35	21	Yes
ISCO 1392	995	AC-DC	Time or Flow	Peristaltic	6.35	61	Yes
Sirco MKVS7	1,275	AC-DC	Time or Flow	Piston	9.52	98	Yes
Pro-Tech CG-125P	580	Gas	Time or Flow	Gas Lift	3.17	207	Yes
QCEC CVE	620	AC	Time	Piston	6.35	61-152	Yes
N-Con Scout	450	DC	Time	Peristaltic	6.35	7.6	Yes
N-Con Surveyor	275	AC	Time or Flow	Impeller	12.70	36	Gravity
N-Con Sentinel(c)	Unknown	AC	Time or Flow	Optional	NA	Variable	NA

(a) Multiply by 0.0394 to obtain inches

(b) Multiply by 0.0328 to obtain fps

(c) Loaned courtesy of manufacturer

(d) Mean

not readily available items, they will not be discussed in this report.

The names and addresses of the manufacturers of the compositors shown in Table I can be found in the appendix. The cost figures for each compositor represented the basic unit only and do not reflect such optional extras as rechargeable battery packs, flow-proportioning devices, or multiplexing units, etc. Type of sample refers to whether the instrument is restricted to taking a time-composite sample or if it has flow-proportional capability (optional extra). It can be seen that most of the units can collect both types of samples. Intake tube ID and liquid intake velocity refer, respectively, to the inside diameter of the sample intake line and to the velocity of the liquid in this line during the sampling cycle. Table I also indicates whether or not the sampler has a purge cycle to prevent hose clogging and to reduce cross contamination of discrete samples or aliquots.

a. SIGMAMOTOR MODELS WA-2 AND WD-2

The operation of these two compositors is identical with the exception of the alternate battery pack power source on Model WD-2. These units rely on a timer and peristaltic pump for collection of time-composite samples. Six of these units have been used for several thousand hours of running time. The units are durable and easily installed in manholes. Routine sampling with 4.5-m (15-ft) heads is possible. Because of the 3.17-mm (1/8-in.) ID intake line and the 7.9-cm/sec (0.26-fps) liquid intake velocity, these units are best suited to waste streams without large or high density suspended material.

Field use has revealed some operational problems with these units. These compositors have no by-pass switch on the timer and during installation it is necessary to reset the timer to zero several times to check the operation of the pump prior to setting the timer to the appropriate sample collection cycle.

The motor unit of these compositors is at the bottom of the fiber glass case which has a 1.2-cm (0.5-in.) lip on it. If the sample container overflows, this lip will retain enough water to short out and permanently damage the motor. This situation occurred during one of the field surveys of the section and motor replacement cost was $37.40.

Battery operation of the WD-2 model is restricted unless extra batteries and recharger are available. Only one day of operation is possible from a fully charged battery pack.

b. BRAILSFORD MODEL EV-1

This unit collects a single 3.8-l (1-gal) sample during an 8-, 16-, 24-, or 48-hr period. Operation is dependent upon a vacuum pump and metering chamber. Maximum pumping head for this compositor is about 1.2 to 1.8 m (4 to 6 ft). The unit will operate continuously for five days on a 12-v, rechargeable battery. For reliable operation this compositor should be installed level and the metering chamber cleaned at frequent intervals. A build up of solids in the metering chamber will cause the float to stick and will result in incomplete composites. Because of the small diameter sampling hose and low liquid intake velocity, this sampler is best utilized for sampling wastewaters with low suspended solids concentrations.

With an optional head detector and a suitable weir this unit will collect flow-proportional samples.

c. BRAILSFORD MODEL DU-1

This compositor utilizes a small piston pump to collect a single 7.6-l (2-gal) sample over a variable time period. When used in conjunction with a linear head detector and an appropriate weir, this compositor will collect flow-proportional samples. The instrument, with the exception of the optional head detector, is self-contained and can be easily installed in a manhole. Overflow of the sample bottle is prevented by a float activated cut off switch which fits in the top of the bottle. This switch is sensitive to positions from vertical and necessitates level installation of the compositor. If routine servicing is assured, this switch can be by-passed. Maximum head is about 1.2 to 1.8 m (4 to 6 ft).

Battery voltage must be checked routinely on these units. When batteries under power show less than 5.5-v, they should be replaced. Iron and/or lime precipitation and scouring of the piston chamber has been a problem with boiler blowdown and water plant wastes. The discharge nipple of the piston pump is in a restricted location behind the pump mounting plate. Attaching tubing to this nipple is difficult, especially under winter field conditions. Because of the 4.76-mm (3/16-in.) ID intake line and the 0.45-cm/sec (0.18-fps) liquid intake velocity, this sampler is best used on waste streams with low suspended solids concentrations.

d. BRAILSFORD MODEL EP-1

This compositor is an "explosion proof" unit with a cast aluminum housing for motor and 6-v lantern battery power source. Sampling is by a piston pump with a stroke which can be adjusted for different sample volumes or composite periods. The unit does not have flow proportioning capability. Head limitations are about the same as for the Brailsford EV-1 and DU-1.

Operational reliability of these units has been very good with wastewaters having low suspended solids levels. Because of the relatively low cost of these compositors, they are the unit of choice in situations where equipment security is minimal and vandalism is of concern. One of these samplers sustained a shotgun blast with minimal damage.

One operational difficulty with the instrument is the necessity of having to remove nine screws in order to get the aluminum back plate off to change or check the battery. This procedure is time consuming and it would appear that a design using a spring loaded clasp of some sort would be just as effective. Inadvertently, these units have been totally submerged several times and have continued to operate; however, as there is no gasket between the back plate and the motor housing, they will admit water. Whether or not these units are actually explosion proof has not been determined by the authors.

e. HANTS MARK 3B

This sampler is a vacuum operated sampler which collects twelve discrete 400-ml (13.5-oz) samples at time intervals ranging from 0.5 up to 12 hr, depending upon the particular spring-wound timer that is interfaced with it. Samples can be analyzed individually, combined on an equal volume basis, or proportioned on the basis of readings taken from external flow measuring equipment. The sample bottles are evacuated by means of a manually operated pump supplied with the unit.

These compositors are reliable, relatively well constructed, and almost goof proof. Because of the high liquid velocity, these units are well suited for sampling wastewater with high solids levels.

This unit has a separate intake tube for each sample container and it is difficult to adequately clean these twelve intake lines in the field. The large tube nest and screened intake make it impossible to use this compositor in flow velocities above 0.46 m/sec (1.5 fps) or in depths of less than 15 cm (6 in.). Also, the screened intake is not streamlined and tends to collect solids which should be removed at frequent intervals to avoid possible bias in the sample data.

Replacement parts are not readily available for this sampler since the United States distributor does not maintain an inventory and needed items must come from England. Parts orders take more than sixty days, even for the simplest items, and the company will not accept parts orders for less than $25.

f. ISCO MODEL 1391-X

The Field Investigations Section has accumulated about 1,500 hr of experience with three of these units and has had minimal operational problems with them. As many as 28 discrete, 500-ml (17-oz) samples are collected at a preset time interval by a peristaltic type pump which purges the intake line after each cycle. Flow-proportional sampling is possible by interfacing the unit with a flow metering device or by manually compositing individual samples according to an external flow measurement record.

The unit is self-contained, operates from either line or battery power source, and is designed to fit in a manhole. The bottom half of the unit, which holds the sample containers, is insulated and has room for about 2.3 kg (5 lb) of ice. Data compiled by the section (Chapter IV) would indicate that these units are best suited for sampling wastewaters with low suspended solids concentrations.

The only significant operational problem has been due to occasional clogging of the intake line. Although the pump back cycles after each collection interval, this is not always sufficient to clear the line. The case of these units is molded of a black plastic and the manufacturer suggests that the units be painted white if they are to be operated in direct sunlight. This precaution will increase the life of the electronics and of the ice in the sample container. In warm weather, ice will not last for 24 hr in these units.

As of this writing, the Model 1391 is no longer being produced and has been replaced by the Model 1392 which has a higher liquid intake velocity. The 1391 can be modified at the factory to increase the intake velocity. The Field Investigations Section has had its three units modified at a cost of $125 each.

g. ISCO MODEL 1392

The section has accumulated about 600 hr of experience with four of these units. This model is practically identical to the 1391-X with the exception of the liquid intake velocity which has been increased to 61 cm/sec (2 fps) in an attempt to improve solids capture efficiency. The water chemistry data accumulated by the section are too limited to determine whether or not this unit can effectively be used on high solids level wastes.

h. SIRCO MODEL MKV7S

Field experience with this unit has been limited to about 300 hr of operation of a model which was loaned to the section prior to receipt of its own sampler. The primary reasons for purchasing this instrument were the AC-DC operation, discrete (24-bottle) sample collection, and the high, 98-cm/sec (3.2-fps), liquid intake velocity which was believed to be more suitable for high solids level raw wastes.

To date, field use has not revealed any operational difficulties with the sampler; however, cleaning of parts which come in contact with the sample is somewhat laborious.

The unit purchased by the section was checked out in the laboratory upon arrival and several deficiencies were noted: (a) polarity of battery was reversed and not as indicated on battery terminals, (b) an electrical component and some wiring were burnt out and were replaced at a cost of about twenty dollars, and (c) functions of electrical toggle switches on the instrument panel were not well marked, i.e. off-on switch reads left to right and switch moves vertically. The operation manual supplied with this unit is extremely "sketchy" and should be expanded to give more detailed operational information.

The precision of the discrete sample volumes was also checked out in the laboratory by putting the intake line in a container filled with tap water and running the unit through the 24-bottle collection cycle. With a mean sample volume of about 280 ml (9.5 oz) the standard deviation was ±30 ml (1 oz). One reason for this variation is due to the design of the sample container compartment which is a round plastic tub and the 24 sample bottles which are wedged shaped segments of the sampler compartment. Although there is a retainer plate to hold the sample bottles in position, the bottles are somewhat undersized in relation to the diam of the container compartment and there is an accumulated space of about 1.3 cm (0.5 in.) in the 24-bottle sample ring. Consequently, the mouths of the sample bottles are not self-centering with respect to the stops of the sample distributor arm. This space is sufficient to allow the arm to discharge samples outside the mouths of some of the sample bottles and down into the plastic tub. Another reason for the sample volume variation is the high velocity of the sample as it enters the metering chamber. Discrete sample volumes are controlled by the vertical spacing of electrical probes within the metering chamber. The turbulence in the metering chamber as a result of the liquid intake velocity is sufficient to vary the water level at which the electrical probes sense completion of the sampling cycle.

i. PRO-TECH MODEL C6-125P

Two of these compositors were purchased because of the explosion-proof feature and because of the partial purge of the intake screen during each sampling interval.

This unit is pressure operated with small canisters of freon gas and collects a single 3.8-l (1-gal) sample over a variable time period. With an optional sensing device the instrument will collect flow-proportional samples.

Personnel in the Field Investigations Section have accumulated about 600 hr of experience with this compositor and have been plagued with minor problems related to poor assembly. Most of the case screws have fallen out at one time or another and all internal hoses have been replaced due to leaks in the gas system. When repaired, the samplers performed very well on wastes with high solids because of the screen area of the intake and the purging action of the gas flow.

Experience has revealed several operational difficulties: (a) the 22.9-cm (9-in.) intake sample chamber must be installed vertically in the waste stream and requires about 30.5 cm (12 in.) of water for reliable operation, (b) considerably more individual expertise is required to obtain satisfactory performance with this unit than with other compositors, (c) the unit is difficult to repair and service due to restricted access to the case interior, and (d) the design is such that only a 3.8-1 (1-gal) sample container can be housed inside the case.

j. QCEC MODEL CVE

These samplers were developed by the Dow Chemical Company and are made under license. Sampler operation is accomplished by a solenoid-controlled vacuum pump similar to laboratory pumps used by microbiologists for Millipore filtrations. The variable timer activated pump draws sample portions through a 6.35-mm (0.25-in.) ID tube at a velocity which can be adjusted from 61 to 152 cm/sec (2 to 5 fps). The intake and discharge line of the unit are blown clear before and after each sampling cycle. Equal volume sample increments composited at a preset time interval or according to flow based on signals from external flow metering equipment are drawn into a 3.8-1 (1-gal) glass jug.

Because of the high vacuum and the purge cycle this unit seldom clogs and is the compositor of choice for sampling raw wastewaters with high solids levels.

Use of these units has revealed several operational deficiencies: (a) lid retaining straps break and rubber gaskets around the edges of the fiber glass case have to be reglued on a regular basis, (b) samples have frequently been missed due to loss of vacuum in the system; vacuum loss commonly occurs at the mouth of the glass jug sample container because of vibration or temperature changes which cause the rubber stopper to lose its seal; screw caps over the stopper have been used to rectify this problem but are an inconvenience, (c) if one wants to use the self-contained sample container compartment sample volumes are limited to 3.8 l (1 gal) because of space restrictions, (d) because the compositor draws a vacuum in the sample container glass containers must be used, (e) the sample container compartment is not insulated and ice cannot be maintained for a practical length of time, and (f) the sampler is not suited for installation in manholes or other restricted areas because of its weight and apparently unnecessarily large bulk.

k. N-CON SCOUT

The Field Investigations Section has one of these compositors in use. They are a well-made, DC-powered unit equipped with a peristaltic pump and a very flexible timer. This instrument is suited only for time-composite samples and because of the 7.6-cm/sec (0.25-fps) liquid intake velocity it is best utilized on wastewaters with low concentrations of suspended solids.

Although the timing mechanism is somewhat complex and fragile, this unit is preferred by the Field Investigations Section over other similar samplers due to the self-purging feature, DC capability, and lower cost.

l. N-CON SURVEYOR

Operational problems include the limited 1.8-m (6-ft) suction head and a 12.7-mm (0.5-in.) ID constriction on the intake side of the pump which is threaded for a standard garden hose coupling. This constriction has been a constant source of clogging when the compositor is used to sample wastewaters with appreciable suspended solids concentrations. An additional problem is the diverter tube which transports about fifteen percent of the throughput to the sample contained. This tube must be kept above the liquid level in the sample container or back siphoning of the sample will occur. Transport through the diverter tube seems to work best when back pressure on it is maintained by raising a portion of the intake line to an elevation which is above the point where the diverter tube couples to the pump.

m. N-CON SENTINEL

The Field Investigations Section does not have any of these compositors and experience has been limited to about forty hours of operation on a raw waste with a unit provided courtesy of the manufacturer.

This is the only unit the section has had the opportunity to evaluate which has a refrigerated sample container compartment. In operation, a portion of the waste stream is continuously diverted to an integral flow through sampling chamber by gravity or external pump. In the sampling chamber a dipper arm rotates through an arc of approximately 90 degrees at a preset time interval or in response to signals from an integrating flow meter and collects a sample from the diverted waste stream. As the dipper rotates above level, it pours the collected aliquot into a funnel which delivers it to a container in the refrigerated compartment below.

Although this unit appears to be almost clog proof, two features were noted which could possibly bias the representativeness of the collected composite. On the model tested, the discharge end of the dipper was not centered over the funnel. On the upstroke of the dipper arm during a sampling cycle, the dipper was observed to pour some of the collected waste outside of the funnel and back into the flow-through, sampling chamber. It would appear that heavier suspended material could have been lost. Secondly, the sampling chamber has a relatively large cross-sectional area with a flow-through velocity which is dependent upon the volume of water supplied to it. This increase in area and corresponding decrease in velocity could result in heavier material settling to the bottom of the sampling chamber below the reach of the dipper arm.

This sampler because of its size, 0.64 x 0.79 x 1.52 m (25 x 31 x 60 in.), and weight, 113 kg (250 lb), is best suited for long-term or permanent monitoring programs.

2. INCIDENCE OF SAMPLER MALFUNCTION

The information presented in Table II shows the incidence of malfunction of eleven different makes and models of samplers. These data resulted from two surveys of industrial and municipal wastewater treatment facilities in the greater Kansas City Metropolitan Area.

Referring to Table II, the data show the total number of times each sampler was used as well as whether it was used on raw or treated waste. The reason for the lower use of compositors at effluent stations was due to the number of lagoons included in the surveys. Lagoon effluents were manually grab sampled. Incidence of sampler failure is also broken down as to influent or effluent station. Those incidents of failure are only those instances in which a 24-hr composite was short or missed altogether as a direct result of a sampler malfunction which could not reasonably have been prevented by the field sampling team. The predominate cause of malfunction was plugging of the intake lines with suspended solid material; secondary causes included loose tubing and assorted hardware. In considering the data on the three Brailsford samplers (DU-1, EV-1, and EP-1), it should be pointed out that these units are termed effluent samplers by the manufacturer. However, because of site conditions and the absence of line current at many sampling points the section has found it necessary to use these compositors on raw wastes. It should also be pointed out that the data in Table II do not include all possible combinations of field team personnel and, therefore, could be biased as a result of differences in field routine and individual expertise of team members.

Statistically, the data are too limited to recommend or reject any particular compositor; however, it is apparent that sampling of raw wastewaters produces the major number of compositor malfunctions and that considerably more reliable operation can be expected when sampling treated wastewaters.

TABLE II

INCIDENCE OF SAMPLER MALFUNCTION

Automatic Wastewater Sampler	Total Times Used	Total Times Failed	Overall Failure Rate Percent	Influent Sampling Stations			Effluent Sampling Stations		
				Used	Failure	Failure Rate Percent	Used	Failure	Failure Rate Percent
Sigmamotor WA-2	24	6	25	8	4	50	16	2	13
Sigmamotor WD-2	31	4	13	15	2	13	16	2	13
Brailsford DU-1	45	15	33	40	13	33	5	2	40
Brailsford EV-1	29	5	17	26	5	19	3	0	0
Brailsford EP-1	63	6	10	55	6	11	8	0	0
QCEC CVE	90	4	4	77	4	5	13	0	0
Pro-Tech C6-125P	10	4	40	NOT BROKEN DOWN					
ISCO 1391-X	16	4	25	16	4	25	0	0	0
ISCO 1392	17	1	5	15	1	7	2	0	0
N-Con Scout	14	2	14	14	2	14	0	0	0
N-Con Surveyor	7	3	43	5	3	60	2	0	0
Totals and Mean Failure Rates	346	54	16	271	44	16	65	6	9

The overall ability of the Field Investigations Section to obtain a complete 24-hr composite sample probably runs between 80 and 84 percent since the 16 percent compositor malfunction rate does not reflect mistakes in installation, variations in the expertise of different field teams, excessive drops in head, submerging of compositors, or winter operation.

B. INSTALLATION AND OPERATION OF SAMPLING EQUIPMENT

In the field, the engineering staff works closely with the technicians. At new locations which have not been previously sampled it is a policy of the Field Investigations Section to have a professional present to select the sampling point, to inspect the flow measurement equipment of the facility or determine a suitable measurement method, and to supervise installation of the sampling equipment. It is felt that this practice reduces the risk of compositor malfunction and missed samples, improves the representativeness of the data, and results in a more detailed and informative report.

The primary reason for the large variety of compositors used by the section is due to the plethora of sampling requirements, waste stream characteristics, and site conditions encountered in the field. Utilization of the sampling equipment of choice is often precluded by the physical characteristics of the point of interest including accessibility, site security, and the availability of power.

Raw municipal wastewaters are preferably sampled at points of highly turbulent flow in order to insure good mixing; however, in many instances the desired location is not accessible. Raw waste sampling points in order of preference are: (a) the upflow siphon following a barminutor*, (b) the upflow distribution box following pumping from main plant wet well, (c) aerated grit chamber, (d) pump wet well, and (e) flume throat.

In order to provide position stability and to reduce velocity displacement, a sash weight, sole plate or other weight, secured with a rope, is tied to the end of the sampler intake tube which is positioned at mid-depth in the flow.

The section has experienced incidents of theft and vandalism of equipment. This is an item of major concern at sites which are outside the confines of fenced treatment facilities. Manhole installations in which battery-operated equipment can be put in the manhole and the cover replaced will generally provide sufficient security. In exposed locations which require composite samples, one must either risk loss and tampering with equipment or utilize manual sampling methods. If manpower limitations require use of unattended equipment, obviously only low-value compositors should be considered. As "water pollution" is a popular subject with the general public, tampering with equipment can sometimes be reduced if people in the area are aware of the nature and purpose of the activity. One of the authors experienced this situation during a

---

* In absence of grit chamber

survey of a receiving stream in a rural area downstream from a treatment facility.

In every case the field team will utilize electrical line current if it is available at the sampling site. Generally, line-operated compositors are more reliable than battery-operated models and, in the sampling of raw wastewaters, the incidence of intake tube plugging is reduced due to the high vacuum and purging feature of the samplers which are preferably used on these wastes. Line current has been available at about 50 percent of the treatment facilities which the section has surveyed. In a survey of over 100 private, municipal, and industrial waste treatment plants in the greater Kansas City area, only 45 percent of the facilities had an electrical power source. Power availability at lagoons, which accounted for 55 percent of the survey, was even less.

The physical and chemical characteristics of the waste stream also play a part in determining the type of sampler to use. Wide fluctuations in pH, strength, color, and volume encountered with some industrial wastewaters will generally require a discrete sample collector in order that aliquots can be analyzed individually.

With the exception of cold weather sampling conditions, all samples are kept on ice during the composite period. The ISCO, QCEC-CVE, and Sirco units are the only compositors used by the section which have an integral ice compartment. With the other units samples are chilled by placing the sample collection container in an ice chest* along with a 2.27-kg (5-lb) bag of ice. The ice chest is stood on end with the drain hole on top and the discharge tube of the sampler is threaded through this hole and into the sample contained.

Winter operation of sampling equipment can be a trying experience. During particularly cold weather sampler malfunctions due to freezing of intake lines may run as high as 60 percent.

If possible, the samplers should be installed in manholes below the freezing line by taping (fiber glass tape) the unit to steps or by suspending with a rope tied securely to a stake in the ground. When installing samplers in manholes or wet wells, care should be taken to position it at a level which will not result in submergence of the compositor in the event of precipitation. Because of the limited suction head of many of the battery-operated compositors, it is not always possible to maintain an adequate elevation. If heavy rainfall appears probable, the sampling should be postponed or use of a Brailsford EP-1 considered. Section personnel have inadvertently submerged several of these units without any apparent damage. However, they do admit water to the case and it is recommended that the backing plate be removed and the interior of the case allowed to dry prior to additional usage.

If below ground installation is not possible during freezing weather and line current is available, 1.2- to 1.8-m (4- to 6-ft) heat tapes** can be wrapped around the sample container and the

---

* Progress Refrigeration Company, Louisville, Kentucky - Model A-52
** Thermostatically protected 3°C

intake lines. To provide insulation, large plastic bags* can be wrapped around the intake line and heat tape and loosely placed over the sampler.

When using the Brailsford EP-1 models where 110 v AC is available, it is possible to place the entire unit with sample bottle in an ice chest and wrap a heat tape around the bottle for protection. If the chest drain plug is removed and the chest set or hung vertically with the drain plug on the bottom, the intake tube can be run out the drain hole and also heat taped to provide sampling reliably below 0°C.

As of this writing, the vast majority of the samples collected by the section (estimated 95 percent) have been time composited. When flow-proportional sampling is done, discrete samples are manually composited on the basis of readings from external flow or level recorders. As a result of data presented and discussed in Chapter IV, the Field Investigations Section continues to have mixed opinions regarding flow-proportional samples.

---

* Airline trash bags, 10 mil, GSA FSN #8105-848-9631

IV. SAMPLING METHODS AND DATA VARIABILITY

A. PERFORMANCE OF AUTOMATIC WASTEWATER SAMPLING EQUIPMENT

As the Field Investigations Section acquired and gained experience with a number of different makes and models of commercially available samplers and with the accumulation of large volumes of water quality information, discrepancies in data were noted which appeared to result from variations in compositor performance.

As of this writing, the section has conducted five field studies for the purpose of comparing the water chemistry data of samples collected concurrently with the various compositors listed in Table I. Samples were analyzed according to Standard Methods (2) for five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and nonfilterable solids (NFS)*. Data obtained from different compositor combinations were compared to each other and to those data resulting from manual sampling methods.

1. RICHARDS-GEBAUR AFB STUDY

The AFB is served by a 5,680 cu m/day (1.5 mgd) standard rate trickling filter plant with effluent chlorination. Three sampling stations were set up at this plant. The stations were: (a) the raw waste (upstream of the Parshall flume and digester supernatant return), (b) the effluent from the primary clarifier, and (c) the final effluent.

A QCEC Model CVE sampler was installed to collect time-composite samples (15-min cycle time) at the influent and,

* Also termed total suspended solids

concurrently, an ISCO Model 1391-X was used to collect discrete samples at 2-hr intervals for manual flow proportioning and compositing. Flow measurements were obtained with a Manning Dipper Stage Recorder* and a staff gage installed in the throat of the 22.9-cm (9-in.) Parshall flume located at the plant influent.

At the effluent of the primary clarifier a Sigmamotor Model WD-2 compositor was used to collect time-composite samples (15-min cycle time) and a Hants Mark 3B was used to collect discrete samples at 2-hr intervals for manual flow proportioning and compositing. A 90-degree, V-notch weir equipped with a Manning Dipper Stage Recorder* and a staff gage was temporarily installed in order to get flow measurements at this station.

At the plant final effluent a Brailsford DU-1 mechanical compositor was used to collect time-composite samples (4-min cycle time) and a Hants Mark 3B sampler was installed to collect samples at 2-hr intervals for manual flow compositing. For flow measurements a 90-degree, V-notch weir was temporarily installed and equipped with a Belfort Float Stage Recorder* with stilling well and staff gage.

At each of the three stations the intake lines of the compositors were tied together and suspended at mid-depth in the waste stream. Grab samples were manually collected at 4-hr intervals for individual analysis and for flow compositing at each of the three stations in order to provide additional data for comparison.

---

* See Page 95

Because of plant operation problems, compositor malfunctions, and a heavy rainfall, there were some departures from the planned sampling effort. On May 21 the plant operators by-passed for two 10-min periods at 1300 and 1400 hr in order to facilitate rodding out of a clogged digester line. On May 22 a period of heavy rainfall occurred between 0030 and 0530 hr with about 5 cm (2 in.) of total precipitation. The temporary weir at the primary effluent was submerged for several hr during this period and flow rates were taken from readings on the Parshall flume located at the influent. Because of this rainfall the plant by-passed a portion of the raw waste for a period of nine hr. The total by-passed waste volume was estimated to be 17,000 cu m (4.5 mil gal). Several afternoon thundershowers also occurred on May 22 and increased plant flows but did not necessitate further by-passing.

Difficulty was experienced with the clock mechanism of the Hants 3B samplers located at the primary and final effluent. At the primary effluent the flow-composite samples obtained with this instrument were short two and four hr, respectively, on May 22-23 and 23-24. At the final effluent the May 22-23 composite was short two hr and on May 23-24 four of the twelve bottles of the Hants sampler were about twenty to thirty percent short of the volume necessary to make the flow composite.

In addition to sampler malfunctions, a cursory examination of the facility during the study revealed the following plant operational problems:

a. Comminutor seals were gone and large solids passed the comminutor without removal.

b. Sludge removed from the primary tanks was accompanied by large volumes of water which caused excessive amounts of digester supernatant to be returned to the plant. During the entire survey the primary effluent appeared black and septic.

c. Only one trickling filter was in operation and no recirculation was practiced. There were 27 hourly periods during the 72-hr survey when plant flows exceeded the 2,840-cu m/day (0.75-mgd) capacity of the trickling filter unit. Filter capacity was exceeded several times each day during the survey at periods which were not related to rainfall.

d. One of the secondary clarifier units was septic during the entire investigation and clumps of sludge up to 15.2 cm (6 in.) in diam continuously rose to the surface and were discharged with the clarifier overflow.

All samples were kept on ice and delivered to the EPA, Region VII, Laboratory where they were analyzed according to Standard Methods (2). No special attempts were made during the collection period to refine compositing methods or sample delivery procedures. In the laboratory, normal personnel assignments and rotations were observed; consequently, the water chemistry data represented the work of several professional analysts. These data are presented in Tables III, IV, and V. The flow data are shown graphically in Figure 1.

An examination of Table III, which shows the water chemistry data of the samples collected from the raw waste by the four different sampling methodologies, would indicate that the results obtained with the QCEC compositor differed significantly from the data of samples collected by the other methods. Looking at the

BOD_5, COD, and NFS of the grab samples collected manually, it can be seen that there was a definite decrease in strength of the waste during the early morning hours. Discounting other factors, the time-composite samples collected with the QCEC would be expected to have been biased low because the samples included equal volume aliquots of the low-flow, low-strength, early-morning waste. However, for each of the three parameters it is evident that the QCEC samples were of higher strength than the flow-composited ISCO samples, the manually-collected flow-composited samples, or the arithmetic mean of the manually-collected grab samples. In all but four out of fifty-four analyses for the three parameters, the QCEC samples were of greater strength than any of the discrete, manually-collected grab samples.

Table IV, which shows the water chemistry data of samples collected from the primary effluent, also indicates a bias. Except for BOD_5 on May 22 and COD on May 23, the flow-composited samples obtained with the Hants unit were of higher strength than those flow-composited samples collected manually.

Table V presents the water chemistry data of the final effluent samples and does not indicate any apparent bias with respect to the four different sampling techniques.

The NFS data for the three days of sampling are summarized in Table VI and presented in the form of ratios after unitizing the results on the basis of the concentrations found in the manually-collected and flow-composited samples. Examination of this table

TABLE III

RICHARDS-GEBAUR SEWAGE TREATMENT PLANT
RAW WASTE

Date May 1973	Sample Type And Time	BOD_5 mg/l	COD mg/l	NFS mg/l
21-22	24-hr Mech Flow Comp (ISCO)	95	330	120
	24-hr Mech Time Comp (QCEC)	215	588	254
	24-hr Manual Flow Comp (4-hr Grabs)	113	279	121
	Mean of 4-hr Interval Grab Samples	124	356	148
	Grab: 1200	195	492	250
	1600	183	467	278
	2000	165	539	153
	2400	104	238	86
	0400	22	72	68
	0800	73	328	52
	Grab Sample Standard Deviation, ± mg/l	63	163	88
	Coefficient of Variation, percent	51	46	60
22-23	24-hr Mech Flow Comp (ISCO)	84	165	47
	24-hr Mech Time Comp (QCEC)	140	388	126
	24-hr Manual Flow Comp (4-hr Grabs)	99	223	109
	Mean of 4-hr Interval Grab Samples	97	177	74
	Grab: 1200	107	171	128
	1600	111	223	72
	2000	162	351	106
	2400	109	143	62
	0400	18	40	9
	0800	74	135	66
	Grab Sample Standard Deviation, ± mg/l	44	95	37
	Coefficient of Variation, percent	45	54	50
23-24	24-hr Mech Flow Comp (ISCO)	153	306	149
	24-hr Mech Time Comp (QCEC)	153	526	186
	24-hr Manual Flow Comp (4-hr Grabs)	107	252	106
	Mean of 4-hr Interval Grab Samples	98	236	87
	Grab: 1200	131	282	107
	1600	97	304	81
	2000	153	334	141
	2400	80	197	80
	0400	16	50	16
	0800	110	250	94
	Grab Sample Standard Deviation, ± mg/l	43	94	38
	Coefficient of Variation, percent	44	40	44
	Arithmetic Mean Of All Data Points	123	319	127
	May 21-22	137	388	161
	May 22-23	105	238	89
	May 23-24	128	330	132

TABLE IV

RICHARDS-GEBAUR SEWAGE TREATMENT PLANT PRIMARY EFFLUENT

Date May 1973	Sample Type And Time	BOD_5 mg/l	COD mg/l	NFS mg/l
21-22	24-hr Mech Flow Comp (Hants)	150	480	333
	24-hr Mech Time Comp (Sigmamotor)	97	209	83
	24-hr Manual Flow Comp (4-hr Grabs)	57	151	106
	Mean of 4-hr Interval Grab Samples	94	226	104
	Grab: 1200	127	279	112
	1600	155	309	144
	2000	104	249	88
	2400	110	290	82
	0400	29	139	142
	0800	39	94	58
	Grab Sample Standard Deviation, ± mg/l	45	81	32
	Coefficient of Variation, percent	48	36	30
22-23	24-hr Mech Flow Comp (Hants)	125	324	123
	24-hr Mech Time Comp (Sigmamotor)	100	192	56
	24-hr Manual Flow Comp (4-hr Grabs)	132	264	80
	Mean of 4-hr Interval Grab Samples	124	235	78
	Grab: 1200	102	179	80
	1600	133	243	84
	2000	125	203	73
	2400	117	243	60
	0400	54	145	32
	0800	213	394	138
	Grab Sample Standard Deviation, ± mg/l	47	79	32
	Coefficient of Variation, percent	38	34	41
23-24	24-hr Mech Flow Comp (Hants)	180	268	187
	24-hr Mech Time Comp (Sigmamotor)	175	318	125
	24-hr Manual Flow Comp (4-hr Grabs)	158	318	129
	Mean of 4-hr Interval Grab Samples	152	317	151
	Grab: 1200	126	260	96
	1600	129	296	124
	2000	163	308	136
	2400	160	310	128
	0400	141	324	178
	0800	192	495	246
	Grab Sample Standard Deviation, ± mg/l	23	75	49
	Coefficient of Variation, percent	15	23	32
	Arithmetic Mean Of All Data Points	129	275	129
	May 21-22	99	267	156
	May 22-23	120	253	84
	May 23-24	166	305	148

TABLE V

RICHARDS-GEBAUR SEWAGE TREATMENT PLANT FINAL EFFLUENT

Date May 1973	Sample Type And Time	BOD_5 mg/l	COD mg/l	NFS mg/l
21-22	24-hr Mech Flow Comp (Hants)	43	143	84
	24-hr Mech Time Comp (Brailsford)	35	137	51
	24-hr Manual Flow Comp (4-hr Grabs)	29	128	62
	Mean of 4-hr Interval Grab Samples	28	137	59
	Grab: 1200	25	143	60
	1600	33	181	53
	2000	25	154	51
	2400	26	141	59
	0400	34	98	78
	0800	27	105	56
	Grab Sample Standard Deviation, ± mg/l	3.7	28	8.8
	Coefficient of Variation, percent	14	20	15
22-23	24-hr Mech Flow Comp (Hants)	23	147	29
	24-hr Mech Time Comp (Brailsford)	23	137	30
	24-hr Manual Flow Comp (4-hr Grabs)	16	153	39
	Mean of 4-hr Interval Grab Samples	24	126	31
	Grab: 1200	32	146	35
	1600	27	199	49
	2000	19	96	30
	2400	21	109	28
	0400	--	96	16
	0800	22	110	28
	Grab Sample Standard Deviation, ± mg/l	4.7	37	9.9
	Coefficient of Variation, percent	20	29	32
23-24	24-hr Mech Flow Comp (Hants)	26	173	86
	24-hr Mech Time Comp (Brailsford)	17	181	76
	24-hr Manual Flow Comp (4-hr Grabs)	12	141	62
	Mean of 4-hr Interval Grab Samples	15	149	75
	Grab: 1200	11	133	86
	1600	21	137	86
	2000	22	185	82
	2400	14	173	78
	0400	12	141	55
	0800	8	123	61
	Grab Sample Standard Deviation, ± mg/l	5.1	22	12
	Coefficient of Variation, percent	35	15	16
	Arithmetic Mean Of All Data Points	24	146	57
	May 21-22	33	136	64
	May 22-23	22	141	32
	May 23-24	18	161	75

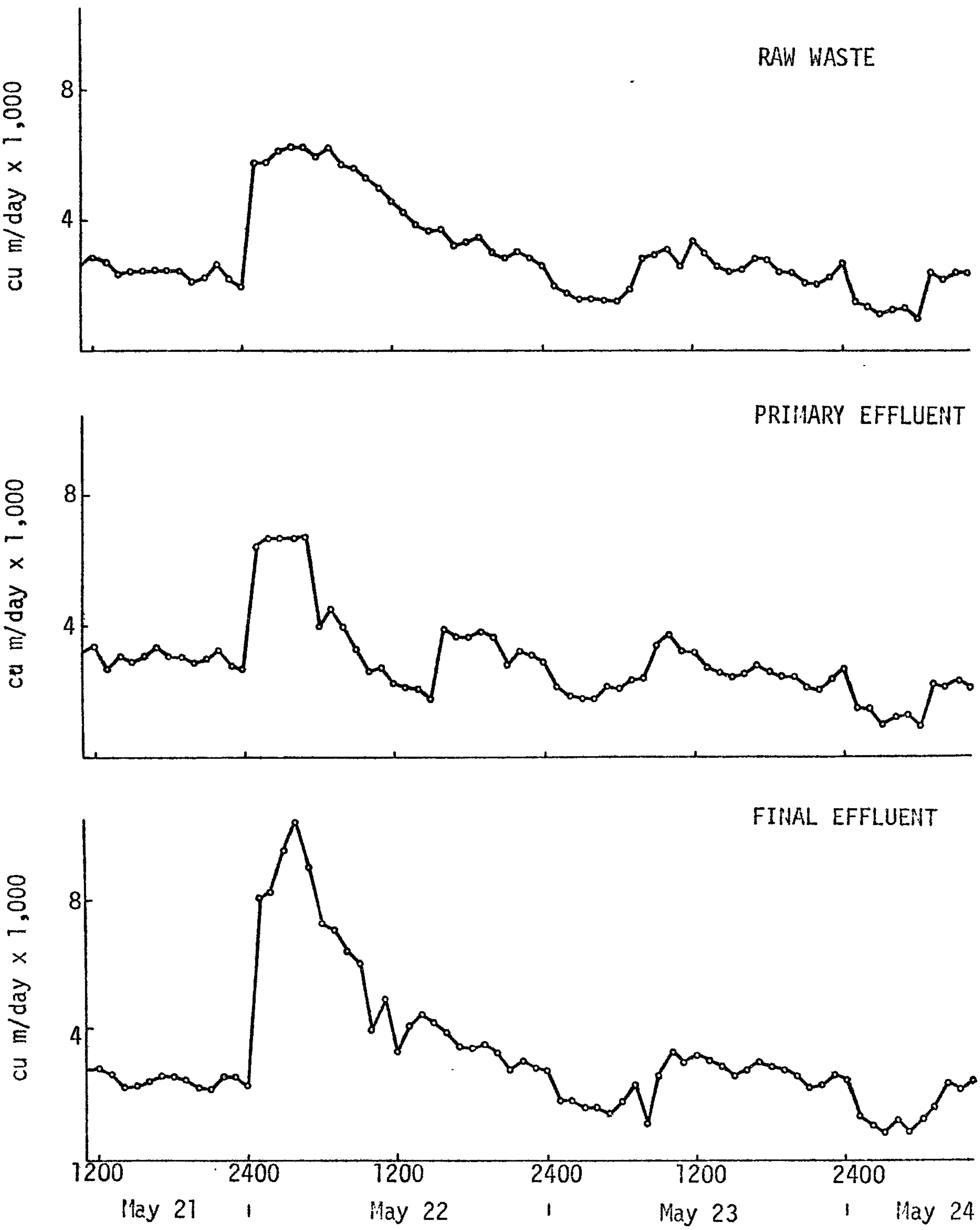

FIGURE 1 - Flow Rates - Richards-Gebaur Sewage Treatment Plant

TABLE VI

RICHARDS-GEBAUR SEWAGE TREATMENT PLANT NFS COMPARISON
RATIO OF SAMPLING METHOD VALUE TO MANUAL FLOW VALUE

Station	Sample Method	Date			Average
		May 21	May 22	May 23	
Influent	QCEC	2.099	1.155	1.755	1.669
	ISCO	0.991	0.431	1.406	0.942
	Manual Flow	1.0	1.0	1.0	1.0
	Manual Grab	1.223	0.679	0.820	0.907
Primary Effluent	Hants	3.141	1.537	1.449	2.042
	Sigmamotor	0.783	0.700	0.968	0.817
	Manual Flow	1.0	1.0	1.0	1.0
	Manual Grab	0.981	0.975	1.170	1.042
Final Effluent	Hants	1.354	0.743	1.387	1.161
	Brailsford	0.822	0.769	1.225	0.939
	Manual Flow	1.0	1.0	1.0	1.0
	Manual Grab	0.951	0.794	1.209	0.985

would show that in eight out of nine comparisons with the high vacuum (650- to 700-mm Hg) QCEC and Hants units the solids levels exceeded those of the manually collected samples. In seven of nine cases the samples collected by the slower-acting peristaltic and piston type compositors (ISCO, Sigmamotor, and Brailsford) yielded lower solids levels. One could also calculate similar ratios for BOD_5 and COD. These calculations would show that in eight out of nine and seven out of nine cases for BOD_5 and NFS, respectively, the QCEC and Hants samplers resulted in higher parameter concentrations.

The apparent removal efficiencies of the Richards-Gebaur facility can be calculated in a number of ways. Table VII shows the sixteen combinations of sampling methods and removal efficiencies resulting from the four 24-hr sampling methods used on the plant raw waste and final effluent. An examination of this table would indicate that the apparent removal efficiencies for BOD_5, COD, and NFS ranged between 71-89, 39-73, and 36-72 percent, respectively. The table also shows that apparent removal efficiencies of COD and NFS with the QCEC on the influent increased significantly and that there was a corresponding increase in the coefficients of variation. With the QCEC combinations excluded the mean BOD_5, COD, and NFS removals were 77, 43, and 47 percent, respectively. Considering the QCEC combinations alone these corresponding percentages increased to 86, 71, and 70 percent, respectively. Considering all the sixteen combinations of sampling methods the coefficients

TABLE VII

APPARENT REMOVAL EFFICIENCIES OF RICHARDS-GEBAUR FACILITY WITH VARIOUS COMBINATIONS OF 24-HR SAMPLING METHODS

Sample Method Combination		Removal Efficiencies Percent		
Influent	Effluent	BOD_5	COD	NFS
Manual Flow Comp	Manual Flow Comp	82	44	52
	Hants Flow Comp	71	39	41
	Mean of Manual Grabs	79	45	51
	Brailsford - Time Comp	76	39	54
ISCO Flow Comp	Manual Flow Comp	83	47	49
	Hants Flow Comp	72	42	37
	Mean of Manual Grabs	80	49	48
	Brailsford - Time Comp	77	43	50
Mean of Manual Grabs	Manual Flow Comp	82	45	48
	Hants Flow Comp	71	40	36
	Mean of Manual Grabs	79	46	47
	Brailsford - Time Comp	76	41	50
QCEC Time Comp	Manual Flow Comp	89	72	71
	Hants Flow Comp	82	69	65
	Mean of Manual Grabs	87	73	71
	Brailsford - Time Comp	85	70	72
Mean and Coefficient of Variation Including QCEC Combinations	Mean, mg/l	79	50	53
	Coefficient Variation, %	6.6	25	21
Mean and Coefficient of Variation Excluding QCEC Combinations	Mean, mg/l	77	43	47
	Coefficient Variation, %	5.3	7.2	12
Mean with QCEC Combination Alone, mg/l		86	71	70

of variation of the removal efficiencies were 6.6, 25, and 21 percent for BOD_5, COD, and NFS, respectively.

Given the present refinement of sampling technology, these variations in removal efficiencies are believed to be typical of what can be expected with routine surveys and monitoring programs. The impact of these variations in determining whether or not a particular facility is in compliance with permit requirements is obvious.

The grab sample data in Tables III, IV, and V indicated wide fluctuations in water chemistry data over a 24-hr period which decreased as the wastewater passed through the plant. The coefficient of variation of the NFS data range from 44-60, 30-41, and 15-32 percent, respectively, in the raw waste, primary effluent, and final effluent.

Table VIII was constructed using the three days of grab sampling data and the manual, flow-composite data of the raw waste and the plant final effluent. This table shows apparent NFS removal efficiencies as a function of number of grab samples collected per day, time of collection, collection interval (24, 12, 8, or 4 hr), and the number of days of sampling. These grab sample efficiencies are compared to the removal efficiencies resulting from the manual-collected and flow-composited, 24-hr samples. An examination of this table would indicate that the NFS removal efficiency as a result of collecting one sample from the influent and effluent at 2400 hr on the first day of sampling was thirty-one

TABLE VIII
RICHARDS-GEBAUR
NONFILTERABLE SOLIDS REMOVAL EFFICIENCY AS A FUNCTION OF NUMBER OF GRAB SAMPLES, TIME OF COLLECTION, COLLECTION INTERVAL, AND DAYS OF SAMPLING

Sta							Raw Waste																																						
	Days of Sampling						1st													2nd													3rd												
		Grab Samples per day					1						2			3		6	24-hr Man Flow Comp	1						2			3		6	24-hr Man Flow Comp	1						2			3		6	24-hr Man. Flow Comp.
			Grab Sample Interval (hours)				24						12			8		4		2						12			8		4		24						12			8		4	
				Starting Time (mil)			1200	1600	2000	2400	0400	0800	1200	1600	2000	1200	1600	1200		1200	1600	2000	2400	0400	0800	1200	1600	2000	1200	1600	1200		1200	1600	2000	2400	0400	0800	1200	1600	2000	1200	1600	1200	
					Daily Mean NFS mg/l		250	278	153	86	68	52	168	173	102	157	139	148	121	128	72	106	62	9	66	95	41	86	81	67	74	109	107	81	141	80	16	94	94	48	118	88	85	86	106
						Daily Cum Mean NFS mg/l	250	278	153	86	68	52	168	173	102	157	139	148	121	189	175	129	74	38	59	132	107	94	119	103	111	115	162	144	133	76	31	71	119	88	102	109	97	103	112
Final Effluent	1st	1	24	1200	60	60	76	78	61	30	12	-15																																	
				1600	53	53	79	81	65	38	22	-02																																	
				2000	51	51	80	82	67	41	25	02																																	
				2400	59	59	76	79	61	31	13	-13																																	
				0400	78	78	69	72	49	09	-15	-50																																	
				0800	56	56	78	80	63	35	18	-08																																	
		2	12	1200	60	60							64	65	41																														
				1600	66	66							61	62	35																														
				2000	53	53							68	69	48																														
		3	8	1200	63	63										60	55																												
				1600	56	56										64	60																												
		6	4	1200	60	60												59																											
		24-hr Man Flow Comp.			62	62													49																										
	2nd	1	24	1200	35	48														75	73	63	35	-26	19																				
				1600	49	51														73	71	60	31	-34	14																				
				2000	30	40														79	77	69	46	-05	32																				
				2400	28	44														77	75	66	41	-16	25																				
				0400	16	47														75	73	64	36	-24	20																				
				0800	28	42														78	76	67	43	-11	29																				
		2	12	1200	32	46																				65	57	51																	
				1600	32	49																				63	54	48																	
				2000	29	41																				69	62	56																	
		3	8	1200	27	45																							62	56															
				1600	35	46																							61	55															
		6	4	1200	31	46																									59														
		24-hr Man Flow Comp			39	51																										56													
	3rd	1	24	1200	86	60																											63	58	55	21	-94	15							
				1600	86	63																											61	56	53	17	-103	11							
				2000	82	54																											67	63	59	29	-74	24							
				2400	78	55																											66	62	59	28	-77	23							
				0400	55	50																											69	65	62	34	-61	30							
				0800	61	48																											70	67	64	37	-55	32							
		2	12	1200	82	58																																	51	34	43				
				1600	70	56																																	53	36	45				
				2000	72	51																																	57	42	50				
		3	8	1200	74	55																																				50	43		
				1600	75	55																																				50	43		
		6	4	1200	75	55																																						47	
		24-hr Man. Flow Comp.			62	54																																							52

percent. It can be seen that the removal efficiency based on the first day 24-hr manual flow composites was 49 percent. In a similar manner, the treatment efficiency resulting from collecting one sample per day at 2400 hr for three days from the influent and effluent was 28 percent based on the mean of the three samples collected at each station. The mean flow-composite sample efficiency over this three-day period was 52 percent. Table VIII also shows those efficiencies based on collecting: (a) two samples per day at 12-hr intervals as a result of collecting the first sample at 1200, 1600, or 2000 hr, (b) three samples per day at 8-hr intervals as a result of collecting the first sample at 1200 or 1600 hr, and (c) six samples per day at 4-hr intervals as a result of collecting the first sample at 1200 hr. All efficiencies on the diagonal of the table are the result of collecting samples from each of the two stations at the same time. Those efficiencies shown below and above the diagonal resulted from the effluent samples which were collected at multiples of 4-hr intervals following or preceding collection of the raw waste samples.

The table clearly indicates the fallacy of relying upon single grab samples and demonstrates that varying collection time will change apparent plant efficiency over a broad range. Looking at the efficiencies resulting from collecting one sample per day for three days it can be seen that the removals ranged from -103 to +70 percent. It is apparent that as the daily frequency of grab sampling increased the resulting efficiency range narrowed and approached those efficiencies resulting from the manual, flow-composited samples. Comparing six grab samples per day with the flow composites for one, two, and three days the differences were 10, 3, and 5 percent, respectively.

The variation in analytical results obtained with different sampling techniques can be studied in relation to the interlaboratory variation resulting from analytical quality control (AQC) studies. Standard Methods (2) contains a discussion of precision and accuracy for BOD_5, COD, and NFS based on the results of a number of cooperating laboratories analyzing artificially prepared identical samples. These discussions are excerpted below.

BOD_5 Precision and Accuracy

> "There is no standard against which the accuracy of the BOD test can be measured. To obtain precision data, a glucose-glutamic acid mixture was analyzed by 34 laboratories, with each laboratory using its own seed material (settled stale sewage). The geometric mean of all results was 184 mg/l and the standard deviation of that mean was ±31 mg/l (17%). The precision obtained by a single analyst in his own laboratory was ±11 mg/l (5%) at a BOD of 218 mg/l." (2, p. 494)

COD Precision and Accuracy

> "A set of synthetic unknown samples containing potassium acid phthalate and sodium chloride was tested by 74 laboratories. At 200 mg/l COD in the absence of chloride, the standard deviation was ±13 mg/l (coefficient of variation, 6.5%). At 160 mg/l COD and 100 mg/l chloride, the standard deviation was ±10 mg/l (6.5%), while at 150 mg/l COD and 1,000 mg/l chloride, the standard deviation was ±14 mg/l (10.8%).
>
> The accuracy of this method has been determined by Moore and Associates. For most

organic compounds the oxidation is 95 to 100% of the theoretical value. Benzene, toluene and pyridine are not oxidized." (2, p. 499)

NFS Precision and Accuracy

"The precision of the determination varies directly with the concentration of suspended matter in the sample. The standard deviation was ±5.2 mg/l (coefficient of variation 33%) at 15 mg/l, ±24 mg/l (10%) at 242 mg/l, and ±13 mg/l (7.6%) at 1,707 mg/l (n = 2; 4 x 10). There is no satisfactory procedure for obtaining the accuracy of the method on wastewater samples, since the true concentration of suspended matter is unknown." (2, p. 538)

Table IX was constructed using the coefficients of variation resulting from the AQC studies reported in Standard Methods (2) and the water chemistry data of the manually flow-composited samples. In construction of this table, it was assumed that the manually flow-composited samples most accurately described actual wastewater characteristics and that data resulting from the other techniques were normally distributed about the manual flow analyses. This table indicates that 62 of the analyses (77 percent) resulting from the other sampling methods were outside the range of the manual flow sample data ±1 standard deviation* (s). In a similar manner, it can be shown that 39 analyses (48 percent) were outside the range of ±3s. Since the range of ±3s for COD and NFS included all interlaboratory analyses (assuming normal distribution) it is apparent that the variation in data from the Richards-Gebaur study is greater than can be explained by laboratory analytical variation

* Arrived at by multiplying manual flow data by Standard Methods coefficient of variation.

TABLE IX

RICHARDS-GEBAUR AIR FORCE BASE STUDY
ANALYSES OUTSIDE RANGE OF MANUAL FLOW-COMPOSITED SAMPLES

Date May 1973	Type Of Sample	Analyses Out Of Range (*)						Total Out Of Range
		BOD_5		COD		NFS		
		Conc. mg/l	Std.* Dev. ± mg/l	Conc. mg/l	Std.* Dev. ± mg/l	Conc. mg/l	Std.* Dev. ± mg/l	
Influent		Standard Methods Coefficient of Variation						
		5%		6.5%		10%		
21-22	Manual Flow	113	5.6	279	18.1	121	12.1	8
	ISCO - Flow	95	*	330	*	120		
	Manual Time	124	*	356	*	148	*	
	QCEC - Time	215	*	588	*	254	*	
22-23	Manual Flow	99	5.0	223	14.5	109	10.9	8
	ISCO - Flow	84	*	165	*	47	*	
	Manual Time	97		177	*	63	*	
	QCEC - Time	140	*	388	*	126	*	
23-24	Manual Flow	107	5.4	252	16.4	106	10.6	8
	ISCO - Flow	153	*	306	*	149	*	
	Manual Time	98	*	236		87	*	
	QCEC - Time	153	*	526	*	186	*	
Primary Effluent		Standard Methods Coefficient of Variation						
		5%		6.5%		10%		
21-22	Manual Flow	57	2.8	151	9.8	106	10.6	8
	Hants - Flow	150	*	480	*	333	*	
	Manual Time	94	*	226	*	104		
	Sigmamotor - Time	97	*	209	*	83	*	
22-23	Manual Flow	132	6.6	264	17.2	80	8.0	8
	Hants - Flow	125	*	324	*	123	*	
	Manual Time	124	*	235	*	78		
	Sigmamotor - Time	100	*	192	*	56	*	
23-24	Manual Flow	158	7.9	318	20.7	129	12.9	5
	Hants - Flow	180	*	268	*	187	*	
	Manual Time	152		317		151	*	
	Sigmamotor - Time	175	*	318		125		
Final Effluent		Standard Methods Coefficient of Variation						
		5%		6.5%		33%		
21-22	Manual Flow	29	1.4	128	8.3	62	20.5	6
	Hants - Flow	43	*	143	*	84	*	
	Manual Time	28		137	*	59		
	Brailsford - Time	35	*	137	*	51		
22-23	Manual Flow	16	0.8	153	10.0	39	12.9	5
	Hants - Flow	23	*	147		29		
	Manual Time	24	*	126	*	31		
	Brailsford - Time	23	*	137	*	30		
23-24	Manual Flow	12	0.6	141	9.2	62	20.5	6
	Hants - Flow	26	*	173	*	86	*	
	Manual Time	15	*	149		75		
	Brailsford - Time	17	*	181	*	76		
Analyses out of Range		-	24	-	22	-	16	62

* Manual flow data multiplied by coefficient of variations reported in Standard Methods

alone. Real variations in sampling methods become particularly evident when one considers that 17 BOD_5 analyses (63 percent) were outside the ±3s (3 x 5 percent) variation reported by a single laboratory and that the AQC statistical data used for the COD and NFS comparisons include interlaboratory systematic variation which was not a factor in the AFB study.

The standard deviation and coefficient of variation of the three water chemistry parameters resulting from the four sampling techniques employed at each of the three stations are shown in Table X. The coefficients of variation are all greater than those values reported in Standard Methods (2, p. 494, 499, 538) for the corresponding parameters. Included in the statistical data shown in Table X would be: (a) differences in compositor performance and manual sampling methods, (b) actual variations in water quality, and (c) laboratory analytical random errors.

2. THERESA STREET SEWAGE TREATMENT PLANT - LINCOLN, NEBRASKA

A comparative study of compositor performance was undertaken at the Theresa Street Sewage Treatment Plant in Lincoln, Nebraska, June 25 through 28, 1973.

The Theresa Street facility is currently undergoing an extensive expansion with the addition of expanded activated sludge facilities. The present plant is a 113,550-cu m/day (30-mgd) facility with all wastes receiving preaeration grit removal and primary clarification. Approximately 18,900 cu m/day (5 mgd) of the flow is then treated by a trickling filter system while the remaining

TABLE X

STATISTICAL SUMMARY OF RICHARDS-GEBAUR STUDY

Station	BOD_5			COD			NFS		
	Mean mg/l	S ± mg/l	Coefficient Of Variation Percent	Mean mg/l	S ± mg/l	Coefficient Of Variation Percent	Mean mg/l	S ± mg/l	Coefficient Of Variation Percent
Influent	123.3	35.5	28.7	318.8	125.1	39.2	126.3	51.7	41.9
Primary Effluent	128.6	29.2	22.7	275.2	81.5	29.6	129.5	72.4	55.9
Final Effluent	24.2	8.5	35.1	146.0	15.7	10.7	57.0	20.1	35.3

waste is treated by a high rate activated sludge system with secondary clarifiers.

The three sampling stations selected were the raw waste at the distribution box to the preaeration tank and the plant final effluent with one station at the overflow of the secondary clarifiers and the other at the outfall to Salt Creek. At the influent an ISCO Model 780 sampler* with an uniced sample container compartment was set to collect discrete samples at 1-hr intervals for manual flow compositing each morning between 0730 and 0800 hr. This sampler was installed and operated by city laboratory personnel who provided a portion of the composited sample to the EPA field investigations team each morning. Concurrently, the EPA field team used a QCEC-CVE compositor with iced sample chamber at the same sampling point. This sampler was set to take 25-ml sample aliquots at 14-min intervals. A portion of this time-composite sample was split with city laboratory personnel.

The EPA field team used a Brailsford DU-1 (6-min cycle time) with an iced sample chamber set to collect final effluent samples at the secondary clarifiers. A portion of this sample was given to city laboratory personnel. At the outfall to Salt Creek city personnel used an ISCO Model 780 compositor with an uniced sample compartment to collect discrete samples at 1-hr intervals for manual flow compositing according to hourly readings taken from the plant influent flow recorder. A portion of this composite sample was supplied to the EPA field team.

---

* Similar to Model 1391 but not suitable for manhole installation

Table XI presents the results and arithmetic means of the analyses reported by the EPA, Region VII, Laboratory on the samples collected by the city and by EPA. An examination of this table would show that the BOD_5, COD, and NFS concentrations of the raw waste samples collected with the QCEC compositor were, respectively, 125, 134, and 182 percent greater than the levels found in the samples collected with the ISCO unit. The corresponding percentages for the effluent samples were 104, 129, and 92.

3. ASHLAND, NEBRASKA, SEWAGE TREATMENT PLANT

A third comparison study was conducted at the Ashland, Nebraska, sewage treatment plant during the week of July 28, 1973.

An ISCO Model 1391 and a Hants Mark 3B sampler were paired and set to simultaneously sample the raw waste in the throat of a 15.24-cm (6-in.) Parshall flume and the final effluent at the discharge of the chlorine contact chamber overflow weir. The intake lines of the samplers were tied together and suspended at mid depth at each of the two stations. The instruments collected discrete samples at 2-hr intervals which were manually flow composited according to the flow recordings of the influent Parshall flume.

The data resulting from the 5-day sampling effort at the influent and effluent are shown in Tables XII and XIII, respectively. The variation in wastewater chemistry data resulting from the two different compositors is apparent. The arithmetic mean BOD_5, COD, and NFS concentrations of the raw waste samples collected with the Hants compositor were, respectively, 179, 183, and 334 percent

TABLE XI

THERESA STREET SEWAGE TREATMENT PLANT
LINCOLN, NEBRASKA
WASTEWATER CHARACTERIZATION

Station And Compositor	Date June 1973	Time Military	Flow* cu m/day	BOD_5 mg/l	COD mg/l	NFS mg/l
Influent ISCO-780 City Operated	25-26	0800 To 0800	103,000	335	536	186
	26-27	0800 To 0800	104,000	360	598	190
	27-28	0800 To 0800	108,000	173	661	192
	Arithmetic Mean		105,000	289	598	189
Influent QCEC-CVE EPA Operated	25-26	1025 To 0945	--	310	875	385
	26-27	0945 To 0745	--	465	610	328
	27-28	0745 To 0745	--	310	924	322
	Arithmetic Mean		--	362	803	345
Effluent ISCO-780 City Operated	25-26	0800 To 0800	--	37	107	53
	26-27	0800 To 0800	--	51	92	31
	27-28	0800 To 0800	--	57	106	32
	Arithmetic Mean		--	48	102	39
Effluent Brailsford EPA Operated	25-26	1015 To 1015	--	80	188	58
	26-27	1015 To 0750	--	48	88	16
	27-28	0750 To 0755	--	22	121	35
	Arithmetic Mean		--	50	132	36
Influent	$\frac{\text{Mean QCEC Data}}{\text{Mean ISCO Data}}$ X 100, %			125	134	182
Effluent	$\frac{\text{Mean Brailsford Data}}{\text{Mean ISCO Data}}$ X 100, %			104	129	92

* Multiply by 264.2 to obtain gpd

TABLE XII

ASHLAND, NEBRASKA, SEWAGE TREATMENT PLANT

RAW WASTE

Date July 1973	BOD_5 mg/l		COD mg/l		NFS mg/l	
	ISCO	Hants	ISCO	Hants	ISCO	Hants
23-24	180	220	622	1,064/900	180	476
24-25	136	246	424	669	110	330
25-26	277	520	728/688	1,744	320	805
26-27	258	450	556	972	300	860
27-28*	--	470	-	1,270	--	1,335
Arithmetic Mean	213	381	604	1,103	228	761
BOD/COD-BOD/NFS Ratio	--	-	0.35	0.34	0.94	0.50
$\frac{\text{Hants}}{\text{ISCO}}$ X 100, %	179		183		334	

* ISCO Compositor Malfunctioned

TABLE XIII

ASHLAND, NEBRASKA, SEWAGE TREATMENT PLANT
FINAL EFFLUENT

Date July 1973	BOD_5 mg/l		COD mg/l		NFS mg/l	
	ISCO	Hants	ISCO	Hants	ISCO	Hants
23-24	13	22	41	65	8	3
24-25	15	10	29	45	<1	5
25-26	22	39	28	44	2	9
26-27	8	17	32	40	3	10
27-28	6	11	36	48	10	27
Arithmetic Mean	13	20	33	48	5	11
BOD/COD-BOD/NFS Ratio	--	-	0.39	0.42	2.6	1.8
$\frac{Hants}{ISCO}$ X 100, %	154		146		220	

higher than the values resulting from these samples collected with the ISCO compositor. The effluent samples also indicated a significant difference in compositor performance with the BOD_5, COD, and NFS values resulting from use of the Hants compositor being, respectively, 154, 146, and 220 percent greater than the concentrations of the samples values collected with the ISCO sampler.

Tables XII and XIII show that the BOD_5/COD ratios of the raw waste samples collected with the ISCO and Hants compositors were 0.39 and 0.42, respectively. These ratios were 0.35 and 0.34 for the effluent samples. The close agreement between those ratios indicates high laboratory analytical quality control and further emphasizes real differences in sampling efficiency between the two compositors.

Table XIV presents the apparent removal efficiencies of the Ashland sewage treatment plant for the three parameters using each of the four possible combinations of compositors. It can be seen that the removal efficiency for BOD_5, COD, and NFS range between 91-97, 92-97, and 95-99 percent, respectively.

4. KANSAS CITY, KANSAS, KAW POINT SEWAGE TREATMENT PLANT - OCTOBER 1973

A fourth comparison test was conducted on October 10 and 11, 1973, at the Kansas City, Kansas, Kaw Point primary sewage treatment plant.

Three samplers were installed and set to time composite the raw waste of the plant for a period of about 20 hr at a point immediately upstream from the bar screens. The compositors used

TABLE XIV

APPARENT REMOVAL EFFICIENCIES OF
ASHLAND, NEBRASKA, SEWAGE TREATMENT PLANT

Compositor Combination		Parameter Percent Removal		
Influent	Effluent	BOD_5 Percent	COD Percent	NFS Percent
ISCO	ISCO	94	95	98
ISCO	Hants	91	92	95
Hants	Hants	95	96	99
Hants	ISCO	97	97	99

included a QCEC Model CVE, a Sirco MKV7S, and an ISCO Model 1391. These compositors, the intake lines of which were tied together and suspended about 46 cm (18 in.) below the liquid surface, collected equal volume aliquots at intervals of 15, 40, and 60 min, respectively.

The collected samples were delivered to the EPA, Region VII, Laboratory where duplicate analyses for NFS were run. The results of those analyses are indicated below.

Compositor	NFS mg/l	Mean NFS mg/l
QCEC	1,250 1,080	1,160
Sirco	760 680	720
ISCO	644 520	582

It can be seen that the Sirco unit produced samples with NFS data intermediate between those values resulting from the ISCO and QCEC compositors. Referring back to Table I (page 11), it can be seen that the liquid intake velocity of the Sirco unit also lies between the velocities of the other two samplers.

5. KANSAS CITY, KANSAS, KAW POINT SEWAGE TREATMENT PLANT - DECEMBER 17-19, 1973

A more comprehensive comparison study was conducted at the Kaw Point sewage treatment plant during December 17, 18, and 19, 1973. Sixteen different methods, including four manual sampling techniques, and twelve different makes and models of automatic compositors were employed to concurrently sample the raw waste of this facility.

Time and flow-proportional samples were collected and composited manually at 2-hr intervals using a bucket as well as a submersible pump*. This variation in manual sampling methods was introduced to determine if solids were settling out in the bucket during transfer from the waste stream to the laboratory sample containers. Using the submersible pump, samples were pumped directly from the source to the container.

The twelve samplers, the intake lines of which were tied together and suspended in the middle of the waste stream, were used to take time-composite samples by drawing equal volume aliquots at intervals which ranged from continuous up to 1 hr. Samples were collected over a period of approximately 24 hr on both December 17-18 and 18-19. With the exception of an N-Con Sentinel sampler which has a refrigerated sample container compartment and which was provided courtesy of the manufacturer, none of the samples were kept refrigerated during the sampling period. The collected samples were analyzed by the EPA, Region VII, Laboratory for BOD_5 (December 18-19 only), COD, and NFS which were run in duplicate. Random laboratory analytical errors for NFS were minimized by drawing aliquots with a wide-mouthed pipette from the samples during agitation with a magnetic stirrer.

* Teel Submersible Pump, Model 1P809, Dayton Electric Manufacturing Company, Chicago, Illinois 60648

The results of the comparison test are presented in Table XV and are arranged according to the liquid intake velocity of the particular technique or compositor used. An examination of this table would indicate that there was no correlation between concentration of parameter and liquid intake velocity. Calculation would also show that there was no correlation between cross-sectional area of the intake line and concentration nor between an intake tube cross-sectional area-velocity product factor and concentration. The data resulting from this comparison test do not support those results obtained in previous tests and the reason for this is not entirely understood. The nature of the waste which included meat processing scraps, soap, grease, and fiber glass was probably a contributing factor. Without constant attention upon the part of the two sanitary engineers who were on duty throughout the sampling period, most of the compositors would have failed. Over the two-day period the following equipment malfunctions were noted and corrected:

<u>Brailsford EP-1</u> - Cleaned eight times, solids visibly accumulated in the bottom of loops in the intake hose during the entire sampling period.

<u>Sigmamotor WA-2</u> - Clogged three times, cleaned with compressed air.

<u>ISCO 1391-X</u> - Completely clogged twice and one bottle short on the first day, four bottles empty on the second day.

<u>N-Con Surveyor</u> - Completely clogged six times with meat and skin scraps at the constriction on the intake side of the pump.

TABLE XV

RAW DATA AND STATISTICAL SUMMARY OF SAMPLER COMPARISON STUDY AT KANSAS CITY, KANSAS, KAW POINT SEWAGE TREATMENT PLANT

Sampling Method Or Compositor	Intake Velocity cm/sec(a)	Time Or Flow Composite	BOD_5 Dec. 18-19 mg/l	COD, mg/l Date Dec. 1973			NFS, mg/l Dec. 17-18, 1973				NFS, mg/l Dec. 18-19, 1973			
				17-18	18-19	Mean	Determination 1	Determination 2	Mean	Diff. |1-2|	Determination 1	Determination 2	Mean	Diff. |1-2|
1. Manual Sampling - Bucket	-	Time	630	3,190	2,120	2,660	1,280	1,410	1,340	130	1,060	1,010	1,040	50
2. Manual Sampling - Bucket	-	Flow	800	3,170	2,030	2,600	1,240	1,530	1,380	290	1,250	1,100	1,180	150
3. Brailsford EP-1	0.46	Time	550	3,580	1,530	2,560	390	420	400	30	420	440	430	20
4. Sigmamotor WA-2	7.9	Time	720	2,040	1,960	2,000	810	840	820	30	1,380	920	1,150	460
5. ISCO Model 1391-X	21	Time	620	2,950	2,180	2,560	1,200	1,330	1,260	130	1,070	1,000	1,040	70
6. N-Con Surveyor	36	Time	780	3,680	1,990	2,840	940	960	950	20	830	840	840	10
7. ISCO Model 1392	61	Time	680	2,220	2,400	2,310	950	930	940	20	990	1,020	1,000	30
8. QCEC-CVE	61	Time	680	3,170	2,470	2,820	1,310	1,310	1,310	0	1,080	1,100	1,090	20
9. QCEC-CVE	91	Time	710	2,770	2,560	2,660	1,410	1,700	1,560	290	1,240	1,330	1,280	90
10. Sirco MKV7S(b)	98	Time	700	3,050	2,250	2,650	910	1,070	990	160	1,150	960	1,060	190
11. QCEC-CVE	122	Time	490	2,770	2,060	2,420	1,080	1,190	1,140	110	1,000	1,320	1,160	320
12. QCEC-CVE	152	Time	560	2,750	1,840	2,300	1,080	1,080	1,080	0	1,000	1,000	1,000	0
13. Pro-Tech C6-150	207	Time	740	3,000	2,090	2,540	1,250	1,280	1,260	30	1,060	1,070	1,060	10
14. Manual Sampling - Pump	300	Time	590	2,670	1,730	2,200	1,080	1,080	1,080	0	970	830	900	140
15. Manual Sampling - Pump	300	Flow	590	2,730	1,750	2,240	1,150	1,180	1,160	30	930	870	900	60
16. N-Con Sentinel(b)	332	Time	700	2,690	1,890	2,290	980	1,030	1,000	50	950	950	950	0
Arithmetic Mean, mg/l			660	2,900	2,050	2,480	1,070	1,150	1,100	82	1,020	985	1,000	101
Standard Deviation (s), ±mg/l			84	412	270	229	237	289	260	-	204	198	185	-
Coefficient of Variation, Percent			13	14	13	9	22	25	24	-	20	20	18	-
Methods Out of Range(c)			9	5	6	7	5	8	6	-	6	5	5	-
Standard Deviation Due to Sampling (S_b), ±mg/l			--	-	-	-	214	271	240	-	177	170	155	-
Arithmetic Mean Excluding Brailsford EP-1, mg/l			670	2,860	2,090	2,470	1,110	1,190	1,150	86	1,060	1,020	1,040	107
Standard Deviation (s), ±mg/l			82	385	242	235	165	227	193	-	137	144	115	-
Coefficient of Variation, Percent			13	13	12	10	15	19	17	-	13	14	11	-
Methods Out of Range(c)			8	7	5	6	5	9	8	-	11	6	8	-
Standard Deviation Due to Sample (S_b), ±mg/l			--	-	-	-	130	203	164	-	92	102	55	-

(a) Multiply by 0.0328 to obtain fps

(b) Provided courtesy of the manufacturer

(c) Range is result from manual flow sampling with bucket ± coefficient of variation

ISCO 1392 - Clogged once, three bottles empty and three short on the first day - two bottles empty on the second day.

QCEC-CVE (61 cm/sec) - Clogged once, cleaned with compressed air.

Sirco MKV7S - One bottle short the first day - sampler time appeared to be about twenty percent fast as all twenty-four bottles were filled in nineteen hours.

Pro-Tech (6-150) - Clogged completely four times and cleaned by reversing inlet and outlet lines for one sample cycle.

Teel Submersible Pump - Twenty-four failures due primarily to fiber glass batting clumps and in several instances grease.

It is apparent that only the three QCEC samplers which were operated at liquid intake velocities above 61 cm/sec (2 fps) and the N-Con Sentinel performed satisfactorily.

It is felt that the high solids level in the wastewater, particularly the fiber glass, may have acted as a straining mechanism in the tubes and orifices of the various compositors to an extent that would have masked those effects due to liquid intake velocity. With the exception of the December 18-19 COD data, the flow-proportional samples collected with a bucket were of higher strength than the arithmetic mean of the concentrations found in the samples collected by other methods. Looking at the arithmetic mean of the NFS data for each method, it can be seen that only one compositor (QCEC-CVE set at 91 cm/sec) produced higher strength samples than those resulting from manual flow-proportional sampling with a bucket. If this manual technique is assumed to be the most accurate, it is apparent that the data resulting from the other methods are not normally distributed.

Because the results obtained with the Brailsford EP-1 (method 3) differed significantly from the other data, the mean, standard deviation (s), and the coefficient of variation were calculated with and without the Brailsford data. Except for the December 17-18 COD data, deletion of the Brailsford results increased the mean and decreased the s. Looking at the NFS s, it can be seen that excluding the Brailsford data resulted in throwing more of the compositor data outside the range of the manual flow data ± one standard deviation.

The duplicate analyses for NFS made it possible to determine the variation due to random laboratory error and that which could be attributed to variations in sampler performance. Using the method developed by Youden (3) for statistical analysis of inter-laboratory collaborative tests, the standard deviation due to variations in sampler performance can be calculated from the equations:

$$s^2 = s_b^2 + s_r^2 \qquad \text{Formula (1)}$$

$$S_r = \sqrt{\Sigma d^2/2n} \qquad \text{Formula (2)}$$

where:

s = standard deviation of the raw data

s_b = standard deviation due to variations in sampling technique and compositor performance

s_r = standard deviation due to random laboratory analytical error

d = absolute value of difference between duplicate analyses

n = number of samples

Because taking the difference between duplicates cancels out all factors affecting data variability except those due to random laboratory error, a single estimate of s_r can be obtained using the data for both days (n = 32). Using the differences calculated in Table XV it can be shown that s_r for the NFS data is equal to ±101 mg/l. Solving Formula (1) for s_b and using the s of the raw data it is a simple matter to calculate s_b. These values are shown in Table XV for the NFS raw data with and without the Brailsford results. Disregarding the means of the duplicate analysis it can be seen that s_b ranged from ±92 to 271 mg/l. Computation would show that the coefficient of variation due to sample performance varied from 9 to 22 percent.

B. COMPARISON OF TWO MANUAL GRAB SAMPLING METHODS

In addition to variations in water chemistry data resulting from differences in performances of automatic wastewater compositors, the Field Investigations staff has also found evidence of data variability due to different manual grab sampling techniques.

The data shown in Tables XVI and XVII and presented graphically in Figures 2 and 3 were extracted from an "ongoing" study of an extraneous flow facility. This facility, which is essentially a primary treatment plant, is activated by the rising water level in a sanitary sewer resulting from storm water infiltration. This unit takes flows in excess of sewer capacity, chlorinates, and provides approximately thirty minutes of sedimentation. The clarifier overflow is piped to a stream and the settled solids are returned to the sewer. The raw waste to this facility is residential in character and becomes progressively weaker in strength as rainfall and infiltration continue.

The influent and effluent of this facility have been sampled on three separate occasions during suitable rainfall events. The data shown in Tables XVI and XVII were selected from the raw waste sampling results from the first two events. During the first event (September 7, 1972) the raw waste was sampled with a bucket at 10-min intervals from the time the clarifier started filling. During the second event (November 6, 1972) the raw waste was sampled with a submersible pump* suspended at mid depth in the entering waste stream. During the first event, five laboratory containers were filled from the bucket. During the second event, the five containers were filled directly from the discharge end of the pump hose which had an estimated liquid velocity of 4.4 m/sec (14.4 fps). In the laboratory, aliquots for BOD_5 and NFS determinations were extracted from the same sample container. Aliquots for COD analysis were taken from a separate, preserved, sample.

Comparing Tables XVI and XVII, it can be seen that the duration of sampling was longer for the second event and that there was a

---

* Teel Submersible Pump, Model 1P809, Dayton Electric Manufacturing Company, Chicago, Illinois 60648

TABLE XVI

INFLUENT - EXTRANEOUS FLOW PROJECT - SEPTEMBER 7, 1972

GRAB SAMPLING WITH BUCKET

Time Military	Elapsed Time Hours + Minutes	BOD_5 mg/l	COD mg/l	NFS mg/l	$\frac{BOD}{COD}$ Ratio
1030	00 + 00	170	271	308	0.63
1035	00 + 05	185	427	320	0.43
1040	00 + 10	185	247	312	0.75
1050	00 + 20	155	199	288	0.78
1100	00 + 30	170	632	220	0.27
1110	00 + 40	198	389	388	0.51
1120	00 + 50	188	228	288	0.82
1130	01 + 00	163	226	192	0.72
1140	01 + 10	165	156	168	1.06
1150	01 + 20	153	330	176	0.46
1200	01 + 30	168	192	188	0.88
1210	01 + 40	203	178	120	1.14
1220	01 + 50	170	175	156	0.97
1230	02 + 00	215	194	308	1.11
1240	02 + 10	160	148	152	1.08
1250	02 + 20	188	182	268	1.03
1300	02 + 30	273	190	728	1.43
1310	02 + 40	215	154	216	1.40
1320	02 + 50	235	205	180	1.15
1330	03 + 00	230	203	104	1.13
1340	03 + 10	255	224	728	1.14
1350	03 + 20	253	233	204	1.08
1400	03 + 30	235	207	212	1.14
1410	03 + 40	268	205	200	1.31
1420	03 + 50	225	233	200	0.96
1430	04 + 00	205	195	116	1.05
1440	04 + 10	253	207	124	1.22
1450	04 + 20	243	218	148	1.11
1500	04 + 30	265	247	276	1.07
1510	04 + 40	213	177	144	1.20
1520	04 + 50	225	171	132	1.31
Mean		207	234	244	0.98
Standard Deviation (s)		±36	±95	±145	±0.30

TABLE XVII

INFLUENT - EXTRANEOUS FLOW PROJECT - NOVEMBER 6, 1972
GRAB SAMPLING WITH SUBMERSIBLE PUMP

Time Military	Elapsed Time Hours + Minutes	BOD_5 mg/l	COD mg/l	NFS mg/l	$\frac{BOD}{COD}$ Ratio
1025	00 + 00	255	416	192	0.61
1035	00 + 10	203	404	172	0.50
1045	00 + 20	230	446	216	0.52
1055	00 + 30	303	544	320	0.56
1105	00 + 40	275	435	276	0.63
1115	00 + 50	243	412	264	0.59
1125	01 + 00	195	879	400	0.22
1135	01 + 10	245	577	360	0.42
1145	01 + 20	233	492	352	0.47
1155	01 + 30	188	356	356	0.53
1205	01 + 40	190	456	284	0.42
1215	01 + 50	213	414	332	0.51
1225	02 + 00	145	326	290	0.44
1235	02 + 10	148	257	230	0.58
1245	02 + 20	137	289	220	0.47
1255	02 + 30	140	305	174	0.46
1305	02 + 40	105	213	174	0.49
1315	02 + 50	110	285	142	0.38
1325	03 + 00	130	180	102	0.72
1355	03 + 30	90	159	94	0.57
1425	04 + 00	105	150	84	0.70
1455	04 + 30	110	183	70	0.60
1525	05 + 00	80	148	54	0.54
Mean		177	362	224	0.52
Standard Deviation (s)		± 63	±167	±101	±0.11
1555	05 + 30	70	115	44	0.61
1625	06 + 00	118	181	54	0.65
1655	06 + 30	115	142	41	0.81
1725	07 + 00	100	140	37	0.71
1755	07 + 30	100	162	32	0.62
1825	08 + 00	165	144	38	1.14
1855	08 + 30	115	167	35	0.68
1925	09 + 00	140	204	39	0.69
1955	09 + 30	180	225	38	0.80
2025	10 + 00	150	252	40	0.59
2055	10 + 30	168	302	68	0.56
2125	11 + 00	153	263	41	0.58

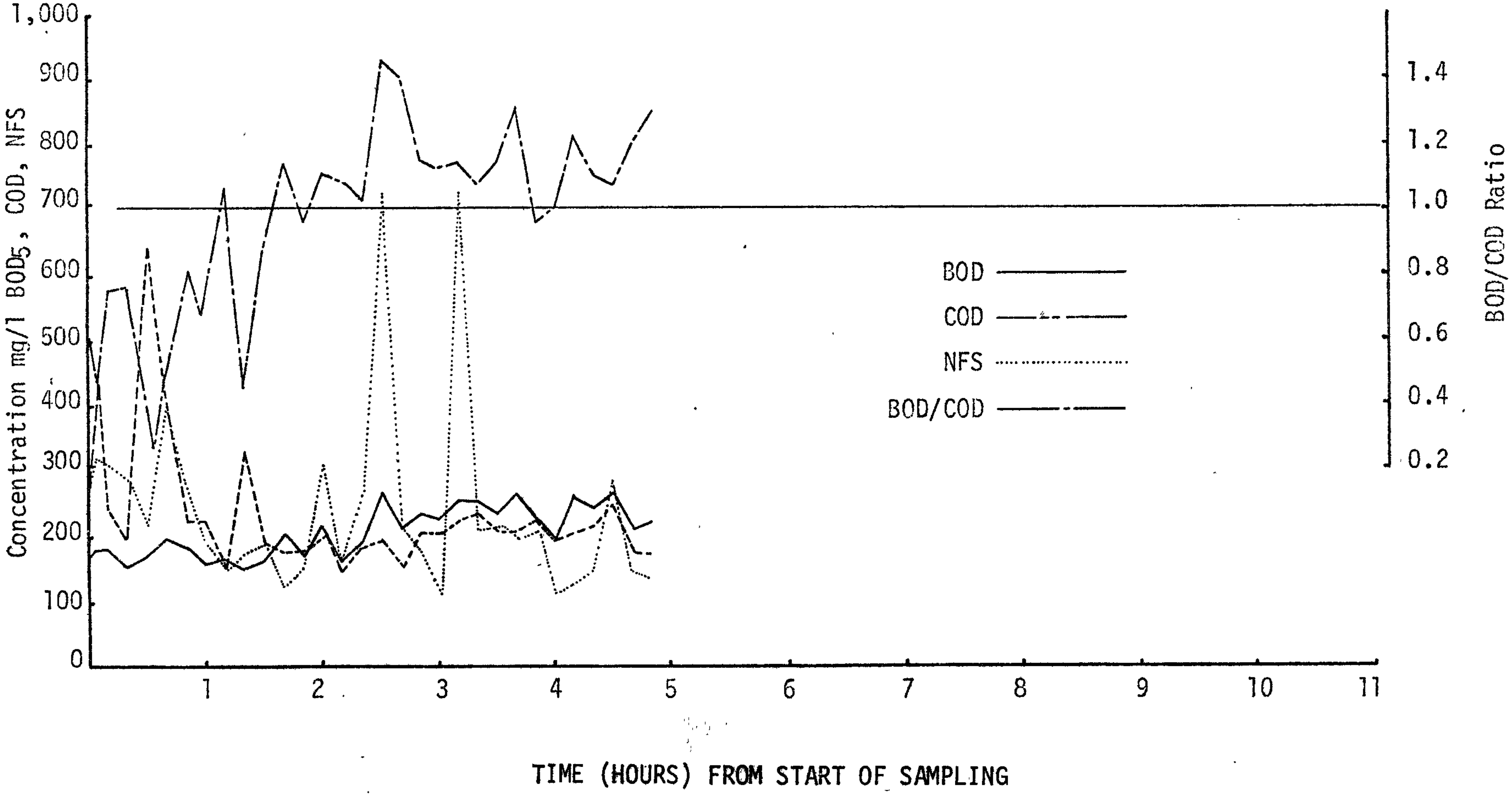

FIGURE 2 - Extraneous Flow Project - Grab Sampling of Influent With Bucket - September 7, 1972

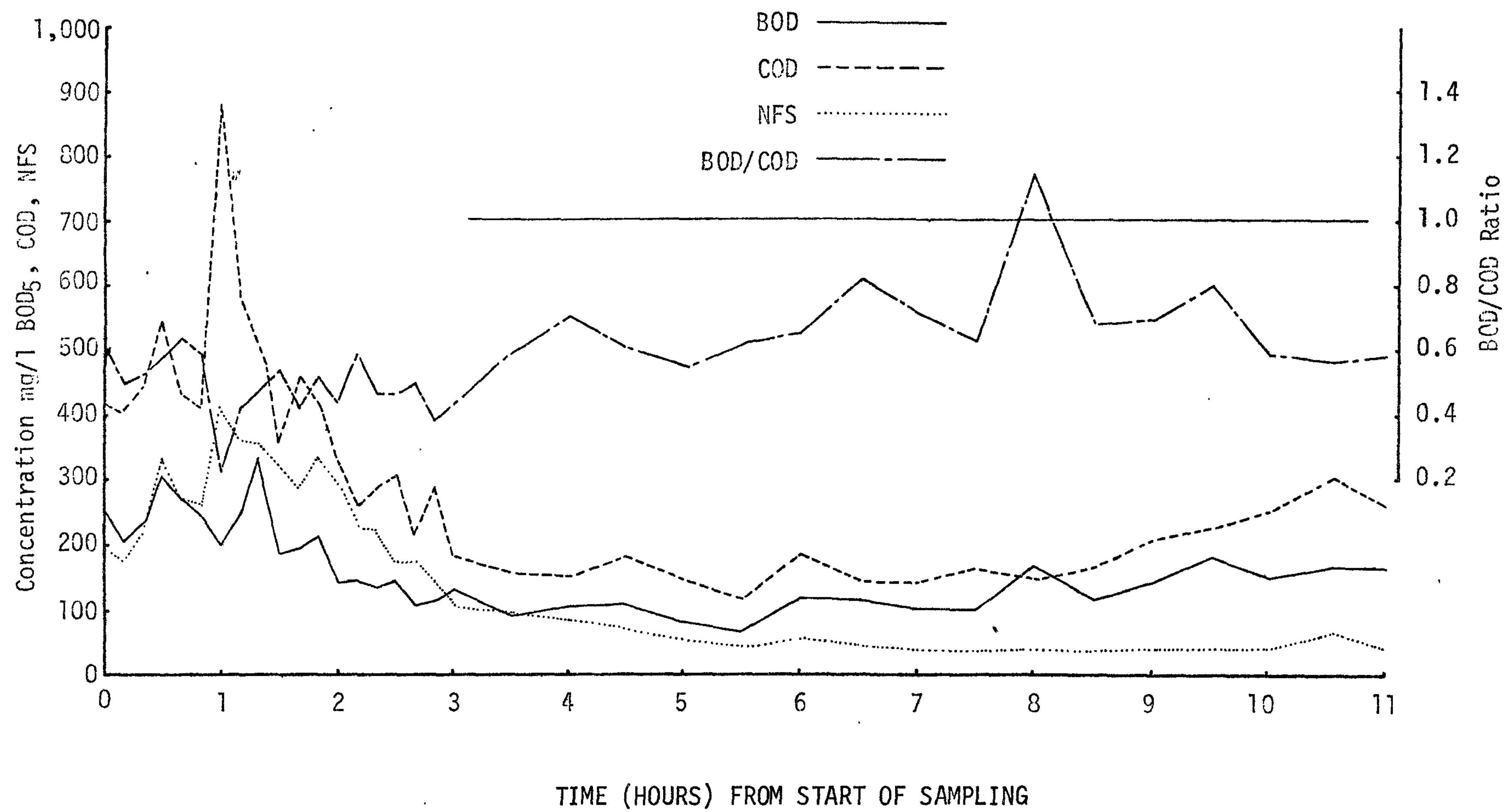

FIGURE 3 - Extraneous Flow Project - Grab Sampling of Influent With Submersible Pump - November 6, 1972

progressive decrease in strength of the raw waste over this longer time period. Consequently, the water chemistry data are compared over the approximate same elapsed time period.

Figure 2 shows the fate of BOD_5, COD, and NFS levels with time for the first event and indicates that the concentrations, particularly NFS, did not follow or reflect each other very well and that 19 of the 31 sets of grab samples collected (61 percent) had BOD_5/COD ratios greater than unity. The mean BOD/COD ratio was 0.98 with a standard deviation (s) of ±0.30. Figure 3, which shows the data for the second event using the submersible pump, indicates that there was an improvement in the manner in which the parameters followed each other and that only one data point out of thirty-five had a BOD_5/COD ratio greater than one. An evaluation of the data from the second event over the same elapsed time period as that of the first event resulted in a mean BOD/COD ratio of 0.52 with a s of ±0.11. Table XVII also shows a decrease in the s of the NFS data from ±145 mg/l to ±101 mg/l.

A BOD_5/COD ratio greater than unity is never encountered in a domestic waste and very seldom encountered in an industrial waste. The raw waste of this facility originates in a residential area with no known industrial wastes or toxicants which would affect BOD_5 values. Analyses from the first event which are not reproduced here indicated only negligible concentrations of heavy metals and a mean effluent BOD_5/COD ratio of 0.68 (twenty-four samples) with all ratios less than one.

Although these two events were completely independent and the data from the first event could conceivably represent actual wastewater characteristics, the data resulting from use of the bucket is at least questionable. Comparing the two events, it can be seen that there was a decline in BOD_5 and NFS concentrations of the samples collected during the second event; however, the NFS/BOD_5 ratios, which were 1.18 and 1.27 for event 1 and 2, respectively, were in approximate agreement. Although the BOD_5 and NFS levels decreased during the second event, there was a 55 percent increase in COD. Since it is impossible to agitate the contents of a pail and fill a small-mouthed container simultaneously, it is believed that use of the bucket to collect samples allowed some of the heavier, nonbiodegradable solids to settle out. The high discharge velocity of the pump is believed to have effectively prevented any settlement and to have resulted in a more representative sample.

Data comparison from these two events cast suspicion upon manual methods of sampling which involved dipping of samples out of raw waste sources and, consequently, raised the question of whether or not manual grab sampling is a suitable "yardstick" for evaluating the performance of automatic wastewater samplers.

C. INTERLABORATORY VARIATIONS

On April 15 through 18, 1973, Field Investigations personnel conducted a performance test at the 113,500-cu m/day (30-mgd) Kaw Point primary wastewater treatment plant in Kansas City, Kansas. Two Hants 3B samplers were installed at the influent and were timed to alternately collect samples at hourly intervals. An ISCO 1391-X compositor was installed at the effluent and set to collect samples at hourly intervals. Between 0800 and 1000 hr each morning the discrete samples collected at each of the two stations were manually composited according to the hourly pumping rate records for the three influent pumps serving the plant. The composited samples, with no preservation other than icing, were split between the treatment plant laboratory and the EPA, Region VII, Laboratory for analysis.

In addition to the flow-proportional composite samples, two grab samples were manually collected each morning at both of the sampling stations. During the last 24-hr composite period, grab samples were collected at 2-hr intervals from the influent and analyzed for COD. The grab samples were not split with city personnel.

The data resulting from this investigation are presented in Table XVIII which also shows the calculated removal efficiencies for the three parameters using the EPA and city analyses of the composite samples and the EPA analyses of the grab samples. An examination of this table would indicate wide ranges in removal efficiencies as a result of variations in interlaboratory analyses and grab sample characteristics.

It can be seen that the greatest interlaboratory variation was in COD analysis. The four-day arithmetic mean COD of the influent samples analyzed by EPA and the city was 1,990 and 1,030

TABLE XVIII

INTERLABORATORY ANALYTICAL AND SAMPLE VARIATION
KAW POINT SEWAGE TREATMENT PLANT - KANSAS CITY, KANSAS
APRIL 1973

Station	Sample Collection Times				Flow Rate cu m/min[a]			BOD, mg/l			COD, mg/l			NFS, mg/l		
	Grab Samples		Composite Sample And Flow Measurement Period		Max	Min	Mean	Grab Sample And (Mean)	Composite Sample		Grab Sample And (Mean)	Composite Sample		Grab Sample And (Mean)	Composite Sample	
	Date	Time	Dates	Time Period					EPA	City		EPA	City		EPA	City
Influent	15 15	0835 0910	14-15	1000-0800	129	20	69	41 175 (108)	140	186	148 527 (338)	440	420	110 148 (129)	696	1,620
Effluent	15 15	0855 0925	14-15	1000-0800[b]				96 96 (96)	97	100	250 319 (284)	318	301	76 94 (85)	80	96
Percent Removal								11	31	46	16	28	28	34	89	94
Influent	16 16	0835 0945	15-16	1100-0900[c]	119	43	83	216 540 (378)	369	488	1,020 1,890 (1,455)	2,320	493	300 1,050 (675)	2,080	1,450
Effluent	16 16	0830 0940	15-16	1000-0900				150 260 (205)	104	66	330 580 (455)	310	-	150 290 (220)	112	80
Percent Removal								46	72	86	69	87	-	67	95	94
Influent	17 17	0825 0855	16-17	1000-0800[d]	106	38	63	690 485 (588)	530	651	2,300 2,000 (2,150)	2,890	1,522	430 476 (453)	2,310	1,340
Effluent	17 17	0815 0900	16-17	1000-0900				250 360 (305)	270	287	570 650 (610)	670	596	132 196 (164)	204	144
Percent Removal								48	49	56	72	77	61	64	91	89
Influent	18 18	0815 0845	17-18	1000-0800[e]	81	43	61	520 650 (585)	800	858	750 1,460 (1,105)	2,300	1,681	184 660 (422)	2,250	1,220
Effluent	18 18	0805 0835	17-18	1000-0900				300 340 (320)	430	398	645 675 (660)	785	868	120 136 (128)	188	166
Percent Removal								45	46	54	40	66	48	70	92	86
Four-Day Arithmetic Means																
Influent, mg/l								415	460	546	1,260	1,990	1,030	420	1,830	1,410
Effluent, mg/l								231	225	213	502	521	588	149	146	122
Percent Removal								44	51	61	60	74	43	65	92	91
Influent	17	1000										2,270				
	17	1200										1,050				
	17	1400										2,180				
	17	1600										2,950				
	17	1800										1,820				
	17	2000										2,020				
	17	2200										1,030				
	17	2400										-				
	18	0200										2,110				
	18	0400										1,400				
	18	0600										1,560				
	18	0800										1,540				
Arithmetic Mean, mg/l												1,810				
Standard Deviation, ± mg/l												545				
Coefficient of Variation, Percent												30				

(a) Multiply by 264.2 to obtain gpm. Flow rate error estimated at ±15 to 20 percent.
(b) Nine bottles empty on 24-hr composite
(c) Aliquot collected at 1500 hr was 300 ml short
(d) Aliquot collected at 1400 hr was 200 ml short
(e) Five bottles empty on 24-hr composite, 7 hr of flow data missing

mg/l, respectively. On April 15 and 16 the variation was even more pronounced with concentrations of 2,320 and 493 mg/l, respectively. This difference is in excess of interlaboratory variations reported in Standard Methods (2, p. 499). Investigation of laboratory technique revealed that the EPA laboratory used larger aliquots which were either drawn from a well-mixed sample with an open tip pipette or poured into a graduated cylinder. The manner in which these larger aliquots were drawn is believed to have resulted in greater and more representativeness amounts of nonfilterable residue.

The data clearly indicate the inadequacy of relying upon a limited number of grab samples for determining wastewater characteristics or plant performance. In every case, the removal efficiencies calculated from the grab sample data were less than those efficiencies determined from the composite sample data reported by the two laboratories. The COD analyses of the raw waste grab samples collected at 2-hr intervals April 17-18 ranged from 1,030 to 2,950 mg/l, had a mean of 1,810 mg/l, and a standard deviation of ±545 mg/l (coefficient of variation, thirty percent).

D. SUMMARY AND DISCUSSION

1. SAMPLER PERFORMANCE

In every case, the sampler comparison studies on raw waste indicated variations in water chemistry data which were greater than could be explained by laboratory analytical error. This variation was particularly marked with the NFS parameter. The Richards-Gebaur study resulted in data which showed that in eight of nine cases the high-vacuum, high-liquid intake velocity Hants 3B and QCEC-CVE samplers produced time-composite samples with NFS levels that range from 15 to 214 percent greater than the concentrations found in manually-collected, flow-composited samples.

Nonfilterable solids concentration in the raw waste samples collected with the QCEC compositor range from 15 to 100 percent greater than the levels present in those samples collected manually. This sampler was used to collect time-composite samples which included equal volumes of the early morning low-flow, low-strength waste that would, in theory, have biased the sample low in relation to the flow composites.

A statistical analysis of all the raw waste data resulting from the three-day Richards-Gebaur study resulted in coefficients of variation of 29, 39, and 42 percent, respectively, for BOD_5, COD, and NFS. Included in this variation were: (a) actual changes in wastewater characteristics, (b) differences in sampler performance and manual techniques, (c) field errors in manual compositing methods, and (d) laboratory random analytical errors. Standard Methods reports (2, p. 494, 499, 538) coefficients of variation of 5, 6.5, and 10 to 33 percent, respectively, for these three parameters as a result of interlaboratory analytical collaborative tests on identical samples. As an estimate of the analytical error which could be expected from a single laboratory, the Standard Methods variance for COD and NFS are high since systematic errors of a number of laboratories are included. It is apparent that the major source of data variability is due to actual changes in water chemistry and field techniques.

The comparison study of the QCEC-CVE and ISCO samplers at the Theresa Street sewage treatment plant in Lincoln, Nebraska, showed that the QCEC compositor produced time-composite samples that were, respectively, 125, 134, and 182 percent higher in BOD_5, COD, and NFS than those flow-composite samples obtained with an ISCO Model 780. The corresponding percentages for the effluent samples were 104, 129, and 92.

A comparison of raw waste flow-proportional samples collected over a five-day period with the Hants 3B and ISCO 1391 at Ashland, Nebraska, also indicated a bias. The mean BOD_5, COD, and NFS concentrations of the Hants samples were 179, 183, and 334 percent higher than the levels found in the ISCO samples. The corresponding values for the effluent samples were 154, 146, and 220 percent, respectively.

Raw waste samples collected concurrently with a QCEC-CVE, Sirco MKV7S, and an ISCO sampler at the Kansas City, Kansas, Kaw Point plant had mean NFS concentrations of 1,160, 720, and 582 mg/l, respectively. These concentrations had the same relationship to each other as did the liquid intake velocities of the samplers.

The comparison study at the Kaw Point plant using four different manual sampling techniques and twelve different compositors did not show any correlation between liquid intake velocity and parameter concentrations. This lack of correlation was felt to be due to a straining mechanism resulting from the high levels of suspended solids in the waste. Because duplicate analysis for NFS was run for this study, it was possible to isolate and estimate data variability due to laboratory random analytical error and that due to differences in compositor performance. Standard deviation of laboratory error was ±101 mg/l (coefficient of variation, approximately 10 percent). The deviation due to sampler performance ranged from ±92 to 271 mg/l (coefficient of variation 9 to 24 percent), depending upon whether or not the Brailsford EP-1 sample data was included.

The comparison studies indicated that the high vacuum, high liquid intake velocity samplers were more effective in capturing solid material. Although these units also produced higher concentrations of BOD_5 and COD, the increase in NFS was disproportionately greater. It would appear that the slower-acting peristaltic and piston pump type samplers are either not capturing settleable materials or that after introduction to the intake line particle settling velocities are higher than liquid intake velocities. Another factor could be the agitation of sample increments during collection. The greater intake velocities of those compositors which have yielded high strength samples may be breaking up larger size suspended material as the aliquot passes through the sampling train and into the collection container. In the laboratory, suspension of smaller sized particles would be more amendable to extraction of representative amounts of residue with routine pipetting procedures.

2. ADDITIONAL PERFORMANCE STUDIES

The Richards-Gebaur study indicated extremely wide ranges in apparent facility removal efficiencies as a function of grab sample data which was manipulated to show effects of collection time, sampling frequency and interval, and days of sampling. Additional comparison studies using identical sampling equipment to collect discrete, time-composite, and flow-composite samples would be useful in developing more adequate grab sampling methodologies.

At this point the Field Investigations Section is of the opinion that little more can be gained from field evaluation of sampling equipment on the basis of sample representativeness. Under field conditions, variables cannot be controlled, actual concentrations of wastewater chemistry parameters are unknown, and manual grab sampling is of questionable value as a "yardstick" against which to measure the performance of automatic sampling equipment.

The variability of NFS concentrations indicates that it is especially difficult to obtain representative sample concentrations of this parameter because of its sensitivity to changes in collection methodologies. Given the "state of the art" of currently available compositors and ever-increasing varieties of equipment coming on the market, there is an urgent need for development of a synthetic suspended solids waste to evaluate samplers under controlled laboratory conditions. A suitable synthetic waste: (a) could be used as a performance specification in purchasing samplers,

(b) could be used to determine the representativeness of samples collected by various makes and models of compositors, (c) could determine the suitability of specific equipment for particular applications, (d) would be a step toward standardization of sampling methods, (e) could result in reduced water chemistry variability, and (f) would increase data credibility for enforcement activities.

Development of a synthetic solids waste to be used in conjunction with laboratory evaluation of sampler performance would require consideration of the following variables: (a) particle size and specific gravity, (b) sampler liquid intake velocity, (c) intake tube diameter, (d) orientation of intake line with respect to waste stream velocity vectors, and (e) liquid temperature and viscosity.

3. SELECTION OF SAMPLING EQUIPMENT

Although the results of the sampler comparison studies are not conclusive and additional work is needed, it is the opinion of the Field Investigations Section that high-vacuum, sampling equipment produces more representative samples. On waste sources with appreciable concentrations of large and/or heavy settleable material such as a raw municipal wastewater, the section makes every effort to install a high vacuum unit when compatible with site conditions and data requirements. Since these units yield higher results, they are of advantage to treatment plants in determination of removal efficiencies.

Variations in compositor performance at effluent sampling stations were found to be smaller due to water chemistry equalization resulting from plant retention times and, it is felt, to the lower levels of suspended material which are smaller, more uniform, and of lower density than the particles found in raw waste. Although high-vacuum samplers can be effectively used on these wastes, the data would indicate that well-treated effluents with no visible solids can be representatively sampled with the slower acting compositors.

4. FLOW PROPORTIONAL SAMPLING

With present sampling technology, the section feels that flow compositing of raw municipal wastewaters and other wastes with appreciable settleable solids is neither necessary nor justified. The variations in sampler performance and manual sampling techniques completely mask actual changes in wastewater chemistry characteristics. At best, variations traceable to differences in compositor performance ranged from ±9 to 24 percent. In some instances differences in NFS levels were over 300 percent. Data discrepancies of this magnitude do not warrant the extra time and expense involved in installing sophisticated sampling equipment and flow measurement devices.

The comparison studies on treated wastes would indicate that well-treated, sparkling effluent with no visible solids are amenable to flow-proportional sampling and that a suitable compositor can be selected without regard to variations in performance.

This would also apply to industrial wastes which were all in solution form.

Because of work load, the need for expediency, and the limited scope of most surveys the section generally does not collect flow-proportional samples. Approximately 5 percent of the sampling stations the section surveys have weirs or flumes equipped with flow totalizers which are in proper working order suitable for manual compositing of flow-proportional samples. Most of these totalizers are located at the facility influent. About 40 percent of the stations have only a weir or flume and 50 percent have no measurement device of any sort. It is extremely rare to find a facility with suitable flow-measurement devices on both influent and effluent stations.

Most of the flow-proportional sampling efforts of the section are confined to data gathering for enforcement activities, in-depth evaluations of new and existing treatment facilities, and investigations of industrial processes where mass balances are of critical importance.

It should also be pointed out that manual flow compositing of discrete grab samples, whether collected with an automatic sampler or manually, introduces another possible source of error and requires more time of the professional in the field. Sources of error would include: (a) not shaking the discrete sample prior to compositing, (b) miscalculation of correct sample volumes as a result of having to use a slide rule or electronic calculator to determine discharge rates from exponential functions based on head measurements, and (c) misreading of graduated cylinders. It would appear that those automatic collection devices which collect flow-proportional aliquots and composite them in a single container would be most effective in eliminating this source of error.

5. SAMPLING METHODOLOGY

Data from grab samples collected during the comparison studies showed wide fluctuations in wastewater strength over a 24-hr period. The Richards-Gebaur study resulted in NFS coefficients of variation which ranged from 44 to 60 percent on the raw waste, 30 to 41 percent on the primary effluent, and 15 to 32 percent on the final effluent. Based upon collection of one grab sampler per day for three days, it was shown that the apparent solids removal efficiency of the Richards-Gebaur facility ranged from -103 to +70 percent depending upon sample collection time. Comparing six grab samples per day with 24-hr manual flow composites for one, two, and three days, it was shown that mean grab sample efficiencies differed from the mean manual composite efficiencies by 10, 3, and 5 percent, respectively.

The raw grab sample data from the Kansas City, Kansas, Kaw Point sewage treatment plant investigation of April 15 to 18, 1973, resulted in a COD standard deviation of ±545 mg/l and a coefficient of variation of 30 percent. Removal efficiencies of this facility calculated on the basis of two grab samples were in some instances only a third of the efficiencies obtained with composite sample data.

These variations emphasize the importance of an adequate sampling program and appropriate equipment. A poll of EPA, Surveillance and Analysis staff members around the country resulted in a general concurrence that for normally variable domestic wastewaters a minimum of 8 evenly-spaced grab samples collected over a 24-hr period, repeated for a minimum of 3 wk days, will result in a fair estimate of water chemistry characteristics.

It is the opinion of the Field Investigations Section that either time or flow-proportional sampling should be used in routine surveys and monitoring of municipal treatment plants unless those variations which occur throughout the day are of interest. Analyses of an adequate number of discrete grab samples to characterize wastewaters and plant efficiencies is an inordinate drain of laboratory resources and is not economically justified. The use of automatic compositors can easily be offset by savings in analyses costs.

The section confines most of its grab sampling efforts to special studies and enforcement activities. Because of the strict chain of custody procedures which can be exercised with manually collected grab samples, they are often used to support those data resulting from use of unattended compositors.

Considerable judgement is required for industrial wastewater flows which vary widely in composition and volume throughout the work day. Initial surveys of industrial wastewaters should be carried out only after a thorough understanding of plant processes. Surveys should include 24-hr-a-day composite sampling for a period of 5 days, including the normal second shift Friday cleanup period. For max information of wastewater quality and variability, it is frequently a good idea to install two compositors - one with discrete sample jars and on an hr cycle to provide for a flow proportional composite and also individual hourly samples for analysis. A second compositor taking small aliquots at more frequent intervals (10 to 15 min) can be used to obtain a second composite sample which should contain portions of all of the batch discharges of short duration. Comparison of analyses from the two composites should give a good indication of whether or not sampling at a 1-hr frequency is adequate. There are several varieties of discrete bottle compositors now on the market with a multiplex capability which provides for frequent samples to be composited in each of the hourly sample jars negating the need for a second sampler.

6. THE IDEAL AUTOMATIC SAMPLER

Manufacturers of samplers have yet to produce a unit which will meet all the sampling requirements and the physical site conditions encountered by the Field Investigations Section. Development of such a unit would greatly simplify the logistical problems of providing an adequate stock of spare replacement parts and would save that time now spent in becoming familiar with the operation and repair of a large variety of samplers.

As a result of field experience and sampler performance comparison studies, the section has developed a list of the features which the "ideal" sampler would incorporate.

1. Capability for AC/DC operation with adequate dry battery energy storage for 120-hr operation at 1-hr sampling intervals.

2. Suitable for suspension in a standard manhole and still provide access for inspection and sample removal.

3. Total weight including batteries under 18 kg (40 lb).

4. Sample collection interval adjustable from 10 min to 4 hr.

5. Capability for flow-proportional and time-composite samples.

6. Capable of collecting a single 9.5-l (2.5-gal) sample and/or collecting 500-ml (0.13-gal) discrete samples in a minimum of 24 containers.

7. Capability for multiplexing repeated aliquots into discrete bottles.

8. One intake hose with a minimum ID of 0.64 cm (0.25 in.) and a weighted streamlined intake screen which will prevent accumulation of solids.

9. Intake hose liquid velocity adjustable from 0.61 to 3 m/sec (2.0 to 10 fps) with dial setting.

10. Minimum lift of 6.1 m (20 ft).

11. Explosion proof.

12. Watertight exterior case to protect components in the event of rain or submersion.

13. Exterior case capable of being locked and with lugs for attaching steel cable to prevent tampering and provide some security.

14. No metal parts in contact with waste source or samples.

15. An integral sample container compartment capable of maintaining samples at 4 to 6°C for a period of 24 hr at ambient temperatures up to 38°C.

16. With the exception of the intake hose, capable of operating in a temperature range between -10 to 40°C.

17. Purge cycle before and after each collection interval and sensing mechanism to purge in event of plugging during sample collection and then collect complete sample.

18. Capable of being repaired in the field.

7. THE PROFESSIONAL IN THE FIELD

The data has shown many sources of data variability and emphasizes the importance of having a professional in the field to select sampling locations, equipment, and methodology. It is obvious that those individuals responsible for surveys and sample collection activities can use any of the generally accepted sampling techniques and equipment and still intentionally or unintentionally manipulate apparent wastewater chemistry characteristics and facility removal efficiencies.

The practice of using low-paid, unsupervised personnel to collect samples for analysis by highly-paid professional chemists is a misappropriation of technical and economic resources which can only result in unrepresentative data.

It is little wonder that there are so many disagreements among various responsible Federal, state, city, and individual groups regarding water chemistry characteristics and facility performance. When variations in sampling methodology and laboratory systematic and random errors are further compounded by errors in flow measurements, differences can become astronomical. Without an adequate monitoring program and tight controls on sampling techniques, equipment, and laboratory procedures, data interpretation can be reduced to little more than an exercise in futility.

V. HYDRAULIC MEASUREMENTS

Calculation of loadings, effluent limitation quantities, and flow-proportional sampling require hydraulic measurements. The need for accurate rate measurements is just as great, if not greater than the need for good representative water chemistry data. Ideally, the professional in the field surveying a wastewater system strives to develop a materials mass balance using the combination of flow rate and parameter concentration. Because of biological activity, errors in flow measurements, sampling methods, and laboratory analytical random errors, a mass balance is seldom achieved in practice.

Because of the variety of sampling station configurations encountered and the essentially empirical nature of most measurement techniques, flow rate accuracy remains as one of the weakest aspects of the field survey.

The Field Investigations Section has no special expertise in the area of hydraulics and a detailed discussion of the subject is beyond the scope of this report and would be presumptuous and redundant in light of the number of excellent references (4, 5, 6, 7, 8, 9) available. Personnel responsible for flow measurement data would be well advised to obtain and study the first four of these references, particularly (4) which discusses most of those methods likely to be of use in the field.

This chapter reports these methods and equipment which the Field Investigations Section has used in its surveys and indicates those factors which can result in significant error.

A. WEIRS, FLUMES, AND RECORDING EQUIPMENT

1. WEIRS

Approximately 50 percent of those sampling stations surveyed by the section have no flow measurement device of any sort and it is frequently necessary for the section to make temporary installations of equipment. Weirs can be placed relatively quickly and are generally used at those sites requiring discharge measurements.

Weirs commonly installed by section personnel or encountered at wastewater treatment facilities have included: (a) 90° V-notch, (b) 60° V-notch, (c) contracted rectangular, (d) suppressed rectangular, and (e) Cipolletti. The following necessary conditions are reported (4, p. 12-13) for setting weirs and getting accurate discharge rate measurements:

a. The upstream face of the bulkhead should be smooth and in a vertical plane perpendicular to the axis of the channel.

b. The upstream face of the weir plate should be smooth, straight, and flush with the upstream face of the bulkhead.

c. The entire crest should be a level, plane surface which forms a sharp, right-angled edge where it intersects the upstream face. The thickness of the crest, measured in the direction of flow, should be between 1 to 2 mm (0.03 to 0.08 in.). Both side edges of rectangular weirs should be truly vertical and of the same thickness as the crest.

d. The upstream corners of the notch must be sharp. They should be machined or filed perpendicular to the upstream face, free of burrs or scratches, and not smoothed off with abrasive cloth or paper. Knife edges should be avoided because they are difficult to maintain.

e. The downstream edges of the notch should be relieved by chamfering if the plate is thicker than the prescribed crest width. This chamfer should be at an angle of 45 deg or more to the surface of the crest.

f. The distance of the crest from the bottom of the approach channel (weir pool) should preferably be not less than twice the depth of water above the crest and in no case less than 0.305 m (1 ft).

g. The distance from the sides of the weir to the sides of the approach channel should preferably be no less than twice the depth of water above the crest and never less than 0.305 m (1 ft).

h. The overflow sheet (nappe) should touch only the upstream edges of the crest and sides.

i. Air should circulate freely both under and on the sides of the nappe.

j. The measurement of head on the weir should be taken as the difference in elevation between the crest and the water surface at a point upstream from the weir a distance of four times the max head on the crest.

k. The cross-sectional area of the approach channel should be at least eight times that of the overflow sheet at the crest for a distance upstream from fifteen to twenty times the depth of the sheet.

It is probably safe to say that the Field Investigations Section has never encountered a weir installation which met all of the preceding requirements. Weir crests are not chamfered, are covered with debris and biological growth, are not flush with bulkhead plates, and are too close to bottom and sides of approach channel. Velocities of approach (Va) are too high as a result of the weir pool being underdesigned to start with or as a result of deposition of solids. A Va between 0.305 and 0.61 m/sec (1 to 2 fps) can result in a discharge rate error ranging from -10 to -35 percent. If weir pool Va are significant, they should be measured with a current meter* or estimated with floats (if nothing else is available) and corrected for (4, p. 25-26).

Some observed weir deficiencies can be corrected; however, from a practical standpoint a loss of accuracy must be expected as it is seldom feasible to optimize all installation requirements. Even at those locations at which the section installs equipment, site conditions such as limited space, hydraulic head, and concrete abutment structures impose investigative restraints which are a compromise between time, economics, and data requirements.

2. FLUMES

The Parshall flume is one of the most common types of flow measurement devices installed at wastewater treatment facilities and is preferred because: (a) it can operate with relatively small losses of head, (b) it is relatively insensitive to velocity of approach, (c) if properly installed, it will give good measurements over a wide range of downstream submergence, and (d) flow velocities are sufficiently high to eliminate solids deposition.

Because of the time required to properly install these devices, the section has not set Parshall flumes at any survey sites and

---

* See Page 102

experience has been confined to those flumes encountered at wastewater treatment facilities.

Prior to taking water measurement data, a Parshall flume should be checked to see that: (a) longitudinal and lateral axes of crest floor are level, (b) side walls are parallel and throat dimensions close to design tolerances, (c) approach flows are uniformly distributed in the upstream convergence section, (d) head measurement devices (if installed) at correct location, and (e) flow variations are within the range for which the flume is accurate.

3. FLOW RECORDING EQUIPMENT

a. FACILITY RECORDERS

About 25 percent of those facilities which have weirs or flumes also have continuous flow recording equipment. Approximately half of these installations have recorders which are in proper working order.

Sources of measurement error with recording equipment are common to both weirs and flumes and include:

(1) Stilling well in wrong location with respect to weir or flume crest.

(2) Trash and debris in stilling well and conduit between flume and well plugged.

(3) Float dirty, punctured, not vertical, and rubbing against side of stilling well. Slack in float cable.

(4) Wrong recorder multiplier and chart paper. Pen not inked and not giving responsive trace. Recorder does not zero. An error in calibration of 1.5 cm (0.60 in.) can cause an error in rate measurement ranging to several hundred percent at low depths on small weirs and twenty to thirty percent for

moderate depths in flumes with throat widths under 30.5 cm (12 in.).

Prior to using flow data from plant recorders, the instrumentation should be manually checked by taking an instantaneous head measurement with a staff gage or rule, calculating a discharge rate, and checking this rate against the recorder.

b. PORTABLE RECORDERS

(1) BELFORT LIQUID LEVEL RECORDER

The section has three Belfort Portable Liquid Level Recorders* which have been in use for four or five yr. These recorders are relatively rugged and extremely reliable when properly installed. The units have many positive features which include the following:

(a) Fairly inexpensive at approximately $320 each.

(b) Accurate and easily read head measurements over a limitless range of water levels because the pin traverses up and down over the full width of the chart as water levels rise or fall.

(c) Optional recording times available from six hours to eight days per chart revolution.

(d) Mechanism is mechanically simple and in most cases can be repaired in the field.

The primary disadvantage of the Belfort Recorder is related to installation. The unit requires a stilling well for a float and must be mounted level. One can easily spend an entire day in construction and installation of stilling well and mounting platform and calibration of recorder. The min diam of the stilling well (dependent upon float) is about 10 cm (4 in.). This well offers an

* No 5-FW-1, Belfort Instrument Company, 1600 South Clinton Street, Baltimore, Maryland 21224

obstruction to flow and, consequently, the unit cannot be used for small channels or in high velocity channels carrying large amounts of debris. The instrument is almost impossible to install in manholes.

(2) MANNING DIPPER RECORDER

The Manning Dipper Recorder* senses and records water levels by means of a weighted electrical probe on the end of a thin metal cable which extends from the bottom of the recorder. The probe follows the surface of the water and merely swings aside when hit by debris.

The primary advantages of this instrument are an adaptability to an almost limitless variety of site configurations and its ease of installation. At most locations the unit can be installed and calibrated in fifteen to twenty min. The adjustable bracket included with the unit makes it particularly suited for manhole installations where it can be installed up to 7.6 m** (25 ft) above the water surface. Since the unit operates on a 6-v battery***, manhole installation provides good equipment security as all components are below street grade and manhole covers are replaced.

The disadvantages of this unit include: (a) cost, units are about $835 each, (b) limited recorder range with respect to changes in water level, (c) accuracy, recorder chart cannot be read

---

* Model P70015, Manning Environmental Corporation, 112 Dakota Street, Santa Cruz, California 95060

** Longer cables are available

*** Eveready Hot Shot #1461, Ray-O-Vac #641, or equivalent closer than 1.27 cm (0.5 in.), and (d) units are fairly sophisticated electronically and generally cannot be repaired in the field.

c. DISCHARGE CALCULATIONS

It should be pointed out that many portable recorders, including the Belfort and Manning units discussed previously, record water level only and do not have an internal integrating mechanism for totalizing flows. With Parshall flumes and most weirs flow rate is a nonlinear function of head and must either be determined from published tabulations (4) or calculated with the different exponential formulas reported for various flumes and weirs. Since many tabulations do not cover every variety of flow measurement device, it is frequently necessary to make these calculations in the field when flow proportioning samples. Although any good slide rule is suitable for these calculations, they are slow, introduce a greater probability of error, and are definitely not "technician proof." To reduce time and increase accuracy, it is recommended that the individual have a portable electronic calculator* with an exponential function key as part of his field equipment.

B. WET WELL VOLUME DISPLACEMENT

Wastewaters are often collected in a wet well prior to introduction to a treatment system. In the absence of flow measurement devices, these wells can be used to obtain rate measurements by

* Hewlett Packard Model HP-35 or 45, Texas Instruments Model SR-50, Sharp PC-1801, or equivalent

using the cross-sectional area of the well and the frequency of "pump down" which can be established with the Belfort or Manning units.

C. FLOW RATES IN PIPES

1. VOLUMETRIC MEASUREMENT

On small discharges, the section frequently uses a container of known capacity and a stopwatch to determine instantaneous flow rates. With the plastic sampling buckets normally used by the section, discharge rates are limited to a maximum of about 76 l/min (20 gpm).

2. PIPE WEIRS

The section has three sets of V-notch weirs*, designed for pipe installation, which were purchased at a cost of approximately $350 each. The weir is of a clear plastic material calibrated in gpd and is mounted in a semicircular aluminum frame which has a rubber gasket around the outside to insure a good pipe fit. Proper installation of the weir is aided by a bubble level attached to the frame. The weirs are held in place by extended rods which are slipped into a screw thread and socket and forced up against the crown of the pipe.

Maximum weir flow rates with 15.2-, 20.3-, 25.4-, 30.5-, and 38.1-cm (6-, 8-, 10-, 12-, and 15-in.) diam pipes are 143; 244; 586; 1,071; and 2,951 cu m/day (10,000; 17,000; 40,900; 74,750; and

---

* N. B. Products, 35 Beulah Road, New Britain, Pa.

206,000 gpd), respectively. The set also has six adaptor plates which the weirs can be set into in order to fit them to larger size pipes. These adaptor plates do not increase the weir capacities.

Although these weirs provide a quick method for getting instantaneous flow rates, the likelihood of error is appreciable since variations in approach velocities cannot be corrected for. In addition, max weir capacities are much lower than max pipe capacities since the weir and frame obstruct a significant part of the cross-sectional area of the pipe.

3. TRAJECTORY METHODS

a. CALIFORNIA PIPE METHOD

The "Water Measurement Manual" states four essential requirements for this method: (1) discharge pipe must be level, (2) it must discharge partially full, (3) it must discharge freely into air, and (4) the velocity of approach must be a min. Discharge rates are computed from the formula:

$$Q = 8.69 \left(1 - \frac{a}{d}\right)^{1.88} d^{2.48}$$

where: Q = discharge rate, cfs

a = distance measured in the plane at the end of the pipe, from the top of the inside surface of the pipe to the water surface, ft

d = internal diam of the pipe, ft

This formula was developed from experimental data for pipes 7.62 to 25.4 cm (3 to 10 in.) in diam and tests have shown that the formula does not hold up at an a/d ratio of less than 0.5 (4, p. 197). This formula should not be used with corrugated metal pipes.

b. PURDUE METHOD

This is a more general form of the trajectory method which can be used with pipes flowing full and with high velocities. Basically the method consists of measuring the horizontal (X) and vertical (Y) coordinates of the path of a jet of water issuing from a level pipe. The reader is referred to the "Water Measurement Manual" (4, p. 200-203) for a description of this method and for graphs showing discharge rates of different size pipes as a function of the X and Y coordinates.

4. ORIFICE BUCKET

As of this writing, the Field Investigations Section has no experience with the orifice bucket and is presently evaluating the device in the laboratory. Basically the unit is nothing more than a sturdy 18.9-l (5-gal) or larger can with a number of rubber stoppered holes in the bottom and with a graduated piezometer tube on the outside for reading water levels. A screen or dispersion device of some sort should be mounted in the bucket to reduce direct velocity impingement on the orifices. Prior to field use the device must be calibrated in the laboratory by removing one of the rubber stoppers and determining the flow rate through the orifice at different constant heads with a known, variable water source. From the laboratory data a rating curve is developed for the bucket showing gpm versus head for one orifice. If hole size tolerances are carefully controlled, it is not necessary to develop a rating curve for two or more orifices open, as flow rate through each orifice will be the same and equal to that rate determined for one orifice. Consequently, in the field larger discharge rates are determined by multiplying the rate for one hole by the number of holes open. Since it is necessary to have a constant head in the bucket, this device is obviously not suitable for those discharges with rapid fluctuations in volume. Additional information can be found in (10, p. 30) and (11).

5. MANNING FORMULA

Discharge rates can also be calculated by determining the cross-sectional area of the flow and the average velocity in the cross section. With circular conduits the section frequently uses the Manning formula to estimate velocity.

$$V = \frac{1.486}{n} r^{2/3} s^{1/2}$$

where: V = average velocity, fps

r = hydraulic radius, a/p

a = area of cross section of stream, sq ft

p = wetted perimeter of pipe, ft

s = slope, ft per 100 ft

n = roughness factor

The roughness factors for various pipe materials can be found in hydraulic reference and text books (12, 13).

Flow rates for pipes 0.152 to 1.22 m (6 to 48 in.) in diam at various depths of flow and slopes are available in tabulated form (6) and are relatively inexpensive.

In the field, section personnel use a carpenters square with an attached, pocket-size, inclinometer* to measure pipe slopes. If one is working at the open end of a pipe, the depth of flow should be measured as far up in the pipe as possible, otherwise errors due to drawdown will be introduced into the discharge calculation. If one is interested in a number of measurements and is not certain about a roughness factor (n), it is frequently possible to gage pipe discharges at a downstream point in an open channel and then solve the Manning Formula for n.

6. FLOWMETER

The section has also used a number of different velocity meters to determine pipe flow rates. One such meter is a digital flow** device with a built-in counter that counts the revolutions of a propeller. Velocities are determined from a rating curve supplied with the instrument. This is a rugged instrument which is not sensitive to low velocities and is, therefore, best suited to those high velocity flows which might damage other types of meters.

At times the section has also used Price type current meters to determine pipe velocities. These meters should be used with

---

* Keuffel and Esser Company, New York

** Digital Flowmeter, Model 2030, General Oceanics, Inc., 5535 Northwest Seventh Avenue, Miami, Florida 33127 caution since they are quite sensitive and subject to damage in high velocity, turbulent flows.

D. OPEN CHANNEL FLOW

1. STREAM GAGING

In its field activities, the section also does a significant amount of stream gaging at locations where receiving water quality is of interest. Basic items of equipment required for stream gaging include: (a) current meter, (b) wading rod, (c) sound box or earphones to indicate meter revolutions, (d) stopwatch, (e) tag line, and (f) small clipboard and discharge measurement forms. Meters, wading rods, earphones, and tag lines are available from a number of suppliers*. It is recommended that one purchase equipment from a single manufacturer, as components are not always interchangeable. The discharge measurement forms** used by the section are printed on a rubberized paper and are supplied by the General Services Administration (Form No. 7-EPA-5300-1).

As of this writing, the section has relied upon the Price type current meter (both standard and pygmy) for stream gaging. In the near future, the section will also have the Ott meter available. The Ott meter is of advantage in some situations where vertical velocity gradients are a problem.

---

* Weather Measure Corporation, P. O. Box 41257, Sacramento, California 95841 - Kahlsico Scientific Corporation, P. O. Box 1166, El Cajon, California 92022 - EPIC, Inc., 150 Nassau Street, New York, New York 10038

** The Field Investigations Section will furnish one copy of this form for examination or duplication

Both of these meters are precision instruments and should be treated accordingly. The Price type meters are especially sensitive to worn pivots and errors in velocity measurement of 20 percent of flow under 0.15 m/sec (0.5 fps) are common with worn pivots, bent cups, and solids under the cup and bushing. When using a current meter with a questionable pivot pin or old rating, it is better to look for a site with velocities of about 0.30 m/sec (1 fps) or better as errors due to inertia of the meter will be minimized. Regular oils should not be used on these meters during winter weather as the increase in viscosity can seriously affect the accuracy of rate measurement. The silicone type lubricants are not affected by changes in temperature.

Although there are a number of types of wading rods available, the section uses the USGS type top-setting rod. These rods are made under contract for the USGS and sources change from year to year. Within the Region, current information on these rods would be available from the USGS Water Resources Division, Rolla, Missouri. It is understood that this division must endorse orders for this rod.

The section has received some requests for information concerning meter calibration. Manufacturers no longer supply current meters which have been calibrated by the National Bureau of Standards and the section relies upon those rating tables furnished with each meter. If desired, the bureau* will calibrate meters. In 1972 the cost for calibration to government and private agencies was $116 per meter.

2. ELECTROMAGNETIC WATER CURRENT METER

The section has one of these units** which has received rather limited use in the past two yr. This is a battery-operated, portable instrument which gives a direct meter readout in fps of X and Y velocity components. The velocity sensing probe is all magnetic, has no moving parts and is an integral part of a 1.3-cm (0.5-in.) diam cable leading from the meter. This cable, with attached probe, can be purchased in desired lengths. The meter has a recorder output terminal.

This unit has been used, primarily, in pipes with high velocity discharges and in small open channels. Although the unit is portable, it is rather heavy and not suited to a one-man operation for gaging streams. Since velocity readout is affected by probe orientation, the probe must either be held by hand or fixed on a rigid rod when taking measurements. The price ($2,500) and complexity of this unit prohibits rough handling or any service in the field.

A trial run of this instrument (see Section E) when it was first received resulted in meter fluctuations of 0.5 fps at a full

---

* (Correspondence Only) National Bureau of Standards, Hydraulics Section, Washington, D.C. 20234 - (Meters should be sent to) National Bureau of Standards, Hydraulics Section, Route 705, Quincy Orchard Road, Gaithersburg, Md. 20760

** Model 721, Marsh-McBirney, Inc., 10453 Metropolitan Avenue, Kensington, Md. 20795 scale setting of 1 fps while being held at a single position in a flowing stream. As a result of this, the meter was returned to the factory and an alternate 5-sec "time constant" was added to dampen out meter fluctuations. With this addition the instrument has a toggle switch to select the standard, 1-sec time constant* or alternate 5-sec constant. This addition has greatly increased the usefulness of the instrument.

E. PRECISION OF THREE MEASUREMENT METHODS

Soon after the section received the Marsh-McBirney current meter (MMCM) a water course was sought in which it could be compared with the Price type pygmy current meter (PPM). As a result of a previous investigation, the weir pool upstream of a 61-cm (24-in.), sharp-crested, contracted, rectangular weir** was selected. With this discharge it was possible to get three independent flow rates simultaneously. These three rates were: (1) the rated weir discharge, (2) the rate resulting from MMCM velocity readings and the weir pool cross-sectional area (plane parallel to weir bulkhead), and (3) the rate resulting from the PPM velocity readings and the pool cross-sectional area.

The cross section selected was about 2.13 m (7 ft) upstream from the weir bulkhead, had formed vertical sides 1.83 m (6 ft) apart, and was relatively uniform in depth. The arithmetic mean

---

* After positioning probe, user must wait three times the time constant before recording a velocity reading

** Midwest Solvents Company discharge in Atchison, Kansas depth (25 measurements) was 30.7 cm (12.1 in.) with max and min depths being 35.6 cm (14.0 in.) and 26.7 cm (10.5 in.), respectively.

Traversing of the cross section began at 1115 hr and ended at 1535 hr June 3, 1972. Using both the MMCM and PPM, which were mounted on essentially identical wading rods, velocity measurements were made at 7.6-cm (0.25-ft) intervals across the section at depths of 6.1, 12.2, 18.3, and 24.4 cm (0.2, 0.4, 0.6 and 0.8 ft).

The weir head during the cross sectioning ranged from 18.9 cm (0.62 ft) to 20.4 cm (0.67 ft) and the mean head (8 readings) was 19.8 cm (0.65 ft).

Table XIX shows the flow data resulting from cross sectioning with each of the two meters. The weir discharge rate and a summation of the incremental flow rates resulting from each meter were as follows:

	l/sec	cfs	
Weir	93.2	3.29	
Price Pygmy Meter (PPM)	117.2	4.14	
Electromagnetic Current Meter (MMCM)	98.8	3.49	
Mean	103.1	3.64	±(10 to 14 percent)

These data would indicate that under ideal circumstances the section cannot determine flow rates any closer than ±10 percent. It should be pointed out that in routine surveys the section would never take 96 velocity readings in a 1.83-m (6-ft) cross section

TABLE XIX

SUMMARY OF FLOW DATA OBTAINED USING A PRICE TYPE PYGMY METER (PPM) AND A MARSH MCBIRNEY CURRENT METER (MMCM)

Distance From Initial Point, ft[(a)]	0.00		0.25		0.50		0.75		1.00		1.25	
Depth, ft[(a)]	1.08		1.08		1.12		1.08		1.17		1.08	
Area, ft^2[(b)]	0.27		0.27		0.28		0.27		0.29		0.27	
Depth From Water Surface Of Velocity Measurement, ft[(a)]	Velocity, fps											
	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM
0.2	0.00	0.0	0.08	0.0	0.06	0.0	0.23	0.20	0.17	0.15	0.45	0.20
0.4	0.00	0.0	0.04	0.0	0.06	0.0	0.09	0.00	0.12	0.05	0.20	0.30
0.6	0.00	0.0	0.07	0.0	0.02	0.0	0.03	0.00	0.07	0.00	0.06	0.00
0.8	0.00	0.0	0.05	0.0	0.04	0.0	0.02	0.00	0.03	0.05	0.24	0.00
Mean	0.00	0.0	0.06	0.0	0.05	0.0	0.09	0.05	0.10	0.04	0.24	0.13
Discharge, cfs[(c)]	0.00	0.0	0.016	0.0	0.014	0.0	0.024	0.014	0.029	0.014	0.065	0.027
Velocity Ratio PPM/MMCM	-		-		-		2.0		2.0		2.5	

Distance From Initial Point, ft[(a)]	1.50		1.75		2.00		2.25		2.50		2.75	
Depth, ft[(a)]	1.08		1.08		1.00		1.00		1.00		1.00	
Area, ft^2[(b)]	0.27		0.27		0.25		0.25		0.25		0.25	
Depth From Water Surface Of Velocity Measurement, ft[(a)]	Velocity, fps											
	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM
0.2	0.56	0.20	0.74	0.60	0.96	0.70	1.21	0.75	1.37	1.00	1.42	1.00
0.4	0.43	0.40	0.86	0.60	1.11	0.70	1.25	0.85	1.24	1.05	1.28	1.10
0.6	0.22	0.40	0.42	0.50	0.80	0.60	1.05	0.85	1.09	0.80	1.11	0.90
0.8	0.09	0.40	0.16	0.15	0.38	0.20	0.57	0.65	0.80	0.65	0.75	0.80
Mean	0.32	0.35	0.54	0.45	0.81	0.55	1.02	0.80	1.12	0.90	1.14	0.95
Discharge, cfs[(c)]	0.086	0.094	0.146	0.122	0.202	0.137	0.255	0.200	0.280	0.225	0.285	0.237
Velocity Ratio PPM/MMCM	0.90		1.20		1.50		1.30		1.25		1.20	

(a) Multiply by 0.3048 to obtain m

(b) Multiply by 0.0929 to obtain sq m

(c) Multiply by 1.7 to obtain cu m/min

TABLE XIX (CONTINUED)

SUMMARY OF FLOW DATA OBTAINED USING A PRICE TYPE PYGMY METER (PPM) AND A MARSH MCBIRNEY CURRENT METER (MMCM)

Distance From Initial Point, ft(a)	3.00		3.25		3.50		3.75		4.00		4.25	
Depth, ft(a)	1.00		0.96		0.96		0.96		0.96		0.92	
Area, ft^2(b)	0.25		0.24		0.24		0.24		0.24		0.23	
Depth From Water Surface Of Velocity Measurement, ft(a)	Velocity, fps											
	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM
0.2	1.39	1.15	1.33	1.15	1.30	1.20	1.38	1.15	1.35	1.20	1.38	1.25
0.4	1.24	1.05	1.20	1.05	1.14	1.05	1.25	1.05	1.22	1.05	1.22	1.15
0.6	1.08	0.90	1.00	0.80	0.86	0.90	1.06	0.80	0.96	0.90	1.00	1.00
0.8	0.77	0.65	0.67	0.65	0.28	0.50	0.60	0.50	0.38	0.15	0.20	0.30
Mean	1.12	0.95	1.05	0.90	0.90	0.90	1.07	0.85	0.98	0.80	0.95	0.90
Discharge, cfs(c)	0.280	0.238	0.252	0.216	0.216	0.216	0.257	0.204	0.235	0.192	0.218	0.207
Velocity Ratio PPM/MMCM	1.20		1.15		1.00		1.25		1.20		1.05	

Distance From Initial Point, ft(a)	4.50		4.75		5.00		5.25		5.50		5.75	
Depth, ft(a)	0.92		0.92		0.92		0.92		0.88		0.88	
Area, ft^2(b)	0.23		0.23		0.23		0.23		0.22		0.22	
Depth From Water Surface Of Velocity Measurement, ft(a)	Velocity, fps											
	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM	PPM	MMCM
0.2	1.38	1.25	1.37	1.35	1.38	1.30	1.12	1.00	0.66	0.70	0.57	0.60
0.4	1.21	1.10	1.29	1.15	1.30	1.20	1.04	0.80	0.76	0.65	0.74	0.60
0.6	1.01	0.95	1.07	0.95	1.23	1.00	1.29	0.90	0.80	0.75	0.65	0.45
0.8	0.62	0.80	0.65	0.50	0.84	0.80	0.81	0.55	0.46	0.50	0.26	0.25
Mean	1.05	1.00	1.09	1.00	1.17	1.10	1.07	0.80	0.67	0.65	0.56	0.50
Discharge, cfs(c)	0.242	0.230	0.251	0.230	0.274	0.253	0.246	0.184	0.147	0.143	0.123	0.110
Velocity Ratio PPM/MMCM	1.05		1.10		1.10		1.35		1.05		1.10	

(a) Multiply by 0.3048 to obtain m

(b) Multiply by 0.0929 to obtain sq m

(c) Multiply by 1.7 to obtain cu m/min

that was only 30.7 cm (12.1 in.) deep. In routine work a max of twelve measurements would have been taken. General flow measurement precision in routine surveys is probably on the order of ±20 or 25 percent.

VI. CONCLUSIONS

As a result of experience, sampler comparison studies, and accumulated survey information, the Field Investigations Section has reached the following conclusions:

1. Overall failure rate of commercially available samplers is approximately 16 percent.

2. Major cause of sampler malfunction is due to plugging of intake lines.

3. Operational reliability of commercially available samplers varies significantly and application is a major factor in selecting appropriate equipment.

4. Variations in nonfilterable solids concentrations of raw waste samples as a result of differences in sampling equipment or collection method are at least 9 to 24 percent.

5. Currently available sampling equipment cannot be relied upon to produce representative samples.

6. High vacuum samplers produce more representative samples and should be used on raw municipal wastewaters and other wastes with significant levels of large heavy suspended material.

7. Any sampler compatible with site conditions and data requirements can be used to sample well-treated effluents with no visible solids.

8. Flow-proportional sampling of raw municipal wastewaters with currently available sampling equipment is neither necessary nor justified.

9. Adequate discrete grab sampling programs for routine surveys and monitoring of municipal wastewaters require an inordinate amount of laboratory resources and should be replaced with automatic compositing equipment.

10. Current sampling equipment and methodologies need to be refined to improve data reproducibility and accuracy.

11. Apparent wastewater chemistry characteristics and facility removal efficiencies can easily be manipulated by choice of sampling equipment and methodology.

12. There is need for development of a synthetic suspended solids waste to evaluate sampler performance under controlled laboratory conditions.

13. Under ideal conditions the precision of flow measurement by section personnel is ±10 percent.

APPENDIX

NAMES AND ADDRESSES OF MANUFACTURERS AND SUPPLIERS OF SAMPLERS LISTED IN TABLE I

Sigmamotor Model WA-2 and WD-2

Sigmamotor, Inc.
14 Elizabeth Street
Middleport, New York 14105

Brailsford Model EV-1, DU-1, and EP-1

Brailsford and Company
Milton Road
Rye, New York 10580

Hants Mark 3B

Testing Machines
400 Bayview Avenue
Amityville, New York 11701

ISCO Model 1391 and 1392

Instrumentation Specialties Company
P. O. Box 5347
Lincoln, Nebraska 68505

Sirco MKV7S

Sirco Controls Company
401 Second Avenue West
Seattle, Washington 98119

Pro-Tech C6-125P

Pro-Tech, Inc.
Roberts Lane
Malvern, Pennsylvania 19355

QCEC Model CVE

Quality Control Equipment Company
2505 McKinley Avenue
Des Moines, Iowa 50315

N-Con Scout, Surveyor, and Sentinel

N-Con Systems Company, Inc.
Clean Waters Building
New Rochelle, New York 10801

BIBLIOGRAPHY

1. Shelley, P. E., and Kirkpatrick, G. A., "An Assessment of Automatic Sewer Flow Samplers," Prepared for Office of Research and Monitoring, U.S. Environmental Protection Agency, EPA-R2-73-261, Washington, D. C. (1973).

2. "Standard Methods for the Examination of Water and Wastewater," 13th Ed., Amer. Pub. Health Assn., New York, N. Y. (1965).

3. Youden, W. J., "Statistical Techniques for Collaborative Tests," Assn. of Offic. Anal. Chemists, Washington, D. C. (1973).

4. "Water Measurement Manual," 2nd Ed., U.S. Dept. of Interior, Bureau of Reclamation (1971) - Available from Super. of Documents, U.S. Gov. Printing Office, Washington, D. C. 20402 - Order No. I 27.19/2: W29/2.

5. "Hydrographic Data Book," 8th Ed., Leupold Stevens, Inc., P. O. Box 25347, Portland, Oregon 97225.

6. "Flow Tables for Circular Pipes," Manning Environmental Corp., 112 Dakota Ave., Santa Cruz, Calif. 95060.

7. "Stream-Gaging Procedures," Water Supply Paper 888, U.S. Dept. of Interior, Geological Survey (1962) - out of print.

8. Bauer, S. W., and Graf, W. H., "Free Overfall as Flow Measuring Device," Jour. Irrigation Drain. Div. Proc. Amer. Soc. Civil Engr., 97, IR1., 7987 (1971).

9. "Peerless Pump Cat. B-127," Peerless Pump Div., Food Machinery and Chem. Corp., 301 West Ave. 26, Los Angeles 31, Calif.

10. Smoot, C. W., "Orifice Bucket for Measurement of Small Discharges from Wells," Water Resources Div. Bull., Illinois Water Survey, Champaign, Illinois, Nov. (1963).

11. "Memos from Smitty," Water Well Journal, May-June (1955).

12. King, W. K., and Brater, E. F., "Handbook of Hydraulics," 5th Ed., McGraw-Hill, New York (1963).

13. Davis, C. V., and Sorensen, K. E., "Handbook of Applied Hydraulics," 3rd Ed., McGraw-Hill, New York (1969).

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 907/9-74-005	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Wastewater Sampling Methodologies and Flow Measurement Techniques		5. REPORT DATE June 1974 - Issue 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Daniel J. Harris and William J. Keffer		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency, Region VII 1735 Baltimore - Room 249 Kansas City, Missouri 64108		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED Technical Studies 10/72-11/73 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

The Superintendent of Documents classification number is: EP 1.2:W28/10

16. ABSTRACT

The structure and activities of the Environmental Protection Agency, Region VII, Field Investigations Section are summarized and some 90,000 hours of collective field operational experience with thirteen makes of commercially available automatic wastewater samplers is presented. The results of five separate sampler performance studies are reported which indicated significant differences in the wastewater chemistry of samples collected concurrently by different automatic compositors and manual sampling methods. High vacuum samplers were found to collect concentrations of nonfilterable solids which were in some instances two and three times as great as levels found in samples collected by slower acting samplers and by manual methods. Minimum variations in solids data directly traceable to differences in samplers and collection methods were on the order of 9 to 24 percent. Hydraulic measurement methods related to wastewater sampling activities are discussed. The precision of three independent flow measurements were found to be approximately ±10 percent.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
wastewater sampling, sampling equipment, field sampling techniques, sampler performance, wastewater characterization, treatment plant performance		

18. DISTRIBUTION STATEMENT Initial Printing - 500 Copies / Available upon application to Region VII Public Affairs or through NTIS on microfiche	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES 130
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA Form 2220-1 (9-73)

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
Leave blank.

7. **AUTHOR(S)**
Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
Leave blank.

15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
(a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

    (b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

    (c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.