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Environmental Monitoring Series

RECOMMENDED DESIGN OF SAMPLE INTAKE SYSTEMS FOR AUTOMATIC INSTRUMENTATION

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Environmental Monitoring and Support Laboratory
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RECOMMENDED DESIGN OF SAMPLE INTAKE SYSTEMS FOR AUTOMATIC INSTRUMENTATION

by

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Program Element No. 1HA327

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The Instrumentation Development Branch, EMSL, has provided functional designs relating to water quality instrumentation systems. This report, which discusses a variety of water sample intake designs, provides considerations for field personnel in acquiring samples for quiescent monitoring.

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ABSTRACT

Pumping systems for automatic water quality monitors are discussed, and recommendations on sample change, residence time, site selection, pipe size, pump selection, system cleaning, and overall design are given. Experimental data showing sample degradation because of biological metabolism, cavitation, and aeration are presented. A recommended system to overcome past problems is presented and alternative approaches for system installation are also shown.

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SECTION I

CONCLUSIONS

Considerable engineering time and money are spent on the design of water quality monitoring instrumentation, including functional components such as computers and telemetering. All of this is in vain if the water sample delivered to the instrument is not representative. Therefore, adequate engineering effort, time, and funds are required to design an accurate intake system.

Normally, the basic objective for ambient monitoring is to observe a representative stream cross section. To fulfill this objective, pumping systems should be designed to deliver a sample that is representative of most of the water in the stream. This is accomplished when the sample is drawn from the river channel.

Because sample degradation resulting from the biological metabolism of sludge and slime microbes within the pipeline should be insignificant, high sample velocity through a pipeline of consistent cross section is required. The system should be designed so that raw water flows directly from the river through a pump and to the instrumentation shelter.

Mechanical sample change because of cavitation, reaeration, and damping can be avoided by using a positive pressure system with low residence time.

Automatic cleaning may not be required on a system that is designed for minimal biological sample degradation. Obviously there is a sample velocity for a specific line length and exposed internal surface above which biological degradation would be insignificant. This velocity may be so high when sampling polluted water that cleaning with a bactericide during warm weather would always be required. Cursory results show that for lines of specific length and exposed surface, an optimum velocity is attainable that would eliminate the need for automatic cleaning. More research is needed in this area, but initial design should be aimed toward this optimum system without automatic line cleaning. Periodic manual cleaning of the intake strainer is required, and system design should include easy access to this component.

System maintenance must be considered in the design. Access to all components from the river bank during the most adverse stream conditions is necessary.

SECTION II

RECOMMENDATIONS

Automatic instrumentation can be installed at existing facilities such as water, power, and industrial plants along the stream if these locations provide meaningful data. A thorough study should be made, however, to prove that the sample, as received by the instrument, is representative and nondegraded before locating at these facilities. Pumping systems may also be located at bridges and docks along the stream, but again, a thorough investigation is required to insure that meaningful and nondegraded data will be obtained.

When no existing facilities are available, the type-1 system described in this report is recommended. With this system, water travels directly from the river through a pump and to the monitor. The intake should be located up from the river bottom sludge and should draw water from the stream channel. Water velocity within all parts of this system should be greater than 4.7 feet per second for minimal sample degradation. Positive pressure throughout all parts of this system is recommended. This system is designed so that every component can be maintained from the river bank during all stream conditions. The intake system should be designed so that sample degradation is minimal or insignificant, thereby eliminating the need for an automatic intake cleaning system. High sample velocity along with nonporous pipeline materials (such as Celanese ultrahigh molecular density type) will minimize sample degradation.

Type-2 and type-3 systems are described in this report as alternatives if the type-1 system is not feasible at a specific location. The type-2 system operates under negative pressure and therefore requires the use of a screw-type pump to prevent dissolved oxygen (DO) loss because of cavitation. Aeration will take place at loose connections. Therefore, this system will require frequent data verification to prove that DO readings are accurate. The type-3 system is a well, and cleaning with a bactericide is recommended twice a week during warm weather to keep sample degradation minimal. Removal of sediment is also required. A larger-than-normal pump is recommended for the well to minimize the effect of damping.

SECTION III

INTRODUCTION

Small, reliable pumping systems are needed to bring sample water to automatic instrumentation. In most cases, it is not practical to place sensors in the stream because thay are inherently delicate and should not be exposed to rough water conditions where sand, debris, turbidity, high velocity, biological growth, and other factors can introduce spurious signals.

In the past, everything imaginable has happened to intake systems for instrumentation. At existing facilities, monitors have sampled from dead water mains, lagoons, recirculating pools for power plants, and other undesirable places. Samples have been drawn from long pipelines of low velocity, from clogged wells, cavitating pumps, reaerating systems, lines where chemicals were being added, and other meaningless locations. Pumping system components have failed, and intakes have been washed out and covered with sandbars or debris. There have been times when service was impossible because of high water.

This study determines, in theory, the biochemical and mechanical reasons for sample change. A method for obtaining representative samples at remote locations is given. During the investigation, tests were made on different types of pumping systems, and data were obtained to confirm the theory for sample change. Recommendations are given to overcome past difficulties, and a design is presented that gives a representative sample, minimizes degradation, and is serviceable under all river conditions.

SECTION IV

PROBLEMS THAT HAVE OCCURRED WITHIN PUMPING SYSTEMS

BIOCHEMICAL SAMPLE DEGRADATION

Loss in DO has frequently been detected across intake systems pumping polluted water during warm weather periods. When oxygen loss is due to microbial metabolism, other less conspicuous parameters will also change; but since oxygen change is the most noticeable and easily detectable it is the most frequently discussed. Oxygen depletion is due to one or more of the following: biochemical oxygen demand (BOD) of the water sample during travel, BOD of the sludge deposits within the pipeline, and BOD of the slime growth on the inner pipe walls.

BOD of Water Sample - The BOD of a slug of water as it travels from the river to the sample probe is conventionally formulated as:

$$BOD = L_a \left(1 - 10^{-kt}\right) \qquad (1)$$

where BOD = O_2 consumed during travel

L_a = ultimate BOD of the water sample

t = travel time, days

k = reaction velocity constant

Oxygen deficit resulting from the BOD of the sample should be insignificant, because k is low for river water, and t should only be a few minutes or less for a properly designed system.

BOD of Sludge Deposits - These sludge deposits may form at an enlarged section of pipe where the velocity of the water is low; also, if the intake pipe is resting on the river bottom, the sample may pass over a pile of sludge just before entering the intake. Velz[1] discusses the effect of sludge deposits in streams and presents theoretical information that shows that DO can be depleted significantly because of the BOD of accumulated sludge. His reasoning is here applied to pumping systems. The BOD of sludge deposits in streams can be defined by equation 2.

$$L_d = \frac{P_d}{2.3k'}\left(1 - 10^{-k't}\right) \qquad (2)$$

where L_d = cumulative BOD of the deposit, pounds

P_d = BOD added to the deposit, pounds per day

k' = specific rate of oxidation of the deposit (usually 0.03 per day)

t = time of accumulation, days

Velz tabulated Table 1 from equation 2.

Table 1. SLUDGE ACCUMULATION AND DEMAND*

Time in days	Accumulation as a percentage of the BOD of the daily deposit	Daily demand from the accumulation as a percentage of the BOD of the daily deposit
2	187	12.9
3	271	18.7
4	350	24.1
5	423	29.2
10	724	49.9
20	1,086	74.9
30	1,267	87.4
40	1,359	93.7
50	1,404	96.8
60	1,427	98.4
70	1,438	99.2
80	1,444	99.6
90	1,447	99.8
Ultimate	1,450	100.0

*Source: C. J. Velz[1].

Table 1 shows that after sludge has accumulated for a long enough period of time, the rate of biological oxygen demand from the sludge pile is equal to the BOD of the daily deposit (equilibrum). Therefore, oxygen within the sample could eventually be depleted by an amount equal to the BOD of the suspended solids within the water sample. The table shows that after only 10 days, DO is being depleted at a rate of 49.9 percent of the BOD of the suspended material that is settling. This reasoning is theoretical and assumes constant and aerobically decomposable suspended solids conditions. It is idealistic to think that sludge will form in a pumping system exactly according to the equation. The equation does, however, clearly point out the fact that sludge deposits in sampling systems could significantly lower the DO reading.

BOD of Slime Growth on Pipe Walls - Organic materials (substrate) in the water sample are consumed by the thin coating of slime bacteria on the inner surface of the pipeline. If this substrate upon which they feed is sufficient, then the number of these bacteria is proportional to the surface area upon which they live; therefore, DO depletion within the sample would increase with sample residence time as long as the required substrate were present. Hence a long pipeline exposed to an enriched sample with sufficient residence time could deplete dissolved oxygen significantly.

Data showing oxygen losses occurring because of sludge deposits and slime growth mentioned earlier are included in Table 2. Station 1 was located at the intake in the river and Station 3 was located just ahead of the monitor. The two stations were connected by 450 feet of 1-1/4-inch diameter plastic pipe. The table shows significant DO loss before cleaning, but DO loss after cleaning was insignificant. Cleaning consisted of removing a sludge deposit from within the inlet strainer and flushing the system with a solution of chlorine to kill slime bacteria.

MECHANICAL SAMPLE DEGRADATION

Mechanical sample degradation includes DO change because of cavitation, reaeration, and damping.

Cavitation

Cavitation can occur when the pressure within the pumping system drops below the vapor pressure of the dissolved or condensed gases within the sample. Table 3 shows DO loss across a centrifugal pump operating at suction lifts of 20 feet and 2 feet of water, respectively. Station 1 was the river intake, station 2 was the high pressure side of the pump, and station 3 was located just ahead of the monitor. There were 350 feet of 3/4-inch plastic pipe between stations 2 and 3. The table shows insignificant DO losses at

Table 2. DISSOLVED OXYGEN CHANGE RESULTING FROM SLUDGE DEPOSITS AND SLIME GROWTH

Date and time	Suction lift (ft)	DO (ppm) at station no. 1	DO (ppm) at station no. 3	Error (ppm) station (1) minus (3)	Temperature (°F) station 3	Flow (gpm)
			Before cleaning			
8/25/69						
11:45	13.4	10.9	10.1	0.8	76.0	---
12:30	13.4	11.0	10.1	0.9	76.5	---
12:55	13.4	11.6	10.2	1.4	77.5	---
1:30	13.4	11.3	8.3	3.0	78.0	---
3:07	0.0	11.3	9.6	1.7	79.5	---
3:25	0.0	11.3	9.7	1.6	80.0	---
8/26/69						
8:17	0.0	8.3	7.5	0.8	74.5	---
8:53	0.0	8.9	8.1	0.8	75.0	---
9:38	0.0	9.8	9.4	0.4	75.5	---
10:06	0.0	10.7	9.6	1.1	75.5	---
10:36	0.0	11.5	10.0	1.5	76.0	---
11:02	0.0	11.9	10.3	1.6	76.5	---
12:07	0.0	12.7	10.7	2.0	77.5	---
12:33	0.0	12.9	10.7	2.2	78.0	---
12:59	0.0	12.7	10.3	2.4	78.5	12.3
1:25	0.0	12.6	10.0	2.6	79.0	---
3:03	13.4	13.3	9.1	4.2	80.5	10.1
3:40	13.4	14.25	8.85	5.4	81.0	---
4:17	13.4	14.85	8.9	5.95	---	---
8/27/69						
8:13	13.4	8.45	7.0	1.45	74.5	---
8:55	13.4	9.0	7.65	1.35	---	---
9:48	13.4	10.4	8.8	1.6	75.0	8.5
11:00	13.4	12.5	11.0	1.5	76.5	8.8
9/24/69						
11:54	13.8	5.2	4.6	0.6	67.5	---
			After cleaning and backflushing with chlorine			
12:00*	---	---	---	---	---	---
3:00*	---	---	---	---	---	---
3:05	13.6	7.0	7.0	0.0	68.5	---
3:15	13.6	7.3	7.25	0.05	68.0	---
3:30	13.6	7.35	7.30	0.05	---	---
3:55	13.6	7.4	7.4	0.0	---	---
9/25/69						
8:15	12.1	6.65	6.6	0.05	65.5	11.9
8:30	12.1	6.8	6.7	0.10	---	---
8:45	12.1	6.9	6.8	0.10	---	---
9:00	12.1	7.0	6.85	0.15	65.5	---

*System flushed with chlorine solution.

suction lifts of 2 feet. DO losses were significant at suction lifts of 20 feet; hence, cavitation was experienced at the eye of the impeller, and oxygen came out of solution, passed through the impeller, and was severely agitated at the periphery. Table 3 shows that DO loss was most critical at station 2, with some oxygen being redissolved during travel between station 2 and 3. Oxygen bubbling out of solution (similar to CO_2 loss from a carbonated beverage) was visible when drawing the DO sample at stations 2 and 3.

Table 3. DISSOLVED OXYGEN DEPLETION RESULTING FROM CAVITATION

Date and time	Suction lift (ft)	DO (ppm) Station 1*	Station 2†	Station 3‡	Temp. (F)	Saturation level of DO (ppm)
1968						
10/22						
4:45	20	9.40	8.25	8.71	61.5	10.0
10/23						
7:35	20	8.60	7.95	8.39	54.0	10.8
8:20	20	8.70	7.50	8.30	55.5	10.6
10/25						
4:25	20	9.70	8.50	9.32	52.5	11.1
10/28						
8:55	20	10.00	8.80	9.64	49.0	11.3
11:20	2	10.60	10.50	10.50	49.5	11.3
2:20	2	10.80	10.75	10.75	49.5	11.3

*River intake.
†High pressure side of the pump.
‡Located just ahead of the monitor.

Similar testing with a positive displacement screw-type pump showed insignificant DO losses in most samples when the system was operated carefully and conscientiously. Data on this type of system are presented later in the report.

Reaeration

An example of reaeration is given in Table 4. These data were collected during the evaluation of a well-type pumping system. Figure 1 depicts the well-type system and shows the station

Table 4. REAERATION: COMPLETE TABULATION OF DISSOLVED OXYGEN DATA BEFORE CLEANING

Date	Time		DO (mg/l)				DO difference (mg/l) across			
	Start	Stop	Station 1	Station 2	Station 3	Station 4	Inlet Pipe (2 minus 1)	Well (3 minus 2)	Pressure Pipe (4 minus 3)	Overall (4 minus 1)
8/4/70*	8:30	8:36	---	2.75	7.45	7.45	---	4.70	0.00	---
	9:00	9:06	7.60	2.60	7.40	7.35	-5.00	4.80	-0.05	-0.25
	10:00	10:06	9.25	3.20	7.35	7.70	-6.05	4.15	0.35	-1.55
	10:30	10:36	10.05	3.65	7.25	7.30	-6.40	3.60	0.05	-2.75
	11:00	11:06	10.85	3.70	7.60	8.05	-7.15	3.90	0.45	-2.80
	11:30	11:36	12.00	3.85	8.15	8.55	-8.15	4.30	0.40	-3.45
8/5/70*	8:30	8:36	7.35	3.60	7.90	7.75	-3.75	4.30	-0.15	0.40
	9:00	9:06	7.50	2.90	9.30	8.75	-4.60	6.40	-0.55	1.25
	9:30	9:36	7.70	2.65	9.75	9.10	-5.05	7.10	-0.65	1.40
	10:00	10:06	8.05	2.85	10.65	9.10	-5.20	7.80	-1.55	1.05
	10:30	10:36	8.50	3.15	7.10	7.10	-5.35	3.95	0.00	-1.40
	11:00	11:06	9.10	3.05	9.50	8.85	-6.05	6.45	-0.65	-0.25
	11:30	11:36	9.40	3.25	10.35	8.95	-6.15	7.10	-1.40	-0.45
	1:00	1:06	9.80	3.80	9.10	9.80	-6.00	5.30	0.70	0.00
8/6/70*	11:30	11:36	10.30	3.50	5.90	5.15	-6.80	2.40	-0.75	-5.15
	1:00	1:06	11.75	4.85	6.60	6.20	-6.90	1.75	-0.40	-5.55
	1:30	1:36	12.05	4.75	7.70	6.25	-7.30	2.95	-1.45	-5.80
	2:00	2:06	12.80	4.85	6.80	6.55	-7.95	1.95	-0.25	-6.25
	2:30	2:36	13.25	5.05	7.00	6.70	-8.20	1.95	-0.30	-6.55
	3:00	3:06	13.95	4.90	7.85	7.80	-9.05	2.95	-0.05	-6.15
	3:30	3:36	14.45	5.25	8.20	8.30	-9.20	2.95	0.10	-6.15
	4:00	4:06	14.95	5.30	8.75	8.30	-9.65	3.45	-0.45	-6.65
Average	---	---	10.51	---	---	---	-6.66	4.28	-0.30	-2.71
8/10/70†	---	---	6.10	0.50	10.90	---	-5.60	10.40	---	---

*Pump spraying water and sucking air.
†Pump sucking air.

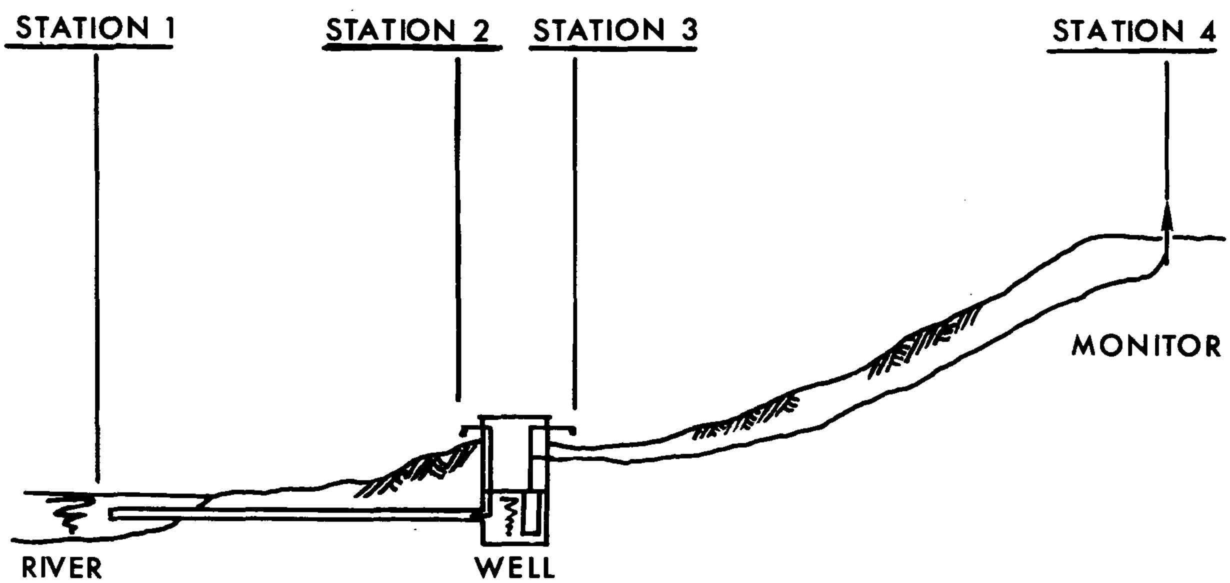

Figure 1. Well-type system.

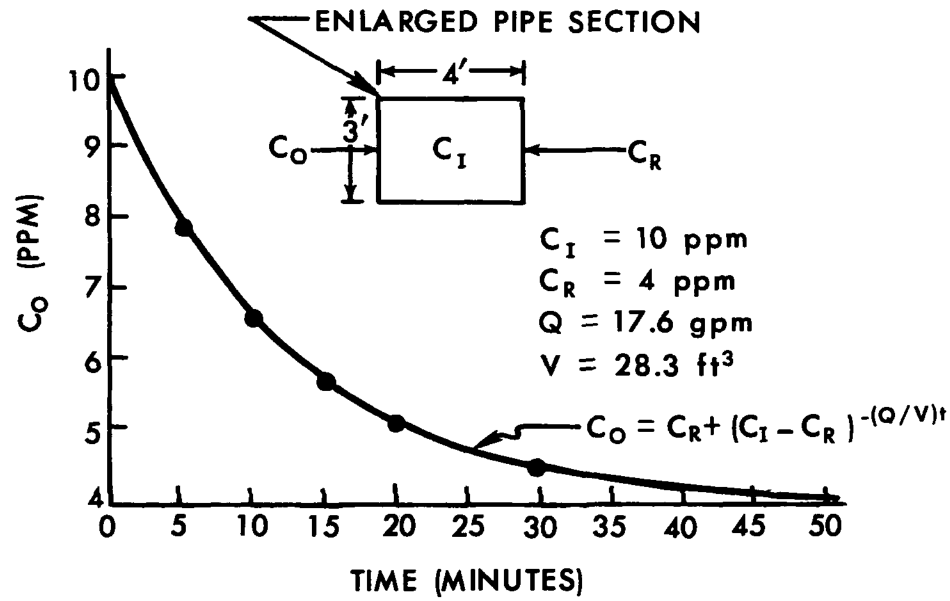

Figure 2. Example of damping (complete mixing assumed).

locations. The DO readings at station 3 were higher than those at station 2, indicating reaeration. A visible inspection revealed that the inlet pipe was clogged, the flow was very low, and the well was drawing down below the pump inlet; hence the pump was sucking water and air. The tremendous oxygen loss between station 1 and 2 is an excellent example of all three types of biochemical sample degradation taking place.

Damping

Travel time of the sample from the river to the monitor should be minimal. The velocity of the sample water should be as rapid as possible without causing an excessive pressure drop in the pipe lines. Low velocity of flow and enlarged pipeline sections should be avoided. An example of damping that could take place in a system with an enlarged section is given below:

Assume an enlarged cylindrical section with the dimensions given in Figure 2. The initial DO concentration in the enlarged section is 10 ppm (C_I = 10 ppm). A slug of highly polluted water (C_R = 4 ppm) comes down the river. How long will it take for the outflow from the enlarged section (C_o) to indicate the river condition? If complete mixing can be assumed, then the following fundamental charge/discharge equation can be used:

$$C_o = C_R + [C_I - C_R]\, e^{-(Q/V)^t} \qquad (3)$$

A plot of this equation for the condition stated is given in Figure 2. As shown, it will theoretically take 20 minutes for the monitor to read 5 ppm. It takes 40 minutes for the monitor to read 4.2 ppm, or within 5 percent of the true condition. By this time, the serious pollution may have passed. Modern instrumentation is built for fast response, and components of the pumping system should not significantly impair the overall response time.

MAINTENANCE

Maintenance problems have included pump failure, clogged intake, equipment covered with sandbar, washed-out equipment, damage from floating debris, high water, etc. Most of these problems are related to poor design and/or inadequate funds. Most of the engineering time and money for an automatic monitoring facility is put into the instrumentation and system components such as telemetering, computers, etc., with little attention paid to the system that delivers the water sample. A continuous, representative, and nondegraded sample is required; and therefore an appropriate proportion of engineering hours and funds must be allocated to the intake system.

SECTION V

DESIGN APPROACHES

EXISTING STRUCTURES

Many water quality monitors have been installed at water, power, and industrial plants along a stream. The raw water sample to the monitor is tapped off the plant's supply, a practice that eliminates the need to install and maintain a separate pumping system. This approach is good if it is certain that the sample is representative of the desired river location and if the sample is not changed within the pipeline before reaching the monitor. The object is to obtain meaningful water quality data. An easy installation is fine if it is not made at the expense of obtaining good data.

The pumping system may also be located from a bridge pier or dock if it is situated where meaningful data can be obtained. In such cases, some engineering design is still required; but the time and expense should be less because a substantial structure is already provided for mounting the system.

NO EXISTING STRUCTURES

When existing structures are not available, conscientious engineering time and adequate funds are required to design and install a dependable sampling system.

Good engineering judgment is required for site selection. One must be certain that the intake is not located where the river could deposit a sandbar. A homogeneous sample that is representative of most of the water in the river at the specific location is desired. This type of sample can most likely be collected from the river channel; therefore, an economical method of sampling the channel is required. The channel is not always in the center of the river, but in many cases is close to one bank. Figure 3 shows one instance where nature brings the channel close to the bank, and this is the logical location of an intake.

In Figure 3, the inset of section A-A illustrates a river cross section with the channel nearly centered. At section B-B, the channel is much closer to the bank; hence it is easier and more economical to locate the intake at section B-B. The river will

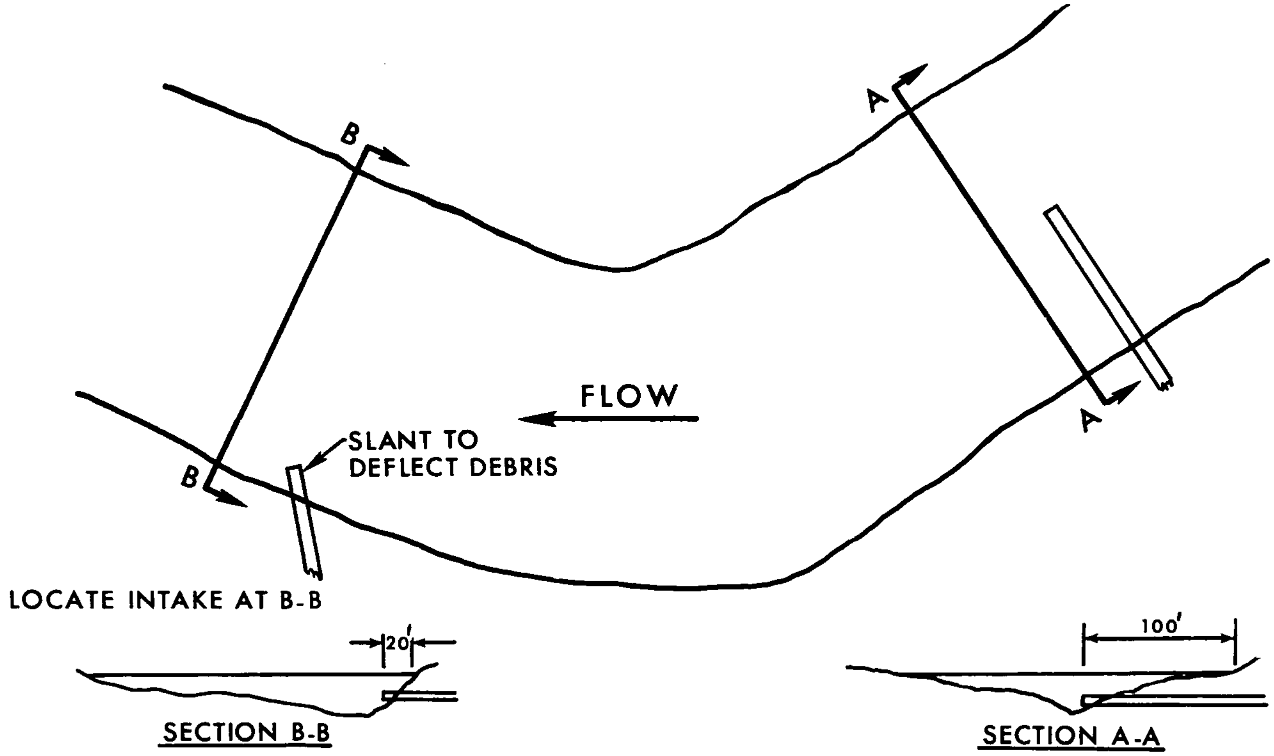

Figure 3. Site selection: note that the channel is naturally close to one bank and is thus the logical location of an intake.

tend to score at section B-B. This tendency is advantageous in that it will keep settlement and debris from covering the intake, but it may be necessary to place heavy riprap on this bank to prevent erosion.

The above conclusions are logical, but it is still necessary to obtain confirming proof of sample representativeness before intake installation by making both a longitudinal and cross sectional sample study.

Intake system maintenance along with sample representativeness must be considered in the design. The system should be designed so that pumps and intake strainers can be serviced and cleaned during the most adverse stream conditions. Three types of systems that are rugged and allow maintenance during most river conditions are presented. The type-1 system is recommended first for ease of maintenance and minimal sample degradation, and types 2 and 3 could be used as alternatives if for some reason the type-1 system is not feasible.

Type-1 System: Low-Residence-Time Positive Pressure

The type-1 system is shown in Figure 4. Site selection was made as described above. The system consists of a pump that slips from the shelter, through a casing, into the river. The intake strainer protrudes 8 to 12 inches beyond the end of the casing. A winch can be used to pull the pump and strainer back to the shelter for servicing. This system has no enlarged sections, and the residence time is very low. Note that a pile supports the end of the casing and keeps it up out of the river bottom sludge. A small contractor's pump could be used at the river. These units are rugged, but shut off head is only about 45 feet of water. Therefore a booster pump may be required in the shelter or midway between the river and shelter. A positive displacement screw type pump could also be used at the river. These units can overcome considerable

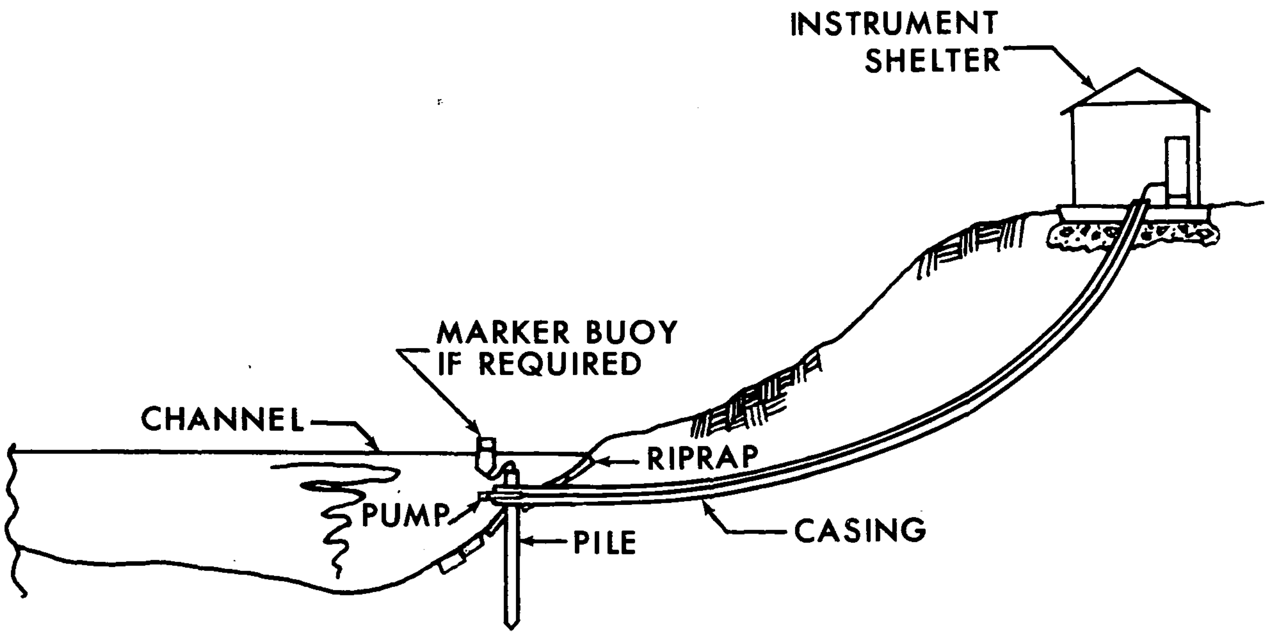

Figure 4. Type-1 system (low-residence-time positive pressure).

head and a booster pump would not be required; however in the past this pump has been known to fail. Cause of failure has been traced to the thrust bearing within the electric motor and the universal joint connecting motor and pump. The unit has head vs. flow characteristics that are very desirable for a monitoring installation, and the pump head can withstand the mild abrasives found in raw river water. The author feels that the past problems of failure with this pump can be solved.

The type-1 system can be designed with a high velocity of flow from river to shelter, and therefore backflushing with a chlorine solution is probably not required. This system has many attributes, and it is highly recommended by the author.

Type-2 System: Low-Residence-Time Negative Pressure (Alternate)

This system is similar to the type 1, except that only an inlet strainer is pushed through the casing to the river. A positive displacement screw-type surface pump is installed within the shelter. Table 5 shows that it is possible to pump at pressures less than atmospheric with insignificant DO loss if the screw-type pump is used. It is recommended that the pressure at the pump inlet be no less than 1/2 atmosphere. The suction line must be tight so that no air leaks into the system. DO data from this system are easily subject to suspicion, and for this reason it is best to use the type-1 system, if possible. Advantages of the negative pressure system are the ease with which a small strainer could be slipped through the casing, reduced weight (which eliminates the need for a winch), the fact that no electric cable is required, and the smaller casing.

Type-3 Well System (Alternate)

A sketch of this system was shown in Figure 1. Conventional, submersible, centrifugal, clear well pumps have operated longer without failure in the well than other type of system. These pumps are conventionally mounted in a vertical position, as their design intended, and sand, which is frequently encountered in river flow, settles within the well before passing through the pump; therefore, pump life is prolonged. Tests[2] have shown that good data with little sample degradation can be obtained from the well system if a frequent cleaning schedule is maintained. Cleaning requires flushing the lines with a chlorine solution twice a week during warm weather and removing sediment from the well about once a week. Well-type systems are relatively inexpensive.

Table 5. AVERAGE DISSOLVED OXYGEN ERROR WITH SCREW-TYPE AND CENTRIFUGAL PUMPS*

Pump number	Suction lift (ft)	Number of readings	Station 1 minus station 3: Avg. error (ppm)	Station 1 minus station 3: Std. dev.	Number of readings	Station 1 minus station 2: Avg. error (ppm)	Station 1 minus station 2: Std. dev.
1†	2	6	.05	.05	6	.08	.05
1	8	9	.05	.10	8	.05	.16
1	14	12	.02	.10	10	.05	.08
1	20	6	.00	.08	5	.07	.09
2†	20	17	.03	.05	16	.01	.05
For all readings Pumps 1 & 2		50	.03	.08	45	.04	.09
3‡	20	5	.41	.18	5	1.08	.24
3	2	2	.08	.04	2	.08	.04

*Station 1 was the river intake.
Station 2 was the high pressure side of the pump; there was 150 feet of 3/4-inch plastic pipe between station 1 and 2.
Station 3 was within the instrumentation shelter, there was 300 feet of 3/4-inch plastic pipe between station 2 and 3.
†Positive displacement screw-type, 1/2 hp.
‡Jet centrifugal, 1/3 hp.

SECTION VI

SIZING PUMPS AND PIPELINES

Pipelines should be sized for a high velocity of flow to prevent settling and to keep slime growth scored out. There are practical limits for velocity, since increasing it causes greater friction loss and thus puts greater pressure strain on the system and demands more pump horsepower. Stierli[3] et al show minimal DO loss if the Reynolds number is kept above 25,000. Recent DO data taken across pumping systems indicate that velocity of flow should also be considered. Table 6 rationalizes this point.

Table 6. VELOCITY INCREASE WITH CONSTANT REYNOLDS NUMBER

D Pipe diameter (in.)	Q Flow (gpm)	A Surface area ($in.^2/in.$)	R Reynolds number	V Velocity (ft./sec.)	Residence time per 100 ft. (sec.)	A/Q Number bacteria per rate of flow
1.0	9.0	3.14	29,970	3.70	27.0	.349
1.5	13.5	4.71	29,970	2.44	41.0	.349
2.0	18.0	6.28	29,970	1.83	54.6	.349

The table illustrates three pipelines with internal diameters of 1, 1.5, and 2 inches. The Reynolds number* is held constant as the diameter increases by increasing flow proportionately. The table shows velocity decreasing from 3.7 to 1.83 feet per second and a proportionate increase in residence time. Assume that a certain number of slime bacteria can occupy a unit area of pipe surface; then the A/Q column shows that the number of bacteria on the pipe surface per rate of flow is constant. Hence, with increasing

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* $$R = \frac{4Q}{\pi D \nu}$$

where R = Reynolds number
Q = flow, $feet^3$ per second
D = pipe diameter, feet
ν = kinmatic viscosity of water (0.00001 $feet^2$ per second for water at 25C)

residence time, the same number of bacteria are given a longer period to oxidize the substrate within the water sample, and the DO consumption will be greater. Therefore it is better to use the 1-inch line with a 3.7-feet-per-second velocity than the 2-inch line with a velocity of 1.83 feet per second. If the Reynolds number were the only criterion, then all three lines would be equal. More tests are needed in this area, but cursory results indicate that velocities of 4.7 feet per second or higher are required to give accurate DO readings without cleaning for pipelines 400 feet long. Lower velocities and/or longer lines may require automatic cleaning with a low concentration of a strong oxidant such as chlorine. The following example for sizing a pump and pipeline is given:

Required raw water flow to monitor	=	18 gpm (0.04 feet^3 per second)
Pressure drop across monitor	=	15 psi
Elevation of monitor above river	=	30 feet (13 psi)
Total length of pipeline	=	400 feet
For velocity > 4.7 feet per second		

$$D = \frac{4Q}{\pi V}$$

$$D = 2 \frac{.04}{4.7\pi}$$

$$D = .104 \text{ feet}$$

$$D = 1\text{-}1/4 \text{ inch}$$

Pressure drop in 400 feet of 1-1/4-inch smooth pipe at 18 gpm	=	14 psi*
Total pressure drop	=	43 psi.

Therefore a pump that will deliver 18 gpm at a total dynamic head of 42 psi should be purchased.

*Bureau of Standards Report BMS 79.

SECTION VII

AUTOMATIC CLEANING

Automatic cleaning is probably not required with a properly designed pumping system such as the type-1. There may be some cases, such as the well system or a system having very long pipelines, that require cleaning. Eckoldt[4] discusses backflushing with compressed air, and an automatic cleaning system that periodically flushes the lines with a low concentration of chlorine has been discussed by this author.[5] Systems requiring an inlet strainer, such as the type-1, should be designed so that manual cleaning from the river bank is possible.

SECTION VIII

DISCUSSION

Pumping systems for automatic water quality instrumentation have presented many problems in the past. This report describes the cause of these problems and gives recommendations for avoiding them. These recommendations are based on the experience of the author and others with intakes and includes tests on the well[2,6], negative lift systems[7], various pumps, and automatic chlorination[5].

The type-1 system described in this report is recommended as a method to overcome past difficulties. This system presents a new technique in that it has a high sample velocity with no enlarged sections, and it is completely serviceable from dry land during all stream conditions. If built as described, the type-1 system is rugged, could not get washed out or buried in sand, and would provide a continuous representative and nondegraded sample. Installation of the system is made from the riverbank, and costs are relatively low.

SECTION IX

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16. ABSTRACT

Pumping systems for automatic water quality monitors are discussed, and recommendations on sample change, residence time, site selection, pipe size, pump selection, system cleaning, and overall design are given. Experimental data showing sample degradation because of biological metabolism, cavitation, and aeration are presented. A recommended system to overcome past problems is presented and alternative approaches for system installation are also shown.

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