EPA-600/2-77-071
August 1977

Environmental Protection Technology Series

EVALUATION OF FLUIDIC COMBINED SEWER REGULATORS UNDER MUNICIPAL SERVICE CONDITIONS

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report describes the evaluation, under normal municipal operating conditions, of a new technical approach for the regulation of combined sewer flows. The program demonstrated that this approach can provide municipalities with more cost effective combined sewer regulation, so that the pollution of receiving waters from overflows can be minimized, at lower capital and operating costs than required by currently used regulators.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report describes a USEPA Demonstration Program undertaken by the Philadelphia Water Department, in which a novel combined sewer regulation concept is evaluated under municipal service conditions. This concept uses fluidic technology to generate dynamic regulation characteristics without mechanical moving elements in the sewage flow. This concept had previously been the subject of a USEPA Research Program.

The report describes the chosen sites, the desired regulation functions, design rationale and analyses, and construction details for two fluidic regulator installations, representing small, and fairly large flow requirements. The construction of the sites, regulators, and appurtenances, together with laboratory tests and site calibrations are described, including difficulties encountered, and design modifications generated to achieve the desired system performance.

The two fluidic regulators are compared in detail with equivalent conventional static regulators, from the standpoints of hydraulic performance; surveillance, maintenance and repair; and initial and operating costs. The report concludes with recommendations for system and hardware design improvements.

This report was submitted in fulfillment of USEPA Demonstration Grant 11022 FWR, by the Philadelphia Water Department under partial sponsorship of the U.S. Environmental Protection Agency. The report covers the period from February, 1971, to March, 1975, and the work was completed as of September, 1976.

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LIST OF ABBREVIATIONS AND SYMBOLS

Q Water flow, in general
Q_{tot} Total water flow passing through regulator
Q_{out} Water flow passing through fluidic regulator outfall discharge
Q_{in} Water flow passing through fluidic regulator interceptor discharge
cfs Cubic feet/second, normal measurement of water flow
h Hydraulic head of water upstream of regulator, in ft.
h_n Height of fluidic regulator inlet nozzle, in ft.
h_d Height of fluidic regulator outfall discharge above regulator floor, or invert, in ft.
h_D Height of water level above regulator dam, in ft.
w_n Width of fluidic regulator inlet nozzle, in ft.
a Inlet nozzle aspect ratio, $= h_n/w_n$
A Inlet nozzle, or orifice area, in general, in $ft.^2$, or $in.^2$
A_n Inlet nozzle area, in $ft.^2$
DWF Combined sewer dry weather flow, in cfs
D Fluidic regulator flow diversion capability, in maximum percent of Q_{tot} diverted to regulator outfall discharge
NPT National Pipe Thread, (F) female, (M) male
PVC Polyvinylchloride, plastic material
PE Polyethylene, plastic material
V Velocity, in general
fps Feet/second, measurement of velocity
EL Elevation above mean sea level, ft.
C_D Regulator, or orifice discharge coefficient
d Diameter, in general; in ft. or in. as indicated
p Pressure, in general; in in. of water or as indicated

ACKNOWLEDGEMENTS

The author wishes to acknowledge the technical support given by Mr. Richard Field, Chief, Storm and Combined Sewer Section (Edison, NJ), USEPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio, and his staff during the conduction of this program.

Similarly, the author wishes to acknowledge the considerable, enthusiastic work performed by the Philadelphia Water Department under the direction of Water Commissioner Carmen F. Guarino, including the Chief of the Water Pollution Control Division, Mr. Michael D. Nelson; the Chief of the Interceptor Service Section, Mr. William Barnes; and the Project Director, Mr. M. Stewart Cameron, and his staff. Without the efforts of this organization the project could not have been accomplished.

The author also wishes to acknowledge the Bowles Fluidics Corporation, who pioneered the basic technology behind this program, and who provided the project with competent mechanical design, model shop construction, laboratory test, and editorial services.

The author finally wishes to express thanks and appreciation to Mrs. M. Stewart Cameron for her gracious and helpful service in providing the author with clean coveralls during the field test and calibration phases of the program.

SECTION 1

INTRODUCTION

PROJECT BACKGROUND

The subject program has been established as part of the USEPA's overall objective to improve the regulation of combined sewer flows to minimize overflows and thus relieve the resulting pollution of receiving waters. This project demonstrated and evaluated the fluidic combined sewer regulation concept. This concept was previously investigated at the pilot-scale level by Bowles Engineering Corporation under USEPA sponsorship (Ref.#1). This earlier project included the basic analytic and experimental exploration of the concept, and the derivation of application design criteria. The project also included an investigation of several major cities in the eastern part of the U.S. to determine both applicable sites and municipal interest in participating in a USEPA Demonstration Grant concerning the concept. As a result, the City of Philadelphia was selected, and has furnished two combined sewer sites applicable to the evaluation of fluidic combined sewer regulators. This report describes the results of the Demonstration Grant program.

CURRENT PRACTICE

Combined sewer regulation is currently being performed by either static, or dynamic regulators. The static systems are simple, have no mechanical moving parts, are relatively reliable and easily maintained. However, the hydraulic performance of a static regulator is typically determined only by the flow conditions in the combined sewer, independent of flow conditions in the interceptor sewer. As a result, these devices tend to either overflow before using all the available capacity of the interceptor during areawide light storm flows, or surcharge the interceptor during areawide heavy storm flows. The result is either unnecessary pollution of receiving waters, or a flood/surcharge condition to the interceptor sewer structure, and overloading of the water pollution control plant. Dynamic type regulators can provide much better hydraulic performance, in response to either or both combined and interceptor sewer conditions. These systems are, however, much more complex, costly, less reliable and more difficult to maintain in service.

FLUIDIC REGULATOR CONCEPT

The fluidic regulator concept, as illustrated in Figure 1, offers most of the flexibility and performance of the dynamic regulator, yet retains the low cost, simplicity, reliability of operation, and ease of maintenance of the static regulator. The fluidic regulator consists of a structure with no mechanical moving parts in the sewage flow stream, and permanently open flow passages. The construction is from standard, non-corrosive materials such as concrete, high grade plastics, stainless steel, etc. These characteristics render the fluidic regulator minimally susceptible to common problems such as blockages, corrosion, fouling, jamming, etc. affecting standard moving part regulators of the type shown in Figure 2; and essentially equivalent to standard static regulators.

Another significant advantage of the fluidic regulator is that it is self-powered. Control energy is derived directly from the sewage flow, thus eliminating the requirement, and initial and maintenance costs of external electric, hydraulic, mechanical, etc. power. The elimination of dependence on external power assures greater reliability, particularly during storm events when municipal power outages occur most frequently.

The fluidic regulator obtains operational flexibility comparable to that of complex dynamic regulators through the sensing of water levels by simple dip tube sensors, which can be located in the interceptor, or upstream of the regulator in the combined sewer, or both. Remote command control of a fluidic regulator can be implemented using an electrically actuated pneumatic valve operated at low power levels easily transmitted over standard telephone lines.

REGULATOR OPERATION

As shown in Figure 1, a large fluidic diverter is embedded in a dam across a combined sewer. One discharge is elevated and flows through the dam into the outfall. The other discharges into the interceptor. The regulation logic is as follows:

1) Dry weather flow proceeds directly to the interceptor, since the outfall discharge is elevated. This action is similar to that of a conventional static regulator.

2) With light to moderate storm flow, the hydraulic head upstream of the dam increases above the regulator inlet, causing it to flow full. The resulting control action of the regulator occurs: With full flow, the venturi shape of the inlet generates a sub-ambient pressure at the control ports which tends to aspirate ambient air into the regulator. If the interceptor-side control port were blocked, and the outfall-side port opened to atmosphere, a pressure differential would be exerted transversely across the incoming flow stream toward the interceptor-side discharge, and the flow would exit entirely to that

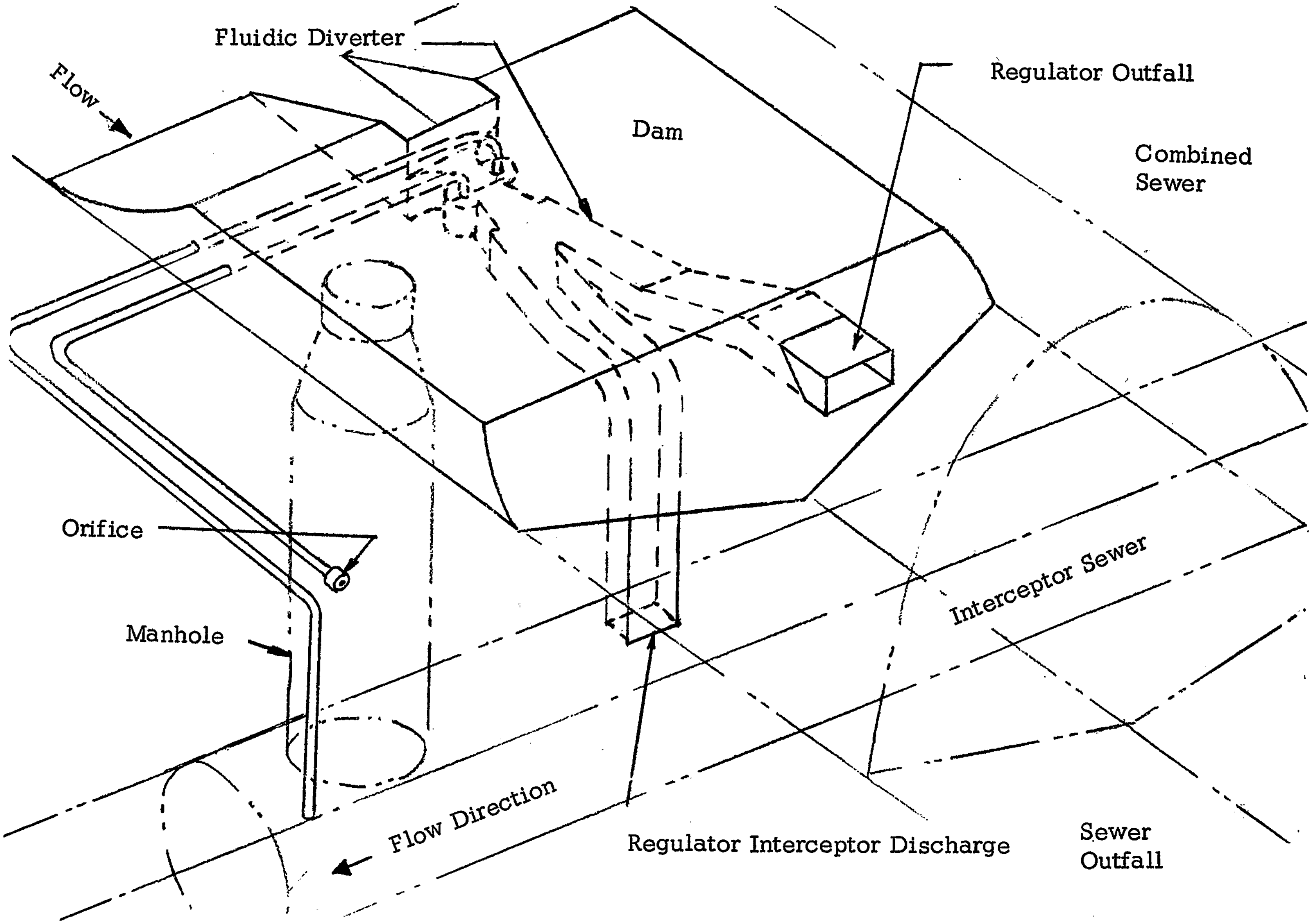


Figure 1 Schematic Arrangement, Fluidic Combined Sewer Regulator

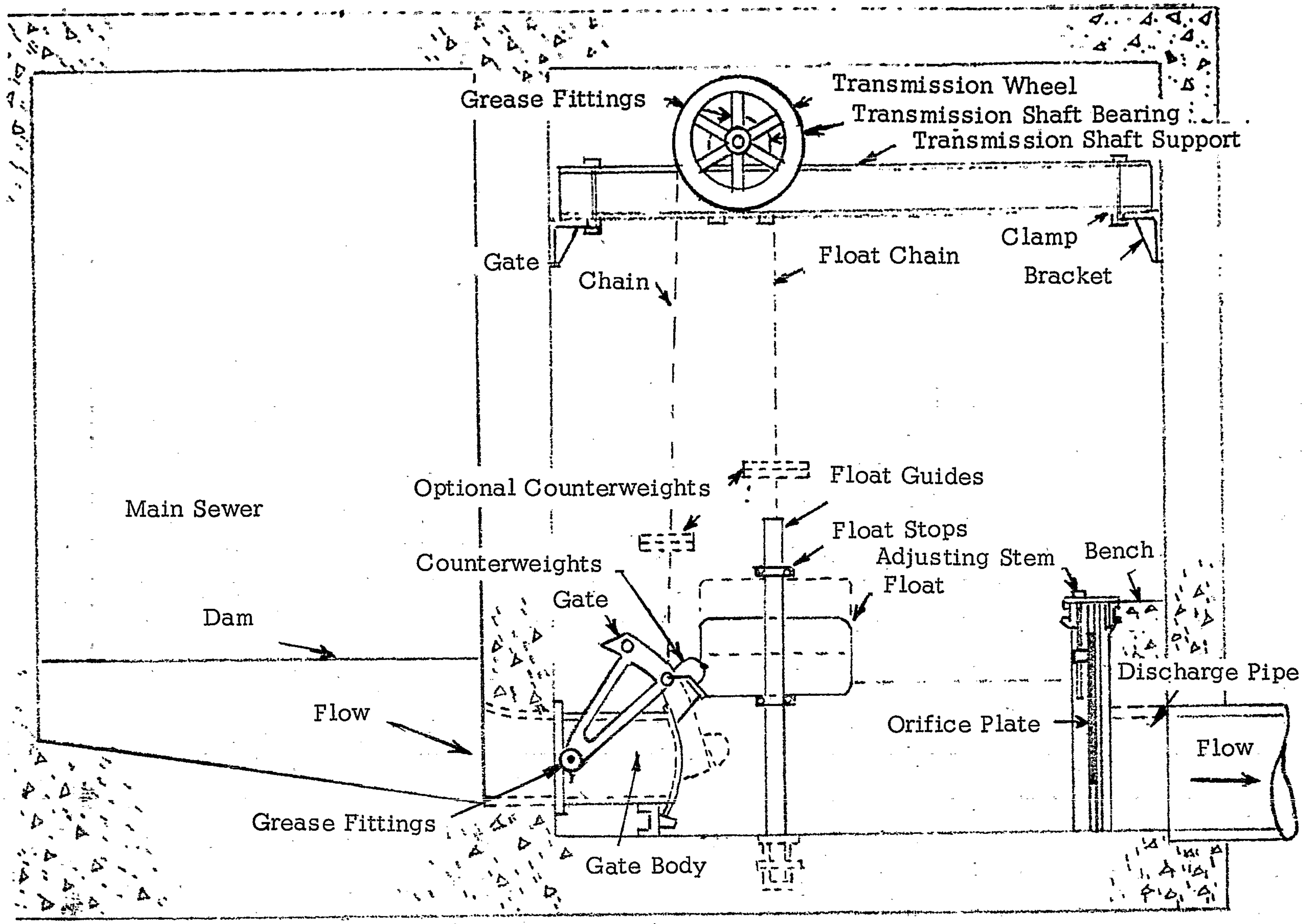


Figure 2 Conventional Mechanical Combined Sewer Regulator

side, despite the fact that the upstream water level may be higher than the outfall discharge elevation. If the control port closure is reversed, the pressure differential across the incoming flow stream would also reverse, and a significant fraction of the flow would discharge over the outfall; the higher the upstream head, the greater possible fraction of total flow over the outfall.

In the simplest regulator configuration, the interceptor-side control port would be connected to ambient atmosphere through a small orifice, while the outfall-side control port is connected to a dip tube level sensor located in the interceptor. If the interceptor water level is below the dip tube, indicating a condition of additional capacity in the interceptor, atmospheric air is aspirated freely into the outfall-side control port, maintaining the regulator flow toward the interceptor. If the interceptor level rises above the end of the dip tube, indicating a condition of interceptor near-capacity, the aspirated airflow into the outfall-side control port is cut off, and the pressure differential will reverse toward the outfall side, causing most of the regulator flow to shift to the outfall, preventing interceptor surcharging. The regulator thus prevents any outfall flow as long as the interceptor has sufficient flow capacity. Only when its capacity is reached does outfall discharge occur, thus minimizing pollution in the receiving waters.

3) In heavy storm flows the upstream head will rise above the dam crest, and large outfall flows will occur over the dam. With increasing hydraulic head, however, the regulator will direct an increasing fraction of its flow to the outfall, and the actual flow to the interceptor will be reduced, thereby continuing the prevention of surcharging of the interceptor.

The above-described logic is basically digital in nature, in which the regulator acts as a flow switch, depending on the condition of submergence of the dip tube in the interceptor. The fluidic regulator is also capable of proportional regulation action, through the use of the sensor arrangement shown in Figure 3. Here the simple dip tube is replaced by a multiple tube assembly, whose open ends are graduated in elevation. Each tube is connected to the connecting air line through an orifice, so that the aspirated airflow reaching the outfall-side control port is decreased proportionately as the interceptor water level rises above the end of each tube. As the airflow into the control port is attenuated, the internal pressure drops proportionately below atmospheric ambient. The line to this control port is also connected to the closed end of a "U-tube" sensor containing a low volatility fluid. As the internal pressure decreases, the fluid level in the U-tube sensor closed end rises, while the level in the open end falls, in the manner of a manometer. A multiple, graduated dip tube sensor assembly, similar to that in the interceptor, is suspended in the open end of the U-tube sensor, so that all of the tubes are submerged when the U-tube fluid levels are the same. Thus, as dip tubes are successively submerged by rising water level in the interceptor, the dip tubes in the U-tube sensor are successively uncovered, thus allowing an increasing

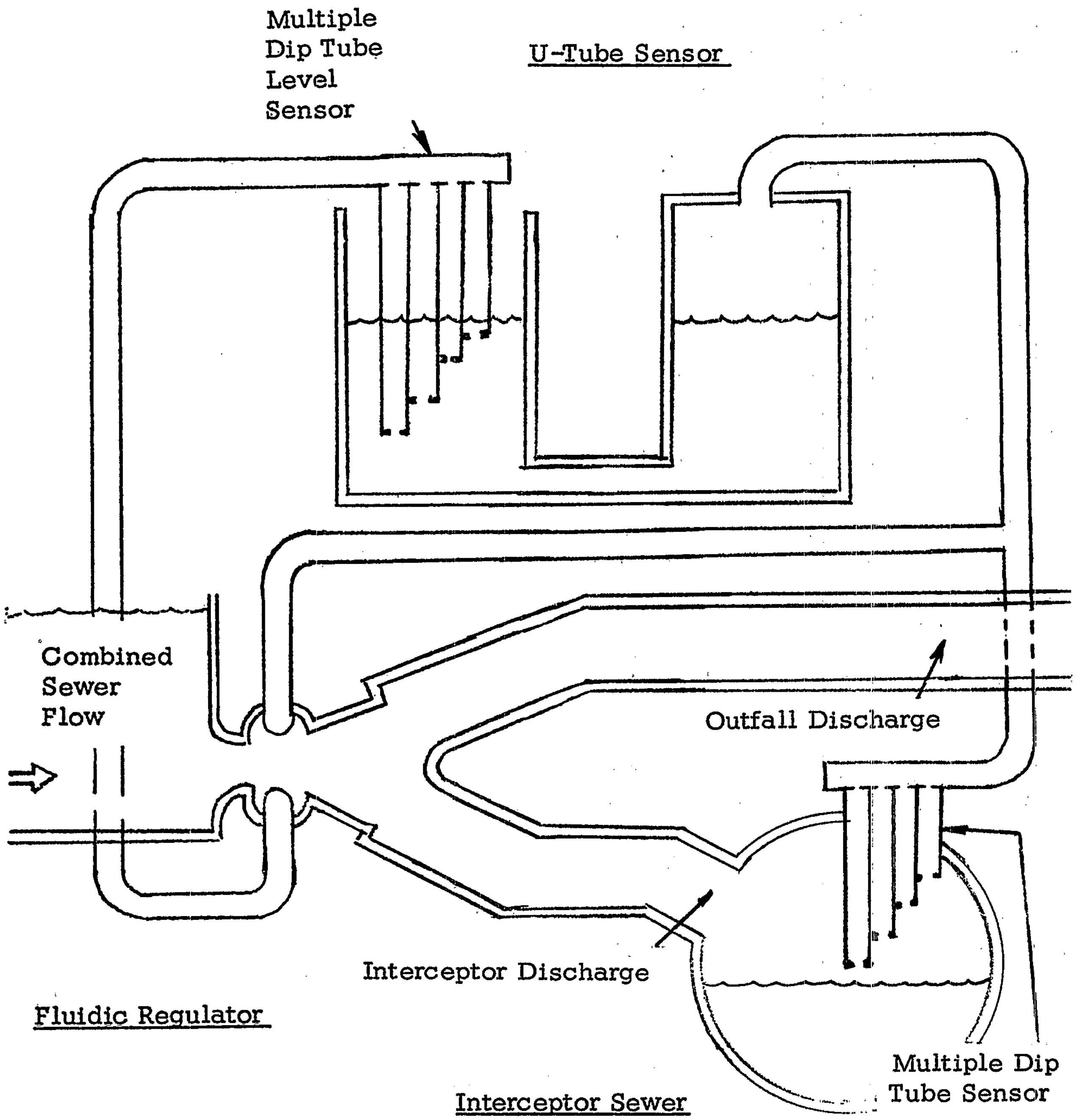


Figure 3 System Schematic Arrangement using U-Tube Sensor

airflow into the interceptor-side control port. This action results in a smooth, proportional transfer of regulator flow away from the interceptor as its reserve flow-carrying capacity decreases. It will be noted that while the sensor arrangement is more complex, no mechanical moving parts in the water flow are required, thus preserving the basic intrinsic desirable characteristics of the fluidic concept.

PROJECT OBJECTIVES AND APPROACH

The specific project objectives and work description, as stated in Demonstration Grant (11022 FWR) agreement are as follows:

1. Design, construction and operation of a fluidic regulator for a flow range below 2 cfs with a minimum of reconstruction. The unit will be capable of demonstrating fluidic action on demand by use of city water to simulate storm flow and a transparent top for observation.

2. Design, construction and operation of a fluidic regulator for a 4 cfs peak dry weather flow. This will demonstrate the use of a fluidic device at higher flows on combined sewage. The automatic control of the overflow will be done by sensing the interceptor level. No overflow will occur until the interceptor reaches a pre-determined limit.

3. Evaluate the operation of above fluidic devices for one year, and relate their performance, both advantages and disadvantages to conventional regulators throughout the Philadelphia sewer system.

4. Assembly of all data from the evaluation and testing program including rainfall data, overflow vs. sensor height so that the application of fluidics to sewer regulator design can be demonstrated on a full-scale basis.

Enlarging the foregoing, this project would evaluate fluidic combined sewer regulators using both the digital and proportional modes operation, as described above. In addition, the digital mode would also be evaluated using a simple diaphragm valve in combination with the dip tube sensor. The digital operational mode would be evaluated at a diversion site near 67th and Callowhill Sts. in Philadelphia, and would be included in item #1 of the Project Objectives. This site has been previously regulated using a plate-type static regulator. Also located at this site was the test set-up used in USEPA Demonstration Grant #11023 (Ref.#3), designed to evaluate the effectiveness of a rotary microstrainer in improving the quality of combined sewer flows. In selecting this site for the subject program, it was felt that the availability of the test set-up would facilitate the testing and calibration of the fluidic regulator through the uses of existing facilities.

The proportional operational mode of regulation was planned as part of item #2 of the Project Objectives. The selected site was a diversion point near the intersection of Bingham St. and Tacony Creek. This site had previously been regulated using a diversion dam across the sewer, with an upstream, manually positioned sluice gate to regulate flow into a connecting sewer to the interceptor.

The fluidic regulators to be constructed at both sites would be evaluated per items #3 and #4 in the Project Objectives.

SECTION 2

SUMMARY

Two Combined Sewer Fluidic Regulator Systems have been designed, constructed, and installed at two diversion sites in the City of Philadelphia, PA, replacing conventional static regulators. The first, handling combined flows up to about 2 cfs, has operated well for a period of over 36 months, providing hydraulic performance similar to that of dynamic regulator with the same low incidence of blockages and other service problems of comparable static regulators. The second, handling combined flows up to about 25 cfs, has operated for a period of about 30 months, with virtually no blockage or service problems, but has been prevented from reaching its desired hydraulic performance by unforeseen, abnormal flow impedance in the connecting sewer to the interceptor. This problem has unfortunately not been correctible within the scope of the program.

The project has accomplished 75% of its specific objectives; 100% for the small unit, and about 50% for the large unit.

A number of recommendations have been formulated for system modifications to improve regulator performance, mechanical design, installation, reliability, and maintainability, and are described within the report.

SECTION 3

CONCLUSIONS

The principal conclusions from this program is that the fluidic combined sewer regulator can provide much-improved hydraulic regulation performance, currently obtainable only from complex dynamic regulators, with equivalent or improved reliability and maintenance performance, as compared to conventional static sewer regulators. The improved hydraulic performance will result in fewer and less serious overflows during light to moderate storm flows, with a much reduced tendency to surcharge the interceptor during heavy storm flows. The excellent reliability and maintenance performance will result in low operating costs, and overall greater cost effectivity than either conventional static or dynamic regulators.

The basic design criteria and rationale generated in the previous research phase (Ref. #1), which was used as the basis for design for this project, is considered demonstrated for fluidic regulators handling flows up to 25 cfs, and probably practical for flows up to 50 cfs.

The 5 in. x 5 in. inlet dimensions of the small regulator operated on this program proved workable, but are judged to be the minimum practicable for future fluidic regulator designs.

The surveillance, maintenance, and repair procedures developed by the Philadelphia Water Department for the fluidic regulators, proved simpler, faster, and somewhat less costly than those for the conventional static units they replaced. In all cases, these operations were performed with minimum skill-level personnel. These procedures were considerably simpler and less costly than those required for conventional dynamic type regulators, which generally require high skill-level personnel.

The costs for retrofitting a fluidic regulator into the two chosen sites were estimated on the average at about 40% more than retrofitting a conventional static regulator. The cost of installing a fluidic regulator into a new location was estimated at only about 10% more than for the conventional static unit. In general, the costs for retrofitting conventional dynamic regulators into existing static regulator sites are expected to be considerably greater than for fluidic regulators. Although specific cost ratios were not generated due to the wide variation in dynamic regulator characteristics, it was found that equipment costs for conventional dynamic regulators are much greater than fluidic regulators per quantity flow handled; (for example, a 4 cfs mechanical float-operated regulator recently cost the Philadelphia Water Department $13,000; the corresponding fluidic regulator cost is estimated at $4,500). In addition, it was estimated that site modification and installation costs would run 25% to 50% greater for conventional dynamic regulators due to the combination of requirements for precision assembly, and alignment of mechanical assemblies, construction of additional flow chambers or passages, and installation of operational energy supply facilities. A rough estimate of the overall conventional dynamic/fluidic regulator retrofit cost ratio would be at least 2:1.

The costs for installing conventional dynamic regulators into new locations would be greater than for fluidic regulators for the same reasons given above. However, the total cost ratios would not be as great as for the retrofit case, since the cost of basic excavation and construction common to either type regulator, generally exceeds the equipment and installation costs.

In addition, a number of conclusions were reached regarding specific points of regulator system and hardware design, construction, and maintenance. These concerned the desirability of: locating interceptor level sensor air lines outside the connecting sewer (to facilitate sewer maintenance); fluidic element construction using prefabricated plastic or metal shells to achieve lower cost, better dimensional control, elimination of nozzle erosion; the installation of manual valves in sensor air lines to facilitate on-site calibration, and routine maintenance checkout; the exploration of alternate regulator-to-sensor communication techniques to reduce cost, and the exploration of remotely controlled regulator operation to facilitate computerized municipal area flow route control.

SECTION 4

RECOMMENDATIONS

The recommendations resulting from this program fell into two categories: recommendations to achieve the project objectives that were precluded by the connecting sewer flow impedance problem encountered at the Bingham Street site; and recommendations pertaining to regulator design improvements.

PROJECT OBJECTIVE RECOMMENDATIONS

The recommendations to achieve project objectives are:

1. Proceed with the necessary repair to the connecting sewer at the Bingham St. site. The present condition prevents proper operation of <u>any</u> type of combined sewer regulator.

2. As an interim measure, in order to fully demonstrate the proportional mode of operation in a larger size unit, the present installation should be fitted with a removable invert that would reduce the inlet nozzle area to match the present flow-carrying capacity of the connecting sewer. Upon the eventual repair of the connecting sewer, the regulator would be returned to its present condition, at which normal design operation could be expected.

3. The present 4 in. air line to the interceptor dip tube sensor should be removed from the connecting sewer and a suitable alternate sensor and/or communication means installed so that interceptor level regulation logic can be demonstrated while permitting normal maintenance procedures in the connecting sewer without the interference of the air line.

4. An alternate, multiple dip tube sensor should be installed upstream of the dam so that the U-tube sensor also can be fully demonstrated, at least during system calibration runs.

DESIGN IMPROVEMENT RECOMMENDATIONS

Recommendations for system design improvement are:

1. In view of the practicality demonstrated by the diaphragm valve in

the digital operational mode, development should be started on a proportional operational mode diaphragm valve, which would be compared with the all-fluidic U-tube sensor.

2. Development should be initiated on means for remote command control of regulators, so that they can be integrated into large, computer-controlled sewage flow networks. The communication links could be either hard wire (telephone line) or wireless in nature.

3. Suitable means should be designed into a regulator installation to obtain direct access to the regulator control ports, while bypassing sensor connecting lines, to facilitate the calibration and trouble-shooting of the system.

SECTION 5

PROJECT HISTORY

The Phase I effort was started during February, 1971. Phase I work consisted of regulator design analyses for the two selected sites. This work, performed by the Bowles Fluidics Corporation during the spring and summer of 1971 included the inlet sizing; the prediction of regulator flow and diversion capability vs. upstream hydraulic head; and the design calculations and drawings for the regulators, sensors, and connecting lines to the sensors.

Phase II work consisted of the design of the site installations, and was performed by the Philadelphia Water Department. The 67th/Callowhill regulation site construction was completed during the winter of 1973; the Bingham St. site was completed in early summer 1973, completing Phase II.

The calibration and checkout of the 67th/Callowhill site was completed in October of 1973. Calibration of the Bingham St. site was started during the summer of 1973, and continued sporadically until the following spring, during which it became evident that a modification in the regulator outfall discharge design was required. A 1/6 scale model was constructed and tested, and a design modification generated. The installation was reworked during the summer and fall of 1974, and additional calibration attempts were made during October and November. During these calibration attempts, the potential for normal performance was shown, but successful calibration was prevented by excessive flow impedance in the 24 in. connecting sewer, which caused a flow backup before full regulation action could be established. (This condition had obviously been present in some degree through all the calibration attempts.) Further calibration was suspended, pending a detailed investigation of the interior of the connecting sewer, which was conducted by the Philadelphia Water Department during the spring and early summer of 1975. This investigation, which employed a remotely controlled TV camera, showed some blockages, which were removed, and considerable deterioration of the sewer walls, which permitted heavy infiltration from Tacony Creek and, in effect, generated the observed flow impedance.

The results of the investigation were discussed at a meeting at USEPA, Edison, NJ, on December 19, 1975, attended by representatives of Peter A. Freeman Associates, Inc. and the Philadelphia Water Department. In view of the large cost and expected time delay in repairing the connecting sewer, and in consideration that the 67th/Callowhill regulator had operated successfully from both hydraulic performance and maintainability standpoints, it was agreed that the basic objectives of the program had been sufficiently met, that this Phase of the program should be concluded and reported.

SECTION 6

REGULATOR DESIGN ANALYSIS

GENERAL

Several factors must be considered in the selection of a fluidic regulator inlet size. From the standpoint of pollution abatement, the regulator should admit as much flow as possible before overflowing the dam, in order that the maximum possible flow within the reserve flow-carrying capacity of the interceptor can be diverted to the treatment plant. This is particularly important in the early stages of a storm event, where a maximum of pollution from both sanitary flow and "first flush" flow is present. The desirability for maximum flow thus calls for a maximum size inlet. On the other hand, a fluidic regulator requires a minimum hydraulic head (approximately 2.5 inlet heights above the inlet) in order to provide a practical range of regulation of about 50% of the total regulator flow. This requirement, within the constraint of the maximum dam height allowable within a particular sewer, may limit the inlet size. The size of the connecting sewer to the interceptor can be another limitation to inlet size, particularly in situations where a fluidic regulator is to be retrofitted into an existing diversion site. The fluidic regulator research program (Ref. #1) showed that for proper flow impedance matching of the regulator to the connecting sewer, the regulator inlet area should not exceed about 50% of the connecting sewer area. As it happened, this requirement provided the limiting factor for the regulator inlet areas for one of the selected sites. The effect of improper impedance matching proved critical, as described in Section 8, in the calibration of the Bingham St. regulator. The details of the design analyses discussed in this section can be found in Appendix A.

67th/CALLOWHILL SITE

The location for this site is on the western boundary of Philadelphia. The drainage area is approximately 11.2 acres and land use is composed primarily of two-story row type residential housing. Figure 4 shows the drainage area, with dotted lines indicating the subdrainage areas and solid lines the sewers. A combined sewer system services the area and normal dry weather flow averages 1,000 gallons per hour.

The regulator is located in a portion of Cobbs Creek Park. The park runs

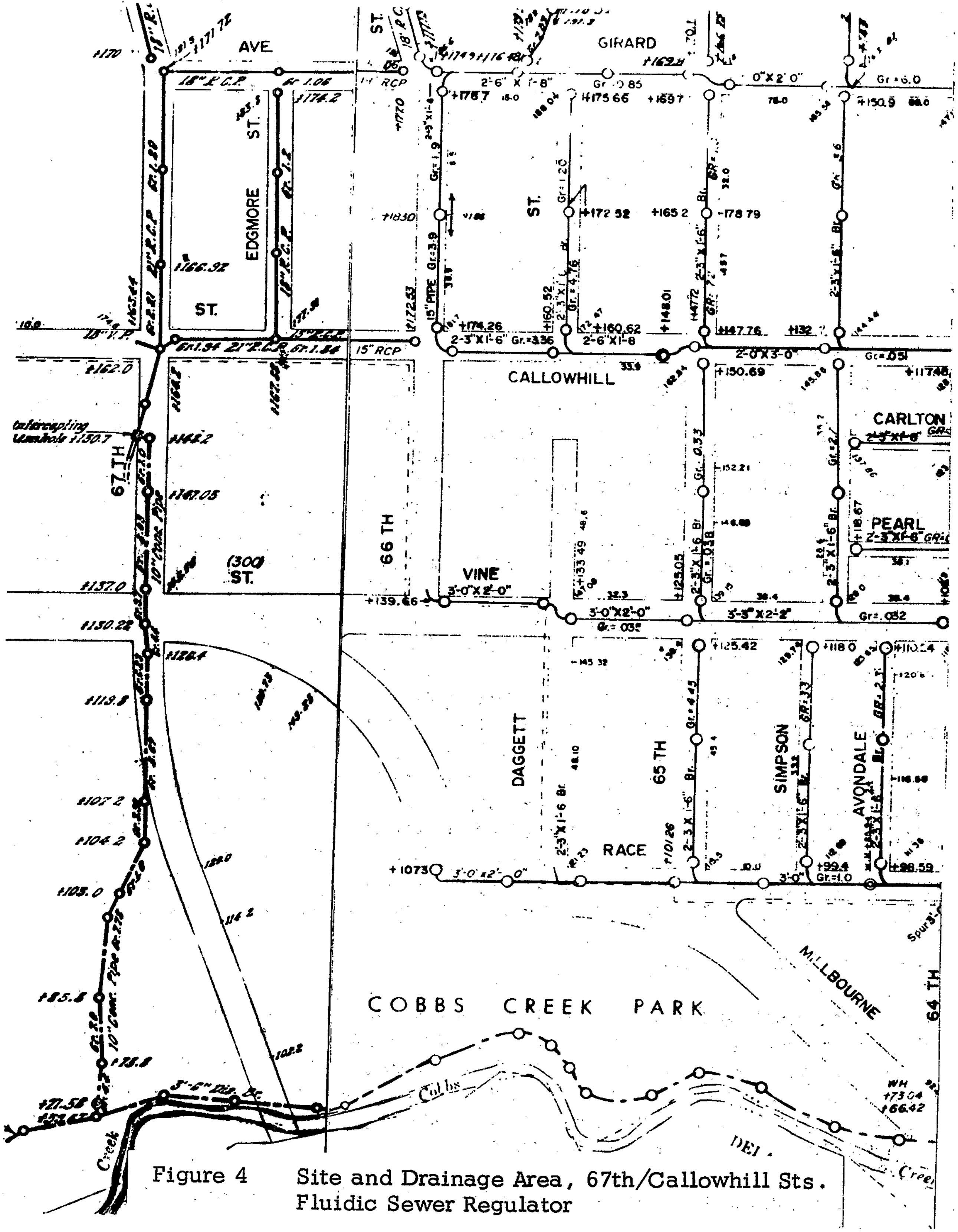


Figure 4 Site and Drainage Area, 67th/Callowhill Sts. Fluidic Sewer Regulator

parallel to Cobbs Creek, which is a tributary of the Delaware River.

The original regulating device was an adjustable slot, or leaping weir, feeding into a 24 in. outfall. The outfall has a theoretical capacity of 37 cfs. The connecting sewer from the regulator to the interceptor sewer is 10 in. in diameter, and runs 1500 ft. with a change in elevation of 91 ft.

The design maximum outfall flow of about 30 cfs permits a maximum dam height of 12 in. above the sewer invert, assuming a maximum allowable surcharge of 5 ft. upstream from the dam, with enlargement of sewer area to 2 ft.^{2} above the dam. The connecting sewer area is 78.9 in.^{2}; thus the inlet area would be limited to about 40 in.^{2} from a hydraulic loading standpoint, corresponding to an inlet size of 6.3 in. x 6.3 in. However, with the established dam height of 12 in., and the maximum allowable excavation of the sewer invert, the maximum available head was 14 in., which would not permit the required 2.5 inlet heights of head for 50% regulation performance. As a result, an inlet nozzle size of 5 in. x 5 in. was selected.

The predicted hydraulic performance for this regulator is shown in Figure 5. This prediction is based on the criteria developed (Ref. #1). Figure 5 shows an increasing available flow regulation to the outfall, in terms of % of total regulator flow, with increasing hydraulic head, reaching a value of 71% at a dam overflow head of 14 in. Also shown are the total regulator flow, and the predicted minimum interceptor flow. The minimum interceptor flow exceeds the Philadelphia Water Department criterion of 2 x $DWF_{max.}$ est'd, normally used in the design of static regulators. This deviation was acceptable considering the small values of the flow relative to the magnitude of the interceptor flow, and the need to maximize the regulator inlet size to avoid blockages.

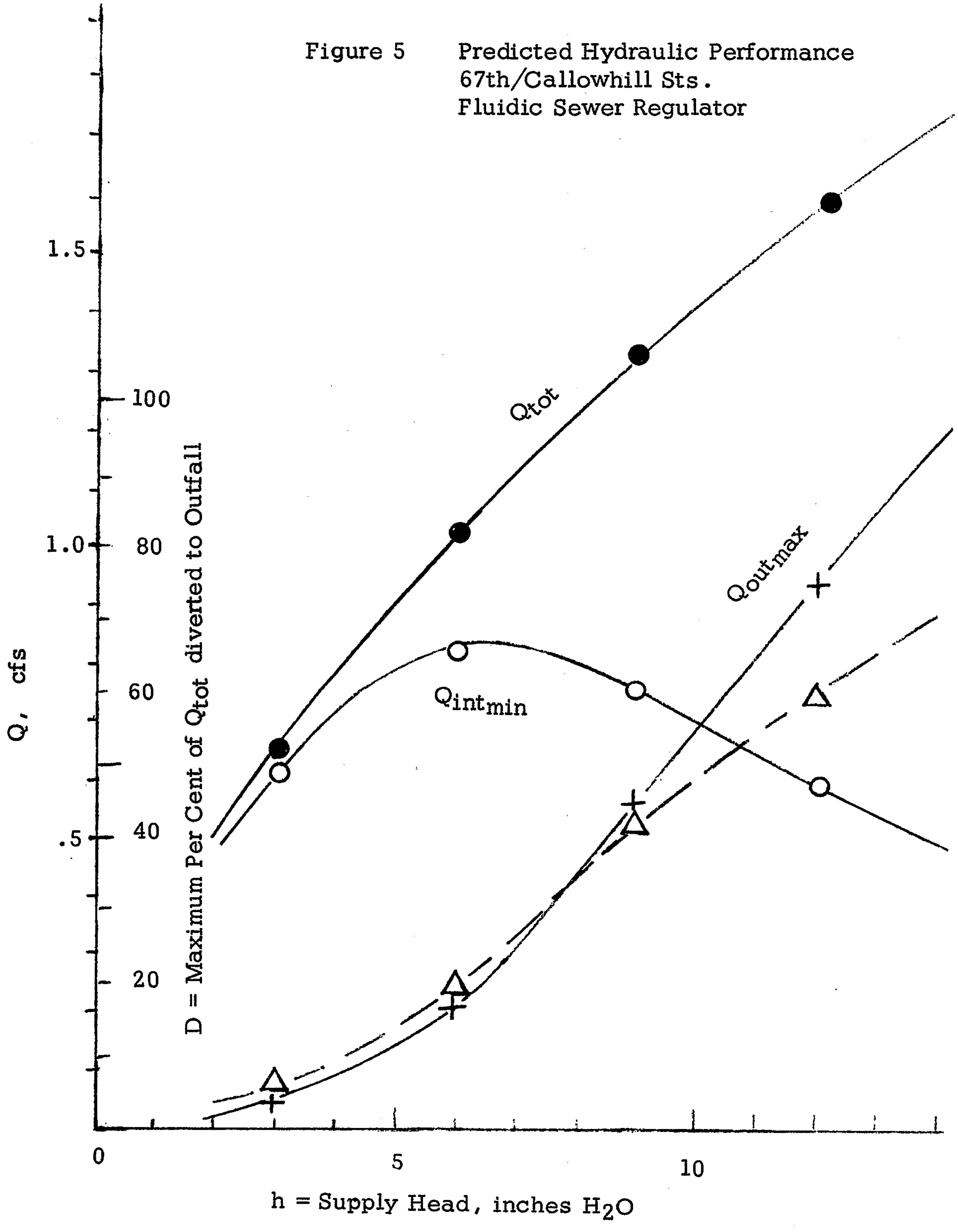
BINGHAM STREET SITE

This site is located in the near Northeast section of the City of Philadelphia. The drainage area is one of the larger areas within the city, encompassing 298 acres. Land use is devoted to light industry, shopping areas and residential with an average imperviousness of 67%. The sewer system handles a combined storm and sanitary flow. This drainage area is shown on Figure 6.

A large, unreinforced concrete arch storm sewer, 7.50 ft. high, and 10.25 ft. wide at the base, accepts the combined flow from the area. This main sewer terminates in a concrete outfall that diverts storm water into the Tacony Creek.

Within the arch section, a dam approximately 2 ft. high and a manual 3 ft. x 2 ft. sluice gate comprise the original storm water regulating device. Dry weather flow was contained behind the dam and entered a 24 in. diameter

Figure 5 Predicted Hydraulic Performance
67th/Callowhill Sts.
Fluidic Sewer Regulator



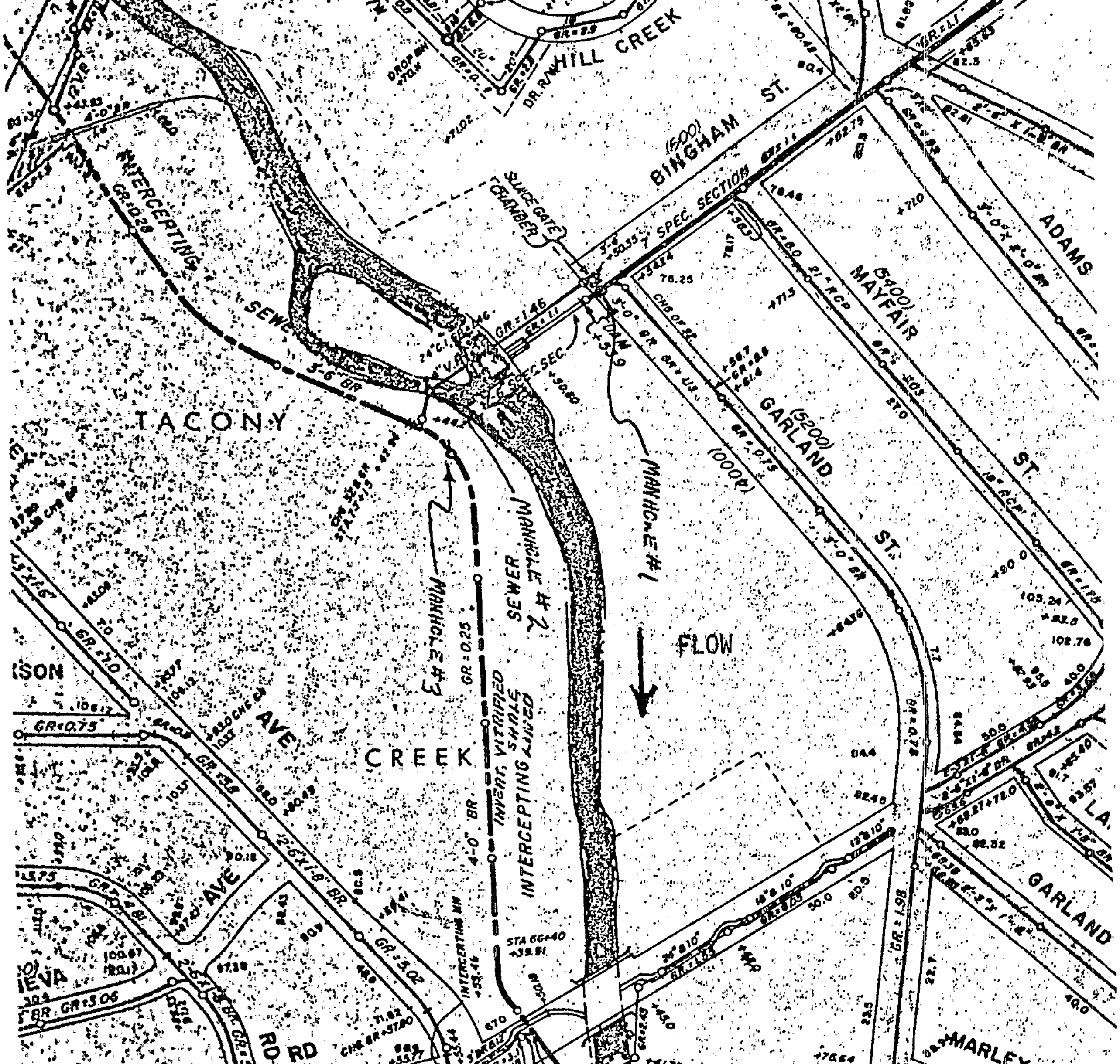


Figure 6 Site and Drainage Area, Bingham St. Fluidic Sewer Regulator

connecting sewer through the sluice gate.

The 24 in. sewer is constructed of vitrified pipe encased in concrete. It runs 450 ft. from the regulator to the Frankford High Level Collector on the west bank of the Tacony Creek. Approximately 200 ft. of the concrete encasement serves as a low dam across the creek.

The sluice gate and arched main sewer are located 25 ft. below a park area on the low bluffs overlooking and paralleling the stream.

As described, the connecting sewer has an area of 3.14 $ft.^2$. To provide the proper flow impedance match with the connecting sewer, and to allow for the approximately 60^o elbow at the junction of the connecting sewer and interceptor-side discharge, the regulator inlet nozzle area was set at 1.5 $ft.^2$. The inlet nozzle aspect ratio, a (height/width) was chosen at 1.5, giving a nozzle size of 12 in. x 18 in. This configuration was chosen to obtain improved diversion performance with reduced overall horizontal dimensions, based on design criteria (Ref. #1), in comparison to a square (aspect ratio = 1) inlet. The upstream head at dam overflow was set at 3.5 ft. The ratio of upstream head to nozzle height was 2.33, which was felt to be adequate in view of the improved predicted performance available with the higher aspect ratio nozzle.

The predicted hydraulic performance for the Bingham St. regulator is shown in Figure 7. In this case, the criteria for maximum allowed flow to the interceptor = 2 x $DWF_{max.est'd}$ = 20 cfs is not exceeded by the minimum interceptor flow curve. The maximum predicted flow regulation capability reaches about 65% of the total regulator flow at the dam overflow head of 3.5 ft.

SENSOR DESIGN

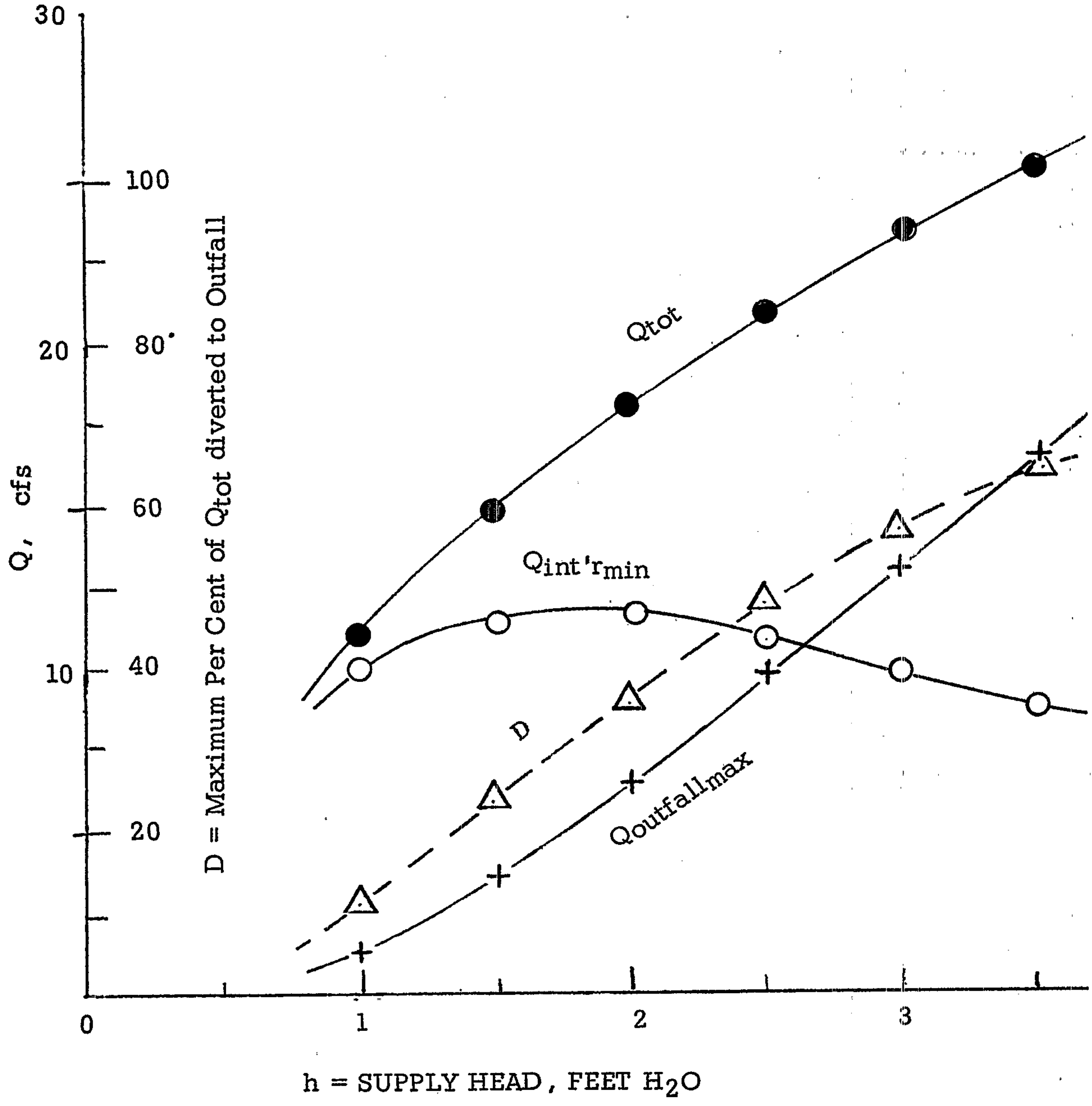
67th St./Callowhill Site

As described earlier, this site had been selected to demonstrate the digital mode of regulator operation. Because of the length of the connecting sewer to the interceptor, about 1500 ft., it was decided that the dip tube sensor should be located in a man-hole approximately 50 ft. upstream of the diversion site, thereby demonstrating regulator operation at minimum construction cost. Two versions of digital operation logic were considered, as described earlier in Section 2: a) using a fixed air orifice on the interceptor-side control port; and b) using a simple diaphragm air valve. These are described as follows.

Orifice Version --

Using the criteria established (Ref.#1), orifice and connecting line diameters were established as follows:

Figure 7 Predicted Hydraulic Performance, Bingham St. Fluidic Sewer Regulator



Interceptor-side Control port Orifice Dia.	7/32 in.
Outfall-side Control port Orifice Dia.	3/8 in.
Connecting Line I.D. (75 ft. run)	1-1/2 in.

The recommended vertical position of the dip tube sensor was chosen to correspond to an upstream regulator hydraulic head = 4.5 in., or 7.5 in. below the dam crest. (Note: The regulator head is measured above the outfall weir elevation.) This position provided regulator switching action when the regulator total flow reached 0.83 cfs, which corresponded to the minimum interceptor flow maximum value, as shown on Figure 5.

Diaphragm Valve Version--

During the research program (Ref. #1), it was found that improved flow switching to the outfall discharge was obtained if maximum airflow were admitted into the interceptor-side control port, as against the partial flow admitted through the fixed orifice. A convenient method of accomplishing this was through the use of a diaphragm valve, operated by the suction generated at the outfall-side control port. It was recognized that the use of a moving-parts device represented a departure from the all-fluidic system approach; however, it was felt that in this case the system reliability would not suffer, since the device operated only on airflow, without contact with the sewage flow. The operation of the diaphragm valve version is shown schematically in Figure 8.

The closed side of the diaphragm valve is connected to the dip tube connecting line, while the valve movement is connected to the interceptor-side control port. The diaphragm is spring-loaded so that the valve movement is normally closed when ambient atmospheric pressure is on the closed side of the diaphragm, a condition occurring when the dip tube is above water. When the dip tube is submerged, aspirated airflow is cut off, and the pressure drops below atmospheric ambient, causing the diaphragm to open the valve movement, allowing air to enter the interceptor-side control port. This causes the regulator to transfer a large fraction of its flow to the outfall discharge.

The diaphragm valve was designed to start opening at -1 in. H_2O pressure, and to be completely open at -2 in. H_2O pressure. The interceptor-side orifice and connecting line sizes were selected to be the same as for the orifice version, permitting field interchangeability, if desired.

Bingham St. Site

This site was selected to demonstrate the proportional, or analog mode of regulator operation, using the U-tube sensor, as described in Section 1. The multiple dip tube sensor would be located in the interceptor, on the Northeast side of Tacony Creek, a distance of about 400 ft. from the regulator location. The U-tube sensor would be located in a man-hole about 30 ft. from the regulator. The U-tube sensor fluid would be ethylene glycol (auto antifreeze)

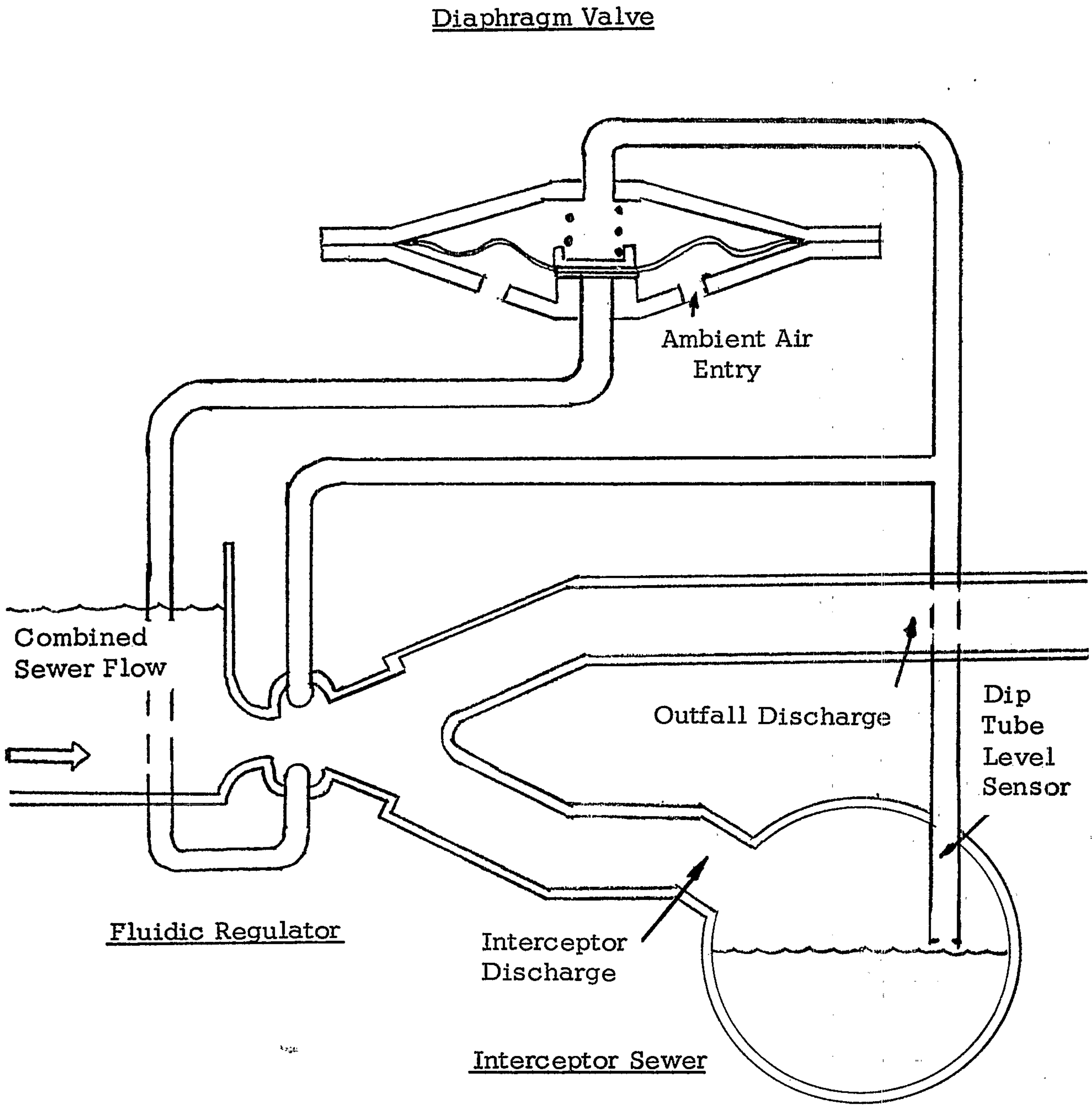


Figure 8 System Schematic Arrangement using Diaphragm Valve

on account of its low freezing temperature, low volatility, general chemical inertness, and general availability.

Using Bernoulli's equation, the maximum suction at either control port, at maximum upstream hydraulic head, was computed to be about -12 in. H_2O. This value would establish the minimum vertical dimension of the dip tube sensors and U-tube, in order to prevent either sewage, or U-tube fluid from entering the connecting air lines. It was found, however, that this value is very dependent on nozzle discharge coefficient, so that for operational margin, a value of 18 in. was selected in the actual design. In the event that the -12 in. H2O value proved accurate, the dip tubes could be easily shortened to the correct lengths, whereas the reverse situation would require major rework of the whole U-tube assembly.

Figure 70 from Ref. #1 was used to define the vertical locations of the dip tube ends, so that linear flow diversion with interceptor level change would be achieved. This analytical procedure is described in Appendix A. Also included in the final design analysis was the effect of the higher density of ethylene glycol on dip tube length, and adjustment in dip tube length to compensate for the effect of the fluid volume contained in the dip tubes as they empty successively with falling U-tube fluid level. This effect was minimized by selecting the section area of the U-tube large in comparison with that of each dip tube.

A connecting air line inside diameter of 4 in. was selected using Figure 13 of Ref. #1. Each dip tube inside diameter was set at 1 in., while an inside diameter of 12 in. was selected for the U-tube.

SECTION 7

DESIGN AND CONSTRUCTION

GENERAL

This section describes the specific approaches used in the design and construction of the fluidic regulator elements, their appurtenances, and the overall sites, for both the 67th/Callowhill and Bingham St. installations.

DESIGN

67th/Callowhill Site

The design objectives for this installation were to replace a small conventional (1.05 cfs) static slot (or leaping weir) regulator with a fluidic type, obtaining the much improved hydraulic performance of a dynamic type regulator, with minimum reconstruction costs.

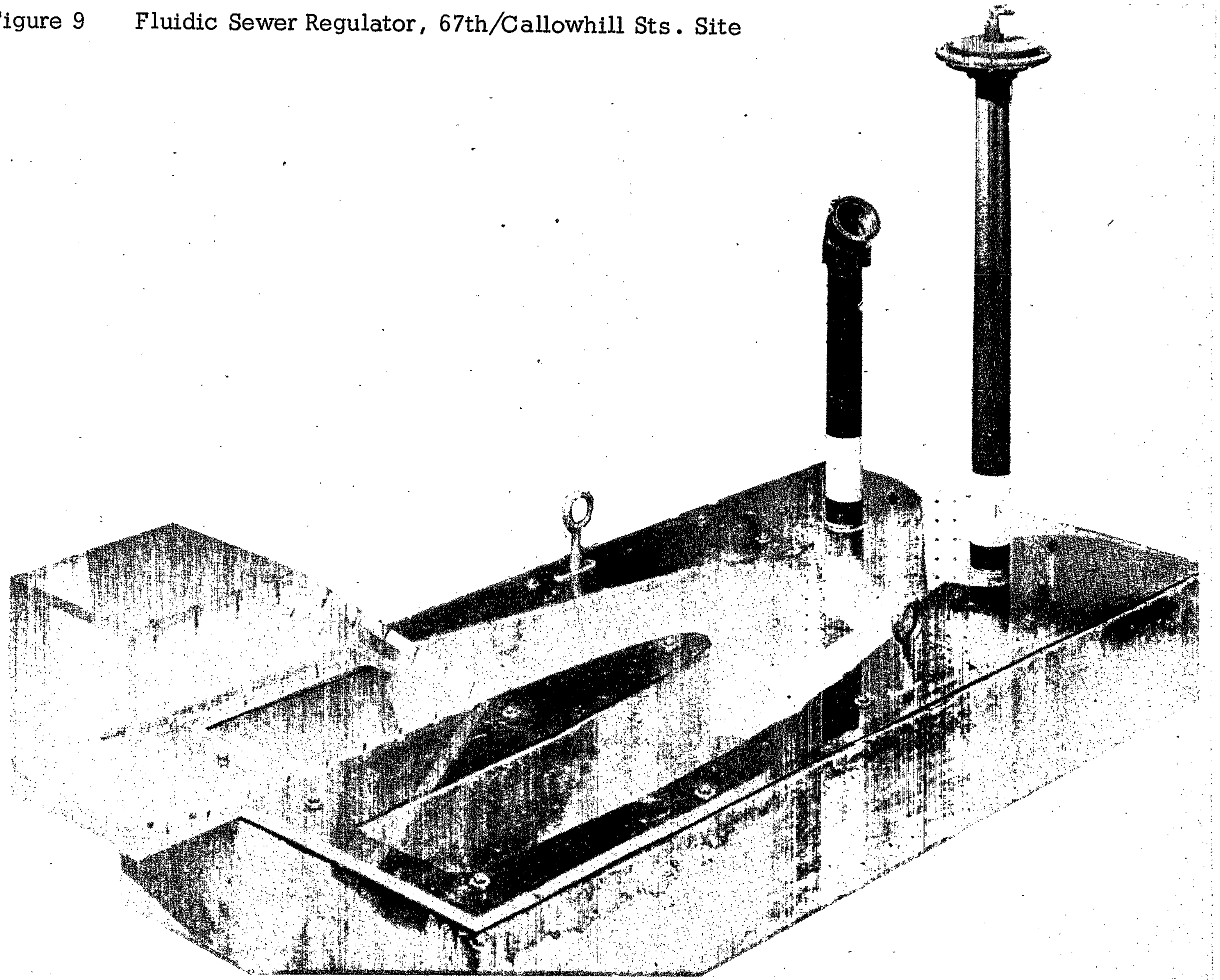
Regulator--

The selected construction material was reinforced concrete. The unit was poured around a male core, contoured to the inside flow passage geometry. Hoisting hooks and studs for attachment of the regulator cover and the securing of the regulator to the upstream dam were molded into the concrete. The regulator cover was designed from transparent plastic, as an aid to demonstrating the fluidic regulation action. The regulator was designed so that interceptor flow would be discharged through a drop opening in the regulator base, while outfall flow would be discharged over an elevated weir and through a shroud constructed as part of regulator cover. Air and water seals were accomplished by a foam rubber gasket between the cover and regulator body. The outline of the fluidic element shape was cut out of the gasket to permit viewing of the internal flow. Control port connections were made by NPT (F) bosses in the plastic cover. The regulator is shown before installation in Figure 9.

Sensors--

The dip tube sensor was designed for construction from standard PVC Schedule 40 pipe and fittings. Orifices were designed as 1/8 in. sheet PVC discs, cemented into the control port fittings. The diaphragm valve was designed for construction from PVC shells, with a neoprene sheet diaphragm

Figure 9 Fluidic Sewer Regulator, 67th/Callowhill Sts. Site



clamped between. The valve was assembled using aluminum screws. The valve spring was spring steel wire, protected from corrosion by rust-resistant enamel. The valve flap was a PVC sheet disc, cemented to the diaphragm.

Site--

A comparison of the site before and after modification is shown in Figure 10. As shown, the modification consisted of the removal of the curved plate, and minor excavation in the invert and crown of the sewer at the slot location, for the installation of the fluidic regulator element and dam. The level sensor was located in an upstream manhole 75 ft. from the regulator. The sensor was protected from flow-borne debris by an aluminum deflector. PE pipe, 1-1/2 in. in diameter was mounted on the sewer crown to provide pneumatic communication between the sensor and regulator. The diaphragm-valve was mounted on the manhole wall, over the regulator. Site design drawings for this installation are shown in Figures 11 and 12.

Bingham St. Site

The regulator site at Bingham Street and Tacony Creek dictated a different design approach. The larger size of the regulator element, (DWF = 4 cfs) necessitated the construction and hydraulic testing of the regulator on-site.

Regulator--

The fluidic regulator element was designed for construction of reinforced concrete, with a stainless steel splitter nosing. A 3/8 in. thick stainless steel plate would form the element cover, and would contain the connections for the sensor connecting air lines. It would be placed as a unit below the invert of the outfall, and a concrete dam would be constructed above it. A number of possible locations were studied for the installation of the regulator. The existing outfall structure is comprised of unreinforced concrete arch sections 7 ft. high by 10 ft. 3 in. wide, approximately 15 ft. below the existing ground line. Important considerations were the depth and volume of excavation, and the potential structural problems that might result from cutting into the existing concrete sections. The three most promising approaches were:

1. The removal of the existing dam, and the reconstruction of a 20 ft. section of the outfall, with the regulator element located beneath a new, higher dam, and the sewer crown excavated to provide sufficient flow area over the dam for heavy storm flows.

2. The location of the regulator element below the existing dam, and below the existing sewer invert. The regulator outfall discharge would flow into a closed parallel pipe below the existing sewer structure, which would reenter the sewer near its opening into Tacony Creek.

3. The location of the regulator element as in 2., but with the regu-

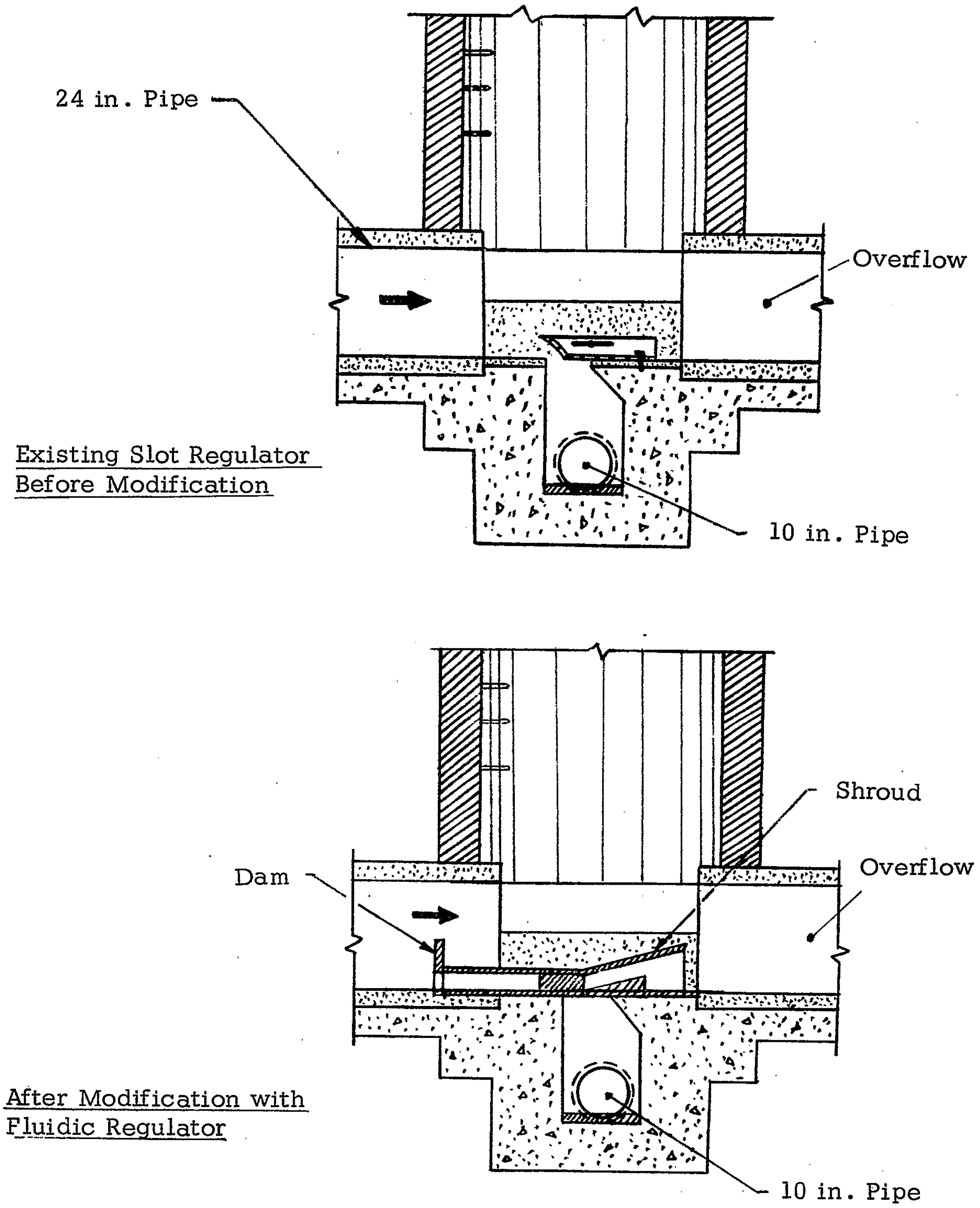


Figure 10 67th/Callowhill Regulator Site, Before and After Modification

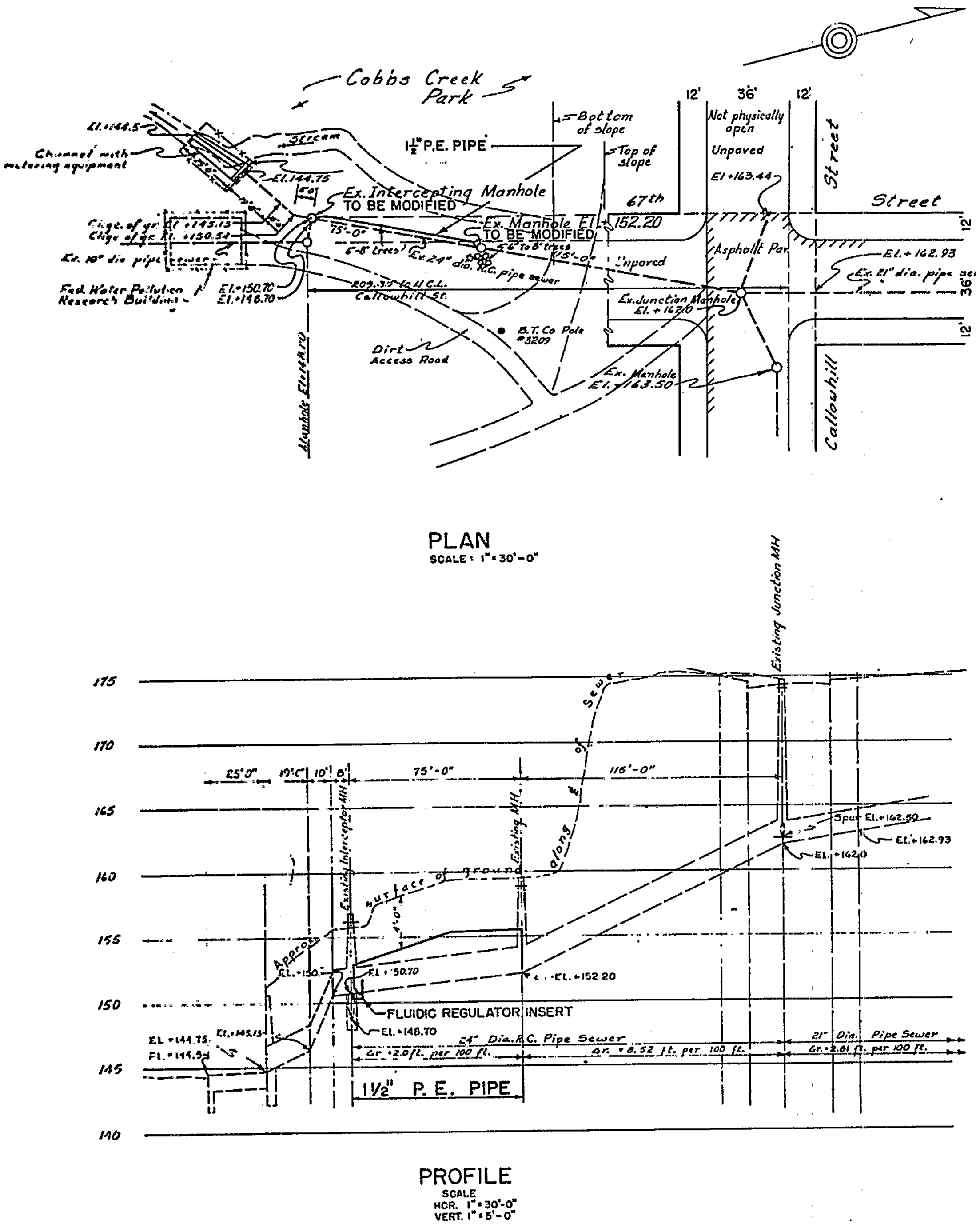


Figure 11 Site Design, 67th/Callowhill Sts.

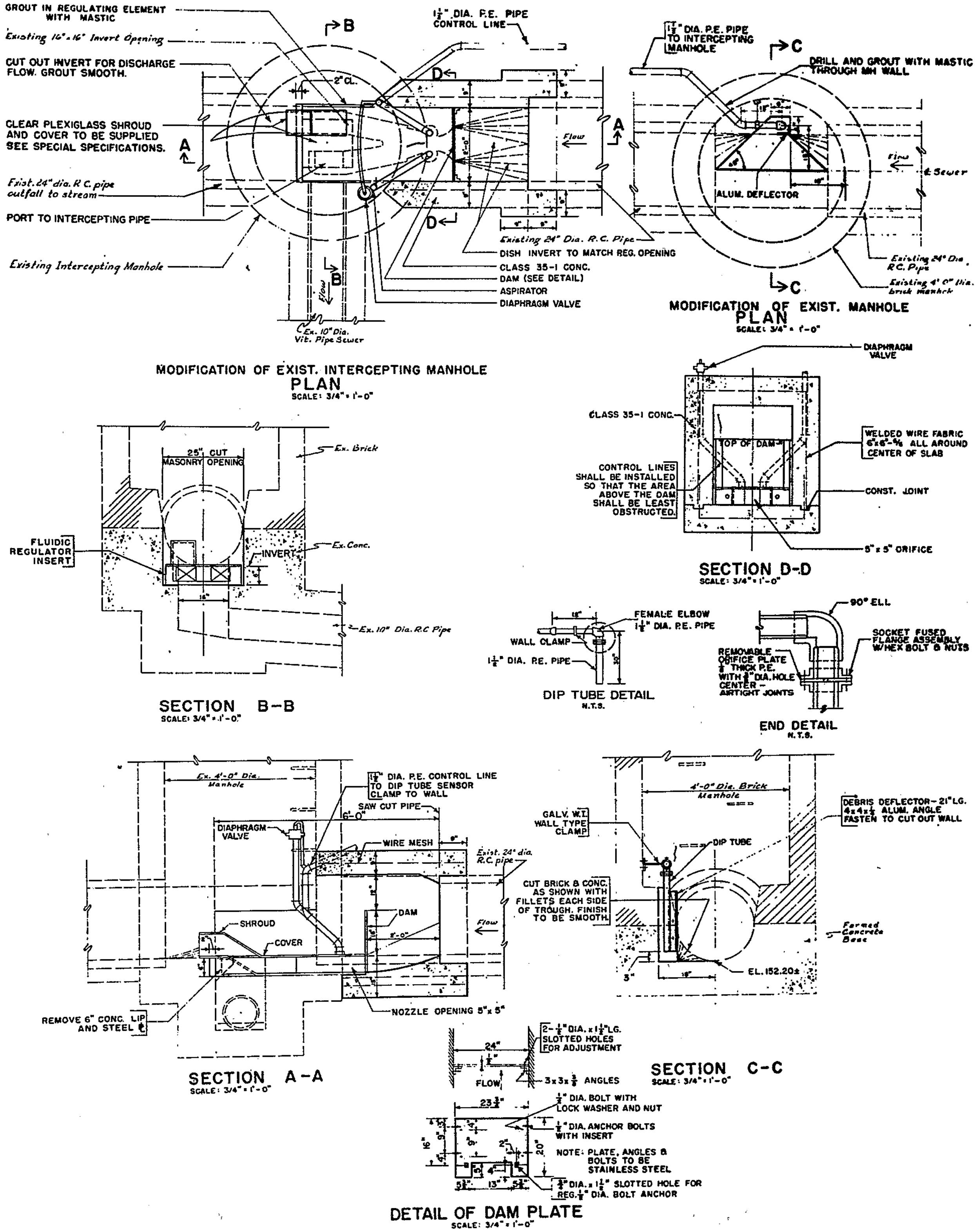


Figure 12 Site Design, 67th/Callowhill Sts.

lator outfall discharge flowing into an open channel, 18 in. wide, cut into the sewer invert with a starting depth of about 1 ft. near the element, tapering to zero at a point about 100 ft. downstream.

After evaluating the above with respect to hydraulic performance, structural feasibility, and cost, it was decided to pursue approach #1. Site design drawings are shown in Figures 13 through 16.

Sensor-to-Regulator Communication--

At this site, the distance between the interceptor sewer dip tube sensor and the regulator element was about 400 ft. Based on the control line size criteria, page 26, Ref. #1, a line inside diameter of 4 in. would be required. Alternatives considered were pneumatic-mechanical, and electro-mechanical systems. In view of their greater complexity, the probable need for an auxiliary energy source, and the desirability of demonstrating the "no-moving-parts" fluidic approach, these alternatives were rejected.

To save additional excavation and construction costs, it was decided to locate the 4 in. control line inside the 24 in. connecting sewer. The selected control line material was PE. The line was to be secured in the manholes at each end of the connecting sewer, and allowed to float free in between, thus eliminating the need to break into the connecting sewer to provide attachment.

Sensors--

The interceptor sewer dip tube sensor was designed for construction from a section of 4 in. PVC Schedule 40 pipe, with 1 in. PVC pipe dip tubes threaded into the lower side. The U-tube sensor was designed for construction of sections of 12 in. diameter PVC pipe sections, welded to end pieces of 1/4 in. PVC sheet. The dip tubes would be varying lengths of 1 in. PVC pipe.

CONSTRUCTION

Bingham St. Site

Figure 17 shows this site under construction. The completed dam installation is shown in Figure 18. The interceptor and U-tube sensors are shown in Figures 19 and 20.

When construction was completed, the existing manual gate upstream from the dam was closed and dry weather flow was directed through the fluidic regulator. Controls were set for maximum flow diversion to the interceptor, pending the field calibration phase.

67th/Callowhill Site

Construction for the 67th/Callowhill site required only 7 working days.

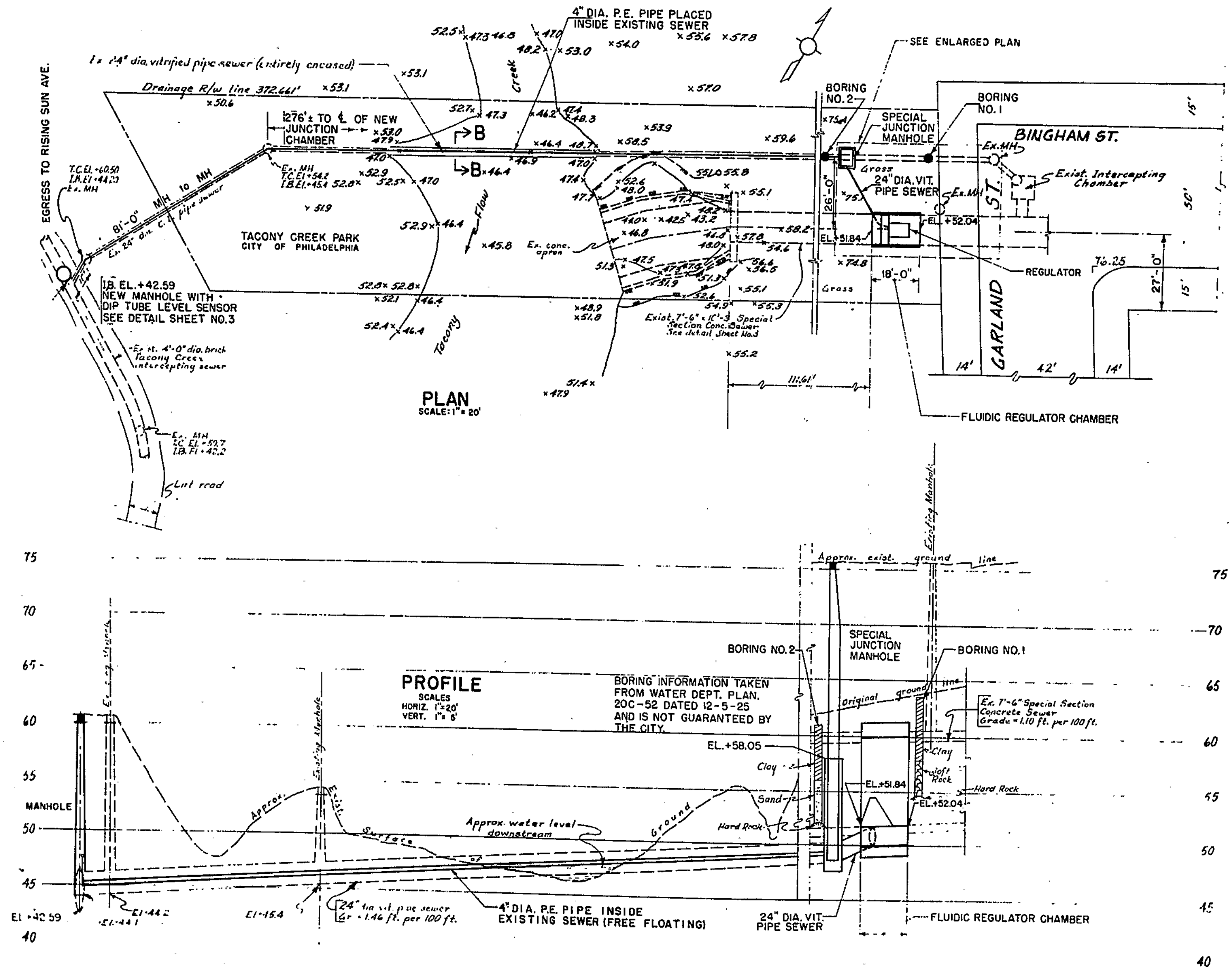
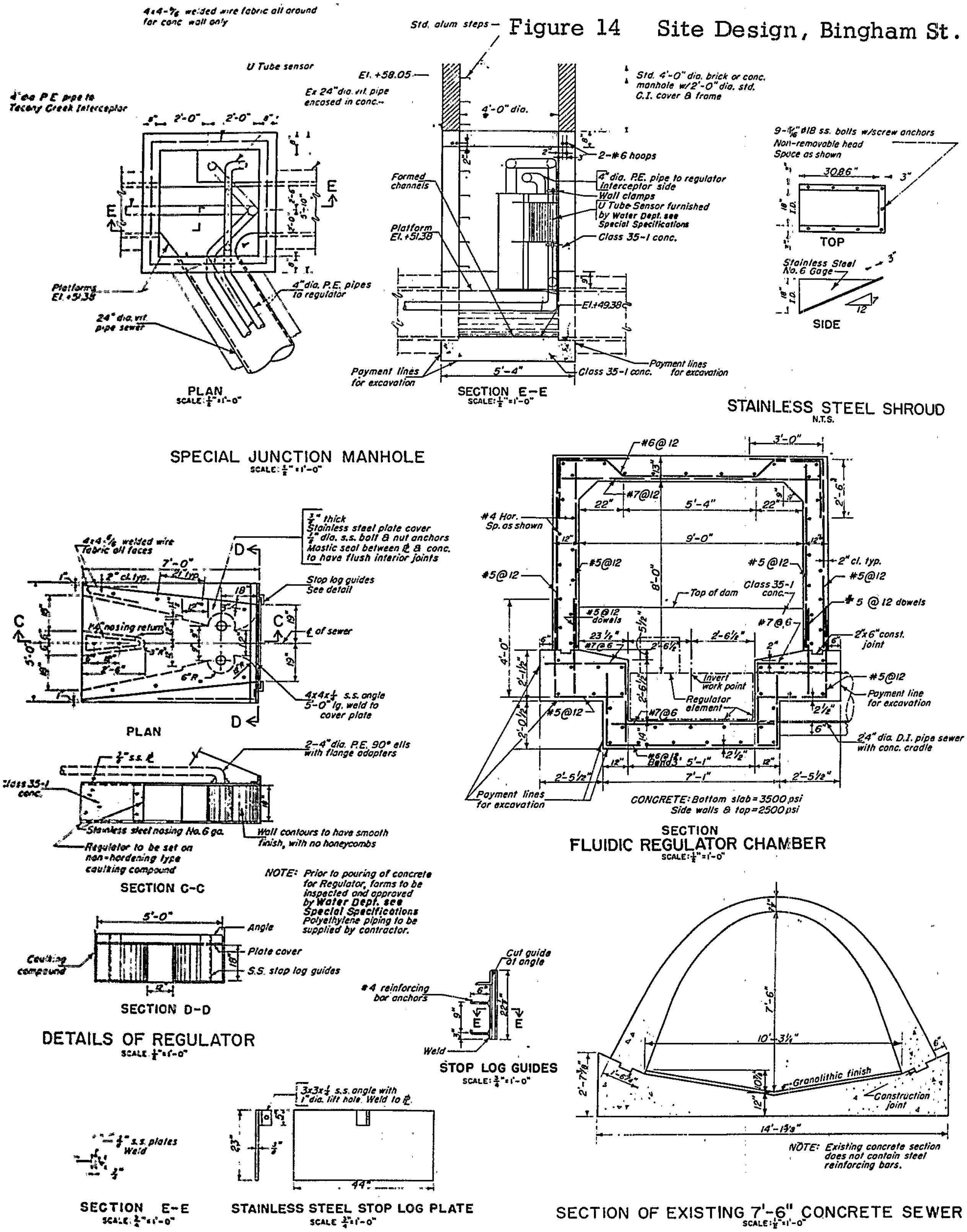


Figure 13 Site Design, Bingham St.

Figure 14 Site Design, Bingham St.



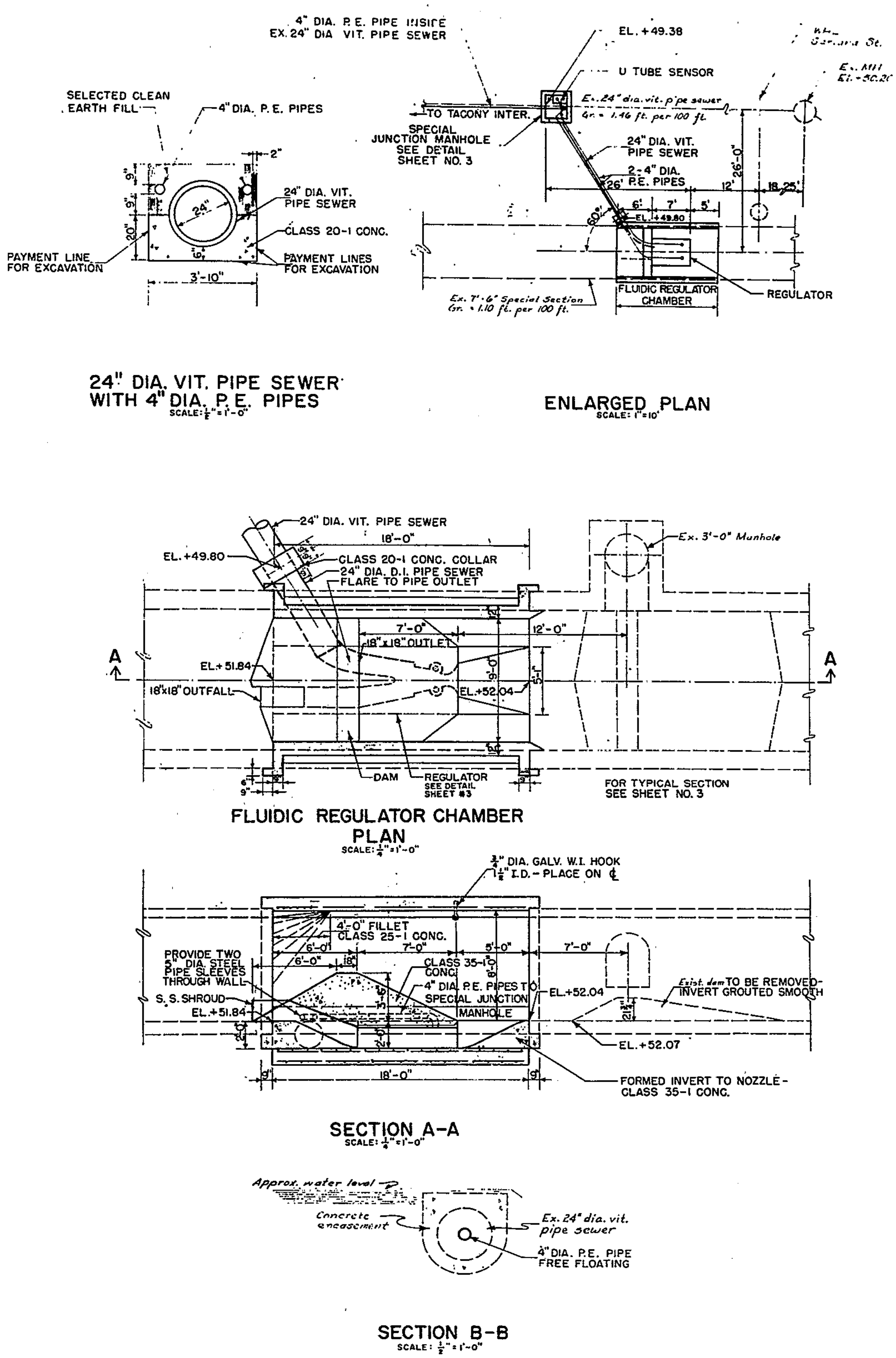


Figure 15 Site Design, Bingham St.

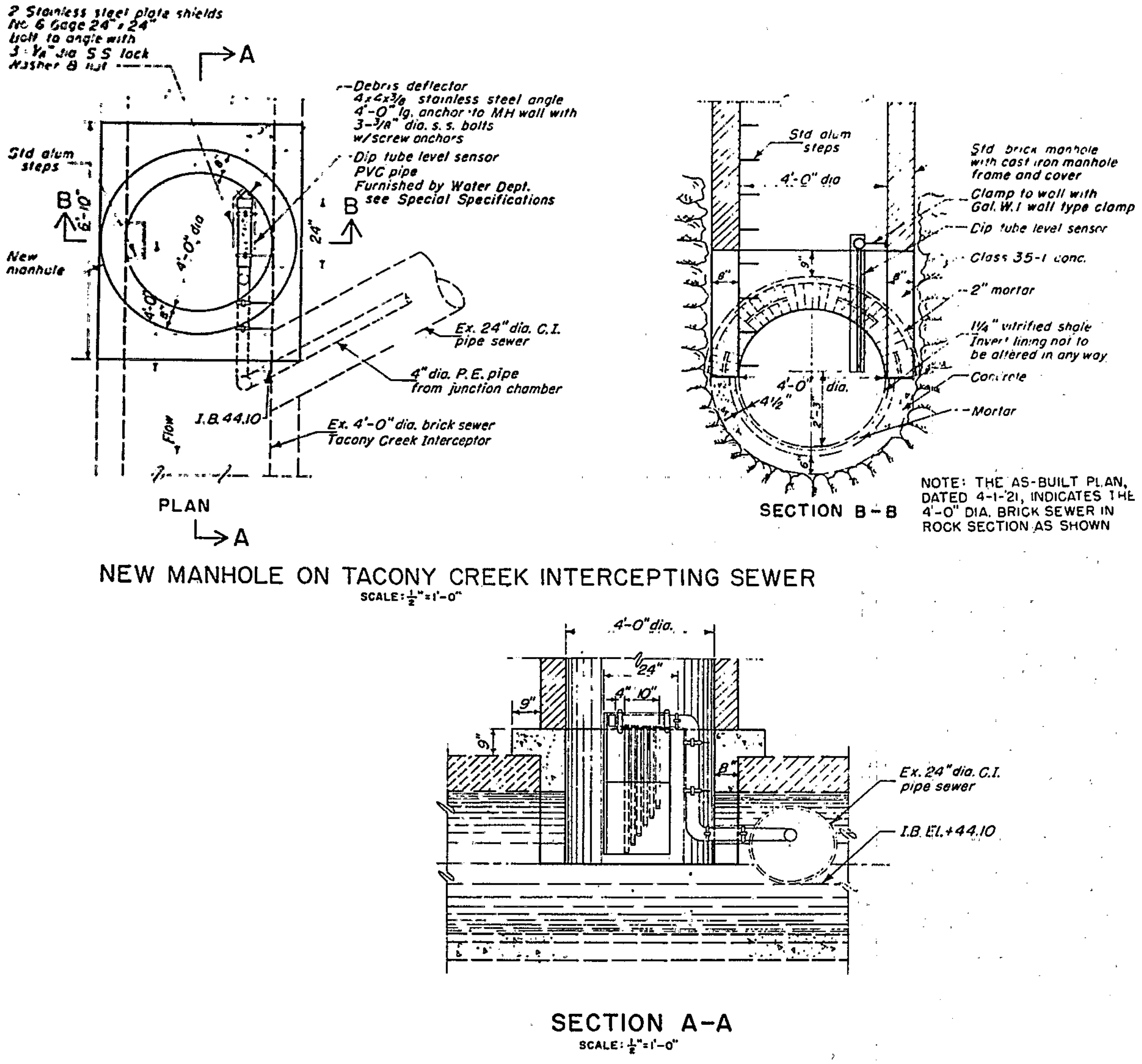


Figure 16 Site Design, Bingham St.

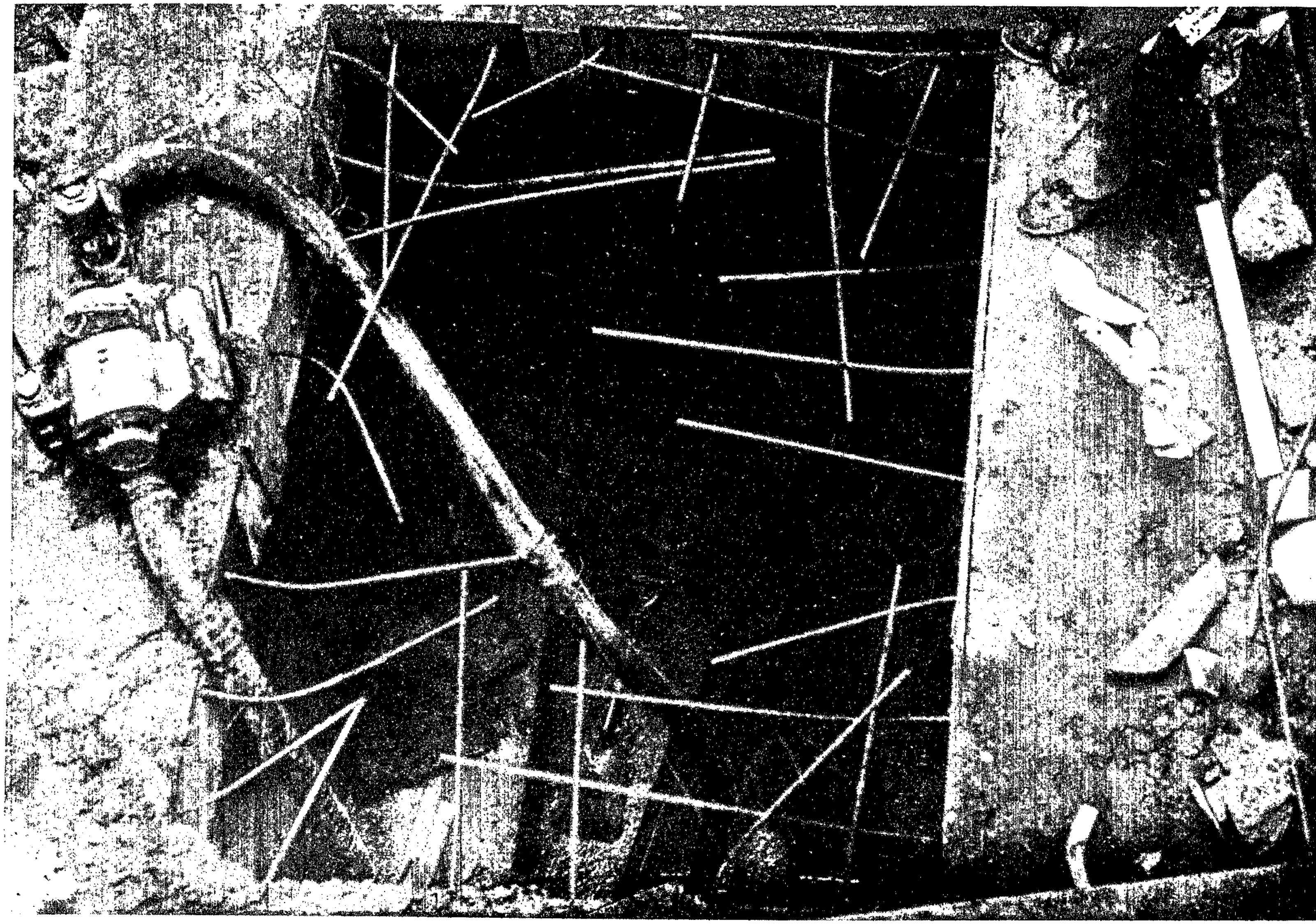


Figure 17 Bingham St. Fluidic Regulator under Construction

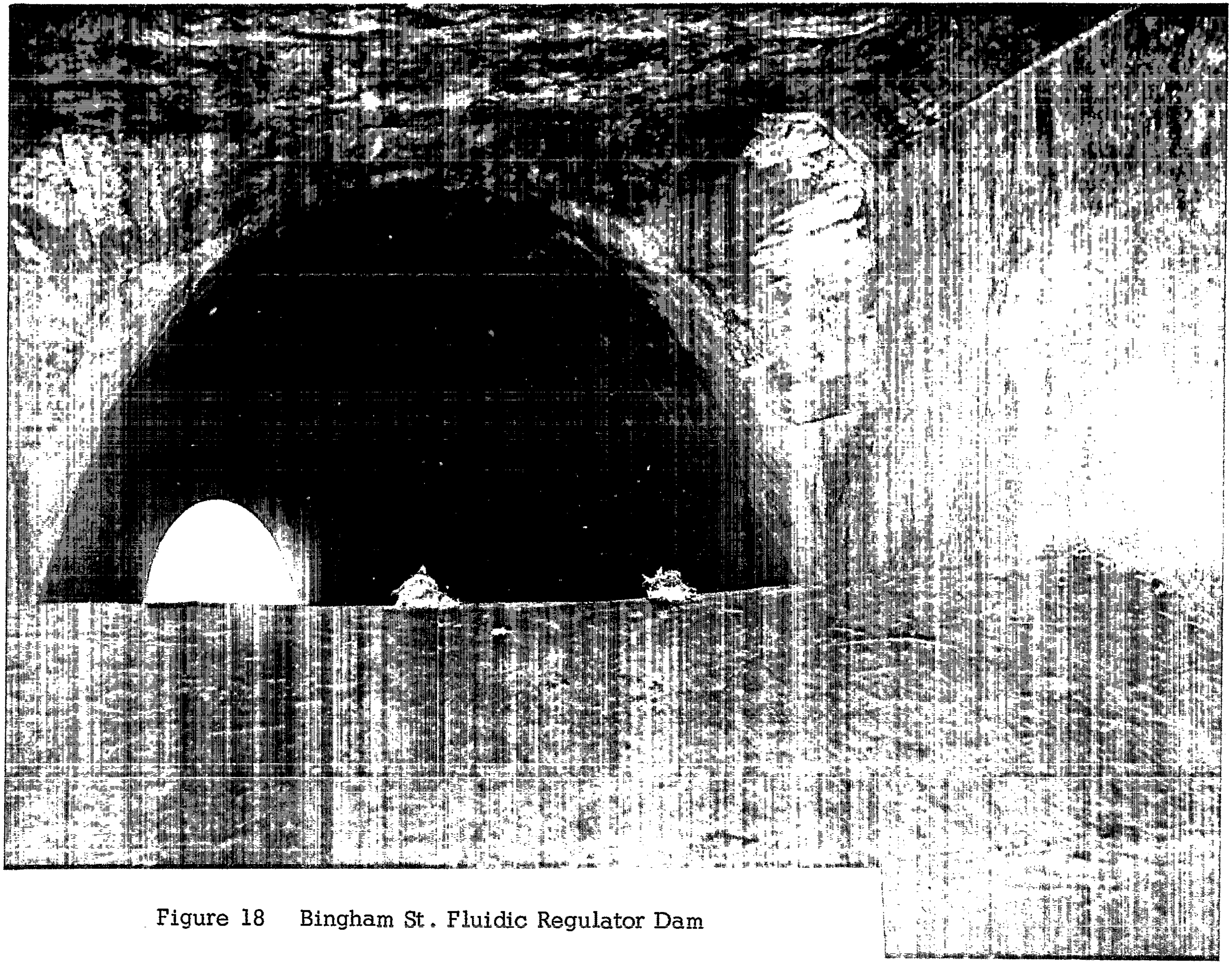


Figure 18 Bingham St. Fluidic Regulator Dam

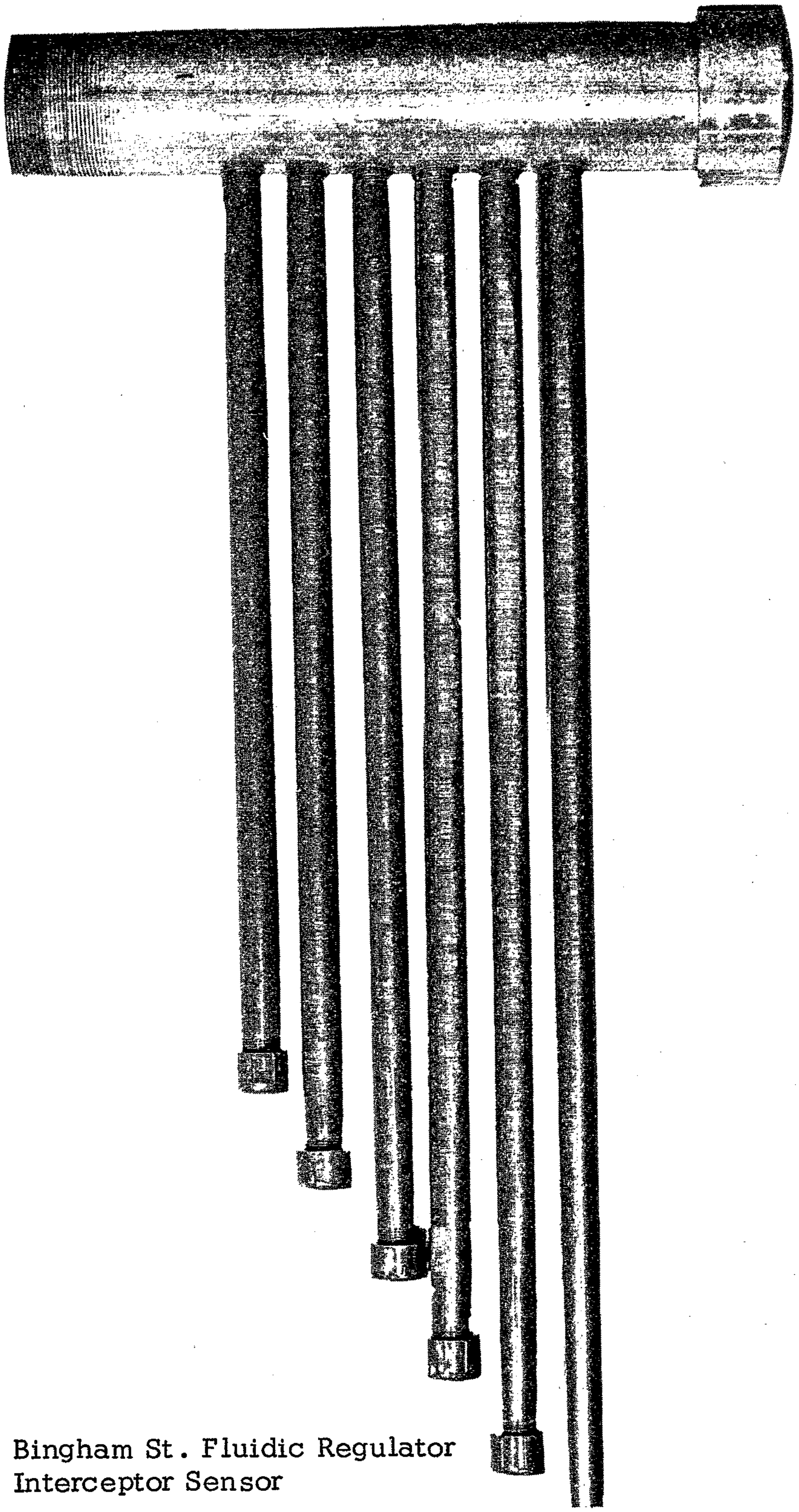


Figure 19 Bingham St. Fluidic Regulator Interceptor Sensor

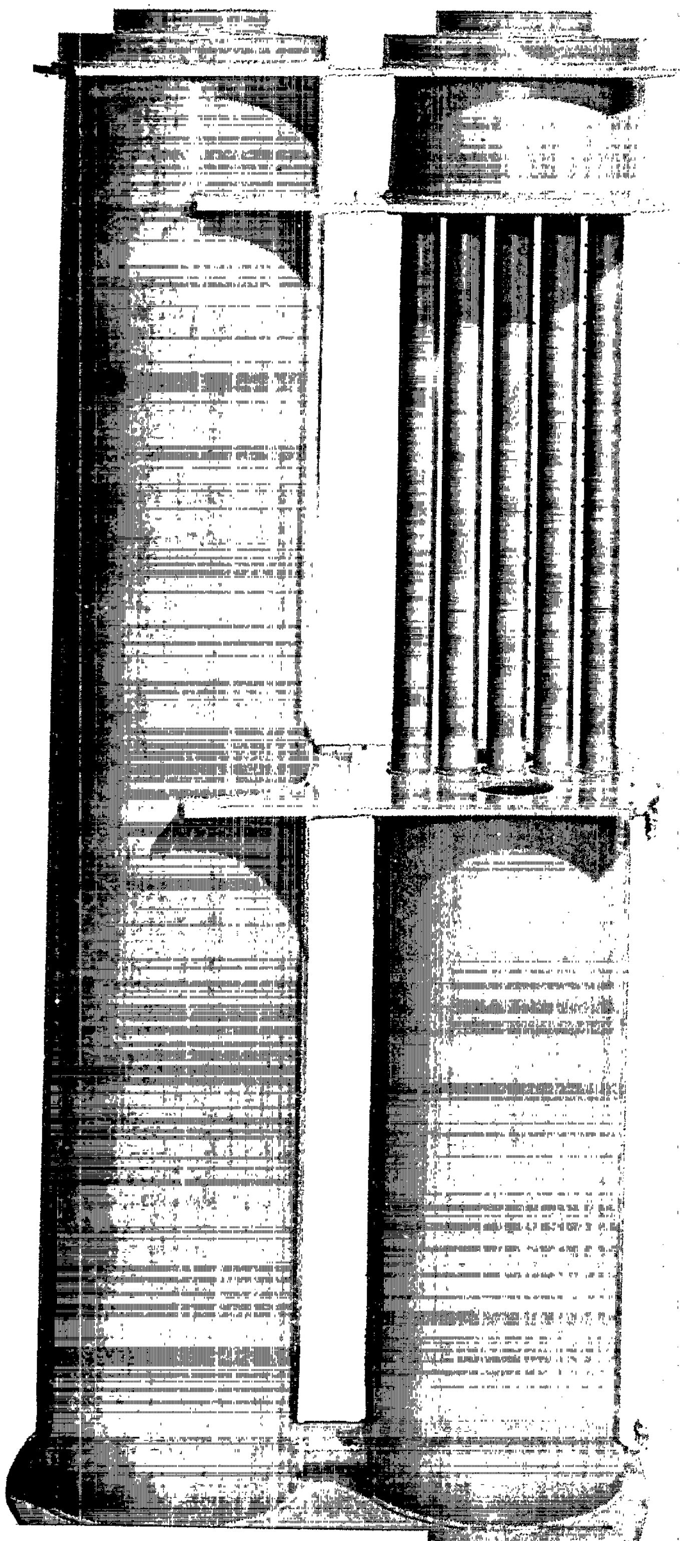


Figure 20 Bingham St. Fluidic Regulator
U-Tube Sensor

This was attributed both to the smaller size of this regulator, and the fact that it was prefabricated off-site, and required only insertion into place. The existing brick manhole for the slot-type regulator, as shown in Figure 21, was replaced with a precast unit which also speeded construction. Completion of the construction contract for both sites was accomplished by July 15, 1973, well within the specified 70 working days. The completed regulator installation is shown in Figures 22 and 23. The completed dip tube sensor installation is shown in Figure 24.

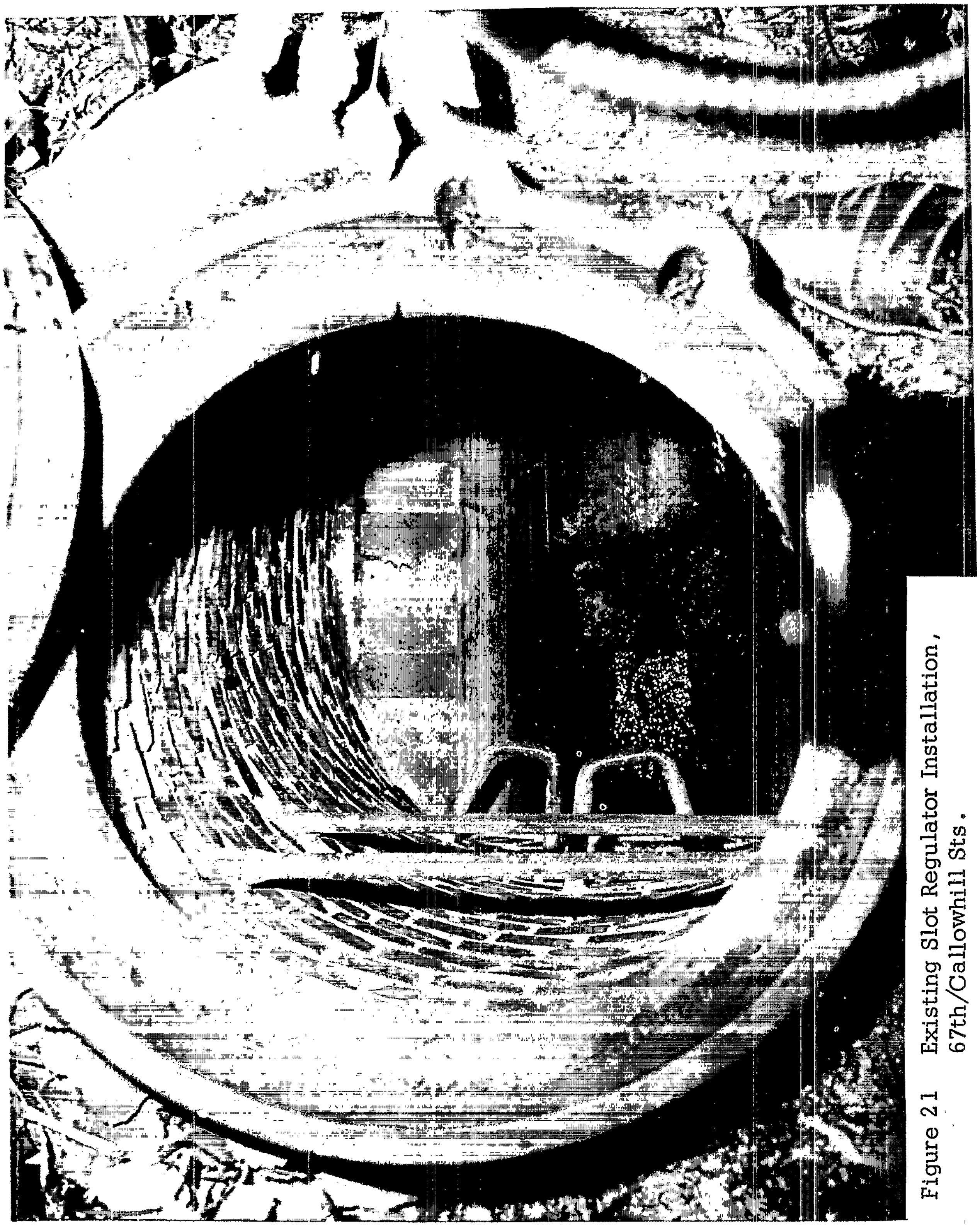


Figure 21 Existing Slot Regulator Installation, 67th/Callowhill Sts.

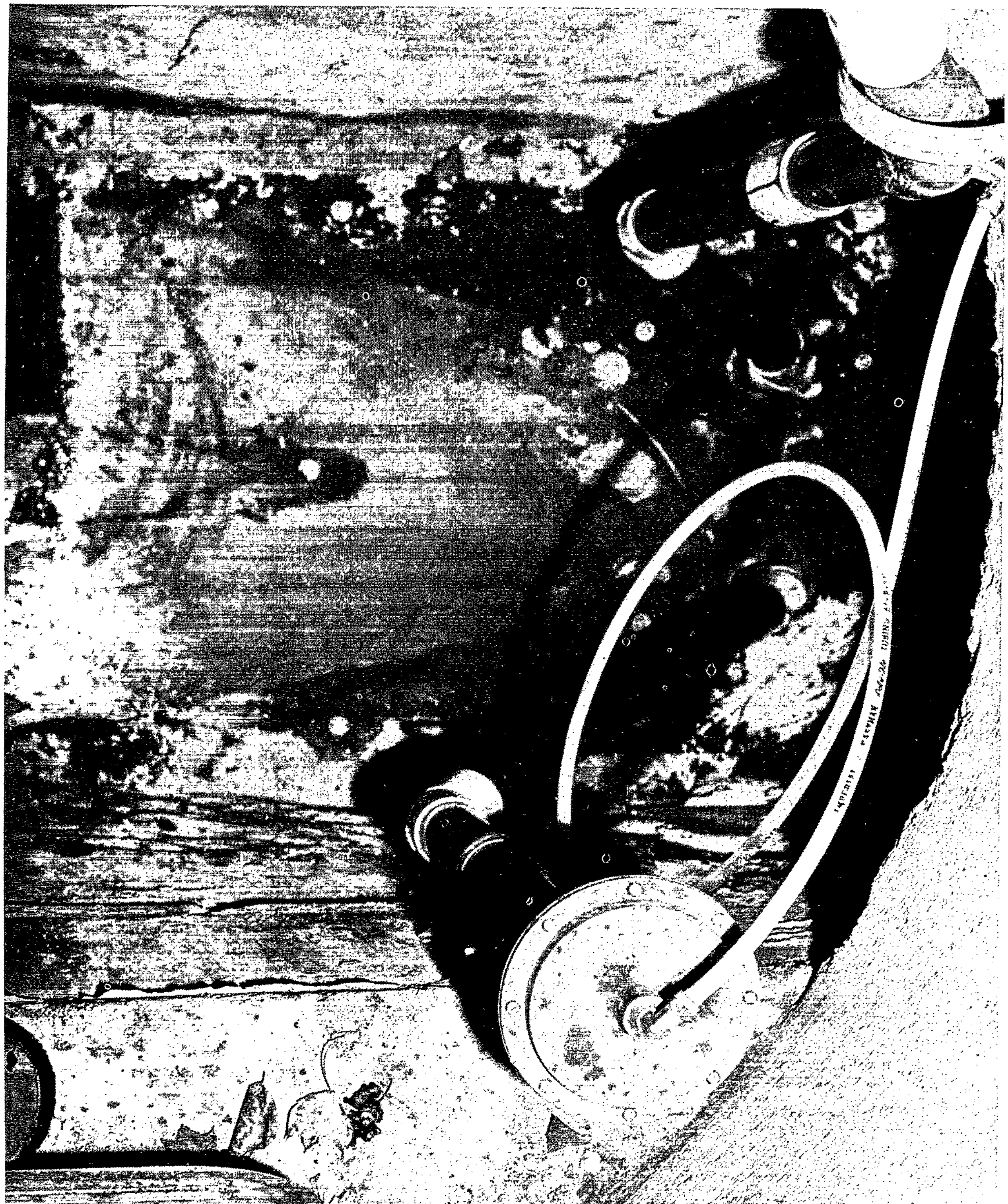


Figure 22 Fluidic Regulator Installation, 67th/Callowhill Sts.

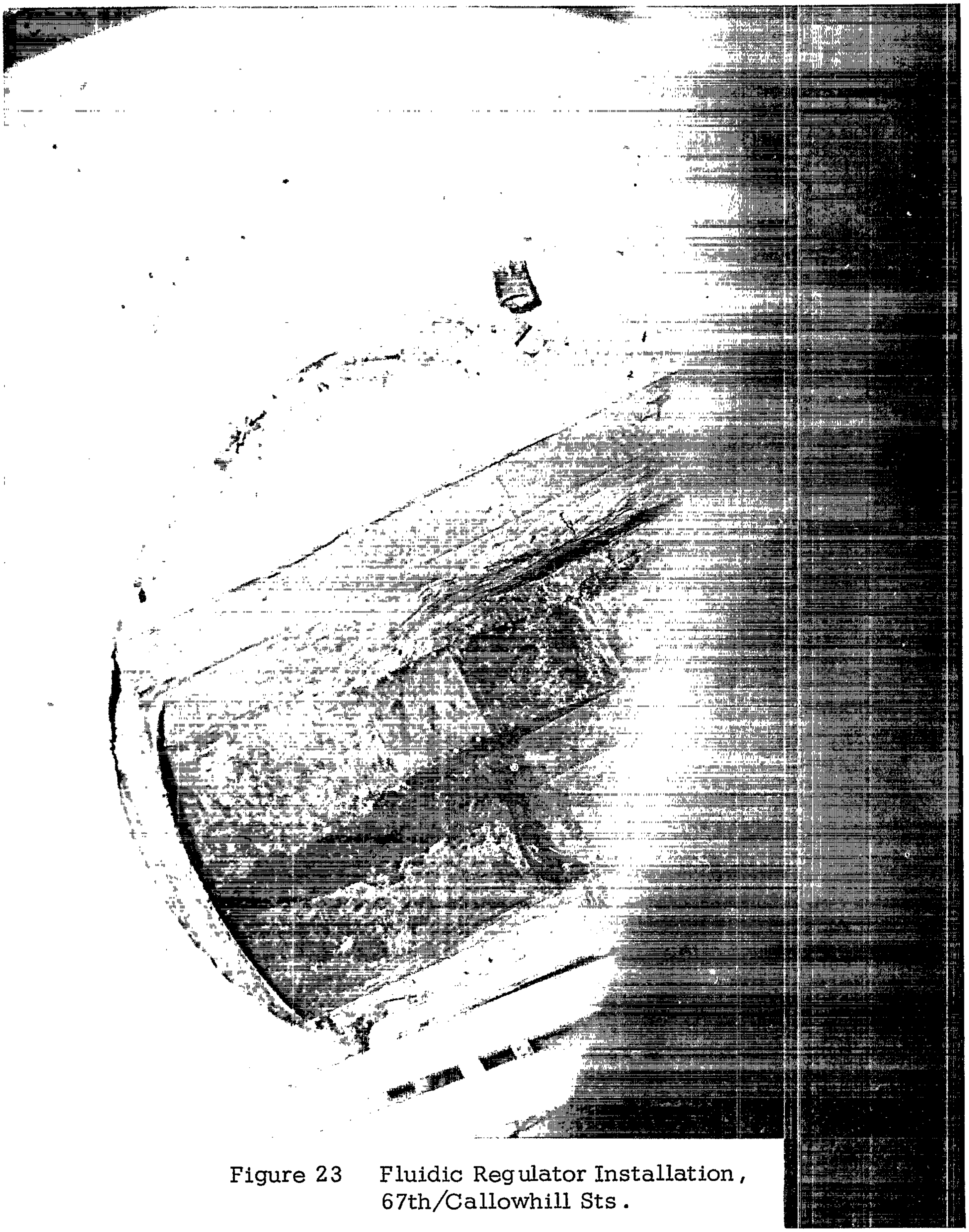


Figure 23 Fluidic Regulator Installation, 67th/Callowhill Sts.

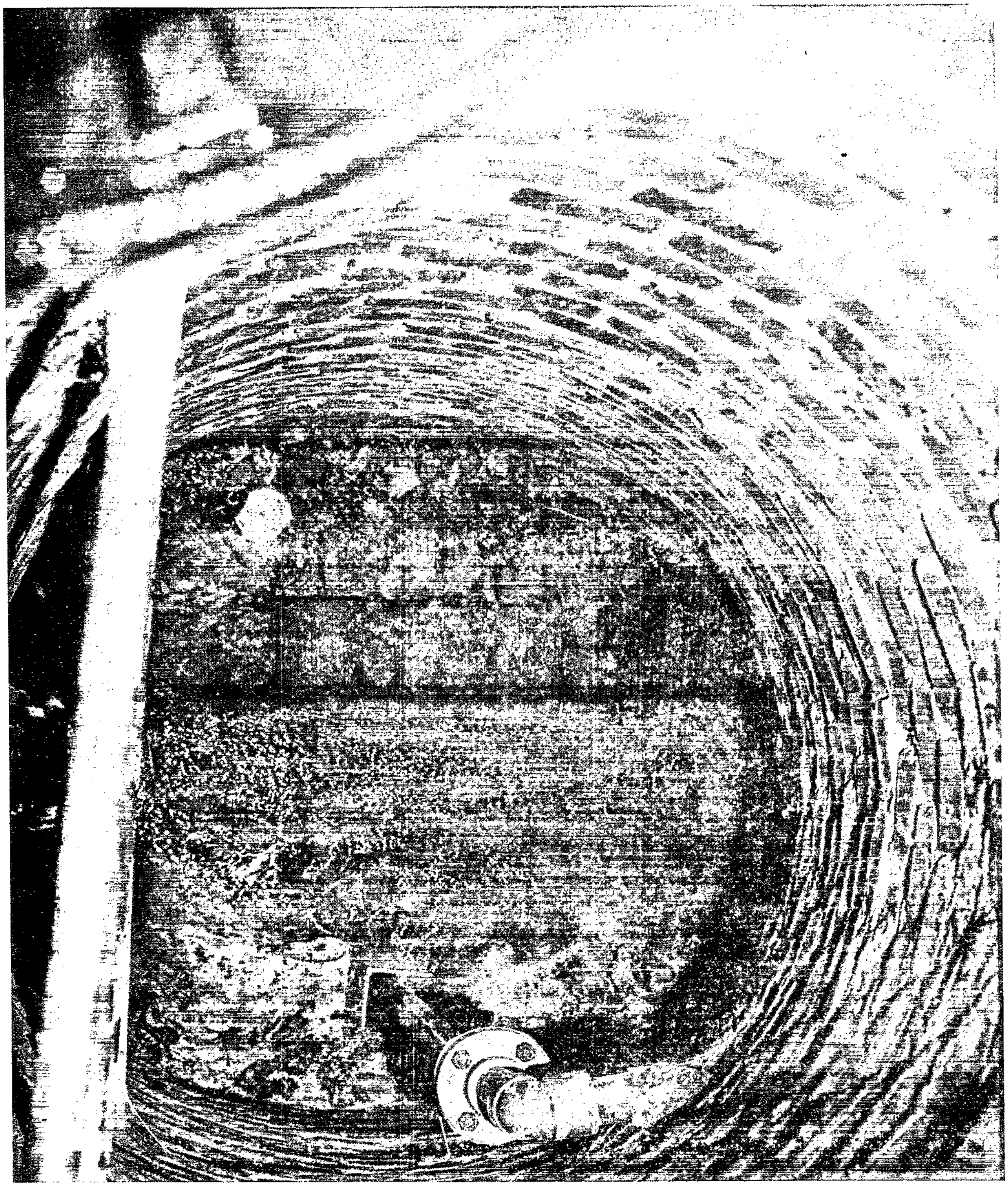


Figure 24 Fluidic Regulator Dip Tube Sensor
67th/Callowhill Sts.

SECTION 8

REGULATOR CALIBRATION

67TH/CALLOWHILL SITE

The calibration procedure for this regulator consisted of determining the flow diversion ratios, relative to total regulator flow, for the outfall and interceptor-side discharges, as a function of upstream hydraulic head, for conditions of either dip tube above water, or dip tube submerged. Calibrations were performed on this unit in the laboratory at Bowles Fluidics Corporation, as well as at the field site. Calibration details can be found in Appendix B.

Laboratory Calibration

Two settings of outfall weir height were tested to establish the minimum weir elevation for negligible trickle flow when maximum control was applied toward the interceptor discharge. Total regulator flow was established for the calibration by the flow prediction criteria, page 20, Ref. #1. Outfall flows were estimated using the flow continuity approach: $Q = A \times V$, in which A = flow cross-section area over discharge weir, and V= flow horizontal velocity across the weir. V was determined by measuring the horizontal "jump" distance of the discharge flow stream, while dropping a reference vertical distance, assuming free-fall conditions, and neglecting aerodynamic drag on the flow stream. The interceptor discharge flow was computed as the difference between the total and outfall flows.

Initial runs were made using the simple orifice arrangement of Figure 1. Unacceptably large trickle flows occurred over the outfall discharge when maximum control was applied toward the interceptor discharge. The drop opening area was enlarged, relieving the problem considerably. It was found, however, that trickle flows could only be reduced to a "negligible" level (negligible was established as occurring less than 20% of the time, corresponding to about 0.1% of the total flow) if aspirated airflow through the orifice were cut off completely. Since this condition could be obtained using a diaphragm valve, the orifice configuration was discarded, and the balance of the runs were made with one control port blocked, the other fully open, depending on the direction of applied control. At the same time, development was started on a diaphragm valve.

Upon the availability of a diaphragm valve, the regulator calibration was repeated, using the valve. The results of both calibrations are shown in Figure 25, together with the predicted values from the performance analysis. The calibration values show a diversion margin over the predicted characteristic for all but the lowest values of upstream hydraulic head, thus indicating acceptable performance.

Site Calibrations

Site calibrations were started in July, 1973, and completed in October, 1973. Storm flow was simulated by opening fire hydrants upstream from the diversion site. Total regulator flow was established using the flow vs. head criteria of Ref. #1 and the sum of the measured flows from interceptor and outfall discharges. These were determined using 90^{o} V-notch weirs. Early calibration attempts indicated low values of outfall discharge flow rate, in comparison to the laboratory calibrations. It was found that insufficient time was being allowed in taking these readings, for the water level in a large tank upstream of the V-notch weir to stabilize, particularly at the high head readings. The flow measurement equipment for interceptor flow, used in the Microstrainer Evaluation Program (Ref. #3), also located at this site, proved inoperative, necessitating the construction of the second V-notch weir.

The final calibration results are shown on Figure 26. The total flow curves using the Ref. #1 criteria and the sum of the discharge measurements agree well for all but the highest head readings, again indicating that insufficient time was being allowed before taking the outfall discharge readings. Diversion performance curves were computed using: a) the measured values of outfall discharge flows (curve D), and derived values of outfall discharge flow obtained by subtracting measured interceptor flow from the total flow prediction (curve D'). Also shown on Figure 26 is the Ref. #1 prediction of D. The measured value curve agrees well with the predicted values in the middle range of hydraulic head, but drops slightly lower at the high values of head. The derived value curve exceeds the predicted value for all heads above 7 in. Both curves fall below the predicted range at low values of head, as occurred during the laboratory calibrations.

The general performance characteristics, as shown by this calibration, were considered satisfactory, and the unit was judged ready for active service.

BINGHAM ST. SITE

The planned calibration procedure for this regulator was as follows: A series of calibration runs would be made with the ends of the interceptor dip tubes successively plugged, simulating a rising water level in the interceptor. Each run would be made by temporarily damming the regulator inlet, and allowing the dry weather flow to build up behind the dam until the crest was reached.

Figure 25 Laboratory Calibrations
67th/Callowhill Regulator

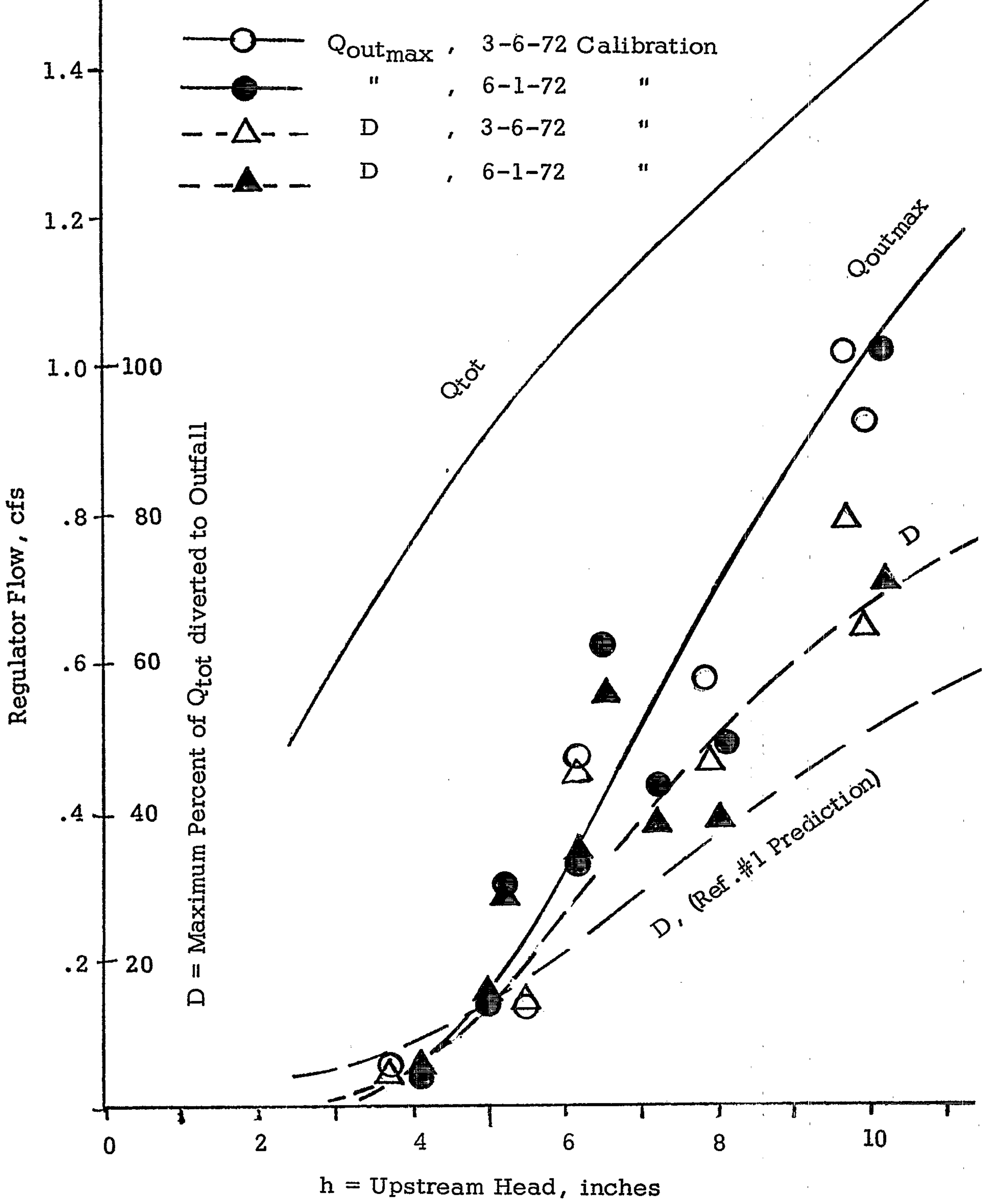
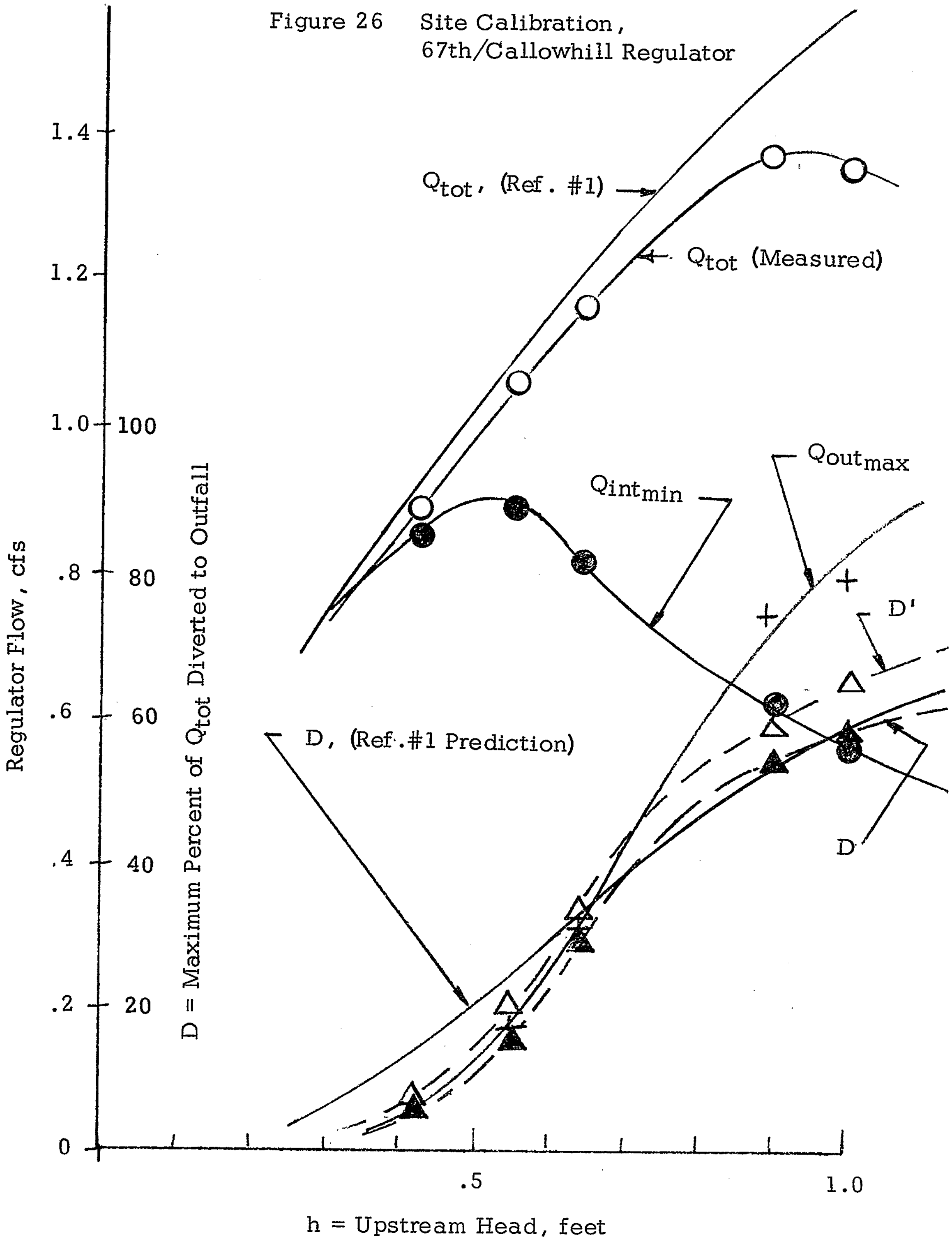


Figure 26 Site Calibration, 67th/Callowhill Regulator



At this time, the inlet was quickly unblocked, providing a calibration run with the hydraulic head decaying from 3.5 ft. to zero over a period of about 3 minutes, after which normal dry weather flow conditions resumed. Flow measurements and hydraulic head readings would be taken at intervals during the run. Total regulator flow would be established using the Ref. #1 flow-head criteria. Outfall discharge flow would be measured using the continuity principle, in which flow rate = outfall flow channel width x flow depth x flow velocity. Flow velocity was obtained using a rotating cup instrument, and also pitot head measurements. The initial runs were made with all the interceptor dip tubes plugged, to determine the maximum diversion capability. Calibration details can be found in Appendix B.

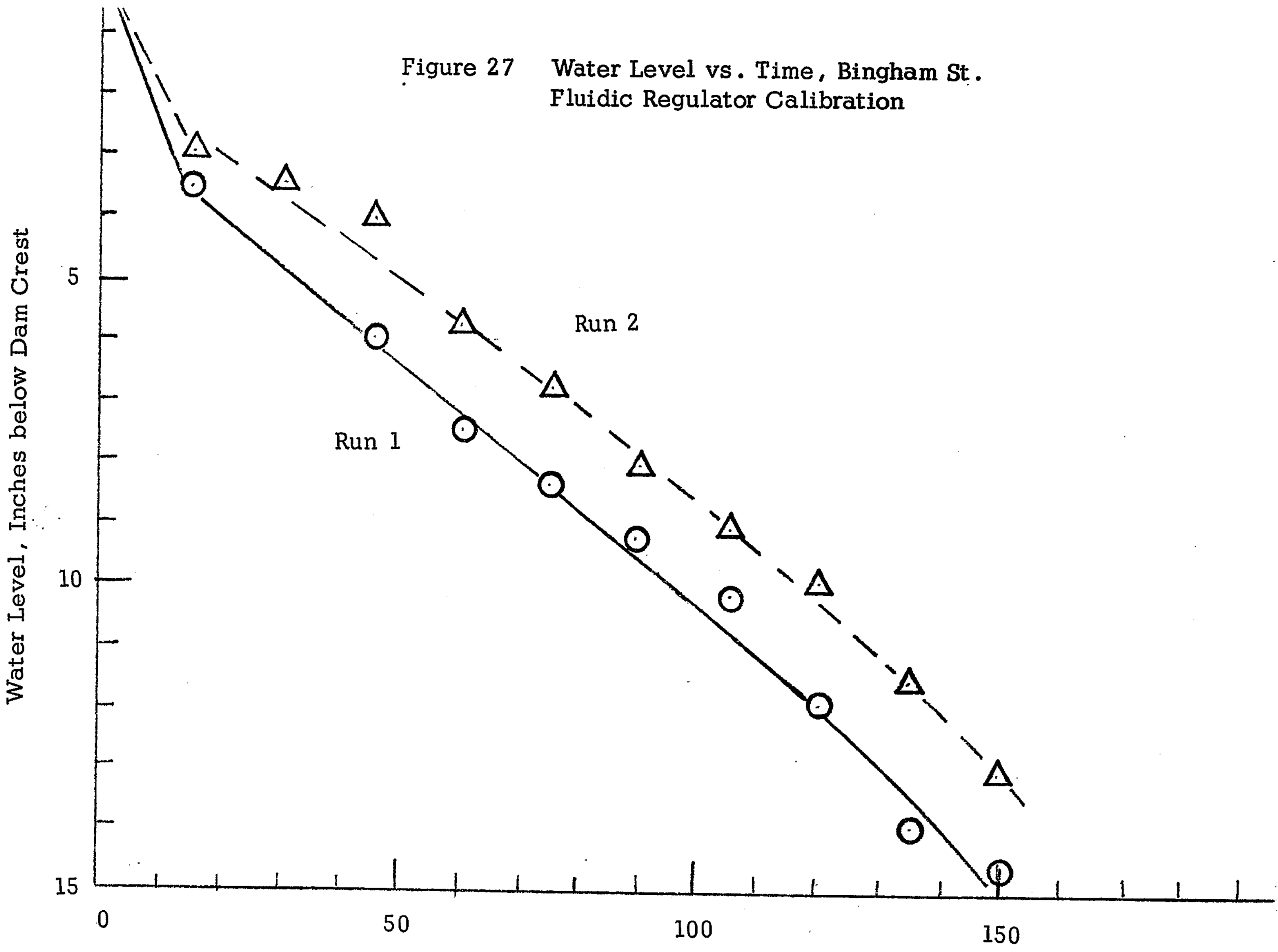
The first attempt was unsuccessful in that hydraulic head could not be built up behind the dam when the inlet was blocked. It was found that the manual sluice gate structure in the by-pass channel had become damaged from the effects of acid in the sewage flow, and was not retaining the flow. The structure was repaired and another attempt was made.

In this attempt, hydraulic supply head was obtained in the desired manner, but the diversion performance was well below the predicted value. A large piece of concrete was found in the bottom of the outfall channel that could not be removed at that time, so maximum diversion runs were postponed pending its removal. A run was made with full control toward the interceptor, to evaluate the trickle flow over the outfall discharge. On this run, the trickle flow was negligible for a period of 15-20 seconds, after which significant flow occurred.

Of interest from this calibration attempt are the supply head time histories of Runs 1 and 2, as shown on Figure 27. Each history shows an abrupt 3:1 decrease in slope in the region of 15-20 seconds after the start of the run, followed by a gradual increase in slope. The gradual increase in slope would be expected as the horizontal dimensions of the impounded water decrease; however, the abrupt decrease in slope indicates a 3:1 decrease in regulator flow rate, presumably caused by a large increase in flow impedance. The piece of concrete found in the regulator did not offer an explanation, since it could have affected only Run 1, even assuming that it entered the regulator 15 seconds after the run start. The sudden appearance of outfall flow on Run 3 also occurred at about 15 seconds after the run start, and was apparently associated with the change in regulator flow.

On the next attempt, with the piece of concrete removed, the diversion performance was improved, but still unsatisfactory, with about 22% of the total flow being diverted to the outfall compared to an expected value of about 50%. The total flow is based on the Ref. #1 criteria and the measured supply head. Readings were made at approximately the maximum supply head only, because of the problem encountered during the previous calibration attempt.

Figure 27 Water Level vs. Time, Bingham St. Fluidic Regulator Calibration



Measurements were also taken of control port pressures, and the outfall-side showed an abrupt change from -12 in. H_2O to -4 in. H_2O after 15-20 seconds of the run, indicating that the flow impedance problem was still present. However, the diversion performance before the impedance change was sufficiently below expectations that it was decided that model tests of the complete regulator configuration should be made to determine the revisions necessary to obtain the desired diversion performance.

Model Test Program

A 1/6 scale model of the Bingham St. installation was constructed and tested, and is shown in Figure 28. The model was constructed with a removable outfall discharge section, since it was felt that this was the area requiring modification. The diversion performance of the model for the existing configuration approximated the observed prototype performance, giving about 35% diversion at the scaled maximum hydraulic head. The model test results for the prototype, and three possible modifications are shown in Figure 29. Accordingly, the model outfall discharge was widened from 3 to 7 in. at the weir crest, maintaining the discharge ramp invert profile. Tests of the revised model configurations showed close agreement between the model diversion performance and the predicted values of the performance analysis. The selected modified configuration (model modification #2) is shown on Figure 30. During the period of revision of the actual installation, a detailed inspection was made of the regulator, and a condition of erosion noted on the inlet nozzle walls. The condition was not considered immediately serious, but indicated the desirability of armoring this area on future installations, particularly where the flow velocity exceeded about 12 fps.

A subsequent calibration attempt involved several runs in which diversion performance was close to predicted values for a few seconds after the run start, dropping to much lower values after about 15 seconds. The outfall-side control port pressures showed a corresponding change from -15 in. H_2O to -5 in. H_2O. On succeeding runs, an observer was placed in the special junction manhole. In each case, the water level was seen to rise to a level about 2 ft. above the connecting sewer inlet after about 15-20 seconds after the run start. This condition acted as a hydraulic overload on the regulator, incapacitating its regulation performance, and confirmed the flow impedance change suspected from previous calibration attempts. Further runs were postponed pending a careful inspection of the conditions in the connecting sewer which might cause the observed flow impedance change. The inspection was performed, resulting in removal of some debris from the connecting sewer between the inlet and a manhole located on an island in Tacony Creek. This operation was significantly impeded by the 4 in. diameter air line.

On the next calibration attempt, representative diversion performance was shown for a short period of time at the beginning of each run, until the

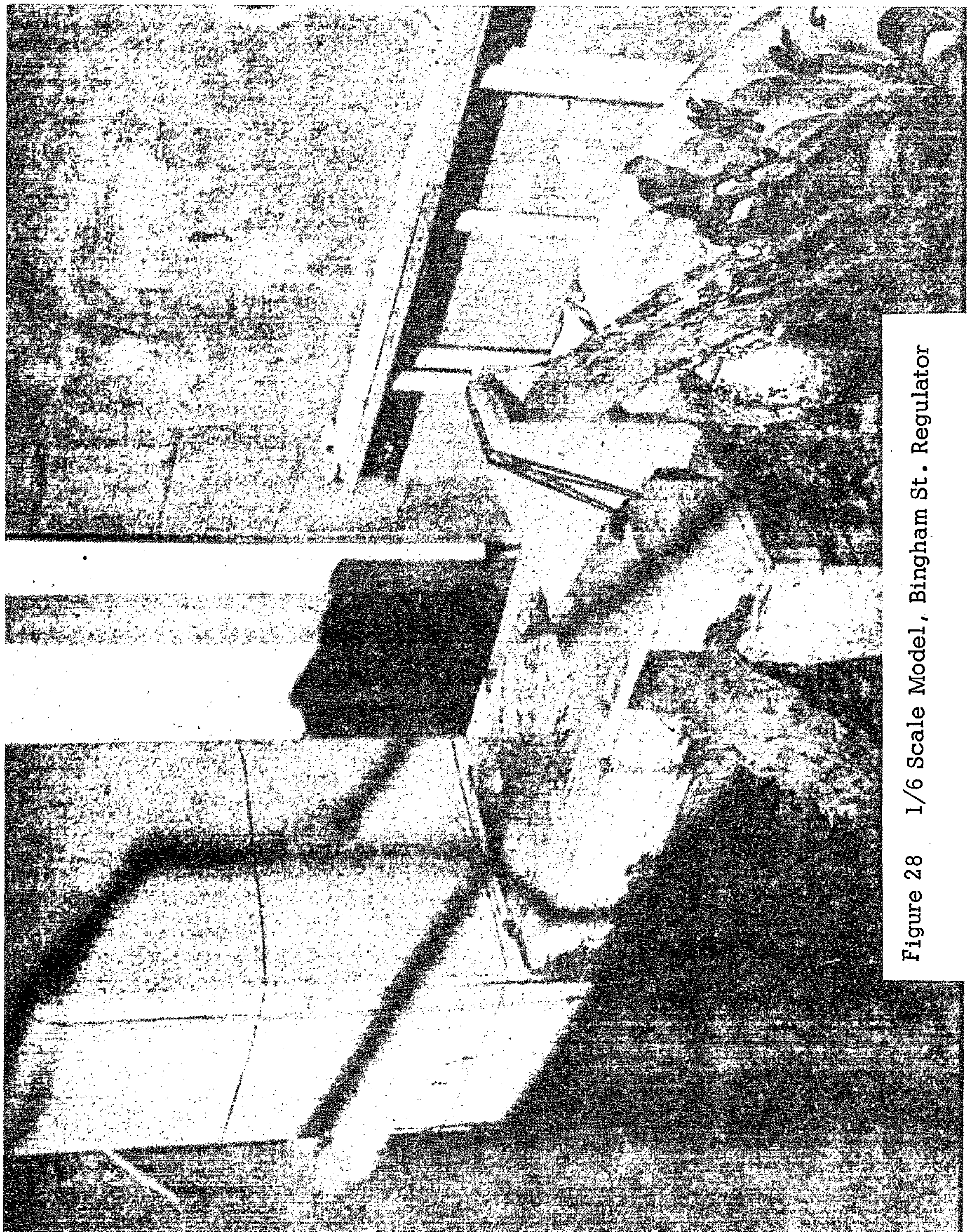
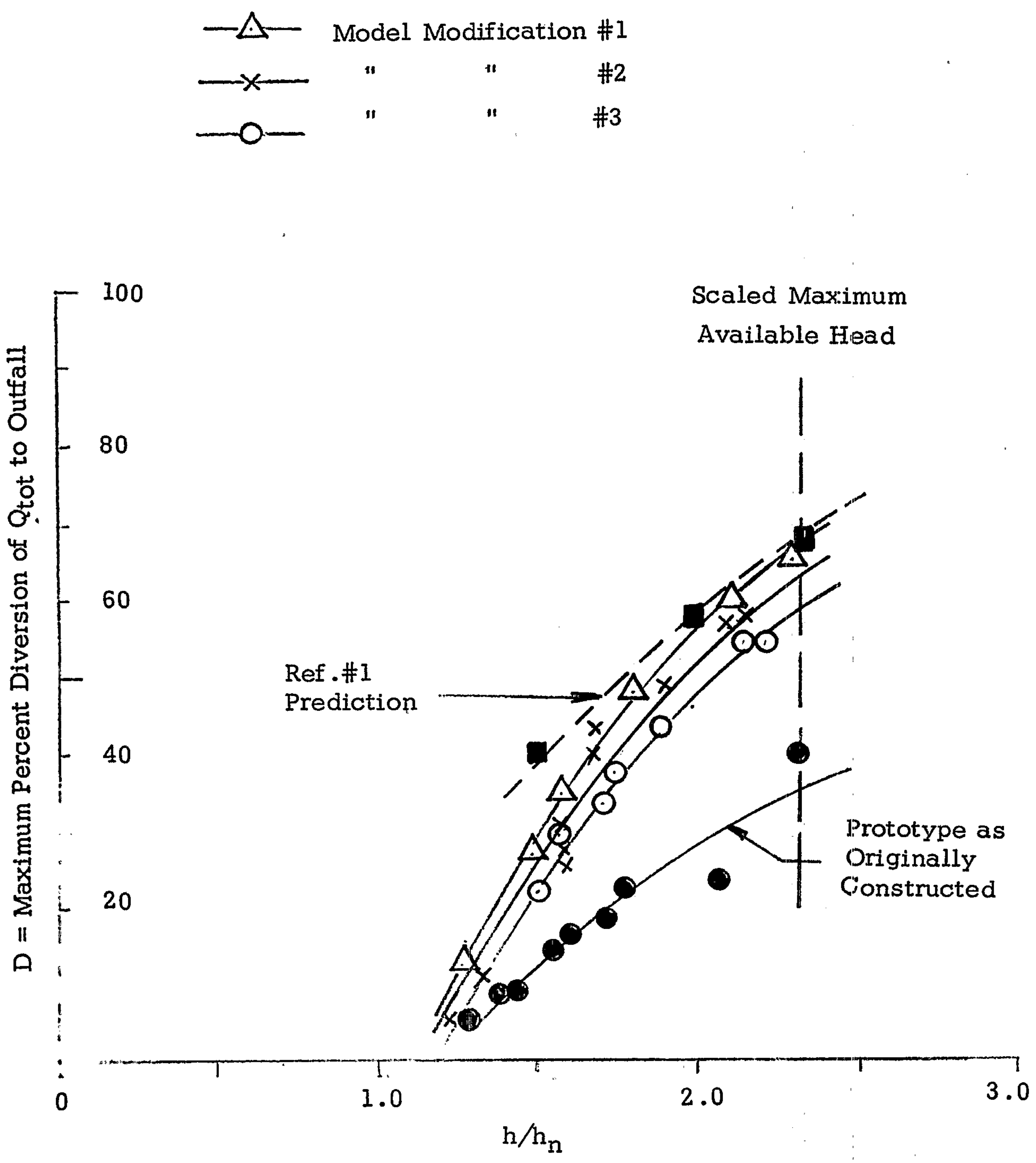


Figure 28 1/6 Scale Model, Bingham St. Regulator

Figure 29   1/6 Scale Model Test Results



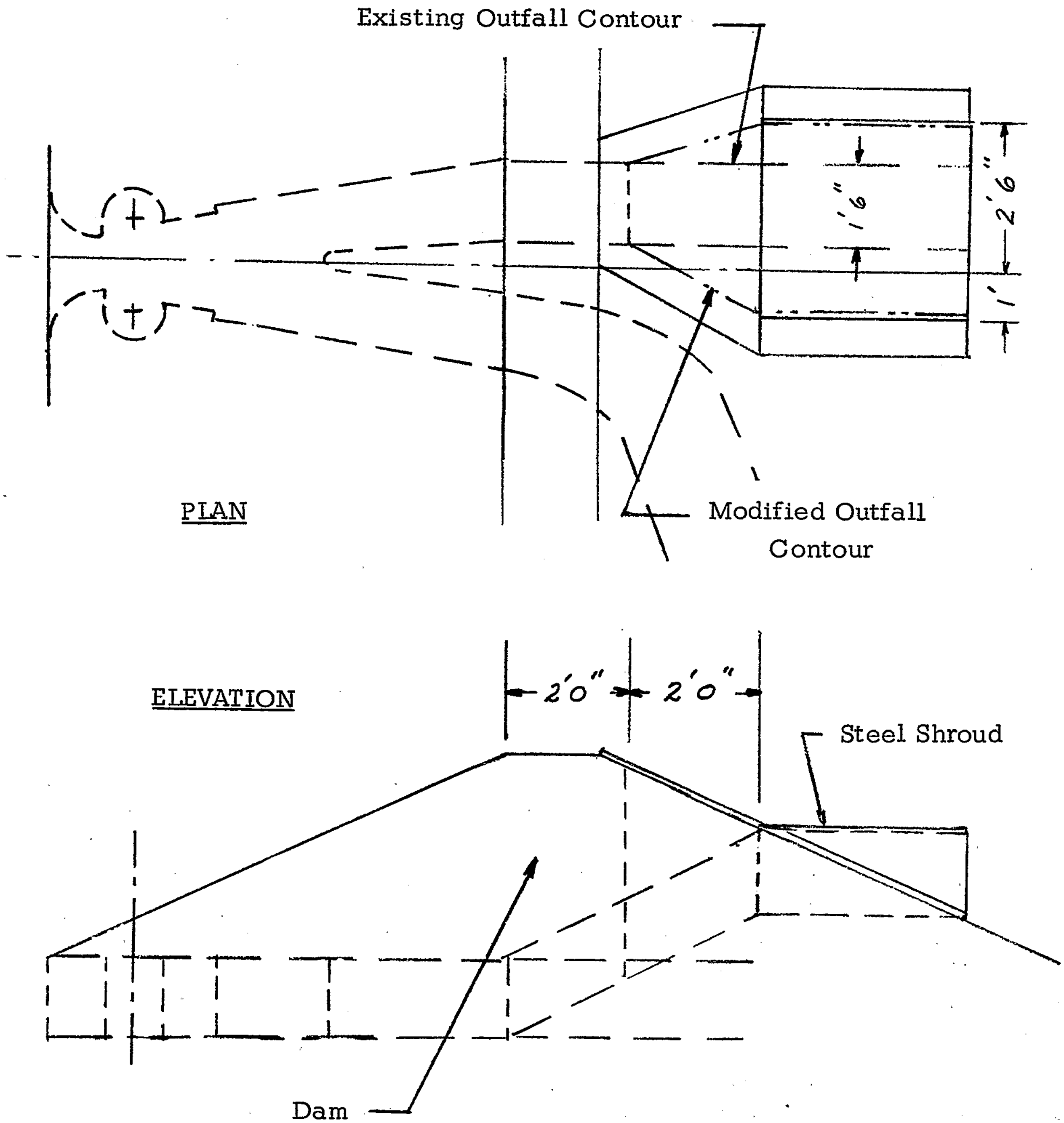


Figure 30 Modified Bingham St. Regulator Outfall Geometry

water backed up at the connecting sewer inlet. It was concluded that a more thorough investigation was necessary, that would include the section of the sewer from the island manhole to the interceptor connection. It was indicated that a new inspection procedure, using a remotely controlled TV camera would be employed.

TV Inspection

In an attempt to determine the cause of the backup in the connecting sewer, several conventional techniques were tried initially. The rodding machine was tried first. However, several attempts to run a rod from the special junction manhole to the interceptor were unsuccessful. An attempt was then made to float a line through the sewer, since the normal dry weather flow was passing through unimpeded. This, too, was unsuccessful.

Next a high pressure sewer jet machine was used, which apparently cleared the blockage. However, attempts to calibrate the regulator showed that the flow impedance problem, while reduced, had not been solved. At this point, the decision was reached to perform a complete detailed inspection of the connecting sewer.

A 24 in. air bag plug was inserted in the mouth of the fluidic regulator and floated through to the leg to the interceptor. The bag was then inflated, and the entire dry weather flow diverted over the outfall. However when the manhole at the junction of the connecting and interceptor sewers was inspected, it was found that the connecting sewer was running half full.

A TV camera inspection of the connecting sewer was the next step. With great difficulty, a line was run through the sewer using the sewer jet machine. The line was attached to the TV camera cable, which was then pulled back to the special junction manhole. The TV camera inspection showed several distinct breaks in the concrete encased 24 in. vitrified pipe under the creek. It also revealed that the 4 in. air line was snaked inside the sewer, acting as a dam in some places, and causing the difficulty in rodding and running lines through the sewer. However, the polyethylene pipe was in remarkably good shape after the abuse it had received in the various cleaning attempts.

At this point it became obvious that any further calibration attempts would be fruitless, with the observed level of infiltration. Also the repairs to the sewer would be difficult and expensive, due to its location at the base of a steep embankment and under a creek. A decision was made to suspend further calibration attempts, and summarize this phase of the program.

SECTION 9

PROGRAM EVALUATION

GENERAL

This section describes the evaluation of the fluidic regulator concept, based on the results of the subject program. The areas to be covered include the hydraulic performance in service, maintenance performance in service, and a direct comparison between the fluidic regulators and their conventional static counterparts from the standpoints of hydraulic performance and costs.

HYDRAULIC PERFORMANCE IN SERVICE

67th/Callowhill Regulator

This unit was placed in normal municipal service as of November, 1972. Because of its small size and close proximity to the Microstrainer Evaluation Project (Ref. #3), specific flow recording equipment was not installed, and thus a quantitative evaluation of regulator hydraulic performance during storm events from November, 1972 to December, 1975, was not obtained. However, the site was inspected frequently during this period for demonstration purposes, and storm events were simulated using upstream street hydrants, as during calibrations. The demonstrations were given to representatives from the City of Philadelphia, the State of Pennsylvania, the USEPA, other municipalities and jurisdictions, as well as consultant firms and others. On all occasions the unit performed properly. From this experience, it was concluded that the unit had performed normally during its service period, except for the very few occasions of blockages.

Bingham Street Regulator

Because of the flow impedance problem described in the previous section, this unit was not placed in municipal service, except as a conventional static regulator.

MAINTENANCE PERFORMANCE IN SERVICE

67th/Callowhill Regulator

After being placed in service, this regulator site was given the same routine inspection and maintenance procedures as for other small static regulator sites in the near vicinity. Figures 31 and 32 show pages from the Philadelphia Water Department fiscal '75 and '76 Interceptor Maintenance Logs, which describe the number of inspection visits, blockages or other malfunctions detected, and corrective action taken for a number of nearby static regulator sites. These sites are located along Cobbs Creek, and are also of the slot type which the fluidic regulator replaced. As can be seen from the reported 3 and 1 blockages for fiscal '75 and '76, respectively, the maintenance record of the fluidic regulator is typical of nearby static units in terms of surveillance required, number of blockages reported, and the time and effort required to restore the unit to normal service. It was reported that the inspection procedure developed for the fluidic unit was actually simpler and faster to perform, in that blockages could be detected by visual means, without the need of probing, or "rodding" as for the slot type units. It was regarded that the fluidic regulator, from the standpoints of surveillance and maintenance, was equivalent or superior to the conventional slot regulator in the small size range typical of the Cobbs Creek area, and that this comparison would likewise exist in the larger sizes. It was felt that the fluidic regulator surveillance and maintenance characteristics would be clearly superior to any conventional type of dynamic regulator involving electro-hydraulic-mechanical elements.

One significant mishap to the fluidic regulator occurred on October 19, 1974, when, through vandalism, the manhole cover was removed, the diaphragm valve stolen, and the plexiglas cover of the regulator cracked by dropping rocks on it. A new valve was supplied, the cover repaired, and the unit was restored to service in about 1 week. It should be noted that the transparent plastic cover was chosen to assist in the demonstration nature of the particular unit, and that a normal construction approach using a heavy gage plastic or metal shell sheathed in concrete would probably have survived the rocks without significant damage.

<u>Bingham Street Regulator</u>

Since the Bingham Street fluidic regulator was not placed in service, except as a static unit, the official surveillance and maintenance records are less complete than for the other unit. However, the fiscal'75 Interceptor Maintenance Log does show a total of 9 surveillance visits to the site with no problems reported except for minor vandalism at one manhole. This regulator functioned as a static regulator from June, 1973 to the present, and the only observed blockage was the large piece of concrete that interfered with the second calibration attempt. In the opinion of the Philadelphia Water Department, this particular blockage could have caused extensive mechanical damage to an equivalent hydraulic or float-operated dynamic regulator, necessitating considerable "down" time and expenditure for the replacement of parts. In contrast, the fluidic regulator suffered no damage, and was immediately restored to service page - 17 -

COBBS CREEK UPPER LEVEL COLLECTOR SYSTEM - 23 Units

C- 1 City Line Avenue at 73rd Street - Slot

98 inspections with 2 blocks reported during the fiscal year.

C- 2 City Line Avenue 100' s. on s side of Creek - Slot

95 inspections during year with no problems.

C- 4 Malvern Avenue at 69th Street - Slot

From 7-1-74 to 12-30-74 we made 68 inspections to this slot with no problems. Contractor started work on relocating the slot and construction of a new slot shortly after the st of January. As of June 30, 1975 the slots had not been turned over to the Interceptor Section although we did clean a block in the one slot on June 75.

C- 5 Lebanon Avenue s.w. of 73rd Street - Slot

During the year this slot was inspected 95 times with no problems reported.

C- 6 Lebanon Avenue at 68th Street - Slot

94 inspections with 3 blocks reported.

C- 7 Lansdowne Avenue at 69th Street - Slot

84 inspections with 1 block reported.

C- 9 64th Street at Cobbs Creek - Slot

This slot was inspected 94 times with 15 problems of blocks encountered.

C-10 Cross Street at Cobbs Creek - Slot

This slot was inspected 95 times - 3 blocks encountered

C-11 Cobbs Creek Parkway s. of Market Street - Slot

In 94 inspections during the fiscal year only 2 blocks were reported.

C-12 Spruce Street at Cobbs Creek - Slot

94 inspections with no problems encountered

C-13 62nd Street at Cobbs Creek - Slot

This slot inspected 93 times with 4 blocks being reported.

C-14 Baltimore Avenue at Cobbs Creek - Slot

This unit was visited 93 times with 13 blocks being reported.

C-15 59th Street at Cobbs Creek Parkway - Slot

94 inspections with 2 blocking problems

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Cobbs Creek Upper Level Collector System - Continued

C-16 Thomas Avenue at Cobbs Creek - Slot

In 88 inspections made to this slot we encountered 6 blocks.

C-17 Beaumont Street at Cobbs\Creek - Slot

68 inspections made during the year with 2 blocks reported.

C-31 Cobbs Creek Parkway s. of City Line Avenue - Slot

During the fiscal year 66 inspections with no problems reported

C-33 S. of Brockton Road at Farrington Road - Slot

72 inspections with only 1 block encountered.

C-34 Woodcrest Avenue at Morris Park - Slot

1 blocking problem in 64 inspections

C-35 Morris Park w. of 72nd Street & Sherwood Road - Slot

1 block in 64 inspections at this slot.

C-36 69th Street - Woodbine Avenue s. of Brebtwood Road - Slot

64 inspections with no problems during year.

C-37 Cobbs Creek Parkway s. of 67th & Callowhill Street - Fluidic ←

This is an expermental unit. 68 inspections with 3 blocking problems reported.

C-32 Cobbs Creek Parkway at 77th Street - Slot

During the fiscal year there wer 64 inspections made to this slot with no problems reported. On 4-29-75 due to a block in the effluent sewer somewhere in the field we blocked the slot opening with sand bags to assist Sewer Maintenance in opening the block.

COBBS CREEK LOWER LEVEL COLLECTOR SYSTEM - 13 Units

C-18 60th Street at Cobbs Creek Parkway - Slot

This unit was inspected 76 times during the fiscal year - 2 blocks reported.

C-19 Mount Moriah Cemetery at 62nd Street - Slot

In 73 inspections we had 7 blocks reported.

C-20 65th Street at Cobbs Creek Parkway - Slot

74 inspections with only 1 block reported on 6-25-75

Figure 31 Interceptor Maintenance Log, 67th/Callowhill Fluidic Regulator, Fiscal '75 page - 16 -

S-43 64th Street & Buist Avenue - B&B

This unit was inspected 50 times with 9 blocks reported.

S-47 69th Street & Buist Avenue - B&B

58 inspections with 5 blocks reported and 2 incidents where the gate didn't open fully.

S-50 43rd Street s.e. of Woodland Avenue - B&B

80 inspections with 5 blocks, all due to material still in sewer from sewer failure several years ago. Unit was taken out of service on two occasions so maintenance could be done on the pumps in the Pumping Station.

S-51 42nd Street s.e. of Woodland Avenue - Slot

70 inspections with no problems being reported.

COBBS CREEK UPPER LEVEL COLLECTOR SYSTEM - 23 Units

C- 1 City Line Avenue at 73rd Street - Slot

59 inspections with 2 blocks reported.

C- 2 City Line Avenue 100' s. on South side of creek - Slot

56 inspections with 2 blocks reported.

C- 4 Malvern Avenue at 68th Street - Slot

57 inspections with 2 blocks reported.

C- 4A 68th Street northwest of Malvern Avenue - Slot

56 inspections with no blocks reported.

C- 5 Lebanon Avenue s.w. of 73rd Street - Slot

56 inspections with no blocks reported.

C- 6 Lebanon Avenue at 68th Street - Slot

57 inspections with 3 blocks recorded and 3 surcharges during the hot weather in June.

C- 7 Lansdowne Avenue at 69th Street - Slot

56 inspections with 3 blocks recorded during the year.

C- 9 64th Street at Cobbs Creek - Slot

59 visits made to this slot with at total of 18 blocks being recorded.

C-10 Cross Street at Cobbs Creek - Slot

57 inspections with 3 blocks being reported.

C-11 Cobbs Creek Parkway s. of Market Street - Slot

58 inspections with one block on 7-16-75 this due to the creek bed being higher than the sewer invert and creek water brings back floating material. On 7-26-75 a temporary sandbag dam was constructed as a test, in the outfall sewer and it work fine. On 8-21-75 Sewer Maintenance was asked to build a permanent dam of bricks high enough to hold out the creek flow. Shortly afterwards the creek bed was lowered and creaned by contract.

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C-12 Spruce Street at Cobbs Creek - Slot

In the 56 inspections made at this unit there were no problems reported.

C-13 62nd Street at Cobbs Creek - Slot

56 inspections with 1 block reported.

C-14 Baltimore Avenue at Cobbs Creek - Slot

58 inspections with 14 blocks reported. Creek bed was also lower and cleaned by contract in the vicinity of the outfall.

C-15 59th Street at Cobbs Creek Parkway - Slot

During the fiscal year this unit was inspected 55 times with 2 blocks on record.

C-16 Thomas Avenue at Cobbs Creek - Slot

6 blocks recorded in the 53 inspections made to this slot during the year.

C-17 Beaumont Street at Cobbs Creek - Slot

44 inpsections with 1 block recorded.

C-31 Cobbs Creek Park south of City Line Avenue - Slot

45 inspections made at this slot with 3 blocks being reported.

C-33 South of Brockton Rd. & Farrington Road - Slot

43 inspections with no problems being reported.

C-34 Woodcrest Avenue at Morris Park - Slot

43 inspections with 3 blocks reported.

C-35 Morris Park w. of 72nd Street & Sherwood Road - Slot

43 inspections with 1 block reported.

C-36 69th Street & Woodbine Avenue s. of Brentwood Road - Slot

43 inspections with 2 problems reported.

C-37 Cobbs Creek Parkway south of 67th and Callowhill St. - Fluidic Unit ←

44 inspections with only 1 block reported.

C-32 Cobbs Creek Park at 77th Street - Slot

43 inspections with no problems reported.

COBBS CREEK LOWER LEVEL COLLECTOR SYSTEM - 13 Units

C-18 60th Street at Cobbs Creek Parkway - Slot

35 inspections with one problem reported.

C-19 Mount Moriah Cemetery at 62nd Street - Slot

35 inspections with 2 blocks reported.

C-20 65th Street & Cobbs Creek Parkway - Slot

35 inspections with no problems reported.

Figure 32 Interceptor Maintenance Log, 67th/Callowhill Fluidic Regulator, Fiscal '76 upon removal of the blockage.

GREASE BUILDUP

In the initial presentations of the fluidic regulator concept to the USEPA, the Philadelphia Water Department, and other agencies, concern was expressed as to the effect of grease, normally occurring in combined sewers, on fluidic regulator operation. It appeared that the semi-cylindrical control "pockets" beneath the control ports would tend to accumulate grease, eventually blocking the control port. No grease buildup was evident in the 67th/Callowhill unit, based on routine surveillance inspections. Such a buildup, if present, would have been easily visible through the transparent plastic cover. The Bingham Street unit received similar routine inspections, and was also examined in greater detail at the time of each calibration attempt and during the outfall discharge modification. These examinations showed an inconsequential grease deposit on the regulator inlet walls at the DWF water level; no accumulation in the control port pockets. Based on laboratory test experience, this accumulation would have a negligible effect on regulator performance. Also, laboratory experience shows a high level of vortex flow in the control port pockets, which apparently supplied sufficient scouring action to keep these areas clean. Consequently, no clean-up of the regulator was felt necessary nor performed.

It is recognized that the above represents only a small sample of the necessary municipal experience to determine the total effect of grease on fluidic regulator operation; however, the initial inputs, based on the subject program, are highly encouraging.

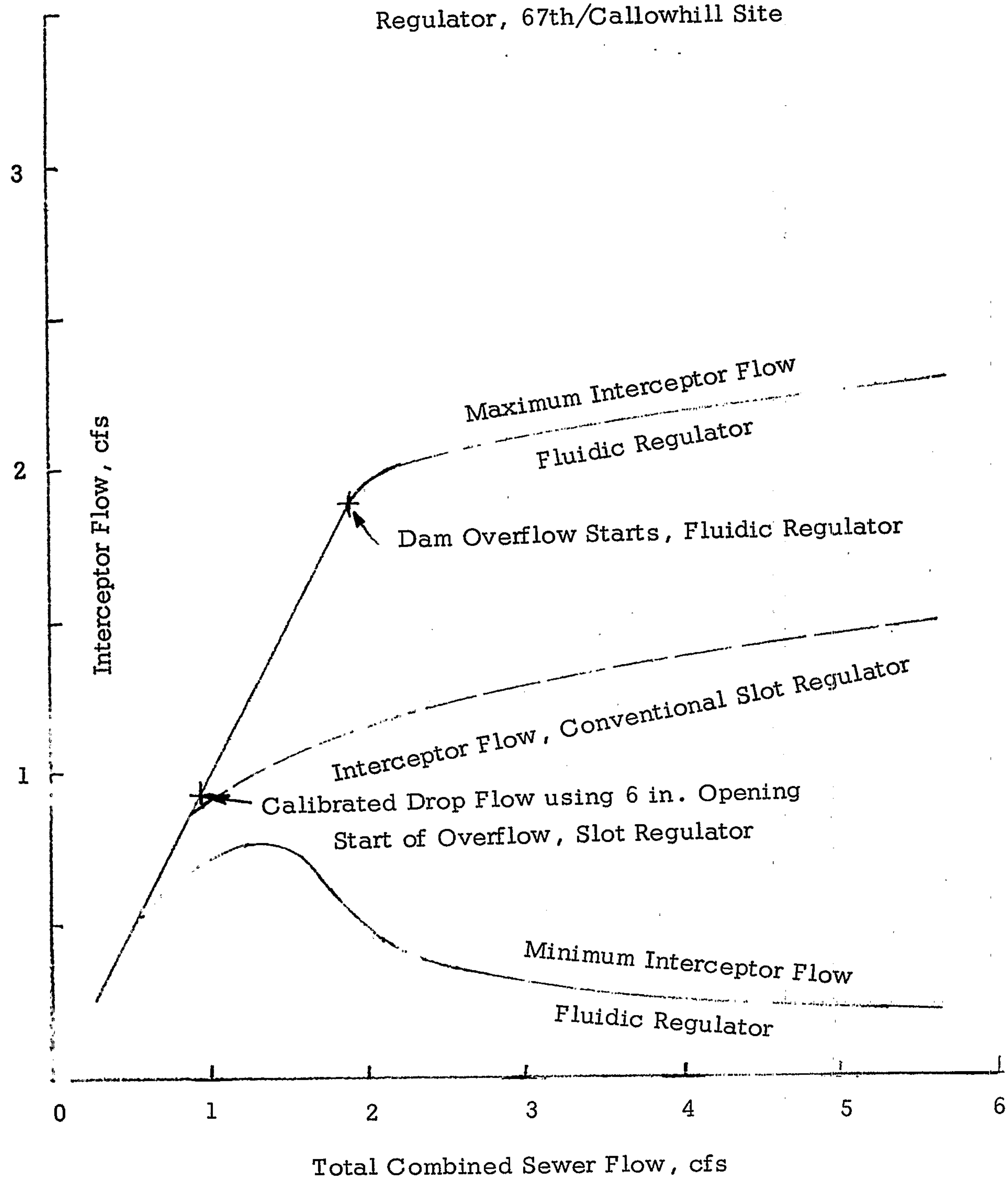
COMPARISON WITH CONVENTIONAL STATIC REGULATORS

Hydraulic Performance

67th/Callowhill Regulator--

A performance comparison between the original leaping weir, or "slot" type regulator used at the 67th/Callowhill site is shown in Figure 33. Regulator flow to the interceptor is shown plotted against total combined sewer flow reaching the regulator. The slot regulator flow curve is shown as a dashed line; the maximum and minimum fluidic flow curves are shown solid. Based on Philadelphia Water Department data, the slot regulator was assumed set so that overflow to the outfall started at a combined flow of 0.9 cfs. Extrapolating the Philadelphia Water Department flow calculations, the interceptor flow is found to reach a maximum of about 1.5 cfs at a combined flow of about 6 cfs, then decrease slightly as the sewer flow velocity increases. This reduces the transit time and vertical drop of the flow stream as it jumps across the slot opening, and thus the admitted flow. These calculations assumed free-fall flow conditions across the opening, clean separation of the flow along the

Figure 33 Hydraulic Performance Comparison Fluidic vs. Conventional Static Regulator, 67th/Callowhill Site



sewer invert, and a uniform vertical flow velocity profile. Calculation details are found in Appendix C.

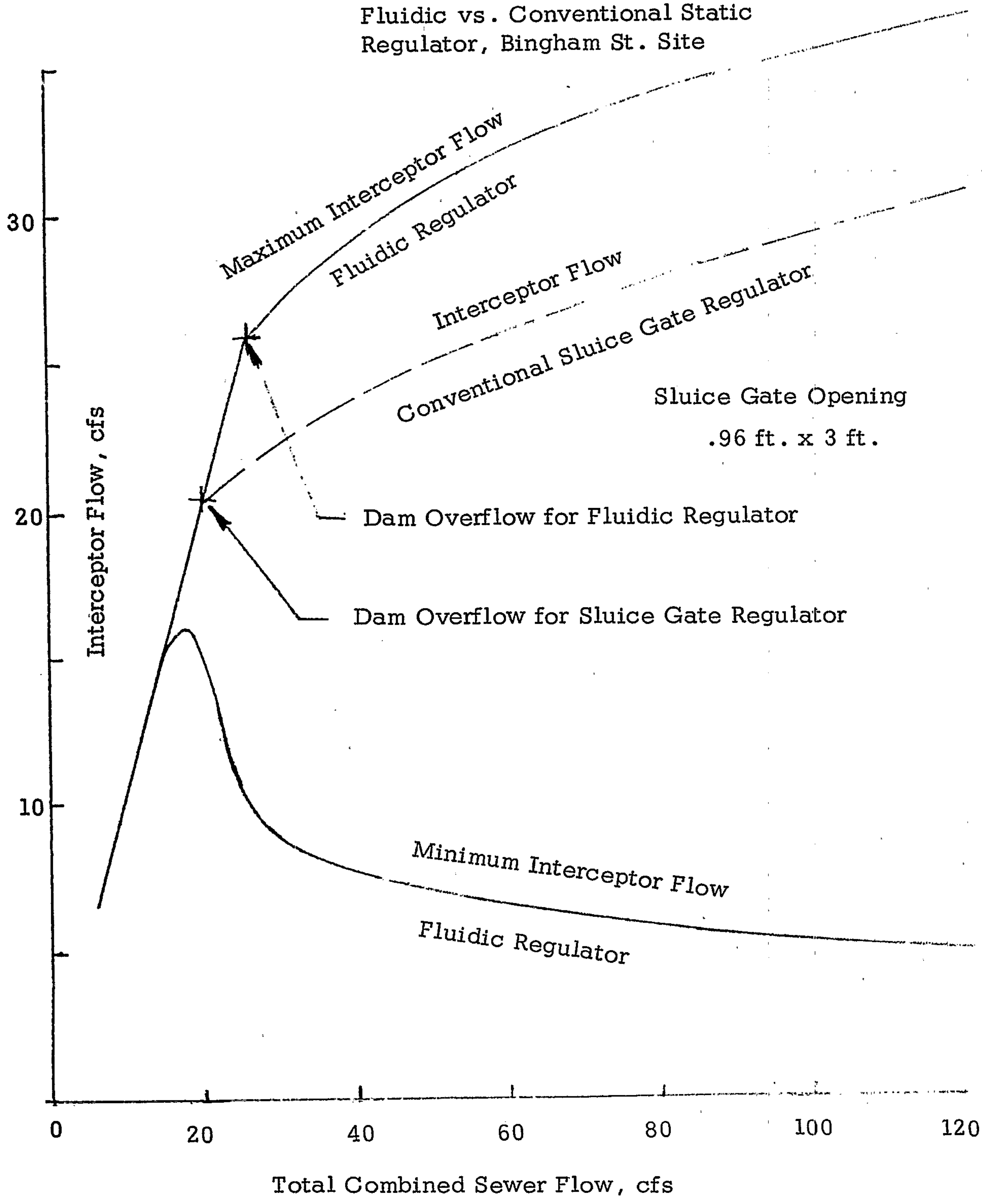
The advantages of the fluidic regulator are directly apparent. Dam overflow with the fluidic regulator does not occur until the combined flow reaches 1.9 cfs, or more than twice the corresponding value for the slot regulator. At this condition, the slot regulator diverts 1.3 cfs to the interceptor and 0.6 cfs to the outfall, while the fluidic regulator can divert as much as 1.9 cfs to the interceptor and none to the outfall if the interceptor has the additional flow capacity, or as little as 0.5 cfs to the interceptor and 1.4 cfs to the outfall if the interceptor is near capacity. The fluidic regulator minimum interceptor flow is only 38% of the slot regulator interceptor flow, thus the tendency to surcharge the interceptor is much reduced. It should be noted that this surcharge relief actually improves as combined flow increases, due to the increase in fluidic regulator diversion capability with upstream head.

The performance of the fluidic regulator fits well with the practical occurrence of pollution loading during a storm event. The maximum pollution loading results typically from a combination of sanitary and "first flush" flows occurring during the early part of a storm before maximum combined sewer and interceptor flow capacity have been reached. The fluidic regulator would thus be able to divert much more of this badly polluted flow to the treatment plant at the time it occurs, with much less surcharging tendency to the interceptor when the maximum (and generally less polluted) storm flows occur.

Bingham Street Regulator--

A similar performance comparison between the conventional static regulator and fluidic regulator, for the Bingham St. site is shown in Figure 34. In this case, the conventional regulator was a 2 ft. high x 3 ft. wide sluice gate, located on the North side of the combined sewer in the sewer sidewall, upstream of a 2 ft. high dam then located across the sewer invert. The sluice gate was retained as part of the fluidic regulator installation, but is kept closed during normal operation. The conventional regulator performance is shown as the dashed curve, the fluidic regulator performance shown as solid curves. In computing the conventional regulator performance, the gate discharge coefficient was estimated at 0.7, considering that the sewer invert is at nearly the same elevation as the invert of the gate opening. A gate opening height of 0.96 ft. was computed to correspond to an interceptor flow of 20 cfs, for a water level at the original dam crest elevation. The corresponding interceptor flow is plotted against total combined sewer flow, together with the maximum and minimum interceptor flow curves for the fluidic regulator. Although the type of conventional static regulator is different for this site (orifice vs. slot or leaping weir), the performance improvement of the fluidic over the conventional regulator is similar: Larger combined sewer flow before dam overflow, and the option of either much more flow to the interceptor if it has additional flow capacity, or a much reduced tendency to surcharge the

Figure 34 Hydraulic Performance Comparison Fluidic vs. Conventional Static Regulator, Bingham St. Site



interceptor if it does not have additional flow capacity.

Cost

This section will present the costs of the fluidic regulators studied under this program in terms of initial costs, and surveillance, maintenance and repair costs. Each category of cost will be compared with those of comparable, conventional static regulators, that might have been retrofitted into the two subject regulator sites in the same manner, and at the same time as the fluidic units. In addition, some general cost comparisons will be made with conventional dynamic regulator systems, whose dynamic performance is closely matched by the fluidic regulator.

67th/Callowhill Installation--

Initial Cost--Based on the Consultant's and Contractor's bid sheets, the major cost breakdown for this installation is shown below. Figures are rounded to the nearest $10.

	Item	Cost
1	Excavation	$ 900
2	Build dam, chamber, regulator mounting, install regulator and appurtenances	5,700
3	Install control lines	500
4	Backfill and reseed	150
5	Consultant, including engineering, liaison, and furnished regulator hardware	4,180
6	Philadelphia Water Dept. engineering costs, (est'd. 200 m-h @ $10/hr.)	2,000
Total		$13,480

The initial cost of retrofitting a comparable conventional static regulator is estimated as follows:

1	Excavation	$ 900
2	Build dam, chamber, date, and connecting sewer	4,500
3	Backfill and reseed	150
4	Procured Hardware	500
5	Philadelphia Water Dept. engineering costs, (est'd. 150 m-h @ $10/hr.)	1,500
Total		$ 7,550

The conventional regulator cost is thus estimated at 56% of that for the present fluidic unit. It is expected that the fluidic regulator consultant cost would be reduced to about $2,000 if the same installation were made again, based on learning and experience from the first. The conventional regulator would then be about 67% of the fluidic unit cost. It can be seen that on a new installation, which would include the additional costs of excavating and constructing additional manholes needed for either installation, the percent difference in cost would be quite small, probably on the order of 10%.

Surveillance, Maintenance and Repair Costs--Initially, in the program it was felt that the fluidic regulator at 67th/Callowhill would require inspection on the average, twice per week. This would be approximately the same level of inspection given a slot, or other static regulator. However, experience proved that the interval could be extended to about once per week. Also, the simplicity of the fluidic regulator, with its lack of electrical, hydraulic, or other complex hardware, allowed inspection by existing interceptor service crews, which consist of one semi-skilled worker and two laborers. These job specifications require no technical training.

Each inspection consisted of visual observation for unimpeded flow through the transparent regulator cover, and checking the dam, inlet, and dip tube sensor for accumulated debris. It was noted that the most troublesome type of debris, in keeping with the small 5 in. x 5 in. inlet dimensions, was beverage cans and plastic bottles. The originally estimated time for an inspection was one hour. However, field experience showed that the actual time required was about fifteen minutes, except when a blockage was encountered, and then the time was about 1/2 hour. Using 1976 average wage rates for the interceptor crews, the surveillance costs are estimated as follows:

Interceptor Serviceman (semi-skilled); $5.21/hr. x 1/4 hr./visit x 60 visits/yr.	$ 78.15
Two Laborers $4.92/hr. x 1/4 hr./visit x 60 visits/yr.	73.80
Total Annual Cost of Surveillance	$151.95

Note that the corresponding cost for a conventional static slot regulator is estimated at 1.5 x this amount, or $227.93.

Normal maintenance costs are essentially zero, since it has a minimum of moving mechanical parts, and these are constructed from corrosion-free material. The only required repair in approximately 4 years of service was occasioned by vandalism, rather than normal service. This incident required the following costs.

Material and Procured Parts:

Diaphragm Valve	$150
PVC pipe fittings	10
Miscellaneous	5
Total	$165
Labor, 8 hrs. @ $5/hr.	40
Total	$205

Bingham Street Installation--

Initial Cost--Based on the Consultant's and Contractor's bid sheets, the major cost breakdown for this installation is shown below:

	Item	Cost
1	Excavation	$14,000
2	Construction of regulator chamber, regulator, regulator installation	23,570
3	Rework junction manhole	6,200
4	Const. new manhole, install dip tube sensor	2,240
5	Install Interceptor Discharge line	820
6	Install 4 in. PE cont. line	3,600
7	Backfill and reseed	150
8	Consultant, incl. engineering design, liaison, furnished hardware	9,000
9	Philadelphia Water Dept. engineering costs (est'd. 300 m-h @ $10/hr.)	3,000
	Total	$62,580

The initial cost of retrofitting a comparable conventional static regulator is estimated as follows:

1	Excavation	$14,000
2	Build chamber, dam, gate	18,000
3	Rework junction manhole	6,200
4	Install Interceptor conn. line	820
5	Backfill and reseed	150

6	Philadelphia Water Dept. engineering costs (est'd. 150 m-h @ $10/hr.)	$ 1,500
7	Procured hardware	1,000
	Total	$41,670

The initial cost of retrofitting a comparable conventional static regulator is thus estimated at 67% of the cost of the fluidic unit. It is expected that the above consultant and regulator construction costs would be reduced at least $5,000, based on the use of a prefabricated PVC element shell, and the experience gained from the present unit. The retrofitted conventional static regulator cost would then be about 72% of the fluidic unit cost, and again for a new installation, the percent difference between the two approaches would be small.

Surveillance, Maintenance, and Repair Costs--The routine surveillance inspection procedure for this type of regulator is basically the same as for the smaller unit, and is performed by the same type of crew. The normal number of annual inspections would be reduced to about 30/year, due to the larger size, and the corresponding lower susceptibility to blockages. Thus the annual surveillance cost would be 1/2 of the 67th/Callowhill unit, or $76 vs. $114 for a comparable conventional static regulator. Normal maintenance and repair costs for this fluidic regulator would be very nominal, and probably consist principally of periodic replacement of ethylene glycol in the U-tube sensor. It is expected that an amount of $50/year would cover materials and labor costs for the fluidic unit. The principal expected maintenance and repair cost of the conventional regulator would be the replacement of parts of the manually positioned sluice gate due to corrosion and damage from debris. Assuming a 10 year operating life, a replacement cost of $1,000, and an annual labor cost of $80 (16 m-h @ $5/hr.), the maintenance and repair cost for the conventional unit is estimated at $180/year.

General Cost Comparison, Fluidic vs. Conventional Dynamic Regulator System --

Because of the wide difference in conventional dynamic combined sewer regulator systems (electrically or hydraulically operated gates, float, or flow-operated gates, siphons, inflatable dams, etc.), a detailed comparison with each type is not possible within the scope of the subject project. The previous discussions have concerned the costs of retrofitting fluidic and conventional static regulators into the two chosen sites. The principal cost items affected by the type of regulator are the regulator equipment cost, and installation and checkout costs. For the fluidic regulators, the 1973 estimated consultant costs (which include engineering installation liaison, and furnished fluidic hardware and appurtenance costs) adjusted by the experience of the present program, were $2,000 for a 1.5 cfs regulator, and about $12,000 for a 25 cfs regulator. A rough comparison with a conventional dynamic (mechanical float-operated gate) regulator is generated as follows. During 1976, the Philadelphia

Water Department purchased a regulator of this type for $13,000, designed to handle flows up to 4 cfs.

The consultant cost, adjusted to 1976, for a 4 cfs fluidic regulator is estimated at $4,500, so that the cost of the mechanical dynamic regulator equipment is approximately 3 times the cost of the fluidic regulator equipment.

In the case of electrically, or hydraulically operated gate-type dynamic regulators, the equipment cost ratio is probably higher, since the costs of operating energy supply equipment such as pumps, compressors, or batteries, must also be included. For example, the 1964 capital cost of 4 cfs, hydraulically-driven gate regulators used by the City of New York was $25,000 (Ref. #4, page 49). Estimating the 1976 cost at $30,000, the dynamic/fluidic equipment cost ratio would be about 6.5.

The costs of site modification, and regulator installation and checkout costs in retrofitting a conventional dynamic regulator are highly dependent on the specific regulator type, and site characteristics, so generalizations are very approximate at best. In the case of the mechanical-float, electric, or hydraulically-operated types of regulators, one or more additional flow chambers, or passages, are required, whose walls and openings require relatively close dimensional tolerances in construction to facilitate the assembly, alignment and checkout of precision mechanical assemblies such as gate frames guides, linkages, cylinders, gear drives, motors, etc. The mechanical assembly of a fluidic regulator is much less critical in comparison. In addition, the electric and hydraulically driven gate types require the installation of operating energy facilities such as electric power lines, potable water lines, or compressed air lines, plus emergency stand-by facilities. With such complex equipment, the labor costs required for assembly, checkout and operational and maintenance personnel training are necessarily much greater than for the fluidic equipment. Accordingly, site modification and installation and checkout costs for conventional dynamic regulators are estimated at least 25% to 50% greater than for fluidic regulators. Thus a rough estimate for the overall conventional dynamic/fluidic retrofit cost ratio would be at least 2:1.

For the case of comparing the overall costs of conventional dynamic/ fluidic regulator systems in new locations, the above discussion applies as well. However, the overall cost ratio will be less, since the basic cost of excavation and construction common to both system approaches (manholes, connecting sewers, outfalls, main chambers, etc.) usually exceeds equipment and installation costs, although it is highly dependent on particular site considerations.

SECTION 10

CONCLUDING COMMENTS

It was concluded from the results of the calibrations of the two fluidic regulator installations that the fluidic regulator design criteria of Ref. #1 are basically sound and accurate for the range of inlet sizes covered by the two specific units, since predicted performance was demonstrated by both units. It was also concluded that the criteria could be extrapolated to units with flows up to 50 cfs, with a high degree of confidence in the predicted performance. The model test, conducted on the Bingham Street configuration, showed the need for refinements to the basic Ref. #1 criteria, in the definition of outfall discharge width as a function of inlet nozzle aspect ratio. It was concluded that the 5 in. x 5 in. inlet nozzle dimensions of the 67th/Callowhill regulator, while workable, represented the minimum desirable size for fluidic regulators.

From the maintenance standpoint, the basic simplicity and capability of the fluidic regulator to remain free from the effects of debris and other contaminants in sewage flow was strongly indicated, since very few blockages occurred, and the grease buildup on the inside flow passages was minimal. It was found that routine surveillance procedures for the fluidic regulators could actually be simpler and faster than those for conventional static regulators, with a resulting significant cost saving. Surveillance and maintenance could be performed with minimum skill level personnel. The indicated cost of repairs and parts replacement was less than for the conventional regulators, since no movable or corrodable mechanical elements operate in the sewage flow. The maintenance characteristics of the fluidic regulator were regarded by the Philadelphia Water Department maintenance officials as clearly superior to any conventional dynamic regulators in service in the city.

From the design improvement standpoint, it was concluded that the connecting air lines between the dip tube sensor and regulator should preferably not be run through the connecting sewer; but if absolutely necessary, should be secured to the sewer crown. The location of these lines at the sides, or invert presents large problems in providing normal sewer inspection, cleaning, etc., and significantly increases the probability of blockages. The fluidic element section of the regulator should be constructed as a prefabricated shell of heavy plastic, or corrosion-resistant metal. This would eliminate the difficulties of holding close tolerances in concrete construction, and the possibility of inlet nozzle erosion, while also reducing project costs. Also shown during the program were:

1. The desirability of installing manual valves in control port air lines to facilitate regulator calibration or checkout;

2. The desirability of investigating other communication techniques for extended dip tube sensor-to-regulator distances; and

3. The desirability of investigating techniques for computerized remote command-control of regulator operation.

From the preliminary planning standpoint, it was concluded that a thorough investigation should be made of the flow capacity of connecting sewers, in selecting sites for retrofitting fluidic regulators, since this appears to be the principal factor in limiting regulator size.

REFERENCES

1. Bowles Engineering Corp., Silver Spring, MD, "Design of a Combined Sewer Fluidic Regulator", USEPA Report No. 11020 DGZ 10/69 (DAST-13), (NTIS-PB 188 914), 1969. 137 pp.

2. Fair, G. M., Geyer, J. C., Okun, D. A., "Water Supply and Waste-water Removal, Volume I", John Wiley & Sons, New York, NY, 1966. approx. 250 pp.

3. Maher, M. B., Crane Co., King of Prussia, PA, "Microstraining and Disinfection of Combined Sewer Overflows—Phase III", Report No. EPA-670/2-74-049, (NTIS-PB 235 771/AS), 1974. 82 pp.

4. APWA, "Combined Sewer Regulator Overflow Facilities", USEPA Report No. 11022 DMU 07/70, 1970. 138 pp.

BIBLIOGRAPHY

1. APWA, "Problems of Combined Sewer Facilities and Overflows—1967", USEPA Report No. 11020---12/67, (NTIS-PB 214 469), 1967. 189 pp.

2. APWA, "Combined Sewer Regulation and Management, A Manual of Practice", USEPA Report No. 11022 DMU 08/70, (NTIS-PB 195 676), 1970. 133 pp.

APPENDIX A

REGULATOR DESIGN CALCULATIONS

CALLOWHILL & 67TH ST. LOCATION

Maximum Storm Flow Conditions:

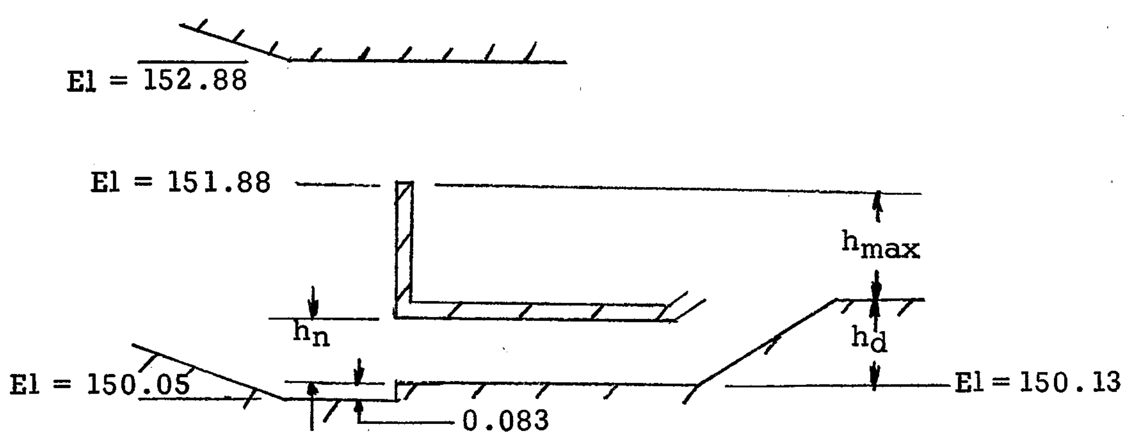
Design Storm Flow, Q_{st}=30 cfs.
Flow Area above dam enlarged to 2.0 ft.^{2}
Assume discharge coefficient, C_D=0.85, since only 1/3 of opening perimeter has sharp edge.

Then required upstream head=$(Q_{st}/C_D\ A)^2 \times 1/64.4 = 4.84$ ft.

This value is within the allowable surcharge of 5 ft.

Regulator Nozzle Size Selection:

Regulator Elevation Sketch:



Regulator Nozzle will be square, i.e., aspect ratio, a=1 to provide maximum opening dimension for admittance of maximum size solids in sewage flow. Then, from page 65, Ref. #1, for diversion capability of 50% of total flow, supply head, h, must be 2.2 h_n. Allowing 1 in. = 0.083 ft. for regulator structure depth, then:

$$\text{max. available } h = 151.88 - 150.05 - 0.083 - 1.4\, h_n$$
$$= 1.747 - 1.4\, h_n$$

But max. available supply head = 2.2 h_n for 50% diversion capability.
Then: $h_n = 1.747/1.4 + 2.2 = 0.485$ ft. = 5.82 in. Select h_n = 5 in. to provide margin of diversion capability above 50% at maximum supply head. Then A_n = 25 in.^{2} = 0.174 ft.^{2} .

Regulator Performance Prediction:

From pages 20, 21 and 65 of Ref. #1, the following values of total flow, Q_{tot}; % diversion of total flow, D; discharge coefficient, C_D; maximum regulator flow to the outfall, $Q_{out_{max}}$; minimum regulator flow to the interceptor, $Q_{int_{min}}$; and supply head have been determined for h = 5 in., and a = 1:

h (in.)	h/hn	C_D	Q_{tot} (cfs)	D	$Q_{out_{max}}$ (cfs)	$Q_{int_{min}}$ (cfs)
3	0.6	0.92	0.64	7	0.04	0.60
6	1.2	1.06	1.04	20	0.21	0.83
9	1.8	1.10	1.33	43	0.57	0.76
12	2.4	1.13	1.57	60	0.94	0.63
15	3.0	1.135	1.77	70	1.24	0.53
18	3.6	1.14	1.95	82	1.60	0.35

Sensor Design:

From page 22, Ref. #1, for digital mode operation using bias orifice configuration; $A_{bias\ orifice} = 0.0015\, A_n$, and $A_{sensor\ orifice} = 0.004\, A_n$. Then $A_{bias\ orifice}$ = 0.0375 in.^{2} and $\text{diameter}_{bias\ orifice}$ = 0.22 in.; $A_{sensor\ orifice}$ = 0.1 in.^{2} and $\text{diameter}_{sensor\ orifice}$ = 0.358 in. From page 26, Ref. #1, air line I.D. was selected as 1.5 in. The minimum dip tube length above the high water level to prevent water from entering the connecting line was computed using Bernoulli equation. Assume negligible velocity head and negligible friction loss in flow entering nozzle. Then:

$$h = h_{static_n} + h_{velocity_n}\ , \text{ or } h_{static_n} = h - h_{velocity_n}$$

where h_{static_n} = static pressure at nozzle, and $h_{velocity_n}$ = velocity head at nozzle.

Then: $h_{velocity_n} = 1/2\rho V_n^2$, and $V_n = Q_{tot}/A_n = C_D\sqrt{64.4\, h}$,

where ρ = mass density of H_2O = 1.9379 slugs/ft.^{3}.

Then: $h_{static_n} = h - 1/2\, C_D^2\, (64.4/0.433 \times 144)(1.9379)(h)$
$= h\,(1 - C_D^2)$, where h is measured in in. H_2O.

Then: h at maximum storm flow = 12 in. + 14 in. = 2.17 ft; h/h_n = 5.2, and C_D = 1.16.

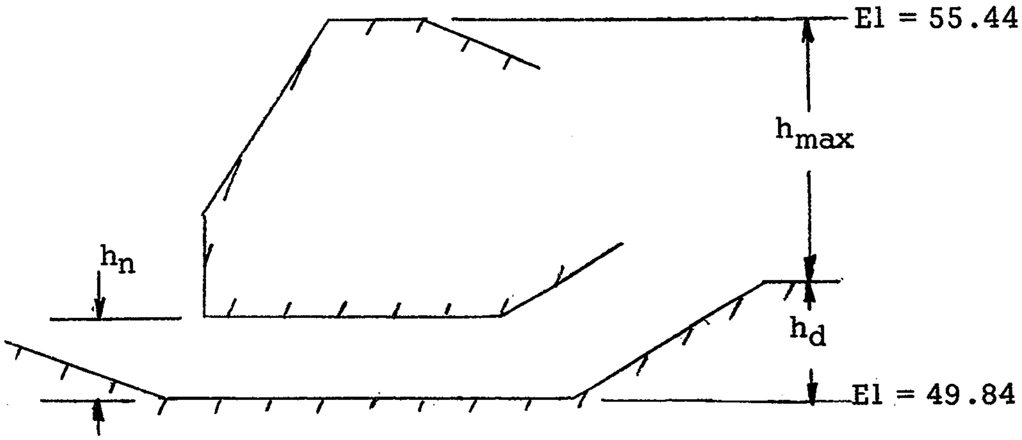
Then: h_{static_n} = -9 in. H_2O .

At maximum sewer flow, the water level at the upstream manhole = 4.84 ft. above dam, or at elevation 156.72 ft. The sewer invert at this location is at elevation = 152.20 ft. Assume lower end of dip tube is 0.5 ft. above invert. Then dip tube length to prevent water from entering connecting line = 156.72 - 152.20 - 0.5 + 0.76 = 4.78 ft.

BINGHAM ST. LOCATION

<u>Regulator Nozzle Size Selection:</u>

Regulator Elevation Sketch:



Selected nozzle area, A_n, is limited by the connecting sewer size, and is selected = 1.5 ft.^{2} = 216 in.^{2}. Compare performance characteristics of nozzles with aspect ratio, a, of 1 and 1.5. Then nozzle dimensions are 14.7 in. x 14.7 in., and 12 in. x 18 in., respectively. For h_n = 14.7 in. = 1.23 ft; h_d = 1.4 x 1.23 = 1.72 ft.

Then: Maximum available supply head = 55.44 - 49.84 - 1.72
= 3.88 ft. = 46.56 in.

Then: h_{max}/h_n = 3.17; from page 65, Ref. #1, D_{max} = 72%

For h_n = 18 in. = 1.5 ft., h_d = 2.1 ft. Then maximum available supply head, h_{max} = 55.44 - 49.84 - 2.1 = 3.5 ft. = 42 in. Then h_{max}/h_n = 2.33, and D_{max} = 66%.

The 12 in. x 18 in. nozzle was selected, since the predicted diversion performance for both nozzles was close, while the horizontal dimension of the

14.7 in. x 14.7 in. nozzle would be 23% larger, and would require a proportionately larger and costlier dam and regulator structure.

Regulator Performance Prediction:

From pages 20, 21 and 65, Ref. #1, the following values of D, CD, and regulator flows vs. supply head have been determined for h_n = 1.5 ft., and, a = 1.5:

h (ft.)	h/h_n	C_D	Q_{tot} (cfs)	D	$Q_{out_{max}}$ (cfs)	$Q_{int_{min}}$ (cfs)
1.0	0.67	0.92	11.07	11	1.22	9.85
1.5	1.0	1.00	14.74	24	3.54	11.20
2.0	1.33	1.065	18.13	36	6.52	11.60
2.5	1.67	1.09	20.75	48	9.96	10.79
3.0	2.00	1.11	23.14	57	13.19	9.95
3.5	2.33	1.12	25.22	66	16.65	8.57
4.0	2.67	1.13	27.20	72	19.58	7.62

Sensor Design:

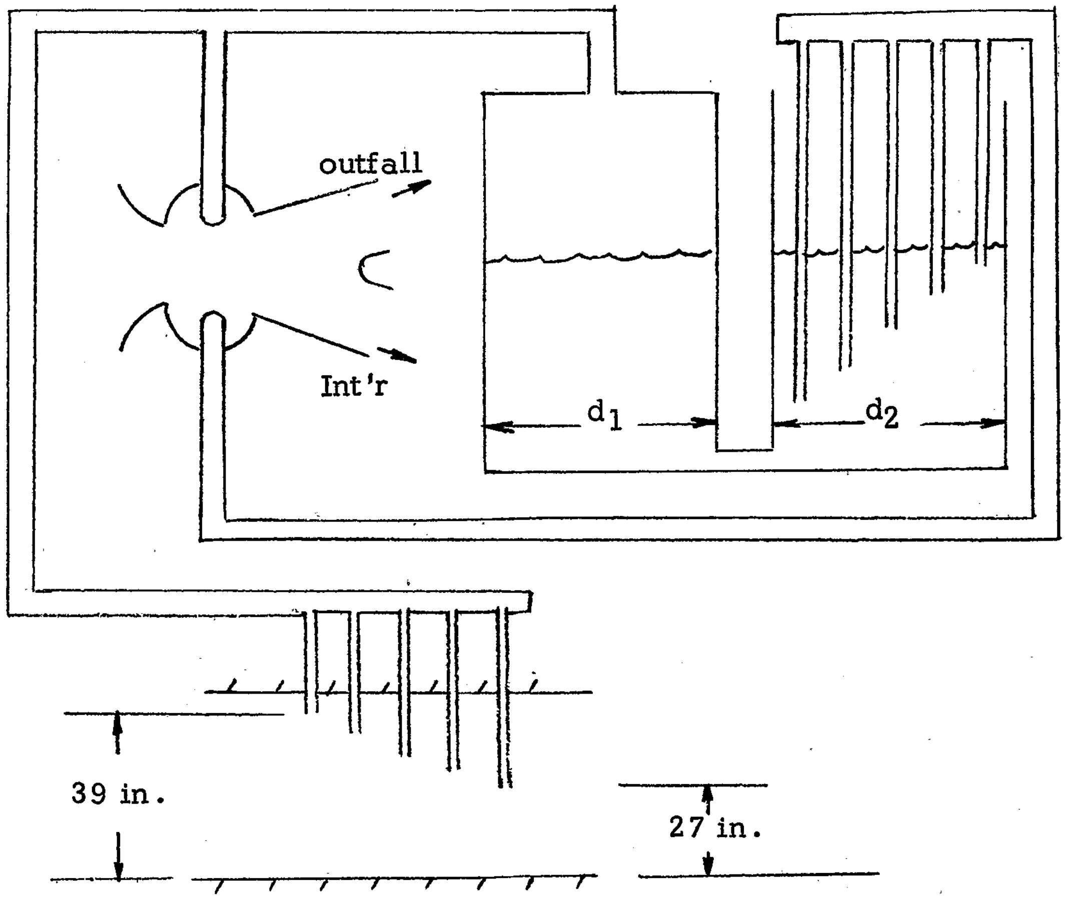
Digital Mode: From page 22, Ref. #1, $A_{bias\ orifice} = 0.0015 A_n$, $A_{sensor} = 0.004\ A_n$. $A_n = 216$ in.^{2}. $A_{bias\ orifice} = 0.323$ in.^{2} and $diameter_{bias\ orifice} = 0.64$ in. $A_{sensor} = 0.865$ in.^{2} and $diameter_{sensor} =$ 1.05 in. From page 26, Ref. #1, an air line I.D. size of 4 in. was selected, assuming a line length to the Tacony Creek Interceptor Sewer of 500 ft. The minimum dip tube length to prevent water from entering the connecting line was found using the same approach as for the other regulator. At maximum storm flow assume water level is 3 ft. above dam crest. Then h = 3.5 + 3 = 6.5 ft. Then $h/h_n = 4.35$, and $C_D = 1.14$. Then $h_{static_n} = 1.95$ ft. Assume end of dip tube is 27 in. = 2.25 ft. above interceptor invert, or 1.75 ft. below top. Then total tube length required = 1.75 + 1.95 = 3.7 ft. = 44.4 in. Thus a length of 45 in. was selected.

Analog Mode: The Philadelphia Water Department established the following desired proportional regulation characteristics:

Depth in Interceptor	% of Q_{tot} to Interceptor	% of Q_{tot} to Outfall
0 to 27 in.	100	0
27 to 39 in.	100 to 25	0 to 75
39 to 48 in.*	25 to 10	75 to 90

*In this range of interceptor flow depth, the regulator is assumed to be exerting maximum control toward the outfall. The actual percentage of Q_{tot}

would depend on the regulator upstream head. The proportional range of depth is 27 in. to 39 in., a difference of 12 in. Assume flow regulation will step-proportional over 5 equal steps, at depth intervals of 3 in. Then system hydraulic geometry is sketched:



Use 45 in. for longest tube, as for digital sensor, to permit interchangeability. From page 24, Ref. #1, the total dip tube area = $0.02\ A_n = 4.32\ in.^2$. Since 5 dip tubes are used, each dip tube area = $0.864\ in.^2$, with an I.D. = 1.05 in. Use nom. 1 in. pipe.

U-Tube Sensor Design

Figure 70, page 82, Ref. #1, shows the flow regulation fraction, R, as a function of sensor airflow, Q_A. This characteristic is approximated by the equation:

$$Q_A = 3\ Q_{A_{max}}\ (R - 0.75\ R^2)$$

Also assume that $A_{sensor} = 0.02\ A_n\ R$.

Then: $$Q_A = A_{sensor} C_D \sqrt{\Delta p}, \quad \text{or } \Delta p = (Q_A / A_{sensor} C_D)^2$$

Substituting: $$\Delta p = K(1 - 0.75R)^2, \text{ where } K = (3\,Q_{A_{max}}/0.02\,A_n C_D)^2$$

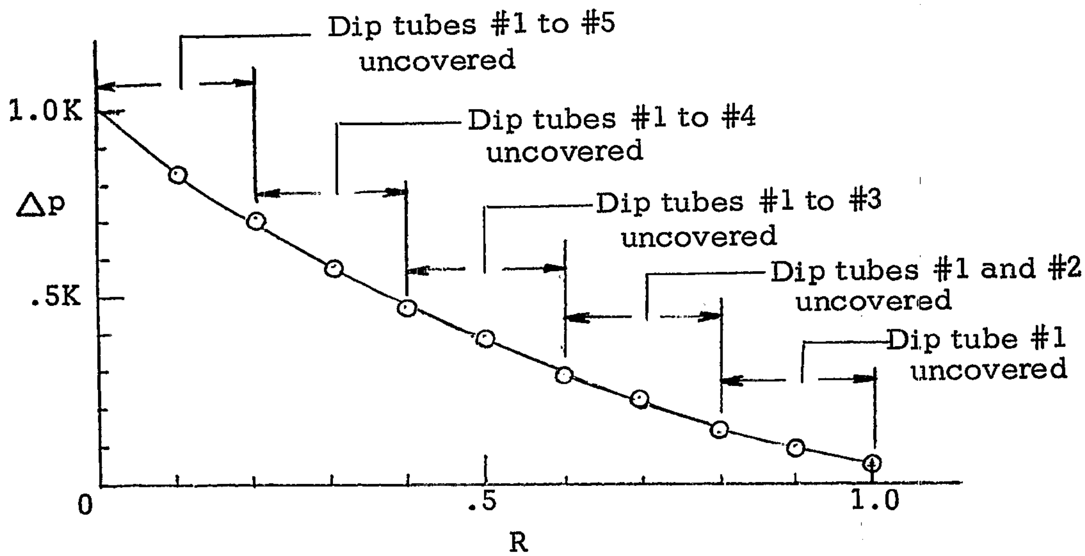
Δp vs. R is plotted, showing the ranges of Δp associated with successive dip tube uncoverings, hence the required lengths of each dip tube, with proportional increments of R. For the purposes of conservatism in the experimental design Δp_{max} was assumed = 18 in. H_2O. (If calibration testing indicates that this value is excessive, the dip tubes could be easily shortened.)

d_1 was selected = d_2 for simplicity of design. d_1 was selected = 12 in. The largest error in U-tube water level occurs at the uncovering of the first, or shortest tube, when water flows from all tubes.

Then: Total outflow volume = 4 x tube area x change in Δp + tube area x 18 in. = 17.42 $in.^3$.

Then level error = outflow volume/U-tube area = 0.15 in. This error is regarded as acceptable. Then dip tube lengths below quiescent liquid levels in U-tube sensor, for water and ethylene glycol, are as follows:

Tubes in uncovering order	Tube submergence, inches water	Tube submergence, inches ethylene glycol
1	1.8	1.62
2	3.78	3.42
3	7.02	6.31
4	10.62	9.55
5	14.76	13.35



APPENDIX B

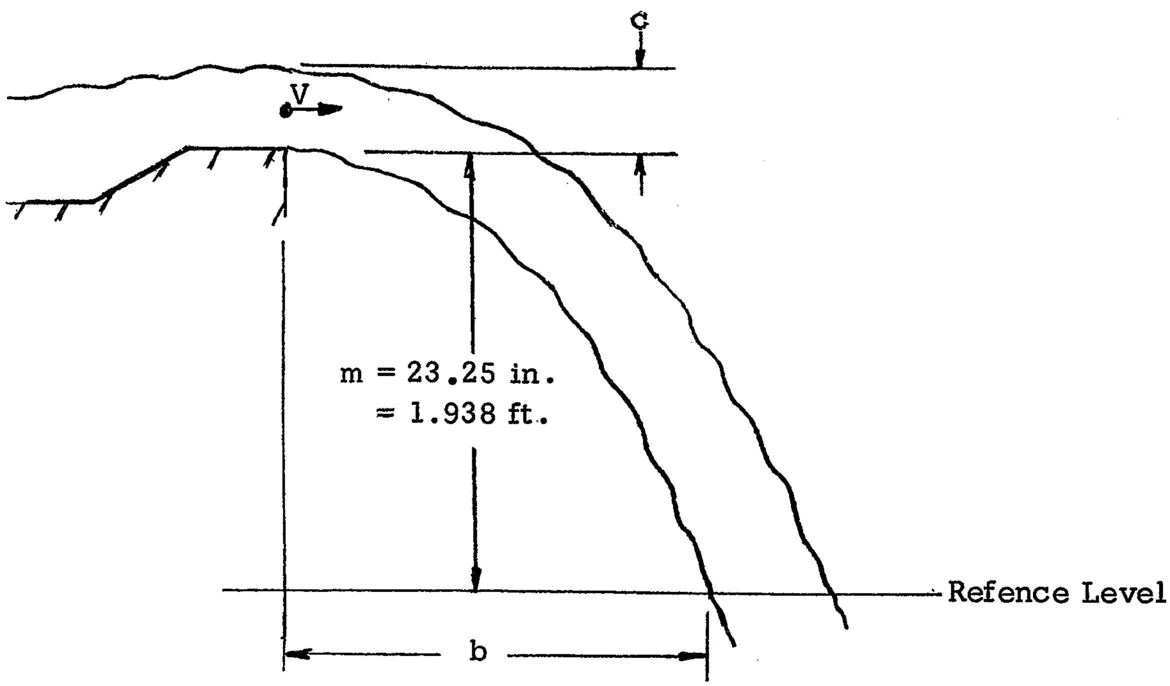
SITE CALIBRATION DATA

CALLOWHILL & 67TH ST. LOCATION

Laboratory Calibrations

March 6, 1972--

Notes: Tests run at Bowles Fluidics Corp., Silver Spring, MD. Total Regulator flow, Q_{tot}, derived using Ref. #1 criteria. Outfall flow, Q_{out}, determined by free-fall trajectory approach, see sketch below. Maximum outfall diversion, D_{max}, measured with outfall-side control port plugged, interceptor-side control port open.



Outfall discharge width = 7.5 in. Then discharge area = 7.5 c in.^{2} = 0.0521 c ft.^{2}. To determine flow velocity over discharge = V; let t = time to drop a distance, m, to a reference level. Then:

$$m = 16.1\, t^2 \text{ , or } t = \sqrt{m/16.1} = \sqrt{m}/4.012 \text{ .}$$

Using above dimensions, t = 0.347 sec. Then: b = V t, or V = b/0.347 (b in ft.) or: V = 0.25 b′ , (b′ in in.).
Then: Q_{out} = 0.24 (0.0521) cb′ = 0.0125 cb′ .

Run No.	h (in.)	c (in.)	b′ (in.)	Q_{out} (cfs)	h/h_n	C_D	Q_{tot} (cfs)	D (% Q_{tot})
1	3.25	0.6	9	0.07	0.65	0.93	0.68	10
2	4.5	1.5	14	0.263	0.90	0.99	0.85	31
3	7.0	2.5	16	0.5	1.4	1.07	1.14	44
4	10.0	4.0	20	1.0	2.0	1.11	1.41	71
5	10.75	4.25	21	1.12	2.2	1.12	1.48	76
6	5.5	2.25	14	0.39	1.1	1.04	0.98	40
7	3.8	5.0	9	0.06	0.8	0.96	0.75	8
8	5.1	2.25	15	0.42	1.0	1.01	0.92	46

To reduce trickle flows to an acceptable level, the outfall discharge weir was raised 1 in. Then Q_{tot} = 0.0122 cb′ .

9	7.9	2.75	17	0.57	1.58	1.09	1.23	46
10	9.9	3.75	20	0.92	1.98	1.11	1.41	65
11	3.7	0.40	7	0.03	0.74	0.94	0.73	4
12	5.4	1.25	9	0.14	1.08	1.04	0.97	14
13	9.7	4.50	20	1.10	1.94	1.11	1.39	79
14	6.1	2.50	15	0.46	1.22	1.04	1.04	44

June 1, 1972--

Notes: Tests run at Bowles Fluidics Corp. Same basic setup as for previous runs #9 to #14. Control ports connected to a diaphragm valve per Figure 6. Q_{out} = 0.0122 cb′.

1	4.1	0.50	6.0	0.04	0.82	0.96	0.78	5
2	6.5	3.50	14.5	0.62	1.30	1.07	1.10	56
3	10.2	4.50	18.5	1.02	2.04	1.12	1.44	71
4	5.0	1.25	10.0	0.15	1.0	1.01	0.91	16
5	5.2	1.75	13.0	0.28	1.04	1.02	0.96	29
6	6.2	2.0	15.0	0.37	1.24	1.06	1.06	35
7	7.2	2.25	15.5	0.43	1.44	1.07	1.15	38
8	8.0	2.5	16.0	0.49	1.6	1.09	1.24	39

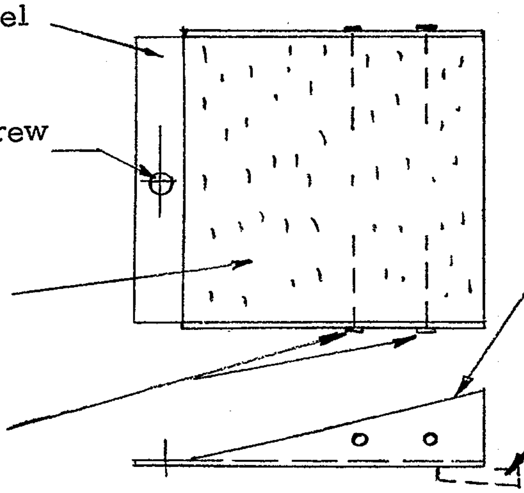
Site Calibrations

July 26, 1973--

Notes: Regulator out-of-level condition was noted upon preliminary inspection. Basic regulator operation appeared similar to laboratory operation. Need noted for increase in outfall weir height to prevent excess trickle flow to outfall when regulator is controlled toward interceptor. Interceptor flow measurement equipment was found inoperative. No quantitative data taken.

August 28, 1973--

Notes: Total flow derived from regulator supply head measurement and Ref. #1 Q vs. h criteria. Outfall flow measured using 90° V-notch weir downstream of a large tank which receives the outfall flow. Interceptor flow determined as the difference between total and outfall flows, since interceptor flow measurement system of Microstrainer Project was still not functional. Total flow to regulator controlled by adjusting opening of fire hydrants along street upstream from site. The outfall weir elevation was raised using an adjustable weir. (See sketch below.) This weir was set so that its elevation was 2.375 in. above the element roof at the discharge end to compensate for an out-of-level condition of 2 in. in the regulator installation.



Run No.	h (in.)	h/h_n	C_D	Q_{tot} (cfs)	h_{weir} (in.)	Q_{out} (cfs)	D (% Q_{tot})
1	5.38	1.05	1.04	0.97	1.4	0.012	1.2
2	10.38	2.08	1.12	1.45	5.25	0.315	21.7
3	6.62	1.32	1.06	1.10	3.4	0.107	9.7
4	8.12	1.62	1.09	1.25	4.0	0.156	12.5
5	5.88	1.18	1.05	1.03	2.75	0.063	6.1
6	4.38	0.88	0.97	0.82	1.5	0.014	1.7

Since the indicated values of D were much lower than expected, although the regulator appeared to be operating as during laboratory calibrations, a rough check on outfall flow was computed as follows: Water depth over discharge weir was estimated at 4 in. for h = 10.38 in. and full control toward the outfall. Then flow section area = 4 x 7.5 = 30 in.^{2} = 0.21 ft.^{2}. Then center of flow area is 2 in. above center of weir, and corresponding head drop is 10.38 - 2 = 8.38 in. = 0.7 ft. Assuming a 50% loss in converting static head to velocity head through the regulator, then velocity head = 0.35 ft. Then velocity = $\sqrt{64.4 \times 0.35}$ = 4.75 fps. Then estimated Q_{out} = 4.75 x 0.21 = 1.0 cfs.

Then estimated D = 1.0/1.45 = 69%, which closely matches the laboratory calibration value, thus indicating a problem in the V-notch weir flow measurement.

September 25, 1973--

Notes: Same basic setup as for previous calibration. Q_{out} measured using 90^o V-notch weir and flow velocity x flow area over weir. Flow velocity measured using pitot tube and propeller spinner. Spinner was calibrated at 1 revolution for 16 in. of water movement, independent of velocity. Interceptor flow estimated using velocity x flow area through a 10 in. diameter pipe. Flow area estimated from flow depth at pipe centerline and also width of flow surface. Velocity measured using pitot tube.

Run 1 - Upstream hydrant opened 1-1/2 turns.

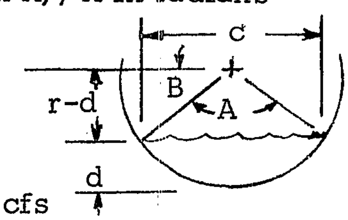
Q_{out} spinner turned 20 revs in 10 sec., depth over weir = 1.75 in.
$A_{flow} = 1.75 \times 7.5/ 144 = 0.0911$ ft.^{2}
$V_{flow} = 20 \times 16/ 10 \times 12 = 2.67$ fps
$Q_{out} = 2.67 \times 0.0911 = 0.24$ cfs
V-notch weir head = 3.5 in. = 0.292 ft. Then $Q_{out}' = 0.11$ cfs

Q_{int} Compute flow area using water depth approach.
pitot head = 9 in. H_2O = 0.75 ft. H_2O. $V_{flow} = 6.95$ fps
Flow area = Area of segment = $1/2\ r^2\ (A - \sin A)$, A in radians

$A = 180^o - 2\ B$, $\sin B = (r-d)/r$

r = 5 in., d = 3.75 in.

$B = 14.48^o$, $A = 151.05^o = 2.64$ rad.



Then flow area = 0.187 ft.^{2}, and $Q_{int} = 1.3$ cfs

Compute flow area using water surface width approach.
c = 9 in. Then $\cos B = 0.5\ c/r$, $B = 25.84^o$, A = 2.24 rad.
flow area = 0.126 ft.^{2}, and $Q_{int} = 0.88$ cfs

Q_{tot} Ref. #1 criteria. h = 4.63 in. = 0.385 ft., $h/h_n = 0.93$
$C_D = 0.99$, then $Q_{tot} = 0.86$ cfs
Correlate with $Q_{out} + Q_{int}$. Use $Q_{int} = 0.88$ cfs

V-notch weir approach: $Q_{tot} = 0.88 + 0.11 = 0.99$ cfs
Flow velocity x area : $Q_{tot}' = 0.88 + 0.24 = 1.12$ cfs

D Ref. #1 prediction for $h/h_n = 0.93$, a = 1; D = 13% Q_{tot}
Laboratory Calibration; D = 17% Q_{tot}
V-notch Weir measurement; D = 11% Q_{tot}
Discharge V x A measurement; D = 21% Q_{tot}

Run 2 - Upstream hydrant opened 2 turns.

Q_{out} Depth over discharge weir = 4.5 in., A_{flow} = 0.234 in.^{2}
V_{flow}; pitot head = 1.5 in. = 0.125 ft; V_{flow} = 2.84 fps
Q_{out} = 0.665 cfs
V-notch weir head = 5.5 in. = 0.458 ft.
Q_{out}' = 0.46 cfs

Q_{int} V_{flow}; pitot head = 8.75 in; V_{flow} = 6.85 fps
A_{flow}; (water surface width measurement); c = 8.75 in.
cos B = 0.875, B = 28.96°, A = 122.08° = 2.131 rad.
A_{flow} = 0.143 ft.^{2}; Q_{int} = 0.98 cfs

Q_{tot} Ref. #1 criteria; h = 8.88 in. = 0.74 ft; h/h_n = 1.78
C_D = 1.1 ; Q_{tot} = 1.32 cfs
Correlate with $Q_{int} + Q_{out}$;

V-notch weir measurement; Q_{tot} = 0.98 + 0.46 = 1.44 cfs
Flow velocity x area ; Q_{tot}'= 0.98 + 0.67 = 1.65 cfs

D Ref. #1 prediction for h/h_n = 1.78, a = 1; D = 35% Q_{tot}
Laboratory calibration; D = 60% Q_{tot}
V-notch Weir measurement; D = 32% Q_{tot}
Flow velocity x area measurement; D = 41%

Using Ref #1 criteria for Q_{tot};

V-notch weir measurement; D = 35% Q_{tot}
Flow velocity x area measurement; D = 51% Q_{tot}

Run 3 - Upstream hydrant open 2-1/4 turns.

Q_{out} Depth over discharge weir = 5.13 in. = 0.43 ft; A_{flow} = 0.267 ft.^{2}
V_{flow}; pitot head = 3.75 in. = 0.313 ft., V_{flow} = 4.49 fps
Q_{out} = 1.198 cfs
V-notch weir head = 7.5 in; Q_{out}' = 0.759 cfs

Q_{int} V_{flow}; pitot head = 7.5 in; V_{flow} = 6.344 fps
A_{flow}; (water surface width measurement); c = 7.5 in.
cos B = 0.75, B = 41.41°, A = 97.18° = 1.70 rad.
A_{flow} = 0.0614 ft.^{2} , Q_{int} = 0.389 cfs

Q_{tot} Ref. #1 criteria; h = 11.375 in. = 0.948 ft., h/h_n = 2.23
C_D = 1.12, Q_{tot} = 1.523 cfs
Correlate with $Q_{int} + Q_{out}$;

V-notch weir measurement; Q_{tot} = 0.389 + 0.756 = 1.145 cfs
Flow velocity x area measurement; Q_{tot} = 0.389 + 0.926
= 1.587 cfs

D Ref. #1 prediction for $h/h_n = 2.23$, a = 1; D = 57% Q_{tot}
Laboratory calibration; D = 76% Q_{tot}
V-notch weir measurement; D = 45% Q_{tot}
Flow velocity x area measurement; D = 79% Q_{tot}

From the above results, it was concluded that measurements of interceptor flow using depth, or width of the flow in a circular pipe were inconsistent as well as difficult to perform, and that a 90° V-notch weir should be constructed for this purpose. The consistent difference between discharge flow x area, and V-notch weir measurements of outfall flow was attributed to insufficient settling times before taking weir head readings.

October 4, 1973--

Notes: Same setup as for the previous calibration, but interceptor flow measured using a 90° V-notch weir. Regulator out-of-level condition was rechecked, and the following relationship to compute supply head was established: $h = 12.125 - d_{wl}$, where d_{wl} was the water line distance below the dam crest, in in. Also, $Q_{tot}' = Q_{out} + Q_{int}$ for comparison with Ref. #1 results. And; $D' = (Q_{tot} - Q_{int})/Q_{tot}$.

Run No.	d_{wl} (in.)	h (ft.)	h/h_n	C_D	Q_{tot} (cfs)	Q_{out} h_w (in.)	Q_{out} Q (cfs.)
1	- (DWF, Regulator not flowing full) -					0	0
2	5.5	0.55	1.32	1.06	1.1	4.0	0.156
3	1.375	0.90	2.16	1.12	1.48	7.4	0.757
4	0.25	0.99	2.38	1.13	1.57	7.6	0.788
5	4.50	0.64	1.54	1.09	1.22	5.4	0.340
6	7.135	0.42	1.0	1.02	0.92	2.5	0.051

Run No.	Q_{int} h_w (in.)	Q_{int} Q (cfs)	Q_{tot}' (cfs)	D* (%)	D' (%)
1	3.0	0.078	0.078	0	0
2	7.9	0.885	1.041	15	20
3	6.8	0.613	1.37	55	59
4	6.6	0.561	1.35	58	64
5	7.7	0.819	1.16	29	33
6	7.8	0.852	0.90	6	7

*Outfall V-notch weir flow measurements appear somewhat low due to large time lag before reaching equilibrium conditions in tank upstream of weir. Time lag on interceptor V-notch weir should be short due to small upstream volume, hence accuracy of readings should be good.

BINGHAM ST. LOCATION

Site Calibrations

April 11, 1974--

Notes: Total regulator flow derived using Ref.#1 criteria. Supply head determined by measuring water level distance below dam crest, d_w. Outfall flow measured using flow velocity x area approach. Flow velocity determined using rotating cup instrument. Flow area determined by depth of flow, d_{flow}, over outfall weir x channel width, (1.5 ft.). Run started when DWF backed up to dam crest elevation, at which time gate over regulator inlet was raised as rapidly as possible, (winching time about 10 sec.). Readings of supply head and outfall flow parameters taken at 15 sec. intervals. Run 1 was a shake-down run which did not include all measurements.

Run 1--

Time (sec.)	d_w (in.)	V_{flow} (fps)	d_{flow} (in.)	h (ft.)	h/h_n	C_D	Q_{tot} (cfs)	Q_{out} (cfs)	D (% Q_{tot})
0	0	0	0	3.5	2.33	1.125	-	-	-
15	3.5	N.T.*	N.T.	3.21	2.14	1.120	24.15	-	-
30	N.T.	"	"	-	-	-	-	-	-
45	6.0	4.0	"	3.00	2.00	1.11	23.14	-	-
60	7.5	4.0	"	2.88	1.92	1.11	22.68	-	-
75	8.5	4.5	"	2.79	1.86	1.10	22.12	-	-
90	9.3	4.5	"	2.73	1.82	1.10	21.88	-	-
105	10.3	4.0	"	2.64	1.76	1.09	21.32	-	-
120	12.0	3.5	"	2.50	1.67	1.09	20.75	-	-
135	14.0	3.5	"	2.33	1.55	1.08	19.84	-	-
150	14.5	N.T.	"	2.29	1.53	1.08	19.67	-	-

* Not Taken

Run 2--

0	0	0	0	3.5	2.33	1.125	-	-	-
15	3.0	N.T.	N.T.	3.25	2.17	1.120	24.30	-	-
30	3.5	5.0	5.0	3.21	2.14	1.120	24.15	3.13	13.0
45	4.0	4.2	5.0	3.17	2.11	1.120	24.00	2.63	11.0
60	5.75	4.2	5.0	3.02	2.01	1.110	23.22	2.63	11.3
75	6.75	4.4	4.5	2.94	1.96	1.110	22.90	2.20	10.8
90	8.0	4.4	4.0	2.83	1.89	1.105	22.39	2.20	9.8
105	9.0	4.4	4.0	2.75	1.83	1.100	21.96	2.20	10.0
120	10.0	5.0	3.5	2.67	1.78	1.100	21.62	2.19	10.1
135	11.5	4.0	3.0	2.54	1.69	1.090	20.92	1.50	7.2
150	13.0	N.T.	2.0	2.42	1.61	1.080	20.21	-	-

A large piece of concrete was found in the outfall-side of the regulator after this run. When this could not be cleared, further diversion performance runs were abandoned pending its removal. Run 3 was made with the outfall-side control port open, the interceptor-side control port closed, to check trickle flow over outfall with full control toward the interceptor. Flow velocity and depth readings were taken at approximately 30 and 60 seconds after the start of the run.

Run 3--

Time (sec.)	d_w (in.)	V_{flow} (fps)	d_{flow} (in.)	h (ft.)	h/h_n	C_D	Q_{tot} (cfs)	Q_{out} (cfs)	D (% Q_{tot})
0	0	0	0	0	-	-	-	-	-
30	4.0	5.0	4.0*	3.17	2.11	1.12	24.00	2.5	10.4
60	7.5	5.0	4.0	2.88	1.92	1.105	22.55	2.5	11.1

*Outfall flow depth was negligible until shortly before first reading, when it abruptly increased to about 4 inches.

May 14, 1974--

Notes: Same setup as for previous calibration. Vacuum readings taken for outfall-side control port. Reading times are estimated, based on Figure 27.

Est'd Time (sec.)	d_w (in.)	V_{flow} (fps)	d_{flow} (in.)	h (ft.)	h/h_n	C_D	Q_{tot} (cfs)	Q_{out} (cfs)	D (% Q_{tot})	C.P. Vac. (in.H_2O)
65	7.0	6.5	6.0	2.92	1.94	1.11	22.8	4.88	21.4	5.0
85	8.0	6.5	6.0	2.83	1.89	1.10	22.4	4.88	21.8	N.T.
115	10.5	6.5	6.0	2.68	1.75	1.09	21.4	4.88	22.9	4.0
125	11.5	4.5	4.5	2.54	1.69	1.09	20.9	2.53	12.1	2.0
140	13.0	4.5	4.5	2.42	1.61	1.08	20.3	2.53	12.5	0

Diversion readings were higher than on previous calibration, but much less than predicted, based on derivation of Q_{tot} using Ref.#1 criteria. Actual Q_{tot} may have been much less due to flow impedance in 24 in. connecting sewer.

1/6 Scale Model Test Program, May 20 to July 8, 1974--

The test model is shown in Figure 28. The model was constructed of laminated particle board waterproofed with clear lacquer. A clear plastic cover allowed direct observation of internal flow patterns. Flow rates were determined by measuring the time taken to fill a 7-gallon container. The measurement accuracy is estimated at 5-10% at max. flow rates; 2-5% at low flow rates. The model was designed with a replaceable outfall discharge section. Tests were conducted on the prototype and three possible modifications. Each modified configuration had the discharge weir widened from 3 in. to 7 in., with variations in the elevation at which the widening started. The test results are shown in Figure 29. Note the large improvement in diversion performance obtained with all the modified configurations, as compared with the prototype. These tests showed the need to supplement the Ref. #1 design criteria to include design characteristics for outfall discharge width as a function of inlet aspect ratio, a. The proposed modifications, prototype, and selected modification configurations are shown on Figure 30. The selected configuration represented a practical compromise between improved diversion performance and excavation cost.

September 27, 1974--

Notes: Basic calibration setup as on previous calibration attempts. Added measurements were pitot head flow velocity, and interceptor-side control port vacuum. Only maximum head readings were taken, at approximately 10 seconds after the run start, to avoid the flow impedance problem discussed earlier. The outfall width was checked and found to be 42 in.

Run No.	d_w (in.)	V_{flow} R-C Ind. (fps)	Vel. Hd. pitot (in.H_2O)	V_{flow} pitot (fps)	d_{flow} outfall (in.)	h (ft.)	h/h_n	C_D
1	6	2.9	N.T.*	-	8.0	3.0	2.0	1.115
2	5	2.5	"	-	8.0	3.08	2.05	1.115
3	6	2.9	3.0	4.0	9.0	3.0	2.0	1.115
4	4	2.5	2.6	3.73	9.0	3.17	2.11	1.12
5	5	2.2	1.2	2.58	7.5	3.08	2.05	1.115
6	3	2.6	N.T.	-	9.0	3.25	2.17	1.125

	Q_{tot} (cfs)	Q_{out} R-C Ind. (cfs)	Q_{out} pitot (cfs)	D R-C Ind. (% Q_{tot})	D pitot (% Q_{tot})	C.P. Vac. (in.H_2O) outfall	int'r.
1	23.3	6.77	-	29	-	- 8	- 4
2	23.6	5.83	-	25	-	- 8	N.T.
3	23.3	7.60	10.53	33	45	- 8	"
4	24.0	6.60	9.80	28	41	-15	"
5	23.6	4.80	5.60	20	27	- 7	"
6	24.4	6.80	-	28	-	- 9	"

* Not Taken

Comments: On runs #5 and #6, flow was observed to back up in the special junction manhole, approximately 24 in. above the inlet to the connecting sewer, at about 20 seconds after the start of the run. Since the backup presumably occurred on all runs, the values of Q_{tot}, as derived using Ref.#1 criteria, are probably significantly larger than actual, since this criteria assumes no hydraulic loading on the regulator. Determination of flow velocity using pitot head readings produced consistently higher values than indicated by the rotating cup instrument. Interceptor-side control port readings were discontinued after run, as the instrument malfunctioned.

November 14, 1974--

Notes: Basic calibration was as on previous calibration attempts. Pitot head readings were taken with a floating sensor, which greatly reduced errors in pitot tube submergence, occurring with hand-held readings. This sensor was directly calibrated in fps. The flow backup into the special junction manhole after about 20 seconds of the run was seen to occur on two runs, and presumably occurred on all runs. Thus the values of Q_{tot} derived from the Ref.#1 criteria are probably higher than actual, and the values of D correspondingly lower. Outfall-side control port vacuum readings were seen to drop from around -10 in. H_2O to about -4 in. H_2O at 15-20 seconds after the runs started. As on the previous calibration, the outfall flow velocity readings from the rotating cup instrument were about 30% lower than from the pitot head sensor.

Run No.	d_w (in.)	V_{flow} R-C Ind. (fps)	V_{flow} pitot (fps)	d_{flow} outfall (in.)	h (in.)	h/h_n	C_D	Q_{tot} (cfs)
1	6	2.8	3.0	8.0	3.0	2.0	1.115	23.3
2	6	2.4	3.25	7.8	3.0	2.0	1.115	23.3
3	6	2.1	3.1	7.5	3.0	2.0	1.115	23.3
4	5	2.6	3.3	8.5	3.08	2.05	1.120	23.6
5	6	1.6	2.75	8.0	3.0	2.0	1.115	23.3
6	5	2.2	2.75	8.0	3.08	2.05	1.120	23.6
7	5	1.6	2.7	7.5	3.08	2.05	1.120	23.6

	Q_{out} R-C Ind. (cfs)	Q_{out} pitot (cfs)	D R-C Ind. (% Q_{tot})	D pitot (% Q_{tot})	C.P. Vac. (in. H_2O) outfall	int'r
1	6.53	7.58	28	33	- 7	0
2	5.46	7.39	24	32	- 5	0
3	4.59	6.78	20	31	- 9	0
4	6.44	8.18	27	35	-10	0+
5	3.73	6.42	16	28	- 5	+2
6	5.13	6.41	22	27	- 6	-1
7	3.50	5.91	15	25	- 6	0+

APPENDIX C

CONVENTIONAL REGULATOR PERFORMANCE ANALYSIS

67TH/CALLOWHILL LOCATION

Compute Depth of Flow vs. Flow vs. Velocity

Q_{max} = 27.6 cfs, V_{max} = 8.8 fps, sewer I.D. = 2 ft.

slope = 0.02, flow area = 3.14 ft.^{2}

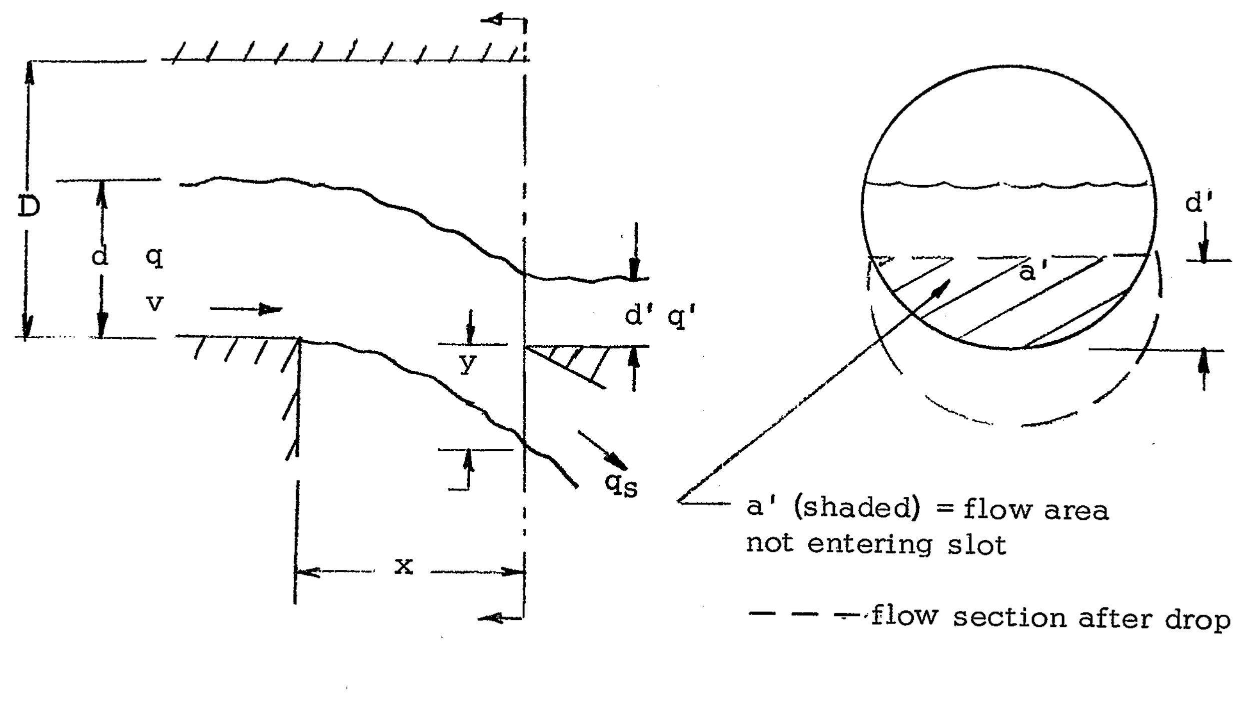
At Q_{max}, flow area = 27.6/8.8 = 3.14 ft.^{2}, indicating full pipe flow. Then d/D = 1.0. Check slope by Manning's equation:

$$V = 1.49\, s^{1/2}\, r_H^{2/3} / n, \ \&\ n = 1.49\, s^{1/2}\, r_H^{2/3} / V \qquad r_H = r = 1 \text{ ft.}$$

$$V = 8.8 \text{ fps}$$

n = 0.024, which appears reasonable.

Find Flow Entering Slot:



Determine y:

fly time = $t = x/v$, $y = 16.1\,t^2$, x set at 0.5 ft. by PWD, then $y = 4.025/v^2$

$D = 2$ ft., $d' = d - y$, $V = 8.8$ fps, $A - 3.14$ ft.^{2}

$Q = 27.6$ cfs, assume n is constant, slot flow $= q_s = q - q'$

d/D	d (ft.)	q/Q	q (cfs)	v/V	v (fps)	y (ft.)	d-y (ft.)	d-y/D	q'/Q	q' (cfs)	q_s (cfs)
0.6	1.2	0.671	18.52	1.072	9.43	0.045	1.155	0.577	0.630	17.39	1.13
0.5	1.0	0.500	13.80	1.000	8.80	0.052	0.948	0.474	0.459	12.67	1.13
0.4	0.8	0.337	9.30	0.902	7.94	0.064	0.736	0.368	0.288	7.95	1.35
0.3	0.6	0.196	5.41	0.776	6.83	0.086	0.514	0.257	0.142	3.92	1.49
0.25	0.5	0.135	3.73	0.699	6.15	0.106	0.394	0.197	0.085	2.35	1.38
0.2	0.4	0.088	2.43	0.615	5.41	0.137	0.263	0.131	0.046	1.27	1.16
0.15	0.3	0.047	1.30	0.530	4.49	0.200	0.100	0.050	0.010	0.26	1.04
0.125	0.25	0.032	0.88	0.465	4.09	0.240	0.010	0.005	0.001	0.01	0.87
0.1	0.2	0.021	0.58	0.401	3.53	0.323	-	-	-	-	0.58
0.075	0.15	0.014	0.39	0.325							0.39
0.05	0.1	0.008	0.22	0.238							0.22

<u>Compute Fluidic Regulator Flow for Overflow Conditions:</u>

Assume dam is sharp-edged weir. Use Francis formula:

$Q_D = 3.33\ l\ h_D^{3/2}$, $h_D = h_R - 1.167$ ft., $l = 2$ ft.

h_R	1.17	1.25	1.33	1.42	1.50	1.58	1.66	1.75	2.167
h_D	0	0.083	0.167	0.25	0.333	0.417	0.500	0.583	1.00
Q_D	0	0.16	0.45	0.83	1.28	1.79	2.35	2.96	6.66
Q_{Reg}	1.90	2.00	2.05	2.10	2.15	2.18	2.25	2.28	2.65
$Q_D + Q_{Reg}$	1.90	2.16	2.50	2.93	3.43	3.97	4.60	5.24	9.31
D	0.72	0.80	0.83	0.86	0.88	0.89	0.90	0.91	0.94
Q_{outmax}	1.37	1.60	1.70	1.81	1.89	1.94	2.03	2.07	2.49
Q_{intmin}	0.53	0.40	0.35	0.29	0.26	0.24	0.23	0.21	0.16

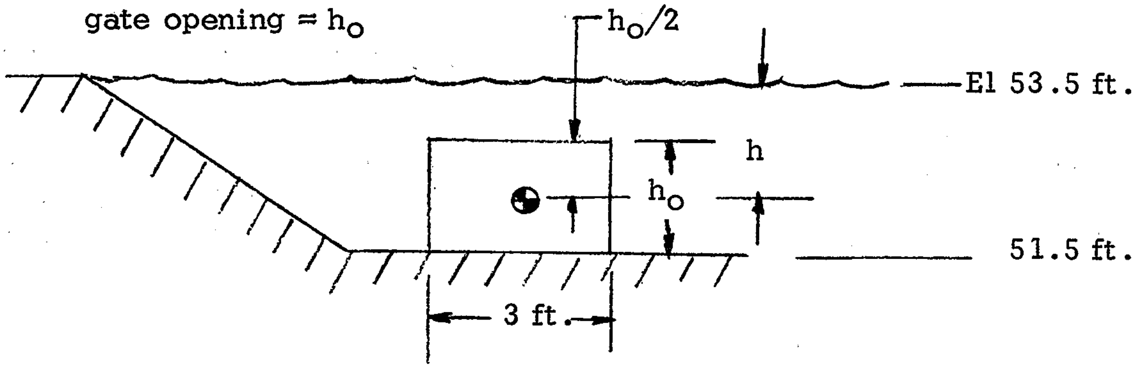
Various Q's, q's, in cfs, various h's in ft. Hydraulic element data obtained from Table 14-3, Page 14-8, Ref. #2. Above data is shown plotted on Figure 33.

BINGHAM ST. LOCATION

<u>Find Static Regulator Flow Relation:</u>

Regulator is manually positioned sluice gate, maximum opening 3 ft.

wide x 2 ft. high. Dam crest of original installation at elevation 53.5 ft. Bottom of gate opening at elevation 51.5 ft. Dam width = 9 ft. Determine gate opening corresponding to dam overflow at 2 x maximum estimated DWF = 2 x 10 cfs = 20 cfs. Assume gate inflow $C_D = 0.7$, since bottom of gate opening is very close to sewer invert.



Equations:

$h = 2\text{ ft.} - h_o/2, \quad A_o = 3\,h_o$

Then:

$$20\text{ cfs} = 0.7\,(3h_o)\,(64.4\,(2 - h_o/2))^{1/2}$$
$$= 16.85\,h_o\,(2 - h_o/2)^{1/2}$$

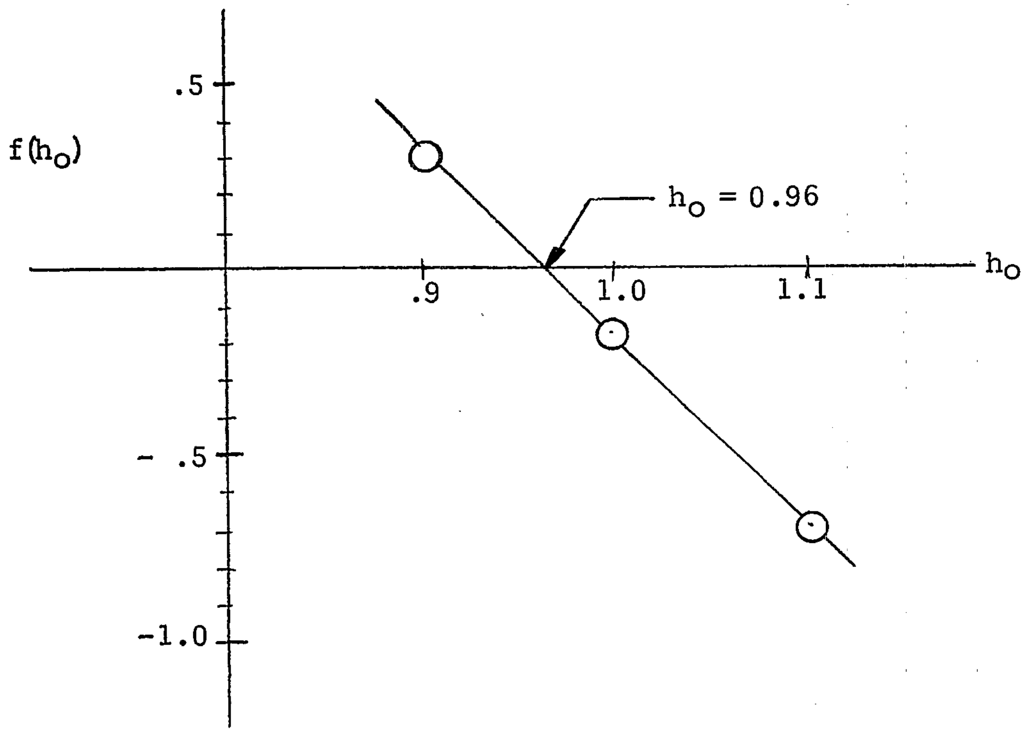
Squaring both sides:

$$400 = 284\,h_o^2\,(2 - h_o/2) = 568\,h_o^2 - 142\,h_o^3, \text{ or}$$

$h_o^3 - 4\,h_o^2 + 2.817 = 0$. Solve graphically. Find value of h_o at which left side of equation = 0.

h_o	1.1	1.0	0.9
Left side of eq'n	-0.692	-0.183	+0.306

Plotting these values:



Check: $h = 2 - h_o/2 = 1.52$ ft., $A_o = 2.88$ ft.^{2}

Then: $Q_{Ref} = 0.7\,(2.88)(64.4 \times 1.52)^{1/2} = 19.95$ close enough to 20

Then relationship for Q_{Reg}:

$$Q_{Reg} = 0.7\,(2.88)(64.4)^{1/2}\,(h)^{1/2} = 16.178\,h^{1/2}$$

Determine relationship for flow over dam, Q_D' vs. h_D. Use Francis formula for sharp crested weir:

$$Q_D = 3.33\,1\,h_D^{3/2} \qquad 1 = 9 \text{ ft.},$$

then $Q_D = 30\,h_D^{3/2}$, and $h_D = h - 1.52$.

<u>Determine Total Flow for Static Regulator:</u>

h	Q_D	Q_{Reg}	$Q_D + Q_{Reg}$
1.52	0	20.0	20.0
2.0	10.0	22.9	32.9
2.5	29.1	25.6	54.7
3.0	54.0	28.0	82.0
3.5	83.6	30.3	113.9
4.0	117.2	32.4	149.6
4.5	154.3	34.3	188.6

Fluidic Regulator Total Flow:

Determine flow characteristics of fluidic regulator under dam overflow conditions, considering maximum regulator control toward either interceptor or outfall. Regulator diversion characteristics derived from 1/6 model test calibration extrapolated. Q_{Reg} derived using Ref. #1 criteria. Q_D determined using Francis formula:

$$Q_D = 3.33\ l\ h_D^{3/2}\ ,\quad l = 8\ \text{ft.},\quad h_D = h - 3.5\ \text{ft.},$$

then:

$$Q_D = 25.64\ h_D^{3/2}\ .$$

h	2.25	2.63	3.00	3.38	3.75	4.13	4.50	5.00	5.50	6.0
h/h_n	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.33	3.67	4.0
D(% Q_{Reg})	16.00	37.00	49.00	59.00	69.00	74.00	80.00	83.00	86.0	88.0
Q_{Reg}	19.00	22.00	23.50	25.50	27.00	29.50	32.00	34.00	36.0	38.0
Q_{out}	3.00	8.10	11.50	15.00	18.60	21.80	25.60	28.20	31.0	33.4
Q_{int}	16.00	13.90	12.00	10.50	8.40	7.70	6.40	5.80	5.0	4.6
h_D	-	-	-	-	0.25	0.63	1.00	1.50	2.0	2.5
Q_D	-	-	-	-	3.33	13.32	25.60	48.90	75.3	105.3
$Q_{Reg}+Q_D$	19.00	22.00	23.50	25.50	30.30	42.80	57.60	82.90	111.3	143.3

Various Q's, in cfs, various h's in ft. This data is shown plotted on Figure 34.

GLOSSARY

Fluidic Nomenclature

Nozzle: Opening where fluid enters the fluidic element having a geometry similar to a venturi throat.

Control Ports: Openings immediately downstream from the nozzle where fluid, gas or liquid, is admitted to influence the direction of nozzle flow.

Splitter: A wall which divides the fluidic element exit area into two sections.

Attachment Walls: Wall of element immediately downstream of control ports to which the nozzle flow jet attaches by the Coanda effect.

Coanda Effect: Wall attachment phenomenon of a jet stream close to a wall which provides a pressure differential to act on the jet stream as a result of entrainment at the wall, producing a low pressure area.

Venturi: A constriction in a flow channel which produces increased velocity and decreased pressure or suction at the constriction.

Aspiration: Drawing of fluid, air in this case, into element control ports due to suction effect of venturi nozzle.

Aspect Ratio: Ratio of regulator inlet nozzle height to width.

Digital Operation: Regulator operating having maximum flow diversion to either discharge.

Analog Operation: Regulator operation having a continuous range of diversion performance between discharges.

Diversion: The capability of a fluidic regulator to direct part of the entering flow toward the higher elevation discharge, away from the lower elevation discharge.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-071	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE EVALUATION OF FLUIDIC COMBINED SEWER REGULATORS UNDER MUNICIPAL SERVICE CONDITIONS		5. REPORT DATE August 1977 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Peter A. Freeman		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Peter A. Freeman Assoc., Inc., Box 2210, Rt. #4, Ocean Pines, Berlin, MD 21811 under subcontract to: Philadelphia Water Dept., 1180 Municipal Sevices Bldg., Philadelphia, PA 19107		10. PROGRAM ELEMENT NO. 1BC611
		11. CONTRACT/GRANT NO. Grant No. 11022 FWR
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin., OH Office of Research and Development US Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
P.O.-Richard Field, Chief, Storm & Combined Sewer Sec., Edison, NJ 08817, 201-321-6674
Prototype evaluation of model developed under previous project as reported in "Design of a Combined Sewer Fluidic Regulator", USEPA Report No. 11020 GZU 10/69 (NTIS PB 188914

16. ABSTRACT
This report describes the evaluation of two fluidic combined sewer regulators operated by the City of Philadelphia Water Department under typical municipal service conditions. The smaller unit provided much better hydraulic regulation performance than the conventional static regulator it replaced, approaching that of a complex, dynamic regulator. The larger unit demonstrated a similar performance potential which was not practicably achieved because of unforeseen, heavy infiltration in the connecting sewer.

The Philadelphia Water Department determined that surveillance and maintenance costs for fluidic regulators were actually lower than for conventional static regulators and much lower than for conventional dynamic regulators. Retrofit costs for fluidic regulators were determined as about 30% greater than for conventional static units, but less than half of those for conventional dynamic regulators. Considering both hydraulic performance and costs, the fluidic regulator was considered to offer greater cost effectiveness than either conventional static or dynamic combined sewer regulators.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Combined sewers, Fluidic devices, Regulators, Overflows-sewers, Hydraulic gates	Diaphragm value, Low cost, Low maintenance, Interceptor variable diversion, Hydraulic sensors	13 B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 105
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1977-757-056/6486 Region No. 5-11