WATER POLLUTION CONTROL RESEARCH SERIES 11020 DHQ 06/72

GROUND WATER INFILTRATION AND INTERNAL SEALING OF SANITARY SEWERS

MONTGOMERY COUNTY, OHIO

U.S. ENVIRONMENTAL PROTECTION AGENCY

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GROUND WATER INFILTRATION

AND

INTERNAL SEALING OF SANITARY SEWERS

Montgomery County, Ohio

by

Montgomery County Sanitary Department
4221 Lamme Road
Dayton, Ohio 45439

for the

Office of Research and Monitoring

ENVIRONMENTAL PROTECTION AGENCY

Project #11020 DHQ

June 1972

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ENVIRONMENTAL PROTECTION AGENCY

ABSTRACT

A program for pollution abatement was undertaken by the Montgomery County Sanitary Engineering Department in Southwest Ohio to research the effects of infiltration reduction by joint sealing and to study closed circuit television techniques.

Water pollution from municipal wastewater treatment plants would be reduced if peak flows from rainfall could be reduced. This study evaluates the effects of remedial repairs to joints by use of pressure grouting of small main line sewers. A minimal measurable amount of quantity flow reduction was attributed to the sewer sealing program. This is to say that infiltration from extraneous storm water, illegal connections, and basement underdrains seem to outweigh the contribution due to leaky joints to such a degree that reduction due to joint sealing was obscured.

The study does show the significance of internal television system as an inspection and maintenance tool. This information on costs, operation, and procedure is of value to anyone interested in this field.

This report is submitted in fulfillment of Project #11020DHQ under the partial sponsorship of the Water Quality Office of the Environmental Protection Agency.

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FIGURES

TABLES

SECTION I

CONCLUSIONS

1. Sealing is an effective process. Rechecking joints after one year revealed no deterioration. See pages 9 and 37.

2. Sealing and televising costs and speeds depend greatly on line conditions and operator experience. See page 59.

3. Televising should precede sealing unless condition of the lines is known. (new lines)

4. The ratio of peak load during a surge due to rainfall to average load exceeded 7 in the study area. See page 32.

5. The sealing of the trunk line joints was not proved to be an economical means of reducing overall infiltration. See Appendix B.

6. Television inspection is an extremely useful tool to determine pipe condition and location of features. See page 36.

7. Television inspection of joints is not an effective method of determining joint condition. See Appendix I.

8. Television inspection revealed many defects not apparent through smoke testing. See page 10.

9. Sewer sealing would not remove the instant peaks in flow (infiltration due to downspouts and illegal connections) but it is possible to remove the long tailing off period after rainfalls. See page 23.

10. The technique of pressure grouting, although slow, cumbersome, expensive, and requiring technical expertise, is a permanent, effective, and economically superior method to digging. Results with this method can be checked and documented, and hence is extremely reliable. See page 37.

SECTION II

RECOMMENDATIONS

1. Unusually low rainfall during the experimental phase of the study may have affected results. Further investigation is warranted. See page 34.

2. An aggressive program to remove illegal connections should precede any program of this type. Infiltration from other sources obscure results. See page 32.

3. Any future work of this type should be performed in a manner that insures legal support of the activities necessary to run the experiment. See page 32.

4. Development of a more effective method of monitoring ground water conditions is necessary. See page 33.

5. Development of a method to measure and record lateral flow is necessary. See page 33.

6. Domestic water flowing into the study area should be metered directly. Frequent house meter readings proved to be impossible due to the objections of study area residents. See page 33.

7. In order to compensate for any other factors which may enter into the study and confuse the results, it is suggested that in the design of future studies an adjacent area be selected, fitted with a flow meter, and serve as a control area. See page 34.

8. In the future studies consideration should be given to the selection of a compound flow meter. Flows differing from those anticipated result in the loss of valuable information due to the inability of the flow meter to measure fluctuating flows. Accurate and precise measurements of the flow conditions over the entire range will enhance results. See page 32.

9. It is desirable to set up a standpipe connected to each monitoring manhole invert with a float and a recording device. This would enable the flow design index to be a more realistic figure. See page 23.

10. A very rough figure for design can be obtained by finding the ratio of the treatment plant peak flow to the plant flow at 8:00 A.M. and then applying this ratio to the study area flow at 8:00 A.M. to get a projected figure. See page 24.

SECTION III

OBSERVATIONS

1. For estimating purposes overall sealing speed during the project was 72 ft/hr/306 ft/day. The cost was $5.79 per joint. Televising cost for the overall project was $1.54 per foot. See Appendix B.

2. The power winch mechanism aids in the speed and economy of the sealing and televising process and permits the use of a three-man crew. A two-man televising crew can televise under ideal conditions. See page 37.

3. The flow-through packer design does not require the pumping of sewage around the area being sealed.

4. Only after periods of continuous rain will the ground saturate and the ground water move upward. After the ground is saturated, moderate rainfall will move the ground water up quite markedly. See page 26.

5. Ground water pipes tend to clog, adversely affecting the reliability of the readings. See page 18.

6. A four-wheel drive vehicle is necessary for this type of work. See page 59.

7. This report can be used most effectively in the areas of cost, equipment, procedures, and organization. See page 36.

SECTION IV
INTRODUCTION

Extraneous water entering sanitary sewer systems reduces the effectiveness of both the collection system and the treatment facility. Ideally, this water should never enter a sanitary sewer system. In reality, however, such water does enter the system through a variety of ways. A sewer system which had none of this water would operate more effectively because the total volume of water throughout would be reduced to a minimum. Extraneous water enters a sanitary system through the following ways: illegal connections, cross connections, underground infiltration, and incorrect uses. It causes surcharges destroying treatment equilibrium in biological processes and reducing the degree of treatment achieved by a wastewater treatment plant. Surcharges flood trunk and connector systems disrupting service by users as well as causing basement backup. Besides flooding basements with diluted sewage, causing a health hazard, the system untreated wastes are discharged directly into natural watercourses through a system of by-passes.

If it were possible to prevent entry of extraneous water, the treatment facility could be designed to treat only the effluents of the users. There would be no need to provide capacity in the treatment plant and the collector system for infiltration loads. Thus reduction of the amount of extraneous water results in more efficient operation, lower capital expenditures, and lower stream pollution levels. Since the sources of this unwanted water are varied and complex, the methods to reduce its level are equally complex.

In order to determine a solution, the problem must be defined. There is a need to know, quantitatively, the amount of infiltration coming from various sources and the cost effectiveness of respective remedial action. It is not feasible to generalize between the sources of infiltration in various systems, or even various locations in the same system due to the wide variation in conditions. Expertise in the effectiveness of different solutions is lacking.

Where corrective action has been undertaken to alleviate basement flooding caused by infiltration problems as maintenance procedures, sufficient controls could not be established to determine the actual effectiveness. In addition there is a need to relate such parameters as the intensity and duration of rainfall, ground water table, soil composition and moisture content, joint type, material type, and normal flow characteristics to the infiltration problem. The best indicator of overall infiltration has been a comparison between total water pumped from its source into an area, and sewage flow from a particular drainage area. Graphs of these flows show a cyclical shift between infiltration and exfiltration which may be correlated roughly with wet and dry periods. These figures are not totally indicative of the quantities because of allowable meter inaccuracies, process water consumption, extraneous water use, i.e. swimming pools, street washing, fire fighting, watering, car washing and by-passes in the sewer system.

The Beavercreek Sewer Subdistrict of the Greater Moraine-Beavercreek Sewer District of Montgomery County, Ohio, has been plagued with infiltration problems and resulting surcharging of its treatment plant since its establishment in 1952. The County began a corrective program of remedial action, in 1957, on the effect of sealing trunk sewers on treatment plant flows.

Because the sewer sealing program was an integral part of normal maintenance operations accurate cost control procedures were not utilized. Smaller size collector lines tributary to the trunk sewer lines sealed contributed such a large volume of flow as compared to the quantity removed by remedial sewer sealing the effect was not assignable. It was with these factors in mind a totally new program was structured. Due to the portion of infiltration assignable to smaller lines a more significant contribution to infiltration abatement could be realized. In smaller lines a contributary area could be readily defined and measured without adjustment for flow from adjacent areas.

In 1968, Montgomery County initiated a three-phase program to eliminate stream pollution: expansion of the wastewater facilities to a capacity sufficient to treat peak flows, construction of two miles of primary trunk sewer to replace existing inadequate pipe, and removal of the source of illegal storm water by inventory of the existing facilities and embarking on an active sewer sealing program.

Montgomery County Sanitary Department submitted a grant request to the Federal Water Quality Administration, under the now Environmental Protection Agency, to study the limited effectiveness of sealing the small diameter collector sewers in a limited study area.

SECTION V
PROGRAM DESIGN

The study required designing a program to determine the effectiveness of sealing on infiltration. Sealing of defective sanitary sewers can be accomplished internally by chemical means. Two types of sewer sealing were considered.

One process includes the instantaneous mixture of two chemicals at the point of injection in the leak in the sewer. The chemicals are forced through the crack in a defective piece of pipe joint and into the earth surrounding the sewer pipe. This material permeates the earth backfill and forms a gel in the void areas in the soil. High pressures are required to mix and inject the chemicals; consequently, this type is known as the pressure grouting process.

A second type of liquid sealing of sanitary sewers is to mix the dry materials in an isolated section of the sanitary sewer in large quantities of water to form a slurry. The upper manhole is filled to a height at least four feet above the outside water table. The solution is then forced through the cracks in defective pipes and joints by hydraulic pressure. The particles in the slurry attach to the edges of the leak and/or soil particles in the backfill. The solids in the slurry absorb water and expand to seal the openings.

As we worked on the first phases of the project there was one basic change in our plan. This was the limitation to a single method of sealing, pressure grouting, and the one particular acrylamide sealant used with it. Our reasons for this were, first, the two methods, hydrostatic and pressure grouting, are sufficiently different so that the effectiveness must also be different. If more than one method were employed in a single section then it would be impossible to evaluate their individual effectiveness. Secondly, the pressure injection method gives the opportunity to test each joint under pressure. It is known that each joint is positively sealed and its condition a matter of record. This method also allows the recheck of each joint after the program to insure conditions did not change during the course of the experiment.

A review of the entire system was conducted to select a suitable test site. Although an entire system may be faulty, a specific area had to be selected where the various effects could be measured.

The next step was to check the individual test sections in detail and make a final selection. The factors used in selecting a test area are reviewed in Appendix B. This entailed watching the relationship between rainfall and flow. This was done as often as possible after significant precipitation and occasionally during dry weather. It was important to go out at the same time every day to get significant readings. It would have been better to have temporary flow gauges with 24-hour charts using an in-pipe flume or a stilling well connected to the invert of the pipe. This was not provided for so that the ruler spot check once a day was used. It is necessary to consider that the pipes flow at different grades in order to compare this information. The monitoring location must also have sufficient straight run of pipes with no drops to assure laminar flow for accurate measurements. Inspections were also made at night during low flow to observe the actual extent of infiltration. The areas were small enough to observe any nighttime flushing activity, so any flow observed was assumed to be infiltration. Infiltration flows are generally clean and clear and flow continuously. The results of all the flow checkings are shown in Figure 1. During this selection period we did not allow for water softener backwashing.

Each area was smoke tested for illegal connections or bad defects. None of our smoke tests showed any defects although further television investigation found many.

Ground water level monitoring pipes were installed in varying manhole locations in the prospective area and extended approximately one foot below the invert of the pipe, as shown on the detailed drawing in Figure 2. They were checked using a float on a light fishing line with the manhole rim as an elevation reference. This was done every time the flow was checked: after every rainfall and occasionally during dry weather.

Knowledge of existence of ground water is an important part of study area selection, because we are sealing the pipes to prevent infiltration which will not exist without ground water. It was important to install more than one pipe in the sections that looked suspicious because impervious layers in a trench could prevent water from entering the pipe.

An independent testing lab was employed to test soil conditions of these test areas. Tests on the site selected are shown in Figure 3.

Installation of a device for determining if the manholes in the area surcharge was an important item because any area which surcharges will obscure the flow measurements at the very time that they are most important; peak flow due to rainfall. Figure 4 shows cans installed at different elevations to determine if surcharging occurred. These cans are not the best solution to surcharge checking as they rust out fast, fill with water that drips in through manhole covers and are hard to empty when full. A better solution is shown in Figure 5.

In our final selection surcharging and high flow during heavy rainfall were given the greatest weight for selection with ground water next in importance.

The other factors involved in selecting a test site were the selection of an area having at least one mile of isolated sanitary sewer,

STUDY AREA SELECTION

FLOW & RAINFALL

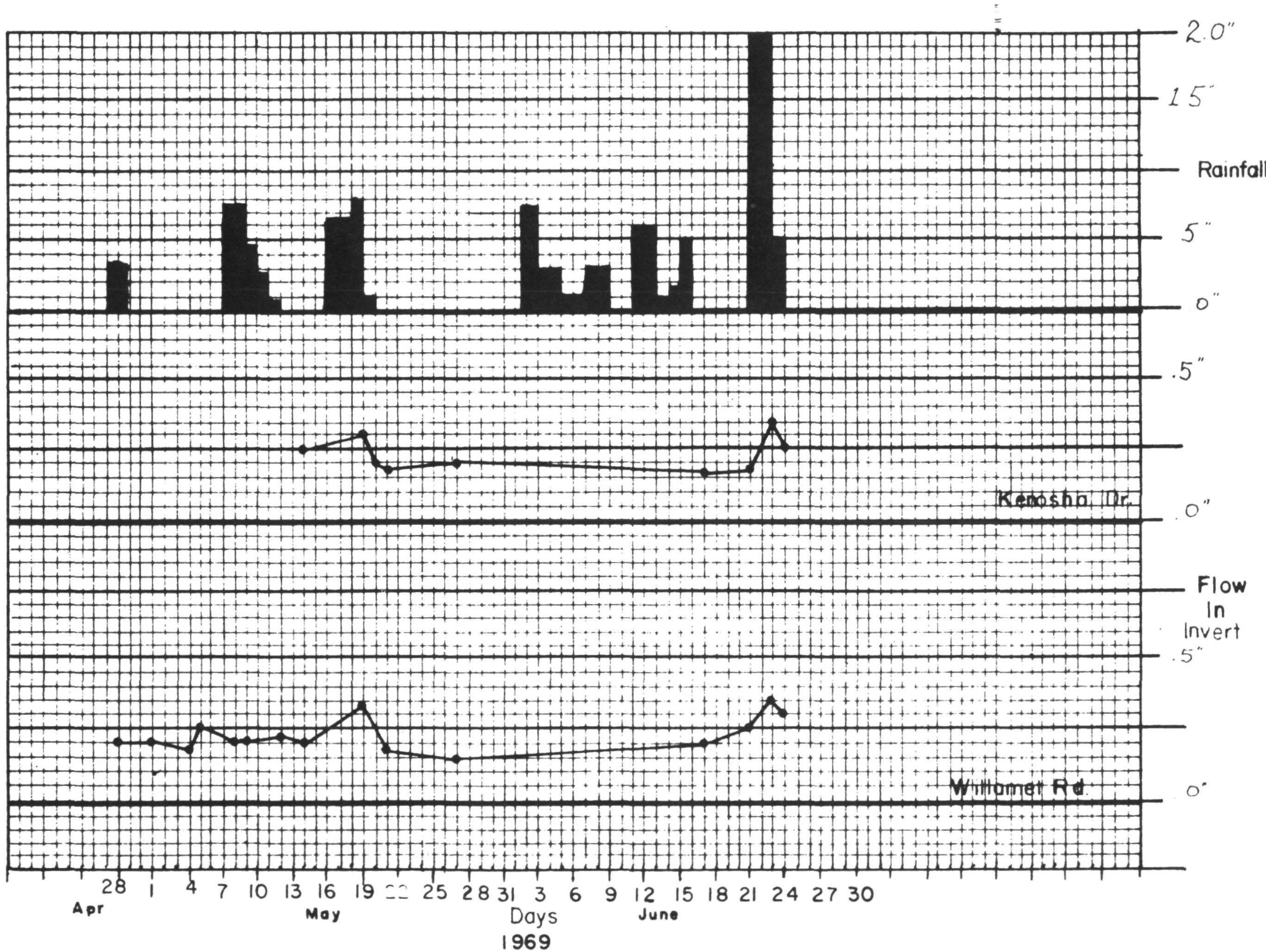


Fig. 1

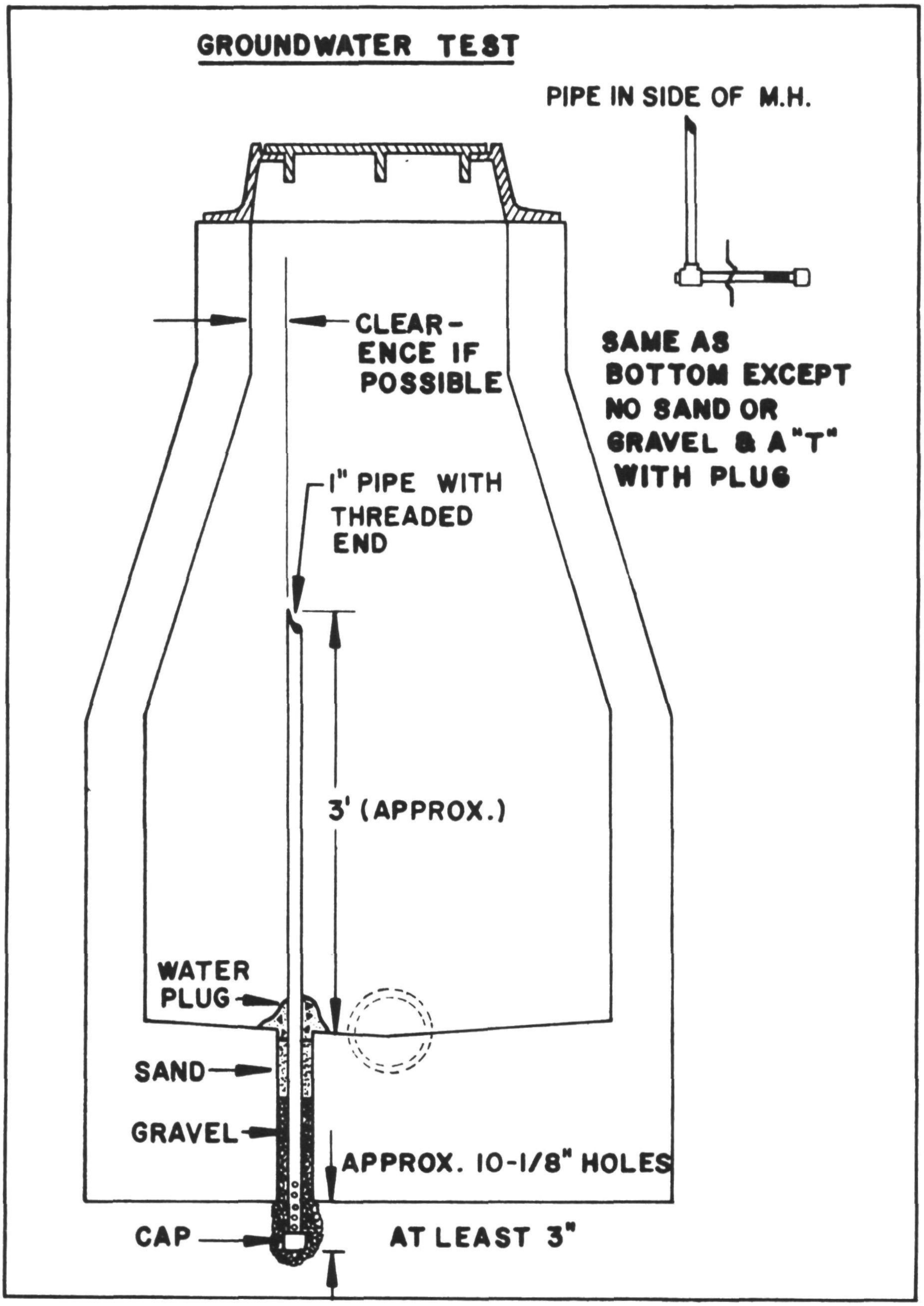

GROUNDWATER TEST
PIPE IN SIDE OF M.H.
CLEAR-
ENCE IF
POSSIBLE
SAME AS
BOTTOM EXCEPT
NO SAND OR
GRAVEL & A "T"
WITH PLUG
1" PIPE WITH
THREADED
END
3' (APPROX.)
WATER
PLUG
SAND
GRAVEL
APPROX. 10-1/8" HOLES
CAP
AT LEAST 3"

Fig. 2

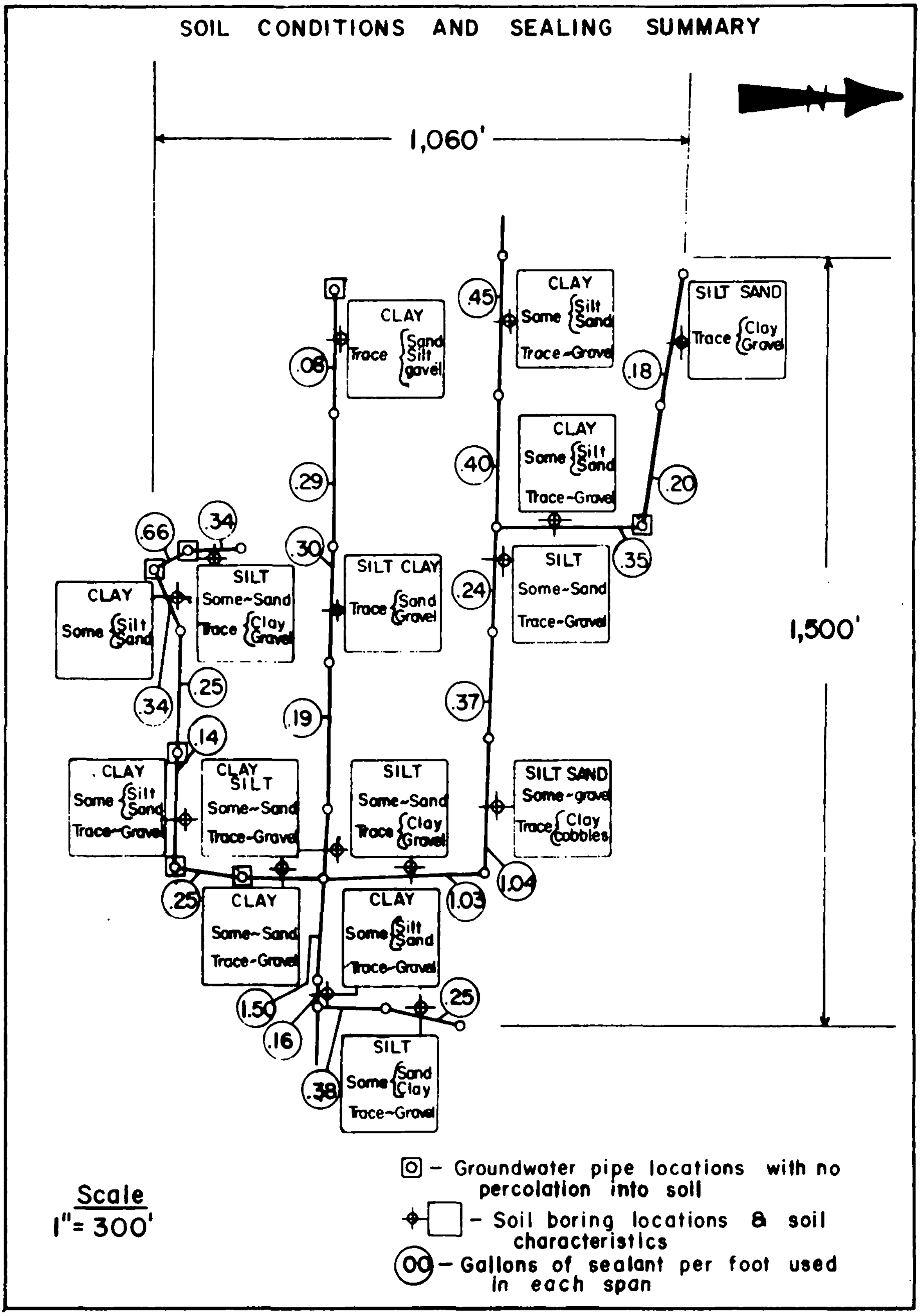

SOIL CONDITIONS AND SEALING SUMMARY
1,060'
1,500'
CLAY
Trace Sand Silt gavel
.08
.29
.30
SILT CLAY
Trace Sand Gravel
.19
CLAY
Some Silt Sand
Trace-Gravel
.45
CLAY
Some Silt Sand
Trace-Gravel
.40
SILT
Some-Sand
Trace-Gravel
.24
.37
SILT SAND
Trace Clay Gravel
.18
.20
.35
.66
.34
CLAY
Some Silt Sand
SILT
Some-Sand
Trace Clay Gravel
.34
.25
.14
CLAY
Some Silt Sand
Trace-Gravel
CLAY SILT
Some-Sand
Trace-Gravel
SILT
Some-Sand
Trace Clay Gravel
SILT SAND
Some-gravel
Trace Clay cobbles
1.04
1.03
.25
CLAY
Some-Sand
Trace-Gravel
CLAY
Some Silt Sand
Trace-Gravel
1.50
.16
.25
.38
SILT
Some Sand Clay
Trace-Gravel
Scale
1"= 300'
- Groundwater pipe locations with no percolation into soil
- Soil boring locations & soil characteristics
00 - Gallons of sealant per foot used in each span

Fig. 3

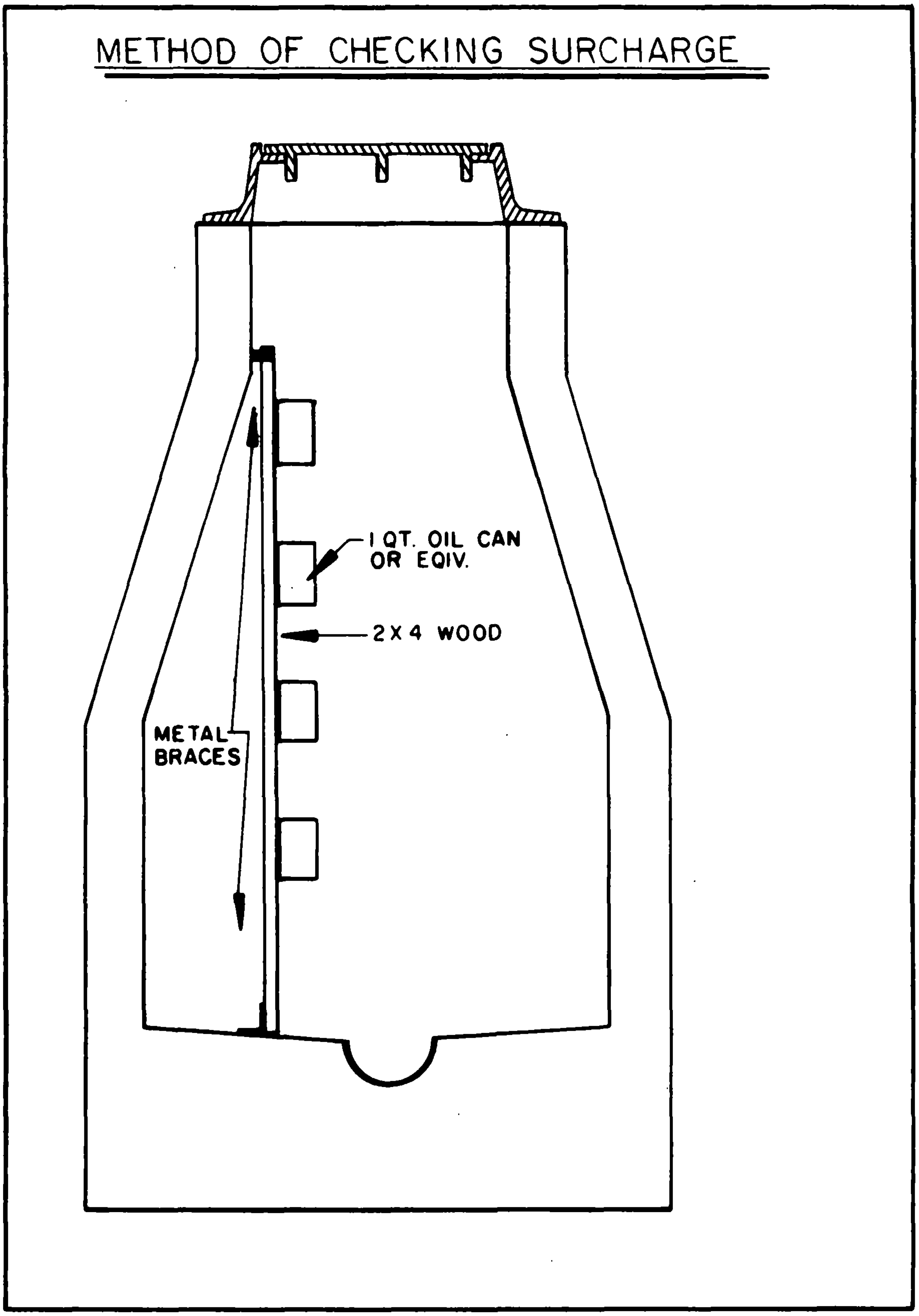

METHOD OF CHECKING SURCHARGE
1 QT. OIL CAN
OR EQIV.
2 X 4 WOOD
METAL
BRACES

Fig. 4

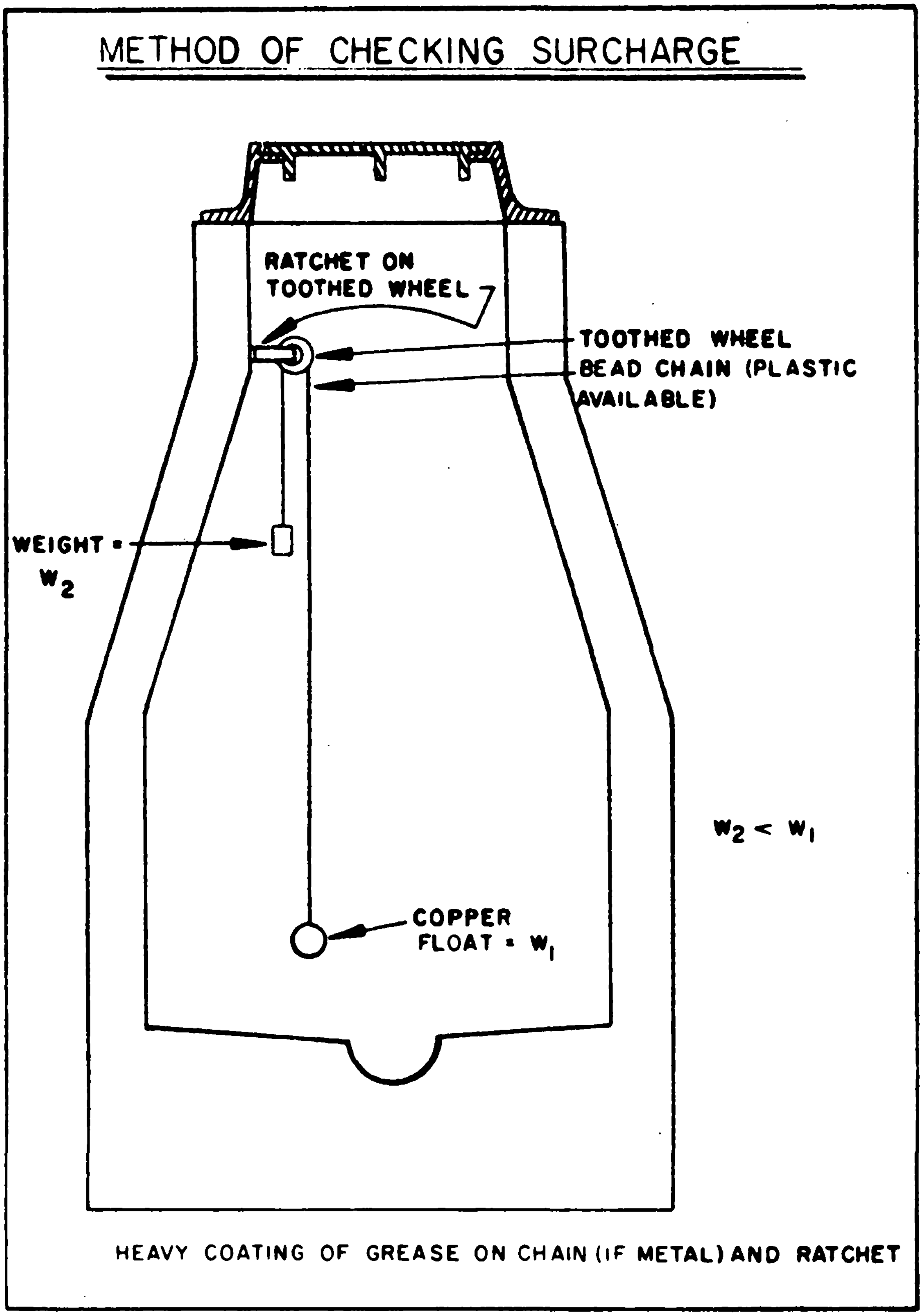

METHOD OF CHECKING SURCHARGE
RATCHET ON TOOTHED WHEEL
TOOTHED WHEEL
BEAD CHAIN (PLASTIC AVAILABLE)
WEIGHT = W2
W2 < W1
COPPER FLOAT = W1
HEAVY COATING OF GREASE ON CHAIN (IF METAL) AND RATCHET

Fig. 5

constructed before premium joints were in use, where an infiltration problem was known to exist. The area selected historically surcharged and flooded basements.

Investigate if removal of illegal connections to the system and other obvious sources of storm water was possible.

Site should be such as to allow establishment of base data on rainfall, ground water, trench conditions, run-off, and sewage flow through a wet season into a dry season.

Inspect the sewer by internal television inspection and seal the sewer collector system 100%, testing each joint for leakage, keeping accurate records of procedures, difficulties, time and materials used.

Considering these factors the site was selected. See Appendix B.

Figure 6 indicates the final study area's layout.

After selection of the test study area was finished, the investigation continued so that a more complete knowledge of test conditions could be determined.

The study area is of entirely residential usage except for a dairy store which was constructed after the flow meter was complete. There are 152 houses tied into 6500 feet of vitrified clay sewer in 24 spans.

The following is a summary of the physical characteristics of the houses contained within the study area.

18 crawl space - 33 slab - 101 basements
5.3 rooms average
6% - 1 bedroom: 22% - 2 bedroom: 65% - 3 bedroom: 7% - 4 bedroom
92% - 1 bath: 6% - 2 baths: 2% - 3 baths
13% dishwashers
91% clothes washers
26% water softeners
3.8 people per house

Run-off conditions: Land Area: total drainage area: 1,513,700 square feet area served by curbed streets and storm sewers: 1,409,600 square feet.

Roof Area Drainage

Roof Area		184,773 sq. ft.	
No Downspouts		10,706 sq. ft.	
Downspouts piped into ground:	Outlet free:		42,538 sq. ft.
	Outlet plugged:		21,659 sq. ft.
No visible outlet:		16,188 sq. ft.	
Direct downspout drainage on splashblocks:		93,681 sq. ft.	

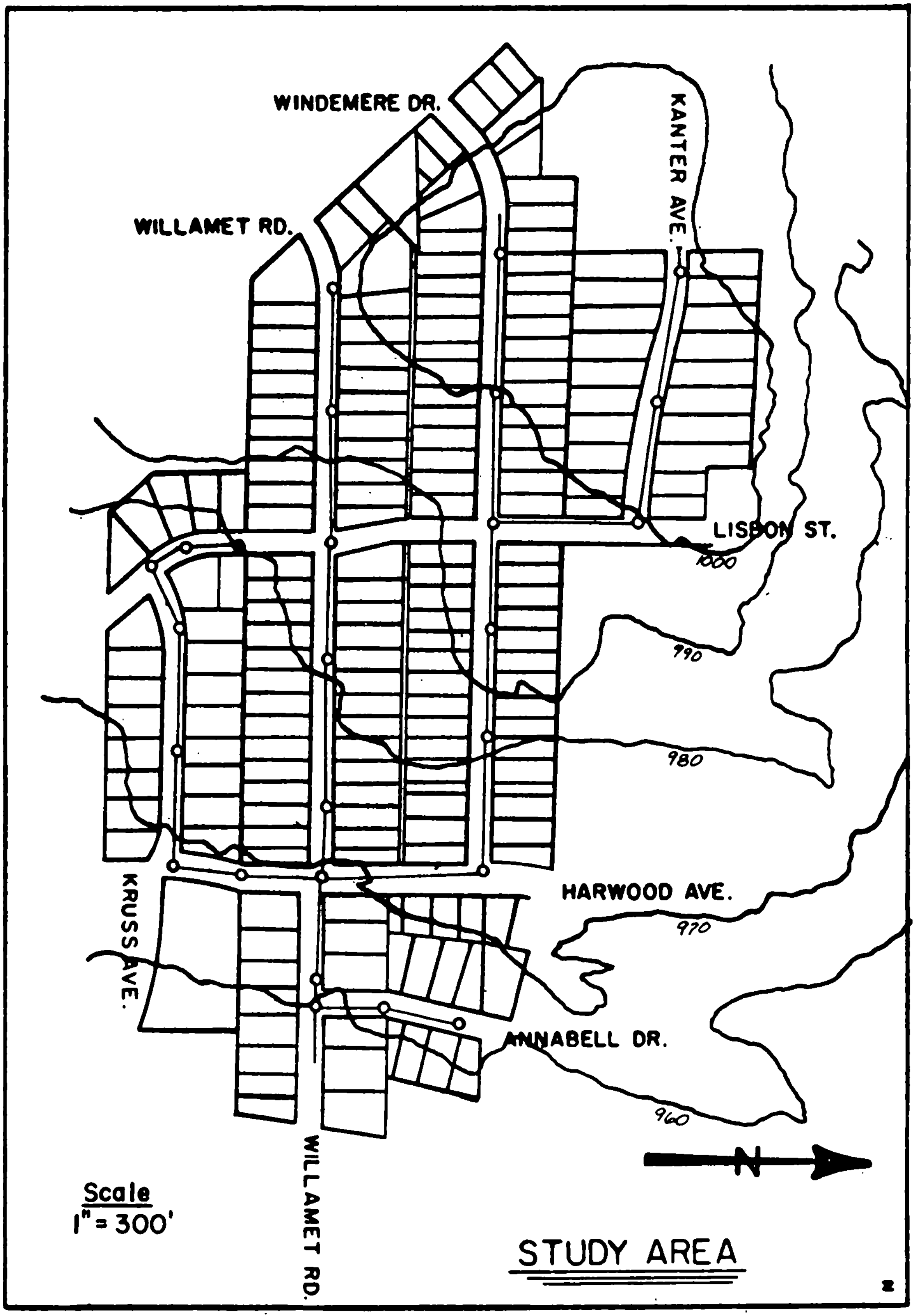

WINDEMERE DR.
KANTER AVE.
WILLAMET RD.
LISBON ST.
1000
990
980
HARWOOD AVE.
970
KRUSS AVE.
ANNABELL DR.
960
N
WILLAMET RD.
Scale
1" = 300'
STUDY AREA

Fig. 6

Total roof area:	184,773 sq. ft.
Sidewalk area:	21,760 sq. ft.
Hard driveway area:	131,349 sq. ft.
Gravel driveway area:	14,346 sq. ft.
Street area:	164,747 sq. ft.
No storm or curb:	23,570 sq. ft.

Soil borings and permeability tests were done in the area to determine the type of trench backfill material and how it percolated water. As was expected, the trenches had been backfilled with the excavated material, predominately clay and silt. All the permeability tests showed no percolation of the water into the soil. The results of these borings are indicated on Figure 3.

Although the permeability tests and soil tests showed that the movement of ground water in the area should be quite slow, the ground water pipes located in the manholes showed that there is a response to rainfall reflected in the height of the ground water in the vicinity of the trench.. Pipes as shown in Figure 2 were installed in all the manholes in the area and checked as soon as possible after rainfall. They were also tested to see if they worked by filling them with water on several occasions and watching the drop in water level. In locations where the pipes were shown to be clogged, new ones, and ones through the sides of the manholes, were installed. These were also tested. When the tests showed to be negative certain locations were rejected for ground water data.

The graph of the ground water characteristics, Figure 7, shows the location for taking the readings of ground water in the operating ground water pipes, determining the height of the ground water above (+) or below (-) the invert of the pipe in each location. These heights were then averaged (using levels above the invert as positive (+) and below the invert as negative (-) to get an index of ground water conditions). This index, shown in Figure 8, is superimposed on a graph of the nighttime flow at 3:00 A.M. and rainfall. Clearly, rainfall influences ground water level in the trench.

As an overall check on infiltration-exfiltration, individual house water meters were read in the study area nearly every day. The intention was to relate these readings to the total flow in the study area. Because of problems with the flow integrator on the flow meter this became impossible. An overall indication can be taken from this comparison for the whole Beavercreek drainage area, found in Figure 9. This graph shows a large amount of water in the sewer above water pumped during the rainy season, presumably from infiltration. During the dry season equally as much water is unaccounted for, due to water used for nonsanitary purposes and exfiltration.

The flow response to rainfall in our test area was quite dramatic. Figure 10 shows an average day in which low flow and no rainfall conditions existed. In the early hours of the morning constant flow

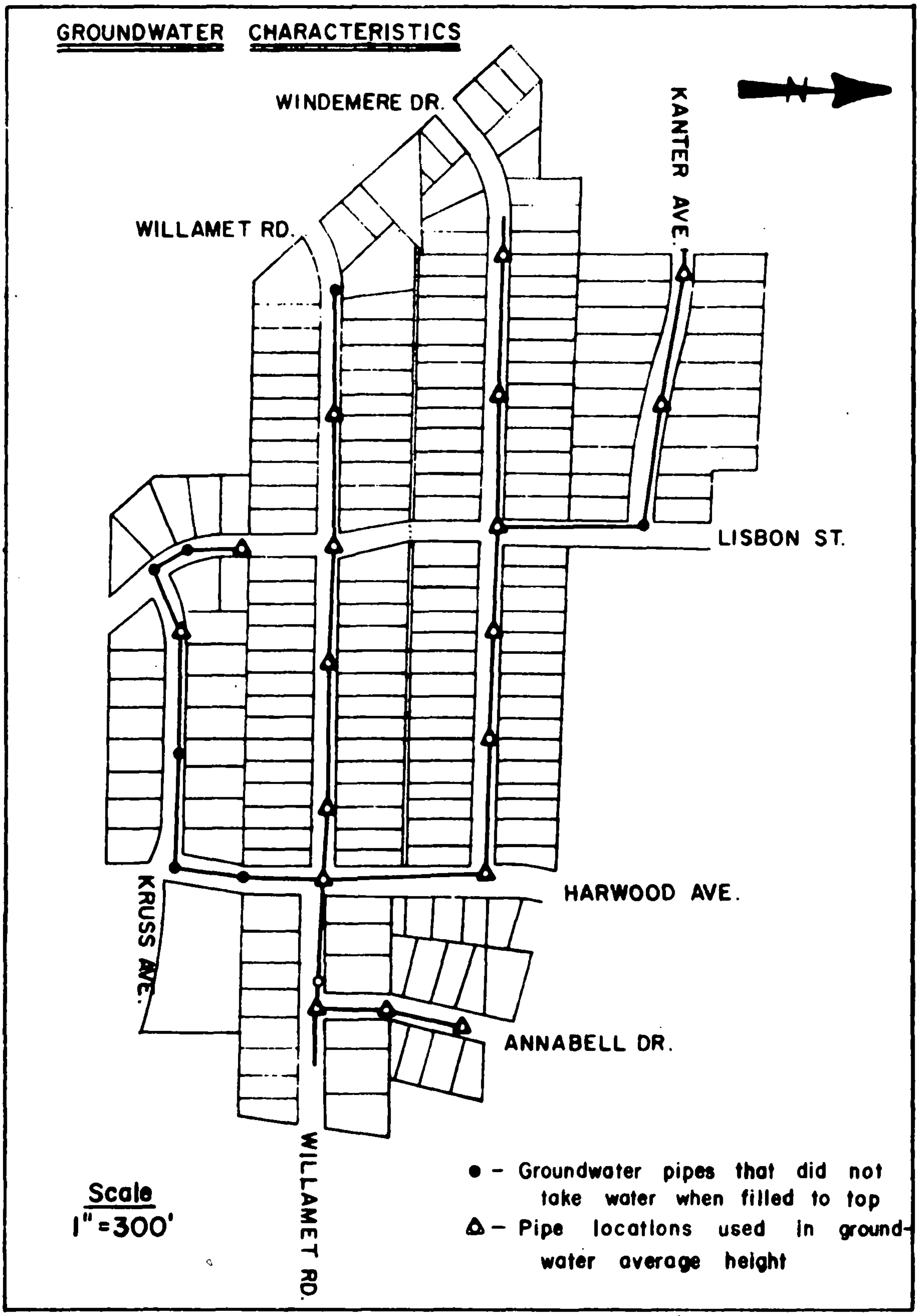

GROUNDWATER CHARACTERISTICS
WINDEMERE DR.
KANTER AVE.
WILLAMET RD.
LISBON ST.
HARWOOD AVE.
KRUSS AVE.
ANNABELL DR.
WILLAMET RD.
Scale
1" =300'
● - Groundwater pipes that did not take water when filled to top
Δ - Pipe locations used in groundwater average height

Fig. 7

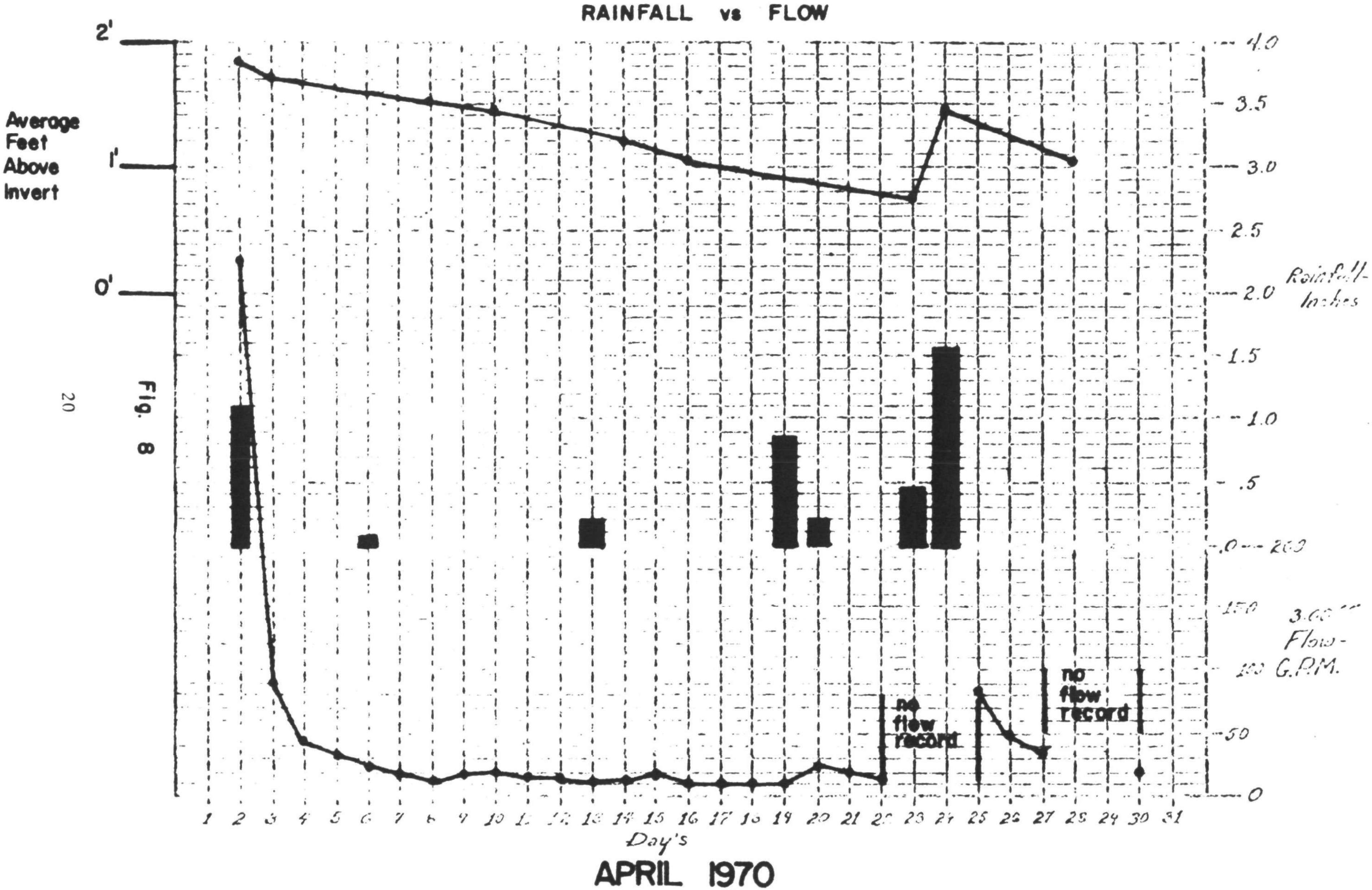
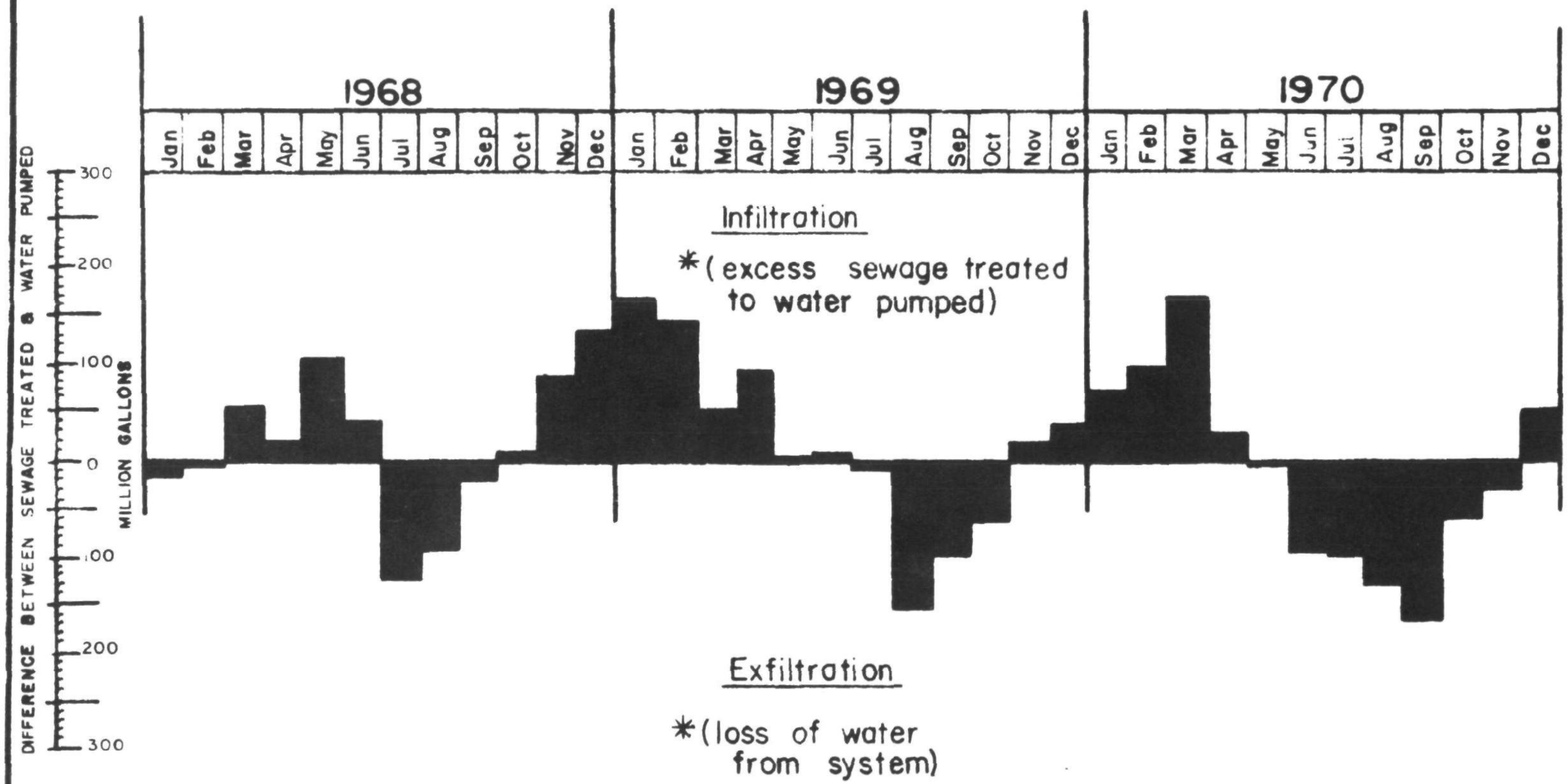

RAINFALL vs FLOW
2'
1'
0'
Average Feet Above Invert
4.0
3.5
3.0
2.5
2.0
Rainfall-Inches
1.5
1.0
.5
.0
200
150
100
50
0
Flow-G.P.M.
no flow record
no flow record
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day's
APRIL 1970

Fig. 8

Fig. 9

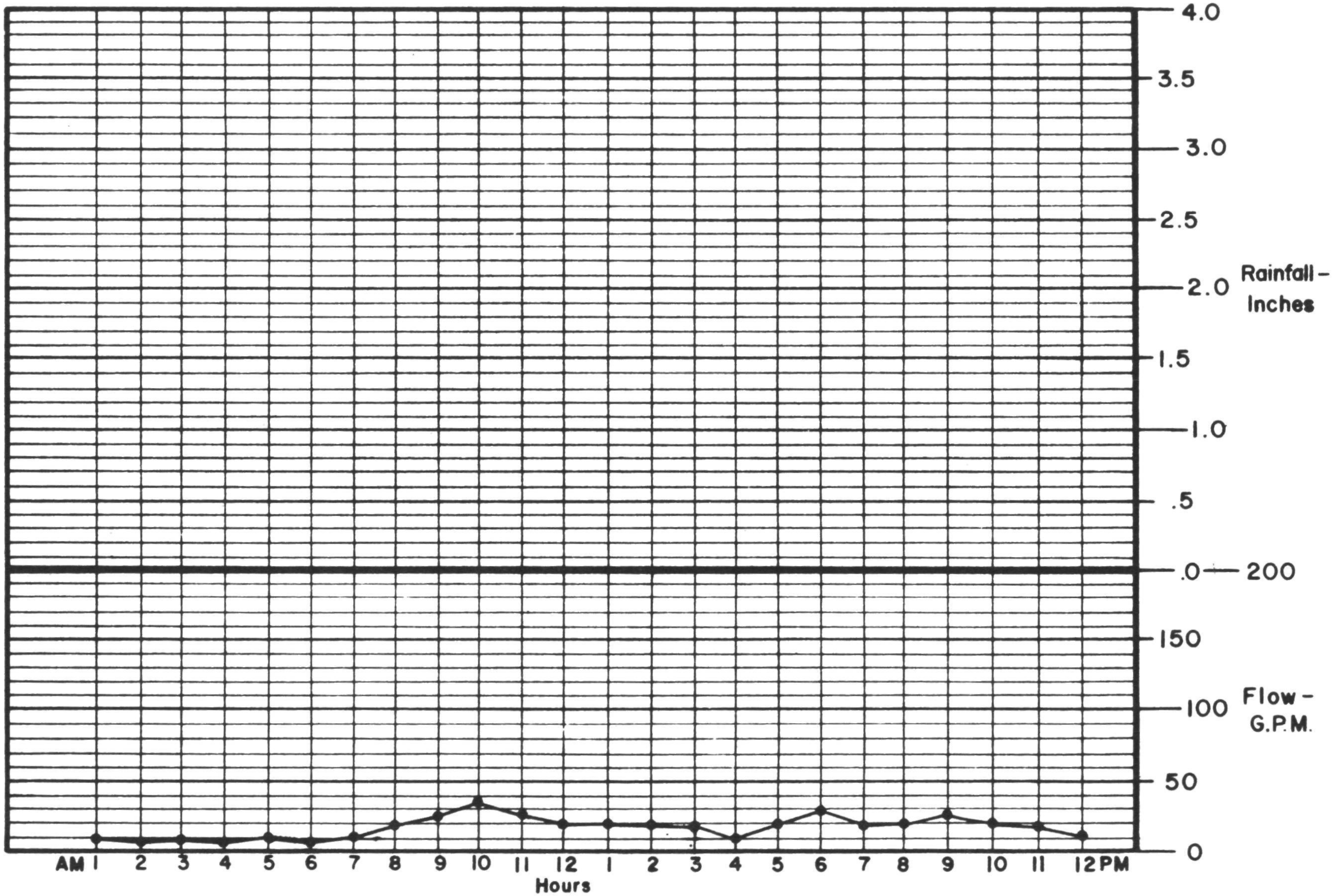
INFILTRATION- EXFILTRATION CYCLE



Sewage: from plants 1, 3, & 6
Water: from Greater Moraine System

*Includes losses due to: watering lawns, filling swimming pools, industrial losses, etc.

NORMAL FLOW DAY



March 16, 1970

Fig. 10

indicates that there is infiltration in the area all the time. The magnitude of this constant infiltration flow is influenced by rainfall and a feeling for it can be gained by looking at a graph of flow at 3:00 A.M. superimposed on rainfall and ground water index. On days when large volume, high intensity rainfall occurred, tremendous jumps in flow were observed. These were transcribed onto expanded scaled graphs to show the hour-by-hour flow characteristics and rainfall.

There are two basic types of rainfall with corresponding effect on flow. The first is the relatively short, high intensity rainfall which causes the flow to jump up suddenly and then drop back to normal. This occurs even when the trench ground water index is low and when the rainfall has no effect on ground water. This indicates that there are relatively direct connections between sources of surface water and the sanitary sewer. The suspect is naturally the basement drains. When the rain intensity reaches a point where the surface run-off is not removing the water rapidly enough then water begins to build up around foundations. House lateral taps drain this off into the sewer. The ground water level in the trench has no effect on this type as it is shown. The second type of high flow is due to an extremely heavy and long rainfall in which the ground water index jumps up and the flow takes more than a week to return to normal. Sewer sealing should not remove the instant peaks in flow due to high intensity rainfalls although it is possible that it may remove the long tailing off period after high volume rainfalls.

A totalizing rain guage was installed in the study area to obtain a more accurate measure of rainfall in the area. Readings from this gauge, run 24 hours, are used throughout the data.

There were three criteria for design of the flow meter. First, the recorder must have sufficient capacity to record any high flow that might occur during periods of heavy rainfall and high ground water table.

Secondly, a 24 hour chart to correspond with the rain gauge and give sensitive results of the response to rainfall must be provided.

Finally, the recorder must have sufficient accuracy at low flow (normal days) to record day-to-day flow with some accuracy. This, however, was a good deal less important than the high flow data.

The low flow data for an area with about 150 houses was taken from a chart of daily, average and peak flows vs. number of residences. The numbers for modern residences with nominal infiltration were: peak flow, 225 gpm; average flow, 40 gpm.

The high flow design figure in the area had to be a combination of judgement and the maximum reading recorded while checking the four study areas for selection. It would have been desirable to set up a standpipe connected to each monitoring manhole invert with a float and a recording device, but this was not done. The information showed a depth reading of .35 feet in an invert of an 8 inch pipe at 3.32% grade (492 gpm). This was taken at 8:00 A.M., 6-1/2 hours after the rain ended (.45 inches from 1:00 P.M. to 5:30 P.M. and 1.65 inches from 11:15 P.M. to 1:30 A.M.). So it was not the actual peak flow.

A very rough figure for design could have been obtained by finding the ratio of the treatment plant peak flow to the plant flow at 8:00 A.M. and then applying this ratio to the study area flow at 8:00 A.M. to get a projected figure. When doing this the amount of high flow by-passing must be taken into account and an estimate added to the plant before calculating the ratio. This method was also impossible as the meter at the plant was off scale and there was no way of measuring the massive overflow, because the flow was beyond the limits of the meter.
Therefore, it was necessary to use the flow measurement and make a judgement about what the maximum flow would have been. The sizing was also affected by trying to keep the meter as sensitive as possible to low flows. The capacity of the upstream line was checked and found to be 560 gpm. This was close to the 492 gpm observed so 500 gpm full scale was chosen. With the 20:1 calibration available with the meter, the low flow calibrated figure would be 25 gpm. This was decided to be the best compromise. A 3 inch parshall flume was used because it would carry up to 800 gpm, well above the capacity of the upstream pipe, even though the recording device would only be calibrated for 500 gpm.

The flume is a prefabricated fiberglass design which was cast solid on concrete in a precast concrete pit. See Figure 11. The sending unit is an in-channel float using a mill balance bridge system to operate the chart indicator needle. The chart and drive is located in a weather proof box with a built-in heater. The system of flume, sending unit, and chart mechanism were provided by Badger Meter Company.

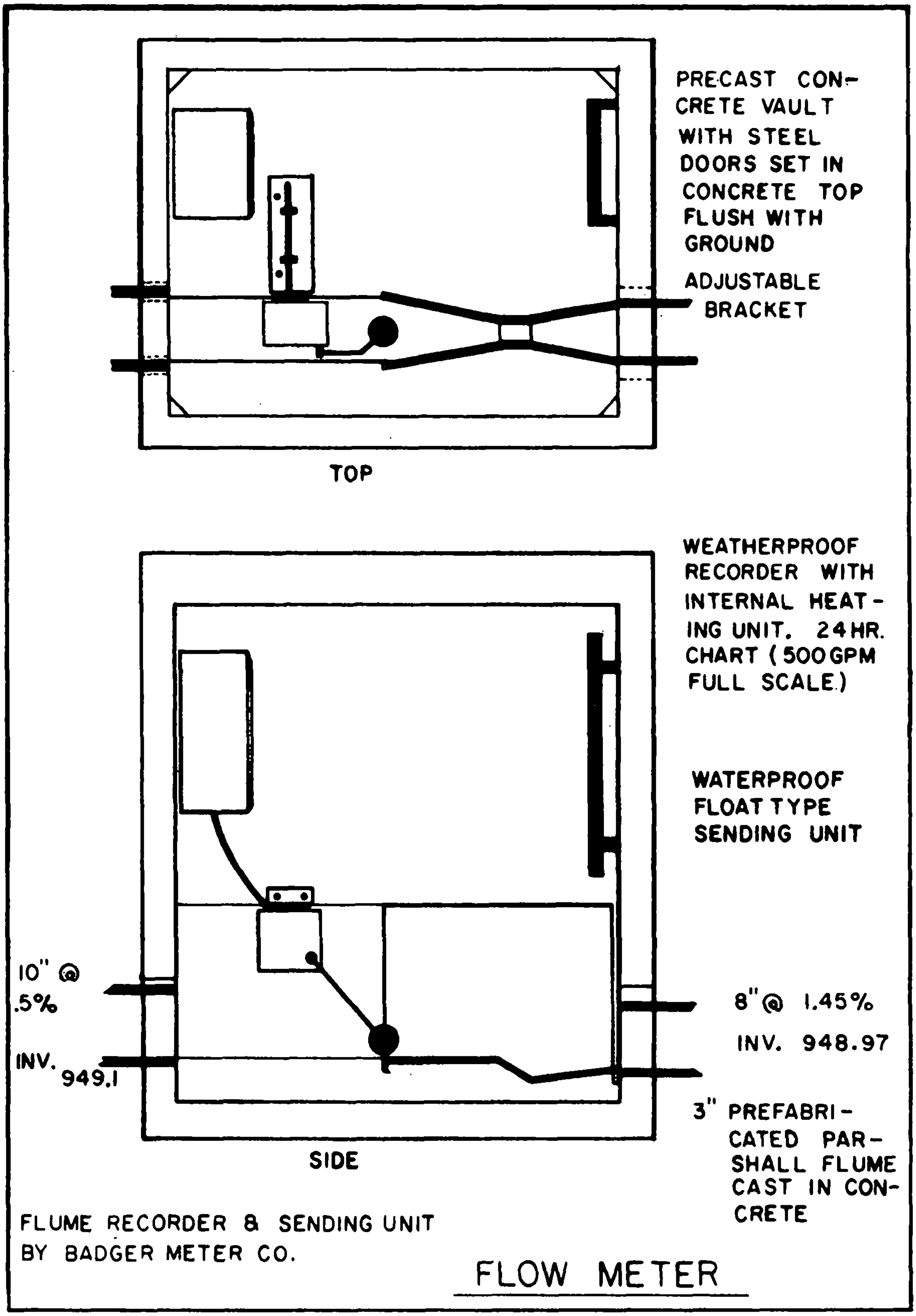

PRECAST CONCRETE VAULT WITH STEEL DOORS SET IN CONCRETE TOP FLUSH WITH GROUND
ADJUSTABLE BRACKET
TOP
WEATHERPROOF RECORDER WITH INTERNAL HEATING UNIT. 24HR. CHART (500GPM FULL SCALE)
WATERPROOF FLOAT TYPE SENDING UNIT
10" @ .5%
INV. 949.1
8"@ 1.45%
INV. 948.97
3" PREFABRICATED PARSHALL FLUME CAST IN CONCRETE
SIDE
FLUME RECORDER & SENDING UNIT BY BADGER METER CO.
FLOW METER

Fig. 11

SECTION VI
CONDUCT OF EXPERIMENT

Having completed the preliminary work, the experiment continued. An estimate was made as to the cost of sealing and televising. Our experience in sealing and televising is included at the end of this report. Appendix C is the Projected Sealing Cost; Appendix D, Actual Sealing Cost; Appendix E, Sealing Crew and Operation Procedures; Appendix F, Sealing Equipment; Appendix G, Equipment Recommendations; Appendix H, Special Details of Sealing Operation; Appendix I, Methods of Determining the Need for Sealing; and Appendix J, Description of Grant. This information is valuable to anyone interested in the operation of this equipment.

As stated in the foregoing, the primary interest in the data on ground water was how much of the pipe line was under the water table. To do this an index was arrived at by which the height of the water in the hydrostatic columns referenced the invert of the sewer. In order to correlate this parameter with the rainfall data some general average for the water table had to be stated. Originally, an arithmatic average of the indexes was used. This presented virtually an unusable gauge of the water table activity because soil conditions at a few pipes gave a negative reading and negative and positive readings tended to cancel each other. The negative readings did not necessarily mean the absence of ground water either. There was reason to believe that the action of an underground stream running through the study area created draw-down on certain adjacent pipes, so that some pipes apparently went down during heavy rains. Although the average index went up during heavy rains, this average index could not be useful in stating that, on the average, the line was submerged.

A rather burdensome solution to this problem, but the most satisfying, was to plot the height of ground water on a scale profile drawing of the sewer for each reading of the ground water. This gave a graphical display of the ground water grade superimposed upon the sewer, showing clearly how much line was submerged. This method is not without shortcomings, for pipes which were clogged would make sections of the ground water grade indeterminant. Figure 12 is an example of the method used. For the sake of space, Appendix K, Table 1, gives this information in percentage of line submerged, which is the result of this graphical method.

It will be noted that the absolute amount of rain or its intensity does not produce proportional results in the vertical movement of ground water. When the ground is dry, water is taken up in the soil and the ground water hardly moves. Only after periods of continuous rain will the ground saturate and the ground water move upward. After the ground is saturated moderate rainfalls will move the ground water up quite markedly.

DETERMINATION OF GROUNDWATER PROFILE

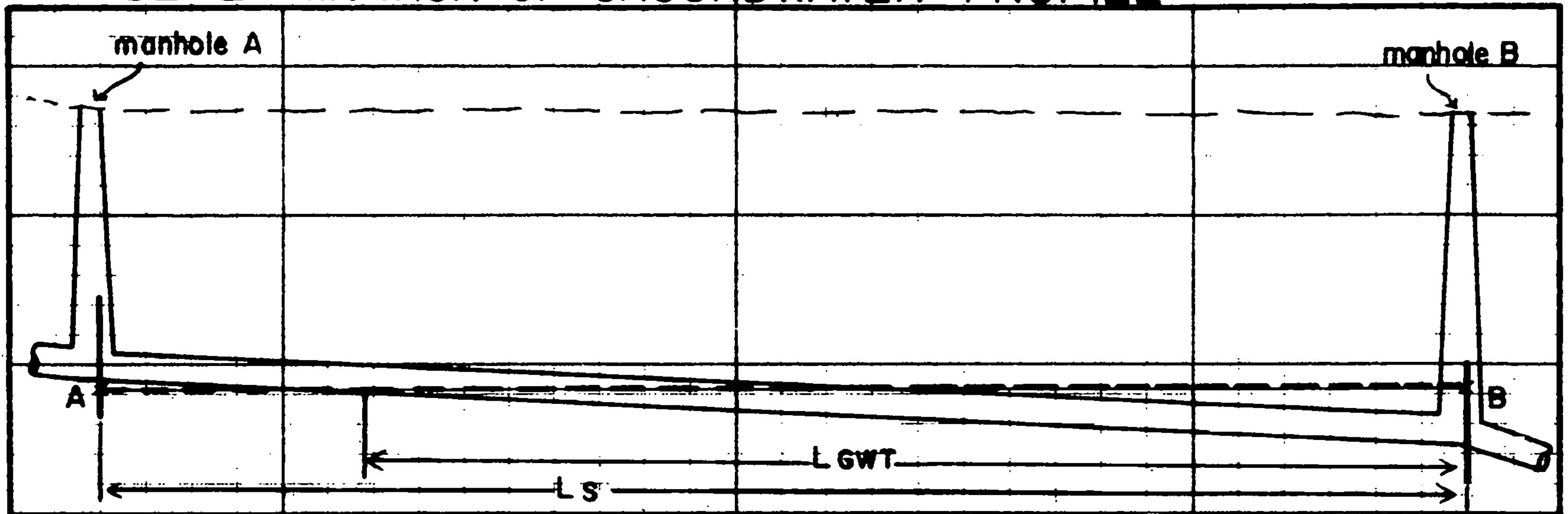


Fig. 12

Procedure:

A. Plot Groundwater Table Elevations, A & B. (See Groundwater Pipe Diagram)

B. Connect Lines (to approximate GWT profile).

C. Estimate % of Line Under GWT

$$\text{Percent Under GWT} = \left(\frac{\text{length of span under GWT}}{\text{length of span}} \times 100\right) = \left(\frac{L_{GWT}}{L_S} \times 100\right)$$

Where:

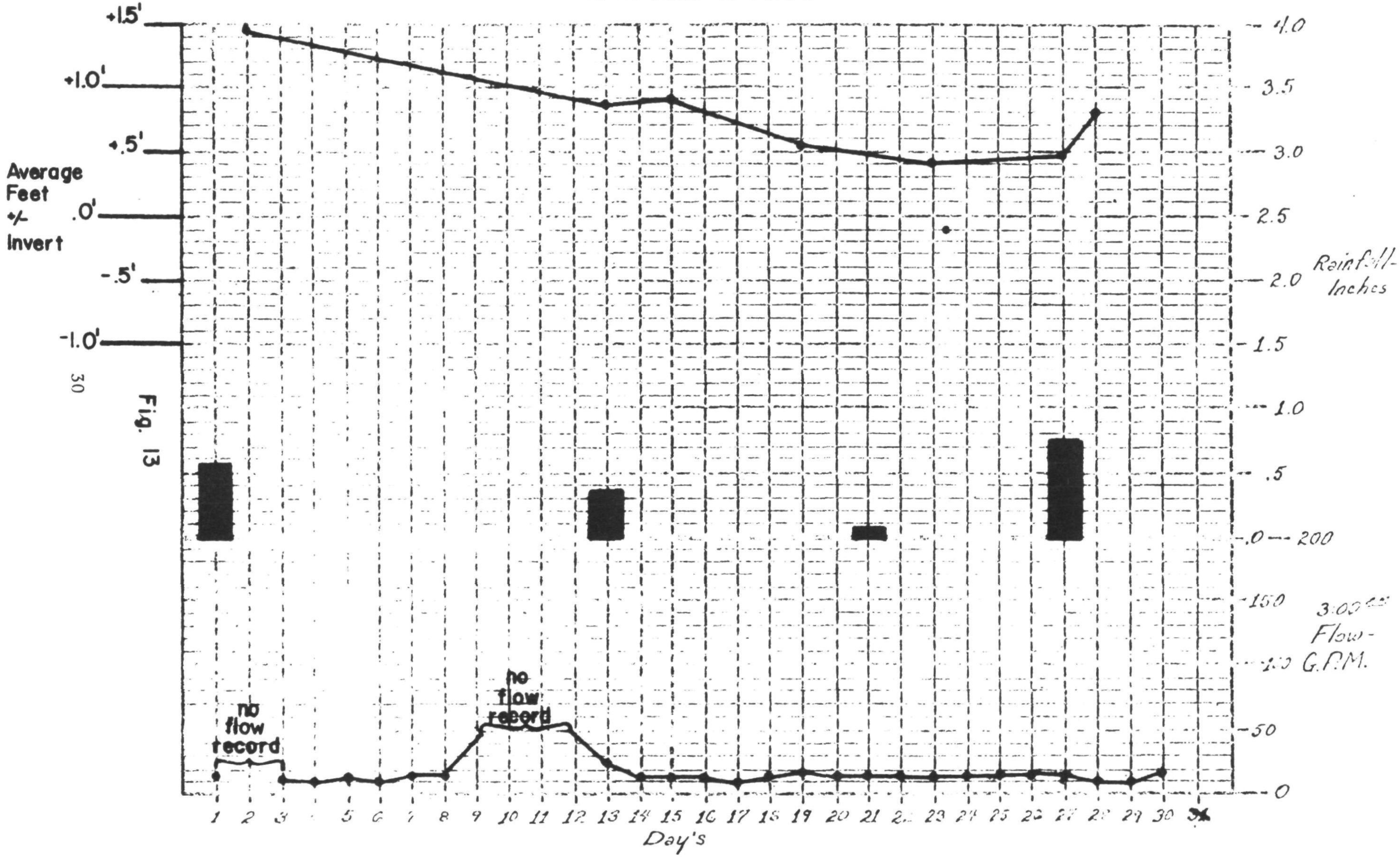
GWT = Groundwater Table
L_{GWT} = Length of Span Under GWT
L_S = Length of Span
A = Elevation of GWT in Well A
B = Elevation of GWT in Well B

Sewer flow in the study area was monitored continuously through the base data collection and after sealing, with the exception of the time during sealing which was a dry period. The flow is plotted against rainfall and average ground water index for 3:00 A.M. in Figure 8, before sealing, and Figure 13, after sealing. The 3:00 A.M. flows were used because this is a period of practically no usage of sanitary facilities so that any flow is attributed to infiltration.

It might be noted that in the selection of the study area this assumption was ill-founded. There are devices such as water softeners in any area which discharge enough water in recharging, specifically during periods of sanitary inactivity, to present a significant flow (60-80 gal/unit). The presence of this source can be confirmed by checking chloride content of the sewage at that hour. For this reason, it is possible that there was not a constant infiltration in the line through the collector system.

The high flows coincident temporarily with rainfall do not necessarily mean infiltration. It takes a short time for direct storm water sources (downspouts and draining manholes) to have their water reach the flow meter; typically, five minutes. Infiltration, where the water has to travel through the earth, will be delayed both in onset and decay. This is most easily seen on the expanded flow chart which plots flow by the hour against rainfall for each incidence of rainfall. Figures 14 and 15 are before and after sealing, respectively. The expanded graph clearly shows that after the end of rainfall and after a reasonable period of delay for manhole drainage, there is clearly an infiltration which stays up (3:00 A.M. constant flow) and slowly decays to a normal flow.

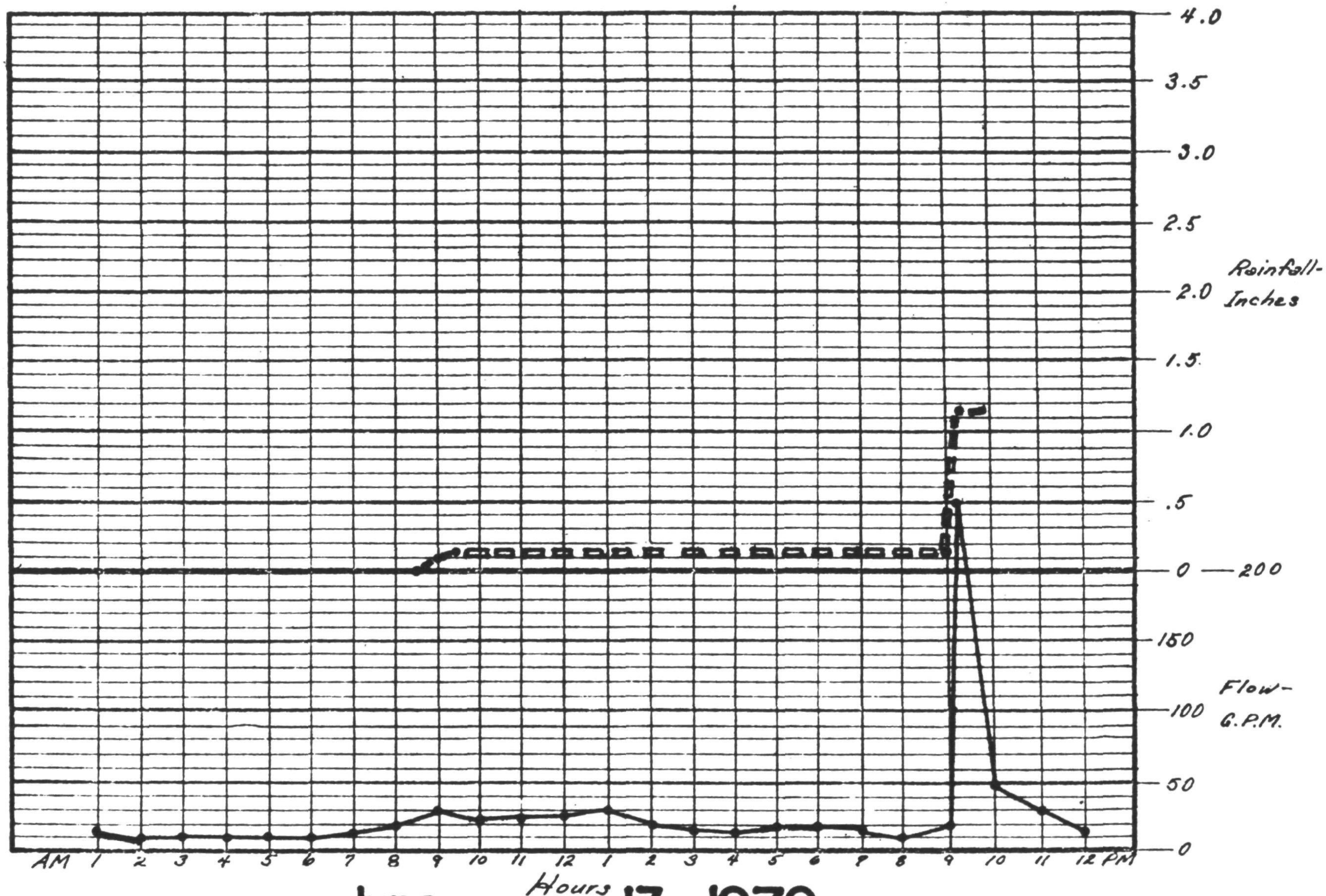
RAINFALL vs FLOW



APRIL 1971

Fig. 13

RAINFALL vs FLOW

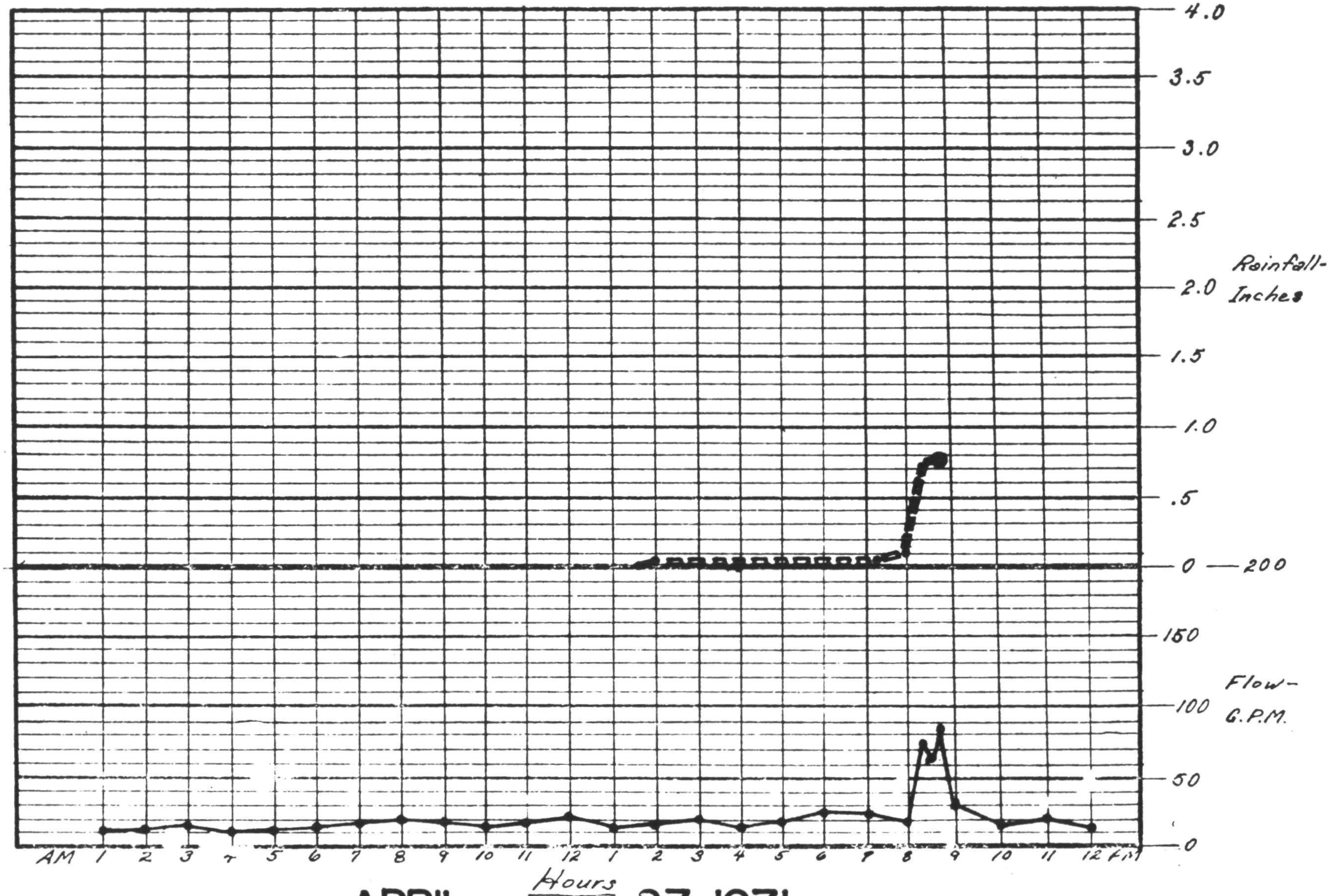


June 13, 1970

Fig. 14

Fig. 15

RAINFALL vs FLOW



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SECTION VII
DISCUSSION

It is the purpose of any research project to extend the knowledge in a particular field beyond that which is presently known. This report, on sewer sealing, provides information and conclusions which add much to this field of knowledge.

Typical of the important information which has resulted from this study is the ratio of peak flow to average flow. It is a current engineering practice to allow 10% oversize capacity for flows resulting from infiltration. Within the study area, a typical residential sanitary sewer system, the ratio of peak flow to average flow exceeded 7. This is significantly higher than had been anticipated, and gives some interesting insight as to the cause of overflows and the significant amount of sewage currently being by-passed.

The main subject of the research, sewer sealing, turned on several factors. Among the requirements for a successful study were the isolation of infiltration due to faulty or leaky joints, the duplication of all other significant conditions before and after sealing of the joints, and the comparison of flows prior to and after sealing. Any compromise in any of these key factors would damage the validity and dangerously discredit the results of the program.

The isolation of infiltration due to leaky joints proved more difficult than had originally been anticipated. Chief among the requirements were the selection of a suitable flow meter and removing as much of the infiltration from sources other than leaky joints as possible. Although much effort had been given to the selection of a proper flow meter, the selection was not within the precision, accuracy, and range to prove most effective for this study. In any future study, consideration should be given to selection of a compound meter. Flows exceeding those anticipated resulted in the loss of valuable information because they were greater than the flow meter could measure. The significance of the low flow characteristics were not fully appreciated. Accurate and precise measurements of the flow conditions over the entire range would have enhanced results.

Another significant factor which was extremely difficult to overcome was the attitude of the residents of the study area. Although there are legal regulations which cover illegal taps and storm connections to the sanitary sewer, no amount of legislation can insure a favorable attitude. The distaste of the residents toward the chores of setting up the experiment and the routine business of collecting data resulted in the loss of valuable information. Any future work of this type should be performed in a manner that insures legal support of the activities necessary to run the experiment. Gaps in the collection of data can result.

The problem of properly connecting downspouts to the curb or to a storm sewer was also significant. This action is necessary to insure that this source of possible infiltration is removed. Although this connection is illegal, the only way to test is to smoke test. The validity of this technique is questionable.

Floor underdrains are connected to the sanitary sewer under present regulations. The load resulting from these connections is not known and should be measured. The only method devised, although untested due to cost and owner attitude, would be to physically reconnect the sewer lateral to a sump pump. The pump could record the electrical consumption and an energy balance should reveal the amount of water pumped.

When an experiment is carried out in a laboratory, the duplication of control conditions is easy compared with the requirements of a field study such as this. The duplication of all conditions was hampered by a very low precipitation year. The weather during the presealing period was never anticipated to be exactly that of the post-sealing period, but they were hoped to be comparable. Such was not the case. Subsequent to sealing, the ground water table lowered to such a level to prohibit comparison. This condition is not a local factor, but regional. The water table of the entire river diminished in excess of forty feet during the same time period. The soil composition of the study area, primarily sand and gravel, makes the ground water table extremely sensitive to precipitation. No economical substitute to recharge the ground water table in the study area was devised. Sufficient rainfall to recharge the ground water table is not anticipated in the time limitation of the report.

The method of measuring ground water also proved more difficult than had originally been anticipated. Two methods were used. Five deep wells of three inch diameter pipe were bored adjacent to the main line, twenty feet from the manholes, to a depth of four feet below the invert. Every manhole was provided with a ground water pipe drilled through the base or through the side to allow the determination of the water level. The ground water pipes tended to clog, adversely affecting the reliability of the readings. The results have no pattern and relationship to all other factors of rainfall, flow, etc., thereby rendering them worthless. Figure 12 indicates the method in which the ground water was graphed and the text provides more specific information. A better method of monitoring the ground water level near the main line would be of great value in studies such as this.

The amount of domestic water entering the study area is of significance. The use of the meter readings was not successful because the residents were not cooperative to the degree necessary, and the collection of the data is time consuming. The study area could be isolated by installing compound water meters in the distribution system in conjunction with check valves. The selection of a device similar to a Detecto check valve to allow adequate fire flows is recommended. This configuration would allow comparison of consumption with respect to the sewer flows.

To compensate for any other factors which may enter into the study and to more closely correlate the results, it is suggested that in the design of future studies an adjacent area be selected, fitted with a flow meter, and serve as a control area. With the results of the flows from this control area, the presealing and postsealing conditions could be better compared.

Considering the foregoing, the comparison of conditions prior to and after sealing was nearly impossible. The comparison, however, was made and the results were these.

In an effort to convey the information quickly, a bar graph, Figure 16, was included. This graph indicates the comparison of conditions measured prior to sealing with those after. They represent the total flows for the month of April, 1970, with those of April, 1971. The selection of the proper method of comparison is a difficult task and the conclusion drawn from a comparison is a difficult task. It was thought that selection of the same months of the two years for comparison would locate the periods in similar positions on the infiltration-exfiltration cycle. This assumption proved incorrect. A sewer pipe with leaky joints would logically infiltrate when submerged below the ground water table and exfiltrate when above. The rainfall during the time spans considered was only 22.64% of its presealing level resulting in a drop in the amount of sewer submerged in water. Using the method discussed in the text, the average portion of the sewer submerged by the water fell to 59.2% from a presealing high of 88.6%.

Although the reduction in sewage flow to a level only 39.73% of its presealing level (a level approximately equal to the estimated water entering the study area through the domestic water system) is an encouraging result, the reduction in rainfall prohibits crediting the reduction entirely to sewer sealing. The low rainfall has as an effect to challenge the validity of the entire program. As previously mentioned, a nearby area could have served as a control to allow for better comparison of results. At present it is mathematically impossible to compensate for the reduction because the mechanisms of the behavior of ground water levels, underground flows, and exfiltration, are not known. Until there is a comparable wet period of long enough duration to allow comparison to the presealing conditions, the results will not be concrete.

The other factors included on the bar graph are the throughput of the Beavercreek Treatment Plant and the amount of domestic water pumped. It is not to be assumed that the areas served by the two systems, or that of the study area, are identical. These graphs are presented to describe general conditions. The decrease in treatment plant activity to 86.93% of its former level, while the water usage rose 8.55% does, however, indicate that the conditions in the study area were common to the entire Beavercreek system.

PRE-SEALING, POST-SEALING COMPARISON

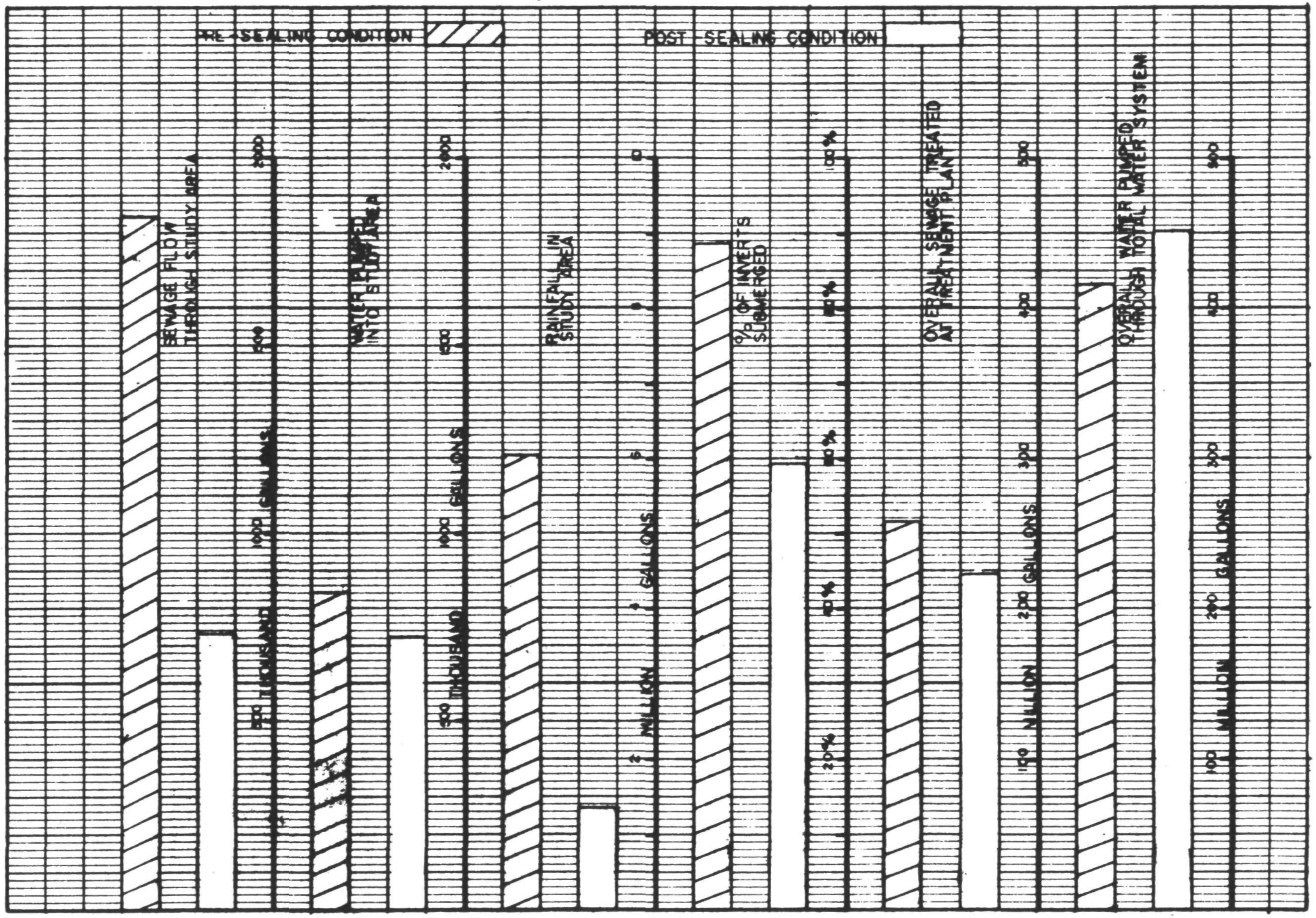

Fig. 16

It is an interesting and not entirely false conclusion that infiltration by a leaky collector system may benefit the system when the invert is above the ground water table. During storm surges, the flows may cause exfiltration which later returns to the sewer during times of low loads. In this way the total peak load on the treatment facility and the amount of sewage by-passed may be reduced to a degree.

As an overview, the procedure selected for this study seemed correct but control is deemed insufficient. This report can be most effectively utilized in areas of cost, equipment, procedures, and organization. The judgemental errors which occurred in the design of the experiment need not be duplicated.

There are several significant items not adequately recorded or even attempted to record in this study.

Consider the mechanisms of the infiltration in the system. In any branched system, like the lateral-collector sewer system, there will be more branches than trunk lines. In the study area, for example, there are 6,500 feet of eight inch collector sewer and approximately 12,000 feet of four inch laterals. Water enters the system in two fashions. An established water level may submerge the pipe and cause infiltration, as is normally the case with a collector pipe, or water may be poured through the ground from above and enter the pipe, as is normally the case with lateral underdrains. However, both types of infiltration will affect both systems. Some laterals will be normally submerged and water may enter a collector through a manhole. For a submerged line, there should be a relationship between the number of joints and the infiltration potential if it is assumed that all joints are nearly alike. If infiltration is taking place through the pipe, there should be a relationship between the diameter of the pipe and the amount. An infiltration potential ratio based roughly on these factors yields a ratio of two to one the potential of the lateral system when compared with the collector system when the entire system is submerged. All of this emphasizes the need for a clearer picture of lateral flows.

No satisfactory method was ever devised to measure and record the contribution and flow characteristics of the laterals except by television inspection. Estimating the depth of flow on each individual service, uncovering the lateral to determine grade, and thereby computing the flows, might be suggested as a method. This method is practical only under specific conditions of minimal consumer usage, low main line flow, and high ground water table.

A great amount of useful information resulted from the television and packer used in the study. This equipment can provide valuable results when properly used. The TV camera by itself has proven its value in visible inspection, including locating underground features such as improper taps, line offsets, pipe failure, pipe condition, obstructions, root invasion, leaks, and illegal cross connections.

The TV, when used as a maintenance tool, insured a minimum traffic hazard because the locations were exact, and failure clearly defined. The only drawback with TV is that it will not pass through too great an off-set or through a highly deteriorated line. It was found that it will pass through nearly everywhere a line could be passed. Another drawback is that the operator must have expertise in the use and positive identification of poor joints is not possible.

The packer is of value when properly used. The equipment used is the most advanced on the market. The flow-through design eliminated the need of by-pass equipment and enhanced the effectiveness of the unit. The use of several lines to transport the grout which is mixed at the packer eliminated the need to clean lines after use, and the wasting of grout as compared to the pre-mixed techniques. The fact that the joint can be tested immediately subsequent to sealing insures complete sealing. The line can be tested joint-by-joint to insure a good seal.

The grout used was not evaluated. It was based on manufacturer's recommendations. It is designed specifically for sewer use and has a satisfactory historical record.

Rechecking all joints in the study area one year after sealing indicated no deterioration with 100% of the joints holding approximately 20 psi pressure.

The grout was readily handled, easily mixed, stable, and effective. The amount of chemical grout necessary to seal was reduced by employing a technique of repeated cycles of injection and waiting for the gel to set. This technique allows the grout to stabilize to a solid and reduces over-use.

The technique of pressure grouting, although slow, cumbersome, expensive, and requiring technical expertise, is permanent, effective, and economically superior to digging. With pressure grouting the results can be checked and documented, thereby making it extremely reliable.

APPENDIX A

DESCRIPTION OF SYSTEM

The sanitary sewage collection system and sewage treatment plant of the Beavercreek Sewer Subdistrict were installed and are operated by the Montgomery County Sanitary Department which is under the jurisdiction of the Board of County Commissioners. The total service area includes portions of the cities of Kettering, Oakwood, Dayton, and a very small area in the City of Centerville, and Mad River Township in Montgomery County. Service is also provided to an area in Greene County contiguous to the drainage area. Nearly ninety percent of this district has been developed since 1950. The area is predominately single family residences of the medium to upper price levels with supporting commercial establishments and one large industrial complex. The residential areas have modern schools, churches, shopping centers and parks. There are plans in progress for development of the small percentage of vacant land remaining.

The sewer district was initiated by establishment of a small plant by the federal government to serve a federally financed housing development under FHA to relieve the post war housing shortage. The original plant consisted of no more than an Imhoff tank with an unknown capacity. The construction of this small plant provided the impetus for the County to establish a sewer district to alleviate the health hazard of inoperable septic tanks in developed areas.

The first large section of Beavercreek Sewer District was established in 1952. Construction included 43 miles of sanitary sewers and the first section of the sewage treatment plant.

The original sewer district has been enlarged since the early 1950's by the addition of approximately 100 miles of sanitary sewer, not including the sewer added within the City of Oakwood, Greene County, and the City of Dayton, which is also served by this system.

The early 1950 project construction contracts for sewers included single strength sewer pipe with individual joints, hot poured asphalt, compound and hemp caulking material. Much of the original project was installed under undesirable conditions of weather and water, consequently, many of the sewers were faulty after construction was completed. Large quantities of ground water infiltrated into the system before any connections were made to the system. An attempt to enforce specifications by the previous sanitary engineer, Earl W. Riber, was deterred by legal action.

During and after periods of rainfall, sections of the trunk sewer would surcharge as capacity in the trunk sewers was surpassed. To eliminate basement flooding, overflows were constructed in key manholes allowing a discharge into the system of creeks and ditches of the Beavercreek drainage area.

The Beavercreek plant was expanded in 1970 to a capacity of 10 MGD primary and 30 MGD secondary, with additional pumping capacity of 30 MGD for use in cases of high flows due to heavy rainfall. Since construction of this plant the use of the by-passes has been restricted to localized areas due to stoppages.

Experience gained in the initial project resulted in establishment of a strict material and construction specification enforced by an inspection division of the Montgomery County Sanitary Department.

Projects under the supervision of the County in the mid 1950's were among the first to require a good quality mechanical sewer pipe joint and hydrostatic testing of all spans of new sanitary sewer. Specifications also required high strength sewer pipe to be used in all installations. This type of control has subsequently produced relatively watertight sanitary sewers.

The original system has presented the greatest problem of large flows during wet conditions and some remedial actions have been taken in the plant. The introduction of internal television inspection of buried pipelines has made it possible to determine the locations of water entering the sewers. The Montgomery County Sanitary Department has made use of this evidence to initiate remedial construction. The department felt that it was in a position, with its past experience, to establish a productive program to determine the cost, effectiveness, and benefits of rehabilitation of sanitary sewers by internal sewer pipe sealing.

APPENDIX B

SELECTION OF TEST AREA

A review of the entire system was conducted to select a suitable test site. Although an entire system may be faulty, a specific area had to be selected where the various effects could be measured.

The Beavercreek area was divided into drainage subdistricts on a 1" = 1000' scale sewer map on which all trunk sewers were outlined. The map was systematically studied and areas which were near a trunk sewer and appeared isolatable for sewage flow were listed. Prospective areas were then reviewed on expanded scale maps (1" = 200') and construction drawings were studied. Every effort was made to select a representative study area. Five areas were selected according to the following criteria:

Age: to assure that the lines were installed before construction and inspection procedures were upgraded and premium joints were in use, a drawing date of prior to 1954 was used.

Length: approximately one mile of sewer line.

Isolation by drainage: no other areas could drain through test section so sewage flow could be measured by one meter and so that data at periods of high flow are not obscured by high flow from another area.

Suitable metering fall: a minimum grade of 3% or a drop manhole in the metering line, the area must fall into a trunk sewer of minimum 12-inch diameter. Both provisions are to minimize the danger of surcharging the meter and losing readings at the critical time of the study, peak flow. A final condition was that the area contain no known unusual soil or water conditions.

Visual inspection with attention to:

Street condition: surface, curbs and storm sewers.

Type of house: slab, or basement, uniformity of type throughout test area.

Downspouts: manner in which they enter ground.

Nonresidential users.

The test sections selected and their qualifications are as follows:

Imperial, Eureka, Dexter, Hale

Age: 1953

Length: 5700 feet
Metering drop: 8.83 feet drop manhole into 20-inch line
Streets: bumpy, patched blacktop, no curb
Storm drainage: poorly maintained ditches, only one possible storm sewer
Houses: 75% basement houses, many varied styles
Downspouts: most exit above ground
Non-residential load: none

Ghent, Kerwood, Prentice

Age: 1954
Length: 4900 feet
Metering drop: 4.2%, then 2.7% grade in 8-inch into 18-inch drop line
Streets: blacktop with concrete curbs
Storm drainage: storm sewers
Houses: no basements, only two or three different styles in entire area
Downspouts: nearly all in ground
Non-residential load: none

Willamet, Kruss, Windemere, Kantner

Age: 1952
Length: 6500 feet
Metering drop: 3% grade in 8-inch into 12-inch line
Streets: blacktop with small amount of concrete, concrete curbs, except 1000 feet of Willamet which has no curbs.
Storm drainage: storm sewers except same 1000 feet of Willamet which has poorly maintained ditches.
Houses: nearly all basements, varied styles
Downspouts: nearly all in ground
Non-residential load: none

Mengel, Kenosha, Villanova

Age: 1952
Length: 3500 feet
Metering drop: 4 feet drop manhole in 8-inch line which leads to 10-inch line after 1300 feet (exception to criteria).
Streets: blacktop with concrete curb
Storm drainage: storm sewers
Houses: 30% basements with varied styles
Downspouts: nearly all in ground though many curb exits are visible
Non-residential load: none

Other areas were eliminated for the following reasons:

Ghent, Kerwood, Prentice: this area was eliminated early before many readings were made because it surcharged and there was little flow variation with rainfall.

Hampton: this area had frequent stoppages with resultant surcharging of the monitoring manhole when the stoppage released. Even though there was ground water in the section no measurable differences in flow were noted after rain.

Kenosha: this area was eliminated because Willamet, Kruss, Windemere, and Kantner were closer to the desired length for the study area.

Willamet, Kruss, Windemere and Kantner were selected because they fit all the criteria: significant flow increase with rainfall, length, no surcharging, sufficient metering fall, and ground water in the section.

APPENDIX C

PROJECTED SEALING COST

A field log was kept of every aspect of the operation, the time and problems involved. The following are problems which we experienced and comments on the effect on the sealing operation and the projected time and cost figures.

Camera lighthead bulb failure.

Roots obstructing line, jamming between packer and camera, obscuring vision and preventing packer from sealing.

Holes punched in packer bladders.

Camera failure.

These are problems, which will always be with the operation and which are included in our time and cost figures. We had two camera failures, only one of which could be traced to abuse. If this frequency of camera failure persisted a backup camera would be needed.

Chemical mixing.

Packer jamming on laterals protruding into line.

These problems could be eliminated by equipment changes and development of an attachment on the cleaning machine for reaming out protruding laterals. See equipment recommendations. These were also included in our time and cost figures.

Smoke from lighthead due to chemical overspray obscuring vision.

Chemical buildup between camera and packer during sealing operation due to excessive chemical overspray from packer.

Electrical failure of power winch due to frayed connections.

These problems can be eliminatea by experience and care in the use of the equipment. It is difficult to estimate the time loss due to them so they tend to make the sealing time overage figure on the conservative side.

Broken down sections of pipe in line necessitating going into span from both ends. That is; sealing normally to obstruction and withdrawing. Then towing cables and hoses through, putting the camera and packer into the downstream manhole, backing back to the obstruction and then sealing normally. This time consuming operation can be removed from the sealing crew by immediate repair of such defects by excavation after their location by the television inspection. The TV is capable of passing through all but the worst pipe breakdown.

This did not happen often enough to significantly affect our time and cost figures.

Faulty check valves causing packer and chemical lines to become plugged necessitating withdrawal and cleaning.

This was the most time consuming of all the problems encountered and can be completely eliminated by installing better check valves. The time lost because of this is not included in our figures of time and cost.

Using our time logs of the individual phases of the project and the problems which occurred to us we developed the following times for each phase of the operation.

Set up time, in line ready to seal: .75 hours average

Chemical mixing time, until ready to seal: .50 hours average. Average usage requires one mix per day.

Actual sealing speed while in line: 72 ft/hr average. A high of 184 ft/hr and a low of 18 ft/hr were recorded. A graph of sealing time vs. amount of chemical used is shown in Figure 17.

Moving time to another span, finish sealing until ready to seal again: .75 hour average.

Tear down and clean equipment and prepare to leave job: .75 hour average.

Using these time figures a typical average day can be developed using a 225 feet average span length.

Transport to job, breaks	1.00 hour
Set up	0.75 "
Span	3.10 "
Chemical mix	0.50 "
Moving	0.75 "
Span	1.15 "
Tear down and clean	0.75
	8.00 hours

4.25 hours sealing average day

72 ft/hr x 4.25 hrs = 306 ft/average day

For our projected figures the following changes were made because of unrealistic conditions in our actual operation.

Increased labor rates, because the County wage scale is abnormally low.

SEALING SPEED VS. SEALANT USED

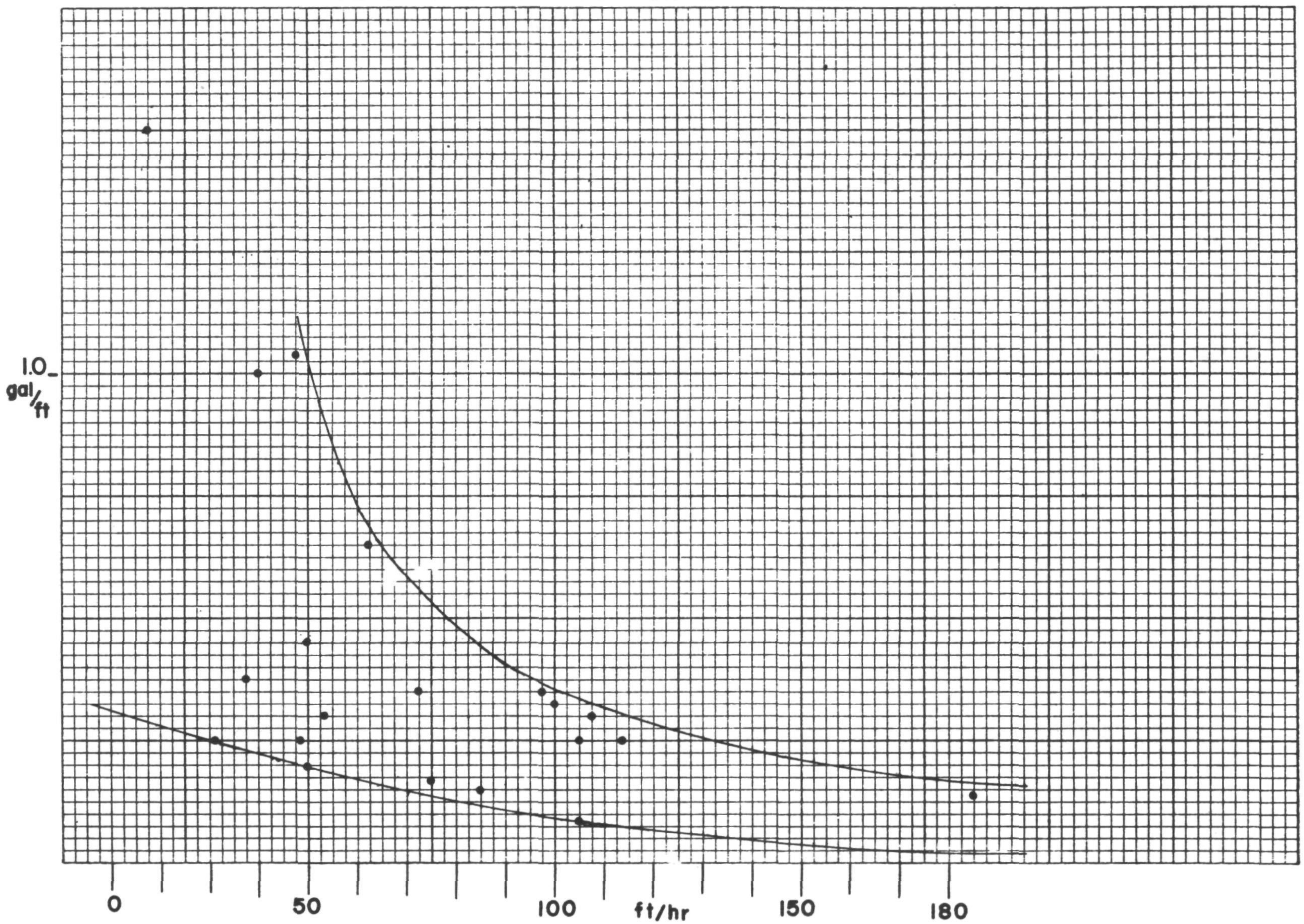

Fig. 17

Inclusion of a four wheel drive vehicle for the tow truck.

Inclusion of an extra camera based on the frequency of failures we experienced. This may not be realistic as our camera may be defective, with a corresponding high frequency of failures.

Decreased cost in televising based on the use of the power winch.

Use of a three man crew with a competent sealing assistant. Assumption that crew is experienced enough to eliminate the need for the project engineer working in the field.

Elimination of the time wasted in working on defective check valves.

With these changes in mind the following is the derivation of the projected cost of sealing.

Equipment

Pickup truck $\frac{\$2000.00}{450 \frac{\text{workdays}}{3 \text{ yrs}}}$ — \$ 4.40/day

Tow truck (FWD) $\frac{\$3600.00}{450 \text{ days}}$ — 8.00/day

Sealing equipment and parts $\frac{\$21,000.00}{450 \text{ days}}$ — 46.66/day

Gas and oil — 3.00/day

\$62.06/day

Labor Costs

Head operator @ \$4.75/hr
Assistant operator @ \$4.25/hr
Sealing assistant @ \$3.50/hr

Total — \$12.50

10% fringe benefit — 1.25

\$13.75/man x 8 hrs = \$110.00/day

General Maintenance Costs

12 full days/year full crew
(12) (110) = \$1320/year $\left(\frac{1320}{150 \frac{\text{days}}{\text{yr}}}\right)$ — \$ 8.80/day

Standby Camera Costs

Repairs

$\frac{2 \times \$112}{5620'}$ = .039/ft

Camera Depreciation

$\frac{\$6750}{450}$ = $15.00/day

$\frac{\$15.00}{5620'}$ = .109/ft

.14/ft .14/ft

Televising Costs

4 spans/day, 224' long

896 ft/day

$180.40/day - labor & equipment & gas

$\frac{\$180.40}{896.00}$ = .20/ft .20/ft

Line Threading Costs (Clean & Set Up)

Based on 60% requiring sewer jet to thread lines .024/ft

Cleaning Costs .10/ft

Chemical Costs .39/ft

Total Projected Costs per foot

Equipment

$\frac{\$62.06/\text{day}}{306\ \text{ft/avg day}}$ = .203/ft

Labor

$\frac{\$110.00}{306}$ = .359/ft

General Maintenance

$\frac{\$8.80}{306}$ = .288/ft

Standby Camera & Repairs	.140/ft
Line Treading	.024/ft
Televising - Cleaning	.100/ft
Chemical Costs	.39/ft
	$1.70/ft

All of our cost figures apply to 8-inch lines, in which every joint is sealed. As noted before the speed of the operation greatly increases as the joints take less sealer so the cost of the operation is highly dependent on the condition of the lines. See the sealing chart for the summary of the condition of our lines, Figure 3, Soil Conditions & Sealing Summary.

APPENDIX D

ACTUAL SEALING COST

In our sealing operation a good deal of time was spent learning about the correct use of the equipment. Certain problems were experienced which obviously could be and were eliminated as the operation progressed. A bad labor situation also existed in which the sealing assistant was not capable of performing all the operational and on-going maintenance activities that were required of him. He was simply not suited to the job but was a problem with which we were forced to live. The general problems in learning about the system resulted in the project engineer working nearly full time with the crew, also an unrealistic situation. His time is also included in the costs, and tends to compensate in speed of operation for the incompetent sealing assistant. The following is a breakdown of our actual costs, which were higher than they should have been due to the aforementioned problems. A projection of costs for a more ideal operation will be done later.

Equipment

Pickup truck $\frac{\$2000.00}{\frac{450 \text{ work days}}{3 \text{ years}}}$	\$ 4.40/day
Trailer Tow Truck $\frac{\$2800.00}{450}$	\$ 6.22/day
Sealing and TV Trailer plus spare parts $\frac{\$21,000.00}{450}$	\$46.66/day
Gas and Oil	\$ 3.00/day
	\$60.28/day

Labor

Operator @ \$3.37/hr
Assistant Operator @ \$3.21/hr
Sealing Assistant @ \$3.23/hr

Total: \$9.81 x 8	\$78.48/day
Plus 10% fringe benefit \$4.00	7.85
	\$86.33/day
Project Engineer @ \$40.00/day Plus 10% fringe benefit \$4.00	\$44.00/day

Camera Repair Costs

Repair and freight	$112.00/repair
3 days labor & equipment depreciation lost time per repair	430.83
	$542.83/repair

Cleaning Costs .10/ft

Televising costs (without power winch)
450 ft/day average

Labor	$ 86.33/day	
Equipment	60.28/day	
	$146.61/day	
	450 ft/day	.32/ft

Line Threading Costs

9 hrs @ $15.00/hr	$135.00 / 5620 ft	
for 5620 ft (only 60% were threaded by sewer jet)		.016/ft

Chemical Costs

2100 gallons x 1.023/gal / 5620 ft	.39/ft

Total Cost per foot

Labor and Equipment for 31 working days	$4,545.22	
Project Engineer for 12.6 working days	554.40	
Total	$5,099.62	
$5099.62 / 5620 ft		.907/ft

Camera Repair Costs
(General maintenance was done on down days because of camera)
2 repairs x $542.83/repair

$1085.66 / 5620	.19/ft
Cleaning Costs	.10/ft

Chemical Costs		.39/ft
Televising Costs		.32/ft
Line Threading		.024/ft
	Total	1.93/ft

APPENDIX E

SEALING CREW AND OPERATION PROCEDURES

The sealing crew should be composed of a minimum of three men whose qualifications are as follows:

Head Operator: Ability to keep coherent records. Knowledge of simple electronics and how to use a V-O-M for trouble shooting. Good mechanical ability for maintaining equipment and for operating sealing and TV controls. Supervising abilities. His job is to coordinate the use of the equipment, order all chemicals and spare parts as needed, trouble shoot equipment in case of failure, help keep records, help set up equipment, operate equipment, and mix chemicals.

Assistant Operator: Identical qualifications except that electrical knowledge is not absolutely necessary. His job is to work closely with the head operator in the set up, operation, records keeping, chemical mixing, and maintenance. He must be able to assume the role of the head operator on days when he is sick or on vacation.

Sealing Assistant: Mechanical ability for maintenancing equipment. His job is to aid in the set up of the equipment, help mix chemicals, clean and maintain the equipment, tend the power winch and generally perform any work required while the head and assistant operators run the sealing rig.

During our experience with sealing we developed a set of procedures which enabled us to set up, tear down and move the equipment from one place to the next. Efficient set up is a necessity.

Pre-operation procedures consist of the following: the line must be televised beforehand in order to insure that all obstructions that would prevent the passage of the packer are located. Line should be strung the day before. This can be done by the sealing assistant while the operation is in progress if there is a hydrant available for flushing or if the flow is high enough. Otherwise a rodder or hydraulic sewer cleaner is needed. Chemicals should be mixed before the men leave for the job. This can be done the night before. Trucks and all equipment should be gassed up the night before. All necessary maintenance and cleaning activities should take place the previous day. Lines should be cleaned within a week of sealing. Often this can be done when line is threaded.

SET UP PROCEDURES

Head Operator	Assistant Operator	Sealing Assistant
Drive van and trailer to job. Approach manhole from downstream.	Precede trailer to job in pickup truck. Set up downstream winch, assemble cable pulley shoe, set up barricades.	Precede trailer to job in pickup truck. Thread rope if necessary. Otherwise help assistant operator.
	Tie cable onto threading line.	Pull downstream winch cable out to length of span plus 2 manhole depths. Loop back to downstream MH. Stay with winch downstream.
Stop at downstream manhole.		Pull out winch power wire reel and start to unreel power cable.
Drive slowly to upstream manhole.	Walk upstream with trailer, making sure winch power wire unreels without fouling.	Hold power wire securely at downstream winch.
Park at upstream location. Start to set up camera, packer, and rear of trailer.	Pull cable through with threading line. Assemble pulley shoe. Set up upstream winch.	Feed cable through winch. Work to prevent cable fouling.
Start generator and compressor. Continue setting up camera. Make connections, test camera and lighthead.	Plug in power winch cable, lock power winch cable reel. Test power winch, take up slack in cable.	Plug in power winch downstream. Put cable pulley shoe in line. Feed cable onto winch until all slack is gone. Install dummy manhole cover.
Operate power winch. Lower camera into hole. Test lighthead and check picture. Set footage meter.	Go down in hole and feed camera into pipe. Check final hookup. Set shoe in hole, lock onto winch.	Go upstream to sealing trailer. And assist.

SET UP PROCEDURES

Head Operator	Assistant Operator	Sealing Assistant
Seal.	Operate power winch and write in sealing log.	Maintenance and activities to insure ease of moving or tearing down. Line threading, chemical readying, cleaning of truck and organization of equipment.
Give slack on power winch. Give slack with all hoses and cables.	Go downstream. Take camera and packer from assistant.	Remove shoe downstream. Go in hole, pull out packer and camera and unhook. Pass up to assistant operator.
Start winding up cables and hoses as soon as they are free.	Load all downstream equipment on truck. Drive upstream to trailer.	Load all downstream equipment in truck. Drive upstream to trailer. Wash camera, clean camera lens, clean packer.
Wind up cables and hoses.	Wind up cables and hoses.	Wind up cables and hoses.
Move trailer to new location.	Move trailer to new location.	Set up downstream equipment at new manhole.
Begin setup procedures.	Begin setup procedures.	Begin setup procedures.

PULLING OUT

Head Operator	Assistant Operator	Sealing Assistant
Give slack on power winch. Give slack with all hoses and cables.	Go downstream. Take camera and packer from assistant.	Remove shoe downstream. Go in hole, pull out packer and camera and unhook. Pass up to assistant operator.
Start winding up cables and hoses as soon as they are free.	Load all downstream equipment on truck. Drive upstream to trailer.	Load all downstream equipment in truck. Drive upstream to trailer. Wash camera, clean camera lens, clean packer.
Cose up rear of trailer.	Load all tools, winch, shoes, and accessories on van.	Load all tools, winch, shoes, and accessories on van.

Fill 60 gallon water tanks. Mix chemicals if necessary.

APPENDIX F

SEALING EQUIPMENT.

1. The Cues-TV Inspection Trailer incorporates the basic TV system with the necessary accessory items such as winches, plugs, downhole equipment, into one unit designed for year round operation.

2. Completely wired 110V AC electronic system for powering the TV system as well as auxilliary lights and hand tools.

3. Electrically started generator insures instant start operation at the unit's electrical system.

4. High quality camera, solid state, automatic electronic controls, 3" diameter, external focus control, 650-lines picture, quartz glass face plate, 400 psi pressure tested housing.

5. Industrial video monitor, 800-lines picture, metal case, dual video input jacks.

6. Power control unit, displays line voltage, controls line voltage, registers line cycles, regulates camera light intensity, automatically regulates camera voltages, operates whole system with single off-on switch.

7. Skid and light assemblies for pipe sizes 6" to 30".

8. Reel assemblies, allows operations of the reels without disconnecting the input side, rotary connector, geared hand crank and power drive, hand controlled positive reel brake.

9. Footage meter, indicates the exact distance the camera is from the center of the manhole, locates on the cable reel, remotely operates footage indicator, accurate to ± 2 feet in 1000 feet. Mounted above monitor to continuously display the footage the camera has penetrated the line.

10. Camera lighthead, operates submerged, no breaking of glass bulbs, rugged housing, waterproof connectors, snap-in quartz bulbs, variable intensity for proper illumination in all pipe 6"" to 30".

11. Camera skid assembly, one yoke for all pipe 6" to 30", instantly replaceable spacer plates for varying pipe sizes, tow lift tow assembly, uses cables to guide over offset joints, dual tow cables eliminates camera rollover, quick disconnect snap hooks, stainless steel runners, designed to keep camera in middle of pipe.

12. Television transmission cable, designed for sewer TV camera, heavy duty 1/16" polyurethane jacket, cut resistant, wear resistant, lightweight (10 lb per 100 ft), five circuits, quick disconnect

connectors, 400 psi, one continuous 500 ft length.

13. Hand winch, sets up over manholes, 500 ft stainless steel cable, approximately 40 lbs weight.

14. Power driven winch, basic hand winch with modification of 1/4 HP Dodge electric motor with right angles gear reducer 11:1 ratio, total 70 lbs weight.

15. Downhole pulleys, guide wheels protects cables from damage on inverts, extension pipes for varying depths of manholes.

16. Polaroid camera assembly, attaches on television monitor, clear photographs of conditions discovered inside pipe lines.

17. Grout-sealing packer, rubber inflating bags seal on each side of defect so full pressure of grout enters defect only, two separate grout holes keep chemical from setting up in lines, acts as partial plug so camera won't get emerged by water while sealing.

18. Chemical tanks, keeps chemical separate until point of injection, 80 psi, 30 gal capacity.

19. Water tank, 60 gal capacity, 100 psi, supplies spare water for mixing chemical in field.

20. Air compressor, 180 psi, 4 HP gas powered motor, supplies constant pressure for chemical tank, water tank and packer.

21. International Harvester Truck, 4-wheel drive.

SUGGESTED INVENTORY FOR TELEVISION INSPECTION RIG

TOOLS

Solder Iron
Allen Wrenches
Needle Nose Pliers
Regular Pliers
Snips
Dykes
Knife
Volt Ohmmeter
Set Wrenches 3/16" - 1"
Crescent Wrenches
Screwdriver Set
Electric Drill
Drills 1/16" - 1/2"
Hand Vice Portable
Hammer
Hack Saw and Blades
Vice Grips
Channel Lock
Stripping Tool
Flashlight
Mirrors
Socket Wrenches
100 feet electric cord
25 feet electric cord
Steel Wool
Electrical Tape Rolls
Filament Tape
Fuses (one of each size)
Rag Bag
Hand Cleaner
Shrink Film Length
Grip Fittings
Polaroid Film Rolls
Miscellaneous nuts and bolts
Hex Head Screws
Swivels and Hooks
18 gauge wire roll
Spark Plugs, Generator
Gas Can
Water Jug
Stainless Steel Cable Splices
Oil
Dow Corning Silicon Grease
5-pin Y Connector (2)
5-pin Female Connector (1)
Two Cables with Snap Hooks
Grease Gun
Oil Can
File
Pipe Wrenches
Fire Plug Wrench
Fire Hose
Coal Chisel
Hand Pump and Hose
Manhole Hook
Crowbar
Shovel
Trash Can

SAFETY

Gas Indicator
Manhole Harness
Reflector Vents
Cones
Night Lights
Wet Suit
First Aid Kit

SUPPLIES

420 Watt Light Bulb (2)
625 Watt Light Bulb (2)
Solder Roll

APPENDIX G

EQUIPMENT RECOMMENDATIONS

After our experience with sealing and televising there are certain changes that we would make in our particular setup. The following are suggestions that would enhance the ease and efficiency of the operation.

All sealing and televising equipment should be mounted in an enclosed truck. The truck should be equipped with four wheel drive if there is any possibility of off-the-road sealing and inspection. The truck should include special mounting for all accessory equipment such as winches, hoses, shoes and tools. Mounting should be designed with security of transport, neat, organized storage and accessibility in mind.

There should be a special compartment for transportation of chemicals, designed with their isolation from other equipment and puncture damage in mind.

Provisions for mixing chemicals while the operation is in progress are necessary. There are many possibilities, several of which are listed here.

Separate mixing tanks and transfer pumps mounted on pickup truck.

Separate mixing tanks and transfer pumps mounted in sealing van.

Two sets of shooting tanks with appropriate valving so one can be open for mixing while the other is in use. This can be made cheaper by substituting a positive displacement shooting pump for pressurized tanks and using fibreglass or lighter gauge metal tanks. Tanks must still have a tight cover to prevent spillage in transit.

A mobile water tank, preferably mounted in the pickup truck should be available in case the auxiliary water tank in the shooting rig is exhausted before the rig can pull out of a span.

A power driven winch is a necessity, with remote controls at the operators station by the TV monitor and the sealing controls. See Figure 18 for the solutions to the power winch problem that we arrived at.

It is worthwhile for an operation that is continuous to have a standby camera. We lost an average of three days of work every time the camera went out.

A device for cutting out extreme protruding laterals that will not permit the packer to pass through the line would be extremely useful.

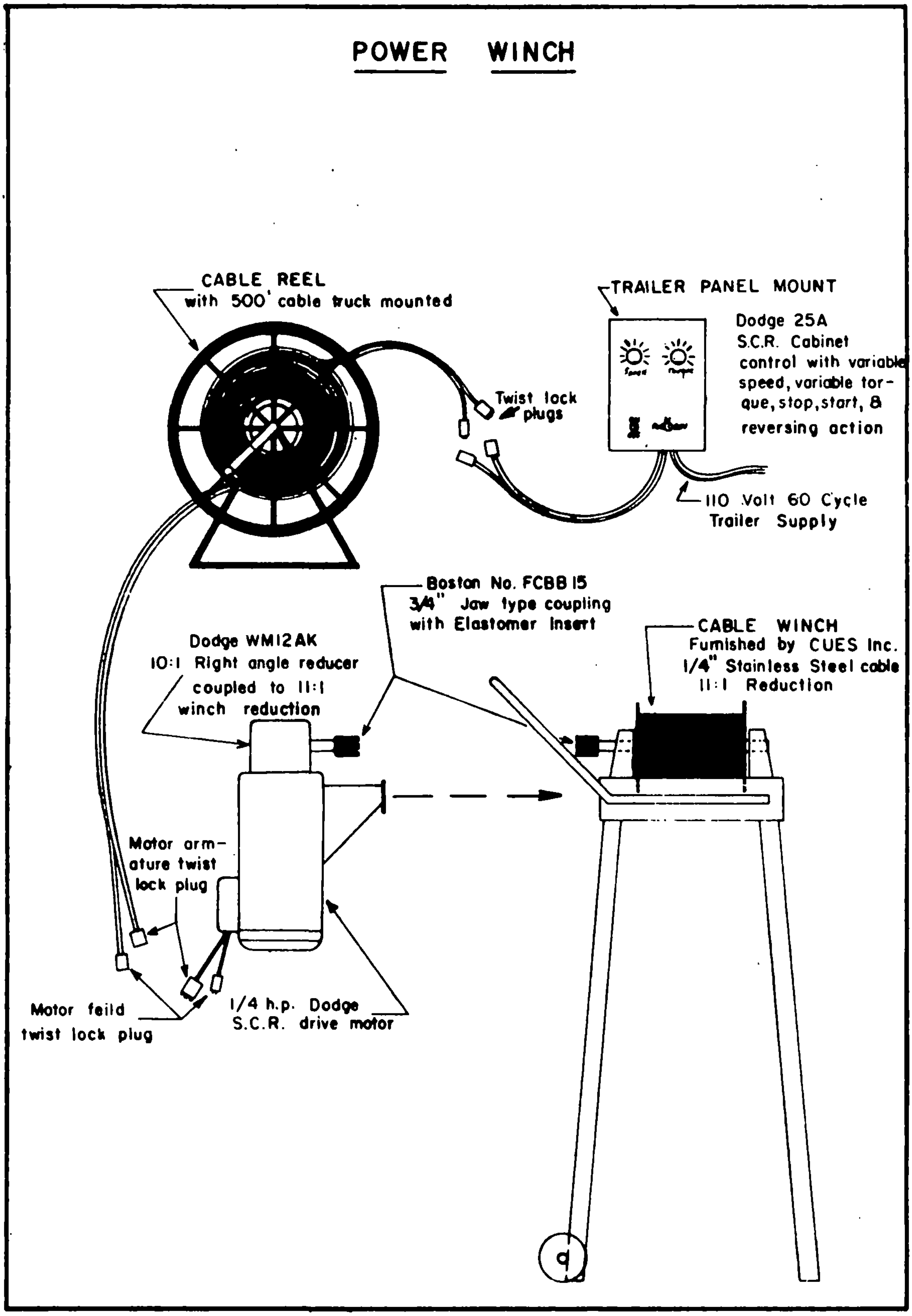
POWER WINCH
CABLE REEL
with 500' cable truck mounted
TRAILER PANEL MOUNT
Dodge 25A
S.C.R. Cabinet
control with variable
speed, variable tor-
que, stop, start, &
reversing action
Twist lock
plugs
110 Volt 60 Cycle
Trailer Supply
Boston No. FCBB 15
3/4" Jaw type coupling
with Elastomer Insert
CABLE WINCH
Furnished by CUES Inc.
1/4" Stainless Steel cable
11:1 Reduction
Dodge WM12AK
10:1 Right angle reducer
coupled to 11:1
winch reduction
Motor arm-
ature twist
lock plug
Motor feild
twist lock plug
1/4 h.p. Dodge
S.C.R. drive motor

Fig. 18

APPENDIX H

SPECIAL DETAILS OF SEALING OPERATION

During the sealing operations we gained a good deal of practical experience regarding the general operation and actual sealing itself. The following information is valuable to someone starting out.

Spans cannot be sealed uphill against the flow for the following reasons: when the packer is inflated it forms a partial plug in the line; if the camera is upstream of the packer it becomes submerged and visibility is gone. When sealing upstream the excess gel downstream (especially in a line with a fairly flat grade) causes the flow to back up and partially submerge the camera lens.

When we encountered obstructions in the line that would not pass the packer we would seal up to that point, pull back, hook all the hoses and cables together, pull them to the downstream manhole, hook on the camera and the packer, back them up the line to the obstruction and resume sealing. This way we avoided moving the trailer and sealing upstream.

The packer must be washed and its holes cleaned every time it is taken out of a span.

When sealing keep the flow rate of both the chemicals identical to avoid backflow and sealing up the holes in the packer. Never turn on one sealant without the other. Start sealing at a fixed flow (we used 2 gpm), and watch the pressure gauges. When the pressure begins to rise above normal steady flow shut off the flow. With experience one can do this before overspray occurs. If both gauges hold more than 2 - 3 psi the joint is sealed.

If a joint will not seal there are several techniques that can be used:

1. Slowing the flow to give the gel longer to take effect.

2. Shutting off completely and giving the existing chemical time to set up. We always ran a minimum of 60 seconds before trying this.

3. Momentarily increasing the Q-Seal A (catalyst) flow rate will speed gel time sometimes and seal a joint faster. This is especially valuable when the sealer is getting away too rapidly through porous soil. Be careful to avoid backflow in the packer when doing this.

After a joint is sealed the packer should remain inflated for the gel time. This prevents a buildup of sealant between camera and packer and buildup downstream which will eventually pile up between the camera and the packer as they are moved down the line. This can be ignored at times of very high flow in steep grades.

If one man operates the sealing panel and the other keeps the logbook and operates the power winch the efficiency of the operation can be maximized.

A gel time of 10 to 12 seconds was used exclusively. Any longer just extends the length of time one must be set up on a joint after sealing.

Alignment of the packer on a joint is accomplished by triangulations with the camera and the top edge of the packer. The length of the tow cables between the two is such that the relationship shown in Figure 19 exists.

METHOD OF SETTING PACKER ON JOINT BY TRIANGULATION

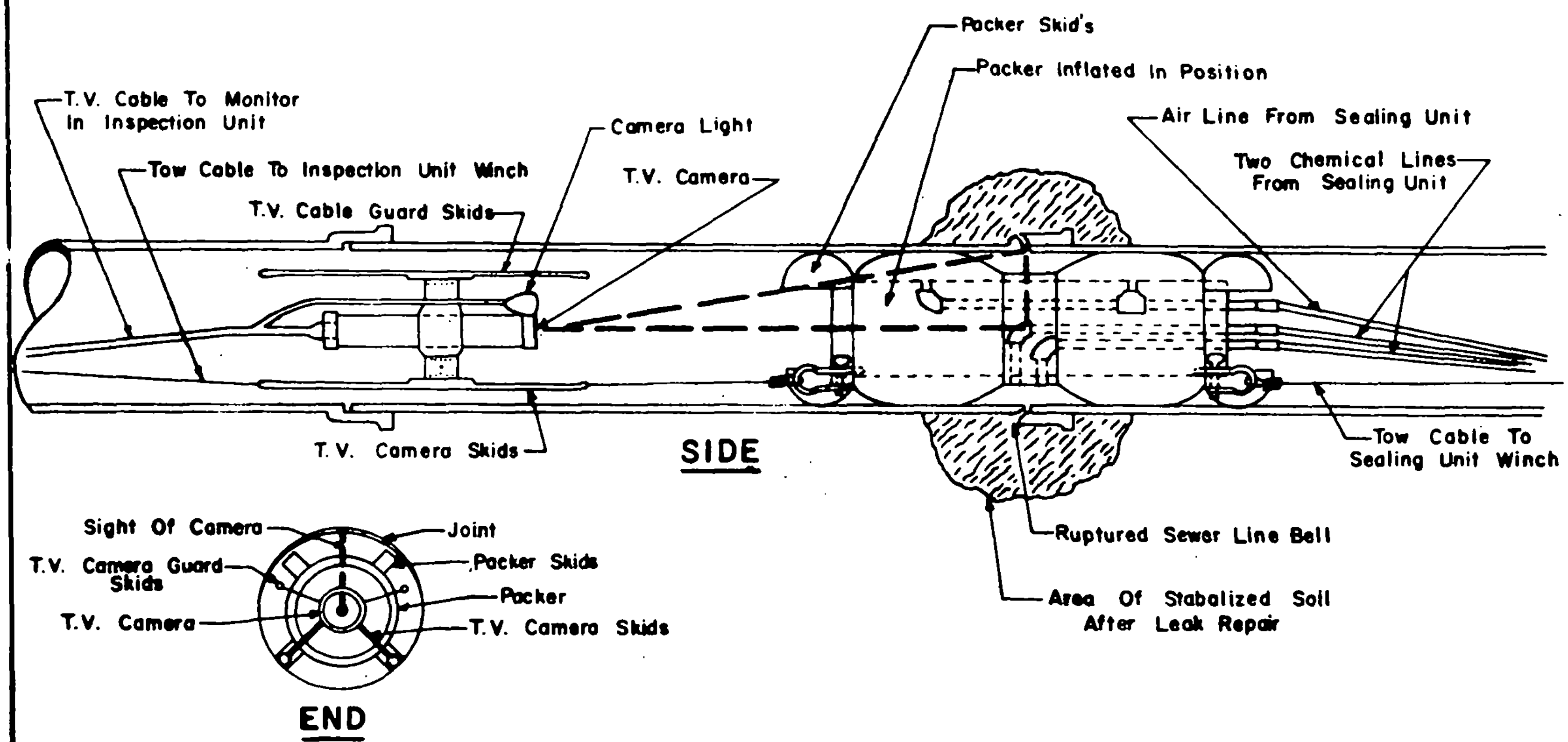

Fig. 19

APPENDIX I

METHODS OF DETERMINING THE NEED FOR SEALING

Television inspection, except in areas of constantly high water table is not conclusive for determining the need for sealing. The following is a summary of the visual and actual joint conditions and their correspondence.

Visually good (perfectly concentric): 782 joints	100%
Actually good (0-.9 gal seal): 583 joints	74%
Actually medium (.9-1.9 gal seal): 138 joints	18%
Actually bad (2.0 gal seal & up): 61 joints	8%
Visually medium (0-1/2" offset): 539 joints	100%
Actually good (0.9 gal seal): 380 joints	70%
Actually medium (.9-1.9 gal seal): 89 joints	16%
Actually bad (2.0 gal seal & up): 70 joints	14%
Visually bad (1/2" offset & up): 273 joints	100%
Actually good (.9 gal seal): 145 joints	53%
Actually medium (.9-1.9 gal seal): 63 joints	23%
Actually bad (2.0 gal seal & up): 65 joints	24%

This shows fairly conclusively that purely visual inspection, when the pipe is not immersed in ground water, is inconclusive for determining the need for repair by sealing.

APPENDIX J

DESCRIPTION OF GROUT

A. Chemical Composition

Q-Seal D

a. Acrylamide and NN' - methylenebisacrylamide white powder (MBA)

b. Beta-dimethylaminopropionitride clear liquid (DMAPN)

Q-Seal A

a. Amonium persulfate white powder

B. Mixing Technique

The ammonium persulfate was mixed with 30 gallons of water and approximately 6 lbs of ammonium persulfate was used.

The NN' methylenebisacrylamide (MBA) was also mixed with the DMAPN in 30 gallons of water. Approximately 20 lbs of MBA and 1 gallon of DMAPN were used.

C. Injection

The chemicals forma stiff gel within 5 to 7 seconds after mixing. The gel is stable in non-dehydrating surroundings, and was also found to be extremely toxic and is designed only for use in sewers.

The grout also contains a weed killer. The composition is a trade secret.

A possible method of determining the probability of a need for sealing in an area is to make test borings to analyze trench conditions. Figure 3 shows soil conditions and non-functional ground water pipe locations (low soil permeability) correlated with the condition of the lines (amount of sealant used per foot of line). The general indication is that in areas where the permeability is low in the trench, the lines are self sealing, even if they may have defective joints. Judiciously placed soil borings could be used as one of the indicators in determining the need for joint sealing in an area. In areas with high permeable backfill material every defective joint is bound to leak under high ground water conditions.

A basic survey of an area to decide the need for sealing should include the following criteria:

Determination of existence of high flow problems.

Determination of trench conditions, either by borings or by knowledge of construction procedures. (The latter is not very reliable in old systems.)

Determination of the existence of non-premium joints.

Determination of the existence of ground water in the area, either constant or responsive to rainfall.

Observation of the methods of foundation and roof drainage. If it is possible that these cause high flow problems then all possible means should be exhausted for removal of these problems before sealing. Smoke testing may be some help in these locations.

Removal of other possible sources of stormwater connections to sanitary before sealing.

APPENDIX K
TABLE I
GROUND WATER INDEX

Date	Avg. Total % Line Underwater	Rain Inches	Intensity (Inches/hour)
3/5/70	72	1.64	.07
3/9/70	79	.00	.00
3/23/70	76	.00	.00
3/31/70	78	.00	.00
4/2/70	100	.19	.09
4/3/70	100	.00	.00
4/8/70	92	.00	.00
4/10/70	92	.00	.00
4/14/70	87	.00	.00
4/16/70	100	.00	.00
4/23/70	71	.47	.13
4/24/70	92	1.57	.28
4/29/70	75	.00	.00
5/1/70	77	.00	.00
5/5/70	72	.00	.00
5/8/70	71	.00	.00
5/12/70	73	.88	.27
5/14/70	67	.00	.00
5/18/70	67	.00	.00
5/22/70	70	.00	.00
5/26/70	69	.00	.00
6/3/70	58	.20	.07
6/9/70	61	.00	.00
6/16/70	74	.00	.00
6/22/70	70	.00	.00
6/24/70	59	.05	.20
6/25/70	69	.00	.00
7/8/70	63	.65	.37
7/9/70	44	.10	.05
7/23/70	64	.00	.00
11/10/70	45	.02	.26
11/17/70	46	.00	.00
12/7/70	73	.00	.00
12/22/70	66	.60	.11
1/8/71	40	.00	.00
1/14/71	32	.02	.13
2/3/71	22	.00	.00
2/5/71	63	.00	.00
2/18/71	46	.00	.00
2/22/71	65	1.50	.31
2/26/71	80	.27	.03
3/9/71	86	.00	.00
3/11/71	83	.00	.00
3/15/71	100	.55	.33
3/22/71	91	.05	Snowmelt

GROUND WATER INDEX

Date	Avg. Total % Line Underwater	Rain Inches	Intensity (Inches/hour)
4/2/71	92	.00	.00
4/13/71	69	.00	.00
4/15/71	50	.00	.00
4/19/71	39	.00	.00
4/23/71	70	.00	.00
4/27/71	45	.73	.48
4/28/71	50	.00	.00
5/3/71	53	.00	.00
5/6/71	69	1.80	.37
5/10/71	97	.00	.00
5/12/71	96	.02	2.0

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1 Accession Number	2 Subject Field & Group	
W		**SELECTED WATER RESOURCES ABSTRACTS** **INPUT TRANSACTION FORM**

5 *Organization*

Montgomery County Sanitary Department

6 *Title*

GROUND WATER INFILTRATION AND INTERNAL SEALING OF SANITARY SEWERS, Montgomery County, Ohio

10 *Author(s)*

Gene E. Cronk
John R. Patterson
Paul Feinstein
Shepherd Goodspeed

16 *Project Designation*

EPA Grant 11020 DHQ

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

*Infiltration, Wastes, Sealants, *Sewers

25 *Identifiers (Starred First)*

*Montgomery County, Ohio, *Television Inspection

27 *Abstract*

A program for pollution abatement was undertaken by the Montgomery County Sanitary Engineering Department in Southwest Ohio to research the effects of infiltration reduction by joint sealing and to study closed circuit television techniques.

Water Pollution from municipal wastewater treatment plants would be reduced if peak flows from rainfall could be reduced. This study evaluates the effects of remedial repairs to joints by use of pressure grouting of small main line sewers. A minimal measurable amount of quantity flow reduction was attributed to the sewer sealing program. This is to say that infiltration from extraneous storm water, illegal connections, and basement underdrains seem to outweigh the contribution due to leaky joints to such a degree that reduction due to joint sealing was obscured.

The study does show the significance of internal television system as an inspection and maintenance tool. This information on costs, operation, and procedure is of value to anyone interested in this field.

Abstractor	*Institution*
Gene E. Cronk	Montgomery County Sanitary Department

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