INFILTRATION/INFLOW ANALYSIS OF THE WASTEWATER COLLECTION SYSTEM OF SMALL COMMUNITIES

By

JERRY B. FARRAR

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Oklahoma State University

Stillwater, Oklahoma

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Thesis Approved:

Richard N. DeVries
Thesis Adviser

James V. Parcher

Marcia H. Bates

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

The control of infiltration and inflow into the sanitary sewer systems is one of the most important operations in controlling the cost of wastewater treatment. This can be controlled in new sanitary sewer collection systems by controlling the quality of design, the quality of the construction materials and the quality of material placements. The majority of infiltration and inflow problems experienced today are found in older sanitary sewer systems. Many of these older systems have undergone material and pipe joint deterioration or were poorly designed and/or constructed.

As population increases and man continues to encroach on the environment of the earth, improved sanitary sewage treatment at a cost-effective rate is required. The reduction, and in some cases elimination, of infiltration and inflow can often substantially reduce the cost of wastewater treatment.

Inflow and infiltration into the sanitary sewer systems have always been a problem; however, the detailed analysis of the problem was normally limited to the larger systems which were in the large cities of the United States. The Federal Water Pollution Control Act Amendments, Public Law 92-500, of 1972 required that after July 1, 1973, all applicants for grants from the Environmental Protection Agency for treatment works demonstrate that each sewer system discharging into the treatment works is not subject to excessive

Infiltration/Inflow. Excessive Infiltration/Inflow is defined as that portion of Infiltration/Inflow which is more economical to eliminate than to transport and treat.

Since all cities, regardless of size, desired grants to assist in the construction of improved sanitary sewer systems, the Infiltration/Inflow analysis became an important function in small cities and communities. Public Law 92-500 also established a source of grants for the determination of excessive Infiltration/Inflow, which is a part of a Step 1 Environmental Protection Agency grant. A Step 1 grant also includes a Facility Plan and an Environmental Impact Assessment.

The purpose of this investigation was to determine the Infiltration/Inflow into the sanitary sewer system of a small community using the requirements of the Environmental Protection Agency. Locust Grove, Oklahoma was the community selected for this analysis. This analysis included: interviewing city officials and operation personnel; field inspections of the system; measuring flow in key locations before, during and after rainfall; analyzing the data, taking into consideration the physical condition of the system; considering geological and geographical factors as they may affect the system correction measures; and identifying Infiltration/Inflow conditions including a review of a past internal inspection of a selected portion of the sanitary sewer collection system.

At the completion of this analysis a cost-effectiveness of proposed system improvements was made to determine if it was more cost-effective to rehabilitate the sanitary sewer collection system to reduce or eliminate the Infiltration/Inflow or to provide additional treatment plant capacity to treat the Infiltration/Inflow.

CHAPTER II

LITERATURE REVIEW

In the past few years there has been an increasing degree of awareness and concern over the problem of infiltration and inflow. The main reasons for this have been the more stringent Federal requirements and the related increased costs of both conventional and advanced treatment systems. Even with this increased awareness, not a great deal has been written, outside of Environmental Protection Agency pamphlets on the subject. The impact of raw wastewater diversion at treatment facilities caused by surcharged sewers must now be seriously considered.

Establishing the quantities of Infiltration/Inflow entering a collection system is not an exact science. The more severe the Infiltration/Inflow problem, the more likely it is that the wet-weather flows will not be contained within the system and that flows will escape through overflowing manholes and bypasses. When lines surcharge, they do not work as a gravity system, but as a pressure system with the rate of inflow entering the system being reduced by the internal pressure.

Gutierrez (4) points out that another important item to be considered is the soil conditions. It has been his experience that despite the groundwater being at a higher elevation than the collection lines, in many cases the infiltration rates were not excessive. He attributes this to the very slow movement of the groundwater through the soil. The impervious nature of the soil would have a direct bearing on this slow movement.

Munson (7) has stated that all the evidence points to the conclusion that it is not economically feasible to completely eliminate infiltration in an existing collection system. Cesareo (1) agrees with this and further states, however, that when correction of infiltration in existing sewer systems has been considered, the main concern has been the out-of-pocket or bond investment for the correction. Little thought has been given to the comparative economics of costs of correction versus the benefits to be derived.

Each sewer collection system is unique. Gutierrez (4), during his studies, has found that on a percentage basis, the Infiltration/Inflow contribution of the three components of a wastewater collection system, collection lines, manholes and service lines, varies widely. In some systems, the collection lines contribute as much as 73% or as little as 4%; in some, the manholes contribute 95%; and in others, as low as 2%. The same applies to the service lines where the range goes from 81% to as low as 1%.

Cesareo (1) sites an example of a choice of action for Infiltration/Inflow correction based upon economic considerations. His example is Locust Grove, Oklahoma. Prior to 1970 Locust Grove experienced a serious infiltration problem which was causing their treatment plant to receive flows many times the design flow during wet weather. Cesareo (1) stated that the community chose to employ the services of a professional pipe grouting firm at a cost of $16,000 to chemically grout portions of the collection system rather than spend several hundred thousand dollars to construct additional treatment capacity to treat the Infiltration/Inflow. Cesareo stated that the action was successful.

Chemical grouting is most commonly used to seal leaking joints in structurally sound sewer pipes. It cannot be used satisfactorily as a structural repair for broken, crushed or badly cracked pipes.

The real effectiveness of a rehabilitation program cannot be evaluated until the actual repair work is completed. Gutierrez (4) feels that whatever amount of Infiltration/Inflow is removed through a well-planned and engineered rehabilitation program will be cost-effective and beneficial to the performance of the treatment and transportation facilities.

Most Infiltration/Inflow investigations involve the use of electronic recorders and other sophisticated techniques. However, McLaughlin (6) has made use of a simple technique to measure flows. He has used plastic cups attached on 6-inch intervals to a board that is tied to the steps of a manhole. As the sewer fills and the manhole surcharges, the cups fill with water. McLaughlin (6) has related the depth of flow recorded by the cups to dry weather and wet weather flow. Although the method is simple, the results are assisting him in evaluating Infiltration/Inflow problems.

The primary goal of an Infiltration/Inflow analysis is the development of a cost-effective solution. However, the most important far reaching factor is the overall impact on water quality. Simple elimination of an Infiltration/Inflow source may seem to be the obvious engineering choice, but its relationship to overall water quality should never be overlooked.

CHAPTER III

MATERIALS AND METHODS

General

Locust Grove is located in Mayes County, Oklahoma, approximately 55 miles east of Tulsa. The population projections for the town through the year 2000 is shown in Table I. The 1970 population figure is from the 1970 U. S. Census. Projections were taken from the Oklahoma Employment Security Commission projections revised in January, 1979.

TABLE I

POPULATION PROJECTIONS

Year	Population
1970	1090
1977	1200
1985	1350
1990	1400
1995	1450
2000	1500

The climate within the Locust Grove area is typical of northeastern Oklahoma. The average winter temperature is 45 degrees, while the summer temperature averages 82 degrees. Precipitation is moderate, with an annual average rainfall of 42 inches.

Locust Grove has a moderately sloping terrain from east to west. The ground elevation is typically 660 mean sea level on the west edge of the city limits and 720 mean sea level on the east edge of the city limits. Flooding is not a major problem for the city. The main stream constituting the watershed for the city is Crutchfield Branch. Two tributaries of this stream traverse through the town providing drainage into Crutchfield Branch. The most abundant soils in the area are silt loams and clay silts with underlying layers of clay and sandstone.

The existing sanitary sewer collection system and treatment plant was constructed in 1958. All of the collection pipe in the system, with the exception of creek crossings, is vitrified clay pipe with hot poured bitumastic joints. The total length of the lines in the collection system is approximately 26,800 linear feet. Approximately 21,900 feet of this is 8-inch diameter; 2,900 feet is 10-inch diameter; and the remainder is 6-inch diameter. No estimate has been made of the total length of the individual sewer connections from homes and commercial establishments. With the exception of one small area, all of the present collection system flows by gravity to the treatment plant. This small area is pumped through a force main to another part of the collection system, where the flow is by gravity.

The treatment plant is a trickling filter plant with its treated effluent being discharged to a tributary of Crutchfield Branch. The capacity of the treatment plant is between 150,000 gallons per day and 200,000 gallons per day. Sewage treatment at the plant involves primary settling, sludge recirculation, trickling filter and final settling. There are also sludge digestion facilities and sludge drying beds.

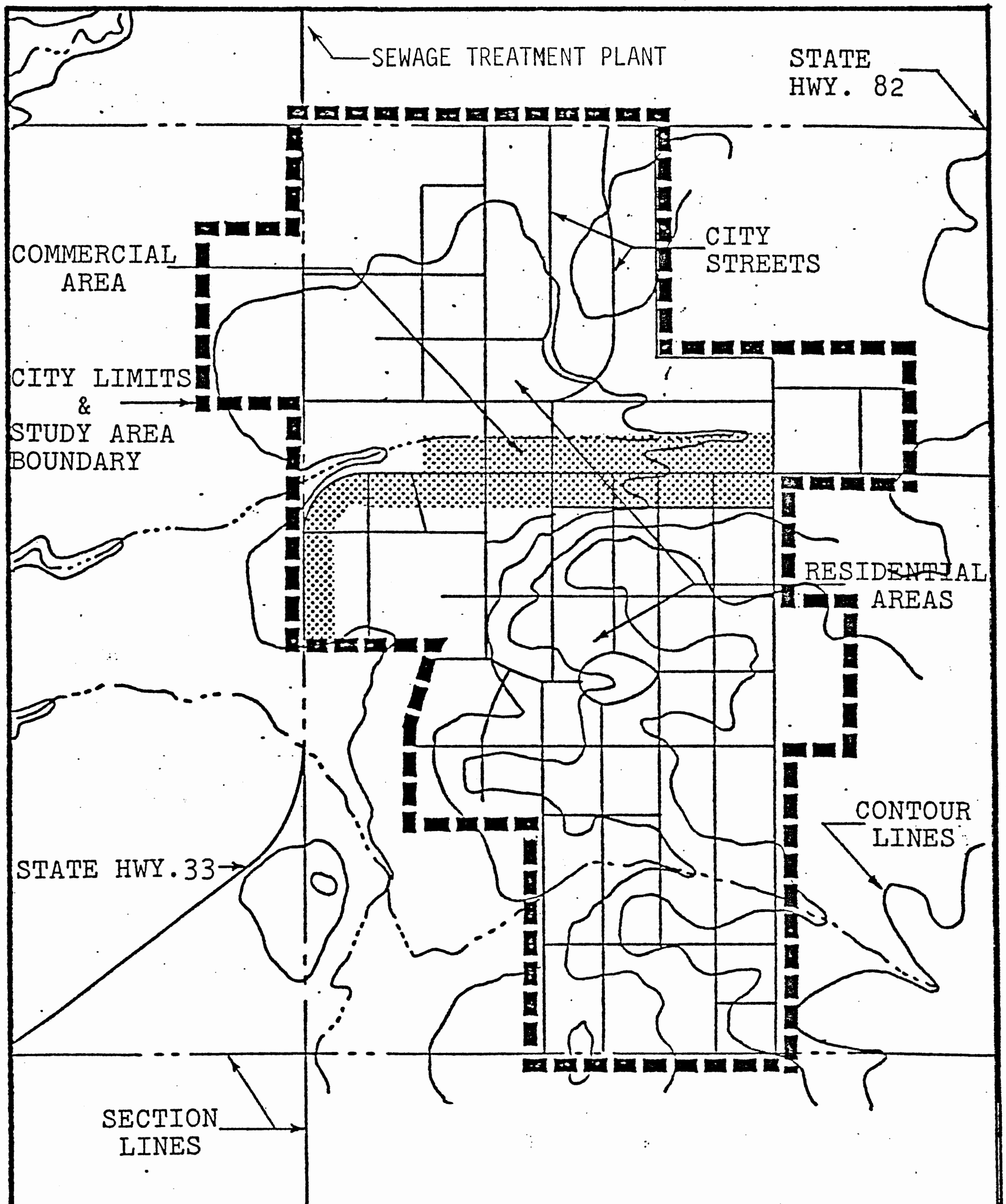
The study area includes all the area within the city limits. Figure 1 is a map of this study area. This figure further shows the terrain of the area.

Flow Monitoring

The sanitary sewer collection system within the study area was studied to determine flow patterns. It was determined that all of the sanitary sewer flowed through two manholes prior to entering the main trunk line to the treatment plant. Therefore, the study area was divided into two sub-areas. Figure 2 is a map showing the collection system within the study area and the boundaries of the two sub-areas. These two key manholes are also noted on the figure.

Electronic measuring devices were installed in these two key manholes to permit continuous monitoring of flow before, during and after a rainstorm.

Portable Manning Dippers were used to record the flow level in the two key manholes. Each dipper was equipped with an 8-inch circular chart on which the flow level was recorded on a 24-hour basis. The Manning Dipper uses a dipping-probe technique to detect the liquid surface. A thin corrosion-resistant metal probe is lowered on a cable controlled by a motor. The probe continuously tracks the changes in liquid level with a regulated dipping action. The probe is neither required to float on nor submerge below the liquid surface; therefore, there is little or no affect due to turbulence, floating debris,



LOCUST GROVE, OKLAHOMA

Figure 1. Study Area

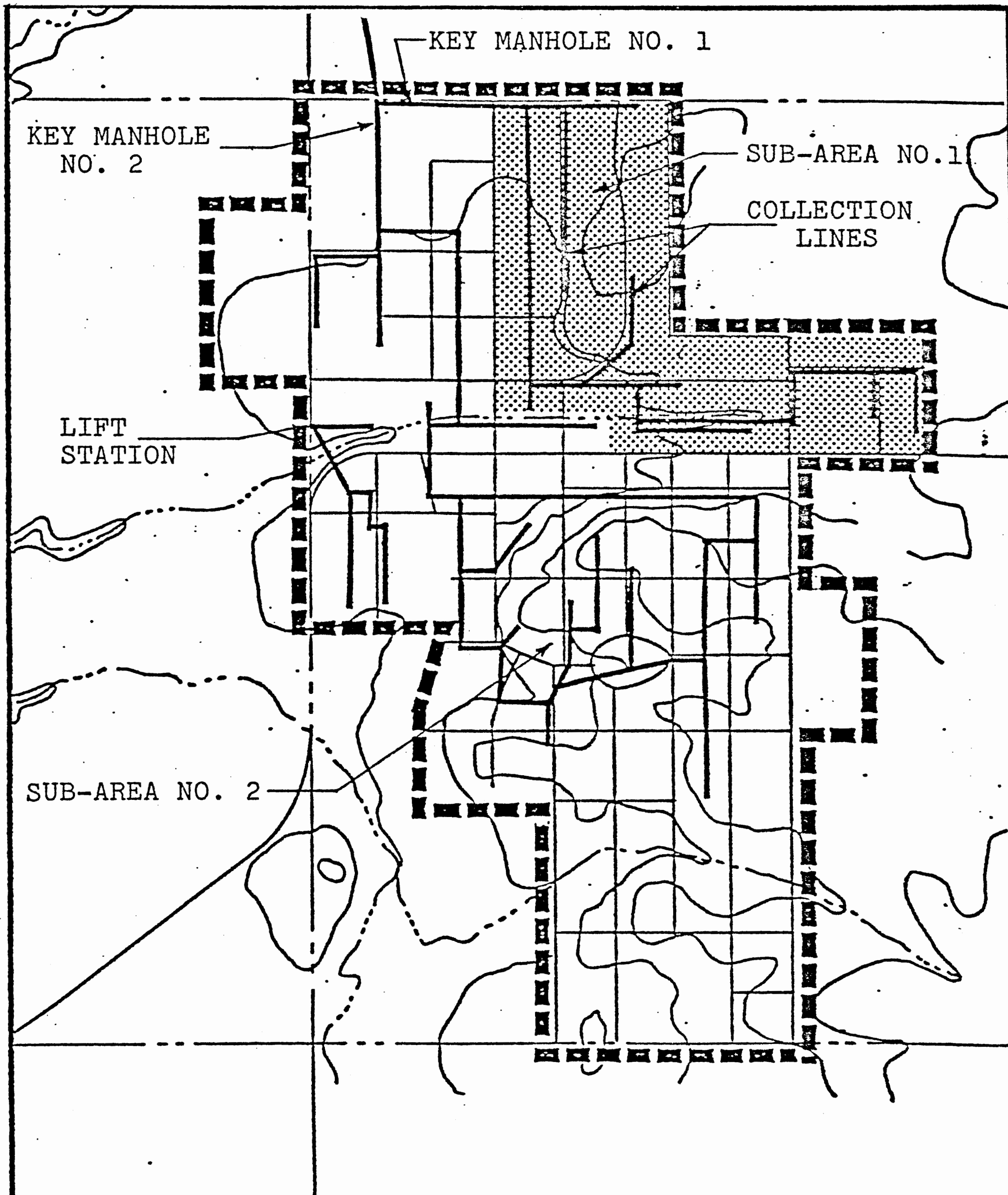


Figure 2. Study Sub-Areas and Collection Systems

solids accumulation, or corrosive chemicals.

The flow recorder at the sanitary sewage treatment plant did not work properly and therefore did not show the variation of flow during the day. The totalizer on the flow recorder did work, however, so that the total flow per day was recorded. Table II is a record of the wastewater flows recorded at the treatment plant during the study period.

The flow recorder at the water treatment plant provided the quantity of treated water produced. This enabled a comparison of the treated water flow versus the inflow to the sanitary sewer treatment plant. Table III is a record of the treated water flow at the water treatment plant during the study period.

Rain guages were installed in the study area to measure the total amount of rainfall. The time was also recorded when the rain began and ended. Both infiltration and inflow are affected by rainfall. The amount of inflow to a sewer system is directly related to rainfall, since inflow enters from aboveground sources, such as roof drains, storm sewer cross-connections and surface runoff. The direct relationship between rainfall and infiltration is not so apparent. While most of the infiltration is caused by the seepage of the groundwater through defective pipes, pipe joints, connections, or manhole walls, rainfall during a high groundwater period aggravates the infiltration problem. The rainfall may reach the groundwater by percolating through the soil and cause a general increase of the groundwater level. If the groundwater level is above or close to the level of the sanitary sewer lines then the addition of rainfall which percolates through the soil will cause an increase in the groundwater level, sometimes to a level

TABLE II

WASTEWATER TREATMENT PLANT TOTAL RECORDED FLOW

Study Day	Flow GPDX1000	Study Day	Flow GPDX1000	Study Day	Flow GPDX1000	Study Day	Flow GPDX1000
1	578.2	23	595.3	45	**	67	580.2
2	584.6	24	561.9	46	**	68	611.0
3	599.4	25	623.8	47	**	69	649.0
4	604.0	26	600.2	48	**	70	641.2
5	590.0	27	601.0	49	**	71	636.8
6	591.6	28	600.4	50	**	72*	657.8
7	591.4	29	561.4	51	602.15	73	594.6
8	596.0	30*	560.4	52*	602.15	74	583.7
9	519.0	31*	563.0	53*	585.1	75	541.87
10	**	32	**	54	611.3	76	541.87
11	**	33	**	55	629.0	77	541.87
12	**	34	**	56	559.3	78	593.4
13	**	35	**	57	553.5	79	587.1
14	**	36	**	58	587.4	80	589.8
15	**	37	**	59	587.4	81	592.7
16	**	38	**	60	595.4		
17	579.2	39	**	61	674.3		
18	590.6	40	**	62	558.9		
19	590.5	41	**	63	558.9		
20	619.5	42	**	64	558.9		
21*	453.0	43	**	65	576.8		
22	595.0	44	**	66	576.8		

* Flows being bypassed at treatment plant
** Data unavailable

above the sewer pipes. This increases the total hydraulic head above the sewer pipes and causes more water to enter the pipes through defective pipes and joints.

Since the groundwater level has an affect on infiltration, the groundwater level was monitored during the study period. Groundwater information can normally be obtained from government water resource agencies or local groundwater users. If this information is not available then field groundwater monitoring must be conducted. Groundwater guages or observation wells are normally used for this purpose. For this analysis, information from local groundwater users was available.

CHAPTER IV

RESULTS

Study Sub-Area 1 contains approximately 8,400 feet of 8-inch diameter sewer line. Study Sub-Area 2 contains approximately 13,500 feet of 8-inch, 1500 feet of 10-inch and 500 feet of 6-inch force main. The equivalent pipe diameter for Sub-Area 2 is 8.14 inches.

Table III contains the water production rate recorded during the study period. The flows over 300,000 gpd were the result of water line breaks, therefore these flow rates were disregarded in the analysis. The resulting average daily water production rate from these recorded rates is 237,700 gpd. These flows were recorded during winter months, therefore lawn watering, irrigation and car washing usage should be very minimal. There are no industries in the area that consume water in their operation.

The population figures in Table I were interpolated to arrive at a 1979 population of 1240. Using the 1979 population figure and the average daily water production rate results in a 192 gallon per capita per day (gpcd) water consumption rate. Of the total population of 1240, approximately 300 had water service, but no sewer service. Therefore, the sewered population is estimated to be 940. Using the water consumption rate of 192 gpcd results in 180,500 gpd of water consumed by the sewered population. It is normally acceptable to assume that 60% to 80% of the water consumed for domestic use will become sewage.

TABLE III

WATER TREATMENT PLANT TOTAL RECORDED FLOW

Study Day	Flow GPDX1000	Study Day	Flow GPDX1000	Study Day	Flow GPDX1000	Study Day	Flow GPDX1000
1	225	23	236	45	*	67	391
2	225	24	230	46	*	68	399
3	177	25	231	47	*	69	551
4	209	26	237	48	*	70	130
5	234	27	263	49	*	71	139
6	207	28	290	50	*	72	203
7	226	29	223	51	243	73	193
8	277	30	191	52	246	74	197
9	202	31	236	53	251	75	262
10	156	32	*	54	190	76	118
11	240	33	*	55	299	77	144
12	526	34	*	56	356	78	420
13	243	35	*	57	316	79	224
14	261	36	*	58	400	80	224
15	227	37	*	59	510	81	224
16	250	38	*	60	375		
17	209	39	*	61	404		
18	222	40	*	62	365		
19	227	41	*	63	510		
20	273	42	*	64	177		
21	239	43	*	65	413		
22	229	44	*	66	386		

* Data Not Available

Using a return rate of 70% of the 180,500 gpd results in a theoretical base wastewater production rate of 126,500 gpd.

The actual base wastewater production rate could not be obtained from the field measurements made with the Manning Dippers or the treatment plant flow recorder. Table IV is a record of the flow recordings made during the study period with the Manning Dippers. Table IV and Table II both show that the wastewater flow to the treatment plant remained consistently far above the dry weather base production rate. The average daily flow recorded at the sewage treatment plant was 587,500 gallons per day (gpd). The average daily flow should normally be greater than the dry weather base flow; however, in this instance it is 4.6 times the theoretical base flow value. It is also interesting to note that this same average wastewater flow is 3.3 times the average water consumption rate of the sewered population.

At this point in the data collection and analysis, all of the meters used in the recording of the flows were checked for accuracy. This check included the Manning Dippers and the flow recorders at the water and wastewater treatment plants. All recorders were found to be accurate within acceptable tolerances.

Groundwater level with respect to sanitary sewer line elevation was evaluated to determine what impact it might have on the flow values being recorded. As stated earlier, information from local groundwater users was available. This information indicated that the groundwater level normally was within five to ten feet of the ground surface. This information was visibly verified during the aboveground inspection of the sanitary sewer collection system, by the presence of springs along the tributaries of Crutchfield Branch.

TABLE IV

FIELD MEASUREMENTS WITH MANNING DIPPER

Study Day	Flow GPDX1000	Study Day	Flow GPDX1000	Study Day	Flow GPDX1000	Study Day	Flow GPDX1000
1	586.5	23	573.9	45	605.1	67	557.9
2	565.3	24	541.1	46	587.6	68	588.5
3	576.6	25	600.4	47	596.3	69	624.1
4	580.4	26	577.9	48	588.7	70	617.2
5	567.6	27	578.2	49	581.3	71	612.3
6	569.2	28	577.8	50	597.2	72	**
7	569.1	29	540.6	51	578.7	73	572.3
8	575.0	30	**	52	**	74	561.3
9	499.8	31	**	53	**	75	520.2
10	*	32	607.3	54	587.8	76	520.7
11	*	33	573.2	55	605.4	77	521.0
12	*	34	553.1	56	537.6	78	571.0
13	*	35	555.6	57	532.5	79	565.1
14	*	36	547.5	58	564.5	80	567.2
15	*	37	547.1	59	565.6	81	570.3
16	*	38	586.4	60	572.3		
17	577.8	39	573.6	61	648.3		
18	562.8	40	567.8	62	538.2		
19	572.6	41	543.3	63	537.9		
20	595.9	42	541.7	64	537.8		
21	**	43	539.8	65	555.1		
22	573.7	44	539.2	66	555.2		

* Manning Dippers Being Checked

** Manholes Surcharged - Dippers Removed

Flow Includes Recordings From Both Key Manholes

In order to verify this condition further, six test borings were made with a 4-inch hand auger to a depth of fifteen feet. Fifteen feet was chosen as the total depth since none of the sanitary sewer lines in the system are deeper than ten feet. The groundwater level was encountered at a depth of 4.5 feet. This level was monitored during the study period to see how it fluctuated with rainfall.

Table V is a record of the rainfall received during the study period. The closest Weather Bureau station is in Tulsa, Oklahoma and, although the rain gauges used are not as accurate as those used by the Weather Bureau, it is felt that the recordings are perhaps more accurate for Locust Grove than a recording made 55 miles away.

The groundwater level did fluctuate during the study period during periods of rainfall. This fluctuation was only a small amount and normally occurred several hours after the rain began.

By comparing Tables IV and V it can be seen that the manholes containing the Manning Dippers became surcharged when the rainfall exceeded 1-inch. The dippers were removed when this occurred to protect them from damage. It should also be noted that the flow was being bypassed at the wastewater treatment plant during these same periods.

Since the surcharging of the manholes occurred rapidly following the beginning of runoff from a fairly heavy rain, it must be concluded that the increased initial flows were the result of inflow. Several low manholes were observed during the course of the above-ground inspection.

Since the Manning Dippers had to be removed during periods of rainfall exceeding one inch, continual flow monitoring by this

TABLE V

RAINFALL

Study Day	Recorded Amount Inches	Study Day	Recorded Amount Inches
5	0.01	38	0.03
6	0.02	40	0.01
7	0.30	45	0.15
9	0.45	47	0.10
18	0.20	51	0.05
19	0.57	52	0.85
20	0.20	53	1.25
21	1.25	60	0.25
23	0.15	61	0.10
28	0.01	70	0.40
30	1.40	71	0.15
31	1.05	72	0.90

technique was not possible. Therefore, the flow recorder at the treatment plant was used to determine the Infiltration/Inflow.

A plot of the theoretical average daily wastewater flow and the flow recorded daily at the treatment plant versus time for the study period was made and is shown in Figure 3. There were two time periods during the study period when the recorded wastewater flows at the plant were not made due to plant malfunctions. The last thirty days of the study produced the most satisfying results. Therefore, that thirty day period was used to calculate the Infiltration/Inflow.

The total Infiltration/Inflow for the thirty day period is the area between the theoretical wastewater production rate and the recorded wastewater flow shown in Figure 3. This total area is 31,960,000 gallons. Dividing this total Infiltration/Inflow value by the thirty day period results in 465,500 gallons per day (gpd).

The total infiltration was determined from this same plot in Figure 3. This was done by calculating the area between the lower limit of the recorded wastewater flow curve and the theoretical wastewater production rate. This area is 12,712,000 gallons, or 423,750 gpd. Therefore, the total yearly infiltration would be 1.547×10^8 gallons.

The total inflow for this thirty day period is the difference between the total Infiltration/Inflow and the total infiltration figure. This amounts to 1,248,000 gallons. The total rainfall recorded during the thirty day period was 3.95 inches. Therefore the total yearly inflow would be 1,248,000 gallons divided by the total rainfall of 3.95 inches multiplied by the average yearly rainfall

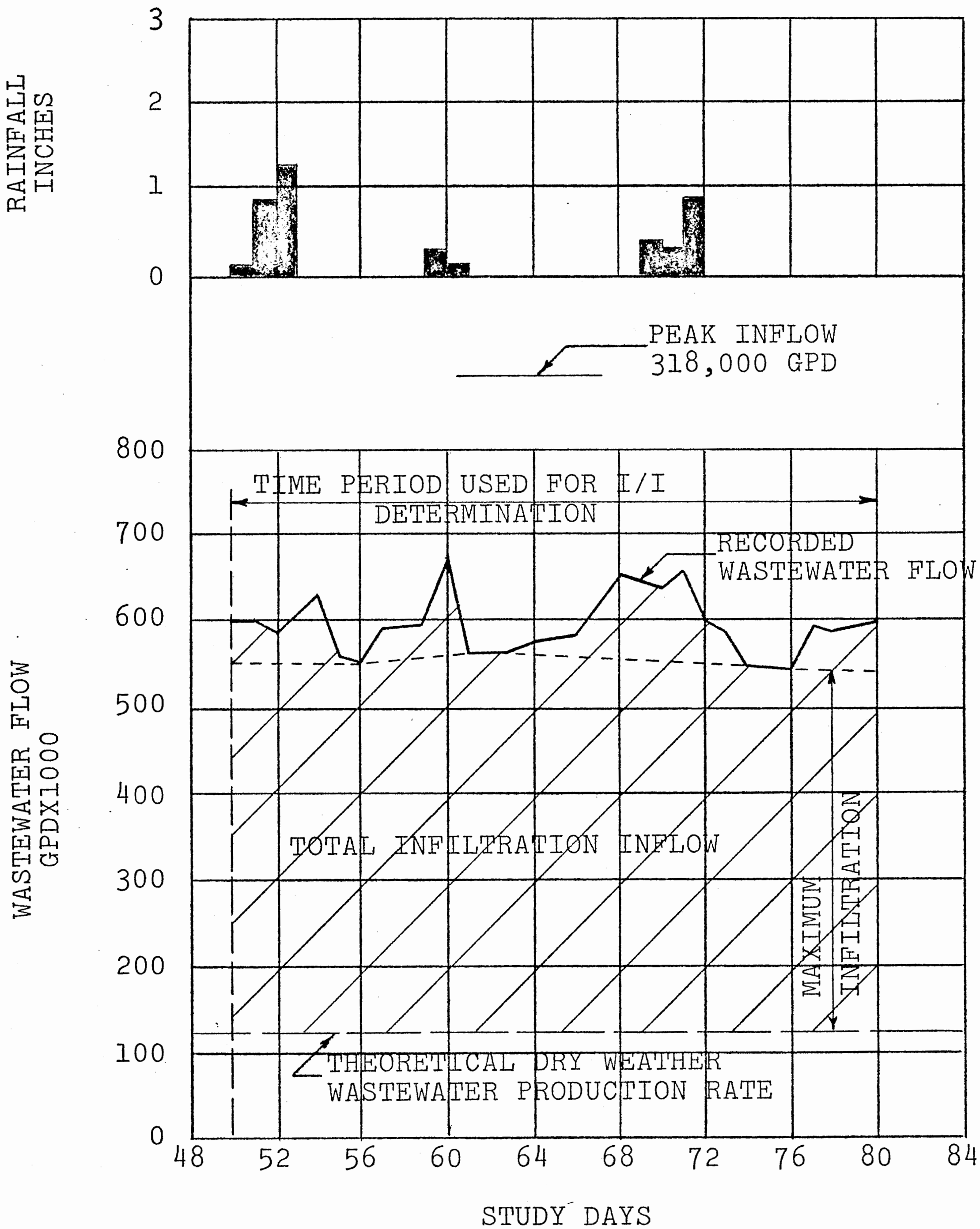


Figure 3. Wastewater Flow Hydrograph

of 42 inches. This equates to a total yearly inflow of 13,269,800 gallons. The total yearly Infiltration/Inflow would be the sum of the total yearly infiltration and the total yearly inflow, or 1.679×10^8 gallons.

The peak infiltration from Figure 3 is 433,600 gpd. The peak inflow was somewhat difficult to determine due to unmeasurable bypass flows at the treatment plant and surcharged flow monitoring stations in manholes during periods of rainfall. The maximum recorded flow during the study period was 674,300 gallons. This was followed by two non-rain days where the recorded flow was 558,000 gallons. This would indicate an inflow of 116,300 gallons. In reality, however, the manholes containing the flow recorders were surcharged, number 1 to a depth of 4 feet and number 2 to a depth of 3.5 feet for approximately three hours. During this same three hour period, flow was being bypassed at the treatment plant. It was impossible to calculate an actual value for the peak inflow since measurements could not be made. A conservative estimate of the peak inflow is 318,000 gpd. This value was determined using pressure flow equations for the sewer lines with the manholes surcharged.

According to Environmental Protection Agency guidelines, it is reasonable to assume that a maximum infiltration rate of less than 1,500 gallons per day per inch of pipe diameter per mile of sewer pipe (gpd/in/mi) is not economical to rehabilitate and is therefore nonexcessive. E.P.A. further states that when the infiltration rate is above the 1,500 gpd/in/mi, a cost-effectiveness analysis is required to determine if further investigation of the problem is warranted.

Using the average infiltration flow of 423,700 gpd calculated earlier, and the equivalent pipe diameter of 8.1 inches for the entire 23,900 linear feet studied in the system, results in an infiltration rate of 11,560 gpd/in/mi. This value is more than 7.5 times the rate requiring the cost-effectiveness analysis.

Since this was an extremely high rate of infiltration, it was determined that further investigation was required to pinpoint the nature of the problem and to determine what rehabilitation might be required to solve the problem. The best method of doing this was felt to be internal inspection. Although inspection of this type is expensive, it provides the best information required for rehabilitation. It should be pointed out that this is not a requirement of an E.P.A. Step 1 project unless a complete Sewer System Evaluation Survey becomes necessary.

During 1970 and 1971 the City of Locust Grove entered into a contract with a professional pipe cleaning and video firm to inspect a portion of the existing collection system and perform corrective action to eliminate infiltration.

Prior to inspection by television the portion to be inspected was cleaned with a rodding machine. The television inspection technique utilizes a closed-circuit television camera to observe the conditions in the sewer lines. The results are shown on a television monitor. Documentation can be made with videotape or photographs of the monitor.

A thorough review was made of the work performed during 1970 and 1971 including a review of all video pictures. The conclusion reached in this earlier report was that the chemical grouting performed on the system reduced the infiltration to a normally acceptable level.

The television inspection supported the earlier estimation that the problem was not limited to one area. Of the 9091 linear feet of 8-inch line videoed, 63% or 5727 linear feet showed problems with infiltration. The remaining 37% had sags in the lines and possibly broken connections, but no major infiltration. Of the 2187 linear feet of 10-inch line videoed, 100% showed problems with infiltration. None of the 6-inch was videoed. Also, 11% of the 8-inch line videoed indicated bad offset joints. Figures 4, 5, and 6 are a sample of the television inspection findings. Figure 4 includes two pictures of typical 8-inch lines having no apparent infiltration problems. Figure 5 includes two pictures of typical 8-inch lines with badly offset joints and infiltration problems. Figure 6 includes two pictures of typical 8-inch lines with infiltration problems.

After reviewing this earlier report, those lines which received chemical grouting were visually monitored by plugging upstream manholes and observing the flow downstream. All of the lines showed flow with the upstream plugged. It therefore appears that the chemical grouting was not of long term benefit. Of course the video pictures indicate many situations, such as offset joints, where correction of this type was not feasible.

Based on the findings of the internal inspection, the same percentages of pipe that showed problems with infiltration was applied to the entire system. Of course it is not possible to know the condition of the individual connections. It is reasonable to assume that the total length of individual connections is equal to

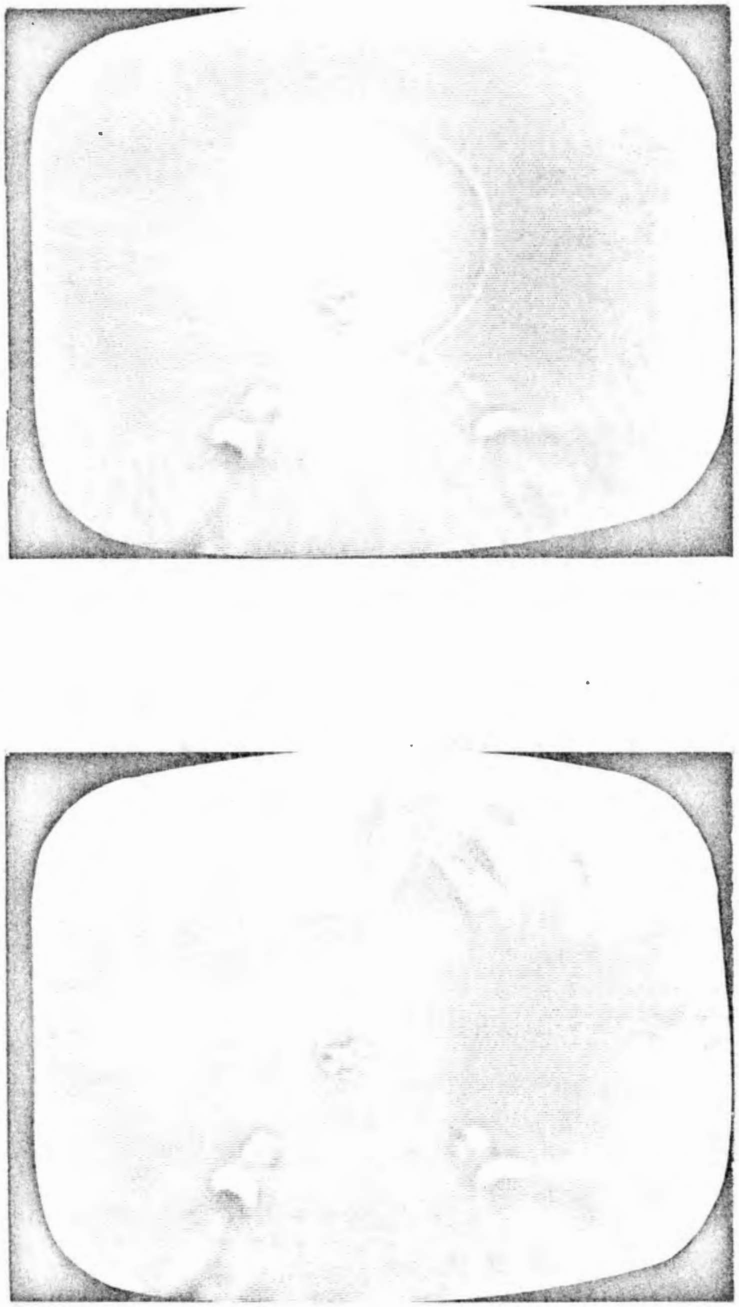
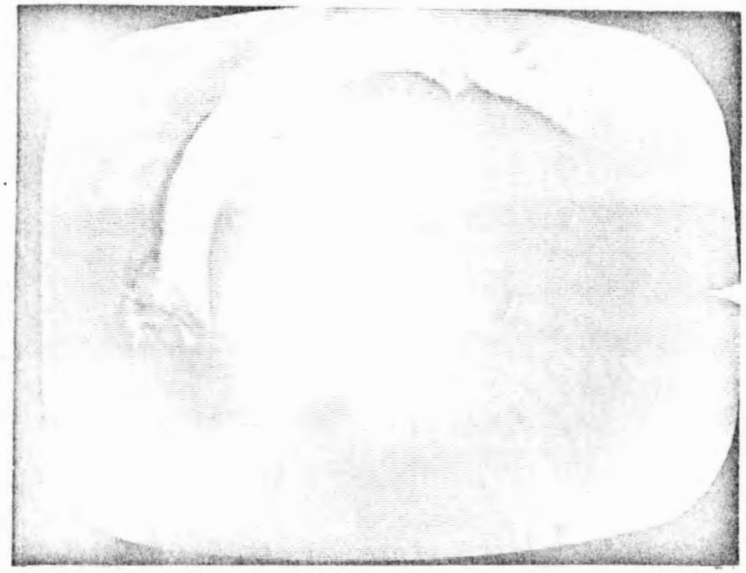


Figure 4. Existing Lines With No Apparent Infiltration



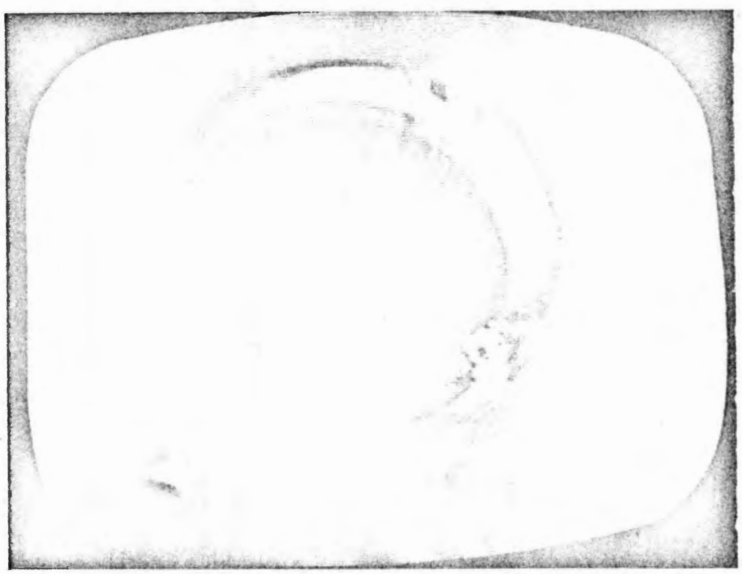


Figure 5. Existing Lines With Offset Pipe Joints

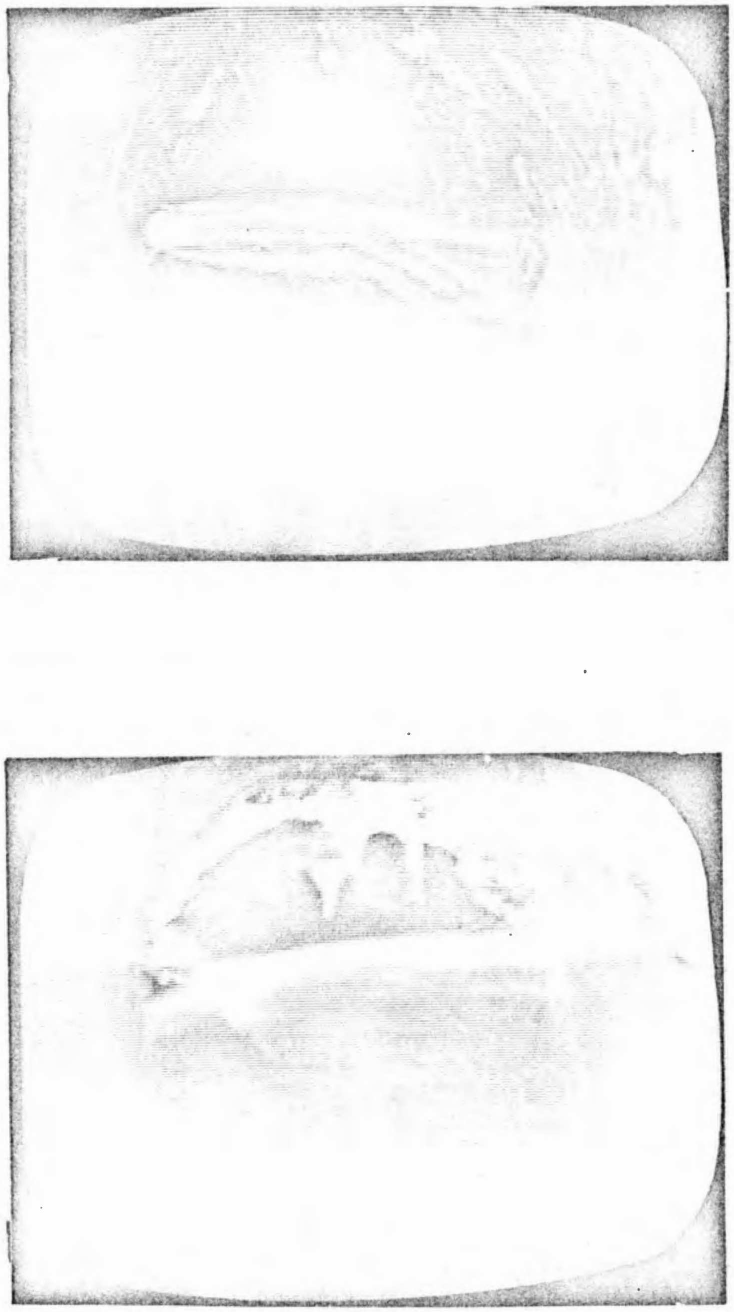


Figure 6. Existing Lines With Infiltration

the total length of the collection system. Also, based on the findings of the internal inspection, and the other inspections and analysis, it is believed that approximately 80% of the infiltration is contributed by the 63% of 8-inch line, 100% of the 10-inch line and 50% of the 6-inch line. These percentages are used in the cost-effectiveness analysis.

Cost-Effectiveness

Cost data used in determining the cost effectiveness was taken from the Environmental Protection Agency, Handbook for Sewer System Evaluation and Rehabilitation. The cost-effectiveness analysis will determine and compare the cost of collection system rehabilitation versus the transportation and treatment of wastewater including Infiltration/Inflow.

The costs developed included replacement of those portions of the system where sliplining is not possible due to offset joints. Sliplining is a technique wherein a liner is placed inside an existing sewer line to seal out the infiltration. Only the 8-inch line showed any offset joints. Representative costs of rehabilitation are as follows:

Sliplining:	
8-inch	$20.75/L.F.
10-inch	$22.50/L.F.
6-inch	$20.00/L.F.
Replacement:	
8-inch	$27.00/L.F.
Manholes	$750.00/ea.

Table VI includes the rehabilitation costs determined for this system.

Table VII includes the costs of transportation and treatment of the wastewater including Infiltration/Inflow.

This would involve increasing the design capacity of the treatment facility as a means of handling the excess infiltration. The waste load allocation for the receiving stream is 20 mg/l B.O.D. and 30 mg/l Suspended Solids. Therefore, a mechanical type plant will be required. Since the existing plant is in extremely poor condition, a new activated sludge extended aeration plant has been considered here.

The cost estimates for rehabilitation and treatment have been summarized in Table VIII. A graph of these costs has also been plotted and is shown on Figure 7.

TABLE VI

SYSTEM REHABILITATION COSTS

% System Rehab. % 8"	% 10"	% 6"	% I/I Removed	Construction Costs ($)	Engineering ($)	Inspection 2% ($)	Construct. Cont. 10% ($)	Total[1] ($)
8	12	16	10	54,500	6,800	1,090	5,450	89,590
16	24	12	20	109,070	11,560	2,180	10,900	155,460
24	36	18	30	163,600	16,360	3,270	16,360	221,340
32	48	24	40	218.140	20,500	4,360	21,800	286,550
40	60	30	50	272,670	24,270	5,450	27,270	351,410
48	72	36	60	327,200	28,470	6,550	32,720	416,690
56	84	42	70	381,740	32,070	7,640	38,180	481,380
63	100	50	80	435,150	35,690	8,700	43,520	544,810
82	100	75	90	539,430	42,080	10,790	53,950	668,000
100	100	100	100	640,000	48,600	12,800	64,000	787,150

1 Includes additional SES costs of $21,750

TABLE VII

TRANSPORTATION AND TREATMENT COSTS

% I/I Removed	Flow to Plant (gpd)	Construction Costs ($)	Engineering ($)	Inspection 2% ($)	Construc. Cont. 10% ($)	Total ($)
0	961,600	875,000	63,000	17,500	87,500	1,043,000
10	886,440	820,000	59,450	16,400	82,000	977,850
20	811,280	755,000	55,500	15,100	75,500	901,100
30	736,120	685,000	51,400	13.700	68,500	818,600
40	660,960	625,000	47,800	12,500	62,500	747,800
50	585,800	560,000	43,680	11,200	56,000	670,880
60	510,640	500,000	39,850	10,000	50,000	599,850
70	435,480	425,000	34,850	8,500	42,500	510,850
80	360,320	360,000	30,600	7,200	36,000	433,800
90	285,160	290,000	25,670	5,800	29,000	350,470
100	210,000	220,000	20,680	4,400	22,000	267,080

TABLE VIII

COSTS ESTIMATES SUMMARY

% Peak I/I Removed	Total Peak I/I Removed (gpd)	Total Peak I/I Remaining[1] (gpd)	Total Flow Remaining[2] (gpd)	Correction Costs ($)	Transport. and Treat. Costs[3] ($)	Total Costs ($)
0	0	751,600	961,600	0	1,043,000	1,043,000
10	75,160	676,440	886,440	89,590	977,850	1,067,440
20	150,320	601,280	811,280	155,460	901,100	1,056,560
30	225,480	526,120	736,120	221,340	818,600	1,039,940
40	300,640	450,960	660,960	286,550	747,800	1,034,350
50	375,800	375,800	585,800	351,410	670,880	1,022,290
60	450,960	300,640	510,640	416,690	599,850	1,016,540
70	526,120	225,480	435,480	481,380	510,850	992,230
80	601,280	150,320	360,320	544,810	433,800	978,610
90	676,440	75,160	285,160	668,000	350,470	1,018,470
100	751,600	0	210,000	787,150	267,080	1,054,230

1 Total Peak I/I is 433,600 gpd Infiltration + 318,000 gpd inflow = 751,600 gpd

2 Average Theoretical Wastewater Production of 210,000 gpd for year 2000 plus Total Peak I/I Remaining

3 Includes engineering, inspection, etc.

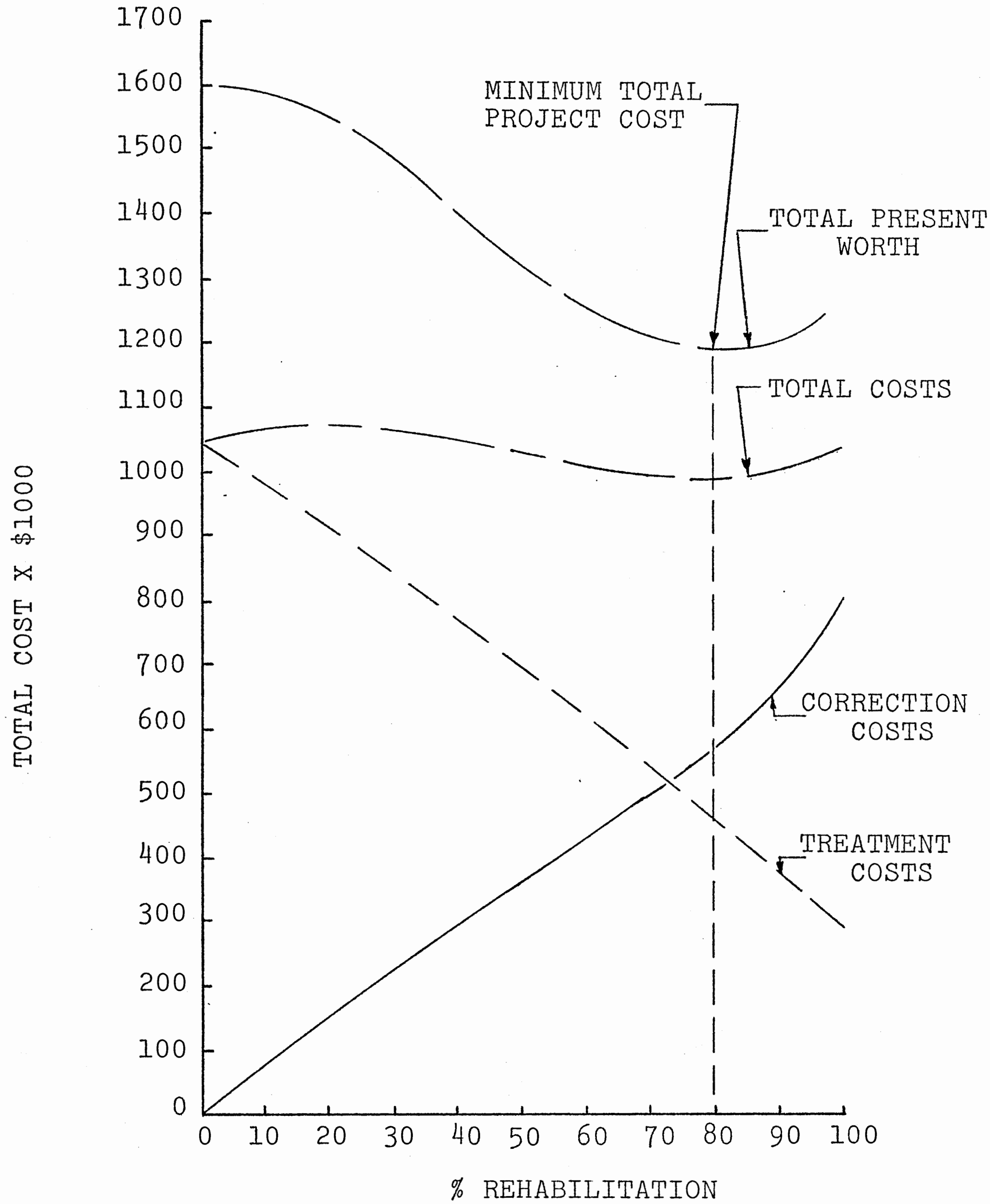


Figure 7. Costs Estimates Summary

CHAPTER V

DISCUSSION

The investigation was conducted to study the Infiltration/Inflow problems of a typical small community and how those problems affect the capability of the system to handle its sanitary sewage. The system was investigated under varying rainfall conditions to study the rainfall impact on the system.

The most obvious result obtained is that the collection system is experiencing a high degree of infiltration caused by the groundwater level. It is also obvious that the existing collection system is in poor condition. It appears that the quality of material placement, including pipe and backfill, was not satisfactory. This is evidenced by the number of cracked and broken tile and offset joints, as well as sags noted in the lines during the television inspection.

These findings support the current trend in engineering to have qualified resident inspectors on the job site during construction. Of course, construction methods are much better today than twenty-two years ago when this system was constructed, and the quality of the pipe has also improved. However, due to poor construction management, the town of Locust Grove must pay to correct the Infiltration/Inflow problem.

This analysis also revealed that record keeping is another item that requires attention. Many small communities do not maintain a a good set of influent flow records of their wastewater treatment plant. In this particular instance if good flow records had been available showing the inflow and how it varied during the day and with wet weather conditions, an analysis could have been made with little effort.

Since good flow records were not available, an effort was made during the interviews with the city employees to determine how long the flows had been of the magnitude recorded during this study. Although no accurate determination could be made, it was generally agreed that flows in excess of the water treatment plant flow had been experienced for the past ten years.

The records of the past video work were invaluable in reviewing the structural condition of the collection system. It is evident from these records and the current infiltration problem, that chemical grouting is not a satisfactory means of controlling infiltration in the Locust Grove system.

The shallow groundwater level maintains almost a constant hydraulic head on the collection system. This fact along with the bad joints and structurally unsound collection pipes aggravates the infiltration problem.

Infiltration is the primary problem with the Locust Grove System. Inflow contributes to the problem during and following rainfall; however, the correction of the inflow problem is rather simple compared to the infiltration correction. Raising of manholes and using sealed manhole covers will provide a significant reduction in inflow.

A Sewer System Evaluation Survey is needed in order to determine the exact nature of the excessive Infiltration/Inflow. Use of the previous video work may aid in reducing the cost of this survey. A small percentage of the system previously videoed could be inspected once again to provide a comparison of the system condition today to that of 1970. If the condition of the system which is reinspected is nearly identical to that in 1970, it may be possible to assume that the remaining system is also nearly identical and therefore eliminate some internal inspection work.

CHAPTER VI

CONCLUSIONS

The results of this investigation support the following conclusions:

(1) Older sanitary sewer collection systems with hot-poured bituminous joints may experience infiltration due to difficulty in making a tight joint and its deterioration.

(2) Chemical grouting as a means of rehabilitating a sewer system should be closely reviewed if the system contains numerous structural defects.

(3) Groundwater level constantly above sewer line elevations need special design considerations and special rehabilitation considerations.

(4) Proper engineering inspection and field testing are absolutely necessary if infiltration is to be kept within allowable limits.

(5) Internal inspection is the best method of determining the exact type of infiltration problem and the required corrective action.

(6) For the City of Locust Grove:

(a) The Infiltration/Inflow is excessive as defined by E.P.A.

(b) It is more cost-effective to rehabilitate a portion of the system than transport and treat the excessive Infiltration/Inflow.

(c) A Sewer System Evaluation Survey to verify the previous internal inspection should be performed.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

From the results of this investigation, the following suggestions are made for the study of Infiltration/Inflow:

(1) The study of Infiltration/Inflow from individual connections.

(2) The study of various pipe joint systems subjected to varying degrees of hydraulic head due to groundwater.

(3) The study of various types of trench backfill techniques with system subjected to varying degrees of hydraulic head due to groundwater.

(4) The study of various types of manhole construction related to Infiltration/Inflow reduction.

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VITA

Jerry B. Farrar

Candidate for the Degree of

Master of Science

Thesis: INFILTRATION/INFLOW ANALYSIS OF THE WASTEWATER COLLECTION SYSTEM OF SMALL COMMUNITIES

Major Field: Civil Engineering

Biographical:

Personal Data: Born August 15, 1945, in Tulsa, Oklahoma, the son of Hazel and Estel Farrar. Married, three children.

Education: Graduated from Bixby High School, Bixby, Oklahoma, in May, 1963; received an Associate of Arts degree in Design and Drafting Technology from Northeastern Oklahoma A&M College, Miami, Oklahoma, in May 1965; received the Bachelor of Science degree in Civil Engineering from Oklahoma State University; Stillwater, Oklahoma, in January, 1972; received the Master of Science degree from Oklahoma State University, Stillwater, Oklahoma, in May, 1980.

Professional Experience: Present--Project Engineer, Civil Engineering Group, Furlow & Associates Engineering Company, Tulsa, Oklahoma; Past Vice President and Chief Engineer, Breisch Engineering Company, Inc., Tulsa, Oklahoma.

Registrations: Registered Professional Engineer, State of Oklahoma

Memberships in Professional Societies:
Oklahoma Society of Professional Engineers
National Society of Professional Engineers