CHAPTER 3

FLOW MONITORING

FIGURES

INTRODUCTION

A periodic flow monitoring program should be implemented as part of the preventive maintenance program to provide early indication of excessive or extraneous flows entering the system such as inflow or infiltration. If the inflow or infiltration is shown to be excessive, measures must be taken to correct the problems. These corrective measures are discussed in Chapter 4 and Chapter 6 of this manual.

Other specific reasons for measuring wastewater flows are to:

1. Provide operating data on sewer system operations. Information such as average, maximum, and minimum flows per day are necessary to assess sewer system capacity.

2. Permit computation of transportation costs where such costs are based upon volume of sewage treated.

3. Obtain basic data from which long-term plans can be made for sewer line capacity.

4. Provide information on the volume of sewage discharged from a subdivision or an industrial plant into the community/agency's sewers. This is particularly important if charges are made to the subdivision or industry.

To determine the extent of infiltration/inflow, the following flows need to be determined:

1. Total wastewater flows, including residential, commercial, and industrial contributions.

2. Bypass flows.

3. Overflow rates.

4. Emergency pumping rates.

Simultaneously with flow measurements, groundwater level and/or rainfall measurements may also have to be taken in some cases.

REQUIREMENTS OF THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

A preventive maintenance program should include the implementation of a periodic flow monitoring program to provide early indication of excessive or extraneous flows occurring in the separate sanitary sewer system. The extraneous flows could indicate the occurrence of inflow or infiltration of clearwater in the separate sanitary sewer system. If the inflow or infiltration is shown to be excessive, measures must be taken to correct the system defects causing the extraneous flows. The amount of excessive infiltration and inflow allowed to enter the sanitary sewer systems depends on which compliance option each agency has selected. Appendix E summarizes the MSDGC wet weather flow requirements for the 150 gpcpd option and ICAP (Infiltration/Inflow Corrective Action Program) option agencies.

Corrective measures for the reduction of infiltration and inflow are discussed in Chapter 6 of this manual.

Chapter 11 and Appendix D should be referred to for suggested scheduling of periodic flow metering.

WASTEWATER FLOW COMPONENTS

It is essential to know how to interpret the flow data to determine if an infiltration and/or inflow problem exists. If the flow data does indicate that excessive volumes of infiltration and inflow enter the sanitary sewer system, knowing how to separate the various components of flow will enable a community to determine which areas will require detailed system investigations and the types of investigations which should be conducted in order to find the clearwater sources.

The wastewater flowrate measured at any one time may include one or more of the possible components of wastewater flow. The components of wastewater flow can be divided into base sewage flow, infiltration, rainfall induced infiltration, and inflow.

Base Sewage Flow

The base sewage flow component in a wastewater stream consists of contributions from the residential, commercial, and industrial water users connected to the sanitary sewer system. The base sewage flow in a system is directly proportional to the sum of the water meter readings of all the customers in a community. If water meter readings are used to estimate base sewage flow, a sewage return factor must be applied to the water meter readings to account for water used for landscape irrigation, street washing, car washing, and extinguishing fires; product water used by commercial and manufacturing establishments; and water used by consumers whose facilities are not connected to sewers. For a community that does not have any industry or industrial water consumers, the base sewage flows can be roughly approximated by using winter water meter readings.

Base sewage flows tend to fluctuate on a daily, weekly, and seasonal basis. The daily flow pattern in a residential area tends to be a minimum during the early morning hours when water use is lowest. The peak base sewage flow normally occurs in the late morning. A second peak smaller than the morning peak normally occurs in the early evening hours.

Weekly flow variations may exist in a residential area if a majority of water users do laundry on specific days of the week. Communities with large commercial or industrial bases may also see variations in base flow depending on the day of the week due to cyclical production practices.

Seasonal variations tend to occur in communities with resort areas, in communities with college campuses, and in communities with commercial and industrial customers which operate differently at different times of the year.

Infiltration

The infiltration component in a wastewater stream consists of water entering the sewer system from the ground through defective service lines and connections, defective pipes, defective joints, defective pipe connections at manholes and other appurtenances, and defective manhole walls.

Most sanitary sewer systems experience some degree of infiltration. The infiltration component of flow will vary seasonally depending on the level of the groundwater. In the Cook County area of Illinois groundwater peaks normally occur in the spring and fall of the year.

Infiltration can be estimated by analyzing flow data during dry weather periods in the early morning hours when base sewage flows are at a minimum. During these conditions, infiltration will make up the majority of flow being measured. Caution must be practiced in communities with large industrial customers who may perform cleanup operations during the early morning hours increasing the base sewage flow component of the total flow measured.

It should be noted that when estimating the infiltration component of a wastewater flow, it may include inflow sources such as cooling-water discharges, and drainage from springs or swampy areas which continually enter the sanitary sewer system independent of rainfall.

Rainfall Induced Infiltration

Rainfall induced infiltration enters the sanitary sewer system through the same types of defects as infiltration. However, rainfall induced infiltration is dependent on rainfall which percolates through the ground. On a graph where sewer flows are plotted against time, rainfall induced infiltration will appear as a steady but gradual increase in flow above the base sewage and infiltration components occurring shortly after a significant rainfall event begins. However, rainfall induced infiltration cannot be determined until after a rainstorm has ended because the increase in flow may also include stormwater inflow. After a rainstorm ends, the inflow component becomes negligible within a couple of hours depending on the size of the wastewater collection system. Once the inflow component becomes negligible, rainfall induced infiltration can be estimated by subtracting off the base sewage and infiltration components. Rainfall induced infiltration may continue to enter the sanitary sewer system for several days after a rainstorm event has ended.

It should be noted that if foundation drainage is discharged directly to the sanitary sewer system it is considered an inflow component. However, since foundation drains will capture rainwater as it percolates through the soil in the same manner as rainfall induced infiltration enters through sewer system defects, it is impossible to separate inflow contributed by foundation drains from rainfall induced infiltration while reviewing sewer system flow data.

Inflow

Inflow sources can be placed into two categories. The first category would include inflow which enters the sanitary sewer system from foundation drains, cooling-water discharges, and drains from springs or swampy areas. These sources of inflow contribute a relatively steady amount of clearwater to the sanitary sewer system and usually cannot be identified separately from infiltration and rainfall induced infiltration. The second category consists of inflow entering the sanitary sewer system as a result of stormwater runoff which causes an almost immediate increase in the sanitary sewer flows. Types of defects which contribute to inflow causing immediate increases in sanitary sewer flows include downspouts, yard drains, area drains, cross connections from storm sewers and catchbasins, manhole covers, and poorly sealed manhole frames.

The inflow component of wet weather wastewater flows can be estimated by subtracting base sewage flow, infiltration, and rainfall induced infiltration from the total wastewater flow.

Figure 3-1 shows an example of a typical sewer system hydrograph for a system which is subject to all four types of wastewater flow components. The determination of infiltration/inflow components is provided in detail in the following reference handbook:

> Handbook for Sewer System Evaluation and Rehabilitation, U.S. Environmental Protection Agency, EPA 430/9-75-021, Washington, D.C., December 1975.

FLOW MEASUREMENT PLANNING

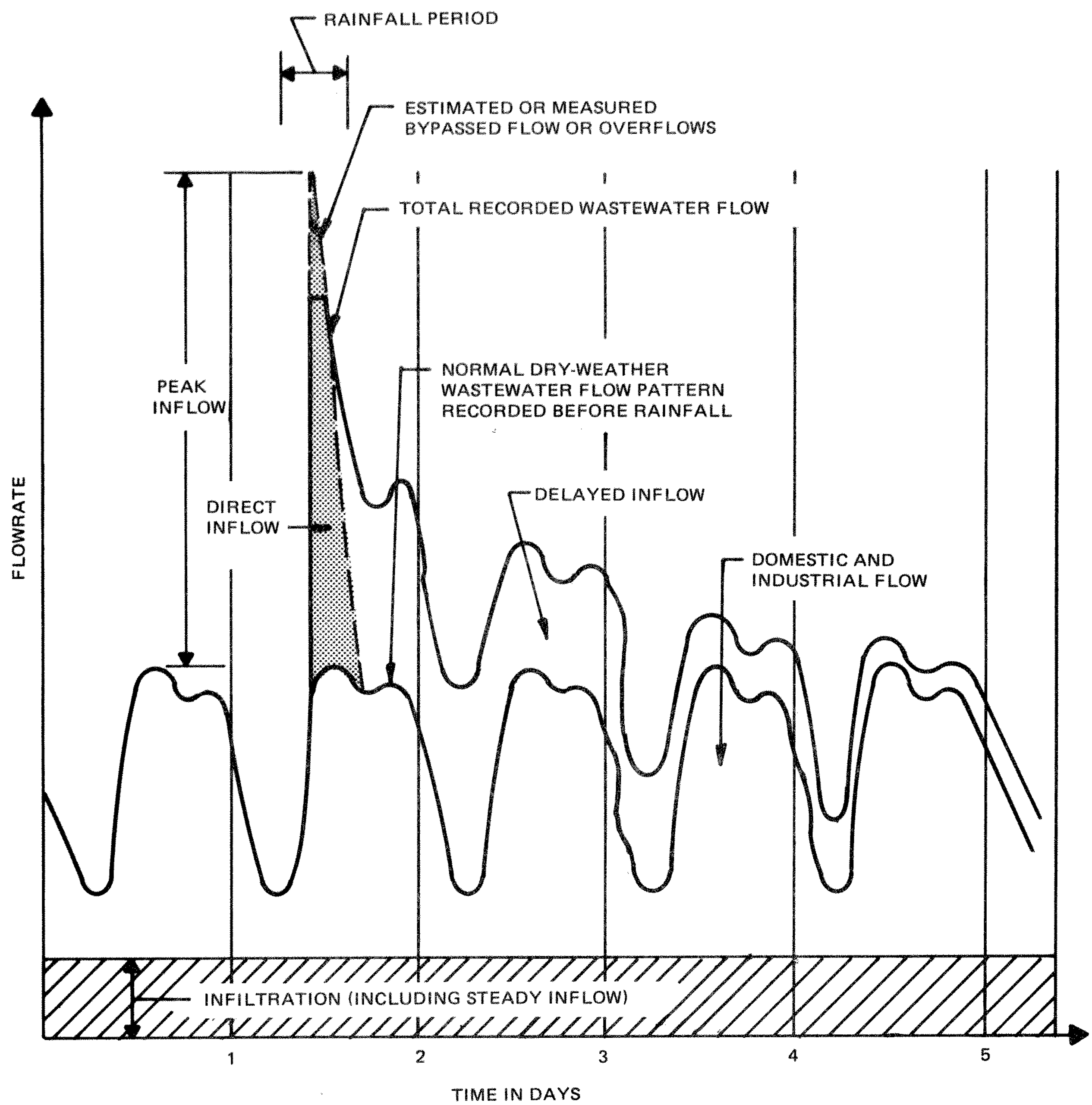
Proper planning is essential to efficiently obtain sufficient flow data for an infiltration/inflow analysis. It is essential to have up-to-date sewer maps of the study area before starting any flow monitoring program. Some valuable information may also be obtained from the United States Geological Survey topographic maps; state agencies such as a department of natural resources, geologic survey, and health department; regional planning organizations; county governments, and utility companies. A review of these data before or very early in the study will be a valuable orientation to the area and may indicate potential trouble spots.

By spending some time setting up a logical flow monitoring program, time and money can be saved when conducting the actual flow monitoring program. The following sections identify some of the more important aspects that should be considered when planning a flow metering program.

Review of Existing Records

The review of existing records can help isolate areas in the system subject to deterioration, structural failure, and excessive infiltration/inflow. Some basic information that the existing records should be reviewed for include:

1. Sewer sizes.
2. Type of pipe material.
3. Depth of sewer mains.
4. Age of sewers.
5. Type of construction of pipe joints and manholes.
6. Location of lift stations.
7. Location of utilities, particularly storm sewers and water mains.



REFERENCE: FROM METCALF & EDDY, INC., WASTEWATER ENGINEERING: COLLECTION AND PUMPING OF WASTEWATER, McGRAW-HILL, 1981.

FIGURE 3-1. GRAPHIC IDENTIFICATION OF INFILTRATION/INFLOW

8. Identification of soil types by area including:

    a. Soil classification; clay, sand, peat, silt, etc.

    b. Structural support characteristics.

    c. Soil corrosivity.

9. Past system flow studies.

10. Bypass and overflow data including locations and frequency of discharge.

11. Areas of known problems; i.e. overflows, frequency of discharge, customer complaints, root problem areas, areas frequently repaired in the past, etc.

12. Areas with past record of illegal private sector connections.

13. Water usage data for residential, commercial, and industrial customers.

14. Population equivalent trends since the last flow monitoring program.

Selection of Suitable Flow Monitoring Period

The flow monitoring period selected depends on the type of flow analysis being conducted. The various components of a wastewater flow stream can be isolated by conducting metering at different times of the year.

Infiltration Analysis. The flow monitoring period suitable for determining infiltration will depend on whether a peak infiltration rate or the average annual infiltration rate is required. For the determination of peak infiltration, flows should be measured during the highest groundwater period of the year. In the Cook County area of Illinois, groundwater levels are normally elevated during the spring and fall months of the year. In general terms, dates between April 15 and June 30 and September 1 and November 15 could be used to determine peak infiltration rates. However, actual groundwater conditions should be verified during the metering program since annual variations in the quantity and monthly distribution of precipitation can be highly variable.

For the determination of average annual infiltration, flows need to be measured during periods typical of other groundwater conditions so that a range of infiltration rates can be averaged. Measurements during minimum groundwater level conditions may also be used to verify the base sewage flow component of the wastewater stream.

The following should be considered when planning and performing an infiltration analysis:

1. Continuous flow measurements throughout a high groundwater period are desirable. However, instantaneous measurements may be sufficient since the groundwater level is normally stable over a period of several days.

2. The measurements should be taken during non-rainfall days preferably 24 hours after a rainfall in order to minimize the direct influence of rainfall.

3. To minimize the interferences caused by domestic, commercial, and industrial flows, measurements should be made between midnight and six a.m. It

should be noted that the industrial component of base sewage flow may still be partially present during these hours.

4. Repeated flow measurements should be taken on at least three consecutive nonrainfall days for each typical groundwater condition.

5. To avoid surge flows, all pumps in the sewer system should be temporarily shut down during instantaneous flow measurements.

Inflow Analysis. For direct stormwater runoff related inflow measurement, system flows should be monitored continuously throughout each rainfall event. To increase the probability of capturing a significant rainfall event, flow monitoring for isolating inflow should be conducted during heavy rainfall seasons. In the Chicagoland area, the heaviest rainfall seasons normally are spring and fall.

Since the quantity of inflow is dependent on a number of variables, it is desirable to capture several significant rainstorms during the flow monitoring period. A significant rainfall event would be one approximately equal to or greater than 1 inch of rain in a 24 hour period. The variables which can affect the quantity of inflow measured include but are not limited to:

1. Soil moisture conditions. The soil moisture conditions at the time of a rainstorm will affect the quantity of stormwater runoff and inflow. Saturated soil conditions will allow a greater percentage of the rainfall to runoff and possibly become inflow into the sanitary sewer system.

2. Rainfall intensity. Greater intensity rainstorms generally produce more runoff and therefore increase the inflow potential when compared to less intense rainstorms. Rainfall intensity is particularly important when calculating peak sewer flows. Peak sewer flows are affected most by relatively short intense storms.

3. Rainfall volume. Rainfall volume is the product of rainfall intensity and rainfall duration. Average daily inflow amounts are generally proportional to rainfall volume. However, it should be noted that peak inflow rates can vary significantly for a given rainfall volume. For example, a 1 inch storm occurring in a 30 minute period would cause a higher peak inflow rate than a 1 inch storm occurring in a 24 hour period. Even though the peak inflows are significantly different, the 24 hour average inflow for both storms could be approximately the same.

Because inflow rates are a function of highly variable soil conditions and rainfall characteristics it is important to note for each inflow measurement taken what the specific soil conditions and rainfall characteristics were to cause the inflow measured.

When planning a flow monitoring program for the purpose of isolating inflow, it is essential to install a continuously recording rain gage within the boundaries of the study area so that the measured flows can be compared to the beginning and end of each rainfall event.

Subsystem Identification

In many communities/agencies it is possible to measure the majority of the sewer system flow at one location. An analysis of the sewer flows at one location will indicate whether or not the community/agency has an excessive infiltration/inflow problem. However, if an infiltration/inflow problem is observed, flow data from a single location measuring flows for the majority of the sewer system will not indicate in which areas investigations should be concentrated to find the sources of excessive infiltration/inflow. Therefore it is common to divide a sewer system into a number of subsystems that can be monitored for flow separately.

The number of subsystems identified for separate flow monitoring will vary depending on the size, configuration, and physical characteristics of each sewer system. A sewer system can be divided into subsystems using any one or more of the following guidelines:

1. Drainage areas. A sewer system can be separated into subsections based on the system configuration. The system configuration may result in sewer flows converging at a point downstream of one drainage area before mixing with flows from another drainage area. Each sewer system may consist of several drainage areas. The sewers within each drainage area would be considered a subsystem and could be monitored separately for flow.

   For a community/agency with several connection points to a MSDGC interceptor, the group of sewers upstream of each connection point could be considered a separate subsystem. Large areas upstream of one particular MSDGC connection point could be further divided into subsystems by drainage area.

2. Sewer age and construction type. Many sewer systems have increased in size over time to keep up with a community/agency's growth. As a result, different areas in the sewer system may have been constructed at different times with different types of pipe material, joint construction, and manhole construction. Since infiltration/inflow problems may vary with age and construction type, a sewer system can be divided into subsystems based on age or construction type. It should also be noted that a new subsection constructed poorly may contribute more infiltration/inflow than an older subsection. For this reason, newly constructed subsystems should not be omitted from a flow monitoring program.

3. Groundwater and soil types. In some of the larger communities/agencies, groundwater levels and soil types may vary in different areas of the system. Groundwater levels in some areas may normally be above the sewer mains either because of naturally high groundwater levels or because the sewer system is quite deep in an area of the system. Groundwater levels would be naturally high in the vicinity of any natural surface water. Since different groundwater conditions can affect the amount of infiltration entering a sewer system, the system can be divided into subsystems using groundwater conditions as the criteria.

   Different soil conditions in a study area may warrant dividing the system into subsystems by soil type. Different soil types can cause varying degrees of infiltration and rainfall induced infiltration. Soil parameters that may be considered for determining subsystems are soil class, soil permeability, corrosiveness, and soil strength.

4. Problem areas. Another criteria that could be used for dividing a sewer system into subsystems would be by isolating problem areas. If certain areas have a history of private sector illegal connections to the sanitary sewer

system these areas can be grouped into subsystems and monitored for flow to determine if illegal connections have been reconnected to the sewer system. Areas reporting basement flooding and system overflows during rainfall events also may be grouped together and monitored separately from the rest of the system.

Selection of Key Manholes

Before a flow monitoring program can be started, the locations for installing the flow metering equipment must be identified. Initially, key manholes can be selected by reviewing the sewer system configuration on the sewer maps. Key manholes are initially selected based on the criteria previously used to divide the sewer system into subsystems. The manholes selected for measuring flow should be along straight sections of pipe with constant slopes both upstream and downstream and should be far enough away from lift stations so that the flow measurements will not be affected by the lift station operation.

After key manholes have been selected on the sewer maps and before initiating the flow monitoring program, the manholes should be inspected in the field for flow metering suitability. The field inspections should include or identify the following items:

1. Verify that the key manhole selected on the sewer map can be located in the field.

2. Take necessary safety precautions before entering the manhole.

WARNING: MANHOLES ARE CONFINED SPACES AND MAY HAVE DANGEROUS ATMOSPHERES. FOLLOW PROPER SAFETY PRECAUTIONS OUTLINED IN CHAPTER 9 WHEN WORKING NEAR AND BEFORE EVER ENTERING A MANHOLE.

3. Make sure the manhole is not subject to frequent surcharging.

4. The manhole should be relatively dry.

5. The size of the manhole opening and inside diameter must be large enough for safe entry and workability inside the manhole.

6. The manhole depth.

7. The stability of the manhole structure.

8. The condition of the manhole steps, or note if the manhole does not have steps.

9. Verify that the flow conditions in the manhole are suited to the type of flow metering equipment being used.

10. The amount of debris that has accumulated in the manhole.

11. Verify that the number of pipe connections in the manhole is consistent with what is shown on the sewer map.

12. Verify that the manhole is suitable for installing the flow monitoring equipment.

13. Study the traffic conditions around the manhole to determine if the monitoring program will affect traffic or if the traffic will pose a serious threat to the personnel conducting the monitoring program.

14. Make an assessment of the possibility of vandalism at the key manholes selected.

If the field inspection indicates that a manhole selected during a sewer map analysis is not suitable for flow monitoring purposes, another more suitable manhole should be selected.

Selection of Flow Monitoring Equipment

When planning a flow monitoring program, the type of flow monitoring equipment used must be determined. There are many types of flow monitoring devices on the market. When selecting flow monitoring equipment it is important to select equipment that will meet the goals of the monitoring program. The following items should be considered when selecting the type of equipment:

1. Ease of installation.
2. Maintenance requirements.
3. Calibration requirements.
4. Accuracy
5. Reliability
6. Expected flow range.
7. Potential for measuring flow during surcharged conditions.
8. Type of monitoring program.
    a. Quick flow measurement checks (instantaneous).
    b. Continuous flow monitoring program.
9. Ease of calculating flow from the data presented.
10. Total manpower requirements for:
    a. Maintaining equipment.
    b. Calibrating equipment.
    c. Analyzing data.
11. Cost.

Agencies electing to monitor flow in a percentage of their sewer system each year on a rotating basis may benefit the most by purchasing and operating their own equipment. Other agencies may find that it is more economical to either rent flow metering equipment or contract out the flow metering work. Agencies that would benefit most by renting equipment or contracting out the flow metering work are smaller agencies that could economically monitor their entire sewer system at the same time.

The different types of metering equipment currently available for measuring sewer system flows are presented in another section of this chapter.

Rain Gages

When planning a flow monitoring program, it is important to make sure the necessary steps have been taken for obtaining accurate rainfall data. Since rainfall amounts and intensities can vary from community to community, it is desirable to collect rainfall data within the area being monitored for flow. Therefore before a flow monitoring program begins, a rain gage needs to be obtained and a location selected for installation.

The type of rain gage selected needs to be one that continuously measures and records rainfall amounts at intervals no longer than once per hour. For the most accurate sanitary sewer flow analysis, rainfall amounts should be recorded every 15 minutes or less. If infiltration/inflow is present in a sanitary sewer system, the immediate sewer flow response to a rainfall event is important to know when estimating the various components of flow.

The basic types of rain gages available include:

1. Tipping bucket.
2. Weigh and record.
3. Calibrated tubes.

Since the tipping bucket and the weigh and record type rain gages are suited for continuous recordings, these types are the most useful in a flow monitoring program. There are a variety of calibrated tube-type rain gages which are designed for manual reading. These types of gages can be used before a monitoring program begins to roughly estimate soil moisture conditions and groundwater levels.

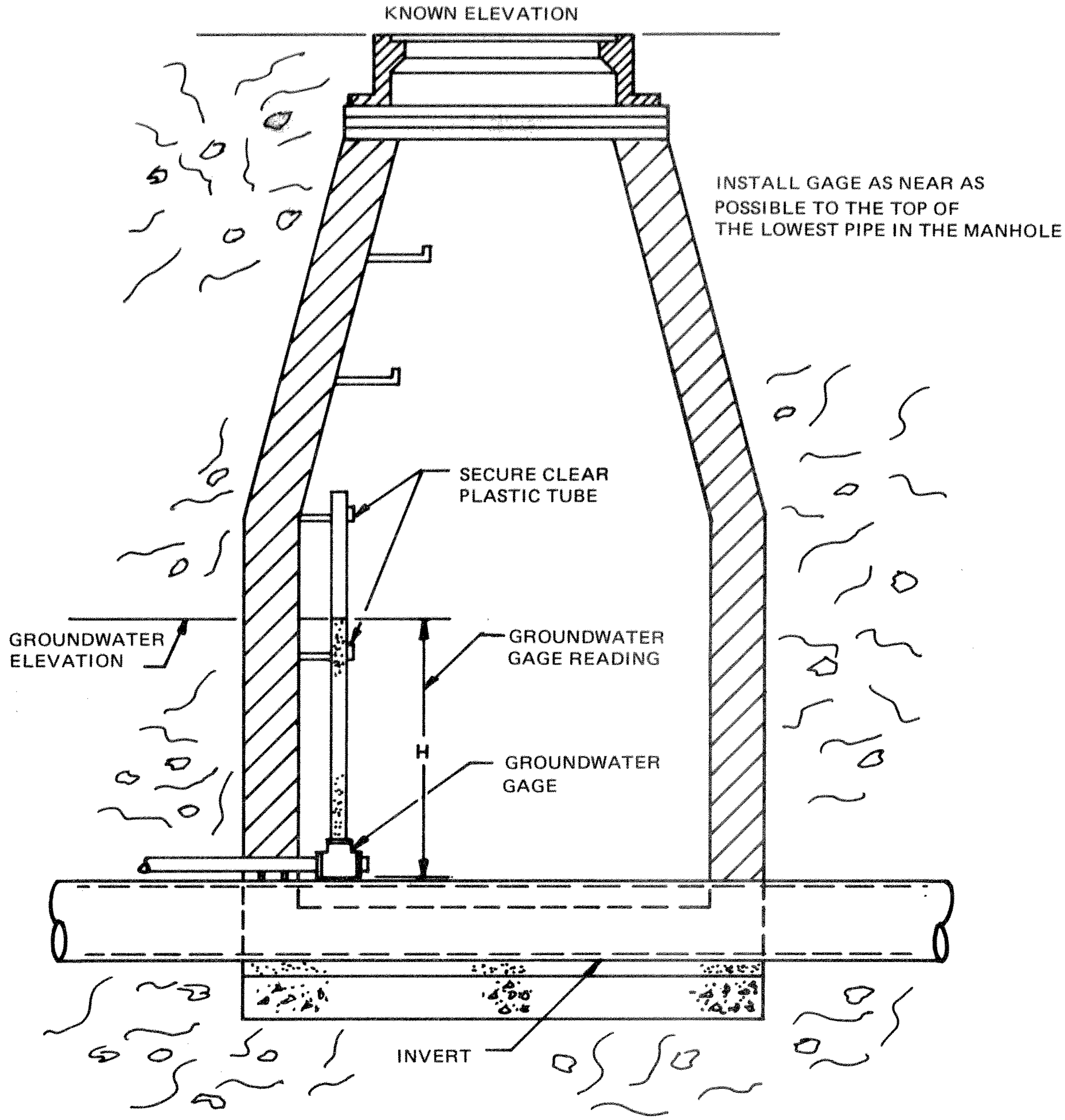
Groundwater Monitoring

A knowledge of the groundwater elevation during a flow monitoring program is important since infiltration is directly related to groundwater levels relative to the sewer system depth.

Groundwater monitors can be installed on a permanent basis so that the data provided by them can be used to plan isolation flow gauging and internal TV inspections. Both isolation flow gauging and internal TV inspections should be conducted when the groundwater levels are higher than normal.

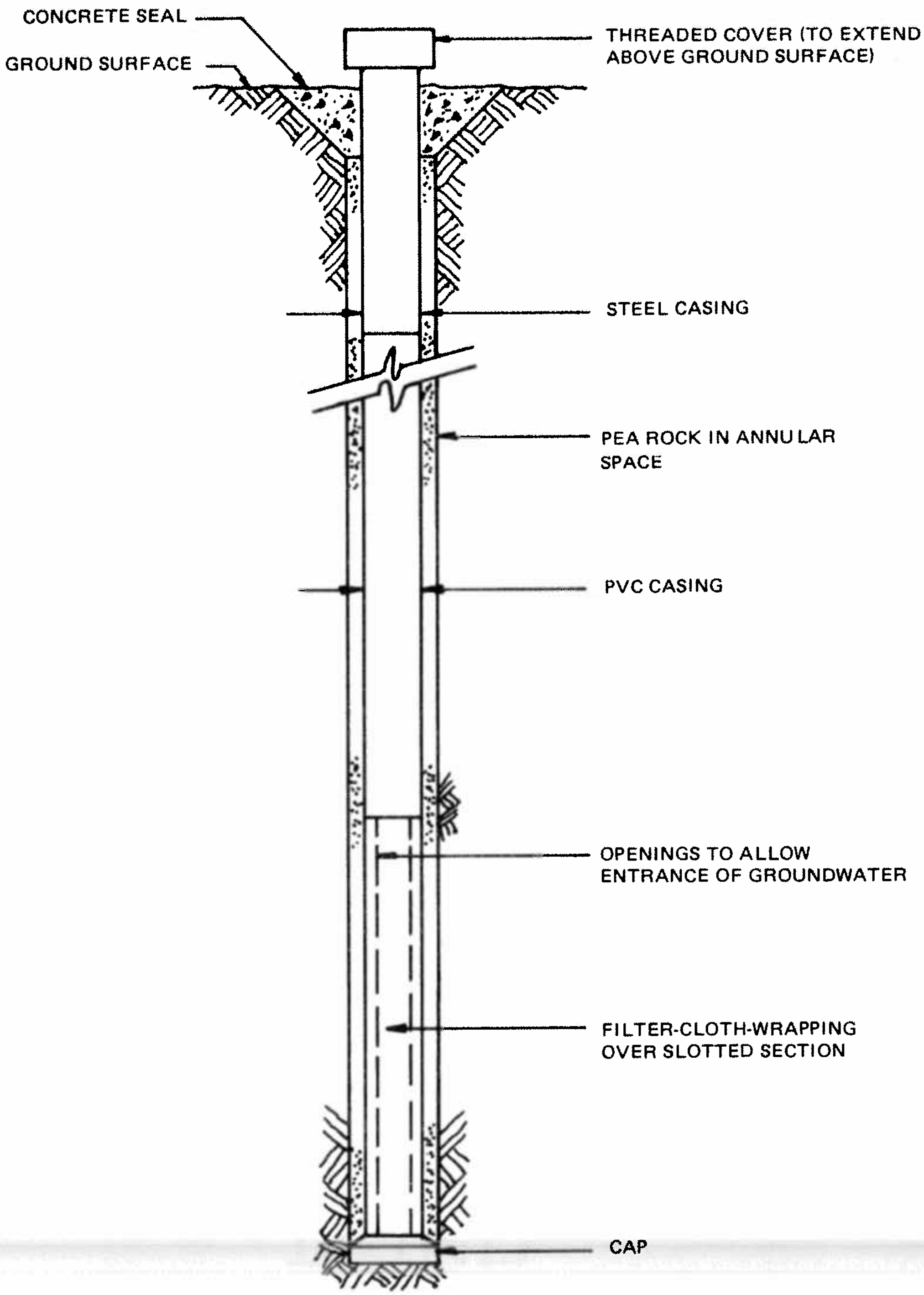
There are two common types of groundwater monitors for measuring groundwater levels. Figure 3-2 shows a groundwater monitor installed inside a manhole. This type of monitor measures the groundwater level next to the manhole. The manhole gage is inexpensive and easy to install but they do commonly clog. Therefore, they need to be cleaned or replaced periodically.

The second type of groundwater monitor commonly used is a piezometer type shown in Figure 3-3. These monitors are more permanent than the manhole gages and are installed using an auger. They are also more expensive than the manhole gages but less likely to



REFERENCE: FROM EXISTING SEWER EVALUATION AND REHABILITATION, ASCE-MANUALS AND REPORTS ON ENGINEERING PRACTICE NO. 62 AND WPCF MANUAL OF PRACTICE NO. FD-6. 1983

FIGURE 3-2. STATIC GROUNDWATER GAGE INSTALLATION ELEVATION



REFERENCE: FROM EXISTING SEWER EVALUATION AND REHABILITATION, ASCE-MANUALS AND REPORTS ON ENGINEERING PRACTICE NO. 62 AND WPCF MANUAL OF PRACTICE NO. FD-6. 1983

FIGURE 3-3. GROUNDWATER GAGE INSTALLATION DETAIL

clog. They should be installed in areas where they will not be damaged by roadwork, landscaping operations, or vandalism and where their installation will not damage other buried utilities.

FLOW MEASUREMENT TECHNIQUES

Monitoring flows within a wastewater collection system is important. The resulting data form the basis for determining user costs, volume of rainwater or groundwater entering the system, existing line capacity, treatment plant operations, effectiveness of a rehabilitation program, and future design needs. It is therefore necessary to use a sound approach and good measurement techniques to ensure reasonable flow monitoring results. Flow measurements may be taken at several locations, one of which is at a key manhole, as previously described. Flow measurements may also be obtained at treatment plants, pumping stations, known infiltration or inflow sources, industrial waste sources, and overflows and bypasses.

There are a variety of methods and equipment available for measuring flow in sewers. The selection of the proper method or equipment depends on the cost, source to be measured, accessibility, available manpower, degree of precision, and type of data required. Several of the most common techniques are presented below with their advantages, limitations, and equipment requirements.

<u>Manual Flow Measurements</u>

Manual flow metering equipment is only useful for obtaining instantaneous flow measurements. Their usefulness in a flow monitoring program is therefore limited to spot checks. Spot checks are a quick and easy way to determine if a subbasin is contributing excessive inflow or infiltration to the system.

<u>Weirs.</u> Weir measurements are made by observing the water level above the crest of the weir and converting this measurement to a flow with the use of calculations, nomographs, or tables.

<u>Types of Weirs</u>:

1. Triangular or V-notch.
    a. Designed to measure small flows (0-3 cfs).
    b. Ideal for small diameter sewer pipe flow measurement.
2. Rectangular - Suppressed.
    a. Crest is same width as channel.
    b. Not designed for pipe flow measurement.
    c. Designed for rectangular channel measurement.
    d. Designed to measure large flows.

   e. Complex discharge equation.

3. Rectangular - Contracted.

   a. Weir crest is fitted with end contractions.

   b. Designed for rectangular channel or pipe flow measurement.

   c. Designed to measure large flows.

   d. Complex discharge equation.

4. Trapezoidal or Cipolletti.

   a. Similar to contracted rectangular weir.

   b. Trapezoidal shape simplifies discharge equation.

5. Compound weir.

   a. Two weirs, usually a V-notch and a rectangular are used in conjunction.

   b. Designed for pipe flows which are normally low, but occasionally increase substantially.

   c. Measurements made at the transition zone between the two weir types may not be accurate.

<u>Maintenance</u>:

1. Minimal amount of maintenance required.

2. Sewer should be clean prior to weir installation.

3. A check for debris buildup at the base of the weir and on the weir crest should be made prior to each weir reading.

<u>Advantages</u>:

1. Inexpensive.

2. Easy installation.

3. Quick, accurate results.

4. Knowledge of the sewers physical parameters not required.

<u>Disadvantages</u>:

1. Accuracy affected by approach velocity.

2. Accuracy affected by debris accumulation upstream of the weir.

3. Accuracy affected by turbulent flow.

4. Fairly high head loss, which could cause sewers to surcharge.

5. Results not accurate during surcharged conditions.

6. Must enter manhole to take readings and to install.

Flumes. A flume is a device which acts as a restriction in a pipe or channel. The flume creates critical flow in its throat. The depth of flow above the flume throat can be converted into a flow by the use of calculations, nomographs, or tables.

Types of Flumes:

1. Parshall.

   a. Designed for permanent installation in rectangular channels.

   b. Requires a minimum head-loss of three inches which could cause sewers to surcharge.

   c. Not practical for sewer pipe flow measurements.

2. Palmer-Bowlus.

   a. Designed for installation in round bottom channels or pipes.

   b. Easy to install.

   c. Portable.

   d. Small head-loss requirements.

3. H-Flume.

   a. Designed to measure a large range of flows.

   b. Best suited for stormwater or combined sewer flow measurements.

   c. Large head-loss is required to measure flow.

4. Trapezoidal.

   a. Designed for a rectangular channel.

   b. Measures small flows only.

   c. Small head-loss is required to measure flow.

Maintenance:

1. Before taking depth readings, the flume should be checked for silt deposits and cleaned if necessary.

Advantages of Flumes Suited for Sewer Pipe Flow Measurements:

1. Self-cleaning.

2. Easy to install.

3. Portable.

4. Small head-loss required to measure flow.

5. Quick, accurate results.

6. Knowledge of the sewer's physical parameters not required.

Disadvantages of Flumes Suited for Sewer Pipe Flow Measurements:

1. Results not valid during surcharging.

2. Flow must be laminar at the entrance to the flume. Therefore manholes with converging flows or bends are not suitable for flume readings.

3. Must enter the manhole to take readings and to install.

Dye-dilution. This manual metering technique consists of feeding fluorescent dye at a constant rate to an upstream manhole. Samples are collected at a downstream manhole and analyzed for dye concentration. Flow can then be calculated by knowing the concentration of the dye in the sample.

Equipment:

1. Solution feeder.

2. Glass containers for samples.

3. Sampler.

4. Dye/tracer analyzer (fluorometer).

5. Some commonly used fluorescent dyes: Rhodamine WT, Fluorescein, and Uranine.

Maintenance:

1. Solution feeder battery will need to be changed every other week.

2. Fluorometer battery will need to be changed every 2 days.

Advantages:

1. Manhole entry not required.

2. Accurate for surcharged sewers.

3. Simple.

4. Quick.

5. Knowledge of the sewer's physical parameters is not required.

Disadvantages:

1. Expensive equipment costs.

2. Temperature and sunlight can affect results of sample analysis.

3. Labor intensive.

Dip Stick. Flow depth measurements are taken with a dip stick, yard stick, or similar measuring device and flows are then calculated using the Manning equation.

Equipment:

1. Measuring stick.

Maintenance:

1. None.

Advantages:

1. Manhole entry not required.

2. Easy.

3. Inexpensive.

Disadvantages:

1. Not accurate for most sewers. The following conditions must exist in order to accurately apply the Manning equation:

   a. The pipe upstream of the flow measuring point should be straight for a minimum of 200 feet.

   b. The channel in the manhole must approximate the shape of a round pipe.

   c. The inverts of the influent and effluent pipes of a manhole must be the same.

   d. Flow through a manhole must be a single stream and travel straight through.

   e. There must not be any downstream blockages.

2. The Manning roughness coefficient should be determined in the field for best results.

Manual Pressure Meter. The Manual Pressure Meter measures the head on a V-notch weir by sensing the pressure differential between the liquid and the atmosphere. Pressure is read from a manometer and converted directly to a flow using calibrated metering sticks.

Installation:

The metering insert is placed in the pipe from outside of the manhole with the use of up to sixteen feet of interlocking aluminum pole. The metering insert is stabilized in the pipe with an inflatable rubber collar.

Maintenance:

1. Metering inserts need to be cleaned after use.

2. Manometer must be filled and emptied with water before and after use, respectively.

Advantages:

1. Manhole entry not required.

2. Since manhole entry is not required, one person can make the measurements.

Disadvantages:

1. Can only be used in 6, 8, 10 and 12 inch diameter pipes.

2. Cannot be used in manholes which are deeper than 16 feet.

Continuous Flow Measurements

There are two types of continuous flow meters; depth recorders and depth/velocity meters. Depth recorders are automatic metering devices which continuously record the depth of flow in a pipe, the head over a weir, or the depth in the throat of a flume. Depth measurements are recorded on circular charts, strip charts, or electronic memory. It is strongly recommended that a primary device (weir or flume) be used in conjunction with a depth recorder. The primary device simplifies calculations and increases accuracy.

Depth/velocity meters do not require a primary device. Flow information is stored on electronic memory or can be sent to a central computer through telephone lines. These meters are the most accurate because flow is calculated directly from the velocity and depth measurements.

Depth Recording Meter - Probe. This meter continuously records water level in a pipe, the head over a weir, or depth in the throat of a flume. Depth measurements are recorded when a battery operated electrical probe makes contact with the water surface. This contact completes an electrical circuit which causes the chart pen arm to record the reading. The probe then retracts slightly from the water surface and will repeatedly seek the water surface every few seconds.

Installation/Calibration:

For best results, installation should include a stilling well and primary measuring device. The meter can be mounted in the manhole with a bracket. The probe hangs down to the stilling well water surface. Calibration is accomplished by manually reading the head on the weir and adjusting the pen arm to correspond to the manually observed flow height. Depth recordings can be easily converted to flows using published flow charts for the primary device used.

An alternate installation, which is not recommended, consists of mounting the probe in the manhole with no primary device. Depth of flow in the pipe is then measured directly. The Manning equation is then used to convert depth measurements to flow. Accuracy of this method is dependent on the parameters used in the Manning equation. For most sewer systems the Manning equation does not yield accurate results unless detailed field investigations are done prior to flow metering to accurately determine the parameters. Calibration is accomplished by measuring depth in the pipe with a dip-stick and adjusting the pen arm to correspond to the observed flow height.

Maintenance:

1. Battery must be re-charged weekly.
2. Spring clock must be wound weekly.
3. Recording pen should be changed every 50 charts or as needed.
4. Recording charts should be changed daily or weekly.
5. Meter should be checked after a significant rain event.
6. Probe should be checked weekly for proper operation and debris.
7. Recorder calibration should be checked weekly.
8. The primary measuring device should be checked weekly for debris.

Advantages:

1. Easy to install, manhole entry not required.
2. Debris is not likely to attach itself to the probe due to the dipping action.
3. Versatile installation.
4. Easy to understand and troubleshoot.

Disadvantages:

1. Turbulence affects accuracy.
2. Foaming affects accuracy.
3. Cannot be used to measure flow during surcharged conditions.

Depth Recording Meter - Float. This meter records water level with a float which continuously rides on the water surface. A mechanical pen arm is connected to the float and records water depth.

Installation/Calibration:

For best results installation should include a stilling well and a weir as the primary measuring device. The recorder can be mounted in the manhole with a bracket. The float sits in the stilling well and measures the water surface. Calibration is by measuring the head on the weir and adjusting the pen arm on the recorder accordingly.

Installation can also be with a scow float. A scow float is anchored to the side of the manhole to keep the float from drifting. Depth of flow in the pipe is measured directly since no primary device is used. The Manning equation is then used to convert depth measurements to flows. Accuracy of this method is dependent on the parameters used in the Manning equation. For most sewer systems, the Manning equation does not yield accurate results unless detailed field investigations are done prior to flow metering to accurately determine the parameters. Dip-stick readings are used for calibration.

Maintenance:

1. Battery must be re-charged weekly.
2. Spring clock must be wound weekly.
3. Recording pen should be changed every 50 charts or as needed.
4. Recording charts should be changed daily or weekly.
5. Meter should be checked after a significant rain event.
6. At a minimum, the float should be checked weekly for debris.
7. Recorder calibration should be checked weekly.
8. The primary measuring device should be checked weekly for debris.

Advantages:

1. Easy to install.
2. Versatile installation.
3. Easy to understand and troubleshoot.

Disadvantages:

1. Stilling-well installation requires manhole entry.
2. Floating debris affects accuracy.

3. Turbulence affects accuracy.

4. Debris is likely to attach to the float.

5. Cannot be used to measure flow during surcharged conditions.

Depth Recording Meter - Bubbler. This meter measures actual water depth by sensing the pressure differential between the bottom of the pipe and atmospheric pressure. This pressure differential is converted to a depth reading. A bubbler tube is placed on the bottom of the pipe and a constant bubble rate is supplied by air tanks or air compressors. The pressure required to maintain the bubble rate is measured, and this is proportional to the depth of flow which is recorded on a strip chart.

Installation/Calibration:

The meter is installed with a primary device. The bubbler is mounted on the bottom of the pipe with the use of a collar. The meter is hung from the manhole steps with a harness. Calibration is accomplished by manually reading the primary device and adjusting the pen arm to record the observed height.

Maintenance:

1. Battery must be re-charged weekly.
2. Spring clock must be wound weekly.
3. Recording pen should be changed every 50 charts or as needed.
4. Recording charts should be changed weekly or after a significant rain event.
5. Meter should be checked after a significant rain event.
6. Bubbler should be checked weekly for clogging or debris.
7. Recorder calibration should be checked weekly.
8. The primary measuring device should be checked weekly for debris.
9. Air tanks should be replaced when empty.
10. Air compressors should be maintained in accordance with the manufacturer's recommendations.

Advantages:

1. Accuracy is not affected by floating debris, foam, turbulence, temperature or velocity.

Disadvantages:

1. Manhole entry required for installation.
2. Bubbler may become clogged if flow contains large amounts of suspended solids or grease.

3. Cannot be used to measure flow during surcharged conditions.

Depth Recording Meter - Pressure Sensor. This meter measures the pressure of the liquid directly and converts this pressure reading to a flow depth. Readings are recorded on a strip chart or on electronic memory. Data stored on memory can be retrieved with a lap top computer, magnetic tape, or telephone modem.

Installation/Calibration:

The sensor can be mounted on the bottom of the pipe with a collar or can be snapped onto specially designed flumes. Strip chart and electronic memory calibration are completed at the manufacturer's factory. Calibration checks can be made in the field by measuring the depth of flow in the primary device and comparing that reading to the strip chart position or the flow rate on the liquid crystal display if storage is on electronic memory.

Maintenance:

1. Battery needs to be charged every 6 months.
2. Strip charts must be changed every 20 days or more frequently if desired.
3. Data stored on electronic memory should be retrieved every 6 weeks, or more frequently if desired.
4. Meter should be checked after a significant rain event.
5. Sensor should be checked weekly for debris.
6. Calibration should be checked weekly.
7. The primary device should be checked weekly for debris.

Advantages:

1. No moving parts.
2. Floating debris does not affect accuracy.

Disadvantages:

1. Manhole entry required for installation.
2. More difficult to evaluate operational problems due to the electronic components.
3. Temperature affects accuracy.
4. Turbulence affects accuracy.
5. Cannot be used to measure flow during surcharged conditions.

Depth Recording Meter - Ultrasonic. This meter records the amount of time it takes for an echo to reflect off the water surface and return to the sensor. This time increment is then converted to a flow depth and recorded on electronic memory or on a strip chart. Data stored on memory can be retrieved using a lap top computer, magnetic tape, or telephone modem.

Installation/Calibration:

The sensor is installed in the crown of the pipe with the use of a collar. A primary device should be used and a stilling well is recommended because turbulence will affect the readings. The computer chip which converts the time interval to a flow depth is calibrated at the manufacturer's factory. Chips are programmed for a primary device or can be programmed for a pipe diameter. If a chip is programmed for a pipe diameter, a new chip will need to be purchased if the meter is to be installed into a different diameter pipe.

Maintenance:

1. Battery needs to be changed every 6 months.

2. Strip charts must be changed monthly, or more frequently if desired.

3. Data stored on electronic memory should be retrieved every 6 weeks, or more frequently if desired.

4. Meter should be checked after a significant rain event.

5. Calibration should be checked weekly.

6. The primary measuring device should be checked weekly for debris.

Advantages:

1. Very low maintenance.

2. Automatically compensates for temperature (temperature affects the speed at which sound moves through air).

Disadvantages:

1. Manhole entry required for installation.

2. Accuracy is affected by foam.

3. Accuracy is affected by turbulence

4. Not suited for winter use. Calibration must be re-set if sensor freezes.

5. Echo can be interfered with by machinery which creates cyclic vibrations.

6. Cannot be used to determine flow during surcharged conditions.

Depth/Velocity Meter - Pressure Sensor/Doppler. This meter measures depth of flow with a pressure sensor and velocity using the Doppler method. It is not used with a primary device. Flow readings are stored on electronic memory and can be retrieved with a lap top computer, magnetic tape, or telephone modem.

Installation/Calibration:

The depth/velocity probe is mounted to the invert of the pipe. Calibration of the probe is completed at the manufacturer's factory. Calibration checks for depth can be made by placing the probe in a bucket with a known depth of liquid and comparing the sensors depth reading with the known depth. Velocity can be checked in the field with a portable velocity meter.

Maintenance:

1. Battery must be changed every 6 months.
2. Flow data should be retrieved from the memory using a lap top computer, magnetic tape, or telephone modem every 6 weeks, or more often if desired.
3. Meter should be checked after a significant rain event.
4. Calibration should be checked weekly.
5. Probe should be checked weekly for debris.
6. Pipe must be kept clean of sediment.

Advantages:

1. Very accurate.
2. Low maintenance.
3. Data can be transmitted via telephone lines to a central computer.
4. Accurate even during surcharge conditions.
5. No primary device necessary.
6. An optional rain gage can be connected to the unit.
7. Portable.

Disadvantages:

1. Manhole entry required for installation.
2. Debris on the probe will affect the velocity readings.
3. Turbulence will cause erratic velocity readings.
4. Sediment on the pipe bottom affects accuracy. The probe is calibrated for a circular cross-section.
5. Expensive repair cost if repairs are necessary.

6. Must have a minimum depth of flow of 2 to 2.5 inches in order to get an accurate velocity reading.

Depth/Meter - Pressure Sensor/Faraday. This meter measures depth of flow with a pressure sensor and velocity using the Faraday principal. It is not used with a primary device. Flow readings are stored on electronic memory and can be retrieved with a lap top computer or magnetic tape.

Installation/Calibration:

The depth/velocity probe is mounted to the invert of the pipe. Calibration of the probe is completed at the manufacturer s factory. Calibration checks for depth can be made by placing the probe in a bucket with a known depth of liquid and comparing the sensors depth reading with the known depth. Velocity can be checked in the field with a portable velocity meter.

Maintenance:

1. Primary battery must be changed every 35 days.

2. Flow data should be retrieved from the memory using a lap top computer or magnetic tape every 4 to 5 weeks, or more often if desired.

3. Meter should be checked after a significant rain event.

4. Calibration should be checked weekly.

5. Probe should be checked weekly for debris.

6. Pipe must be kept clean of sediment.

Advantages:

1. Very accurate.

2. Low maintenance.

3. Accurate even during surcharge conditions.

4. No primary device necessary.

5. Portable.

Disadvantages:

1. Manhole entry required for installation.

2. Debris on the probe will affect the velocity readings.

3. Turbulence will cause erratic velocity readings.

4. Sediment on the pipe bottom affects accuracy. The probe is calibrated for a circular cross-section.

5. Expensive repair cost if repairs are necessary.

6. Must have a minimum depth of flow of 2 to 2.5 inches in order to get an accurate velocity reading.

Lift Station Monitoring

Wet Well Depth Measurement. An average daily flow from a pump station can be calculated by continuously recording the water level in the pump station wet well and knowing the wet well dimensions. Water level drawdown and return is measured by a continuously recording depth recorder. The volume of flow pumped per day can then be calculated from the number of water level drawdown/return cycles per day.

Velocity Measurement. An alternate lift station monitoring technique consists of recording the amount of time that each pump runs during the day and multiplying this by the average velocity in the discharge pipe. Duration of pump operation is recorded by a continuous event recorder and average velocity is measured with a portable velocity meter. Flow is then calculated by multiplying the average velocity by the cross-sectional area of the discharge pipe.

Advantages.

1. Easy installation of metering equipment.

2. No primary measuring device is required.

3. All types of depth recorders are suitable for wet well installation.

Disadvantages.

1. Velocity method can only be used if the discharge pipe is a long straight section, since turbulence will affect the velocity readings.

2. Turbulence in the wet well will affect depth readings.

3. Flow results are difficult to correlate to a specific storm event.

4. Inflow and rain induced infiltration components of flow are difficult to distinguish.

FLOW MONITORING DURATION

The type of flow data required governs the duration of a flow monitoring program. Monitoring programs can be classified as instantaneous, short-term continuous, or long-term continuous.

Instantaneous Monitoring

Instantaneous monitoring is useful for making quick depth and velocity measurements in the sewer system at a specific point in time. Dry weather flow patterns can be roughly estimated by measuring flows at different times of the day. Periodic instantaneous measurements can identify problems in the sewer system as soon as they occur. Instantaneous flow measurements should also be taken before a continuous flow monitoring program begins so that the equipment selected for the continuous flow monitoring program is compatible with the range of flows in the sewer system.

Since instantaneous flow measurements provide flow data at a specific point in time, they are not useful for accurately estimating wastewater flow components. More specifically, instantaneous flow measurements are not useful for measuring rainfall induced peak flowrates.

Short-Term Continuous Monitoring

Is is necessary to periodically monitor flow continuously at key manholes for a short period of time to gather specific data. If the data required in needed to assess dry weather flow patterns, it may only be necessary to monitor flow for a couple of weeks. If the data required is needed to determine sewer flows resulting from significant rainfall events, a monitoring period of several weeks may be necessary to capture the desired number of rainstorms.

Short-term continuous flow monitoring reports need to be prepared and submitted to the Metropolitan Sanitary District of Greater Chicago once every 5 years as documentation that long-term maintenance programs have been successfully implemented for each agency.

Long-Term Continuous or Permanent Monitoring

There are occasions when it may be useful to establish semi-permanent or permanent monitoring within a community. For instance, it may be beneficial to monitor the effectiveness of a large scale rehabilitation program aimed at reducing infiltration/inflow. Long-term flow monitoring can also provide data necessary to:

1. Plan for sewer system expansion projects necessary to meet the demands of a growing community.

2. Schedule maintenance programs in areas of rapid deterioration indicated by increases in infiltration/inflow.

3. More accurately predict the sewer system response to rainfall as the number of rainstorms occurring during flow monitoring increases.

FLOW MONITORING REPORTS

After a flow monitoring program is completed, it is suggested that a report be prepared which describes the results and findings. The report for a short-term continuous monitoring program should include basic information such as:

1. Raw flow data.

2. Rainfall data.

3. Groundwater conditions.

4. Description of soil moisture conditions during the monitoring period.

5. Type of flow monitoring equipment used and maintenance performed on it.

6. Type of rain gage used.

7. Certification that flow meters were installed and operated properly.

8. Summary of flows measured in each subsystem including:

   a. Average daily dry weather flow.

   b. Average daily wet weather flow.

   c. Average daily infiltration.

   d. Average daily inflow.

   e. Peak 4 hour flow.

   f. Projected peak 4 hour flow for a 3 year recurrence storm with a duration of 2 hours or less (ICAP option communities only).

   g. Projected peak 24 hour flow for a 3 year recurrence storm with a duration of 24 hours or less (150 gpcpd option communities only).

NOTE: Flows should be presented in both units of million gallons per day, MGD, and gallon per capita per day, gpcpd.

9. Percentage of the community's population equivalent monitored.

10. Estimated flows for the entire community if less than 100 percent was monitored.

11. If flows are excessive, a summary of the steps to be taken to reduce infiltration and inflow.

For a community that sets up a permanent flow monitoring program an annual report summarizing the data collected during each year should be prepared and filed for future reference. The information included in the annual report would typically be similar to the information required in a short-term continuous flow monitoring report.