Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Surveys

MassDEP
Commonwealth of Massachusetts
Department of Environmental Protection

May 2017

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I. INTRODUCTION

Extraneous water from infiltration/inflow (I/I) sources reduces the useful life, and the capacity of sewer systems and treatment facilities to transport and treat domestic and industrial wastewaters. Infiltration enters a sewer system through defective sewer pipe joints, breaks, or manhole defects, and occurs when existing sewer lines and manholes undergo material and joint degradation, as well as when sewer lines are poorly designed and constructed. Inflow normally occurs when rainfall enters the sewer system through direct connections such as roof leaders, yard drains, catch basins, sump pumps, defective manhole covers and frame seals, or indirect connections with storm sewers. The mitigation of I/I by sewer system rehabilitation and inflow source removal, combined with an on-going operation and maintenance program, is essential to protect the environment and the significant capital investment in sewers and wastewater treatment facilities made by cities, towns and the Commonwealth.

These Guidelines have been developed to assist cities, towns, and districts with performing these projects.

While this Guidance sets forth an approach to implement an I/I removal program, MassDEP will consider alternative approaches on a case-by-case basis when reviewing plans under 314 CMR 12.04(2). Any alternative approaches should have the same goal of identifying and removing excessive I/I, and the sewer system authority should document the advantages of an alternative approach. In order to establish eligibility for financial assistance under the SRF program, cities, towns or districts shall either follow the guidelines or have an approved scope for an alternative approach.

II. PURPOSE

The intent of these guidelines is to aid communities in performing infiltration/inflow (I/I) analyses by providing a systematic, comprehensive approach for conducting sewer system evaluations; and to provide information to assist sewer system authorities with fulfilling the requirements of the federal and state Clean Water Acts and the Massachusetts Department of Environmental Protection (MassDEP's) regulations at 314 CMR 12.00. Although site-specific conditions may warrant different approaches, these guidelines provide the overall framework for performing the required work. The I/I analyses are typically divided into the following phases or tasks:

- Infiltration and Inflow Analysis
- Sewer System Evaluation Survey
- Sewer System Rehabilitation
- Follow-up Analysis

Revisions to 314 CMR 12.00: Operation, Maintenance, and Pretreatment Standards for Wastewater Treatment Works and Indirect Dischargers require all sewer system authorities to develop and implement an ongoing plan to control I /I to their sewer systems. 314 CMR 12.04 (2) prescribes specific measures to control I/I, and these guidelines provide the details for conducting the various phases of I/I work required. These guidelines should also be followed by communities seeking financial assistance under the state SRF program; and when stipulated in an enforcement action taken by MassDEP to address infiltration and inflow into a community's sewer system.

Strategies to address I/I in any sewer system should reflect not only the approaches articulated in this guidance, but should also take into consideration other reports and initiatives that have been undertaken. Examples include:

- Asset Management/Renewal;
- Capacity, Management, Operations and Maintenance (CMOM) Programs; and
- Basin approaches in which metered tributary areas undergo comprehensive rehabilitation to achieve I/I goals.

While this Guidance sets forth an approach to implement an I/I removal program, MassDEP will consider alternative approaches on a case-by-case basis when reviewing plans under 314 CMR 12.04(2). Any alternative approaches should have the same goal of identifying and removing excessive I/I and the sewer system authority should document the advantages of an alternative approach.

I/I study and rehabilitation is not a one-time event. A regular maintenance program, including pipeline and manhole inspections, cleaning, root treatment and inflow source identification/removal, is critical to maintaining the integrity of a collection system.

III. REGULATORY ASPECTS

MassDEP is responsible for ensuring compliance with the requirements of the Massachusetts Clean Waters Act (G.L. c.21, §§ 26-53) and the regulations adopted under that statute. MassDEP has authority to enforce the Massachusetts Clean Waters Act in response to violations. In April 2014, MassDEP promulgated regulations to require all sewer authorities to develop and implement an ongoing program to control I/I into their sewer systems. 314 CMR 12.04(2) requires a phased I/I evaluation of sewer systems, and requires the evaluation to be consistent with these guidelines. Sewer authorities should also use these guidelines to assist in developing their I/I Abatement Program.

MassDEP may take enforcement actions under the Massachusetts Clean Waters Act when excessive I/I leads to sanitary sewer overflows (SSO), which present serious public health and environmental risks. When MassDEP takes such enforcement actions, depending on the scope and severity of the violations, requirements for I/I abatement may be much more rigorous and go beyond an approach centered on cost-effectiveness. Remedies and schedules imposed by enforcement actions can include:

- Complete system characterization and investigation;
- Permanent sewer system metering;
- Development of sewer system models;
- A comprehensive approach to I/I abatement involving complete sewer system/lateral rehabilitation in some or all subareas, along with elimination of all confirmed inflow sources;
- Restrictions on new or expanded sewer connections to the system, to effectively manage the risk of SSO events; and
- Penalties and fines.

While these guidelines serve as an important resource, they are not a substitute for, nor do they preempt the requirements imposed by MassDEP regulations, or any administrative or judicial enforcement actions.

MassDEP acknowledges the difficulty in defining excessive I/I into sewer systems. While a number of benchmarks have been developed, they are often too simplistic to account for sewer system responses over a range of precipitation events differing in intensity and depth, along with varying groundwater levels at the time of the event. MassDEP considers the following I/I sources as excessive, and they should all be identified and eliminated as part of the I/I Abatement Program:

- I/I sources directly or indirectly contributing substantial volumes to wet weather SSO events, as set forth in a MassDEP enforcement action, or otherwise as necessary to prevent SSO events for a five year storm event, or a twenty five year storm event to areas with sensitive uses, such as public water supplies, bathing areas, shell fishing areas, or endangered species habitats.
- Infiltration sources which can cost-effectively be removed from the sewer system.
- All public and private inflow sources, unless existing conditions render such removal technically infeasible or cost-prohibitive.

Accordingly, at a minimum, all I/I abatement programs must include an approach to identify and eliminate inflow sources, as well as infiltration sources which can be removed cost-effectively.

MassDEP acknowledges the difficulties in addressing private inflow sources to public sewer systems. While all sewer use regulations must prohibit connection of inflow sources, as per 314 CMR 12.03(5), approaches to identifying and removing existing private inflow connections can and should consider the role of private inflow sources in creating SSO risks; the costs to the utility and/or property owner of removing private inflow connections; and the potential for any adverse impacts such as increased flooding or icing of surfaces. In addition 314 CMR 12.03(5)c requires local sewer use ordinance provide, authority to physically access properties connected to the sewer system to ensure compliance with sewer use regulations. These and any other relevant factors will be considered in MassDEP's review of I/I abatement programs, and in determination if such removals are either technically infeasible or cost-prohibitive.

MassDEP also recognizes that many sewer system authorities in Massachusetts have combined sewer systems, and as such, have been designed to collect and convey stormwater flows in addition to sanitary flows. These systems in nearly every case also have combined sewer overflow structures included in their NPDES discharge permits. Communities with CSO discharges are subject to a separate regulatory framework, including the state and federal CSO Control Policies and Guidance. In these communities, the I/I control plan should be consistent with the Long-Term CSO Control Plan, which may supplant the I/I control plan in its entirety, and have approaches and recommendations which differ from approaches in separate sewer systems.

IV. DEFINITIONS

Building Service Connection - Where a building service lateral connects to the public sewer; typically made using a wye or tee, with a chimney for deep public sewers.

Building Service Lateral - The pipe from a building to the public sewer.

Combined Sewer - A sewer intended to serve as both a sanitary and a storm sewer.

Cost-effective I/I Removal - Removal of infiltration sources identified in the study or Sewer System Evaluation Study (SSES), which are shown through a cost-effectiveness analysis to be more economical to eliminate rather than transport and treat.

Defect - A potential source of infiltration/inflow.

Dyed Water Flooding - A detection technique in which dyed water is introduced into catch basins, drain lines, and associated structures suspected of being a source of infiltration or inflow, in order to confirm direct connections or indirect connections between storm drains and sanitary sewers.

Dyed Water Testing - A detection technique in which dyed water is introduced into a suspected public or private source of inflow (i.e., downspouts, area drains, driveway drains, sump pumps, etc.) in order to confirm direct or indirect connections to the sanitary sewer.

Dyed Water Tracing - A technique in which an inflow source is confirmed and located through inspection with a closed circuit television (CCTV) camera.

Excessive Infiltration/Inflow - Sources of I/I which must be targeted and removed as part of an I/I abatement program, including:

- I/I sources directly or indirectly contributing substantial volumes to wet weather SSO events, as set forth in a MassDEP enforcement action, or otherwise as necessary to prevent SSO events for a five year storm event, or a twenty five year storm event to areas with sensitive uses, such as but not limited to public water supplies.
- Infiltration sources which can cost-effectively be removed from the sewer system, based on a comparison of the cost of removal to the cost of transporting and treating the flows.
- All public and private inflow sources, unless existing conditions render such removal technically infeasible or cost-prohibitive.

Five-year, 24-hour Design Storm - a storm with total rainfall depth of 4.61 inches, and a peak hourly intensity of 0.73 inches/hour, as depicted in the hyetograph in Figure 7 in the Technical Exhibits.

Groundwater Migration - The tendency of groundwater to move from one rehabilitated defect to another defect.

Infiltration - Water other than sanitary flow that enters a sewer system (including sewer service connections and foundation drains) from the ground through means which include, but are not limited to, defective pipes, pipe joints, connections, or manholes. Infiltration does not include, and is distinguished from inflow.

Infiltration/Inflow - The quantity of infiltration and inflow (I/I) without distinguishing the source.

Infiltration/Inflow Rehabilitation - Construction associated with the removal of infiltration and inflow from sewer systems.

Inflow - Water other than sanitary flow that enters a sewer system (including sewer service connections) from sources which include, but are not limited to, roof leaders, cellar drains, yard drains, area drains, drains from springs and swampy areas, manhole covers, cross connections between storm sewers and sanitary sewers, catch basins, cooling towers, storm waters, surface runoff, street wash waters, sump pump discharges, or drainage. Inflow does not include, and is distinguished from, infiltration. The total amount of inflow is equal to the sum of the delayed inflow and direct inflow.

Internal Inspection - The inspection of conduits (previously cleaned) or manholes by physical, photographic or closed circuit television (CCTV) methods.

Key Manhole - The manhole through which the entire flow from a sub-system passes.

MACP - National Association of Sewer Service Companies' (NASSCO) Manhole Assessment and Certification Program.

New Flow - As used in MassDEP regulations (e.g. 314 CMR 12.04(2)(d)), new flow shall be defined as:

1. Design wastewater flows from properties with no pre-existing sewer connections; or
2. Where a duly permitted existing sewer connection exists, any increase in design wastewater flows from the flow established in the sewer extension or connection permit. Where an existing connection has not been used and maintained, such as where properties have been vacant, or have had significant change in use or flows, historical sewer flows emanating from the property shall be used for the

purpose of quantifying new wastewater flows, which shall be determined by comparing design flows for new facilities with the preceding 5-year average of daily wastewater flows from existing facility, as determined by water use records, suitably adjusted for consumptive uses.

PACP - National Association of Sewer Service Companies' (NASSCO Pipeline Assessment and Certification Program.

Preparatory Cleaning - The adequate cleaning of sewers previously identified as potential sources of excessive infiltration/inflow prior to internal inspection.

Private Infiltration/Inflow Source - An infiltration/inflow source emanating from private property and discharging to the public sewers.

Public Infiltration/Inflow Source - An infiltration/inflow source emanating from public property and discharging to the public sewers.

Rainfall Induced Infiltration - Infiltration by groundwater seepage percolating through the soil and entering collection systems' defects, due to a temporary rise in groundwater levels after a storm event, and lasting from several days to several weeks.

Sanitary Sewer - A sewer intended to carry sanitary flow.

Sanitary Flow - The component of wastewater which include domestic, commercial, institutional, and industrial sewage, and specifically exclude infiltration/inflow.

Sanitary Sewer Oveflow or SSO - Any overflow, spill, release, discharge or diversion of untreated or partially treated wastewater from a sanitary sewer system to ground or surface waters. The discharge of sewage into a building is not considered an SSO if the discharge was not the direct result of problems in the public sewer system.

Sewer Segment - A length of sewer from one manhole to another, also called a sewer reach.

Sewer System - Pipelines or conduits, pumping stations, force mains, and all other structures, devices, appurtenances, and facilities used for collecting and transporting wastes to a site or works for treatment or disposal.

SRF - State Revolving Fund.

Storm Sewer - A sewer intended to carry only storm water, surface runoff, street wash water and drainage; also called a storm drain.

Storm Water - All water running off from the surface of a drainage area after a period of rain.

Subsystem - An individual drainage basin that is part of a collection system; sizes typically range from 10,000 LF to 30,000 LF, (not including building service laterals). However, the goal is to subdivide the collection system into 20,000 LF subsystems.

Suspect Inflow Source - A potential inflow source which did not smoke during smoke testing, but its discharge location could not be identified. A suspect inflow source could also be identified during building inspections.

Tidally Influenced Infiltration - Infiltration caused by tide cycles that elevate groundwater levels.

Visually Estimated Infiltration/Inflow - The rate of infiltration/inflow observed during internal inspection, and estimated at the time observed.

Wastewater Facilities - All facilities that collect, pump, treat, dispose of, or convey sewerage to wastewater treatment facilities.

Wastewater Flow - Sanitary flow, along with any infiltration and inflow present in the sewer system.

V. INFILTRATION/INFLOW ANALYSIS

An initial infiltration/inflow (I/I) analysis is performed to document the extent of I/I in sewer systems. Through systematic investigation, the analysis should identify the presence, flow rate, and type of I/I conditions which exist in the sewer system. The systematic investigation should include the following tasks:

- Field investigation of the existing wastewater collection system;
- Estimating average residential, industrial, commercial and institutional wastewater flows (which are used for general background, but not usually necessary for I/I determinations);
- Measuring groundwater levels;
- Continuous flow monitoring and, in some cases, flow isolation monitoring;
- Determination of infiltration and inflow rates; and
- Recommendations for further investigation (i.e., a Sewer System Evaluation Survey (SSES) when appropriate.

The following tasks and recommended methodologies are generally included in the I/I analysis phase:

1. INVENTORY OF EXISTING CONDITIONS

PURPOSE

The purpose of the inventory of existing conditions is to gather information on the sewer system to better understand system assets and operation for the purpose of developing the flow monitoring program. The inventory is the first major work task in an I/I analysis, and should be performed prior to any significant field investigations.

METHODOLOGY

Inventory sources of information, including:

- Past engineering studies;
- Maps of both wastewater and storm sewer systems;
- Geographical Information System (GIS) data;
- Interviews with people familiar with the system;
- Existing sewer system O&M program;
- Treatment plant and pumping station flow records;
- Existing flow metering;
- Historical United States Geological Survey (USGS) groundwater data, (http://waterdata.usgs.gov/

ma/nwis/gw) as well as any available groundwater level information collected for the current season during which field investigations are performed;

- Existing computer models of the collection system;
- Existing streamflow monitoring level data; and
- Tidal charts for areas suspected to be influenced by tidal infiltration.

A GIS mapping system that includes the sewer, water and storm drain system is recommended to provide critical data necessary for subsequent investigation. Suggested information could include, but not be limited to, pipe sizes, materials, age, rim and invert elevations, grease/sediment buildup, physical condition rating, infiltration rating, location of overflows, and date of inspection.

Based upon a review of these sources, establish:

- Type of sewerage system (separate or combined);
- Location and extent of any underdrain systems;
- Drainage patterns;
- Number and frequency of occurrence of overflows, bypasses, and surcharging;
- Type and age of sewer lines and manholes;
- Condition of existing facilities;
- Previous problems, I/I investigations, and rehabilitation in the system; and
- Location of any permanent metering equipment in the system.

The inventory of existing conditions should include a physical survey of the collection system that is being evaluated during the I/I investigations. The physical survey is conducted to isolate I/I problem areas, select flow gauging (continuous and/or instantaneous) sites, and provide a basis for a preliminary assessment of the general physical (structural and operational) condition of the collection system. At a minimum, perform the following tasks during the inventory of existing conditions:

a) Inspect a representative number of manholes, which shall generally include 10% of the manholes in the planning area;
b) Walk sites to identify and evaluate manholes in cross-country areas, river bank wetlands, tidal zones, and flood zones;
c) Select sites for continuous and/or instantaneous flow gauging;
d) Determine gauging area boundaries for continuous and/or instantaneous gauging areas;
e) Measure groundwater levels as evidenced by wet ringsand/or leakage within all manholes inspected during the inventory of conditions. The amount of groundwater monitoring required may be dependent on the available data from local USGS gauges that could demonstrate historical trends. (Refer to Section V-3 for groundwater monitoring procedures); and
f) Identify problem areas.

At the completion of the physical survey, a technical memorandum should be prepared. The memorandum should document problems observed, present a preliminary assessment of the condition of the collection system, the location of proposed gauging manholes, groundwater monitoring sites and observed groundwater data, and recommend whether to initiate or postpone flow monitoring based upon groundwater levels observed during field inspections. A sewer system map showing the location of the key manholes/gauging locations and subsystem boundaries should accompany the memorandum.
Both the groundwater monitoring and flow gauging programs can now be more accurately developed, and initial assumptions on subsystems and metering locations can be modified, as required.

1.1 INITIAL FLOW MONITORING

Conduct initial flow monitoring at the onset of I/I analysis at select key locations to determine overall system flow quantities and infiltration trends. MassDEP recommends that no less than 70% of total flow to the treatment works be captured with the least number of meters depending on system characteristics. The flow monitors at the initial flow monitoring locations shall remain in operation as described in Subsection 2.1.

1.2 LIMITED MANHOLE INSPECTION

PURPOSE

In the course of selecting key manholes/gauging locations for the installation of continuous flow recording meters, one or more manholes per subsystem must be entered. Inspect representative number of additional manholes to ascertain the general physical condition of manholes and sewers for inclusion in the I/I Analysis Report, to verify sewer system configurations and meter area boundaries, and to investigate and determine groundwater levels.

METHODOLOGY

The number of manholes inspected will vary from study-to-study but should be sufficient to gauge I/I influence on the system under study at a minimum. During this part of the inventory of existing conditions, it is not necessary to enter the manhole and perform a complete inspection, except for those manholes selected for flow monitoring and groundwater monitoring. However, those manholes partially inspected must be fully inspected as described in the Extensive Manhole Inspection Section VI-5 at the time that the complete extensive manhole inspection is conducted in the 80% inflow area, and in areas exhibiting infiltration, over 4,000 gallons per day per inch diameter per mile of sewer (gpd/idm). In all cases where entry into manholes is required as part of the inspection, proper precautions and training associated with confined space entry must be followed. Partially inspected manholes located in areas falling outside of the two categories stated above may also be completely inspected if deemed advisable, consistent with sound engineering practice, or as an element of an aggressive I/I investigation program to address SSO discharges.

The term 'limited' refers to the quantity of manholes (10% of the total) and not to the thoroughness of the inspection. The intent of the limited inspection is to primarily obtain an initial overall perspective of the condition of the system. However, the option to perform a complete inspection of the manholes at this time is also open if it is deemed desirable due to work scheduling or other project management considerations.

For those manholes to be entered and completely inspected, refer to Section VI-5, Extensive Manhole Inspection, Methodology items 1 through 9, and visual pipe inspection items 1 through 8. Record all pertinent information in an inspection form. (see sample copy in Technical Exhibits – Section XI).

2. SEWER FLOW MONITORING

PURPOSE

The purpose of sewer flow monitoring is to collect accurate, current information on the flow characteristics of the study area. The information provided by flow monitoring will aid in locating those areas that have excessive infiltration/inflow and determine if they warrant further investigation. This task should be conducted at the earliest possible stage in order to minimize the survey costs.

It should be emphasized that the flow monitoring data provides the basis for determining the need for and location of areas where additional, costly field work should be performed as part of the follow-up SSES program (See Sections VI and VII). As such, the need to assure flow data accuracy using sound field data collection and field calibration methods, accurate calculation methods, appropriate analysis procedures, and data QA/QC procedures cannot be over-stated.

2.1 CONTINUOUS METERING METHODOLOGY

The objective of continuous flow monitoring is to obtain information necessary to accurately measure flows to quantify infiltration during high groundwater periods and for rainfall related inflow during wet weather periods. Continuous monitoring should be conducted for a minimum of ten consecutive weeks, typically between March 1 and June 30. However, if it is determined that groundwater levels are sufficient, the flow monitoring program may begin prior to March 1 or extend beyond June 30, in order to document conditions at high seasonal groundwater, or under sufficient wet weather conditions.

Continuous monitors should be installed in a manner to distinguish flows from various subsystems, and each metered area should not exceed 20,000 linear feet of sanitary sewer. Larger or smaller subareas may be proposed based on existing flow information, the age and materials of the existing system, and costs and timeframe to deploy meters throughout the service area.

There are three acceptable methods of continuous flow monitoring, depending on existing field conditions. The methods are, in order of preference:

1. Using a primary device such as a weir or a flume in conjunction with a continuous depth sensing device;
2. Using a continuous monitoring device incorporating a velocity sensor combined with a depth sensor; or
3. Using a continuous depth sensor in conjunction with depth and velocity rating curves developed from a number of instantaneous flow depth and velocity measurements over a wide range of depths.

METHOD 1: The first and most preferred method is the use of a primary device such as a weir or flume in conjunction with a continuous depth sensing device. This method is particularly applicable to sites with smaller diameter pipe in the eight inch to fifteen inch diameter range. This method addresses concerns relating to backwater effects, sediment, slope variations, turbulence, etc., but may not be suitable for large diameter pipe or steep grade locations.

Care should be taken to assure that potential flow rates do not exceed the capacity of the primary device. Care should also be taken to assure that the primary device does not act as a hydraulic restriction causing surcharging.

METHOD 2: The second method is the use of a continuous monitoring device incorporating a velocity sensor combined with a depth sensor. This method is particularly useful in situations where large diameter pipes exist with significant flow depths.

Care should be taken, however, to assure that the depth and velocity sensing probes are sufficiently submerged during minimum flow depth periods to assure proper operation.

METHOD 3: The third method may be utilized when weirs or other hydraulic aids or continuous depth and velocity devices cannot be used due to flow quantity or other physical constraints. Depth and velocity rating curves may be developed from a number of instantaneous flow, depth and velocity readings over a wide range of depths. Monitoring may then be done with a continuous depth recorder. This method is particularly useful in smaller diameter pipes or in larger diameter pipes with little depth or flow.

The Manning formula for flow calculation using depth-only sensors should not be used as the principal method because it is dependent on the slope and coefficient of roughness; parameters which cannot be adequately estimated for old pipe without intimate knowledge of the existing conditions. In addition, the use of pump station run time records should not be used as the principal method because of the possibility of time lags or event masking due to wet wells. Approval of Pump Station run time data should be sought from MassDEP and properly justified prior to conducting flow calculations on this basis.

When using Method #2 or Method #3, accurate determination of the cross sectional area of the flow being measured is required. The dimensions of circular pipe should be measured to verify diameter and determine if a true circular cross section exists. If it is determined that a circular cross section does not exist, or if the meter site is placed in a cross section pipe known to be non-circular, field measurements should be taken using a sound method, such as that described in Appendix B.

Care must be taken to accurately measure the configuration of any debris and include the information into cross-sectional area derivation, if such obstructions cannot be effectively eliminated.

In all cases, determination of average (mean) velocity of the cross-sectional area of flow should be performed over a wide range of flow depths that occur at the meter site. A correlation should be established between the sensed velocities and the field measured mean velocity at each given flow depth using a method similar to that described in Appendix A.

When calculating flow rates using the recorded data, the sensed (continuously recorded) velocities should then be adjusted based on the observed correlation. If poor or inconsistent correlation is found, a stage/velocity calibration curve should be developed and incorporated into the appropriate flow calculation program, using the sensed velocities only to determine when surcharge conditions or backwater conditions exist.

Care must be taken to assure that instances of velocity probe fouling are not misinterpreted as backwater or standing flow conditions. Care should also be taken to continuously review calculated flow rates at each flow monitoring location to assure that upstream and downstream flows balance properly, and any discrepancies should be addressed as early in the monitoring program as possible.

2.2 MINMIMUM GROUNDWATER INFILTRATION

Minimum groundwater infiltration can be estimated using system wide flow data (from the WWTP or any permanent meters) for periods when groundwater levels recede, generally a condition in Summer/early Fall. Nearby groundwater data from USGS monitoring wells or other sources should be used in correlating flow evaluation with low groundwater conditions.

The minimum groundwater infiltration as determined by this method along with the high groundwater infiltration (see Section V-5.1 Flow Data Analysis) should be used for calculating the average annual infiltration.

3. GROUNDWATER MONITORING

PURPOSE

The purpose of groundwater monitoring is to obtain current groundwater data throughout the collection system for relating gauged flow rates and infiltration to groundwater levels. Existing groundwater conditions in the vicinity of the sewer are determined to ensure that optimum conditions exist for the type of investigation being performed (i.e., flow isolation/high groundwater, TV inspection/high groundwater, smoke testing/low groundwater). Data documenting the seasonal fluctuations in the groundwater level is also gathered.

Consideration should also be given to using automated methods to log groundwater levels. Periodic manual reading of gauges may miss fluctuations in groundwater levels.

Most sources of infiltration are impacted by variations in groundwater levels. For this reason, the determination of infiltration quantities in the sewer system should be based on the wastewater flow data collected during high groundwater periods. When reporting high infiltration rates, a comparison of current groundwater observations to historical groundwater data should be made. The results of this comparison should be considered when analyzing the infiltration data collected during the study.

METHODOLOGY
General groundwater information can be obtained from a number of sources which may include the following:

State Water Resources Agencies;
USGS Wells (http://waterdata.usgs.gov/ma/nwis/gw); and
Local Monitoring Wells.

Historical information on groundwater elevations from nearby permanent monitoring well sites should be used to understand the conditions at the time of flow monitoring. Groundwater level measurement field gauging using wet-ring or highest level of condensation within manholes, piezometers, and/or groundwater monitoring wells are all acceptable .

When conducting the inventory of existing conditions, groundwater level information should be collected during manhole inspections. Groundwater monitoring sites should be selected and reported to MassDEP in the Inventory of Existing Conditions Technical Memorandum. No less than two monitoring sites shall be selected per subsystem (based on 20,000 LF subsystems) for monitoring during the field program. The general goal is to have a groundwater monitoring manhole site installed for each subarea. To supplement this information, piezometers can be installed where necessary. At each groundwater monitoring site, groundwater data should be collected at least weekly during the flow monitoring program.

During limited manhole inspections, all manholes inspected shall be investigated for signs of groundwater leakage. Rates of leakage and/or wet ring heights of groundwater above the manhole inverts shall be noted for those selected as groundwater monitoring sites. The initial observations shall be used as references to determine the fluctuation of groundwater levels during the field work. Manholes which indicated groundwater shall be monitored on a weekly basis at a minimum and more frequently as necessary within a subsystem when infiltration identification field work is being conducted within that subsystem.

4. RAINFALL MONITORING

PURPOSE
The purpose of rainfall monitoring is to obtain data to compare variations in gauged flow rates to rainfall intensity, total volume and rate per event, and duration per event for the purpose of identifying inflow and its components. Rainfall data specific to the study area is collected to determine inflow rates during different storm events for conversion to a standard storm event.

METHODOLOGY
Since rainfall data vary from one location to another, rainfall recording devices shall be used within the study area to obtain data. Municipal or other Agency maintained devices may be used as long as accuracy can be verified.

Rainfall data can be obtained from tipping buckets or continuous weighing rain gauges. Rain gauges shall electronically record rainfall for several events and a totalizer that provides a check against recorded data is recommended. Less sophisticated devices such as graduated cylinders are not appropriate.

Preferably one continuous recording tipping bucket rain gauge shall be located for every three to four square miles of the study area, with a minimum of two gauges provided for any monitoring work. Consideration should also be given to climatological anomalies within the overall study area to determine placement and number of rain gauges as well as the area of control ascribed to each gauge. Rain gauges shall be capable of 15 minute precision and be accurate to within 0.01 inches of rainfall.

In addition to the rainfall data collected within the study area, other less site-specific data should be obtained and evaluated. Sources of precipitation data are the National Oceanic and Atmospheric Administration (NOAA), USGS, airports, state weather observers, local radio and TV weather stations, electronic media weather observers, other public works and research agencies and private citizens. NOAA Climatological Data can be found at http://www.erh.noaa.gov/box/dailystns.shtml.

Use of data collected from rainfall monitoring stations run by others is acceptable, provided that the type and the location of that equipment are suitable.

5. FLOW DATA ANALYSIS

PURPOSE

Proper flow data analysis will evaluate the information obtained from continuous flow monitoring and other supplemental data to categorize the wastewater flow into its various components: sanitary flow; infiltration; and inflow. This analysis requires engineering judgment and consideration of seasonal impacts to the collection system being studied. This includes consideration of whether free flow or restricted flow conditions exist and adjustment of inflow to the designated standard design storm. Following the quantification of each wastewater component, accepted engineering principles and noted guidelines are used to make recommendations for further study to identify infiltration and inflow sources within the follow-up SSES phases.

5.1 COMPONENTS OF WASTEWATER FLOW

Wastewater Flow - Wastewater flow is comprised of Sanitary flow, Infiltration and Inflow. A description of these components follows.

5.1.1 Sanitary Flow - Sanitary flow is defined as the component of wastewater which includes domestic, commercial, institutional, and industrial sewage and specifically excludes infiltration/inflow. Sanitary flow does not include year-round (permanent) infiltration. Sanitary flow is generally expected to exhibit a diurnal flow pattern which, typically, is reproduced each weekday and may exhibit a somewhat different flow pattern on weekends.

5.1.2 Infiltration - Infiltration is defined as the component of wastewater which is extraneous water entering the sewer system from the ground through sources such as defective pipes, pipe joints, connections, and manhole walls. Some quantity of infiltration is generally expected to be present in wastewater flow throughout the year. Because infiltration is directly influenced by groundwater fluctuations, the volume of infiltration entering a sewer system is generally expected to fluctuate from season to season with typically larger volumes anticipated in the spring and smaller volumes anticipated in the summer.

Sewer systems physically located in or near coastal areas may be subject to tidal infiltration. Separate components of infiltration are detailed below.

Peak Infiltration Rate is defined as the average of the minimum flow rate observed over a period of several days, during high (or "peak") groundwater conditions which usually occur in early spring after snow melt and/or soil thaw, and is generally measured during low flow conditions – midnight to 6:00 A.M. (note: there may be situations where this time range may not be applicable, such as industrial or commercial areas with late work shifts.)

Minimum Infiltration Rate is defined as the average daily minimum flow rate in million gallons per day (MGD) determined over a period of several days, during low (or "minimum") groundwater conditions.

Annual Average Infiltration is defined as the average daily infiltration rate (MGD) determined over the entire calendar year.

Total Annual Infiltration is defined as the total infiltration volume (gallons or MG) over the entire calendar year.

Tidal Infiltration Volume is defined as the increase in infiltration which may occur when the groundwater table is temporarily elevated due to the impact of high tide. In cases where it is not possible to distinguish tidal infiltration from tidal inflow, the combination may be reported as tidal I/I.

Dry Weather Flow is defined as sanitary flow and infiltration, and tidal infiltration.

<u>5.1.3 Inflow</u> - Inflow is defined as the component of wastewater which is extraneous water discharged into a sewer system from sources such as sump pumps, roof leaders, cellar/foundation drains, surface drains, drains from springs and swampy areas, manhole covers, catch basins, cross-connections from storm drains, leaking tide gates, and other inlets. Inflow differs from infiltration in that it is the result of direct connections of extraneous flow sources into the collection system and, generally, is not linked to fluctuations in the groundwater table. The methodology used to quantify inflow (detailed below) does not allow for the independent quantification of rainfall-induced infiltration; therefore, the quantification of inflow also is likely to include some portion of rainfall-induced infiltration.

Inflow is largely the result of wet weather (stormwater) influence on the sewer system. During dry weather, the quantity of inflow is generally expected to approach zero. During storm events, inflow may rapidly impact the sewer system causing the wastewater flow to increase. The increase in wastewater flow due to inflow may terminate a short time after the storm event or it may influence the sewer system for a prolonged period depending on the type of inflow sources which exist in the system. It is not uncommon for inflow to elevate wastewater flows for a number of days following a rainfall event. Sewer systems physically located in or near coastal areas may also be subject to tidal inflow. Separate components of inflow are detailed below and are identified on Figure 4, in the Technical Exhibits.

Total Inflow volume is defined as the total volume reported as million gallons (MG) of inflow generated from a single storm event including both direct and delayed inflow. Total inflow is the area between the storm event hydrograph and the dry weather hydrograph

Direct Inflow Volume is defined as the portion of total inflow which is generated from direct connections to the collection system such as catch basins, roof leaders, manhole covers, etc. These inflow sources allow stormwater runoff to rapidly impact the collection system and produce an inflow hydrograph which sharply increases soon after the start of the storm and decreases swiftly upon conclusion of the rainfall event. Direct inflow volume is the area between the storm event hydrograph and the dry weather hydrograph, beginning at the initial divergence of the curves, and ending at a time following the conclusion of the storm when the majority of inflow is expected to be produced from delayed inflow sources.

Delayed Inflow Volume is defined as the portion of total inflow volume which is generated from indirect connections to the collection system or connections which produce inflow after a significant time delay from the beginning of a storm. Delayed inflow sources include sump pumps, foundation drains, indirect sewer/drain cross-connections, etc. Through the analysis of metering data, rainfall-induced infiltration cannot be distinguished from delayed inflow. Therefore, by definition, it is included as part of delayed inflow. Delayed inflow sources exert a gradual stormwater impact on the collection system and produce an inflow hydrograph which decreases gradually upon conclusion of the rainfall event, and after peak inflow caused by direct connections. Delayed inflow volume is the area between the storm event hydrograph and the dry weather hydrograph, beginning at the conclusion of direct inflow, and ending at a time when the storm event hydrograph and the dry weather hydrograph converge.

Rainfall-Induced Infiltration Volume is defined as the short-term increase in infiltration which is the direct result of stormwater percolation into the ground and through collection system defects in pipes, joints, connections, or manhole walls which lie near, or are readily reached from the ground surface. Rainfall-induced infiltration (RII) may also be commonly referred to as rainfall dependent infiltration (RDI) or rainfall dependent I/I (RD I/I). By definition, rainfall-induced infiltration is a portion of delayed inflow.

Peak Inflow Rate is defined as the largest inflow rate (MGD) determined over a one hour period which is generated from a single storm event. The peak inflow rate is the largest rate difference between the storm event hydrograph and the dry weather hydrograph.

Design Storm Peak Hour Inflow is the estimate of inflow during the highest intensity hour of rainfall for the 5-year , 24-hour design storm.

Total Annual Inflow Volume is defined as the total inflow volume (MG) determined over the entire calendar year.

Annual Average Inflow Rate is defined as the average daily inflow rate (MGD) calculated over the entire calendar year. It may be estimated by subtracting the average daily dry weather wastewater flow from the average daily total wastewater flow.

Tidal Inflow is defined as seawater entering the sewer system through direct connections such as leaking tide gates and defects in manholes located in salt marshes or other areas subject to tidal influence. In cases where it is not possible to distinguish tidal inflow from tidal infiltration, the combination may be reported as tidal I/I.

5.2 METHODOLOGY FOR ESTIMATING SANITARY FLOW

The sanitary flow component of the total wastewater flow is generally determined through two independent methods of analysis: water consumption; and flow meter data. In the first method, water consumption records can be analyzed and apportioned, based on sewered population, and industrial, commercial, and institutional usage, for each metered subsystem, to estimate the anticipated sanitary flow expected to be measured by the wastewater flow meter.

The second method is an analysis of wastewater flow meter data which has not been influenced by a rainfall event (i.e. metered data from a dry weather period, typically three to five days following a rainfall event). During a dry weather period, sanitary flow can be estimated by subtracting the infiltration portion of the nighttime minimum flow from the average daily wastewater flow which was recorded on the same dry weather day. The methodology for calculating the infiltration portion of the nighttime minimum flow is explained below.

5.3 METHODOLOGY FOR ESTIMATING INFILTRATION

To determine infiltration, wastewater flow meter data should be examined to identify periods of dry weather (generally at least three to five days without a storm event). During selected dry weather periods, nighttime minimum flows should be analyzed to estimate peak, minimum, and annual average infiltration rates. These should be reported in both gpd and gpd/idm units for each subsystem. The unit of gpd/idm normalizes the flow from pipes of different diameters, and is used for subareas with differing pipe lengths.

The nighttime minimum flow represents a period of minimal sanitary flow; therefore, a high percentage of the nighttime minimum flow may be attributed to groundwater infiltration. A portion of the nighttime minimum flow may also be attributed to sanitary flow from 24-hour industrial/commercial operations, institutional flows, and/or some small amount of domestic flow. The portion of the nighttime minimum flow which can be attributed to sanitary flow may be estimated through a combination of the following:

(1) a detailed survey of nighttime large industrial, commercial, or institutional water users;
(2) an estimate, based on engineering judgment, of the expected percentage of the nighttime minimum flow which may be attributable to domestic flow contributions; and
(3) any available water use records for facilities in the tributary area during the times when flow measurements are being made.

The percentage of the nighttime minimum flow which may be attributable to domestic flow contributions is likely to be a small portion. Each individual subsystem should be analyzed to determine the quantity of flow to be deducted. The portion of the nighttime minimum flow attributed to sanitary flow must be subtracted from the total nighttime minimum flow to calculate an infiltration rate.

During high (or peak) groundwater conditions, which usually occur in early spring after snow melt and/or soil thaw, the minimum nighttime flows will be at their highest level. During this period, the peak infiltration rate is quantified by taking the average, over several consecutive days during dry weather conditions, of the portion of the minimum nighttime flows estimated to be infiltration.

During low (or minimum) groundwater conditions, which usually occur in late summer after a prolonged period of minimal rainfall, the minimum nighttime flows will be at their lowest level. During this period, the minimum infiltration rate is quantified by taking the average, over several days, of the portion of the minimum nighttime flows estimated to be infiltration.

The annual average infiltration rate can be calculated directly by analyzing metered flow data for an entire year. However, if metered flow data exists for only a portion of the year, it may be estimated by calculating a weighted average of peak infiltration (for a representative number of high infiltration months) and minimum infiltration (for a representative number of low infiltration months).

A separate analysis must be performed to identify the presence of tidal infiltration. During a dry weather period, nighttime minimum flows corresponding to a high tide should be compared to nighttime minimum flows corresponding to a low tide. Due to the tide cycle, this analysis can be performed on minimum nighttime flow data which occurs about one week apart. This time period is sufficiently short to insure that seasonal fluctuations in infiltration can be largely disregarded. Pump station run times versus tide height can also be used to identify the existence of potential tidal inflow. If a significant flow increase is detected during the high tide period, it may be attributed to tidal infiltration, tidal inflow, or tidal I/I. Care should be exercised when selecting the high tide period for use in this analysis. The elevation of each high tide varies and an extreme high tide elevation is likely to produce a larger volume of tidal infiltration than a moderate high tide elevation.

5.4 METHODOLOGY FOR ESTIMATING INFLOW

Flow meter data and rainfall data should be analyzed to identify periods of wet weather when inflow may be expected to occur. Flow meter data during the wet weather period (generally over several days) should be compared to flow meter data during a selected dry weather period (usually a period immediately preceding the storm) provided this period is representative of similar groundwater conditions and similar diurnal flow conditions. The rate and volume of inflow tributary to a subsystem can be computed by subtracting the dry weather flow data from the wet weather flow data. This analysis is represented graphically in Figures 2, 3 and 4.

For each significant storm event during the flow monitoring period, both the peak inflow rate and the total inflow volume should be calculated and reported. The total inflow volume should also be apportioned into an estimated direct inflow volume and an estimated delayed inflow volume.

The peak inflow rate, as illustrated in Figure 4, is the largest rate difference, during the study duration, determined over a one hour period, between the storm event hydrograph and the dry weather hydrograph. The peak inflow rate should be reported in gpd or MGD for each subsystem metered. For surcharge conditions see Section 5.6.

The total inflow volume, as illustrated in Figure 4, is the area between the storm event hydrograph and dry weather hydrograph. Total inflow can be apportioned into two components: direct inflow and delayed inflow. Direct inflow is the portion of the inflow hydrograph which rapidly increases soon after the start of the storm and decreases swiftly upon conclusion of the rainfall event. Direct inflow begins at the initial divergence of the storm event and dry weather hydrographs, and ends at a time following the conclusion of the storm approximately equal to the inflow response time of the subsystem. The inflow response time of the subsystem can be estimated as being the time differential between initiation of the storm event and the increase in the observed flow. Delayed inflow is the portion of the inflow hydrograph which decreases gradually upon conclusion of the rainfall event and after the peak inflow caused by direct connections. Delayed inflow is the area between the storm event hydrograph and the dry weather hydrograph beginning at the conclusion of direct inflow (as defined above), and ending at a time when the storm event hydrograph and the dry weather hydrograph converge. It is expected that a portion of the delayed inflow may include rainfall-induced infiltration. In some cases, a second storm will impact the flow data prior to the time when the initial storm event hydrograph and the dry weather hydrograph converge. If this occurs, the expected delayed inflow hydrograph may be extrapolated from the flow data collected prior to the second storm. Total, direct, and delayed inflow volumes should be reported in gallons or millions of gallons for each subsystem metered.

A separate analysis must be performed to identify the presence of tidal inflow. During a dry weather period, nighttime minimum flows corresponding to a high tide should be compared to nighttime minimum flows corresponding to a low tide. Due to the tide cycle, this analysis can be performed on minimum nighttime flow data which occurs about one week apart. This time period is sufficiently short to insure that seasonal fluctuations in infiltration can be generally disregarded. If a significant flow increase is detected during the high tide period, it may be attributed to tidal inflow, tidal infiltration, or tidal I/I. The elevation of each high tide varies and an extreme high tide elevation is likely to produce a larger volume of tidal inflow than a moderate high tide elevation.

5.5 DESIGN STORM RECURRENCE INTERVAL AND DURATION

The total inflow volume produced by a storm event is a function of the rainfall volume (inches of rainfall over the subsystem), the intensity (inches of rainfall per hour), and the duration (hours).

A storm recurrence interval is defined as the storm which, based on historical records, will occur on the average of once within the stated recurrence interval. See Precipitation Frequency Figure 6 and Table 5 in the Technical Exhibits Section. Flow monitoring data should be compiled and projected inflow volumes shall be evaluated for the one-year and five-year recurrence interval storms.

Storm duration is defined as the length of time from the initiation of the storm event to the conclusion of the storm event. The one-year, six-hour storm produces approximately 1.72 inches of rainfall in the Boston area, with peak intensity of 0.87 inches per hour and an average intensity of 0.29 inches per hour. The standard storm hydrograph is shown in Figure 1 of the Technical Exhibits.

While the one-year, six-hour storm is the MassDEP baseline for comparing inflow rates and volumes, the level of service provided in the sewer system, i.e. the capacity to convey flows generated during larger storm events, is a critical measure of the performance of the collection system. Accordingly, for each actual storm event analyzed during the flow metering period, an assessment of the recurrence interval, and an account of the associated flows, surcharging, and SSO events, if any, should be included in the subsequent I/I reports. Table 5 and Figure 6 can be used to approximate the storm recurrence interval for storms captured during the metering period, utilizing the storm depth and duration, and using either the Table or Figure to estimate the recurrence interval. While Table 5 and Figure 6 are based on rainfall data in Middlesex County, they represent a suitable basis for estimating storm events across the state since this county is near average rainfall conditions across the state. At the discretion of the engineer, NOAA Atlas 14, Volume 10 data can be used to develop a more site-specific storm recurrence interval.

It is important to note that 314 CMR12.04 requires all sewer system authorities to develop a plan for long-term I/I control. In particular, the plan at a minimum must assess the risk of sewer system overflows from a five-year, 24- hour storm event. Based on a recent data release of the National Oceanic and Atmospheric Administration, MassDEP has defined the statewide average at the upper confidence limit of a five-year, 24-hour storm event as an event with a total depth of 4.61 inches, a peak intensity of 0.73 inch/hour, and an average intensity of 0.19 inches/hour. Hyetograph for the five-year storm events is included in the Technical Exhibits.

Risk of sewer system overflows may include the following approaches:

- A review of the historical flow data for wet weather events equal to and exceeding to the parameters of the five-year design storm;
- A review of the history of wet weather SSO events, and an evaluation of the recurrence interval of the associated storms; and
- Use of a calibrated sewer system model to predict flows, hydraulic grade lines, and any identified areas with risk of SSO events.

5.6 DETERMINATION OF RAINFALL/INFLOW VOLUME RELATIONSHIP

Total inflow volume shall be established for all storm events having an average rainfall of approximately 0.20 inches per hour, and , and for any other storms for which an inflow response is readily observable. For each storm event, the total inflow volume (gallons) metered in each subsystem shall be correlated to total rainfall (inches) produced from the storm. This analysis shall be performed graphically as depicted in Figure 5 in the Technical Exhibits. The total inches of rainfall shall be designated as the X-axis and the gallons of total inflow attributed to a storm shall be designated as the Y-axis.

The graph produced by the rainfall/inflow volume relationship data developed for several storms can be used to estimate the inflow volume expected to be produced from a one-year, six-hour storm event (total rainfall of 1.72 inches in Boston). A linear regression can be performed (or alternatively a smooth curve fit) on the points of the graph. Then, using the one-year, six-hour storm rainfall volume on the X-axis and the derived rainfall/inflow volume relationship (graphed line or curve), the inflow volume expected from the one-year, six-hour storm can be read off the Y-axis.

In some instances it may be advisable to eliminate some rainfall/inflow volume relationship data from the design storm analysis if a reasonable explanation exists as to why the data should not be used. Examples of instances which may produce questionable results include unusually dry antecedent conditions, storm events occurring very close to one another, storms unusually short in duration with high rainfall intensity, collection system surcharging or overflows, etc.

If data is available for only one storm event, despite the recording of flow monitoring data for the prescribed minimum ten week period, then total inflow volume for the standard design storm may still be estimated by assuming: a linear relationship between total inflow volume and inches of rainfall; and that the line passes through the origin of the graph. This would result in extrapolating total inflow volume from the storm of record to the design storm based on the ratio of total inflow volume/inches of rainfall. Other techniques for correlating total inflow volume with rainfall will be evaluated by MassDEP on a case-by-case basis. Use of properly calibrated sewer system models is a generally accepted method of predicting inflow volumes.

5.6 CONSIDERATION OF FREE FLOW VERSUS RESTRICTED FLOW

In portions of collection systems with significant inflow problems, limited reserve capacity, or where a downstream restriction exists, the sewers may surcharge and/or overflow for some period of time during a storm event. If surcharging and/or overflows are known to occur or have been documented during the inventory of existing conditions phase of the project, this condition should be considered when estimating the design storm inflow volume through the regression analysis. During storm events, some combination of the following three flow conditions may exist.

Free Flow (Stage 1)

This condition generally occurs during the early part of the storm event before the design capacity of the sewer is reached, or during storms of lower rainfall intensity. Stage 1 is the condition where the rainfall/inflow volume evaluation is made using a regression analysis technique for several storm events.

Restricted Flow (Stage 2)

As rainfall intensity increases, collection system flows increase to the maximum flow capable of being reliably metered in the system. In a Stage 2 condition, the system is operating under surcharge or what can be described as a restricted state. Caution should be exercised when using the rainfall/inflow volume evaluation under storm events which cause restricted flow in the system. The total inflow volume may be approximately correct but the attenuation of flow may result in a smaller direct inflow volume and a larger delayed inflow volume estimate. Engineering judgment should be used in the analysis under a restricted flow condition.

Restricted Flow (Stage 3)
With increasing rainfall intensity the collection system conveys no more wastewater flow than in a Stage 2 condition, but experiences an increase in the hydraulic gradient until the system overflows. The rainfall/inflow volume evaluation should probably not be made for storm events which cause significant overflows or, if used, some estimate of the overflow quantity which was unmetered should be added to the estimated inflow volume.

5.7 SEWER SYSTEM EVALUATION SURVEY RECOMMENDATIONS

At the conclusion of the flow monitoring program, enough data should have been gathered and analyzed related to extent and volume of I/I in the collection system to develop the preliminary recommendations and associated costs to implement the follow up sewer system evaluation survey (SSES). The following sections summarize the methodology of developing recommendations for follow up work to prioritize sewer shed areas for infiltration and inflow investigations.

5.8 RECOMMENDATIONS FOR FURTHER STUDY TO IDENTIFY INFILTRATION SOURCES

At the completion of the flow data analysis portion of an I/I Analysis (or earlier, see single season two phase gauging in Section VI), an extensive manhole inspection and flow isolation program should be prioritized for all subsystems exhibiting an infiltration rate equal to or greater than 4,000 gpd/idm. Further work on subsystems with a lesser rate, while less of a priority, will often still yield cost-effective I/I removal work, and must be included as a later phased element of the overall I/I abatement program.

The recommendation for performing TV inspection on a small percentage of the collection system (without first performing an extensive manhole inspection and flow isolation program) should be considered. This recommendation should only be made for major interceptors or the community's largest or most critical sewers.

5.9 RECOMMENDATIONS FOR FURTHER STUDY TO IDENTIFY INFLOW SOURCES

At the completion of the flow data analysis portion of an I/I Analysis, the inflow estimated to be produced from the standard one-year, six-hour design storm shall be used to rank all subsystems from high to low on the basis of the following: volume of total inflow; volume of direct inflow; and volume of delayed inflow. On a first-cut basis, an SSES should be performed in the highest priority subsystems which account for not less than 80 percent of the total system inflow volume (including private sources). The use of the 80 percent threshold is only for the purpose of establishing initial priority. All subsystems impacted by inflow shall be evaluated, even if in later phases of work, so that all sources contributing inflow can be eliminated consistent with MassDEP regulatory requirements.

Subsystems which contain a high volume of direct inflow should be targeted for smoke testing and other inflow detection techniques aimed at identification of direct connections to the collection system. Subsystems which contain a high volume of delayed inflow should be targeted for property inspections (to identify sump pump connections) and other inflow detection techniques aimed at identification of indirect connections or connections which produce inflow after a significant time delay from the beginning of a storm. A significant portion of the delayed inflow volume may be generated by rainfall-induced infiltration (RII). SSES techniques for identification and removal of RII are typically less effective than those aimed at identification and removal of direct inflow.

Subsystems which exhibit a high peak inflow rate should be evaluated to determine if they are directly or indirectly contributing to SSO events in the system. The recommendations for proceeding with work to identify and remove inflow and rain-induced infiltration must initially be targeted at any subareas which have been determined to be causing or contributing to wet weather SSO events. It is possible that a large peak inflow rate in a subsystem may not create a significant town-wide or regional impact; however, a large peak inflow rate may create a severe local impact (environmental and/or public health hazard) and, therefore, should be evaluated.

Subsystems which contain tidal inflow should be targeted for physical inspections, with salinity testing at tide gates during high tide events, and other inflow detection techniques aimed at identification of defects allowing seawater to enter the collection system.

The results of these analyses and recommendations shall be presented to MassDEP in report form in accordance with 314 CMR 12.04(2), and are subject to MassDEP approval.

6. SINGLE SEASON TWO PHASE GAUGING

PURPOSE

The single season two-phase gauging program allows an optional approach to progress through an I/I study overview and into an SSES program in a single season. This approach saves one year's time and eliminates the problem of collecting I/I data in one season and comparing it to SSES data collected in a second season.

METHODOLOGY

Prior to the installation of gauges, prepare maps, identify subsystems, calculate inch-miles, and field verify gauge locations. Generally, up to the first four weeks of a ten week gauging program shall be devoted to identifying those sewer subsystems which demonstrate that an SSES program is warranted.

When sufficient dry weather high groundwater data from the initial four weeks gauging program has been collected, a preliminary analysis (principally for infiltration) shall be performed to select areas for further study (flow isolation during high groundwater conditions) based on the 4,000 gpd/idm rule. Flow isolation for areas less than 4,000 gpd/idm may also be pursued at this time but not in place of those areas with higher documented infiltration flows.

When this approach is taken, flow isolation should begin (see Section VI-3), and continuous monitoring of sewer flow in these areas should continue in order to supplement the data gathered during flow isolation. If sufficient wet weather data was not obtained during the initial four week gauging period, continuous monitoring should continue in all study areas to identify inflow.

If upon completion of the flow isolation data collection the 4,000 gpd/idm rule is not used to determine TV inspection eligibility, then the alternative method of prioritizing subareas for infiltration identification and removal should be described in the I/I Analysis Report.

Results of both phases shall be incorporated into a final report containing recommendations for both infiltration and inflow source rehabilitation.

7. SINGLE SEASON TWO PHASE GAUGING AND TV INSPECTION APPROACH

PURPOSE

This approach follows the same steps mentioned in the single season two phase gauging program, but in addition, TV inspection may be performed in the same season instead of performing it in the following spring. This approach saves one year's time and eliminates the problem of collecting flow data in one season and comparing it to TV data collected in a second season. If the flow data collected is satisfactory, this approach fast-tracks the investigation work and is the most preferred method.

METHODOLOGY

If groundwater levels remain high after flow isolation, TV inspection may be performed on manhole reaches exhibiting high infiltration. If possible, all subareas with flow isolation rates exceeding 4,000 gpd/idm should be included.

The measured flow isolation rate shall be compared to the estimated rates observed during TV inspection. In cases where the flow isolation rate is higher than the total of the estimated TV rates, the engineer can assign flow rates to the various defects observed during the TV inspection, taking into consideration the severity of each defect, and using the best engineering judgment. The observed plus the assigned flows should match the measured flow isolation rate, unless there are obvious large defects that should be considered on an individual basis.

8. PREPARATION OF REPORT

The I/I analysis Report must clearly and concisely summarize the findings and recommendations of the field investigations and data analysis. The following information must be included:

1. An Executive Summary highlighting all tasks performed, a subsection of conclusions and recommendations, approximate costs, and schedule for further work. It should also have summary tables and estimates of quantities of extraneous flows;
2. Description of existing wastewater treatment and collection systems;
3. Description of problems (overflows, bypasses, surcharging, etc.) within the system. Note past studies and rehabilitation work;
4. Sewer map delineating subsystems, gauging locations, sewer size, etc;
5. Summary of gauging results, including documentation on how wet weather flows were determined (adjustment to design storm, separate infiltration from base flow);
6. Summary of all information in tabular form (see Tables 1 through 6 in the Technical Exhibits);
7. A cost-effective analysis (if applicable);
8. An assessment of the SSO risk from a five-year design storm, based on findings of field investigations, history of wet weather SSO events, and system performance during similar or larger storms, or based on a calibrated sewer system model;
9. Recommendations – list proposed SSES work, including estimated cost and schedule. For larger sewer systems, SSES work can be proposed in phases which reflect prioritization of areas with the highest identified infiltration and inflow; and
10. Appendices – Include such items as limited manhole inspection sheets, flow hydrographs developed for each gauging area, dry weather flow curves developed for each area, any model calibration data, previous reports, photo documentation, and other pertinent information deemed appropriate.

9. COMPREHENSIVE SUBSYSTEM APPROACH

An optional alternative to the traditional I/I-SSES is the comprehensive subsystem approach. Following the initial flow monitoring, the subsystems are then ranked/prioritized, and the sewer authority moves directly into a design and construct mode, moving through the subareas with the greatest I/I contributions. The comprehensive work typically includes physical inspection of all manholes, TV inspection of all mainline sewers, smoke testing of all sewers, property inspection of all buildings, and some inspection of service laterals. The inspection shall be performed in one year and rehabilitation in the next. The inspection of the second priority subsystem shall begin the year that the rehabilitation of the highest priority system will begin. Under this approach, additional pipeline defects and inflow sources shall be identified and corrected, absent a detailed cost-effectiveness analysis. The entire system in each targeted subarea is rehabilitated in this approach. Given its scope, this approach generally achieves the highest I/I removals, and more sustained I/I removal, but comes at higher costs than simply pursuing cost-effective I/I removal.

VI. SEWER SYSTEM EVALUATION SURVEY

PURPOSE

The Sewer System Evaluation Survey (SSES) is performed as a follow up to the I/I analysis to locate and identify specific infiltration/inflow (I/I) sources in the sewer system. Typically, those sewer system drainage areas where infiltration or inflow was found to be excessive during prior investigations (normally an Infiltration/Inflow Analysis) are included in the SSES. By identifying the type of each I/I source and the flow from that source during the SSES, appropriate rehabilitation methods can be determined. Subsequently, a determination can be made whether removal of the I/I source is cost-effective. The data collected during the SSES may also be used to confirm the findings of the Infiltration/Inflow Analysis and, in particular, the extent of additional investigation, rehabilitation, and/or system improvements required in the areas investigated during the SSES.

1. GROUNDWATER MONITORING

PURPOSE

Groundwater monitoring should be performed during this phase of an SSES to: (1) confirm that the SSES infiltration field investigations are performed during high groundwater periods; (2) confirm that the smoke testing and rainfall simulation field investigations are performed during low groundwater periods; (3) allow a comparison of groundwater levels measured during prior investigations to the groundwater levels measured during the Phase 1 SSES; and (4) determine in which sewer basins/sub-basins included in this evaluation have the most potential for infiltration.

METHODOLOGY

Refer to Section V-3 for a description of groundwater monitoring methodologies.

2. RAINFALL MONITORING

PURPOSE

Rainfall monitoring should be performed to document precipitation events during SSES investigations. As described in the sections that follow, many of the SSES field investigations should be performed during dry weather periods. In addition, the impact of rainfall on groundwater levels can be evaluated using this data.

METHODOLOGY

During an SSES, total rainfall should be monitored using either a temporary rain gauge installed in the study area or an existing, permanent rain gauge located in the study area, if its accuracy can be verified. The rain gauge shall be accurate to within 0.01 inches of rainfall. In addition, the rain gauge shall be capable of electronically recording and totalizing rainfall amounts during each storm. One rain gauge should be provided for every two square miles of study area.

Rainfall data from other sources outside of the study area may also be used as a check against the rainfall data collected by the rain gauge described above, as noted in Section V-4.

3. FLOW MONITORING

FLOW ISOLATION GAUGING (if not done during prior field investigations)

PURPOSE

Flow Isolation is a more intense flow monitoring program that is performed to quantify infiltration within individual pipe sections (manhole-to-manhole). Sewers selected for inclusion in a Flow Isolation program are typically those sewers that are located within drainage areas where high infiltration was measured previously during an Infiltration/Inflow Analysis. In addition, sewer lines that cross under rivers, streams, lakes, marshlands or any other water courses or bodies of water may be included in a Flow Isolation program, even if they are located in sewer drainage areas where excessive infiltration was not measured previously.

METHODOLOGY

Flow Isolation shall be conducted on a manhole reach by manhole reach basis, during dry weather and between the hours of 12:00 A.M. and 6:00 A.M, when sanitary flows are typically minimal. Present and analyze flow isolation results by combining adjacent sewer segments so that the total length of the combined segments is approximately 1,000 LF, where possible, to minimize the potential for groundwater/infiltration migration. Infiltration migration is defined as groundwater infiltration to the sanitary sewer which moves from rehabilitated to non-rehabilitated sources. Rehabilitation of infiltration sources frequently raises in-trench groundwater elevations, which can cause un-rehabilitated defects to leak at greater rates than before rehabilitation or cause previously non-leaking sources to start leaking (e.g., service laterals). Migration does occur over a finite distance, and dissipates as in-trench groundwater dissipates to the soil outside of the sewer trench.

Flow Isolation gauging shall incorporate the use of portable, pre-calibrated weirs, where possible, or flow depth measurements in conjunction with flow velocity measurements, if the Flow Isolation location is not suitable for the installation of a portable, pre-calibrated weir. It is recommended that the upstream end of the sewer segment to be flow isolated be plugged, where possible. Allow flows to stabilize in the sewer prior to recording the flow rate.

Observed infiltration from manholes should be noted at the time of Flow Isolation and deducted from line section measurements, if necessary. The observed infiltration from manholes should be reported on the Flow Isolation logs. If not already available, a manhole numbering system should be developed to identify collection system locations where the Flow Isolation gauging was performed. Photo documents of field observations shall supplement field data.

4. SEWER TV INSPECTION FOR INFILTRATION

PURPOSE

The closed-circuit television (CCTV) inspections will pinpoint the location of I/I sources entering the sewer system and provide information on how the extraneous water is entering the sewer system (e.g., through cracked or broken pipe, open joints, direct pipe connections). This information should be used to confirm Flow Isolation Gauging results and to determine appropriate rehabilitation methods. Work should be conducted following jetting or cleaning of the sewer line. The inspections will provide a visual record of the pipe conditions and the defects observed.

The TV inspections shall provide the following information:

- Reference numbers of the manholes at each end of the inspection;
- Direction of flow and direction of the inspection;
- Sewer length, diameter, joint spacing and material of construction;

- Sewer condition;
- Presence of infiltration and an indication of the severity of the infiltration;
- Potential flow obstructions, including roots, grease and debris; and
- Sewer alignment concerns and the presence of sags.

METHODOLOGY CCTV

Televising for sewers and service connections to locate infiltration sources shall be conducted only during high groundwater conditions, between March 1 and June 30. The preference is that CCTV be performed during the same season as flow isolation. However, if it is determined and documented that groundwater levels are sufficient, and MassDEP receives prior notification, the TV inspections may begin prior to March 1 and/or extend beyond June 30. Nighttime flow isolation shall be conducted immediately prior to television inspection, where possible.

The TV inspections shall be performed in accordance with National Association of Sewer Service Companies (NASSCO) guidelines, as described by the Pipeline Assessment & Certification Program (PACP). Record the TV inspection results on standard log sheets and record a video of the inspection. The video should be accompanied by an audio recording describing defects and features encountered during the inspection. The video should indicate the distance of the camera from the manhole at which the inspection started at increments of 1/10th of a foot. The distances to the defects/features encountered should be identified on the video.

The infiltration rates measured during the Flow Isolation gauging, along with the infiltration rates estimated based on visual observations during the CCTV inspection program, are to be used in the cost-effectiveness analysis (C/E/A) for pipeline rehabilitation. The infiltration rates observed during the CCTV inspection program should be used to aid in estimating the infiltration contribution for each infiltration source observed during the CCTV inspection program.

If the CCTV infiltration rates estimated during the TV inspection program are drastically different from the infiltration rates measured during the Flow Isolation gauging, additional investigations shall be conducted in an effort to account for the differences. For example, where service laterals are observed to be running continuously, or a slug discharge that does not appear to contain waste is observed and the flow appears clear, inquiry at those houses where the services originate should be made to ascertain that no water was being used concurrent with televising, and the location should be added to the building inspection list.

Unless some realistic, documentable method is developed to adjust the infiltration rates observed through television inspection to better match the infiltration rates measured through Flow Isolation gauging, the measured Flow Isolation data, which is expected to be more accurate, should be used for the cost-effectiveness analysis. It is understood that groundwater levels may be different when each original analysis was performed, which could partially account for the difference.

If a sewer shed area is suspected of being influenced by RDII, then one should consider conducting an inspection program within that area during high groundwater and rainfall to ascertain the potential presence of additional sources of inflow not measured during the flow isolation program.

5. EXTENSIVE MANHOLE INSPECTIONS

PURPOSE

Extensive manhole inspections are performed during an SSES to help determine the quantity of I/I entering the sewer system from manholes in the drainage areas where I/I was determined to be high during prior investigations (an I/I Analysis). The SSES extensive manhole inspections typically include each manhole within the areas where infiltration and inflow were determined to be potentially excessive, except for those manholes already inspected during the I/I Analysis.

Manhole inspections provide data on: manhole size, construction and condition; pipeline size, construction and condition (at and near the inspected manhole); the presence of infiltration; the potential for inflow; and debris accumulation at the inspection locations. The manhole inspections can also provide information on the configuration of the sewer system and subsystem boundaries.

METHODOLOGY

The manhole inspections are usually performed during a high groundwater period to capture typical high groundwater infiltration. All the manholes and sewer lines in the subsystems determined to contain infiltration in excess of 4,000 gpd/idm, and in inflow areas which account for 80% of the total inflow based on the I/I Analysis should be included in the first phase of work. If possible, the inspection of manholes that are known to surcharge should take place during off-peak hours, when wastewater flows are more likely to be low, to minimize the potential for manhole surcharging, which could potentially reduce the portion of the manhole that can be viewed for inspection.

Particular attention should be paid to cross-country manholes located within the wetlands and the 100-year flood boundary. Manholes subject to flooding in marsh or wetland areas during significant rainfall periods, or overtopped by rising streams, are likely sources of significant inflow. These areas can be located using GIS mapping. Additionally, manholes located in these areas could be damaged during winter freeze-thaw cycles.

In most cases, the inspections can be completed from the ground surface. However, if the manholes are so deep that the bottom portion of the manhole cannot be viewed from the surface, then manhole entry will be necessary to complete the inspection. In addition, if detailed information on connecting piping is needed, then the manholes should be entered and the pipes should be lamped or, alternatively, a zoom camera may be used to collect information on the connecting piping. Where any manhole entry is required, safety precautions for confined space entry must be employed.

If there is a GIS database of the sewer system under investigation and manhole location information is not currently included in the database, the collection of manhole location information during the manhole inspections using global positioning system (GPS) instrumentation is recommended.

Manhole inspections should include, at a minimum, gathering the information listed below, in accordance with National Association of Sewer Service Companies (NASSCO) guidelines, as described by the Manhole Assessment & Certification Program (MACP) for a Level 1 inspection.

a. Identify the manhole by its discrete map reference number and the street where it is located closest to; or by its GIS unique identification number (where possible).

b. Indicate the manholes immediately upstream and downstream of the inspected manhole.

c. Provide photographs of the inspection location and manhole interior, showing, in particular, the defects observed.

d. Record the material of construction of the manhole components (frame, cover, corbel, walls, invert, shelf, etc.).

e. Document the condition of the manhole components, including especially the presence of cracks, breaks and other defects.

Note the potential for inflow, including:

- Manhole cover type and condition;
- Whether the cover is a locking type and whether it is gasketed;
- Frame condition;
- Condition of risers/brickwork below frame;
- Number of holes in the cover and the size of the holes;
- Whether the cover is subject to ponding;
- An estimate of the drainage area and potential depth of ponding so that an approximate rate of inflow can be assigned to this manhole, if applicable; and
- Condition of the surrounding ground or street (e.g., cracks in the pavement that could be pathways for inflow).

Table 7 in the Technical Exhibits provides suggested inflow rates that can be assigned to the various defects noted.

f. Record active infiltration and signs of previous infiltration. Estimate the rate of active infiltration and compare to infiltration rates observed during Flow Isolation gauging. The higher values should be used for the cost-effectiveness analysis.

g. Document manhole depth and the depths to each connecting pipe (rim to invert at center of pipe.

h. Record the groundwater level in the manhole or invert in and invert out of mainline pipes); and the high water mark, if discernible.

i. Document the presence of roots, grease and debris in the manhole.

Standard forms are recommended so that the information collected at each manhole will be consistent and the potential for missing data will be minimized. A sample manhole inspection form is included in the Technical Exhibits.

6. SMOKE TESTING

PURPOSE

Smoke testing can identify the locations where stormwater/groundwater may be entering the sanitary sewer system. Direct connections, including catch basins, downspouts, area drains, driveway drains, stairwell drains, patio drains, and storm drain inlets or ditches can be confirmed with smoke testing. Potential indirect connections from storm drains or ditches to the sanitary sewer, which require I/I to pass through soil seams, can also be identified with smoke testing.

METHODOLOGY

Smoke testing shall be conducted between July 1 and November 15, during periods of low groundwater, and after sufficient time has elapsed from the previous rain event. However, if it is determined that field conditions are appropriate and documented for smoke testing, and MassDEP receives prior notification, smoke testing may be performed prior to July 1 or after November 15. No testing should be conducted in an area unless groundwater is below the sewer pipe at the groundwater monitoring location in that area, and the ground is not frozen. Prior to initiating smoke testing, property owners, hospitals, clinics, senior housing, police and fire officials should be notified.

If smoke testing has been initiated and subsequently stopped because of rain, re-initiation of testing shall not occur until conditions are suitable. A test segment which was previously tested and had one or more indirect sources with smoke transfer through soil seams may be used as an indication that suitable low groundwater and dry soil conditions have returned. Regional groundwater wells and manhole groundwater monitors may also be used to obtain information for area-wide groundwater levels.

In most cases, smoke testing shall be conducted using a single blower with smoke introduced at the blower. The maximum allowable set-up length shall be no more than two manhole reaches, typically 600 to 800 feet. Field crews shall ascertain that adequate smoke coverage has been obtained by observing smoke concentrations and observing smoke travel using house plumbing vents along the set-up. Smoke shall continue to be introduced at the blower location until adequate smoke coverage has been obtained. In the event that smoke does not travel through the entire reach, the set-up shall be reversed by setting the blower on the opposite end of the set-up and re-introducing smoke. Since this situation may be caused by a line sag, grease or debris buildup, a collapsed pipe, or other obstruction, it should be documented as a potential maintenance problem area.

Isolate the sewer segment to be smoke tested by placing sandbags, cones or plugs at each end, where possible, in order to concentrate the smoke within the test section.

In situations where heavier smoke concentrations are required, two blowers may be used with a smoke blower placed on both the upstream and downstream manholes of the set-up and smoke generated at each blower. The maximum set-up length in this situation will typically be one manhole reach, or 300 LF if the manhole reaches are shorter than the typical reach lengths.

Document confirmed inflow sources to the sanitary sewer. In addition, record suspect inflow sources to the sanitary sewer that may not have smoked or smoked only lightly. Suspect sources may include driveway drains, stairwell drains, window well drains, patio and area drains, and downspouts piped underground or into building foundations. The suspect sources may warrant further investigation, such as follow-up Dyed Water Testing or building inspections.

Care should be taken to inspect all properties for smoking sources. In situations where heavy smoke is exiting a source, and it can be determined and documented through observation that the source is directly connected to the sanitary sewer, further investigation may not be necessary. In all other situations where it cannot be determined conclusively that a source is directly connected to the sanitary sewer, further or follow-up investigation, possibly including dye testing, is warranted.

Confirmed sources that smoked shall be photographed, documented, and if possible the drainage area to that inflow source measured with an estimated inflow rate determined. Make note of all suspected sources.

7. RAINFALL SIMULATION

PURPOSE

Rainfall Simulations can be used to identify/confirm inflow sources to the sanitary sewer system using two possible methods: Dyed Water Testing; and Dyed Water Flooding. Dyed Water Testing is used to identify direct connections to the sanitary sewer (e.g., catch basins, roof leaders, yard drains, etc.). Dyed Water Flooding is used to identify indirect connections between storm drains or drainage ditches and the sanitary sewer. For example, stormwater can leak out of a storm drainage system with structural deficiencies, percolate through the soil, and enter a nearby sanitary sewer through cracks or open joints.

Rainfall simulations can also be performed, in conjunction with sewer flow monitoring, to provide information on inflow rates from each of the identified sources.

Rainfall Simulations shall be conducted between July 1 and November 15, during periods of low groundwater. However, if it is determined that field conditions are appropriate for Rainfall Simulations, and if approval is received from MassDEP, Rainfall Simulations may be performed prior to July 1 or after November 15.

If the infiltration/inflow analysis demonstrates that major inflow problems occur during periods of intense rainfall, a controlled systematic check of all storm sewers that parallel or cross the sanitary sewer system and/or house services should be initiated.

METHODOLOGY

7.1 Dyed Water Testing

As noted above, Dyed Water Testing is performed to identify/confirm direct inflow sources to the sanitary sewer system, such as catch basins, downspouts, area drains, patio drains, window well drains, stairwell drains, sump pumps, and driveway drains. Direct inflow sources may not always be detected through smoke testing due to trapped building service laterals or clogged drains.

Suspect direct inflow sources should be recorded during smoke testing and/or during house-to-house surveys and targeted for subsequent Dyed Water Testing.

Dyed Water Testing is performed by introducing dyed water into a suspect inflow source, and then observing at a downstream sanitary sewer manhole whether dyed water enters the nearby sewer. The presence of dyed water in the sanitary sewer would confirm the inflow source connection.

Obtain permission from property owner prior to performing investigations on private property. Care should always be taken when working with dyed water on private property. Clogged drains should be cleared, where possible, and clear water should be injected into the drain prior to the use of dye to ensure that the drain being tested will accept water.

Dyed Water Testing should not be conducted when temperatures are expected to be near or below freezing.

7.2 Dyed Water Flooding

As noted above, Dyed Water Flooding is performed to identify/confirm indirect inflow sources to the sanitary sewer system, typically from leaking storm drainage piping and/or structures or drainage ditches.

Direct connections between storm sewers and sanitary sewers are normally detected with smoke testing and may be confirmed with dyed water tracing.

Indirect cross connections between storm sewers and sanitary sewers are normally identified with smoke testing and subsequently confirmed with dyed water flooding. Dyed Water Flooding is performed by plugging the ends of a storm drain segment or drainage channel suspected to be leaking into a nearby sanitary sewer and subsequently filling it with dyed water. Fire hydrants are normally used as the water source if permitted by local officials. There should be a waiting period of at least one hour after initiation of Dyed Water Flooding of a drain segment before the test is considered negative. Flow in the sanitary sewer shall be measured both before and after a Dyed Water Flooding test to estimate the flow rate from the cross connection between the storm drain/channel and the sanitary sewer.

Where Dyed Water Flooding identifies an inflow source, that source may requirefurther investigation during the SSES by performing Dyed Water Flooding in conjunction with television inspection (referred to as Dyed Water Tracing) to identify the exact location(s) of the cross connection(s) and how the drainage flow is entering the sanitary sewer (e.g., through pipe cracks, service pipes, etc.). This is described later in these guidelines. After completion of dyed water flooding, and dyed water tracing, inflow balancing should be performed. If the majority of the inflow has been identified from direct connections the flooding of possible indirect connections may not be necessary.

8. PROPERTY INSPECTIONS

PURPOSE

Property inspections or house-to-house inspections are performed to visually identify inflow sources on private property in the drainage areas where high inflow was identified during prior investigations (typically during an Infiltration/Inflow Analysis).

METHODOLOGY

The owner of each property targeted for inspection should be notified that an inspection is planned, the purpose of the inspection, and the extent of the inspection. The public notification effort should be determined on a case-by-case basis, depending on the requirements of the municipalities, public safety officials, and governing bodies. The notification program may include the publication of information on the planned inspections in local newspapers, notification via radio or telephone, social media, and the distribution of door-to-door leaflets to increase public awareness. The goal of the program should be to improve property owner cooperation.

Inspectors should be appropriately dressed and carry a letter of authorization and photo identification from the municipality. They should also carry a copy of the section of the municipality's regulations which address its inspection powers.

Before beginning an inspection on private property, the inspector should introduce him/herself to the owner or tenant of the building, explain the purpose and extent of the inspection, and ask permission to begin the investigation. The investigation should cover the entire property, both indoors and outdoors.

Outside the building(s), the inspector should look for and make note of any:

- yard drains;
- patio drains;
- driveway drains;
- sidewalk drains;
- window well drains; and
- roof downspouts leading underground or through the building foundation

Inside the building(s), the inspector should look for and make note of any:

- Wet or damp basement floors and walls;
- sump pumps, discharge pipe type and discharge location;
- floor drains, and sumps;
- Perimeter drains;
- roof leader or foundation drain pipes coming in from outside; and
- removed, uncapped sewer cleanouts, or cleanouts located below the basement floor elevation.

The inspector should note if any of these potential inflow sources connect directly to the building's sewer service.

If it is not evident where a potential source of inflow drains, then the property owner should be consulted and any information on discharge locations should be verified through dyed water testing, if feasible. Sump pumps with unconfirmed discharge locations shall be recorded as inflow sources.

If available, the smoke testing results should be cross checked with the building inspection results. If a property owner will not allow an inspection, the inspector should document that the inspection was not allowed so that the municipality can determine whether future action to inspect that building is warranted.

A list should also be kept of owners who are not at home during the inspection. A second call back should be made at a different time of the day or on a weekend. If multiple attempts have been made at a property without successful access, or if access is refused, the sewer authority must have a process for notifying the owner of their legal right to an inspection, citing any penalties for non-compliance.

Standard inspection forms are recommended so that the information collected at each property will be consistent, and to minimize the potential that some data will be missed. A sample building inspection form is included in the Technical Exhibits.

9. FLOW DATA ANALYSIS

A preliminary analysis of the SSES data should be performed to determine if additional investigations are warranted. The preliminary analyses are described below for infiltration and inflow.

9.1 INFILTRATION

Sewer segments determined to have excessive infiltration, based on the Flow Isolation gauging, should be included in a television inspection program. Segments with infiltration rates above 4,000 gallons per day per inch of pipe diameter per mile of pipe length (gpd/idm) should all be considered for the television inspection program. As noted previously, the sewer segments should be evaluated in 1,000± foot total lengths, to the extent possible, to minimize the potential for infiltration migration from the rehabilitated defect to another defect. In arranging the individual sewer segments into unit lengths of 1,000± feet, individual segments should not be used more than once.

For sewer segments with infiltration rates lower than 4,000 gpd/idm, a preliminary cost-effectiveness analysis may be performed during this phase of the SSES to demonstrate that these segments with lower infiltration rates are also appropriate for TV inspection. See Section VI 9.3 for a description of the suggested methodology for performing the cost-effectiveness analysis (C/E/A).

If a preliminary C/E/A is performed during this phase, assume 50% peak infiltration removal and assumptions for various forms of rehabilitation. The percent infiltration removal and rehabilitation method can be refined using additional historical information or information collected during Phase 2 of the SSES.

Infiltration is defined as being excessive if:

- The infiltration sources are directly or indirectly substantially contributing to wet weather SSO events, as set forth in a MassDEP enforcement action, or otherwise as necessary to prevent SSO events for a five year storm event, or a twenty five year storm event to areas with sensitive use, such as but not limited to areas of water supply protection; or
- Infiltration sources can cost-effectively be removed from the sewer system, based on a comparison of the costs of removal to the costs to transport and treat the flows.

I/I MECHANISMS FOR ADDRESSING INFILTRATION MIGRATION
Televise sewers for infiltration in clusters to avoid a patchwork approach to rehabilitation. This will minimize remaining infiltration from a large number of leaking sources.

A rehabilitation program to minimize groundwater migration effects should be designed by performing a (C/E/A) on a system-wide basis as opposed to the traditional point source approach.

9.2 INFLOW
The SSES inflow data collected should be reviewed to determine whether Dyed Water Tracing is warranted. As noted previously, if an indirect inflow source was identified during Dyed Water Flooding, that source should be further investigated through Dyed Water Tracing, as described in Section VI 7.2.

9.3 FINAL COST-EFFECTIVENESS ANALYSIS
PURPOSE
A C/E/A must be performed for infiltration as part of an SSES to determine whether the I/I in the system is excessive. Infiltration in the system is defined as being excessive if the costs for the removal of the infiltration source are less than the costs for transportation and treatment of these flows. In limited instances, cost-effectiveness analyses can be done for inflow sources, when costs of inflow removal sources are judged to be extremely high.

METHODOLOGY
General
For the C/E/A, a life cycle evaluation should be performed that considers both capital costs and annual operation and maintenance costs. The annual operation and maintenance costs should be converted to present worth costs so that the capital costs and operation and maintenance costs are on an equal time basis. The planning period for the C/E/A should generally be 20 years, but higher or lower planning periods should be used corresponding to the design life of the rehab fix. The interest rate used to develop present worth costs should reflect the borrowing rate from the sewer authority. Sunk costs and study costs are not to be included in the C/E/A.

The analysis will require engineering judgment regarding the life expectancy of the various rehabilitation methods.

Transport and Treatment Costs
The total cost to transport and treat the flow from an I/I source is the sum of:

(1) The assessed cost/gallon to transport and treat wastewater in the community;
(2) Any capital costs required to improve the sewer collection system and/or the wastewater treatment facility (WWTF) so that they can accommodate the flow from the I/I source (e,g., pump station upgrades, WWTF expansion, etc.); and
(3) The additional operation and maintenance costs related to the flow from the I/I source (e.g., additional chemical costs at the treatment facility, additional electricity usage at the WWTF, additional labor by operations staff, additional electricity usage at pump stations downstream of the I/I source, etc.).

Rehabilitation Costs - Infiltration
As noted previously, rehabilitation costs should be developed for the 1,000± LF combined sewer segments established during the evaluation of the Flow Isolation data to determine whether infiltration removal is cost-effective. Sewer segments were grouped into 1,000 ± LF lengths to minimize the potential for groundwater/

infiltration migration from a rehabilitated defect to another defect. Rehabilitation methods for both mainline sewers and service laterals that may be considered include, but are not limited to:

- Air testing and sealing with a chemical grout;
- Cured-in-place pipe lining (along the entire sewer reach, from manhole to manhole);
- Short liners;
- Spot repairs (dig and replace); and
- Pipe replacement (dig and replace).

Engineering judgment shall be used to estimate the percent infiltration which can be removed based on the observed defects, general pipe condition, percent of infiltration flow from private sources vs. percent of infiltration flow from sources in the public right-of-way, and the effectiveness of the rehab work being recommended.

The estimated rehabilitation cost for each 1,000 feet of sewer, including manholes, shall be based on the appropriate rehabilitation technique required for the removal of the infiltration sources identified during televising. The flows used for the C/E/A of each 1,000 linear foot segment shall be the flows calculated in the infiltration analysis.

<u>Rehabilitation Costs - Inflow</u>
No C/E/A is warranted for inflow sources, as the sewer authority must have a program to prioritize and remove inflow connections to the sewer, which are prohibited. Accordingly, inflow sources must be documented, confirmed, and removed. This is typically done in a phased program, which prioritizes the subareas with the highest inflow contributions. In instances where removal of an inflow source is technically infeasible, or where removal will incur extreme expense, the sewer authority must document this determination in the SSES report.

10. PREPARATION OF REPORT

The report on the SSES must clearly and concisely summarize the findings and recommendations of the field investigations and data analysis. The following information should be included:

a. An Executive Summary highlighting all tasks performed, a subsection of conclusions and recommendations and approximate costs. It should also have summary tables and estimates of quantities of I/I components;
b. Description of existing wastewater treatment and collection system;
c. Description of problems (overflows, bypasses, etc.) within the system, including past studies and rehabilitation work;
d. Delineation of subsystems, gauging locations, sewer size, etc;
e. Outline gauging/internal inspection program;
f. Summary of gauging results. Show how wet weather flows were determined (adjustment to design storm, separate infiltration from base flow). Include rainfall/inflowgraphs;
g. Results of inspections and recommendations for rehabilitation;
h. Cost-effectiveness Analysis – demonstrate how transportation and treatment costs are derived and present in a tabular form. (See Table 3 in the Technical Exhibits);
i. Recommendations – list proposed recommendations including cost and schedule. Recommendations shall include:

1. Any further investigations needed to confirm infiltration and inflow sources;
2. A plan and schedule to address identified inflow sources;

3. A plan and schedule to address cost-effective infiltration removal;
4. A post-construction flow monitoring program to document the effectiveness of the I/I removal work; and
5. Other recommendations to optimize and integrate sewer system maintenance work with the I/I abatement program, such as modification of local sewer use regulations, sewer system modeling, and findings and recommendations of a Capacity, Management, Operation and Maintenance (CMOM) program.

j. Appendix – include such items as manhole inspection sheets, internal inspection logs, smoke test and dye water flooding logs, property inspection data, and other pertinent information, as deemed appropriate.

While the specifics of the post-construction program will be dependent on the characteristics of your conveyance system and the particular rehabilitation methods, any program shall involve flow monitoring at key points within the system. At a minimum, this monitoring shall be conducted during both high and low groundwater periods to determine the actual quantities of infiltration and inflow removed. If either the groundwater conditions or the rainfall events during the initial round of post-construction monitoring do not adequately replicate the original study conditions, then further monitoring and/or additional I/I investigation work will be required.

Even following aggressive I/I abatement work, sewer authorities should continue to budget money to sustain an I/I identification and removal program, as infrastructure conditions continue to change.

VII.
TECHNICAL EXHIBITS

TABLE 1
I/I ANALYSIS
SUMMARY TABLE FOR INFILTRATION

(1)* RANKING	(2) SUBSYSTEM	(3)** SEWER LENGTH Ft.	(4) AVERAGE PIPE DIA in.	(5) PEAK INFILTRATION gpd	(6) INFILTRATION RATE gpd/idm	(7) RECOMMENDED FOR FLOW ISOLATION
1	F	20,000	8	1,288,000	42,504	YES
2	C	22,000	11	833,000	18,175	YES
3	B	18,000	13	700,000	15,800	YES
4	D	23,000	9	500,000	12,750	YES
5	A	19,000	12	400,000	9,263	YES
6	E	21,000	30	835,240	7,000	YES
7	H	20,000	12	190,000	4,180	YES
8	G	24,000	8	100,000	2,750	NO
9	J	18,000	10	60,000	1,760	NO
10	K	19,000	10	40,000	1,112	NO
TOTAL		204,000		4,946,240		

* Ranking based on highest Infiltration rate (column 6)

** Exclusive of house services

NOTE: Above figures are used as an example for illustration purpose only.

TABLE 2
I/I ANALYSIS
SUMMARY TABLE FOR INFLOW

(1)* RANKING	(2) SUBSYSTEM	(3)** SEWER LENGTH Ft.	(4) AVG. PIPE DIAM. in.	(5)*** DESIGN STORM TOTAL INFLOW VOLUME gal	(6) DESIGN STORM TOTAL INFLOW RATE gal/idm	(7) % TOTAL INFLOW	(8) COMMULATIVE PERCENT
1	A	19,000	12	500,000	11,580	30%	30%
1	F	20,000	8	400,000	13,200	24%	54%
3	D	23,000	9	400,000	10,200	24%	78%
4	B	18,000	13	150,000	3,384	9%	87%
5	C	22,000	11	120,000	3,272	7%	94%
6	E	21,000	30	100,000	83	6%	100%
TOTAL		123,000		1,670,000			

* Ranking is based on highest Inflow rate (column 7)

** Exclusive of house services

*** Total rainfall of 1 year design storm event is 1.72 inches
Determination of Design Storm Inflow based on analysis of metered inflow vs. rain data (see **Figure 5)**

NOTE: Above numbers are used as an example for illustrative purposes only.

TABLE 3
SSES
SUMMARY TABLE OF INFILTRATION
COST EFFECTIVE ANALYSIS FOR REHABILITATION
*SUBSYSTEM NO. F

(1) RANKING	(2) SEGMENT MH TO MH	(3) SEWER LENGTH Ft.	(4) PIPE DIAM. in.	(5) TYPE OF PIPE	(6) PEAK INFILTRATION gpd	(7) REMOVABLE INFILTRATION gpd	(8) T&T* COST $	(9) TYPE OF DEFECT	(10) REHAB METHOD	(11) DESIGN LIFE YRS	(12) REHAB COST	(13) COST EFFECTIVE
1	13-15	1,000	8	VC	40,000	20,000	350,000	CRACKS	CIPP		50,000	7.0
3	5-7	1,100	8	VC	12,000	6,000	40,000	CRACKS	T&S		11,000	3.6
4	28-30	950	10	VC	6,800	3,400	5,100	CRACKS	ROOT TR..		1,900	2.7
2	17-20	1,050	8	VC	16,000	8,000	12,000	OFSET JT.	DIG & REPL.		8,000	1.5
5	32-40	1,200	8	PVC	1,800	900	16,000	OFSET JT.	CIPP		50,000	0.32
TOTAL												

* One table for each subsystem

NOTE: Above figures are used as an example for illustration purpose only.

TABLE 4

SUGGESTED GUIDE FOR FLOW [1]

INFLOW SOURCES	AVERAGE INFLOW RATE (gpm) [2]	DESIGN STORM TOTAL INFLOW VOLUME (gal)[3]
MANHOLE DEFECTS		
Ponding Manhole	3.0[4]	1000[5]
Pick or Vent Hole (Per hole)		
Diameter		
½"	1.2[6]	432[7]
¾"	2.7[6]	1000[7]
1"	4.8[6]	1730[7]
1 ¼"	7.5[6]	2700[7]
Rim Seal	1.0-5.0	
Corbel Lead or Cracked Frame Seal	0.5-1.5	
Broken Frame	1.0-2.0	
MAIN SEWER DEFECTS		
Cross Connections	5-25	
PRIVATE SECTOR SOURCES		
Storm Sump Pump to Sanitary Sewer	3.0-6.0	1200
Foundation Drain or Floor Drain	3.0-6.0	
Downspout	3.0[4]	1000[5]
Driveway Drain	3.0[4]	1000[5]
Window Well or Stairway Drain	0.5-1.0	

<u>NOTES FOR TABLE 4</u>

(1) Individual sources may be assigned different rates based on site conditions, and best engineering judgment.

(2) Based on Average rainfall intensity of 0.29 in/hr (Design Storm). Peak flow rate may be also considered based on peak rainfall intensity of 0.87 in/hr.

(3) Based on total rainfall of 1.72 in. (Design Storm).

(4) Flow is calculated by using the rational formula assuming the following: Q = CiA

Area of discharge = A (Acres)
Coefficientof discharge = C
Average rainfall intensity = i in/hr

This yields Q in CF/sec. Q is then converted to gpd.

For accurate calculation area of discharge must be measured in the field and coefficient of discharge will vary according to the type of soil/pavement.

(5) Estimated volume of inflow is based on the same parameters of the flow rate except the intensity used is the total rainfall of the design storm, which is 1.72” (in).

(6) Flow rate is per hole and assuming 2” (in) head of rainfall accumulation.

(7) Estimated volume of inflow is based on a duration of 6 hours of rainfall.

TABLE 5

PRECIPITATION FREQUENCY ESTIMATES (inches)

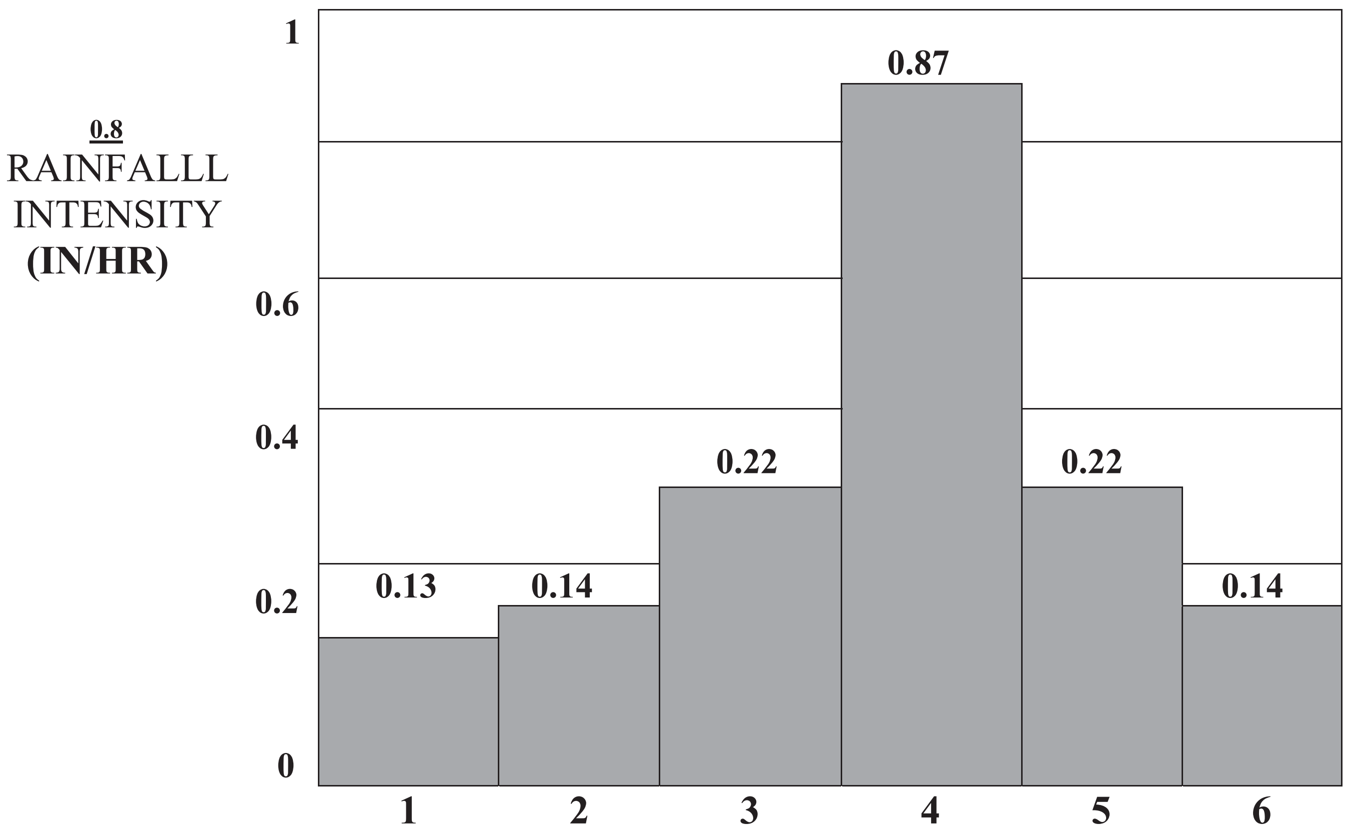
Middlesex County - Weston, MA

Latitude: 42.3833°, Longitude: -71.3167°

Duration of storm	**Average storm recurrence interval (years)**					
	1	**2**	**5**	**10**	**25**	**50**
30-min:	0.71	0.87	1.12	1.34	1.63	1.85
60-min:	0.90	1.10	1.42	1.69	2.06	2.35
2-hr:	1.16	1.42	1.85	2.20	2.69	3.06
3-hr:	1.34	1.65	2.14	2.56	3.12	3.56
6-hr:	1.73	2.12	2.75	3.28	4.01	4.57
12-hr:	2.19	2.68	3.48	4.15	5.06	5.77
24-hr:	2.61	3.23	4.23	5.07	6.22	7.10
2-day:	2.94	3.69	4.93	5.95	7.36	8.44
3-day:	3.21	4.01	5.34	6.44	7.95	9.12
4-day:	3.46	4.30	5.67	6.80	8.36	9.57
7-day:	4.18	5.05	6.48	7.66	9.28	10.53

Data from NOAA Atlas 14 Volume 10 Version 2

BASED ON: LOGAN AIRPORT RAINFALL DATA
JUNE, 1948 – DECEMBER, 1977



TIME (HRS)
TOTAL RAINFALL 1.72 INCHES
ONE YEAR SIX HOUR STORM HYETOGRAPH

FIGURE 1

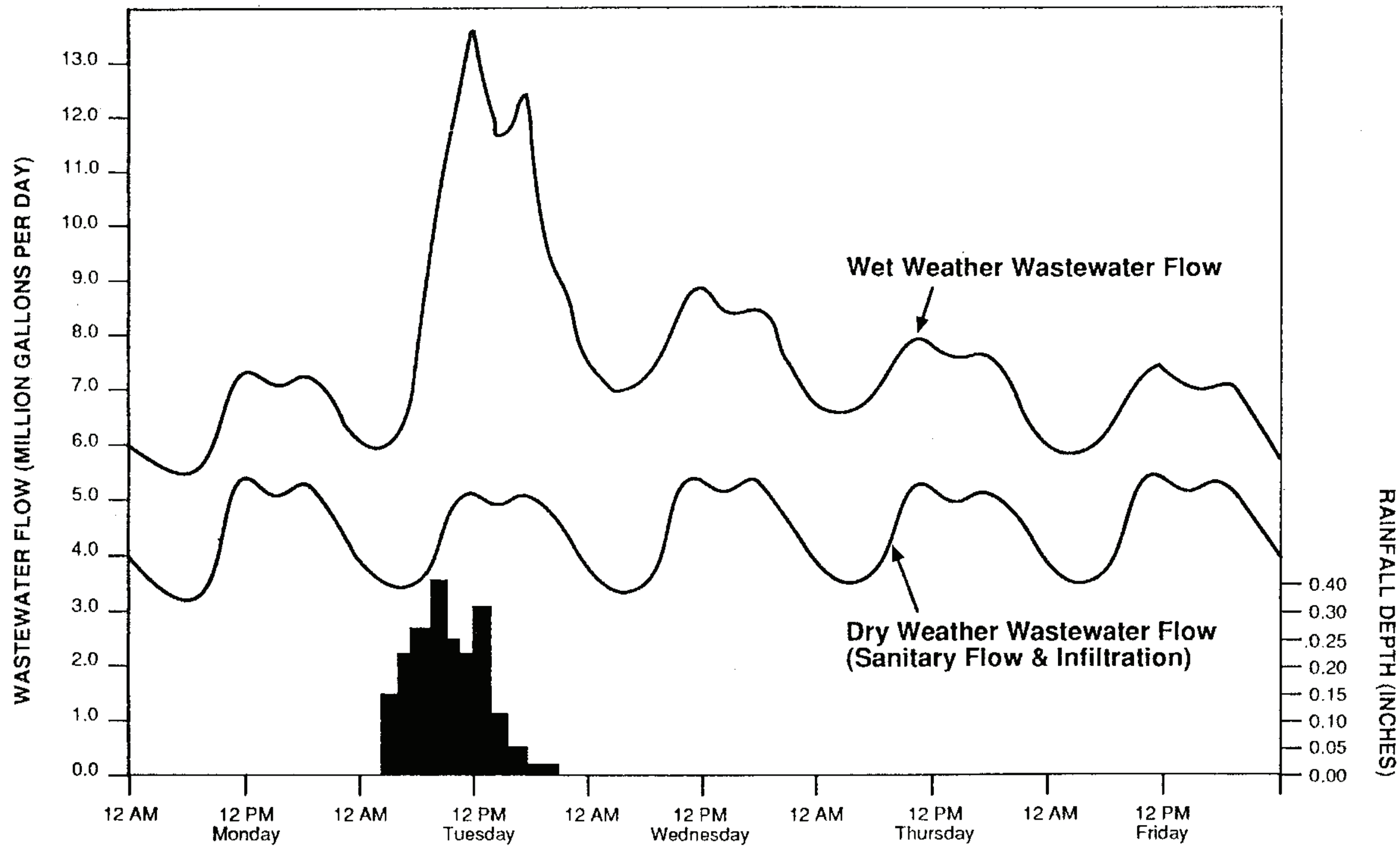


Figure 2
DRY AND WET WEATHER WASTEWATER FLOW WITH RELATED RAINFALL HYETOGRAPH

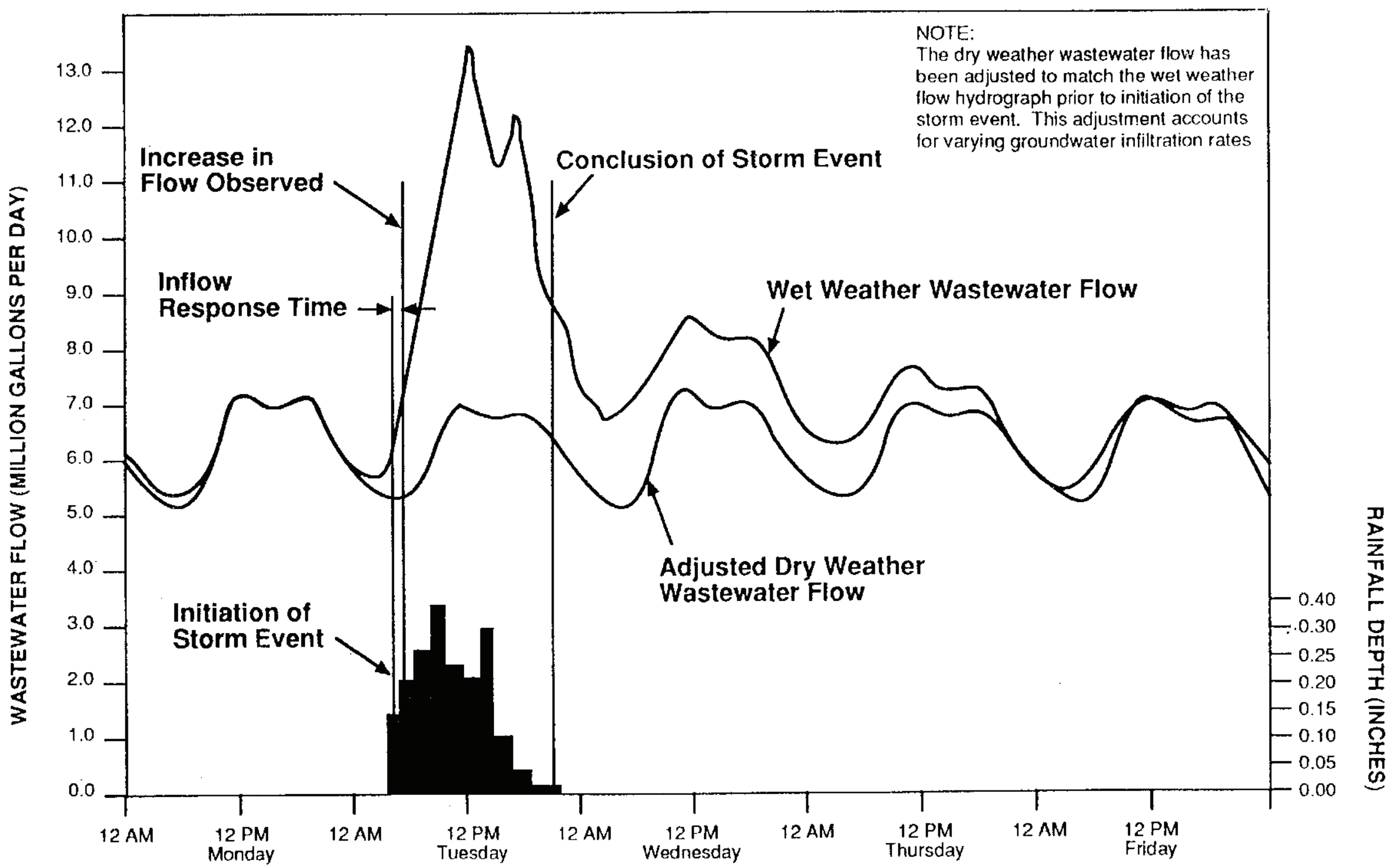


Figure 3
DRY (ADJUSTED) & WET WEATHER WASTEWATER FLOW WITH RELATED RAINFALL HYETOGRAPH

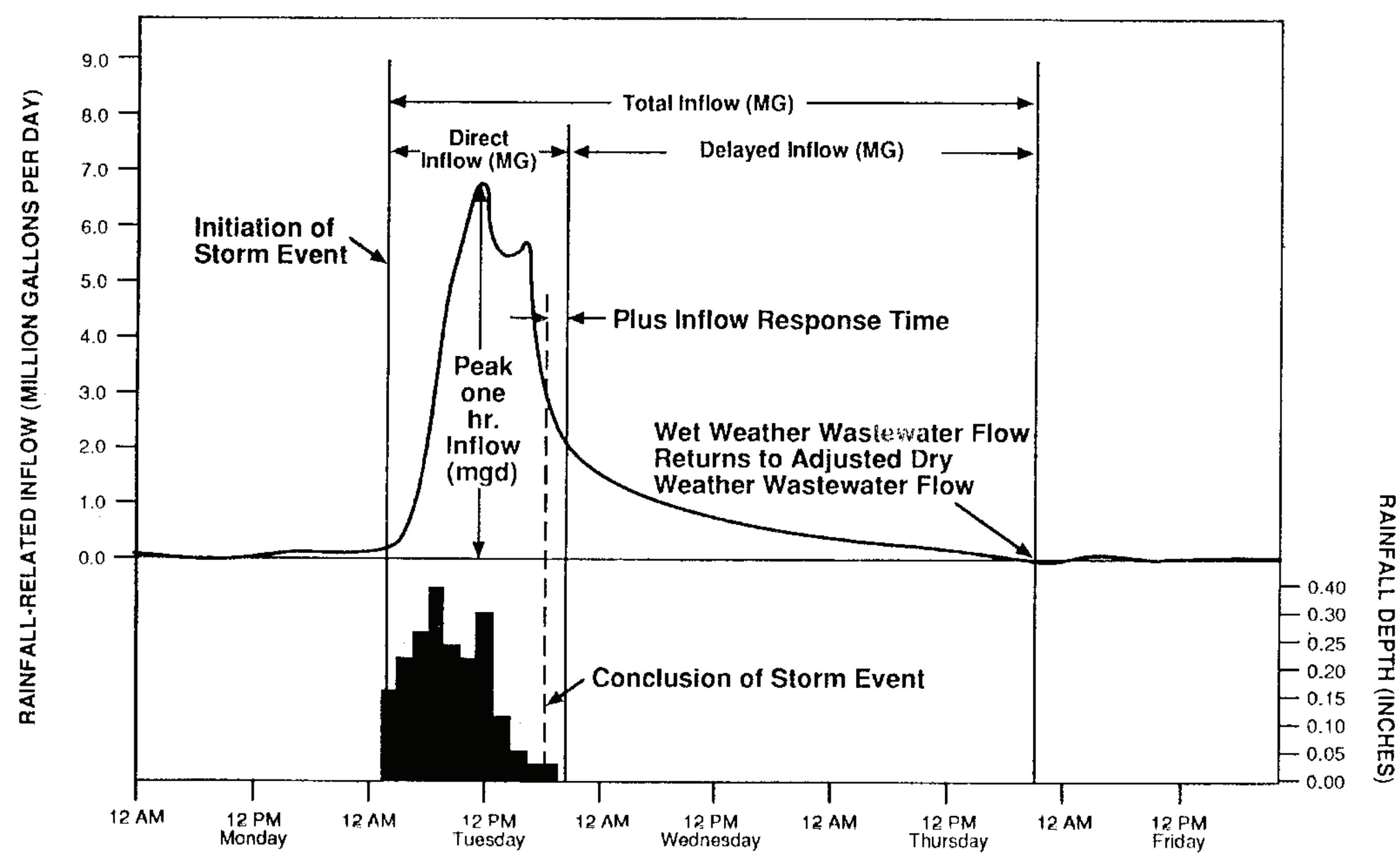


Figure 4
TOTAL INFLOW HYDROGRAPH CURVE WITH RELATED RAINFALL HYETOGRAPH

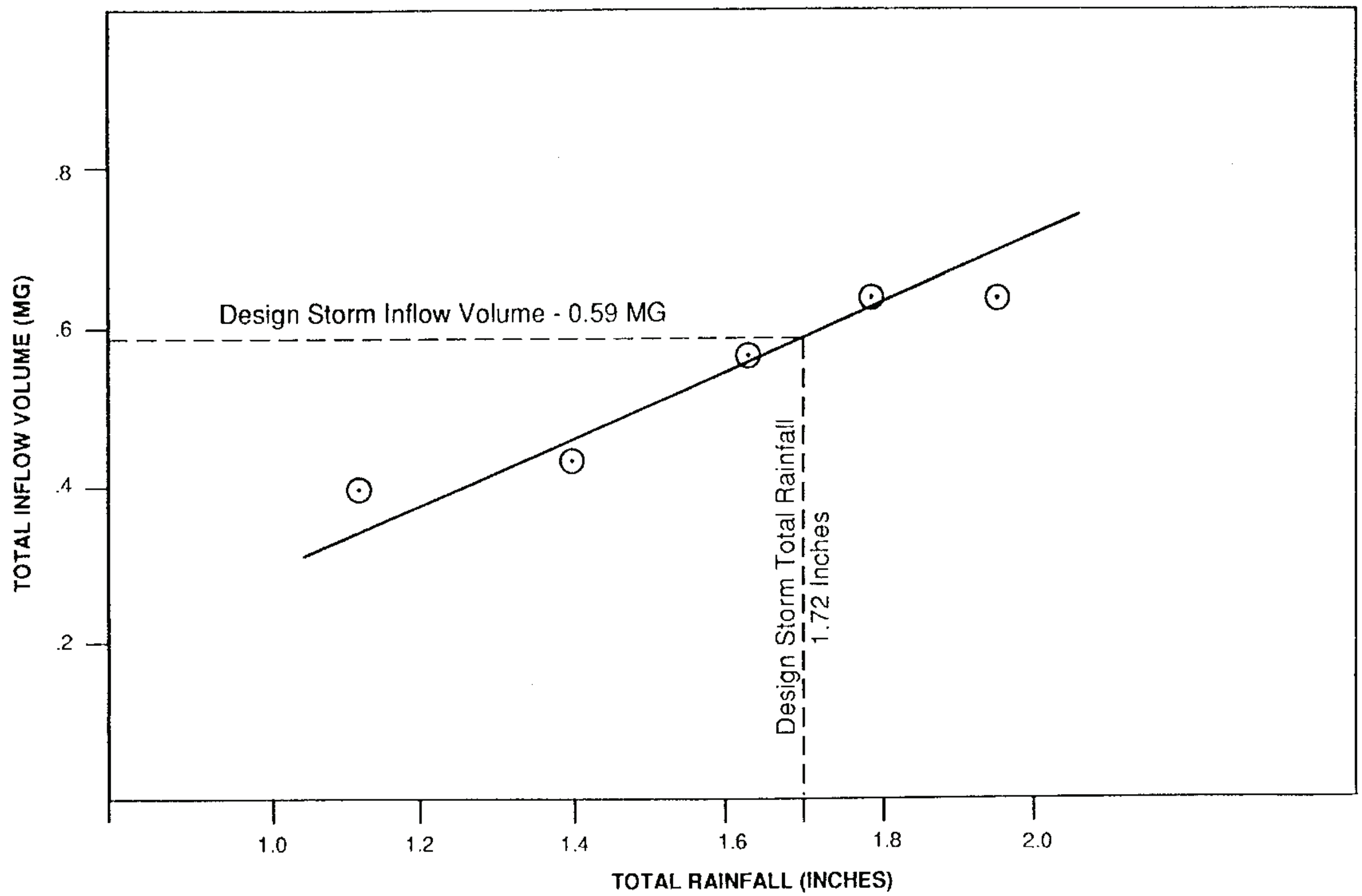
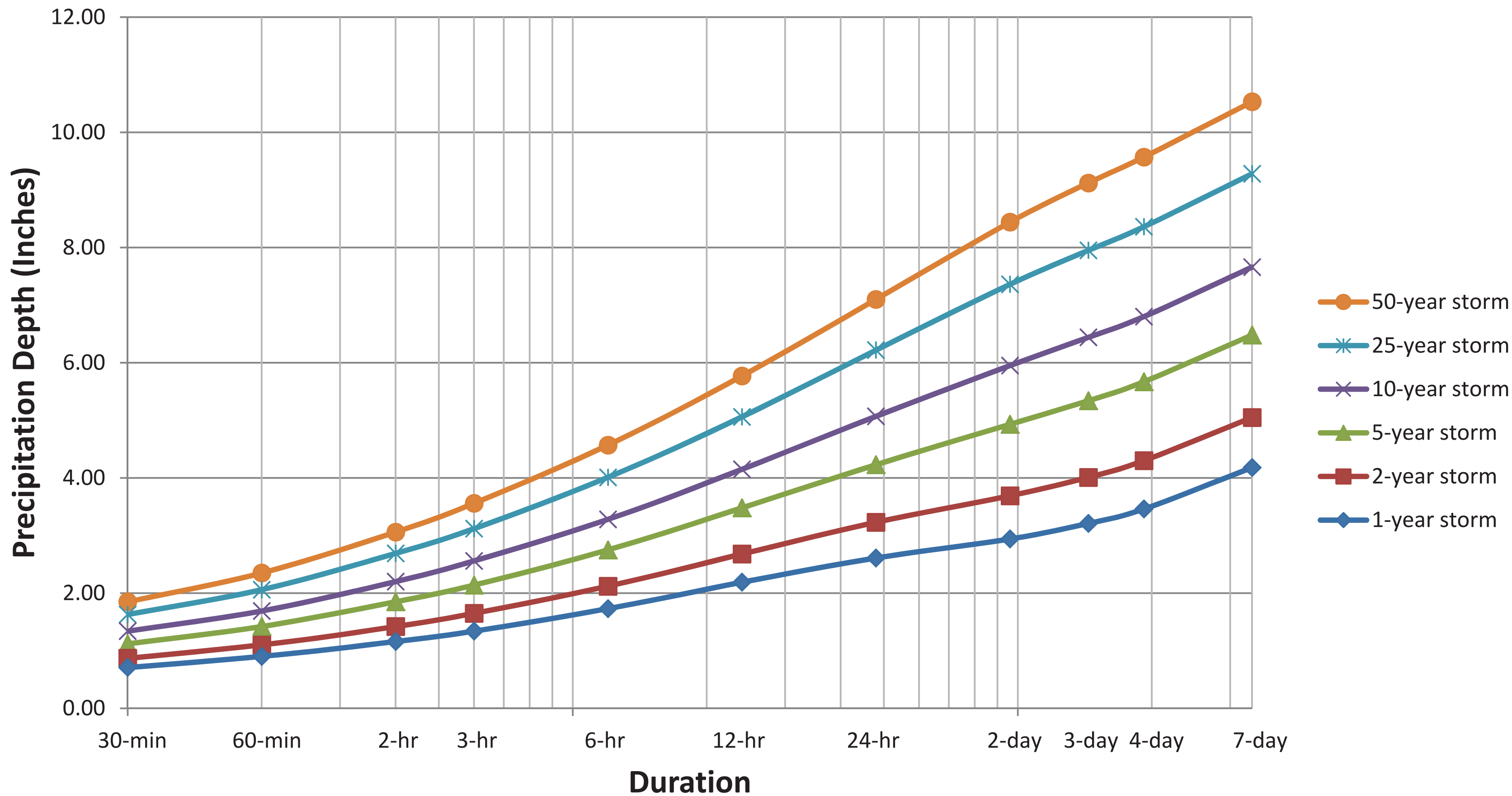


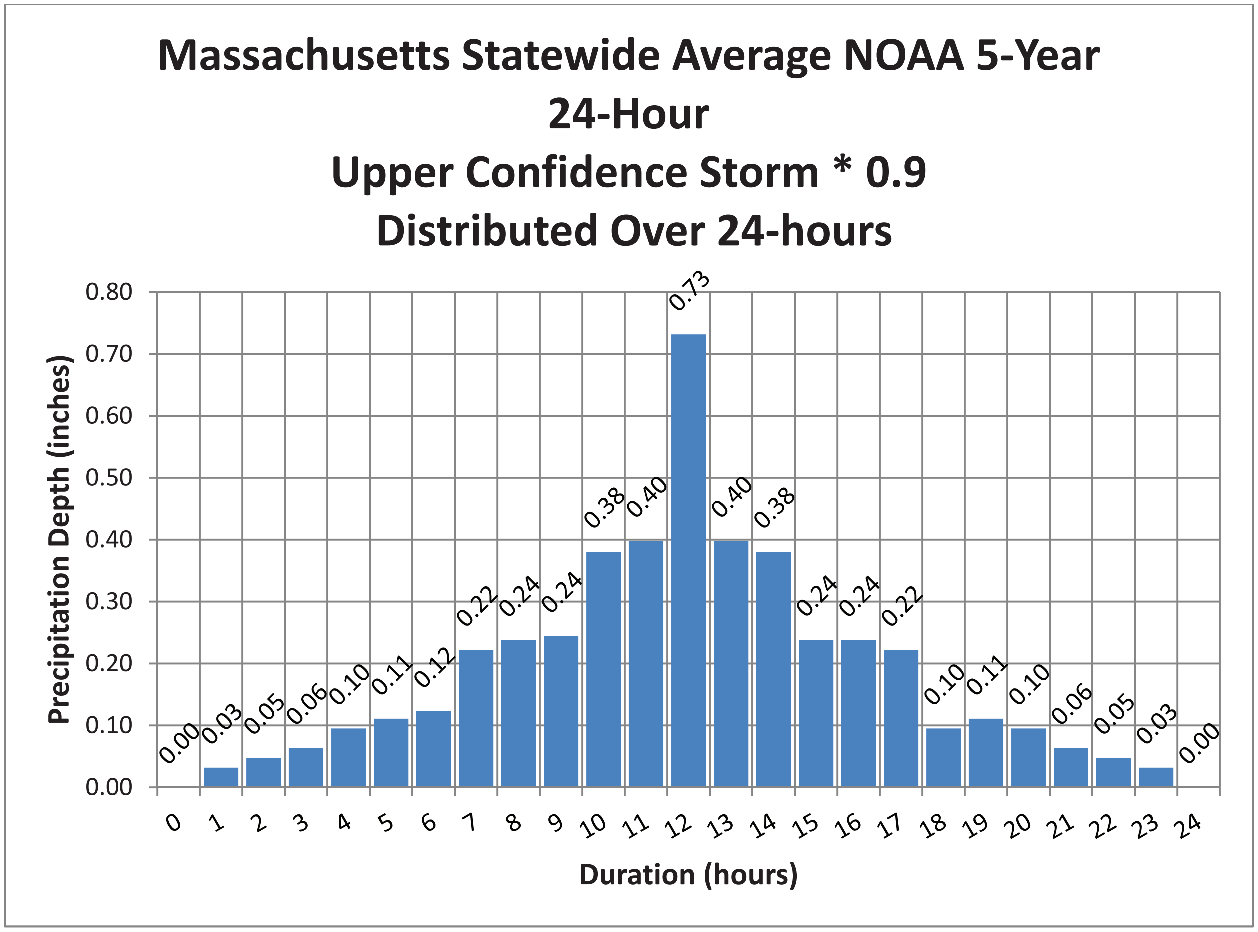
Figure 5
TOTAL INFLOW VOLUME TO TOTAL RAINFALL COMPARISON FOR DESIGN STORM INFLOW ANALYSIS

Figure 6: Depth-Duration-Frequency Curves
Middlesex County - Weston, MA
Latitude: 42.3833°, Longitude: -71.3167°



Data Derived from NOAA Atlas 14, Volume 10, Version 2

Figure 7

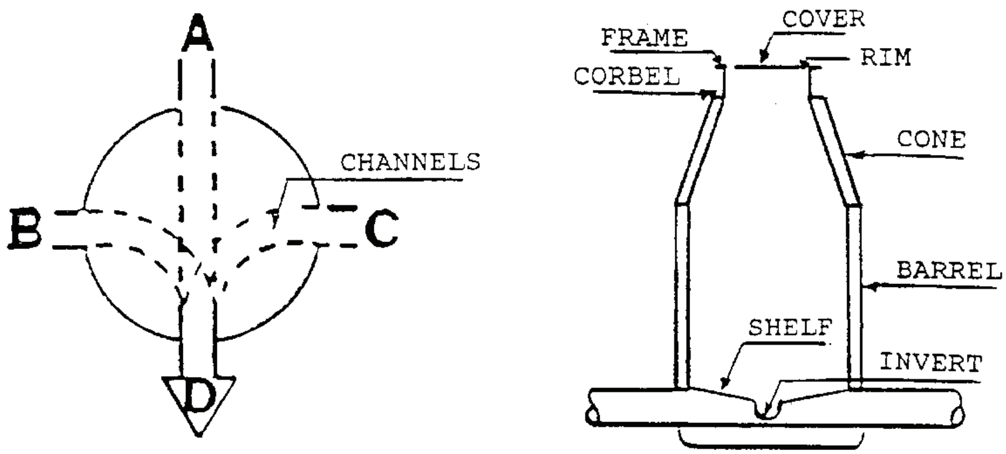

Massachusetts Statewide Average NOAA 5-Year
24-Hour
Upper Confidence Storm * 0.9
Distributed Over 24-hours
Precipitation Depth (inches)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.00
0.03
0.05
0.06
0.10
0.11
0.12
0.22
0.24
0.24
0.38
0.40
0.73
0.40
0.38
0.24
0.24
0.22
0.10
0.11
0.10
0.06
0.05
0.03
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Duration (hours)

SAMPLE OF
MANHOLE INSPECTION REPORT

MH NO.__________ DATE:________ TIME__________ INSPECTOR________________

ELEVATION_______ DEPTH TO INVERT______________ CLEANLINESS_______________

TYPE CONSTRUCTION_____________ STREET REFERENCE_________________________



DEFECTS: (Cover, frame, grout, steps, shelf, pipes, or channels)

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____

(USE REVERSE SIDE FOR ADDITIONAL DEFECTS TO BE NOTED.)

PIPE SIZE	LENGTH	FROM MH# TO MH#	EST. FLOW	TYPE OF FLOW	DEPTH OF FLOW	VEL. OF FLOW
A.______	______	______	______	______	______	______
B.______	______	______	______	______	______	______
C.______	______	______	______	______	______	______
D.______	______	______	______	______	______	______

REMARKS:

(Include need for repairs) ______________________________________
____
____
____

SAMPLE OF
MANHOLE INSPECTION FORM

¼ Section Map No. ____________ Manhole No. ____________ Inspection Date____________

Pipe Size____________ Pipe Material____________ Manhole Depth____________ Crew Leader____________

I. MANHOLE INITIAL INSPECTION

A-Location
1. Roadway
2. Gutter
3. Pave Alley
4. Unpaved Alley
5. Easement
6. Other ________

B-Manhole Cover
1. Serviceable
2. Damaged
3. Displaced
4. Missing
5. Loose
6. Sealed

C-Ring and Frame
1. Serviceable
2. Loose
3. Displaced
4. Missing Grout
5. Needs Raising
6. Needs Lowering

D-Manhole Material
1. Brick
2. Concrete

E-Size MH Cover
1. 24-inch
2. 30-inch

F-Manhole Size
1. 4-foot
2. 5-foot

II. STRUCTURAL INSPECTION

A-Rungs
1. Serviceable
2. Unsafe
3. Missing (No.)
4. Corroded

B-Cone
1. Serviceable
2. Broken
3. Sulfided
4. Misaligned
5. Leaking/Bad Joints

C-Riser
1. Serviceable
2. Broken
3. Sulfided
4. Misaligned
5. Leaking/Bad Joints

D-Shelf
1. Serviceable
2. Broken
3. Dirty
4. Sulfided
5. Bad Base Joint

E-Channel
1. Serviceable
2. Obstructed
3. Sulfided
4. Bad Pipe Joint
5. Silt
6. Poor Struc Cond.

III. HYDRAULIC INSPECTION

A-Inflow Indications
1. Debris onsides/Rungs
2. Debris on Sides/Shelf

B-Surcharge Indications
1. Grease/Debris on Shelf
2. Grease/Debris on Sides/Rungs

C-Clarity of Flow
1. Turbid Sewage Appearance
2. Clear Water Appearance

D-Flow
1. Steady
2. Pulsing
3. Turbulent
4. Surcharging
5. Sluggish

E-Flow Depth Compared to adjacent manholes
1. Same
2. Lower
3. Higher

F-Flow Depth _____inches
Time________AM/PM

IV.

A-Vermine
1. Roaches
2. Rats
3. Other

Observation Summary____________ Foreman II Recommendation & Approval ____________

Remarks____________________________

Recommendations____________ Superisor I Approval____________

SAMPLE NAME OF MUNICIPALITY

PRIVATE SOURCE INFLOW – HOUSE-TO-HOUSE INSPECTION SURVEY

SUBAREA__________ ENTRY PERMITTED_____________ ENTRY DEFFERED________________

NOT HOME --------------------------- ENTRY REFUSED----------------------

2ND ATTEMPT AT ENTRY ALLOWED YES____________ NO_______

PERSON ALLOWING ENTRY WAS OLDER THAN 18 YES_______ NO______

NAME OF PERSON ALLOWING ENTRY____

A. GENERAL PROPERTY INFORMATION

OWNER:___________________________ ADDRESS:_________________________________

PHONE:___________________________

B. GENERAL INFORMATION

INSPECTORS:__________________________________ DATE/TIME:___/___/__________:___

____

C. INTERNAL HOUSE INSPECTION

DOES HOUSE HAVE BASEMENT?______ DOES WATER ENTER BASEMENT______

TYPE OF BASEMENT FLOOR:____

C1. SUMP PUMP INFORMATION

DOES BASEMENT HAVE SUMP PUMP?_____ DISCHARGE LOCATION________
HORSEPOWER OF PUMP__________ PUMP CAPACITY (gpm)__________________
FREQUENCY OF PUMP CYCLING:_________________
IS PUMP ALWAYS ADEQUATE?___________________
IS SUMP PIPE HARD PIPED? YES_________ NO________

C2. FLOW DRAIN INFORMATION

DOES HOUSE HAVE FLOOR DRAINS? YES_____ NO______ NUMBER_________
FREQUENCY OF USE:________________DISCHARGE LOCATION_______________

C3. FOUNDATION DRAIN INFORMATION

DOES HOUSE HAVE INTERNAL FOUNDATION DRAIN CONNECTION:
YES________ NO________
FREQUENCY OF USE:__________DISCHARGE LOCATION____________________

C4. SEWER CONNECTION

IS THERE A SEWER CONNECTION CLEANOUT? YES_________ NO__________
ELEVATION OF SEWER CONNECTION CLEANOUT:
ABOVE BASEMENT FLOOR_______________________
BELOW BASEMENT FLOOR_______________________

IS CLEANOUT SEALED? YES________ NO_______

BACKFLOW PREVENTER ON SERVICE LINE? YES_________ NO_________

C5. LIST OF OTHER INFLOW SOURCES_________________________________

D. EXTERNAL HOUSE INSPECTION

D1. DOES HOUSE HAVE ROOF DOWNSPOUTS THAT ENTER THE GROUND?
YES________ NO________
D2. DOES PROPERTY HAVE A DRIVEWAY DRAIN? YES_______NO_______
D3. DOES PROPERTY HAVE A YAR DRAIN? YES_______NO_______
D4. DOES PROPERTY HAVE A WINDOW WELL DRAIN? YES_______NO_______
D5. DOES PROPERTY HAVE OTHERS? YES________TYPE_________NO_______

INDICATE APPROXIMATE LOCATION OF ALL INFLOW SOURCES

FRONT OF HOUSE

Appendices

APPENDIX A

FIELD DETERMINATION OF AVERAGE (MEAN)

VELOCITY OF FLOW CROSS-SECTION

When using a flow monitoring method not using a primary device such as a weir or flume, the need for accurate determination of the average (mean) velocity of the cross-sectional area of flow being measured cannot be overstated. The recommended method of determining the average (mean) velocity will vary depending on the pipe size and depth of flow.

1. In case of flow depths from 2 to 6 inches, the maximum velocity of the flow cross-section should be noted using a portable hand-held velocity probe. The maximum velocity should be multiplied by a factor of 0.9 and the resulting answer should be interpreted as the mean velocity. It should be noted that the use of direct reading velocity probes is not recommended in situations where flow depths are less than 2 inches because of the likelihood of inconsistent data. In those cases, dyed timing procedures or direct weir readings should be attempted. In the case of flow depths above 6 inches, several techniques should be considered on a case-by-case basis. In the case where the velocities appear to be uniform from side-to-side and flow depths are less than 12 inches, a series of velocity measurements along the centerline at 20%, 40% and 80% of the flow depth averaged together, or a single velocity measurement at 40% flow depth may be an acceptable method of determining the average velocity of the flow cross-section.

2. In the case where velocities appear to be uniform from side-to-side and flow depths are greater than 12 inches, a series of measurements along the centerline of the flow from top to bottom should be taken.

3. If the velocities are not uniform from side-to-side, and additional series of velocities should be taken on each side of the centerline, the number of additional series being dependent on the width of the flow cross-section. The average velocity is then determined by taking a weighted average of each measured velocity point cross-section in relation to the total flow cross-section.

When using Method #3 where continuous velocity sensors are in use in conjunction with continuous depth sensors, the importance of accurately determining the relation- ship between the sensed velocity and the average velocity of the flow cross-section cannot be overstated. Average flow cross-section velocities should be collected for the full range of recorded flow depths and compared to the sensed velocities recorded at the time of velocity data collection. The average velocities and corresponding sensed velocities should be plotted against flow depth to determine the correlation between them.

The sensed (continuously recorded) velocities should then be adjusted during flow computation based on the observed correlation. If poor or inconsistent correlation is found, a stage/velocity calibration curve should be developed and incorporated into the appropriated flow calculation program, using the sensed velocities only to determine when surcharge conditions or backwater conditions exist.

Care must be taken to assure that instances of velocity probe fouling are not misinterpreted as backwater or standing flow conditions.

APPENDIX B

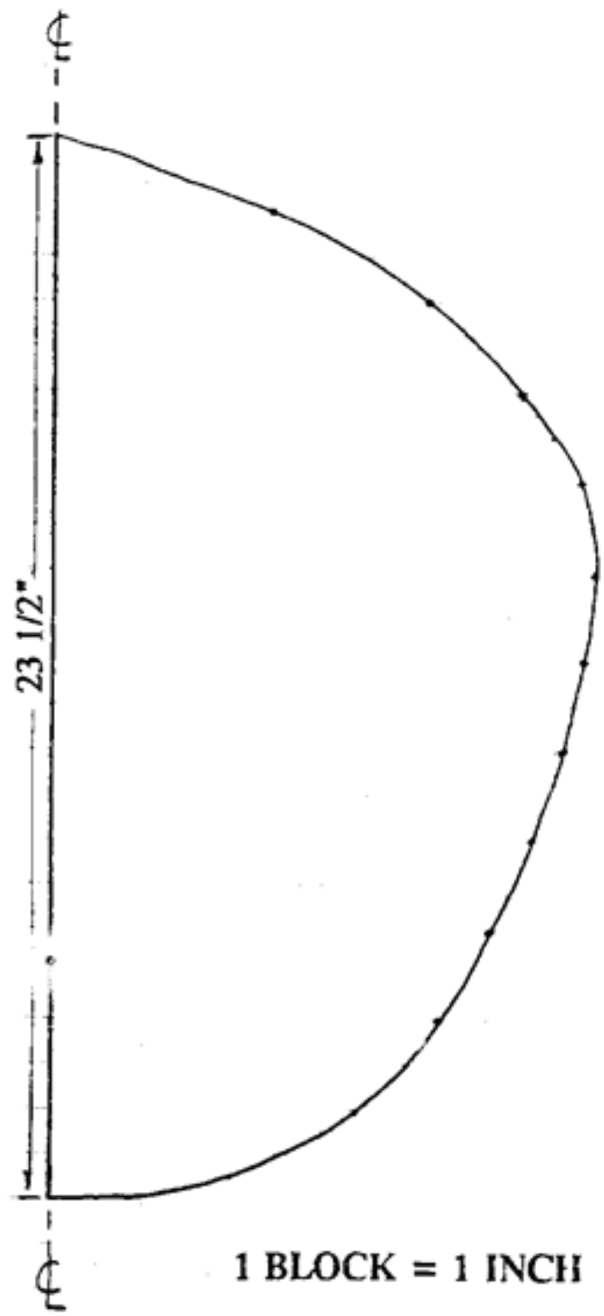
FIELD MEASUREMENT OF CROSS-SECTIONAL AREA OF A SEWER LINE USED FOR FLOW MONITORING

When using a flow monitoring method not using a primary device such as a weir or flume, accurate determination of the cross-sectional area of the flow being measured is mandatory. The dimensions of circular pipe should be measured to verify diameter and determine if a true circular cross-section exists. If it is determined that a circular cross-section does not exist, or if the meter site is placed in known non-circular cross-section pipe, it is recommended that field measurements be taken from a centerline reference point to the sides of the pipe at one to two inch intervals from top to bottom. Figure 9 illustrates this procedure. While it is acknowledged that it can be difficult, accurate measurements must be taken from the centerline to the sides of the pipe under the flow line. This difficulty may be alleviated somewhat by performing this work during nighttime minimum flow conditions.

Field notes of the centerline to pipe side measurements should be reduced onto accurate scale drawings. From the drawings, the cross-sectional area for each one inch increment of depth should be determined by a grid system or by a polar planimeter. Incremental cross-sections should then be interpolated between each whole inch measurement to one-tenth of one inch increments. A table of cumulative cross-sectional areas for each one-tenth of one inch increment of depth should then be compiled and the information entered into the appropriate flow calculation computer program in order to evaluate flows at 0.1 inch increments of sensed depths.

Care must be taken to accurately measure the configuration of any debris and include the information into cross-sectional area derivation.

DETERMINING CROSS SECTIONAL AREA OF ODD SHAPED PIPE



MEASURE INCREMENTAL AREA (SQ. IN.)	TOTAL INCREMENTAL AREA (SQ. IN.)	TOTAL CUMULATIV AREA (SQ. IN.)
0.5	1.0	428.4
3.3	6.6	427.4
5.6	11.2	420.8
7.3	14.6	409.6
8.7	17.4	395.0
9.8	19.6	377.6
10.5	21.0	358.0
11.3	22.6	337.0
11.7	23.4	314.4
11.9	23.8	291.0
11.9	23.8	267.2
11.8	23.6	243.4
11.6	23.2	219.8
11.3	22.6	196.6
11.1	22.2	174.0
10.7	21.4	151.8
10.4	20.8	130.4
10.0	20.0	109.6
9.6	19.2	89.6
9.0	18.0	70.4
8.4	16.8	52.4
7.5	15.0	35.6
6.2	12.4	20.6
4.1	8.2	8.2

FIGURE 9