chapter nine

Maintenance and renewal of water, sewer, and stormwater systems

Introduction

This chapter explains how the maintenance and renewal management systems are used to manage inventories of infrastructure components. Utility companies are learning much about maintenance and renewal, with surprising results. For example, they have learned that it is important to have effective maintenance, but they should avoid too much maintenance. They have also learned that the 3R part of renewal (repair, rehabilitation, replacement) is both important and difficult to get right. This aspect of infrastructure management holds great leverage over the future of financial and service performance of utilities.

Inventory is an important aspect of a maintenance management system (MMS), and is also used in planning, accounting, and other utility functions. Because of its utility-wide importance, it is treated as a separate topic from maintenance. Inventory is also discussed in Chapter 10 because of its close relationship to information technology.

System inventories

As shown in Figure 9.1, an inventory of facilities, components, and equipment is the cornerstone of maintenance management, needs assessment, asset management, and property accounting.

Note that the term “inventory” is also used for supplies, but this discussion is about inventory of capital components. In this section, we explain how basic information about this inventory can be compiled and used.

In some ways, use of the term “inventory” is not fully clear when applied to infrastructure components. The word generally means a list or a record of things in stock, the process of making a record, or the individual items in
Inventory as an accounting concept

The field of accounting provides a framework for inventory. Accounting methods differ for real property, fixed assets, and equipment. Classification systems can break these categories down into specific items or inventory objects, but no method has been published to bring concepts of accounting for property, plant, and equipment together.

An infrastructure inventory is an account of physical assets. Accounting for assets is necessary in all enterprises, especially private businesses, which pay taxes and dividends and are regulated for financial activities. Government entities also account for assets, but in different ways, as explained in Chapter 6.

To account for assets, they must be classified. One classifier is tangible (fixed assets) or intangible. On balance sheets, assets are classified as current and noncurrent, which include property, plant, and equipment, sometimes called fixed or plant assets. The assets we are interested in are intangible
and noncurrent. The distinction among property, plant, and equipment is also used, with the word “plant” originating from manufacturing accounts.

**Accounting field**

Accounting for fixed assets is where the world of inventory begins, and is discussed in Chapter 6. Accounting has different specialties. The field of management accounting refers to accounts produced for the internal use of managers. It is the approach intended for uses such as infrastructure systems management, which requires timely statements so that managers can make decisions about expenses and actions. Financial accounting emphasizes flows of money and financial statements and controls.

Management accounting does not normally produce much information on fixed assets because the information has not been used much by managers, at least not so far. Rather, the situation is more like Raymond Peterson, from the telephone industry, described: for asset management, we “...put it in, use it, if it breaks, repair it; if it breaks too many times, discard it and replace it.” Fortunately, new attention to fixed asset accounting has begun to replace this old attitude.

**Government versus private accounting**

As discussed in Chapter 6, accounting follows Generally Accepted Accounting Practices (GAAP) and rules for specific applications. Accounting rules differ for private-sector businesses and government. Private, regulated utilities are businesses and comply with different accounting rules from those of government departments or utilities.

Most infrastructure management is under government accounting and follows rules of the Government Accounting Standards Board (GASB), which specifies the GAAP for government accounting. The GASB has created a separate category for infrastructure fixed assets, which are “immovable and of value only to the government unit.” Earlier, the GASB authorized nonreporting of public fixed assets (infrastructure) that are immovable and have value only to the government unit for other than enterprises, but this changed with GASB 34 (see Chapter 3). Originally, if accounted for, assets were in a general fixed asset account group (GFAAG), which was to be an auxiliary record to be maintained at historical cost. Depreciation accounting for these assets was not seen to work well. Hopefully, GASB 34 will improve this situation and view.

**Regulated utilities**

In the case of regulated utilities, asset costs are part of the rate base and naturally attract a lot of attention from regulatory commissions. The National Association of Regulatory Utility Commissioners (NARUC) specifies a
uniform system of accounts for the following categories of utilities (Table 9.1). This provides an initial concept for the inventory of fixed assets. 5

**Inventories in asset management systems**

As explained in Chapter 3, an inventory is part of the asset or infrastructure management system. The inventory provides the location and specifications of items and may include or be linked to records of construction, condition assessment, maintenance, and modifications. Displays of the inventory provide information needed by workers to make decisions or perform maintenance.

Because the inventory involves real property, fixed assets, and equipment, a master inventory for an organization brings them together. The only place this happens is in the accounts.

Accounts are good for real property, less so for equipment, and even less so for fixed assets such as buried pipes. This is why Peterson wrote, “Managers have found it necessary to provide separate records for property, plant, and equipment, and created records for insurance, security, utilization, and maintenance.”1 In other words, one might end up with a number of separate records, each one duplicating the information.

In today’s computerized world, the manager can theoretically have all inventory information in one place, but this might not be practical. The main place to centralize data would be in the accounts. Then, if management units could each have their own sub-accounts for inventory, all data could be coordinated. So with the advent of computerized management systems, we are able to integrate information for financial and management uses. This may still be difficult, however.

An inventory can be as simple as a set of drawings indicating where sewer pipes are located in a section of a city. These drawings, with annotations, could be used by maintenance forces to locate and service pipes. On a more sophisticated level, the drawings could indicate other nearby facilities, such as water and electricity lines, and also be used to coordinate services. Even more sophisticated would be coordinated data in a GIS and database format, available on a common basis to different sections of the organization whose work involves shared data, processes, facilities, and staff.

<table>
<thead>
<tr>
<th>Category</th>
<th>Annual operating revenues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water, Class A</td>
<td>$1,000,000 or more</td>
</tr>
<tr>
<td>Water, Class B</td>
<td>$200,000 – $999,999</td>
</tr>
<tr>
<td>Water, Class C</td>
<td>Less than $200,000</td>
</tr>
<tr>
<td>Wastewater, Class A</td>
<td>$1,000,000 or more</td>
</tr>
<tr>
<td>Wastewater, Class B</td>
<td>$200,000 – $999,999</td>
</tr>
<tr>
<td>Wastewater, Class C</td>
<td>Less than $200,000</td>
</tr>
</tbody>
</table>
According to Peterson, generic aspects of inventory are in property record systems, which include more data than might be needed for management purposes:

- Historical cost and how it was established
- Date of acquisition
- Location
- Custodian
- Property tax information
- Vendor or donor
- Restrictions on use
- Depreciation method
- Estimated remaining life
- Future usefulness

Management versions of these records require spatial data, either on a map or GIS, and appropriate descriptive data, either in text entries or a database. According to Peterson, reports that can be generated from the property record system include:

- Forecasts of maintenance
- Asset replacement value
- Management reports of maintenance issues
- Production rate
- Location of equipment
- Responsibility for property

Computers and databases are useful for storing and manipulating databases, and a number of commercial packages are available. Relational databases offer new ways to organize data to facilitate decisions and actions. Communication systems offer ways to link inventory data to other management actions. For example, a system component such as an overflow weir in a combined sewer system can be linked by a wired or wireless system to a central computer system that shows its location and current status, enabling maintenance decisions to be coordinated with operations.

**Accounting for fixed assets**

Fixed assets have not received as much attention from accountants as have current assets, which have more dynamic financial turnovers and greater effects on tax and profit reports. Accounting for fixed assets helps us to emphasize that assets must be managed — not just purchased, used up, and replaced. The objective is to provide not only accounting for assets, but use accounting to help managers get the most out of the company’s investment. Peterson asks, “Do you have in place a process that monitors the current
condition, evaluates the future need for replacement, and brings to your attention needs to modify that plan?"

Accounting concepts for capitalization of private-sector assets cover tax implications or valuation, but do not involve how to set asset policies and apply them within an organization. Fixed assets are depreciated by accountants, but depreciation relates to tax obligations more than it does to condition of assets. In government accounting, including water, sewer, and stormwater units, depreciation of fixed assets has been optional until GASB 34.

If infrastructure managers reform their accounts for long-term tangible assets, the fact that facilities are wearing out will be known, and we can reverse the mentality of “put it in place and forget about it.”

Benefits of maintenance programs

While the need for effective maintenance is obvious to public works professionals, its benefits can impress even a hardened financial officer or uninformed citizen. But the subject is often not presented very effectively to engineers, managers, and boards — and maintenance budgets are easy to cut. Now, with more focus on infrastructure, maintenance gets more attention.

For a simplified case, consider a city of 100,000 with water, sewer, and stormwater systems with a replacement value of about $1 billion. This includes many different types of facilities: source of supply, treatment plants, distribution and collection, and stormwater systems. (We do not know the per-capita replacement value very well, and this figure is probably a little high for a city of 100,000).

Now assume two maintenance strategies — neglect and effective maintenance — and assume that under neglect, the service lives of the facilities are less than those under effective maintenance. Using simple financial analysis, Table 9.2 is produced. It shows that annual capital cost of the infrastructure ranges from a low of $61 million if service life is 60 years and interest cost of money is 6%, to $101 million when service life drops to 20 years and money costs 8% in interest.

The total annual water, sewer, and stormwater budget for a utility in a city of 100,000 is on the order of $40 million (based on the City of Fort Collins, Colorado, which has slightly more population but does not serve

<table>
<thead>
<tr>
<th>Service life</th>
<th>Cost of money in interest</th>
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<tbody>
<tr>
<td></td>
<td>0.06</td>
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<tr>
<td>20</td>
<td>$87,184,557</td>
</tr>
<tr>
<td>30</td>
<td>$72,648,911</td>
</tr>
<tr>
<td>40</td>
<td>$66,461,536</td>
</tr>
<tr>
<td>50</td>
<td>$63,444,286</td>
</tr>
<tr>
<td>60</td>
<td>$61,875,722</td>
</tr>
</tbody>
</table>

Table 9.2 Cost of Money as a Function of Service Life
all customers in the city limits). Thus, if one considers a case in Table 9.2, using maintenance to extend service lives from 30 to 50 years at 7% interest, the result is an annual benefit of about $8 million, or 20% of the total annual budget. The cost to perform this maintenance is not known, but if it added 10% to the budget, or $4 million, then the benefit–cost ratio of the maintenance program would be 2.0. In addition to this benefit, there are also the benefits of the prevented disruption, the higher quality service, and the more positive image of the utility and city that result from good maintenance.

Note that the service lives of most components are probably longer than we think. Recent research from Australia shows that some distribution pipe lives as long as 100–150 years. It appears that Australian utilities are more willing to repair and take some leaks and breaks, and North American utilities would prefer to replace pipes earlier.

For this reason, we are beginning to see utilities question the amount of money spent on maintenance of some components. Too much maintenance is expensive and may affect the bottom line negatively, so it is important to know the financial benefits of maintenance.

**Maintenance management systems**

The framework for organizing maintenance is the maintenance management system (MMS), which brings activities together for a systems approach to investment, organization, scheduling, and monitoring. There are many variations of the MMS, usually specific to an industry such as aviation, railroads, road transportation, and others.

An MMS can be described in different ways, but general functions include inventory, condition assessment, preventive maintenance, and corrective maintenance. Knowledge about MMS is available from a number of sources, increasingly in commercial software systems.

In facilities management (FM), the focus is increasingly on computerized MMS, or “CMMS.” Another term is MMIS, or “maintenance management information system.” According to Graham Thomas, writing in the *Facility Design and Management Handbook*, “The effective implementation of a CMMS or work management program has become mandatory for facility departments. The implementation of a CMMS application represents one of the greatest challenges that a facility department will face, as the potential for radically changing the character of a facility department lies at the heart of a CMMS application.”

Thomas considers the CMMS to be a sophisticated “to-do list,” and to have three parts: a PM schedule, work order tracking, and project management. The scope of a CMMS depends, of course, on how broad the organization wants it to be. Eventually the inventory, condition assessment, preventive maintenance, and corrective maintenance programs must be involved.
Condition assessment

While preventive maintenance is scheduled regularly, condition assessment is required for scheduling corrective maintenance and for needs assessments, budgeting, and capital improvement programs. According to Ronald Hudson, some industries use “on-condition” maintenance, where preventive maintenance is scheduled according to facility condition.8

The condition of a facility refers to how its status compares to new status. One might say, for example, “My car is old but in good condition.” This would be a general statement that embodies paint job, interior, engine, running gear, and other systems. One could rate a car as being in “poor,” “average,” or “like-new” condition, and all of the terms would be familiar, even if there is a conflict of interest in rating one’s own car. The concept of condition of an infrastructure facility is the same. It provides a composite measure of the facility condition compared to a replacement.

If a composite condition index could be compiled, chances are it would yield a relationship such as Figure 1.3, which has been shown from the pavement management field. But the situation will usually not be so simple. Peter Stahre, a public works manager from Sweden, has noted that Scandinavian research showed a strong dependence on initial quality of construction. Figure 9.2 shows how this can affect the assumed condition versus time relationship for an asset.

[Diagram: Infrastructure condition curve for poor construction.]

*Figure 9.2*  Infrastructure condition curve for poor construction.
Condition assessment will be unique for each facility type and component. It requires multi-attribute measurement, and ideally a composite condition index could be compiled for each facility. But there is no single best approach to compile such an index, and condition cannot normally be reduced to a single score — although infrastructure “report cards” do that to emphasize the need for infrastructure investments. Hudson discusses methods of compiling composite condition indices.8

An AwwaRF study found that single condition indices are not feasible for water distribution infrastructure.9 The challenge of assessing condition of hidden infrastructure assets is formidable. A system for condition assessment might include the following attributes of a component:

- Physical condition
- Age
- Capacity
- Performance
- Threats to capacity or vulnerability
- Likelihood of failure
- Safety attributes
- Deferred maintenance or repair cost

Based on these attributes, it should be possible to make schedules for repair, replacement, and rehabilitation.

**Preventive maintenance**

Preventive maintenance (PM) is the ongoing program of care given to equipment or components. In general, PM requires consistent, timely completion of tasks prescribed by documented procedures according to set schedules that include regular follow-up. Information sources for PM are O&M manuals, product information, and experience of workers.10 PM records will include equipment data, the preventive maintenance (PM) record, the repair record, and a spare parts stock card.

**Corrective maintenance**

Generally speaking, corrective maintenance means to repair equipment or components that have failed or deteriorated. It can range from minor to major repair, and drives the “3Rs” of infrastructure — repair, rehabilitation, and replacement. There are actually more than three “Rs,” as one can also renew, refurbish, remodel, restore, and renovate.

Corrective maintenance requires a decision as to whether the deficiency is minor or whether it is major enough to require capital budgeting. If the problem is major, the capital budget incorporates information about new standards and growth forecasts to lead to decisions about rehabilitation and replacement.
Some of the technologies for repair, rehabilitation, and replacement of water distribution pipes include the following:

- Pipe cleaning (flushing, foam swabbing, air scouring, using high-pressure water, pressure scraping, abrasive pigging)
- Lining by nonstructural or semistructural means (epoxy coating, cement mortar coating, close-fit pipe, woven hose, cured—in-place pipe, spirally wound pipe)
- Lining by structural means (continuous pipe, segmented pipe)
- Failure diagnosis lessons-learned database
- Trenchless replacement (pipe bursting, pipe replacement, micro-tunneling)
- Open cut replacement (conventional trench, narrow trench)

Reliability-centered maintenance

At the AWWA 2002 Infrastructure Conference, a speaker from the East Bay Municipal Utility District explained the philosophy of reliability-centered maintenance (RCM). An interesting feature of RCM is that it moves away from “proactive” maintenance to a “run-to-failure” mentality for some equipment. This may lower cost and it places a focus on critical equipment and components, which are defined by water quality violations, productivity, regulations, and safety. Higher maintenance cost is a big factor in rates. RCM is data intensive and uses a multidisciplinary team, including maintenance, mechanical, electrical, and instrument engineers and operational personnel.

Facility management

Much of the maintenance work for water, sewer, and stormwater systems is facility management (FM). According to the International Facility Management Association (IFMA), “Facility management is the practice of coordinating the physical workplace with the people and work of the organization.” IFMA has organized its activities into functional areas, all of which require attention from O&M staff:

- Long-range and annual facility planning
- Facility financial forecasting
- Real estate acquisition and/or disposal
- Work specifications, installation, and space management
- Architectural and engineering planning and design
- New construction and/or renovation
- Maintenance and operations management
- Telecommunications integration, security, and general administrative services
In the past, facility management meant operations and maintenance. Now other considerations such as safety, workplace environment, building air quality, security, and Americans with Disabilities Act issues are involved. IFMA has a certification program for facility managers.

General publications are available through organizations such as the IFMA, such as “Facility Maintenance: The Manager’s Practical Guide and Handbook.”

**Computer-based inventory, record, scheduling, and work management systems**

Computer-based systems are key for today’s maintenance problems. These will be discussed in more detail in Chapter 10. They involve a database system to manage pipe and component data, GIS software for system management, the scheduling of programs, and data on established maintenance procedures for specific components and systems.

**Maintenance of water, sewer, and stormwater systems**

**Maintenance management**

Maintenance management for water, sewer, and stormwater systems involves different facilities and requires general facilities management for buildings, grounds, and some equipment, and specialized maintenance for source of supply, treatment trains, and distribution and collection systems.

Much of the focus in water and wastewater is on distribution systems and wastewater collection systems, which are vast underground networks involving about two thirds of system capital assets. Water and wastewater treatment plants are complex facilities requiring maintenance of buildings and grounds as well as the process trains, which are highly specialized. Failure in maintenance of systems can bring regulatory sanctions, and worse yet, health problems for customers. Sources of supply maintenance can involve reservoirs, wellfields, and other facilities.

Maintenance of these systems applies general principles such as inventory, condition assessment, preventive maintenance, and corrective maintenance to specific systems, components, equipment, and situations. While the systems contain similar components, the equipment and components within them vary.

For example, water distribution pipes, sewers, and storm sewers use different materials and design procedures. A treated-water pump will be different from a flood-control pumping system. A wastewater treatment plant uses different processes than a water treatment plant. But maintenance procedures, records, and management systems will be similar across these different systems.
Guidelines for maintenance programs should begin with facilities management manuals such as “What Is IFMA.” Specialized guides for water and wastewater systems include guides such as the AWWA text for water utility maintenance, which provides concepts and processes that are transferable to wastewater and stormwater systems. Maintenance for wastewater systems is covered by a number of training reports funded by the EPA, and by WEF manuals such as “Wastewater Collection Systems Management.”

Maintenance of stormwater facilities is a new topic, as stormwater maintenance used to be part of street maintenance in most systems. Specialized organizations, such as the Urban Drainage and Flood Control District in Denver, have developed maintenance programs for major drainageways. Examples of routine work include vegetation mowing, trash and debris cleanup, weed control, and revegetation. Examples of restoration work include detention pond mucking, trash rack cleaning, rebuilding steep run-downs, tree thinning and clearing, extending trickle channels, repairing local erosion problems, and doing local channel grading and shaping. Examples of rehabilitative work include rebuilding or replacing drop structures, installing trickle channels, reshaping channels, installing riprap to correct or prevent erosion, establishing maintenance access into drainageways, and providing protection for existing box culverts, retaining walls, or road crossings.

Maintenance of underground stormwater pipes has received little attention compared to that of water and wastewater. When a flood backup occurs, stormwater maintenance crews will fix it, but programs such as historical data on breaks, regulatory sanctions, and performance measure are missing from stormwater, if for no other reason than absence of regulatory oversight.

Other stormwater organizations, including county governments, have manuals for maintenance. These address inspection and monitoring, record keeping, economic studies, sedimentation control, aquatic vegetation control, mosquito control, pollution and erosion control, structural maintenance, safety measures, and multiple use management.

System inventories

A generic inventory system should work for water, sewer, and stormwater systems. Although components differ, their general categories are similar as shown by a classification system.

There are several ways to identify a utility’s assets. For water supply, one method (Table 9.3) outlined by the National Association of Regulatory Utility Commissioners (NARUC) gives a listing by real property, fixed assets, and equipment.

The NARUC also regulates wastewater and should have comparable lists, but it does not regulate stormwater systems. Inventories would be comparable, as shown by Table 9.4.

Inventory technologies are improving, along with sensors, computers, communications, and management methods. Technologies for locating pipe include metal detectors, ferromagnetic locators, radio transmission locators,
nonmetallic locators, and ground-penetrating radar. To locate components, the AwwaRF sponsored a project entitled “New Techniques for Precisely Locating Buried Infrastructure” by Roy F. Weston, Inc. It was to “identify and comparatively evaluate methods and emerging technologies for accurately locating metallic and nonmetallic buried assets in a wide range of environments (i.e., in cities, under roads, with different soils).”

Inventory determines location and status of system components. It requires complete records of pipes, valves, manholes, and other appurtenances. Table 9.5 shows data elements for typical system inventories.

Some utilities developed excellent inventories before computers were available. For example, Leonard Batts described a system that is over 100 years old in Kalamazoo, Michigan, for mapping distribution system records. The manual version of this system began with a wall map of the entire system, which was also available at a reduced size of 6 by 8 feet. Working maps at a scale of 1 inch = 50 feet showed details of each area, and were available in legal size to be bound into books. This was a manual version of today’s GIS capabilities.

The maps showed material and size of main, work order numbers and dates of installation, distances from property lines, fire hydrant data, valves, service lines larger than 1 1/4 inch in diameter, and all location data. Maps were updated annually. Data on system components were maintained on asset files and ledger cards showing initial installation information. Service line information was recorded in the field when connections were made, and main break records were kept.
Table 9.4 Water, Wastewater, and Stormwater Inventories

<table>
<thead>
<tr>
<th>Item for water system (from NARUC list)</th>
<th>Comparable item for sewer system</th>
<th>Comparable item for stormwater system</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Land</td>
<td>Land</td>
<td>Land</td>
</tr>
<tr>
<td>*Structures and improvements Reservoirs</td>
<td>Structures and improvements equalization ponds and large aeration basins</td>
<td>Structures and improvements detention ponds and flood control reservoirs</td>
</tr>
<tr>
<td>Intakes</td>
<td>Discharge and overflow points</td>
<td>Discharge structures</td>
</tr>
<tr>
<td>Wells and springs</td>
<td>Infiltration galleries and tunnels</td>
<td>Wastewater tunnels</td>
</tr>
<tr>
<td>Supply mains</td>
<td>Main and outfall sewers</td>
<td>Large storm sewers</td>
</tr>
<tr>
<td>*Power generation equipment</td>
<td>Power generation equipment</td>
<td>Power generation equipment</td>
</tr>
<tr>
<td>*Pumping equipment</td>
<td>Pumping equipment</td>
<td>Pumping equipment</td>
</tr>
<tr>
<td>*Water treatment equipment</td>
<td>Wastewater treatment equipment</td>
<td>Stormwater treatment equipment</td>
</tr>
<tr>
<td>Distribution reservoirs and standpipes and transmission mains</td>
<td>Collection sewers</td>
<td>Stormwater tunnels</td>
</tr>
<tr>
<td>Services</td>
<td>House sewers</td>
<td>Building drains</td>
</tr>
<tr>
<td>Meters</td>
<td>Measuring equipment</td>
<td>Gaging points</td>
</tr>
<tr>
<td>Hydrants</td>
<td>Office equipment</td>
<td>Office equipment</td>
</tr>
<tr>
<td>*Transportation equipment</td>
<td>Transportation equipment</td>
<td>Transportation equipment</td>
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<tr>
<td>*Stores equipment</td>
<td>Stores equipment</td>
<td>Stores equipment</td>
</tr>
<tr>
<td>*Tools, shop and garage equipment</td>
<td>Tools, shop and garage equipment</td>
<td>Tools, shop and garage equipment</td>
</tr>
<tr>
<td>*Laboratory equipment</td>
<td>Laboratory equipment</td>
<td>Laboratory equipment</td>
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<tr>
<td>*Power-operated equipment</td>
<td>Power-operated equipment</td>
<td>Power-operated equipment</td>
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<tr>
<td>*Communication equipment</td>
<td>Communication equipment</td>
<td>Communication equipment</td>
</tr>
<tr>
<td>*Office equipment transportation</td>
<td>Office equipment</td>
<td>Office equipment</td>
</tr>
<tr>
<td>*Office equipment stores</td>
<td>Stores equipment</td>
<td>Stores equipment</td>
</tr>
<tr>
<td>*Office equipment tools, shop and garage</td>
<td>Tools, shop and garage equipment</td>
<td>Tools, shop and garage equipment</td>
</tr>
<tr>
<td>*Laboratory equipment</td>
<td>Laboratory equipment</td>
<td>Laboratory equipment</td>
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<tr>
<td>*Power-operated equipment</td>
<td>Power-operated equipment</td>
<td>Power-operated equipment</td>
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<tr>
<td>*Communication equipment</td>
<td>Communication equipment</td>
<td>Communication equipment</td>
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<tr>
<td>Sludge drying beds</td>
<td>Manholes</td>
<td>Manholes</td>
</tr>
<tr>
<td></td>
<td>Grates and drainage intakes</td>
<td>Grates and drainage intakes</td>
</tr>
<tr>
<td></td>
<td>Open channel segments</td>
<td>Open channel segments</td>
</tr>
</tbody>
</table>

* Indicates categories that are generically the same. Components within categories may differ. For example, a wastewater pump will normally be of a different type than a water supply pump. For stormwater, curb and gutter would be considered part of streets rather than stormwater systems.
As an example of a wastewater inventory, Brown and Caldwell developed an “Asset Information and Management (AIM) System,” which, according to the firm, converts isolated “knowledge assets” into enterprise-wide solutions. They applied it to create the Orange County (CA) Sanitation District’s (OCSD) Facility Atlas, which resulted from a 1994 needs assessment. The assessment revealed difficulty in compiling information from 50 years of operation and some 300 construction projects at two treatment plants and 650 miles of trunk sewers. The Facility Atlas is an electronic map of facilities that combines GIS, databases, and a document management system. In the system, facility objects are identified as process piping, equipment, surface features, and structures. Facility objects can be studied by using the database to get information on attributes such as construction material and project contract data.

**Condition assessment of system infrastructure**

Condition assessment measures developed for water supply can also apply in general to other systems. Measures that might be used include physical condition, safety, structural integrity, capacity, quality of service, and age.

Failure modes can also be applied to different categories. For pipes, these were listed by Smith. They include installation conditions, loads, routine service conditions, accidents, soil displacements, temperature extremes, and degradation of metal, concrete, or plastic pipe.

Inspection checks will differ by system. For water supply, they may include the following:

- Water quality sampling to include chemical and bacteriological tests to signal if the system is working satisfactorily
- Pressure and flow checks at hydrants to determine if flow characteristics are satisfactory
- Routine inspections to detect damage, unauthorized connections, leaks, vandalism, and other unacceptable threats
- Leak detection to discover small or large system leaks

<table>
<thead>
<tr>
<th>Table 9.5 Data Required for System Inventories</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of data or display</strong></td>
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<tr>
<td>Location and spatial data</td>
</tr>
<tr>
<td>Specifications and descriptive data</td>
</tr>
<tr>
<td>Displays</td>
</tr>
</tbody>
</table>
Condition assessment can involve sensor and analysis techniques, such as location of buried pipelines, leak detection, and nondestructive testing (NDT). Condition assessment techniques include noninvasive, nondestructive techniques (ultrasonic, acoustic emission, remote-field eddy current, magnetic flux leakage), coupon tests, and leak location studies (acoustic, infrared thermography, chemical, and mechanical).

New methods to assess condition include smart pipes with built-in reporting of leaks, structural stresses, corrosion, water quality, pressure, and flow; improved pigging and in-pipe assessment technologies to evaluate variables such as tuberculation and sedimentation; new capability to evaluate joints, valve interiors, and other nonpipe components; and tools to precisely locate problems and make repairs, including trenchless technologies and robotics.\(^{11}\)

Specific methods for distribution systems include the following:

- Water audit
- Flow measurement to test roughness
- Hydrostatic tests to test for leakage
- Zero-consumption measurement
- Network analysis models
- Program to monitor water quality in distribution system

A water audit is a starting point to learn about leaks and losses. It checks master meters for accuracy, tests industrial meters, checks for unauthorized use of water, and locates underground leaks through surveys. An audit results in a balance sheet of accounted-for water and unaccounted-for water. Standard terminology for water auditing has been developed.

Leaks, breaks and unaccounted-for water cause loss in revenue, higher operational costs, and need for greater system capacity. Leak detection and repair can yield important benefits. The State of California found that water audit and leak detection could even benefit communities with low values of unaccounted-for water.\(^{21}\) The leak detection program offers an opportunity to improve the database while solving leak and breakage problems, and to organize data for main replacement decisions. O’Day wrote that a database on main repair would cost $50–100 per mile to develop and $10–20 per mile per year to maintain.\(^{20}\)

For wastewater collection, sewer system evaluation surveys (SSES) are the accepted way to gather information on capital needs. SSES are expensive, so they must be prioritized.

Methods for inspection and condition assessment of collection systems include closed-circuit television (CCTV), cameras, visual inspection, and lamping.\(^{22}\) CCTV inspections are useful in diameters of 4–48 inches, and raft-mounted cameras might be used in larger pipes. In a visual inspection, safety rules are of course paramount. Innovations for sewer condition assessment include light-lines, sonar, sonic caliper, and lasers.
In wastewater systems, condition indicators include structural defect parameters (installation history, material, age, soil type, groundwater, loads, exfiltration, inspection history); corrosion and erosion parameters (material, wastewater temperature and velocity, pollutants, pipe type and structure, inspection history, soil, stray currents, coatings, cathodic protection, debris); and operational parameters (roots, trees, surcharging).

The field of condition assessment is relatively new, and aspects of it remain under development and controversial. For example, Australians, in implementing their new asset management systems, seem to believe that trying to assess the condition of hidden assets is not important — that the emphasis should be on the financial bottom line and on simply repairing breaks when they occur.

**Distribution and collection system maintenance**

Much of the maintenance effort in utilities is on distribution and collection systems, and this will continue in the future because optimizing pipe repair is a factor in controlling service disruption and cost. In addition to pipe itself, distribution and collection systems involve additional components. For example, Figure 9.3 shows the deteriorated condition of a fire hydrant in a large city.

*Figure 9.3* Old leaky fire hydrant in large city.
To achieve infrastructure integrity asset management and condition assessment are critical. Utilities rely on maintenance history to make decisions, but this is not direct assessment. Corrosion, a general term that includes different internal and external processes, is an important issue for distribution systems. Financial stakes in preventing corrosion and deposition are high for water utilities. Corrosion may impact health since metals leached from pipes such as lead can be harmful. Corrosion also causes financial damage such as staining clothes in washers.

On internal corrosion, the AWWA’s policy states that “…water should not be corrosive or encrusting to, or leave deposits on, water-conveying structures through which it passes, or in which it may be retained, including pipes, tanks, water heaters, and plumbing fixtures.”

Deposits can form from tuberculation, or from formation of tubercles on pipe walls from corrosion. These roughen pipe walls, increase the “C factor,” and increase energy required to pump water. Eventually, flow can cease altogether. Pipe replacement may be required to cure the problem.

Postprecipitation that clogs pipe walls with deposits occurs from calcium carbonate, iron, lead, zinc, aluminum, magnesium, polyelectrolytes, and microbial growth. The iron postprecipitation phenomenon is direct corrosion. Zinc and lead reactions are similar to those of iron, but form a more compact precipitate and tough coating. Remedial action requires analysis of reasons, followed by adjustment of treatment processes.

External corrosion in water systems is electrochemical, in which electrons and ions move between anode and cathode areas and erode metal from components. Types of corrosion are uniform and localized, and include galvanic, crevice, and pitting corrosion, and erosion. Corrosion reactions for iron pipe, galvanized pipe, lead pipe, and copper pipe are different in nature. There is also a variety of corrosion potential in treatment plants. Cathodic protection can help prevent metal pipe corrosion.

Recognizing the importance of corrosion to health, the SDWA requires that utilities determine corrosivity of water and soil, as well as that of materials in the distribution and home plumbing lines. This monitoring requirement calls for the design of a program to examine water quality and pipe material determinants of corrosion. Implementation of a corrosion control program can have a positive benefit-cost ratio; thus, water utility managers may consider corrosion control programs as going beyond regulations.

In older systems, many valves may not have been exercised for years. Some, in fact, may not be listed on records. Some tips on developing preventive maintenance programs for valves are given by Dan Skorcz. The AWWA now has a recent publication on valve maintenance.

Cross-connections require preventive programs. The AWWA listed situations to watch: unapproved supplementary supplies, industrial or fire protection water, premises that handle sewage or industrial process water, circumstances in which there is a special possibility of backflow of sewage or contaminated water, and water supply lines that end at piers. Provisions to guard against
these are plumbing changes, relief valves, backflow protection on all supply lines in addition to the primary ones controlled on a property, inspection of backflow protective devices, and the discontinuation of service in some cases.\textsuperscript{28}

The condition of home plumbing systems is complex because the variety of situations encountered is great, and the range of materials is wide. A combination program of sampling, interviewing homeowners and local plumbers, and visual inspection of discarded water heaters and other equipment would be a first step in evaluating them.

Distribution maintenance processes include flushing and cleaning. Flushing at hydrants removes sediments, stale water, slime, and other unwanted constituents. Chlorine additives may be used to kill bacteriological growth. Cleaning may remove deposits in the pipe. Methods of cleaning include mechanical, air purging, swabbing, and use of “pigs.” In the category of corrective maintenance, or rehabilitation, lining in-place with cement mortar may be done after cleaning to prevent rapid reoccurrence of problems.

Maintenance of collection systems affects the operation of the wastewater treatment facility, since flows into the facility are affected. Foster identified five common maintenance problems associated with sewer systems: infiltration of groundwater, inflow of stormwater, clogging, breaks, and damage from unauthorized and improper waste material.\textsuperscript{29} The corrective measures called for fall into seven categories: replacement of damaged pipe with infiltration-resistant pipe, better installation of pipe, sewer cleaning, analysis of infiltration and inflow through flow-measurement techniques, inspection and testing of sewers, grouting, and implementation of a safety program.

Figure 9.4 shows the cleanout located on a sewer main that facilitates maintenance.

\textbf{Figure 9.4} 24-inch sewer line with cleanout. (Courtesy of City of Fort Collins Utilities.)
The Clean Water Act of 1972 and its implementing regulations specified that new plants constructed through the construction grants program had to be preceded by sewer system evaluation and rehabilitation programs, complete with infiltration/inflow analyses (I/I analyses). This led to use of new techniques such as video inspection to find problem areas.

The EPA found by 1978 that original I/I requirements were too burdensome and issued regulations for simplified I/I investigations. A subsequent evaluation showed that expectations of the I/I program were not being fulfilled, that most municipalities did not implement long-term sewer system maintenance programs, and that maintenance budgets were often cut. They observed that operating budgets barely had enough funds for emergencies, much less maintenance.

CMOM, described in Chapter 7, provides guidance and regulations for collection system maintenance.

Because sewer system rehabilitation is important, the ASCE and WPCF completed a manual of practice on the topic. About 26 methods were identified, most of which were developed during the past 20 years. The EPA has issued several reports on sewer system evaluation and rehabilitation, including a training manual prepared by California State University at Sacramento. Topics covered are nature of the system, the operator’s responsibility, organization for O&M, pipeline cleaning and maintenance, repair procedures, administration, and safety.

As an example of sewer maintenance, the Metropolitan St. Louis Sewer District reported on its combined sewer program. The District had about 1100 miles of sewer serving a population of 450,000. Some of the sewers were 125 years old. In 1981 it had 370 failures with repair costs ranging from $5000 to $500,000. Because the cost to detect and repair all of the defective sewers was too high, the District focused on high-risk areas by compiling maps with risk factors to allow inspections with potential payoffs. Detection technologies considered include physical inspections, ground-penetrating radar, gravimeters, and infrared photography. The results of detection will be entered onto system maps using computer-aided design and drafting equipment. Rehabilitation methods to be considered include shotcreting, seal grouting (including chemical and compaction grouting), slippiling, steel plate lining, and in situ forming.

Renewal: the 3Rs of infrastructure

Renewal of water, sewer, and stormwater infrastructure will require more attention in the future than in the past. Consider that growth of U.S. systems has occurred in “spurts” over the past 100+ years, and it is apparent that waves of infrastructure systems will fail in the years ahead. This is the essence of new research for water supply utilities, which studies inventory age of piping and the likelihood that utilities will be hit with crescendos of deferred maintenance, all at once in the future. This would consider different kinds of pipe and services, including water, sewer, and stormwater systems.
The need for renewal can be projected using “Nessie” curves, which show build-up of all kinds of needs. The AwwaRF sponsored a project that used this method to collect data on 20 U.S. water utilities, and this led to needs estimates reported in Chapter 1.

As an example of renewal rates, at the 2002 AWWA Infrastructure Conference, Chicago water officials outlined their capital improvement program, which includes replacement of about 1% of pipe per year. They rehabilitate 125 to 150 miles of pipe per year, and spend $30 per capita per year on rehabilitation. Their prioritization is based on data and coordination with sister agencies. They do about two thirds of construction with in-house forces, giving them the capability to move quickly without the contracting phase, according to Chicago officials. U.K. engineers at the same conference later gave the opposite view — that they got flexibility and efficiency from use of contractor forces. The difference in view may be explained by the public–private difference and the rules that constrain renewal projects. Government funding is being requested to overcome the deferred maintenance in the U.S. inventory. Current legislation (as of March, 2002) is S. 1961, which will authorize up to $35 billion for state revolving funds over 5 years.

The realities of the vast networks of infrastructure must be confronted in any management plan. This includes bureaucracy, politics, budget cuts, unions, workforce issues, liabilities, and other realities of public works.

**Failure mechanisms**

The issue in diagnosis is to be able to predict failure so that pipeline renewal can precede disasters and allow capital planning. There are two schools of thought: one would work from the “bottom up,” and try to use science to build the evidence leading to prediction of failure; the other would work from the “top down,” to try to sense how much information is needed to simply manage breaks and failures that do occur. These two philosophies are contained in the “Nessie” research.

There has been a lot of research on why pipes fail. Paradoxically, older pipes do not necessarily fail more often. Failure rates seem to depend more on construction techniques and factors such as wall thickness. How well main construction is inspected may be a valid predictor for future life, for example. It is also known in some areas that water temperature will be an important factor, with many more breaks in cold weather.

For sections of pipe where no break is acceptable, such as high damage, public safety, public health areas, utilities must ensure that replacement or repair occurs before failure.

Attention has been focused on the water main life cycle of various materials. Fixing components of distribution systems is also a big issue, including water service connections that are owned by the utility up to the property line.

Predicting main life using operational records, rather than from an expensive research project, is a goal of utilities. A main break history database is
very important, and the distance between dots on a map showing breaks may be the best indicator of risk of failure for many utilities.

Management issues

Utilities face a number of management issues in renewal programs, such as deciding when to replace pipelines. Ideally they could have decision support systems for prioritization of rehabilitation. These would require criteria to prioritize replacements, even when little historical maintenance is known. For example, a point scoring system might apply different criteria, but the economic risk of “shooting in the dark” is too high and utilities need better data before they can justify capital expenditures.

A general response to the 3R problem is asset management systems, which are described in Chapter 3. Utilities need these to prioritize asset management expenditures, but still have questions about how to implement them. For example, they need to know how to link data to functional management and how to use GIS and databases together. A number of details must be decided, such as standardization of defect codes and characterizations.

Use of information technology is a key factor in management. An example of use of software is seen in four computer packages used by the Washington Suburban Sanitary Commission (WSSC) for water pipe work: the MMIS, Webmap, GIS, and AutoCad. The MMIS is linked to work programs and contains database information from work orders, contracts, and repairs. It was programmed in the 1980s, and the WSSC is planning a conversion to a new platform. Webmap is based on Autodesk, uses conventional maps, and is linked to the MMIS and document files such as valve cards, drawings, water segment attributes, and equipment location. The GIS, based on the ArcView platform, allows manipulation of spatial data, including many of the features of Webmap. The AutoCad package is used to prepare design drawings and allows importation of information from the other packages.

The importance of the MMIS and its database of pipe break experiences can be readily seen from the WSSC experience.

A big issue for utility rehabilitation work is coordination with associated utilities. Because a major cost component is restoration, utilities need communication between owners of infrastructure in the public right-of-way.

Another management issue is risk. Several European and Canadian presentations at the AWWA 2002 Infrastructure Conference showed innovative approaches to rehabilitation. These included public and private approaches, including work in congested areas. One concept was that of the “risk-owner,” or person responsible for managing a particular type of risk during a project. In the U.K., for example, corporate officers bear a heavy responsibility for risk, with possibility of criminal penalties.

Ultimately, simplicity is an important key to success in rehabilitation. Utilities are constantly under cost pressure and downsizing. They lose knowledge with retirements and it is hard to get skilled people. Finding the
staff and funds to do sophisticated studies may not be possible or of high priority. As each utility is unique, it needs expert technical coordination of consulting work or there will be a lot of uncoordinated activity.

Prioritization of renewal programs is of course a key management issue. Most utilities are doing this by assembling as much data as they can and making judgments that consider impacts on health, business, environment, and traffic. New research leads to techniques such as risk-based rehabilitation strategies (see Chapter 8).\textsuperscript{33,34}

**Repair and rehabilitation technologies**

A number of technologies are available for water and sewer main rehabilitation. These include cleaning and lining, and open-cut and trenchless replacement, with various options, such as insertion of structural liners. Technology is moving rapidly, and \textit{in situ} methods are attractive, but a number of constraints must be overcome. For example, service line replacement is more a limiting factor for water mains than for sewer.

Utilities assume the risk for unproven technology and verification of pipeline rehabilitation technology, although pilot trials can reduce risk. Cleaning and lining is a proven technique and can reduce leaks, but it does not add structural strength or help on beam action breaks. Utilities need a lining methodology that will add strength to the pipe itself.

Given that the need for repairs will increase, new methods to make them faster and better are needed. The AWWA has a new video on water main repair programs. Prepared by the New England Water Works Association, it shows an approach based on people, communications, materials, safety, and risk reduction. The people emphasis includes decision making, operator skills, cross-training, and other employee issues. Communications ensure a fast response and includes techniques such as use of a phone tree. Emergency response and contingency planning techniques are used here. Materials and equipment ensure that supplies are on hand and ready to go. This includes preset loan and sharing arrangements through mutual aid. It may be necessary to have special line-stopping equipment on hand. Safety is of course paramount and includes road, confined spaces, trench, and other safety concerns. DigSafe and OSHA resources may be helpful. Risk reduction includes record keeping, PM and operations, stockpiling materials, and contingency planning.

**Condition assessment**

Condition assessment was discussed earlier in the chapter, and although a number of techniques are available, cost and performance goals are needed. The “Nessie” research, originating in Australia, brought condition assessment
into the prioritization methods introduced through KANEW. That is, pipe condition as well as age is considered in forecasts of replacement needs. Australians use life-cycle management techniques and will tolerate more leaks than U.S. utilities, whereas in the U.S. we have looked more toward replacement than repair as a policy. Given the build-up in the U.S. inventory, it is inevitable that break rates will increase.

Remote monitoring of mains condition is desirable and new technologies are available, including acoustics, magnetic instruments, electric fields, pulse echoes, MRI, and thermal imaging. However, practical applications for these technologies are not, for the most part, proven for use in distribution systems.

The rule for condition assessment ought to be “keep it simple.” Condition assessment should be done as an operational activity, not as a periodic and expensive study.

**Materials**

Research is needed to better understand pipe materials. For example, European utilities may do a better job than U.S. utilities in preparing ductile iron. They use an alloy coating, epoxy, and polyethylene (PE) bags, whereas the U.S. uses only the PE bags. Thus, a scratch on the pipe can initiate corrosion. A simple, valid test for new DIP is needed.

There is a lot of interest in plastic pipe. Utilities would like to know the limits or recommended guidelines for connections to PVC pipe. For example, they would like to know what effect a same size tap has on the integrity of the pipe or what minimum spacing should be maintained between service connections. They would also like to know the types of fittings and connections to PVC pipe and which ones work best. Plastic pipe has advantages, but connections involve a number of questions. Other issues are traceability and permeability near leaking petroleum tanks. Some reports say that the use of PVC is increasing rapidly in the U.S.

**Future issues and needed research**

A number of recent reports focus on new directions and research needs. For example, Smith lists a number of research needs and Boyle’s study of distribution systems offers new ones based on a recent survey. These research needs and future trends focus on new uses of information technology, instruments, operating systems, assessment tools, and renewal techniques. The EPA is working on smart systems for pipes. EPA concerns include health effects and verification of environmental technologies. Trenchless technologies for water and sewer pipe rehabilitation offer great promise. Benchmarking for managers offers a new way to compare performance. A recent tool by Arbour and Kerri uses a benchmark to focus on system characteristics, level of O&M, and system condition.
References