Asset Management Programs for Stormwater and Wastewater Systems: Overcoming Barriers to Development and Implementation

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ABBREVIATIONS AND ACRONYMS

AMP	asset management program
AWWA	American Water Works Association
CIP	Capital Improvement Plan
CMMS	computerized maintenance management system
CMOM	Capacity, management, operation, and maintenance
CUPSS	Check Up Program for Small Systems
CWA	Clean Water Act
EPA	Environmental Protection Agency
GIS	geographic information system
GPS	Global Positioning System
IWA-WSAA	International Water Association–Water Services Association of Australia
MS4	municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
RAMCAP®	Risk Analysis and Management for Critical Asset Protection
SRF	State Revolving Fund
SSO	sanitary sewer overflow
SSMP	sewer system management plan
WFRF	Water Finance Research Foundation

EXECUTIVE SUMMARY

Aging infrastructure is a significant concern for the utilities, service districts, municipalities, and counties responsible for operating and maintaining stormwater, wastewater, and drinking water systems throughout the United States. Many system operators (hereinafter referred to as "utilities") struggle to operate, maintain, and improve systems and infrastructure assets installed decades ago. Uncertainty about the location and condition of infrastructure assets and lack of comprehensive planning often leads to a reactive approach to maintenance and the occurrence of emergency situations stemming from asset failures. To battle this tendency, utilities (particularly wastewater and drinking water utilities) have developed and implemented formal asset management programs (AMPs) to reduce unexpected, expensive, and reactive repairs and increase overall system performance. As the benefits of formal AMPs are becoming more evident, more public and private water utilities are beginning to develop and implement AMPs as a method to proactively address system needs and reduce overall costs.

According to the Clean Water Act (CWA), National Pollutant Discharge Elimination System (NPDES) permits must include requirements for discharging facilities to develop and implement operation and maintenance procedures and financial plans sufficient to ensure their future operational integrity and help them comply with permit discharge conditions. The United States Environmental Protection Agency (EPA) has encouraged drinking water, stormwater, and wastewater utilities to develop and implement AMP tools to provide the tracking and planning framework needed to meet these requirements. EPA has also encouraged water utilities to use modern analytical planning tools to support deployment of greener, more sustainable, better integrated water infrastructure improvements to help implement NPDES permit requirements. As the benefits (both expected and unexpected) of AMPs become clearer through their implementation, the inclusion of formal asset management requirements in NPDES permits is anticipated to increase in the future.

Despite the demonstrated benefits of AMP implementation, the challenges and barriers that can come with developing a new AMP — or integrating existing asset management tools into a formal, centralized AMP — can seem overwhelming to utilities beginning the process. Some of the most common barriers include:

- Obtaining buy-in and support from key stakeholders and decision makers at the onset of AMP development and at each critical step along the journey.
- The perception that decades of deferred maintenance or neglect need to be rapidly addressed.
- Perceived costs and staff effort associated with the AMP planning, software, start-up, and ongoing operation.
- Perceived difficulties, and even redundancy, of creating and maintaining yet another activity tracking and/or work order system.
- Difficulty in effectively communicating the benefits of an AMP to utility management personnel and stakeholders.
- Difficulty incorporating AMP into existing data management systems.
- Finding consensus among key stakeholders for the level of service.

Utilities face challenges in creating, developing, and implementing AMPs at each stage of the process; not the least of which is obtaining buy-in and support from key stakeholders and decision makers at the onset of AMP development and at each critical step along the journey. Various strategies exist for obtaining support from key stakeholders and decision makers (e.g., operations and maintenance staff, engineers, information technology department managers, finance staff, customers, department directors, city council, board of directors), but the key to all of these strategies is showing the benefits to the agency of reducing and stabilizing long-term facility operating, maintenance, and renewal costs — the "no surprises" approach. The bottom-line strategy in obtaining buy-in is helping decision makers to understand that preventing problems is a far less costly and disruptive path than fixing problems and their trickle-down consequences.

When considered broadly, these and other challenges and barriers can seem overwhelming to utilities that are beginning the process. Therefore, the purpose of this paper is to identify the critical steps and factors to be considered during AMP development and highlight real-world examples of encountered barriers to AMP development. This paper consolidates and summarizes work done by EPA and others to guide and document early experiences in using AMPs for stormwater and wastewater utility management. It provides guidance on the basics of developing and implementing a new AMP. It touches briefly on the experiences of several stormwater and wastewater utilities during the infancy of AMP development, including barriers they encountered. It also cites various AMP development and implementation research literature and case studies, which can provide valuable insight and tools for utilities that are just beginning the AMP planning and development process.

It is important to acknowledge that service and systematic differences between stormwater and wastewater utilities create unique variables that influence the development and implementation processes of an AMP. For example, the classification and incorporation of green infrastructure controls, and their unique maintenance requirements, into an AMP can create an additional layer of complexity for stormwater utilities. This paper does not comprehensively address these differences, but instead presents broad AMP concepts to assist water utilities interested in developing and implementing an AMP.

The critical steps and factors further described within this paper include: (1) Identifying overall AMP scope, (2) Establishing the desired level of service, (3) Choosing and implementing asset management software, (4) Cataloging assets, (5) Scoring assets, and (6) Continuing AMP development. As each of these steps can be complex and time consuming, they may often broadly be viewed as "barriers" to implementation in-and-of themselves, with more discreet challenges or barriers to be encountered within each critical step. Where possible, this paper attempts to highlight examples of barriers or challenges that utilities have encountered, and provide a description of how they were overcome on the path to AMP implementation. Based on a review of the available literature and case studies, EPA has identified a number of considerations for utilities when developing and implementing an AMP:

1. Identifying Overall AMP Scope
    a. Identify the types of assets that comprise the overall system and consider the relationship of each type of asset to the system's overall performance of the system.
    b. Prioritize assets based on the functionality of the system and the desired level of service.

   c. In addition to hard assets, consider other types of assets (e.g., natural and soft) to enhance overall system performance.

2. Establishing the Desired Level of Service
   a. Establish a reasonable level of service in order to understand which assets are needed to provide that service to customers.
   b. Establish a level of service that also accounts for NPDES permit compliance needs.
   c. Develop and routinely evaluate performance measures to track whether the level of service objectives are being met.
3. Choosing and Implementing Asset Management Software
   a. Determine whether the size of the utility's AMP warrants the need for unique asset management software (existing tools and data systems may not warrant need for additional software).
   b. Choose or develop a software product with the capabilities needed to ensure the functionality of the system, as well as help meet both level-of-service and regulatory objectives.
   c. Utilize a combination of various information sources — a list of critical projects (according to assets' score and rank), evaluation of recent closed-circuit television inspections, work order history, cleaning history, institutional knowledge — in deciding to authorize a repair/replacement or conduct further monitoring.
   d. Consider a product's ease of use by their staff and ease of incorporation into existing AMP tools and practices.
4. Cataloging Assets
   a. Invest time upfront in cataloging assets to help understand the components of their systems.
   b. Establish a utility-specific standard for defining, identifying, and storing asset data to keep those data consistent and correctly labeled.
5. Scoring Assets
   a. Recognize the appropriate metrics, standardize a methodology, and choose a perspective to create a consistent system.
   b. Evaluate the following components to determine an asset's overall score: (1) Condition, (2) Remaining useful life, (3) Probability of failure, and (4) Consequence of failure (or "criticality").
6. Continuing AMP Development
   a. Establish internal evaluation and benchmarking standards using a set of predetermined criteria.

The application of an AMP, when properly managed and funded, has proven to help utilities meet both regulatory and level of service objectives. The proven primary benefits of an AMP are (1) the reduction and stabilization of long-term costs to keep facilities performing at their desired service levels — making expenditures from focused repairs to general replacements only at the most economically beneficial points in the facilities' service lives, and (2) the ability to provide financial transparency to rate payers for major capital expenditures and rate increases. The overarching outcome of AMPs is first the reduction — and ultimately the prevention — of the facility failure "surprises" that cause havoc with customer needs and utility agency budgets. The development and implementation of AMPs as an NPDES permit requirement is anticipated to increase in the coming years. From EPA's perspective, AMPs have proven to reduce environmental impacts from those occurring under traditionally managed "wait 'til it breaks and then fix it" approaches to facilities maintenance and renewal. For example, enhanced sewer system maintenance can reduce sanitary sewer blockages (and resulting back-ups and overflows) and improve treatment performance to ensure compliance with permit effluent limits.

This paper presents information obtained from case studies and input from utilities at various stages of AMP implementation. EPA thanks the following utilities for their help in the development of this document:

- City of Paso Robles
- City of San Diego Transportation and Storm Water Department
- City of South Lake Tahoe
- East Bay Municipal Utilities District
- Zone 7 Water Agency
- Central Contra Costa Sanitary District
- Ross Valley Sanitation District
- Sonoma Valley County Sanitation District
- Orange County Public Works

TABLE OF CONTENTS

1 INTRODUCTION

Aging infrastructure is a significant concern for the utilities, service districts, municipalities, and counties responsible for operating and maintaining stormwater, wastewater, and drinking water systems throughout the United States. Many system operators (hereinafter referred to broadly as "utilities") struggle to operate, maintain, and improve systems and infrastructure assets installed decades ago. Uncertainty about the location and condition of infrastructure assets and lack of comprehensive planning often leads to a reactive approach to maintenance and the occurrence of emergency situations stemming from asset failures. Meanwhile, assets that have not yet begun to fail are aging, defects that have gone unknown continue to worsen, and the problems of the years and decades to come are developing. To battle this tendency, utilities (particularly wastewater and drinking utilities) have developed and implemented formal asset management programs (AMPs) to reduce unexpected, expensive, and reactive repairs and increase overall system performance. As the benefits of formal AMPs are becoming more evident, more public and private water utilities are beginning to develop and implement them as a method to proactively address system needs and reduce overall costs. However, the challenges and barriers associated that can come with developing a new AMP — or integrating existing asset management tools into a formal, centralized AMP — can seem overwhelming to utilities beginning the process.

> "Assets must be identified, located, and tracked. Condition and performance must be monitored over time. Standards of acceptable performance must be established. Maintenance practices must be planned and executed, and capital planning must take into account risk, costs, and benefits. In a sense, asset management constitutes 'system thinking,' that is, addressing the myriad of elements and processes that make up a modern water or wastewater utility as one interrelated system to be managed, optimized, and maintained to achieve the owner's goals."
>
> — AWWA Research Foundation 2008

This paper documents the findings from a review of existing literature and case studies and includes direct input from several utilities to explore:

- The critical steps and factors for developing and implementing an AMP.
- Barriers to AMP implementation and ways to overcome those barriers.
- Program implementation cost and capital planning considerations.
- Successes and benefits of AMP implementation.

> Asset management has been defined as an integrated optimization process of "managing infrastructure assets to minimize the total cost of owning and operating them, while continuously delivering the service levels customers desire, at an acceptable level of risk."
>
> — AMSA et al. 2002

1.1 Background

Municipalities across the country are experiencing greater urban population growth and increasing water quality requirements. These strains place a growing pressure on their already stressed and aging water infrastructure (U.S. EPA 2016b). The 2012 EPA Clean Watersheds Needs Survey — conducted to assess the capital investment needed nationwide for publicly owned stormwater and wastewater collection and treatment facilities to meet Clean Water Act water quality goals — concluded that about $271 billion in stormwater and wastewater infrastructure capital investment is needed for the nation's approximately 15,000 publicly owned treatment works. Of that sum,

$52.4 billion is needed for secondary wastewater treatment, $49.6 billion for advanced wastewater treatment, $51.2 billion for conveyance system repair, $44.5 billion for new conveyance systems, $48.0 billion for combined sewer overflow correction, $19.2 billion for stormwater management, and $6.1 billion for recycled water distribution (U.S. EPA 2016a). The American Society of Civil Engineers estimated in 2013 that the nation needs to invest about $298 billion of capital in stormwater and wastewater infrastructure over the next 20 years; pipe represents the largest capital need, accounting for three quarters of total needs (ASCE n.d.).

Many utilities have responded to water infrastructure stresses by expanding their operations and upgrading their infrastructure's capacity to manage the growing demand for services (U.S. EPA 2002). However, a lack of focus on managing and maintaining assets, particularly for sanitary sewer collection systems, has forced organizations to focus on reactive emergency actions — rehabilitating and replacing the assets, expensively and abruptly, when they fail. Operating in a reactive mode typically requires utilities to allocate large amounts of resources toward emergency response and replacement or rehabilitation (U.S. EPA 2002). Some utilities, though, have developed AMPs to understand their systems' needs and proactively plan for asset maintenance and replacement with a least-cost approach to help ensure a targeted level of service while achieving regulatory compliance.

An AMP in this context is a strategic, comprehensive tool for managing a utility's stormwater and/or wastewater system assets to help minimize the long-term investment in each asset, keeping expenditure at the lowest level that will maintain the desired performance and meet regulatory requirements. AMPs prioritize the most necessary projects by cataloging assets, identifying performance objectives, completing a life-cycle analysis, identifying appropriate maintenance schedules, and conducting a cost-of-failure analysis of all assets (Bonitz et al. 2015). This exhaustive information-gathering makes it possible to create an extensive timeline for assets by identifying and ranking maintenance needs and listing their costs and potential funding sources. It can also help guide future planning, reduce the cost of that planning, and identify new system needs that may have gone unnoticed or unrecognized. By promoting resource and financial efficiency, an AMP can more than pay for itself over time (U.S. EPA 2002).

According to the Clean Water Act, National Pollutant Discharge Elimination System (NPDES) permits must include requirements for discharging facilities to develop and implement operations and maintenance procedures and financial plans sufficient to ensure their future operational integrity and help them comply with permit discharge conditions. The United States Environmental Protection Agency (EPA) has encouraged stormwater, wastewater, and drinking water utilities to develop and implement AMP tools to provide the tracking and planning framework needed to meet these requirements. EPA has also encouraged water utilities to use modern analytical planning tools to support deployment of greener, more sustainable, better integrated water infrastructure improvements to help implement NPDES permit requirements. As the benefits (both expected and unexpected) of AMPs become clearer through their implementation, the inclusion of formal asset management requirements in NPDES permits is anticipated to increase in the future.

There is immediate need and opportunity for EPA and other organizations to:

- Guide stormwater and wastewater utilities (particularly smaller, less sophisticated systems) in evaluating, developing, and implementing AMP practices.
- Demonstrate how AMPs and stormwater program modeling strategies can be integrated into NPDES permits.

- Show how AMPs can be used as a framework for more innovative approaches to attaining water quality standards, planning land use, adapting to climate change, and reaching other environmental management goals.

1.2 Purpose

Utilities face several challenges in creating, developing, and implementing AMPs. This paper consolidates and summarizes work done by EPA and others to guide and document early experiences in using AMPs for stormwater and wastewater utility management. It provides guidance on the basic components of developing and implementing a new AMP. It touches briefly on the experiences of several stormwater and wastewater utilities during AMP development, including barriers they encountered and lessons learned in overcoming those barriers. It also cites various AMP development and implementation research literature and case studies, which can provide valuable insight and tools for utilities that are just beginning the AMP planning and development process.

It is important to acknowledge that service and systematic differences between stormwater and wastewater utilities create unique variables that influence the development and implementation processes of an AMP. For example, the classification and incorporation of green infrastructure controls, and their unique maintenance requirements, into an AMP can create an additional layer of complexity for stormwater utilities. This paper does not comprehensively address these differences, but instead presents broad AMP concepts to assist water utilities interested in developing and implementing an AMP.

1.3 Paper Development Process and Collaboration with Utilities

Through review of existing literature on AMP development and implementation, information was gathered on:

- Critical factors and planning steps in the process of developing AMP capability.
- Barriers to AMP implementation.
- Program implementation costs and capital planning considerations.
- Successes and benefits (both expected and unexpected) encountered by several wastewater and stormwater utilities as they have implemented AMPs to varying degrees.

Some municipalities that have begun to implement AMPs have recognized the challenges involved with AMP development and worked with universities and government agencies to synthesize their experiences. Their experiences have served as the basis of a number of case studies and useful tools—the case studies evaluated and referenced in this paper include:

- City of Folsom, California
- City of Grand Rapids, Michigan
- City of Minneapolis, Minnesota
- City of San Diego, California
- City of Wellington, New Zealand
- South Placer Municipal Utility District, California

As well as reviewing existing literature and case studies, this paper highlights the experiences of several utilities in California, chosen based on their experience and/or interest in developing AMP capabilities. Through teleconferences and a questionnaire, these utilities described their unique perspectives on AMP planning and development, and also provided direct feedback on the content of this paper. These utilities are:

Utility	Type of System	Service Population	AMP Synopsis
Central Contra Costa Sanitary District	Wastewater	476,400	The Central Contra Costa Sanitary District began development of a formal AMP in 2014 with adoption of an Asset Management Board Policy and development of an Asset Management Implementation Plan; although foundational efforts began in the early 2000s to support asset management, particularly with condition assessments. Additionally, the District replaced its geographic information system (GIS) platform with Esri and is implementing GIS-centric solutions to leverage data integration with: Azteca's Cityworks for computerized maintenance management (CMMS), Innovyze's Infoworks Integrated Catchment Modeling (ICM) for collection system hydraulic modeling, Innovyze's Infomaster for collection system renewal planning, and ITpipes for closed-circuit television inspection of the collection system.
City of Paso Robles Department of Public Works	Stormwater	29,793	The City of Paso Robles operates drinking water, stormwater, and wastewater systems. A master plan for each system was developed to identify future development and infrastructure needs. The City's Department of Public Works began the development of an AMP for its stormwater system in 2007 to help meet the compliance objectives of their municipal separate storm sewer system (MS4) permit. The City does not currently implement a formal AMP for its stormwater system; however, due to a limited budget and lack of dedicated utility fee, an AMP would better equip City staff to manage areas with critical improvement and maintenance needs. The City currently uses a combination of existing documents and tools to track its assets, including master plans, urban water management plans, and its GIS database; however, drinking water, wastewater, and stormwater assets are all tracked separately.
City of San Diego Transportation and Storm Water Department	Stormwater	1,370,000	The City of San Diego began the development of a formal AMP in 2010 as part of an effort to prioritize the needs to improve water quality and manage flood risk. The City completed its first iteration of the plan and is now in the process of refining the management strategies and a process to reconcile the annual activities completed within the AMP.

Utility	Type of System	Service Population	AMP Synopsis
City of South Lake Tahoe Department of Public Works	Stormwater	21,403	The City of South Lake Tahoe began the development of its formal AMP in 2015 as a result of the inability by City staff to track storm system assets, and the amount of accumulated deferred maintenance on those assets. The City solicited proposals from various consultants for a formal AMP and ultimately decided on a package based on the following: (1) Intuitive user interface, (2) integration with other enterprise applications, (3) configurable, (4) work order module, (5) service request module, (6) resources module, (7) asset inventory module, (8) condition inspection module, (9) budgeting and valuation module, (10) reporting module, (11) mobile application included, and (12) data collection provided. The City has already experienced benefits with the budgeting/cost tracking ability, and anticipates additional benefits over time, including a reduction of capital costs, faster response times, more accurate budget tracking, more accurate documentation, and overall increases in system efficiency.
Orange County Public Works	Stormwater	3,000,000	Orange County Public Works is in the early stages of AMP development. A parcel-based land management system which will provide asset management capability is currently being developed. Additionally, asset inventories which historically have been managed in silos are being converted over to an enterprise GIS.
Zone 7 Water Agency	Stormwater and drinking water	240,000	Zone 7 Water Agency is a water wholesaler, and began developing a formal AMP in 2004, for its drinking water assets at the surface water treatment plants and groundwater wells and in the transmission system. A major update of the AMP was completed in 2011, in which the long-term funding forecast methodology was revised and asset classes were created to facilitate data collection and decision making. A stormwater AMP is anticipated for 2017.
Sonoma Valley County Sanitation District	Wastewater	40,000	Sonoma Valley County Sanitation District has a CMMS in place for its treatment and reclamation facilities, a separate maintenance management system for its collection system, and a long term financial plan for prioritizing capital upgrades and replacements. The District is just beginning the process to develop a more comprehensive AMP.
East Bay Municipal Utilities District	Wastewater	600,000	Description unavailable.

Utility	Type of System	Service Population	AMP Synopsis
Ross Valley Sanitation District	Wastewater	50,000	Ross Valley Sanitation District adopted formal asset management practices beginning in 2012, for one of the oldest wastewater conveyance systems in California. The practices were needed to meet state regulatory enforcement orders for reducing sanitary sewer overflows, including implementation of a 5-year, $100 million capital program. The District uses Innovyze CMMS software and Esri GIS software, coupled with custom Structured Query Language (SQL)-Access database tools to manage its AMP.

2 Critical Factors and Overcoming Barriers to Their Implementation

This section summarizes the major critical steps and factors to be considered during AMP development and implementation and highlights examples of encountered barriers. The critical steps and factors further described below are:

- Identifying overall AMP scope
- Establishing the desired level of service
- Choosing and implementing asset management software
- Cataloging assets
- Scoring assets
- Continuing AMP development

As each of these steps can be complex and time-consuming, they may often broadly be viewed as "barriers" to implementation in-and-of themselves, with more discreet challenges or barriers to be encountered within each critical step. Where possible, this paper attempts to highlight examples of those barriers or challenges that utilities have encountered, and provide a description of how they were overcome on the path to AMP implementation.

Utilities face challenges in creating, developing, and implementing AMPs at each stage of the process, not the least of which is obtaining buy-in and support from key stakeholders and decision makers (e.g., operations and maintenance staff, engineers, finance staff, customers, department directors, city council, board of directors) at the onset of AMP development and at each critical step along the journey. Various strategies exist for getting this support; the key to all of them is showing the benefits to the agency of reducing and stabilizing long-term facility operating, maintenance, and renewal costs — the "no surprises" approach. The bottom-line strategy in obtaining buy-in is helping decision makers to understand that preventing problems is a far less costly and disruptive path than fixing problems and their trickle-down consequences.

2.1 Identifying Overall AMP Scope

Wastewater and stormwater utilities typically own thousands of assets[1] (e.g., pipes, manholes, catch basins, pump stations, outfalls), spread throughout their service areas in their collection systems, pump stations, and treatment facilities. By treating all assets as equally important, programs can become bloated and overwhelm staff trying to implement a thorough assessment (Theerman 2016). Thus, it is important to determine upfront which types of assets to include in an AMP (e.g., assets with a certain value threshold, assets that are critical to the system) before embarking on the involved steps of cataloging and scoring assets.

[1] An "asset" is a component of the system with an independent physical and functional identity.

2.1.1 Asset Type

When determining which types of assets to include in the AMP, utilities need not be constrained to "hard" assets (e.g., storm drain system pipes and related appurtences of control). Other asset types, such as "soft" assets (i.e., human-based resources) and "natural" assets (i.e., utility-managed, naturally occurring resources) should be considered for inclusion due the influence of each asset type on system performance. While conventional AMPs typically include only hard assets, utilities are encouraged to think outside the box when identifying the types of assets (e.g., natural and soft) to include in the AMP to enhance overall system performance. However, for smaller systems just beginning the asset management process, the inclusion of natural and/or soft assets can add complexity and create challenges of getting basic AMP steps in place. It is common for utilities with smaller systems or which are just beginning to develop an AMP to initially focus on hard assets.

The **Central Contra Costa Sanitary District** selected physical and software assets having a replacement value greater than $5,000 and a useful life of at least 2 years for inclusion in their AMP.

Ross Valley Sanitation District only includes hard assets (gravity sewer lines, pumped force main lines, pipeline appurtenances such as manholes, air release valves, and pump stations) in its AMP.

Case Study: Watershed Asset Management Planning

City of San Diego

In developing an AMP for its stormwater system, the City of San Diego included "hard" assets with more than $5,000 in replacement costs — but it also included "natural" assets (such as receiving waters, discharges, and land) and "soft" assets (such as public opinion, policies, and relationships). To comply with its NPDES MS4 permit, the City acknowledged in its Watershed Asset Management Plan that it must also manage other "soft" assets including public behavior and relationships, regulatory relationships, monitoring equipment, ordinances and land development standards, the quality of water running into and out of its storm drain system, and the quality of water in the receiving water bodies. Although natural and soft assets cannot be "replaced" per se, the City included them in its Watershed Asset Management Plan to account for the funding needed to manage them at the level of service required by NPDES regulations and desired by the customers (U.S. EPA. n.d.[d]).

2.1.2 Asset Attribute Tracking

Using one comprehensive tool to track the various attributes of these assets (e.g., location, age, maintenance schedule, condition) can help utilities and municipalities more fully understand their complex systems. However, identifying the relevant assets — as well as the appropriate level of detail to track — is a formidable process. For example, utilities may struggle to determine the relevance of different types of assets to overall system performance, the value of privately owned assets that contribute to the system, or even the importance of assets in different geographic areas of the system (i.e., downstream assets vs. assets near the boundaries of the system). Asset cataloging and scoring are further discussed in sections 2.4 and 2.5, respectively.

Orange County Public Works is developing comprehensive reasonable assurance analyses/watershed management plans that identify pollutant load reduction goals, strategies, and schedules. These are significant data gathering efforts that are providing a good opportunity to use asset information to track and measure progress as water quality improvement strategies are implemented.

A valuable tool for beginning to understand a utility's current proficiency in managing assets is the "asset management IQ test" developed by the Southwest Environmental Finance Center and sponsored by the Kansas Department of Public Health and the Environment (Southwest Environmental Finance Center n.d.). This questionnaire explores a utility's current level of need on a number of asset management criteria with a score-based approach. The questionnaire's 30 questions are divided into six areas, allowing utilities that take the test periodically to assess their progress in each of those areas and determine where resources should be diverted.

When identifying the intended scope of an AMP, utilities should consider taking a staged approach to identifying the types of assets that make up the system: they should consider the relationship of each type of asset to the system's overall performance of the system and prioritize assets based on the functionality of the system and the desired level of service. By initially focusing on the largest and most critical assets, followed by gradual inclusion of less critical facilities, a staged approach can help prevent utilities from becoming overwhelmed.

The **Central Contra Costa Sanitary District** took a staged approach to AMP development by initially focusing on the collection system due to CMOM (i.e., reducing sanitary sewer overflows or SSOs). Upon success with implementing asset management for collection system assets, the District expanded the AMP to their wastewater treatment plant. This then led to a more formal pursuit of an AMP in 2014 with a dedicated asset management program coordinator and Asset Management Implementation Plan.

The initial development of the **City of San Diego's** AMP included identification and cataloging of all known storm water assets; however, condition data was only available for a subset of assets. To make up the data gap, the City relied on asset age as a proxy for management decisions. As the City refined the AMP over time, it updated asset conditions and improved the accuracy of the database.

Case Study: Stormwater Asset Management System

City of Minneapolis

Incorporating the various parts of its complex storm sewer system into an asset management system was noted as one of the biggest barriers for the City of Minneapolis to overcome. Specifically, the City struggled to determine the level of detail needed to evaluate its assets and associated attributes (e.g., small segments vs. large segments). It also experienced challenges implementing a standardized asset rating process during AMP development, as no process had yet been developed or implemented (U.S. EPA. n.d.[c]).

2.2 Establishing a Desired Level of Service

Establishing and defining a desired level of service for a system to provide its customers is critical to developing and gauging the success of an AMP. Generally, higher levels of service require more resources and a larger commitment from utilities to deliver to customers; lower levels of service can be less expensive but may not be the best option.

This step is a common area of lost momentum when developing an AMP. To mitigate this, it is recommended that utilities in the initial stages of AMP development begin with simple level-of-service goals, and expand only when solid descriptions or metrics are available.

EPA's "Asset Management for Sewer Collection Systems" fact sheet (U.S. EPA 2002) states that the basic level-of-service definition for most stormwater and wastewater utilities will be to deliver reliable storm/sanitary sewer collection and treatment services at the lowest sustainable cost, consistent with applicable environmental and health regulations. The fact sheet also specifies that level-of-service criteria should be system-specific. However, the following list includes examples of broad levels of service goals that should be considered by wastewater utilities:

- Ensuring adequate system capacity for all service areas (keeping in mind that undefined system capacities can create uncertainty when identifying appropriate budget planning).
- Eliminating system bottlenecks due to pipe blockages through a staged approach (i.e., to a level of performance to not more than "X" per year for the first 5 years of operation, with a goal of Y% reduction in occurrences in each year thereafter until a level of "Z" per year is obtained).
- Reducing peak flow volumes through inflow/infiltration controls.
- Reducing flooding and peak flow velocity through adequate stormwater management controls.
- Providing rapid and effective emergency response service.
- Minimizing cost and maximizing effectiveness of capacity, management, operation, and maintenance programs.

"SMARRT" Criteria

The University of Maryland Environmental Finance Center (2014[a]) suggests using the "SMARRT" criteria for establishing a utility's level-of-service goals:

- **S**pecific
- **M**easurable
- **A**ttainable
- **R**ealistic
- **R**elevant
- **T**imebound

Quality, quantity, reliability, and environmental standards are elements that can define level-of-service and associated system performance goals, both short- and long-term (U.S. EPA 2008). The targeted level of service, and the operations and assets responsible for providing that service, can guide utilities in identifying which assets to catalogue and to what depth, and what metrics to use in assessing how well the targeted level of service is being reached.

As discussed above, utilities should not treat all assets as equally important because personnel can be easily overwhelmed by the magnitude of the process. Utilities should work to identify which assets identified for inclusion in the initial AMP are considered critical to the operation and performance of the system. As the AMP develops, assets of lesser criticality (i.e., with a lower consequence of failure) can be added. According to Theerman (2016), the common measure for criticality is the importance of the asset multiplied by its condition. In other words, the most critical assets are those that are important (from a level-of-service perspective) and in the worst shape. That article notes that utilities should identify a subgroup of critical assets and create a pragmatic set of foundational practices for their assessment. Once these practices have been developed and established, they should be used to scale up the AMP to all assets relevant to the desired level of service.

At the beginning of its AMP process, **Orange County Public Works** implemented a pilot project by first identifying the location, maintenance schedules, and stressors to one type of hard asset, storm drain catch basins. By using only one type of asset at first, it could clearly understand and implement each step of the AMP without becoming overwhelmed by system complexities and funding constraints.

Many utilities have already established desired levels-of-service, but these should be updated to be concurrent with the proactive perspective of an AMP and should be integrated with evolving regulatory requirements, such as NPDES permits. Additionally, the AMP development process should quantitatively evaluate its success at mitigating expensive reactive maintenance and replacement. Setting explicit performance metrics within a utility's targeted level of service can make clear whether or not an AMP is providing benefits to a utility.

Defining level of service goals can be a challenge for stormwater utilities due to a lack of industry standards for storm system maintenance, particularly with storm sewer pipe cleaning. In some cases, the level of service for storm drain cleaning can be guided by regulatory requirements (e.g., MS4 permit). However, development of guidance and/or industry standards associated with stormwater infrastructure asset management in the future could reduce the challenges experienced by stormwater utilities when identifying and establishing a desired level of service.

2.2.1 Assessing Level-of-Service Objectives

Performance measurements — specific metrics designed to assess whether level-of-service objectives are being met — can vary but commonly include the following (U.S. EPA 2002):

- Annual performance goals for sewer system inspection, cleaning, maintenance, rehabilitation, and capital improvement.
- Correlating grease control education and enforcement measures with expected reductions in the number, distribution, and severity of grease blockages.
- Establishing maximum hourly and monthly peak flow volumes.
- Establishing maximum emergency response time to emergency calls, tracking customer complaints and claims for private property restoration (e.g., customer complaints will be responded to within X hours, Monday through Friday).
- Performing cost-benefit analysis of key completed activities, taking into account expected vs. actual outcome and budgeted vs. actual cost.

In summary, after identifying the assets that will be specifically included in the AMP, utilities must establish a reasonable level of service to understand which assets are needed to provide that service to customers. By establishing and routinely evaluating performance measures for the system, utilities can track whether the level-of-service objectives are being met.

Representatives from the **Zone 7 Water Agency** indicated that the Agency has level-of-service goals that are consistent with its mission statement. For above-ground assets, its AMP includes "critical" assets (defined as those assets that are needed to provide service to customers and are required for health and safety). The Agency identified the following measures to help ensure the effectiveness of its AMP, and thus meet the agency-wide level-of-service goals:

- Assign a person to manage the program and conduct ongoing related activities.
- Provide training and involve various internal stakeholders in AMP activities when appropriate (e.g., operations, maintenance, finance, and engineering staff).
- Adopt a Board-approved resolution regarding the necessary increases in water rates to fund the program.
- Make regular (e.g., 5-year) updates.

To better identify its level-of-service goals, Zone 7 Water Agency, a water wholesaler, collaborated with its water retailers in 2012 to update these goals. The new level of service goals established through this collaboration effort provide Zone 7 Water Agency with greater flexibility to manage uncertainty in the long-term reliability of its water supply, respond to prolonged facility outages, and plan its water system using level of service goals that are consistent with industry standards, while allowing the Agency to continue to provide a reliable, high-quality water supply to its customers.

Representatives from the **City of South Lake Tahoe** had not yet defined levels of service for their storm sewer system assets. However, the City endeavors to be more proactive, and uses its AMP software's built-in dashboard to track response times, number of responses, and number of requests to measure progress toward this goal.

Case Study: Stormwater Asset Management Program
City of Grand Rapids

The City of Grand Rapids went through a process of identifying a level of service that supported the following overall goals: (1) healthy natural resources (e.g., river, streams, lakes), (2) improved recreational opportunities, (3) a stronger economy, and (4) making Grand Rapids a more desirable place to live. The City proposed four levels of service (A to D, with A representing the highest level), each of which included various sub-tasks and metrics to achieve the overall level-of-service goal:

- **Level A** — Funding increases, comprehensive system inspection, and preventative/corrective maintenance activities. A system renewal rate of 100 years.
- **Level B** — Inspection and preventative/corrective maintenance activities with a more direct basis for tracking these activities. A system renewal rate of 125 years.
- **Level C** — Inspection and preventative/corrective maintenance activities to identify critical infrastructure and high-priority areas. A system renewal rate of 150 years.
- **Level D** — Existing level of service, with minimum inspection and preventative/corrective maintenance activities (i.e., corrective maintenance only for the most critically failed portions of the system).

The City calculated a cost of achieving each level of service, accounting for asset replacement at the end of each asset's estimated effective life, street sweeping, maintenance, studies and planning projects, and NPDES regulatory and development compliance. The City ultimately approved moving toward level C (which assumes doubling the effective life of infrastructure through rehabilitation and replacement and includes capital investment for green infrastructure practices) over the following 5 years (U.S. EPA. n.d.[b]).

2.3 Choosing and Implementing Asset Management Software

Due to the vast amount of information needed to execute an AMP, it is vital that utilities have access to an effective tool (or tools) to store their asset catalogs, asset condition scores, maintenance schedules, and to provide a platform for identifying the assets in most urgent need of attention. Multiple AMP software products have been developed, with specific features and anticipated benefits to help agencies make informed decisions about asset management. While AMP needs and goals may vary by utility, identifying a software package that meets a utility's specific needs is vital.

Utilities may encounter various challenges in choosing asset management software. Most common are:

- The cost associated with purchasing or developing the software program(s).
- Choosing software that is compatible with existing asset management tools and databases.
- The ease of data migration into the software program(s).
- Ease of use for utility staff.
- The resource investment needed to train utility staff in proper use of the software.
- The inclusion of unique infrastructure assets, particularly for stormwater systems (green infrastructure).

Some utilities have purchased "off-the-shelf" asset management software. This software is designed for the purpose, with asset management capabilities and asset management inventory data included (New Mexico Environmental Finance Center 2006), but it can be expensive and may not be necessary for smaller utilities that do not operate large, complex systems.

Other utilities have created in-house databases. Doing so can take significant time, but it can connect all relevant data across different information systems and establish a robust, utility-specific ranking system to identify the most critical projects.

While off-the-shelf and in-house asset management software may provide similar capabilities, it is important that utilities take the time to understand how the software they are considering can be incorporated into their daily operations and what features they may find especially valuable. Among the software capabilities and usability metrics they should consider:

- Intuitive user interface.
- Ability to integrate with other applications already in use — e.g., GIS; CMMS; sewer system management plan (SSMP); cost management, labor tracking, purchase order, and accounting systems.
- Configurability.
- Enterprise access.
- Analytics to prioritize asset management activities.
- Inclusion of various operational modules, such as:
  - Work order module
  - Service request module
  - Asset inventory module
  - Condition inspection module
  - Budgeting and valuation module
  - Reporting module

Comparative Study of Asset Management Software

Although EPA does not endorse any specific software, in 2012, the Water Finance Research Foundation conducted a comparative study (WFRF n.d.), using a uniform set of criteria to assess 14 popular asset management software systems: Accela, Agile Assets, Azteca System's Cityworks, Cartegraph, Cityview, Energov, IBM's Maximo, Infor/Hansen, Lucity/GBA, Maintenance Connection, Novotx's Elements, Oracle, Pubworks, and VUEWorks.

The study used four key functional categories: asset management, company services, GIS, and work orders. Within each of those categories, it identified several comparative criteria subcategories: software costs, vendor services, support, specialization, work orders, inventory, licensing and permitting, condition assessment, risk management, asset inventory, GIS mapping, Esri GIS integration, 311 systems, mobile devices, and Esri GIS return on investment.

The 14 systems' asset management capabilities were rated from 1 to 5 (5 being highest) in three categories: condition assessment capabilities, risk management, and asset inventory and hierarchy.

Five systems — Oracle, Accela, Cityworks, Maximo, and EnerGov — received perfect scores of 15 and achieved top ranking.

The "Check Up Program for Small Systems" (CUPSS) Asset Management Tool

CUPSS (U.S. EPA 2015) is a free asset management application that may be an option for resource-constrained, smaller utilities that may not need especially robust software. CUPSS may not be the ultimate solution for all small utilities because it does not deliver all of the capabilities of more developed software; however, it is a useful tool for utilities to begin to understand their systems and their needs. CUPSS allows utilities to develop the following:

- A record of assets
- A schedule of required tasks
- An understanding of their financial situation
- A tailored asset management plan

The latest features of the program include:

- Detailed view of an asset's attributes and associated operation and maintenance cost
- Annual reports for total costs of assets
- Ability to attach documents (Word, PDFs, images, etc.) to catalogued assets

EPA has also developed a user community for CUPSS to allow interested parties to be notified about training opportunities and "community calls."

CUPSS is regularly updated and is available for download at http://www.epa.gov/dwcapacity/information-check-program-small-systems-cupss-asset-management-tool.

- Inclusion of and communication with a mobile application (with adequate capacity).
- Data collection ability.

Whether a utility uses an in-house or pre-packaged product, it will need to draw on a combination of information sources — a list of critical assets (according to assets' score and rank), evaluation of recent closed-circuit television inspections, work order history, cleaning history, institutional knowledge — in deciding to authorize a repair/replacement or conduct further monitoring. In addition, it is important that utilities consider the ease of use by utility staff and ease of incorporation into already existing AMP tools and practices.

2.4 Cataloging Assets

Given the number of assets in stormwater and wastewater systems, the task of identifying and cataloging these assets is immense. It often proves to be a significant challenge for utilities that generally are unaware of the assets making up their systems, and/or the characteristics of those assets. Essential staff in various capacities (management, operations, maintenance, information technology, consultants) must collaborate closely to ensure that the appropriate assets are identified and characterized in a manner that will allow a well-functioning AMP to meet a utility's desired level of service.

Utilities may be reluctant to catalog assets due to the potential liability risks of discovering failing assets with the potential to cause property damage prior to their repair or replacement. Utilities can mitigate these liability risks by developing a comprehensive plan for addressing those assets, with management and public support, and by consulting early and often with their legal team.

An asset catalog (also known as an asset register) is a database used to document and maintain specific information about a utility's assets. The primary information to consider for such a catalog includes an asset's location, age, vendor-specified useful life, and recommended maintenance schedule. Soft and natural assets may require additional or unique

The **City of South Lake Tahoe** used a request for proposals process to choose the AMP software that best suited its needs. Some proposals were vastly over budget and were not considered, while others did meet the specifications. Two proposals were deemed to best fit the City's needs and the consultants were invited to give a live demonstration. Although it is early in their AMP implementation, the City's representatives have found the budgeting and cost tracking ability to be extremely helpful. Despite the benefits of the City's AMP, implementation of the software has involved some challenges. These include resistance of staff to institutional change, training of maintenance staff unfamiliar with the technology, a data collection effort that was more expensive and time-consuming than anticipated, and difficulty locating assets that the initial data collection effort did not identify.

In the absence of software that would meet all of its needs, the **Zone 7 Water Agency** uses an in-house Microsoft Access asset management database, developed by a consultant specifically for AMPs and designed for cost-effectiveness and efficiency in populating and implementing. The database features an asset hierarchy and groups assets into classes for which useful lives can be globally assigned. Users can query the database and transfer the data into Microsoft Excel to determine which assets are nearing the end of their useful lives, ascertain which need a condition assessment, and conduct funding analyses. The Agency maintains condition assessment findings separately in Microsoft Word documents. Not all information from the previous systems could be migrated into the database; the Agency therefore finds it useful to access the previous systems to understand how some data were originally developed.

The **Central Contra Costa Sanitary District** was unable to identify one software package that met all their needs. Therefore, the District identified "best-of-breed" vendor-supported software products and considered their ease of integration to meet key needs. Rather than a new enterprise resource planning software that also included CMMS, the District selected a CMMS, hydraulic model, and renovation planning software that are business partners with Esri to leverage their GIS data.

attributes. When cataloging assets, utilities should consider capturing the following information for each asset and recording that information in the selected asset management tool (proprietary software, public software, custom databases):

- Asset type
- Asset type details (e.g., size dimensions, material)
- GPS locations
- Digital pictures
- Unique identifier based on the utility's asset numbering system
- Serial numbers, if applicable
- Maintenance records
- For green infrastructure, soil matrices, fertilizer and pesticide application, and vegetation condition/health
- Name/address/phone for the responsible department (or owner or entity responsible for maintenance, if located on private property)
- Year installed
- Vendor-specified useful life
- Anticipated date of replacement (based on vendor-specified useful life)
- Maintenance schedules
- Installation or replacement cost

Case Study: Collection System Asset Management Program

City of Folsom

The City of Folsom uses GIS to display certain collection system asset information, such as pipe locations, materials, and sizes; manhole rim elevations and depths; and locations of pump stations, force mains, and sewer laterals. The GIS was incorporated with the City's CMMS to avoid duplicate and conflicting databases. It is used to store static asset information, such as size, material, length, and slope, whereas the CMMS stores dynamic operation and maintenance information.

2.4.1 Geographic Information System

A thorough GIS catalog with asset locations and pertinent information is a prerequisite for further AMP development. Asset management software packages or programs can include useful tools for cataloging assets, which can help personnel review and edit data more efficiently and link catalogue attribute data to other components of the AMP, including GIS. Many utilities have GIS databases (with varying degrees of completeness and detail), which typically include asset information such as location, material, and size. GIS information should be updated concurrently with an organization's asset management software, keeping all pertinent information updated across all platforms.

The **City of South Lake Tahoe's** AMP software, VUEWorks, has a GIS component. Information received from consultants and contractors in AutoCAD or other GIS software can be imported directly into the VUEWorks GIS. The City encountered some challenges in creating this system. The initial data collection effort required the collection of a massive amount of data, and many assets were overlooked. To overcome this challenge, the City reviewed the collection process and updated the system.

2.4.2 Data Dictionary

One barrier that a utility may encounter while cataloging system assets is the need to synthesize the broad range of asset definitions that its departments or personnel may use into a consistent set of terms for the asset management tool. Without a utility-specific standard of asset definitions, identification, and storage, assets may be mislabeled or cataloged incorrectly. Creating a "data dictionary" can help ensure that the information collected is useful, relevant, and consistent. Data dictionaries can also be useful in migrating asset information from legacy databases (such as preexisting independent data spreadsheets) into a new AMP asset catalog. Data dictionaries and the use of pre-populated drop-down fields within the catalog ensure conformity of data.

> The **City of South Lake Tahoe** created data dictionaries for each type of asset. Consequently, when they migrated data from their existing GIS, they only needed to make minor adjustments to the attributes. They continue to update the attribute data as needed.

2.4.3 Asset Hierarchy

An asset hierarchy is a set of appropriate, definable classifications that a utility uses to rank assets, based on each one's risk of failure versus its consequence of failure. Typically, asset hierarchies are based on asset type, asset function, or a combination of the two. (A functional hierarchy groups similar assets, or assets that are managed in a particular way, to help define their relationship to the overall system. For example, stormwater catch basins can be classified together regardless of size and configuration.) An asset hierarchy can help identify important assets that may require a higher level of maintenance than other assets that are less important to system performance. Many asset management software products and CMMSs can help utilities develop an asset hierarchy. Regardless of which tool is used, it is vital that a utility ensure that the hierarchy is current and accurate for the sake of sound asset management decision-making.

Utilities should invest time upfront cataloging assets to help understand the components of their systems. There are various ways to catalog a system's assets, but the choice of method may depend on the software being used: many asset management software packages or programs include useful tools to help catalog and use asset data. It is important to establish a utility-specific standard for defining, identifying, and storing asset data to keep those data consistent and correctly labeled.

> The **City of San Diego** developed an asset hierarchy that manages assets at both the division (programmatic, regulatory) and watershed (hydrologic unit, hydrologic area, hydrologic subarea and mainstem outfall drainage area) levels. Because the City's MS4 permit has watershed-based compliance requirements, an asset hierarchy has allowed the City to manage assets across the six watersheds within the City's jurisdiction.

> When defining the level of specificity for cataloging assets, representatives from the **Zone 7 Water Agency** considered how the information would be used. For example, pipelines were initially separated into many segments within the database; however, that level of detail proved unnecessary for assessments or developing future renewal needs. In another case, the Agency found it beneficial to track the roof, coating, and structure of a treated water reservoir as separate assets since they have different useful lives and each have significant replacement costs. The Agency has found it extremely useful to have an asset database adaptable enough that it could be readily adjusted as needed.

> The **Central Contra Costa Sanitary District** established an asset hierarchy for the District's wastewater treatment plant and pump stations, which has helped maintenance and engineering staff recognize the relationship between assets, and consider the whole system when making decisions regarding maintenance and/or renovation/renewal.

2.5 Scoring Assets

Once assets have been identified and all available data centralized, the information can be quantitatively assessed to assign a "score" or rating to help inform future decision-making regarding the assets. (Note that the identification, cataloging, and scoring of assets can be completed at the same time.) Assets can be scored through various lenses; therefore, recognizing the appropriate metrics, standardizing a methodology, and choosing a perspective are crucial to ensuring a consistent system is created. This section discusses four qualities to score: condition, remaining useful life, probability of failure, and consequence of failure.

2.5.1 Asset Condition

An asset's condition is indicative of its performance and remaining useful life. Scoring an asset's condition is imperative to understanding whether it is delivering the desired level of service and how much attention it may need to continue to deliver at the desired level.

Assessments of structural and operational condition can be guided by a condition rating system developed by the utility or a pre-developed rating system, such as the National Association of Sewer Services Companies' Pipeline Assessment and Certification Program (NASSCO 2016) or Bonitz et al.'s (2015) system for ranking asset condition on a scale of 1 to 5. (In the latter system, a 1 indicates that an asset is in good condition, needing only routine maintenance with no associated cost for improvement. A 5 would be assigned to an asset in poor condition, needing replacement, with a cost of improvement above 40 percent of the asset replacement value.)

The condition assessment process should also include details of assets' failure modes, as well as insight on the efficacy of prior maintenance to mitigate future failure (Portland Water Bureau 2013). This information provides context on the asset's current health, its rate of deterioration, and how it may fall short of performance objectives in the future.

To further develop condition assessments, a utility should clearly document repairs by field crews, tracking the type of repair, corresponding costs of labor and material, and any other notes. This information should be uploaded to the asset management software to provide further context for condition assessment and the probability of failure score discussed below (U.S. EPA 2002).

2.5.2 Remaining Useful Life

Determining remaining useful life is critical to ensuring that an asset continues to meet its performance objectives before unforeseen failure. However, calculating useful life may not always be as simple as subtracting an asset's current age from its expected total life. Remaining useful life values should be refined by regular inspection and performance evaluations as an asset ages. It is important that utilities understand and account for the stressors that the asset was (and will continue to be) subject to when scoring its condition and remaining useful life.

The **Los Angeles Department of Public Works** grades assets' useful life on a scale of 1 to 5: an asset with a 1 shows only minor defects and is unlikely to fail in the foreseeable future, while an asset with a 5 has defects requiring immediate attention and will likely fail in the next 5 years (LADPW n.d.).

The **Zone 7 Water Agency** assigns an original useful life to each asset class. The useful life may be vendor-specified; however, when that is unavailable, the Agency may base it upon industry guidelines and experience with the asset class's typical performance in their system.

Remaining useful life score should also consider a replacement planning approach, which identifies when an asset's increasing maintenance costs and declining level of service will become greater than the cost of replacement (U.S. EPA 2002). This should be paired with a maintenance schedule for each asset to ensure that the expected remaining useful life is reached, if not exceeded (New Mexico Environmental Finance Center 2006).

2.5.3 Probability of Failure

Determining an asset's probability of failure is a helpful step to predict and prevent a disruption in service. A probability of failure score can be based solely on an asset's condition or calculated as a composite score incorporating more information, such as age, performance, and maintenance history (U.S. EPA n.d.[b]). Included in this assessment is an evaluation of assets' modes of failure. Because of the complicated nature of assigning probability to all of an asset's failures, specifically designed software offers the most informed score. Alternatively, the Risk Analysis and Management for Critical Asset Protection (RAMCAP®) methodology is a recognized approach to assessing asset vulnerability from an all-hazards perspective (ASME 2009; NJDEP n.d.).

2.5.4 Consequence of Failure

The consequence of failure ("criticality") score indicates the potential for a disruption in service and the magnitude of its effect. It informs utilities of which projects should have priority, and most importantly it illustrates why they should have priority. Calculating an asset's consequence of failure takes into account the social, environmental, and financial consequences of failure, including to community health and safety.

The consequence of failure score is complex because it requires identifying areas where failure would have the greatest impact: for example, assets that deliver services to hospitals are often ranked among the most consequential. Ranking assets in this sense is challenging because the breadth of consequences for each identified asset is wide, and ranking all assets' consequences of failure adjacent to one another is an involved process. Because computing the score is so multi-faceted, specialized software may make the process more efficient and effective (U.S. EPA n.d.[b]).

Consequence of failure is often examined in concert with likelihood of failure. For example, the Portland Water Bureau (2013) presents a "criticality matrix" that balances likelihood of failure (very low to very high) against consequence of failure (very low to extreme).

The **City of San Diego** calculated a business risk exposure score for every asset in its inventory. The business risk exposure score is calculated by multiplying the probability of failure by the consequence of failure. The City ranks assets by score to prioritize the most critical to efficiently plan work.

The **Central Contra Costa Sanitary District** implements Innovyze's Infomaster software, which calculates consequence of failure based on multiple factors and uses GIS spatial analysis (i.e., proximity to schools, hospitals, waterbodies, transportation features such as freeways). For the wastewater treatment plant, the District developed a consequence of failure table based on operational importance (e.g., power systems and headworks most critical, administrative buildings least critical).

The **Ross Valley Sanitation District's** 2013 Infrastructure Asset Management Plan identifies the following parameters used to evaluate consequence of failure for mainline pipes and trunk lines:

- Proximity to a perennial waterway
- Proximity to critical facilities (i.e., schools or parks)
- Impact on primary and secondary arterial roadways
- Area impacted as determined by pipe size

2.6 Continued AMP Development and Improvement

To ensure that utilities' assets and operations provide their desired level of service into the future, AMPs must be regularly evaluated and further developed. AMPs should be iterative in nature — multi-faceted processes that evolve as users further understand their systems' needs, catalog their experiences, review input from stakeholders, and resulting successes and failures. Additionally, access to more data, improved data analysis techniques, and updates to fiscal forecasting methods further inform and progress a utility's AMP (U.S. EPA n.d.[d]). Changes to policy and regulatory requirements also serve to shape and develop AMPs (U.S. EPA n.d.[d]). For example, data record and reporting outputs from asset management software may be aligned with new permit or regulation requirements (e.g., asset inspections, maintenance activities, occurrence of sewer overflows) to help streamline reporting processes for utilities.

As the **City of South Lake Tahoe** was still beginning to implement its AMP, it experienced challenges in training staff across various departments. To address this issue, it held monthly meetings to train staff and allow them to ask questions and voice concerns. These meetings have helped the City understand how the system is increasing efficiency and reducing costs. The City plans to continue these meetings so that each user can use all relevant aspects of the software. To determine the effectiveness of its AMP, the City will use information from the AMP to generate comprehensive reports.

The asset management IQ test mentioned in section 2.1.2 of this paper is a valuable approach for understanding the level of proficiency a utility had when it began its AMP, and how it has progressed. By comparing scores across the tool's multiple sections, as well as over time, communities can better identify areas for further development.

Orange County Public Works is investing in a holistic, adaptive management approach to asset management to support the implementation of watershed management plans designed to achieve specific water quality improvement goals over time. The decision to take this approach followed an asset management pilot project in 2014 with a firm called Ecolayers.

The goal of the project was to explore the potential benefits asset management offered in terms of the ability to optimize routine maintenance of infrastructure that has a direct link to environmental condition. Storm drain catch basins were selected as the asset feature and the maintenance of them as the asset management activity that could be optimized. Storm drain catch basins were selected due to the direct impact they have on stormwater runoff pollutant loading. Maintaining a storm drain catch basin is a labor-intensive activity that increases in complexity with the addition of structural stormwater runoff controls (e.g., filters and screens). This maintenance activity has long been viewed as a fundamental non-structural source control to address stormwater runoff pollution, although little is known about how effective this strategy actually is in terms of reducing pollutant loading from the MS4. To determine effectiveness of this maintenance activity, Orange County Public Works is integrating asset management (inventory and maintenance information) with environmental monitoring data collected at outfall and receiving water stations downstream of catchments where these storm drain catch basins are located.

More information about the pilot project can be found at https://www.casqa.org/asca/improving-stormwater-management-through-integration-environmental-data-asset-maintenance-and.

Lessons learned from AMPs from around the world can help a utility identify where it is succeeding. International comparisons also offer insight into how AMPs can be further developed to meet a utility's objectives.

To ensure that an AMP continues to function appropriately, utilities should establish internal evaluation and benchmarking standards using predetermined criteria. Evaluating and further developing an AMP is an iterative, multi-faceted process, but can help to ensure that a utility is adequately implementing the various components of the AMP while meeting both level-of-service goals and regulatory requirements.

To further improve the cost-saving and maintenance forecasting capabilities of its AMP, the **Portland Water Bureau** joined the International Water Association–Water Services Association of Australia (IWA-WSAA). The Bureau describes its experience with the IWA-WSAA in its report on asset management planning (Portland Water Bureau 2013).

Each year, 40 to 50 utilities join this international benchmarking organization, which the Bureau defines as "the global leader in asset management dedicated to continuous improvement in the water industry." The IWA-WSAA has identified a set of crucial criteria for creating and successfully developing AMPs for drinking water systems, which can also be applied to AMPs wastewater and stormwater systems:

- Establishing credible cost and service performance indicators and benchmarks
- Critically identifying cost-saving opportunities
- Understanding best practices and how they relate to improving performance

The IWA-WSAA uses seven broad categories to compare utilities:

- Corporate policy and business planning
- Asset capability forward planning
- Asset acquisition
- Asset operations
- Asset maintenance
- Asset replacement and rehabilitation
- Business support systems

Organizations score themselves in each of the seven categories, and their scores are compared to those of the other participants. AMP experts independently evaluate the organizations' self-assessments and provide detailed feedback on where they could improve performance. The majority of participants in the IWA-WSAA benchmarking are from the Australia–New Zealand area, recognized as a leader in asset management best practices. The participation of these utilities underscores the value of the independent evaluation and the benchmarking comparison.

3 Program Implementation Cost and Capital Planning Considerations

Asset management is an important tool that can give utilities the data they need to make well-informed, confident decisions for both system capital planning and repair and rehabilitation projects. Sound operational and financial planning based on these data can help utilities plan their budgets around activities critical to sustained performance. But most utilities encounter a large barrier when they start the AMP process: securing and allocating the upfront investment they need to develop AMP tools. Furthermore, utilities must recognize that the continued implementation of the AMP (such as data updates, mapping efforts, and staff training) will become an ongoing operational cost that will need to be forecasted in each year's budget.

For the **City of San Diego**, the annual costs of operating and updating the AMP includes consultant support and dedicate staff time (one full-time equivalent).

In its initial Asset Management Implementation Plan in 2014, the **Central Contra Costa Sanitary District** anticipated a cost of $5 million over 5 years to expand and improve its AMP. The District employs six full-time equivalents in its Asset Management Group, which includes all GIS administration and support and technical support of the CMMS, closed-circuit television software, and other relational software such as Infoworks hydraulic model and Infomaster for asset replacement planning. By presenting the business needs and benefits to customers, District staff have obtained the support of management and board members for necessary investments in the AMP.

Recognizing a difference in cost between near- and long-term maintenance needs, the **San Francisco Public Utilities Commission** developed a cost forecasting scenario, comparing the costs of projects to be performed in 5, 10, and 15 years, as well as those completed, no longer needed, or to be completed within other projects. The results have helped to refine the scope and priority of capital and repair and replacement projects (Bonitz et al. 2015).

In addition to the upfront investment and ongoing operational costs needed to develop and implement an AMP, utilities struggle with securing funding to identify and complete capital improvement projects and to maintain assets at or near the needed levels of service. Utilities can minimize the need for, and extent of, capital improvement projects by prioritizing the maximization of the return on investment of existing assets through the AMP. This is especially true for stormwater utilities, which are better served by using AMP to optimize utilization of existing assets instead of emphasizing planning for new capital expenditures. Thereafter, an AMP becomes a useful ally by providing sound data on operations and finances, information the utility needs to justify new and replacement projects to customers and other stakeholders.

Key to the appropriation of funds is determining the costs associated with near- and long-term maintenance as well as refurbishment. Well-informed, robust asset management software can quantify the costs of impending maintenance/replacement forecasts. Near-term financial forecasting should extend over 5 to 10 years, be updated annually, and be included in utilities' financial reports.

In June 2014, President Obama signed the Water Resources Reform and Development Act that, in part, amended provisions of the Clean Water Act affecting the Clean Water State Revolving Fund (SRF) program. As a result, utilities requesting SRF financing must develop and implement a fiscal sustainability plan, which is functionally equivalent to an AMP, as a condition for receiving a loan. Thus, utilities that have an AMP in place are better positioned to obtain financing through the SRF.

Funding mechanisms differ greatly between wastewater and stormwater utilities, and depend on the revenue sources of each utility. The following sections outline the funding options for both wastewater and stormwater utilities and present real-world experiences of both wastewater and stormwater utilities that have struggled with funding the development, implementation, and evolution of AMPs.

3.1 Wastewater Program Funding

The operation and maintenance of a wastewater utility is typically funded solely by a system's revenue. Some utilities also see a "cash drain" from service revenues collected, which are diverted to fund other "general fund" obligations. Service rates set by the utility will determine the system's revenue, which must also be used to replenish any reserves used for emergency activities. A well-thought-out rate structure will account for system needs in both the current and future years. Accounting for AMP development and implementation costs will most likely result in an increase in user rates; however, rate increases based on sound asset management principles can be more clearly defended to the public (New Mexico Environmental Finance Center 2006).

Some wastewater utilities have secured and appropriated funding by developing multi-annual repair and rehabilitation (R&R) plans for their most necessary projects and concurrent capital improvement plans (CIPs) (U.S. EPA n.d.[a], n.d.[e]). Funding sources include a variety of user fees (monthly service charges, participation chargers from developers, etc.; as well as debt financing options (e.g., bonds).

Typical Funding Sources for Wastewater Programs

System Revenues	System Reserve Funds	System-Generated Replacement Funds	Non-system Revenue
• User fees • Connection fees • Stand-by fees • Late fees • Penalties • Reconnect charges • Developer impact fees	• Emergency reserves • Capital improvement reserves • Debt reserves	• Bonds • Taxes	• State grants • State loans • Federal grants • Federal loans • State or federal loan/grant combinations

Information from New Mexico Environmental Finance Center 2006

Case Study: Collection System Asset Management Program
South Placer Municipal Utility District

The South Placer Municipal Utility District has used an R&R plan funded through maintenance and operations revenue (collected through monthly service charges) for maintenance-related work to improve functionality, reduce the amount of corrective maintenance performed, and reduce the overall probability of asset failure. The District's CIP is funded through depreciation revenue (also collected through monthly service charges) and local participation charges from developers. The CIP is used for replacement of pipes that have reached or exceeded their useful life and cannot perform their designed function identified through the condition assessment process, and for upsizing pipes based on results of the sewer collection system evaluation and capacity planning.

3.2 Stormwater Program Funding

Stormwater managers often face additional challenges securing funds for program implementation. Though many communities fund stormwater management through property taxes paid into their general funds, stormwater management improvements are often a low priority. There are alternatives to general funds, though, including service fees based on property type or impervious area, special assessment districts or regional funding mechanisms, system development charges (also known as connection fees or tie-in charges), grants, and low-interest loans (U.S. EPA 2009). Over 800 communities across the country have implemented stormwater utility fees assessed to property owners in efforts to create a more stable source of program funding and open the door to newer financing mechanisms such as community-based public-private partnerships.

Implementing a stormwater utility fee or user rate structure can be a large barrier for stormwater utilities, especially for municipalities/counties that operate a stormwater programs but are not stormwater utilities per se. It is important to inform the public of the inadequacies/deficiencies of the community's current stormwater management program and present the benefits experienced by other communities that use stormwater fees. When an AMP can provide transparent financial and environmental benefits for such funding mechanisms, customers will be more likely to support its implementation.

California's stormwater programs have been severely limited in their ability to establish stormwater utility fees by **Proposition 218**, which was passed in 1996. This law requires that a tax collected for a specific purpose (e.g., stormwater program funding) be approved by two-thirds of the voters because it qualifies as a "special tax." In addition, balloted, property-related fees would require approval of 50 percent of property owners. Based on information from EPA Region 9, since 2003 in California, three communities have passed stormwater-related fees as special taxes, seven communities have passed balloted property-related fees to help fund stormwater programs (though one of the fees was recalled and reduced while another fee was overturned in court), and five other communities could not pass balloted property-related fees.

The California Water Conservation, Flood Control and Stormwater Management Act was a proposed ballot measure in 2016 that would have established an alternative funding method authorizing utilities to:

- Establish user rates to encourage water conservation, prevent waste, and discourage excessive use of water.
- Charge additional user fees for flood control and stormwater management to protect coastal waters, rivers, lakes, streams, groundwater, and other sources of drinking water from contamination and to comply with the federal and state laws.
- Reduce water and sewer rates for low income customers.

The intent of this alternative funding method was to allow utilities (and other local agencies) to invest in the water supplies, water quality, flood protection, and water resource management and conservation programs need, while protecting customers and guaranteeing a high level of accountability by the service providers.

In December 2016, supporters decided not to move forward with the proposed ballot measure citing lack of polling support. Thus, Proposition 218 remains a barrier to obtaining proper funding for many storm water utilities.

3.3 Utility Examples of AMP Funding

Funding sources typically vary based on the service provided by the utility. While wastewater utilities are funded mainly by system revenues, stormwater utilities that may not charge customers a user fee or are funded solely by a general fund may encounter more barriers. Other funding options — including service fees based on property type or impervious area, special assessment districts or regional funding mechanisms, system development charges, and grants and low-interest loans — can create a stable source of funds for AMP-identified maintenance projects and management.

The **City of Grand Rapids** developed its AMP in response to the need to eliminate its combined sewer overflows and update its aging stormwater infrastructure (West Michigan Environmental Action Council 2014). Through the support of a citizen's stakeholder group, the West Michigan Environmental Action Council, the City was able to channel its need for an AMP into community outreach and win support for the initial investment. The City began developing its stormwater AMP in 2008 and was able to finance its initiative through a voter-approved income tax increase in 2010 (U.S. EPA n.d.[b]). Of a Commission-approved budget of $450,000, the City invested approximately $382,000 to complete its asset management plan, which serves as the base for its stormwater infrastructure and capital program.

The **Zone 7 Water Agency** includes AMP on-going implementation and 5-year updates in the CIP as projects funded from the renewal and replacement fund. When there was insufficient funding for all of the desired tasks in a recent AMP update scope, the tasks were prioritized. For example, rather than performing a condition assessment on as many assets as possible, the Agency assessed a few key assets and used the remaining resources to develop a condition assessment program that staff could carry out throughout the year and in the course of their work. The Agency is a water wholesaler, so funding comes from existing customers of its retailers through water rates. Having an AMP helps to justify and secure funding for the program through transfers from water sales to the renewal and replacement fund.

The **City of Minneapolis** has implemented a stormwater utility fee for residents since 2005, identified as a line item on utility bills. The stormwater utility fee provides funding for stormwater management, including the City's asset management system. The City was able to garner support of its stormwater asset management system from elected officials, which helped increase support from other parts of the City's management. The fee depends on work completed and the City's ability to meet the six motivating factors:

- Improve the system
- Identify criticality of system components
- Identify life-cycle costs
- Improve documentation/recordkeeping
- Improve future decision-making as a result of data and analysis
- Take a proactive versus a reactive approach

The **City of Paso Robles** funds its wastewater AMP through individual enterprise funding mechanisms. It has no dedicated funding source (enterprise fund) for its stormwater program, so it does not have the funding necessary to develop a robust AMP for its stormwater system. A certain percentage is carved out of the annual budget to fund asset depreciation. The City's representatives believe that developing an AMP for the stormwater program would allow them to understand the number and age of the assets. This would allow their staff to better understand what assets would need replacement or repair, set aside depreciation funding, and prepare a 5- to 10-year CIP to systematically improve the infrastructure.

The **City of South Lake Tahoe** appropriated funds in its 2015 budget cycle for the cost of the contract to develop its AMP and for additional data collection. Specific funding was requested for an asset management system. (The City already had a robust GIS program, whose data were migrated into the AMP.) The AMP was still in its infancy, but City representatives anticipated that it would increase efficiency and response time as well as reporting and future budgeting. Given the increased efficiency of their staff, they are hoping to save on costs through asset management in the future and allocate those funds elsewhere. The AMP will be used to provide a more structured justification for CIP approvals from the City Council.

Orange County Public Works is the principal permittee under the Phase I MS4 Permits for Orange County. Only one municipality in Orange County has a voter-approved stormwater utility fee in place (City of San Clemente). Orange County Public Works funds road and flood CIPs primarily through a gas tax (road) and property taxes (flood). The 34 municipalities of Orange County fund countywide elements of a regional stormwater program administered by Orange County Public Works (such as public education/outreach and monitoring) through a cost-share budget which has averaged just over $5 million the last several years. Grant funding (Propositions 50, 84, and 1) has been used to fund regional structural water quality improvement projects. Also, the Orange County Transportation Authority has a voter-approved half cent sales tax called Measure M2 which they have used a portion of to provide funding to municipalities for water quality improvement projects since 2010.

The **City of San Diego** has a storm drain fee, established in 1996, which is collected on the water/sewer service bill. The revenue received from this fee is transferred to the General Fund which is used to partially support storm water expenditures. Storm Water CIP projects are funded by a variety of sources including the General Fund, financing, and TransNet. These funding sources vary from year to year. The development of the City's AMP was a consultant task order funded by the General Fund. The City invested over $1 million over a 5-year period towards AMP development. This investment resulted in the City's Watershed Asset Management Plan that is now the basis for future increases in funding requests (also allows for efficiently managing limited resource to pay for critical upgrades/repairs prior to costly system failures).

4 Benefits of AMP Implementation

One of the most evident benefits of AMPs is a framework for prioritizing a municipality's most critical projects and meeting its targeted level of service (U.S. EPA n.d.[b]). A crucial component of a successful framework is the ability to forecast as much as 100 years of maintenance, refurbishment, and appropriate funding in advance of an asset's failure (Bonitz et al. 2015). An AMP can help a utility save on operational and planning costs while providing a consistent level of service to its customers with fewer unexpected disruptions in service. Ultimately, proactive maintenance that meets customers' needs can make the region a more desirable place to live and ultimately grow the tax base (U.S. EPA n.d.[b]). In addition, AMPs can give utilities the data they need to project future failures, reducing the potential for catastrophic failures that often lead to environmental degradation and regulatory non-compliance.

AMPs' benefits will vary by utility; below are some potential benefits of formally implementing an accurate, useable AMP:

- Reduced overall costs for both operations and capital expenditures.
- Establishing adequate user rates and stabilizing future rate increases based on sound operational and financial planning while providing transparency to customers and stakeholders.
- Prolonged asset lifecycle and enhanced long-term asset performance.
- Confidence in capital planning regarding rehabilitation, repair, and replacement decision-making.
- Reduced life cycle costs from better-focused resource use.
- Enhanced return of investment on capital spending and increased efficiency of resource allocation.
- Meeting defined level-of-service and customer expectations with a focus on system sustainability.

Ross Valley Sanitation District has used asset management to eliminate unnecessary capital projects recommended from traditional capital planning efforts. A single project, eliminated by use of asset management, reduced the total cost of the District's capital program by approximately $4 million. By utilizing asset management, the District revamped its $100 million capital program to reevaluate and ultimately eliminate multiple poorly defined and improperly prioritized projects, and helped ensure the funds went to projects with the highest return to the level-of-service goals established by the District during the asset management process.

The District has also found that having a sound AMP is valuable communicating the basis for major capital programs and related rate increases to ratepayers. By having a sound AMP, the District was able to approve a 5year schedule of rate increases, totaling over 40%, with minimal public opposition.

The **City of San Diego** invested over $1 million over a 5-year period towards AMP development. This investment resulted in the City's Watershed Asset Management Plan that is now the basis for future increases in funding requests, and also allows for efficiently managing limited resource to pay for critical upgrades/repairs prior to costly system failures. Implementation of the plan is saving the City in maintenance and reparation costs over the life of the City's storm water assets.

The plan also attempts to integrate the City's flood control and water quality programs to get a true "cost" of stormwater and flood control management and identify opportunities to implement projects that meet the goals of both programs while minimizing costs. In addition to cost savings, the use of an AMP has created a synergy between the two programs.

- Budgeting focused on asset maintenance/replacement critical to sustained system performance.
- Reduced environmental impacts and meeting regulatory requirements.
- Improved emergency response.
- Improved asset security and safety.
- Improved integration with flood control and water quality programs.

Since 2002, the **Central Contra Costa Sanitary District** has reduced SSOs by approximately 70% by implementing a closed-circuit television sewer inspection program and increasing maintenance staff and equipment. Data obtained from the AMP is used for capital improvements and preventive maintenance scheduling.

Case Study: Collection System Asset Management Program
South Placer Municipal Utility District

Using an AMP for its collection system enabled the District to allocate the necessary personnel to the most critical needs while deferring less-immediate projects. This has reduced the needed number of employees by 10 percent per mile of pipe (U.S. EPA n.d.[e]).

Case Study: Collection System Asset Management Program
City of Folsom

In 2006, the California State Water Resources Control Board adopted the Statewide General Waste Discharge Requirements for Sanitary Sewer Systems, which require municipalities to develop and implement SSMPs to ensure proper funding and management of sanitary sewer systems. The City developed and implemented an SSMP that established five specific goals (U.S. EPA n.d.[a]):

- Provide uninterrupted service.
- Minimize the risk of SSOs; mitigate unforeseen SSOs determined to be preventable through adequate system inspection and maintenance.
- Ensure adequate sewer line capacities throughout the service area.
- Sustain the aging sewer infrastructure by developing and implementing an AMP to extend asset lifecycle.
- Ensure adequate funding support and resources to sustain long-term asset management.

Implementing an AMP — integrating capital improvement projects, condition assessments, funding, operation and maintenance, and risk and service levels — was critical in achieving these goals. Afterward, the City experienced a number of benefits, including a reduction in the number of sewer spill events by 80 percent since 1998 and an average spill rate well below the regional and state averages. A 2012 audit of the program by the Central Valley Water Board concluded that the collection system was in good operating condition and that the system has adequate capacity for sewage flow, indicating a substantial improvement in operations since a 2000 spill (U.S. EPA n.d.[a]).

4.1 AMP Application for NPDES Permit Compliance

As a condition of coverage by an NPDES permit, wastewater and stormwater dischargers must operate and maintain their systems in compliance with certain conditions. AMPs can help utilities meet these and other regulatory requirements. As the ever-degrading condition of stormwater and wastewater assets becomes more evident (based on SSOs, service disruptions, and expensive reactive replacement/rehabilitation projects), and AMPs

Representatives from the **City of South Lake Tahoe** are planning to align tracking and reporting requirements from the NPDES permit with actual reports that can be provided in the AMP, which will alleviate the need for disparate databases and program tracking.

show more success in achieving regulatory compliance, NPDES permits are requiring formal AMPs more often.

Meanwhile, impending regulatory requirements will bring noncompliance penalties in the tens of thousands of dollars; incorporating stormwater quality standards (e.g., total maximum daily loads) into the asset management perspective can help meet these requirements as well (U.S. EPA n.d.[d]).

Again, more NPDES permits are expected to require AMPs in the coming years. And, when properly managed and funded, AMPs have proven to help utilities meet both regulatory and level-of-service objectives.

Orange County Public Works is subject to a Phase I MS4 permit along with 34 other co-permittees, and implements a stormwater management program as a requirement of the permit. Representatives of Orange County Public Works explained that the implementation of an AMP is vital to a stormwater management program and a necessary means to achieving and maintaining MS4 permit compliance. However, since the MS4 permit does not require the implementation of an AMP, support for the initial investment in an AMP has been lacking from county management. Orange County Public Works is optimistic that the inclusion of AMP requirements within the Phase I MS4 permit can help garner support for the formal development of an AMP that can be useful NPDES compliance-related activities, such as reporting and tracking these activities.

Currently, Orange County Public Works compiles both county and co-permittee data for the MS4 permit annual report. Data compilation can be difficult, and often results in large amounts of useful but unusable data for overall asset management. Representatives of Orange County Public Works anticipate that an AMP that is coordinated closely with the AMPs of the co-permittees would ease the compilation of compliance data for the MS4 permit, and help organize the datasets into information that can be used in the future. Therefore, they are working with other co-permittees under the Phase I MS4 permit to educate them about the usefulness of an AMP and build momentum within county management to develop and implement a formal AMP.

5 References

- AMSA (Association of Metropolitan Sewerage Agencies), AWWA (American Water Works Association), AMWA (Association of Metropolitan Water Agencies), WEF (Water Environment Federation). 2002. *Managing Public Infrastructure Assets to Minimize Cost and Maximize Performance.* Alexandria, VA: AMSA.

- ASCE (American Society of Civil Engineers). n.d. "2013 Report Card for America's Infrastructure: Wastewater." http://www.infrastructurereportcard.org/a/documents/Wastewater.pdf (accessed 3/9/2016).

- ASME (American Society of Mechanical Engineers). 2009. *All Hazards Risk and Resilience: Prioritizing Critical Infrastructure Using the RAMCAP Plus™ Approach.*

- AWWA Research Foundation. 2008. *Asset Management Research Needs Roadmap.* http://www.waterrf.org/PublicReportLibrary/91216.pdf (accessed 5/19/2016).

- Bonitz, P., Desai, J. Henderson, B., Lam, V., Powell, J., Wong, D. 2015. "Asset Management: Balancing Program Constraints." *WE&T* (September). http://www.waterenvironmenttechnology-digital.com/waterenvironmenttechnology/september_2015?sub_id=2tgOKY5RCk1Q&pg=80#pg80 (accessed 1/27/2016).

- LADPW (Los Angeles Department of Public Works). n.d. "Conditional Assessment Program." http://ladpw.org/smd/SMD/CAPdefectgradedescrp.pdf (accessed 1/27/2016).

- NASSCO (National Association of Sewer Service Companies). 2016. "Training & Recertification: Pipeline Assessment & Certification Program." http://nassco.org/training_edu/te_pacp.html (accessed 5/20/2016).

- New Mexico Environmental Finance Center. 2006. *Asset Management: A Guide for Water and Wastewater Systems.* https://www.env.nm.gov/dwb/assistance/documents/AssetManagementGuide.pdf (accessed 5/19/2016).

- NJDEP (New Jersey Department of Environmental Protection). n.d. "Asset Management Guidance and Best Practices." http://www.nj.gov/dep/watersupply/pdf/guidance-amp.pdf (accessed 2/10/2016).

- Portland Water Bureau. 2013. *Asset Management Planning at the Portland Water Bureau.* https://www.portlandoregon.gov/water/article/473693 (accessed 2/8/2016).

- Southwest Environmental Finance Center. n.d. "Asset Management IQ." https://southwestefc.unm.edu/AssetManagementIQ/main.php (accessed 2/23/2016).

- Theerman, J. 2016. "Water Utility Rx." *BC Water News* (March 1). http://www.brownandcaldwell.com/1water/?GUID=37E83D82 (accessed 3/1/2016).

- University of Maryland Environmental Finance Center. 2014[a]. *Applying Asset Management to Stormwater: A Guidebook for the City of Scranton, Pennsylvania.* https://efc.umd.edu/assets/scranton_asset_management_guidebook_11.30.14_compressed_(1).pdf (accessed 5/19/2016).

- URS Corporation. 2013. *Watershed Asset Management Plan.* CSD-RT-13-URS57-01. https://www.sandiego.gov/sites/default/files/legacy/stormwater/pdf/wamp2013.pdf (accessed 8/2/2016).

- U.S. EPA. 2002. "Fact Sheet: Asset Management for Sewer Collection Systems." http://www3.epa.gov/npdes/pubs/assetmanagement.pdf (accessed 2/9/2016).

- U.S. EPA. 2008. *Asset Management: A Best Practices Guide*. EPA 816-F-08-014. https://www.epa.gov/sites/production/files/2015-02/documents/asset_management_best_practices_guide.pdf (accessed 5/19/2016).

- U.S. EPA. 2009. *Funding Stormwater Programs*. EPA 901-F-09-004. https://www3.epa.gov/region1/npdes/stormwater/assets/pdfs/FundingStormwater.pdf (accessed 5/27/2016).

- U.S. EPA. 2015. "Information on Check Up Program for Small Systems (CUPSS) Asset Management Tool." http://www.epa.gov/dwcapacity/information-check-program-small-systems-cupss-asset-management-tool (accessed 2/23/2016).

- U.S. EPA. 2016a. *Clean Watershed Needs Survey 2012: Report to Congress.* EPA 830-R-15005. https://www.epa.gov/sites/production/files/2015-12/documents/cwns_2012_report_to_congress-508-opt.pdf (accessed 8/1/2016).

- U.S. EPA. 2016b. "NPDES Wastewater & Stormwater Permits." http://www3.epa.gov/region9/water/npdes/asset-mgmnt/index.html (accessed 5/19/2016).

- U.S. EPA. n.d.[a]. "Case Study: City of Folsom Collection System Asset Management Program." http://www3.epa.gov/region9/water/npdes/asset-mgmnt/pdf/npdes-asset-mgmnt-case-study-folsom.pdf (accessed 2/16/16).

- U.S. EPA. n.d.[b]. "Case Study: City of Grand Rapids Stormwater Asset Management Program." https://www3.epa.gov/region9/water/npdes/asset-mgmnt/pdf/npdes-asset-mgmnt-case-study-grand-rapids.pdf (accessed 1/27/2016).

- U.S. EPA. n.d.[c]. "Case Study: City of Minneapolis Stormwater Asset Management System." http://www3.epa.gov/region9/water/npdes/asset-mgmnt/pdf/npdes-asset-mgmnt-case-study-minneaopolis.pdf (accessed 1/27/2016).

- U.S. EPA. n.d.[d]. "Case Study: City of San Diego Watershed Asset Management Planning." https://www3.epa.gov/region9/water/npdes/asset-mgmnt/pdf/npdes-asset-mgmnt-case-study-san-diego-wamp.pdf (accessed 5/19/2016).

- U.S. EPA. n.d.[e]. "Case Study: South Placer Municipal Utility District Collection System Asset Management Program." http://www3.epa.gov/region9/water/npdes/asset-mgmnt/pdf/npdes-asset-mgmnt-case-study-south-placer-mud.pdf (accessed 1/27/2016).
- West Michigan Environmental Action Council. 2014. *Sustaining Stormwater Investments in Grand Rapids*. http://wmeac.org/wp-content/uploads/2014/10/Sustaining_Stormwater_Investment_in_Grand_Rapids.pdf (accessed 1/26/16).
- WFRF (Water Finance Research Foundation). n.d. *The 2012 Comparative Review: Municipal Maintenance and Infrastructure Asset Management Systems*. http://www.cityworks.com/wp-content/uploads/2013/02/2012-Municipal-Maintenance-and-Infrastructure-Asset-Management-Systems-Review-v3.pdf (accessed 8/2/2016).