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Water Infrastructure Asset Management Primer

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WATER INFRASTRUCTURE ASSET MANAGEMENT PRIMER

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ABSTRACT AND BENEFITS

Abstract:

Water infrastructure systems are essential for sustaining societal quality of life. However, they face a variety of challenges and potential threats to sustained performance, including aging, deterioration, underfunding, disruptive events, and population growth, among others. Infrastructure asset management can contribute significantly to address those challenges and sustain system performance in the long term. Current infrastructure asset management frameworks focus mostly on performance management, and although sustainability and resiliency management are considered at some degree, it is necessary to advance the understanding and integration of more practical and comprehensive sustainability and resiliency enhancing methods and tools into mainstream asset management practice. Furthermore, the integration of infrastructure sustainability and resilience methodologies with asset management is convenient given the increase in risks to infrastructure performance worldwide.

This primer presents an integrated understanding of water infrastructure management in terms of performance management, sustainability management, and resiliency management. It also presents a discussion on the state-of-the-literature and the state-of-the-practice on these three infrastructure management topics as observed by the WATER*i*D research team while developing the national knowledge database. Finally, this primer compares both the theoretical and practical domains to identify gaps and formulate recommendations for improving holistic water infrastructure asset management.

Benefits:

- Provides a basic guidance on application of integrated and holistic water infrastructure management practices.
- Presents a discussion on the state-of-the-literature and the state-of-the-practice on water infrastructure management in terms of performance management, sustainability management, and resiliency management.
- Compares both the theoretical and practical realms to identify gaps and formulate recommendations for improving infrastructure system management and for advancing infrastructure asset management theory and practice in the water sector, integrated with both sustainability and resiliency concepts.

Keywords: Holistic asset management, performance management, sustainability management, resiliency management, WATER*i*D.

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AM	Asset Management
AMP	Asset Management Plan
BAP	Best Appropriate Practice
BRE	Business Risk Exposure
CAM	Corporate Asset Management
CCTV	Closed Circuit Television
CIP	Capital Investment Program
CIPP	Cured-in-Place Pipe
CNAM	Canadian Network of Asset Managers
CoF	Consequence of Failure
CSO	Combined Sewer Overflows
DHS	Department of Homeland Security
EMS	Environmental Management Systems
ERASMUS	Effective Resilience Assessment Methodology for Water Utilities
FAF	Financial Accounting Foundation
FASB	Financial Accounting Standards Board
FHWA	Federal Highway Administration
FTA	Fault-Event Tree Analysis
GAAP	Generally Accepted Accounting Principles
GASB	Governmental Accounting Standards Board
IAM	Infrastructure Asset Management
IIMM	International Infrastructure Management Manual
ISI	Institute for Sustainable Infrastructure
ISR	Infrastructure Status Report
LEED	Leadership in Engineering and Environmental Design
LoF	Likelihood of Failure
LoS	Level of Service
MD&A	Management Discussion and Analysis
MCEER	Multidisciplinary Center for Extreme Event Research
NAMS	National Asset Management Steering Group
NIPP	National Infrastructure Protection Plan

O&M	Operation and Maintenance
PCCP	Prestressed Concrete Cylinder Pipes
PoF	Probability of Failure
PWB	Portland Water Bureau
RCM	Reliability-Centered Maintenance
RSI	Required Supplementary Information
SIMPLE	Sustainable Infrastructure Management Program Learning Environment
SPU	Seattle Public Utilities
SSO	Sanitary Sewer Overflows
TBL	Triple Bottom Line
TRB	Transportation Research Board
USDOT	U.S. Department of Transportation
U.S. EPA	U.S. Environmental Protection Agency
USGBC	U.S. Green Building Council
Water*i*D	Water Infrastructure Database
WSSC	Washington Suburban Sanitary Commission

CHAPTER 1.0

INTRODUCTION

The Water Infrastructure Database (WATER*i*D) contains a wealth of information regarding asset management (AM) practices in water and wastewater utilities in the U.S. and abroad, particularly for managing buried assets. The main topics currently covered are Condition Assessment, Renewal Engineering, Management Practices, Performance Benchmarking, Product Qualification, Utility Locating, and Cost Information.

The information contained in WATER*i*D was obtained directly from over 100 participant utilities. The research team directly observed the state of practice in AM aspects related to system performance, sustainability, and resiliency. The knowledge of the state of the practice represents an outcome from that research project, which is distinct from the nearly 300 case studies produced.

The objectives of this primer are:

- To present a summarized state-of-the-art background on the three topics of infrastructure AM: performance management, sustainability management, and resiliency management for drinking water and wastewater infrastructure systems.
- To present the observed state-of-the-practice in these three topics as observed at the participating utilities during the development of WATER*i*D.
- To present theory and practice on the three topics, enabling the identification of significant gaps, the formulation of recommendations toward bridging those gaps, and proposing a roadmap for future research work.

This document is based on the experiences of nearly 100 participating water and wastewater utilities in WATER*i*D. The state-of-the-art review is based on comprehensive literature reviews of journal papers, conference proceedings, and major industry reports. This primer is for use by utility staff and public officials, particularly those involved with different aspects of Infrastructure Asset Management (IAM) practice. This document is provides general observations on three fundamental topics for water sector utilities and officials.

The theoretical backgrounds provided on AM, performance, sustainability, and resiliency are not intended to be exhaustive, but rather to present key aspects of each concept in order to provide a general understanding on each of those fields.

Given the high number of individual water and wastewater utilities in the U.S. and worldwide, the number of participant utilities for creating WATER*i*D is not statistically significant. For that reason, it is not claimed that the research team observations presented here have any statistical validity or can be generalized for application to every utility. Instead, this document is intended exclusively for general guidance, compiling the observations and experience gathered by research team members during the development of WATER*i*D.

Key expected benefits of this primer are: 1) To raise awareness about the need to advance infrastructure asset management (IAM) in the water sector, integrating performance, sustainability, and resiliency management considerations in a deeper and more practical way, and 2) contribute by providing some general guidelines and suggestions for achieving such advances for sustainable water infrastructure management.

Figure 1-1 contains a conceptual map of WATER*i*D. This primer addresses the upper most level, where sustainability, performance, and resiliency management are integrated for sustained improvement of the U.S. water and wastewater infrastructure systems.

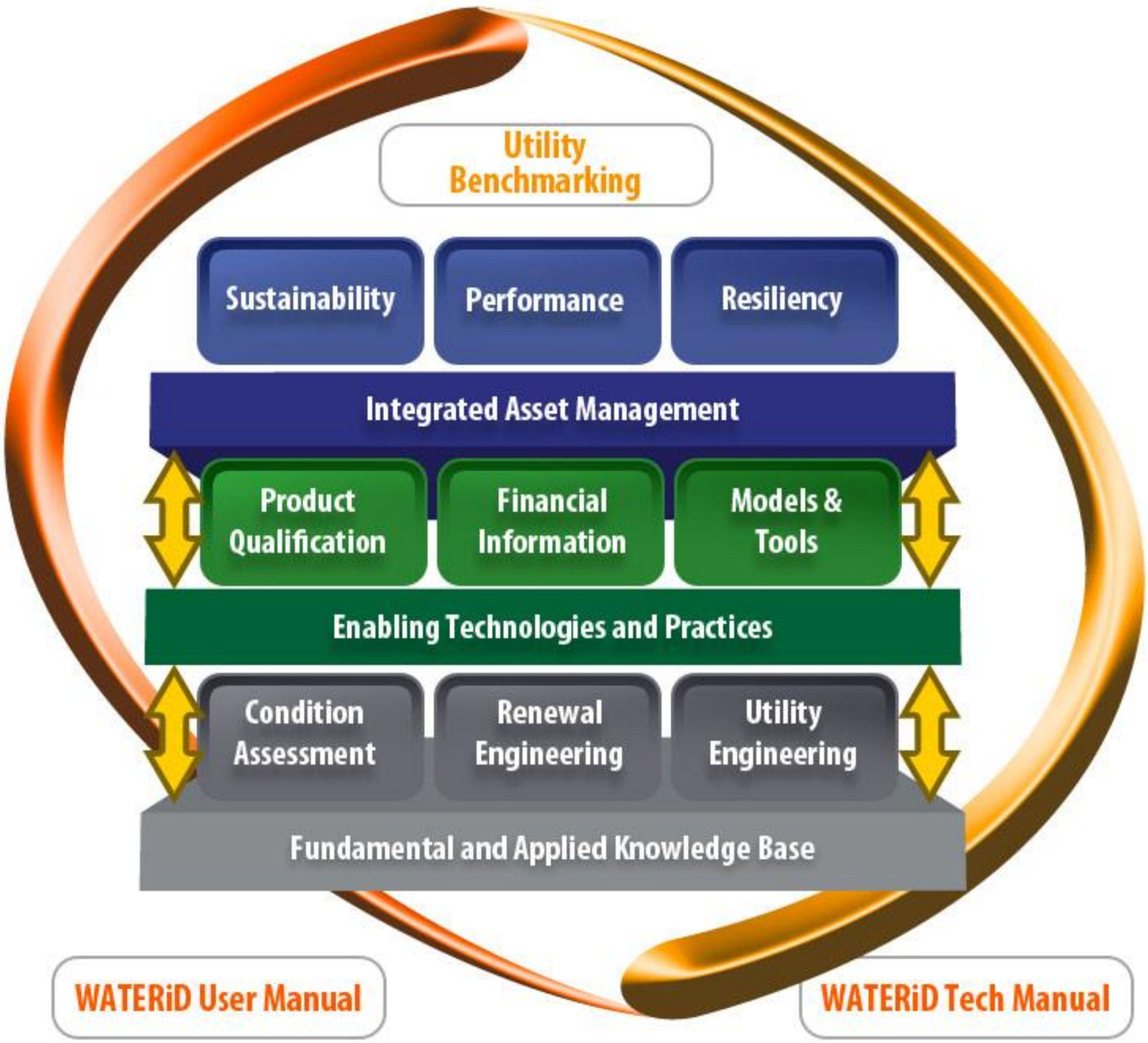


Figure 1-1. Conceptual Map of WATER*i*D Contents.

Figure 1-2 represents the importance of sustaining and improving civil infrastructure performance and legacy through the advancement of performance management, sustainability, and resiliency pillars of water sector infrastructure. The underlying Triple Bottom Line (TBL) factors (societal, economical, and environmental) provide a foundation for these pillars.

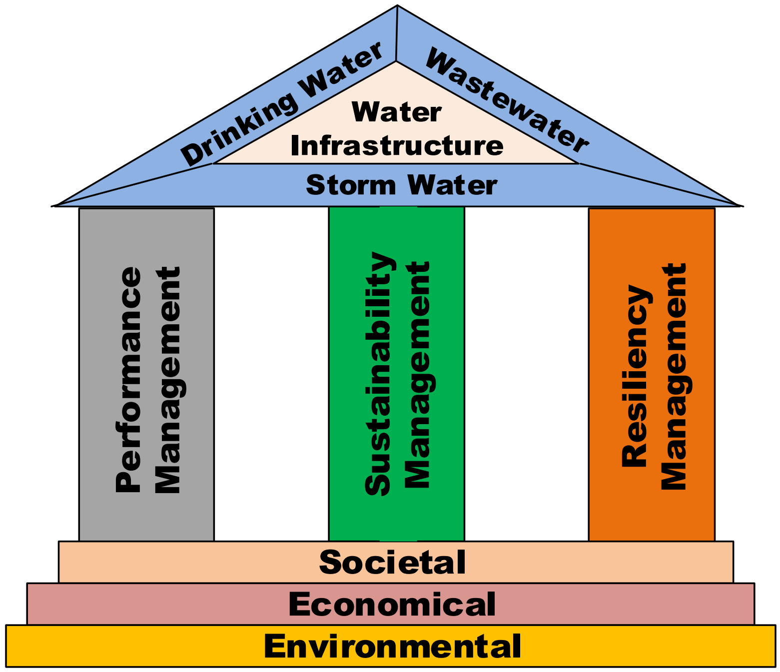


Figure 1-2. Water Infrastructure Management Pillars and Triple Bottom Line Foundation.

The Three Core Goals of IAM are:

- **Performance:** Achieving a target level of system performance requires a systematic approach that addresses the systemic and holistic needs of the entire enterprise.
- **Sustainability:** Refers to "the ability of a given system to perform indefinitely, in a dynamic equilibrium with its context." The integration of environmental, economical, social, and even organizational considerations allows the application of sustainability principles in the daily operation of infrastructure systems.
- **Resiliency:** The ability of a system to persist. For civil infrastructure systems, "resilience is the capacity of an infrastructure system to minimize damage due to a disruptive event, and to recover the pre-disruption performance level within acceptable predefined time and cost limits."

All three core goals are subject to various management practices across the three management levels (operational, tactical, and strategic). As adapted from IAM's method, management practices follow three core approaches:

- **Systematic:** AM requires a systematic approach that provides a structured management system integrated to meet both holistic and systemic AM needs so that the three goals of AM can all be achieved.
- **Systemic:** AM requires a systemic approach. As taught by the IAM, this implies looking at assets in their system context, rather than simply as components. The system context of the management systems must also be considered.
- **Holistic:** AM requires a holistic approach within the various disciplines across all departments. AM cannot just be considered within the context of financial and accounting

requirements, but must also incorporate other departmental requirements such as customer service, legal, environmental, information technology, engineering, construction, operations, maintenance, and renewal requirements, and others.

CHAPTER 2.0

ASSET MANAGEMENT

Civil infrastructure systems support social and economic development by providing essential services enhancing quality of life. However, sustaining the performance of these systems is becoming challenging due to issues such as resource constraint, population growth and urbanization, infrastructure aging, and ecological degradation, among other trends.

Civil infrastructure systems built 50 or 100 years ago are nearing the end of their economic service lives. As the physical assets comprising infrastructure systems age, their condition and efficiency deteriorates; and such deterioration impacts system performance and increases operation costs while decreasing system reliability. In addition, the failure of some critical assets may pose significant risks for people and the natural environment. Total cost of system failure is also very significant in terms of recovery costs, lost revenue, and impacts on other infrastructure systems and the overall economic activity in a city or region.

Furthermore, there is a worldwide urbanization trend (U.N. High Level Panel on Global Sustainability, 2012). Currently, more people live in urban centers than ever before. Urban centers are concentrations of interdependent infrastructure systems, and these systems are under pressure from increasing demands. Most civil infrastructure systems originally designed 70 or more years ago have been expanded to accommodate growing demand as the need arises and economic resources become available. Some existing sections may have not received adequate maintenance to instead finance other system expansions and new system developments. In many cases, unplanned infrastructure system expansion and lack of maintenance or renewal compounds to generate operational inefficiencies, accelerate system deterioration, and in general increase risks from infrastructure failure. The performances of civil infrastructure systems that enable the quality of life of urban and rural populations needs to be sustained at an adequate level, which is becoming increasingly difficult.

Design and implementation of effective IAM programs can significantly contribute to addressing those challenges described above. IAM is a business process and a decision support framework for all types of civil infrastructure systems such as roads, water distribution systems, wastewater collection systems, and power generation and transmission facilities. IAM emerged in response to the need for maintaining an adequate civil infrastructure system performance level in the most cost effective way possible. Current trends such as financial resource constraints, the demands for sustainable development, and increasing risks posed by aging systems all reinforce the pertinence of IAM. The objectives of IAM include sustaining the Level of Service (LoS) of the system, minimizing life cycle cost, at a level of risk that is acceptable to the organization. Most civil infrastructure systems can, in theory, operate indefinitely; but to achieve this goal, proactive management is necessary. Infrastructure systems represent enormous capital investments and sustaining adequate performance and levels of service also requires significant resources.

Five Core Questions: Whether a city or municipality is looking at highways, utilities, water, or other sectors, AM implementation comes down to asking five core questions:

- What is the current state of my assets?
- What is my required LoS/performance?
- Which assets are critical to sustained performance?
- What are my best investment strategies for both operations and maintenance and capital improvement?
- What is my best long-term funding strategy?

Cities and municipalities that have AM programs have discovered that answering these questions provides the foundation for an AM plan, which establishes strengths, where improvements are needed, and the type and quality of information required to establish whether an envisioned course of action is the best choice available.

AM in its current form was significantly influenced by developments in Australia and New Zealand, most notably with the publication of the International Infrastructure Management Manual (IIMM). In the U.S., the Environmental Protection Agency, the Department of Transportation, the Department of Energy, and other federal agencies actively promote the use of IAM principles in those infrastructure sectors they are responsible for.

In their AM Fact Sheet for Sewer Collection Systems (U.S. EPA, 2002), the EPA summarizes key aspects of IAM. For example, in a "Run to Failure" AM model (Figure 2-1), assets are never regularly maintained or renewed. This leads to faster deterioration and probably higher costs for replacement and emergency response; although in some particular cases the "Run to Failure" management is the best management approach. For example, when a low-risk asset is to be replaced due to obsolescence or other reason, it may be better to wait until it fails and then replace it. In Figure 2-1, the vertical axis represents asset condition and the horizontal represents time (U.S. EPA, 2002).

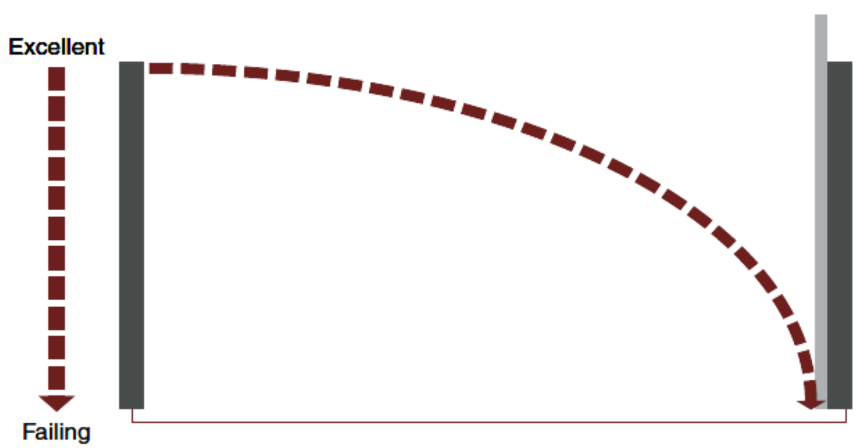


Figure 2-1. Asset Condition in a Run to Failure Management Model.
(U.S. EPA, 2002)

The deterioration curve shown in Figure 2-1 assumes that the asset is never maintained, which may not be realistic. Although maintenance activities do not stop system deterioration, they ensure that such deterioration takes place at an acceptable and expected rate, and not faster. Figure 2-2 represents two deterioration curves, one assuming zero maintenance (red, at left) and the other with regular maintenance (blue). The condition of well-maintained systems and assets deteriorates at a slower rate, achieving longer service lives. The time difference between no maintenance and regular maintenance curves at the minimum acceptable LoS is represented by a "service life gap." There is also a reactive management style, or "Crisis Management." In this mode, assets are repaired when they fail and not before. Crisis Management mode may make sense in some cases.

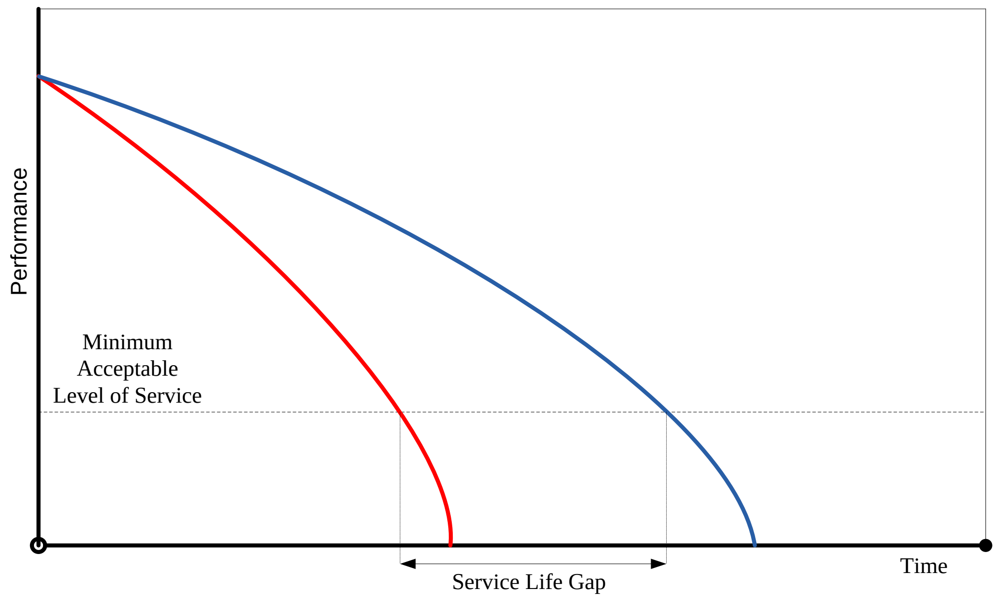


Figure 2-2. Effect of Maintenance on Asset "Service Life Gap."

With the implementation of an AM system, assets are regularly maintained, repaired, rehabilitated, and eventually replaced (Figure 2-3). Assets are replaced when their deterioration is such that the cost of maintenance, repair, or rehabilitation outweighs the benefits from keeping the asset. As a result, the asset is managed to optimize its benefit to cost ratio over its entire service life cycle. In this way maintenance and renewal costs are distributed more evenly throughout the asset life (Figure 2-3).

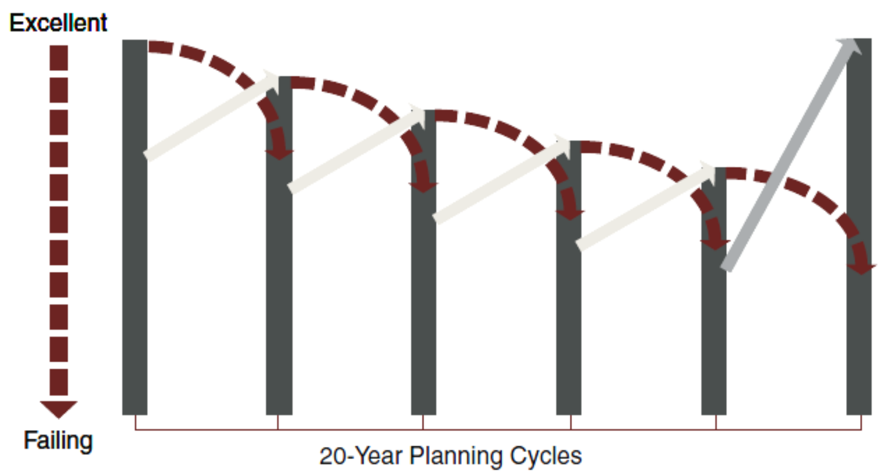


Figure 2-3. Asset Management Model.
(U.S. EPA, 2002)

IAM can take a variety of forms, depending on the specific needs of the infrastructure system to be managed. Despite particular differences, all IAM systems are continuous improvement processes and have the following guiding principles (U.S. EPA, 2002):

Customer Focused: The implementation of AM has to represent tangible benefits for customers, for example in the form of responsible and cost effective use of public funds, improved system performance, and improved system reliability.

Mission Driven: All AM systems are driven by the infrastructure mission, and therefore their ultimate goal is to reinforce such mission.

System Oriented: AM has to have a systems scope. The infrastructure has to be improved as a system because some individual changes over some assets may have an undesirable impact over the system as a whole. All impacts and feedbacks have to be considered beforehand to ensure maximum benefit for the infrastructure system as a whole.

Long-Term Outlook: Many of the benefits from AM are in the long term. AM is not highly effective with a short-term scope.

Accessible and User Friendly: AM is not a black box. The management system has to be accessible and user friendly because it is implemented across many departments in the organization, and at different decision levels such as those represented in Figure 2-6.

Flexible: AM has to be flexible to accommodate unforeseen circumstances and inevitable adjustments that will have to be made during implementation. Since the scope of AM is long term, the uncertainty associated with particular events and outcomes in the future may be high.

2.1 AM Definitions

Definitions of IAM vary slightly across infrastructure sectors according to the scope and particular objectives of the organization producing it. In this section some different definitions are presented. The basic definition for this primer is that of Sustainable Infrastructure Management Program Learning Environment (SIMPLE) (WERF, 2007).

Although, The U.S. Environmental Protection Agency (U.S. EPA) has defined IAM as *"a continuous process that guides the acquisition, use, and disposal of infrastructure assets to optimize service delivery and minimize costs over the asset's entire life"* (U.S. EPA, 2002);

In SIMPLE, AM is defined as "*A management paradigm and a body of management practices that is applied to the entire portfolio of assets at all levels of the organization, that seeks to minimize the total cost of acquiring, operating, maintaining and renewing the assets within an environment of limited resources while continuously delivering the service levels customers desire and regulators require at an acceptable level of business risk to the organization.*"

In their AM primer (FHWA, 1999), the Federal Highway Administration (FHWA) included several definitions of strategic AM in the transportation sector. Some of them are shown in Figure 2-4.

"...a methodology needed by those who are responsible for efficiently allocating generally insufficient funds amongst valid and competing needs." (American Public Works Association.)
"Asset Management… goes beyond the traditional management practice of examining singular systems within the road networks, i.e., pavements, bridges, etc., and looks at the universal system of a network of roads and all of its components to allow comprehensive management of limited resources. Through proper asset management, governments can improve program and infrastructure quality, increase information accessibility and use, enhance and sharpen decision-making, make more effective investments and decrease overall costs, including the social and economic impacts of road crashes." (Organization for European Cooperation and Development)
"In the transportation world, asset management is defined as a systematic process of operating, maintaining, and upgrading transportation assets cost-effectively. It combines engineering and mathematical analyses with sound business practice and economic theory. The total asset management concept expands the scope of traditional infrastructure management systems by addressing the human element and other support assets as well as the physical plant (e.g. highway, transit systems, airports, etc.). Asset management systems are goal driven and, like the traditional planning process, include components for data collection, strategy evaluation, program development, and feedback. The asset management model explicitly addresses integration of decisions made across all program areas. Its purpose is simple -to maximize benefits of a transportation program to its customers and users, based on well-defined goals and with available resources." (NYSDOT)

Figure 2-4. Asset Management Definitions from Transportation Sector.

2.2 Governmental Accounting Standards Board (GASB) Statement 34

The world of governmental financial management is in a state of fundamental transition. GASB overhaul of its financial reporting model for governmental agencies, as codified in its Statements 34 and 37, will bring wide-ranging change, with implementation scheduled over a seven-year period, as measured from the date of adoption of Statement 34 by GASB.

Through Statements 34 and 37, GASB is moving governmental financial reporting to more closely emulate private sector reporting. Private sector reporting is about the management team fairly reporting the full cost and value of operations of the organization to shareholders, investors, creditors and employees. Failure to achieve and maintain a desired financial status as reported in the financial statements often leads to changes in management, and questions about the organization to survive as a going concern. The questions that every utility manager should ask include:

- What is a "reporting model?" What exactly is "financial status" and how is it measured? How is financial status to be disclosed in the new reporting model?
- What impact does such reporting have for strategic organizational management? How does Management Discussion and Analysis (MD&A) impact the senior management team?
- What impact will the valuation of capital assets have on enterprise organizations?
- What about AM – Will the new reporting requirements assist in funding "deferred maintenance?" And what about "depreciation" versus preservation – is GASB trending toward a disclosure of unfunded maintenance?
- What are the ramifications for the lending industry? How will it impact my rate structure? My bond rating?

What is GASB and What is Statement 34/37?

All organizations execute financial transactions in the course of daily operations, such as:

- Writing payroll checks.
- Booking revenues.
- Paying vendors.
- Incurring and paying debt.

Financial records (both public and private) that track these transactions are generated and maintained according to standard accounting conventions called Generally Accepted Accounting Principles" (GAAP) (Figure 2-5). These principles govern how and when financial transactions are recorded and how they are reported in financial statements. GAAP are developed by a not-for-profit organization called the Financial Accounting Foundation (FAF)." Within FAF are two separate but coordinated bodies, the Financial Accounting Standards Board (FASB) and the GASB. FASB has long been charged with developing, clarifying and codifying the accounting principles used in private sector organizations. GASB was established in 1985 to consolidate governmental accounting practices, statutes and conventions in effect up to that time. GAAP for both are set through an exhaustive interactive process that incorporates extensive discussion and debate by accountants and financial professionals from the private, public and academic sectors.

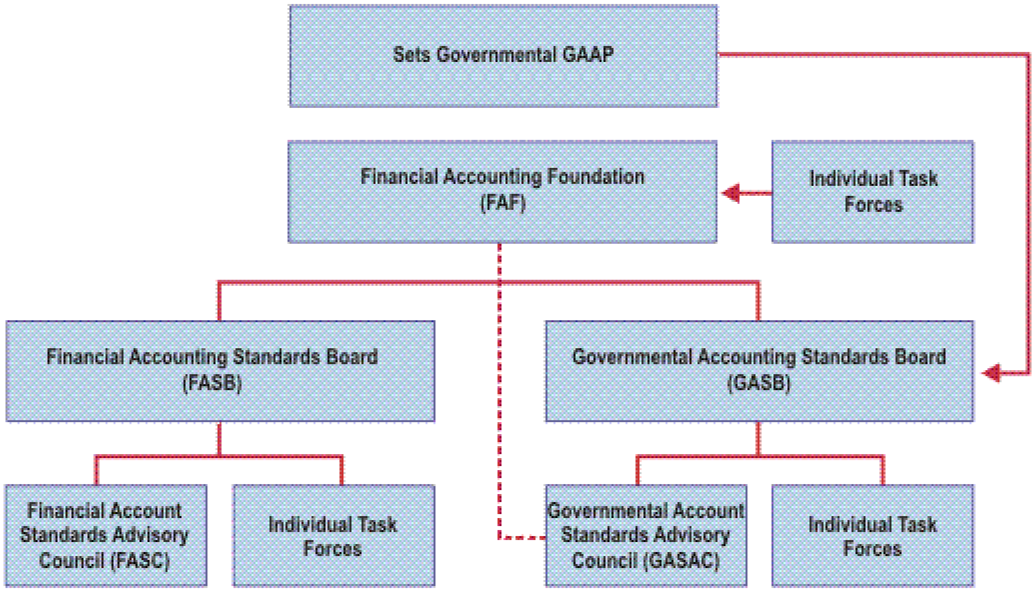


Figure 2-5. Organizational Structure Around Governmental Accounting Standards Board.

It is important to note that GASB's charge is to modify FASB's body of private sector rules to fit the unique aspects of governmental organizations. That is, the genesis of governmental accounting is found in FASB's private sector accounting principles. In June 1999, GASB released a new "rule" – Statement 34 – which is, without doubt, the most significant rule promulgated since GASB was formed. This statement made up of over 150 numbered paragraphs and illustrations and running some 403 pages, is often referred to as the "reporting model rule" because it radically changes the rules by which governmental financial statements are to be organized and presented.

Statement (GASB-34) establishes financial reporting standards for state and local governments, including states, cities, towns, villages, and special-purpose governments such as school districts and public utilities. The basic financial statements should include:

1. Government financial statements consist of a statement of net assets and a statement of activities – Prepared using the economic resources measurement focus and the accrual basis of accounting, these statements should report all of the assets, liabilities, revenues, expenses, and gains and losses of the government. Each statement should distinguish between the governmental and business-type activities of the primary government and between the total primary government and it's discretely presented component units by reporting each in separate columns. Fiduciary activities, whose resources are not available to finance the government's programs, should be excluded from the government-wide statements.
2. Fund financial statements consist of a series of statements that focus on information about the government's major governmental and enterprise funds, including its blended component units. Fund financial statements also should report information about a government's fiduciary funds and component units that are fiduciary in nature. Governmental fund financial statements (including financial data for the general fund and special revenue, capital

projects, debt service, and permanent funds) should be prepared using the current financial resources measurement focus and the modified accrual basis of accounting. Proprietary fund financial statements (including financial data for enterprise and internal service funds) and fiduciary fund financial statements (including financial data for fiduciary funds and similar component units) should be prepared using the economic resources measurement focus and the accrual basis of accounting.

Special-purpose government entities that are engaged in only governmental activities (such as some library districts) or that are engaged in both governmental and business-type activities (such as some school districts) normally should be reported in the same manner as general purpose governments. Special-purpose government entities engaged only in business-type activities (such as utilities) should present the financial statements required for enterprise funds, including MD&A and other Required Supplementary Information (RSI).

Important Aspects of Government Financial Statements

Governments should report all capital assets, including infrastructure assets, in the government-wide statement of net assets and generally should report depreciation expense in the statement of activities. Infrastructure assets that are part of a network or subsystem of a network are not required to be depreciated as long as the government has an AM system in place and being used that has certain documented characteristics that the assets are being preserved approximately at (or above) a condition level established and disclosed by the government.

The net assets of a government should be reported in three categories – invested in capital assets net of related debt, restricted, and unrestricted. This statement provides a definition of the term restricted. Permanent endowments or permanent fund principal amounts included in restricted net assets should be displayed in two additional components – expendable and nonexpendable.

The government-wide statement of activities should be presented in a format that reports expenses reduced by program revenues, resulting in a measurement of "net (expense) revenue" for each of the government's functions. Program expenses should include all direct expenses. General revenues, such as taxes, and special and extraordinary items should be reported separately, ultimately arriving at the change in net assets for the period. Special items are significant transactions or other events that are either unusual or infrequent and are within the control of management.

Important Aspects of the Fund Financial Statements

To report additional and detailed information about the primary government, separate fund financial statements should be presented for governmental and proprietary funds. Required governmental fund statements are a balance sheet and a statement of revenues, expenditures, and changes in fund balances. Required proprietary fund statements are a statement of net assets; a statement of revenues, expenses, and changes in fund net assets; and a statement of cash flows. To allow users to assess the relationship between fund and government-wide financial statements, governments should present a summary reconciliation to the government-wide financial statements at the bottom of the fund financial statements or in an accompanying schedule.

Each of the fund statements should report separate columns for the general fund and for other major governmental and enterprise funds. Major funds are funds whose revenues, expenditures/expenses, assets, or liabilities (excluding extraordinary items) are at least 10% of corresponding totals for all governmental or enterprise funds and at least 5% of the aggregate amount for all governmental and enterprise funds. Any other fund may be reported as a major fund if the government's officials believe that fund is particularly important to financial statement users. Non-major funds should be reported in the aggregate in a separate column. Internal service funds also should be reported in the aggregate in a separate column on the proprietary fund statements.

Fund balances for governmental funds should be segregated into reserved and unreserved categories. Proprietary fund net assets should be reported in the same categories required for the government-wide financial statements. Proprietary fund statements of net assets should distinguish between current and noncurrent assets and liabilities and should display restricted assets.

Proprietary fund statements of revenues, expenses, and changes in fund net assets should distinguish between operating and non-operating revenues and expenses. These statements should also report capital contributions, contributions to permanent and term endowments, special and extraordinary items, and transfers separately at the bottom of the statement to arrive at the all-inclusive change in fund net assets. Cash flows statements should be prepared using the direct method.

Separate fiduciary fund statements (including component units that are fiduciary in nature) also should be presented as part of the fund financial statements. Fiduciary funds should be used to report assets that are held in a trustee or agency capacity for others and that cannot be used to support the government's own programs. Required fiduciary fund statements are a statement of fiduciary net assets and a statement of changes in fiduciary net assets.

Inter-fund activity includes inter-fund loans, inter-fund services provided and used, and inter-fund transfers. This activity should be reported separately in the fund financial statements and generally should be eliminated in the aggregated government-wide financial statements.

Required Supplementary Information (RSI)

To demonstrate whether resources were obtained and used in accordance with the government's legally adopted budget, RSI should include budgetary comparison schedules for the general fund and for each major special revenue fund that has a legally adopted annual budget. The budgetary comparison schedules should present both (a) the original and (b) the final appropriated budgets for the reporting period, as well as (c) actual inflows, outflows, and balances, stated on the government's budgetary basis. This statement also requires supplementary information for governments that use the modified approach for reporting infrastructure assets.

Effective Date and Transition

The requirements of this statement were in effect for all sizes of government after June 15, 2003. The statement was made effective in three phases based on a government's total annual revenues in the first fiscal year ending after June 15, 1999. Phase 1 was for governments’ with total annual revenues (excluding extraordinary items) of $100 million or after June 15, 2001, phases 2, between $10 and $100 million after June 15, 2002, less that $10 after June 2003. For phase 1 and phase 2 governments, retroactive reporting was required four years after the effective date on the basic provisions for all major general infrastructure assets that were acquired or significantly reconstructed, or that received significant improvements, in fiscal years ending after June 30, 1980. In Phase 3 governments are encouraged to report infrastructure retroactively, but may elect to report general infrastructure prospectively only.

2.3 Decision Level and Life Cycle Phase AM

IAM has different decision levels, from daily operational decisions to long-term strategic plans (Figure 2-6). The three levels are strongly interconnected and overlap to provide flexibility in decisions. The strategic level involves the allocation of resources at the system level, generally with a long-term scope. The tactical level refers to the allocation of resources for work involving most of the infrastructure system. Finally, the operational level involves specific projects and daily operations, and has a short-term scope.

Figure 2-6. Decision Level Asset Management.

The three levels together constitute what is called "Decision Level AM". Decision level AM is important because management of infrastructure systems spans varied time domains, from the immediate maintenance or repairs, to the long-term vision required for optimizing resource allocation and minimizing total life cycle cost at a level of risk acceptable to the organization.

One model of AM addresses the three levels, acknowledges their interrelations, and provides a framework for them to work together seamlessly.

Figure 2-7 represents the life cycle of an asset, from planning and design, to decommissioning and system renewal. The Operation and Maintenance (O&M) phase is significantly longer than the other two.

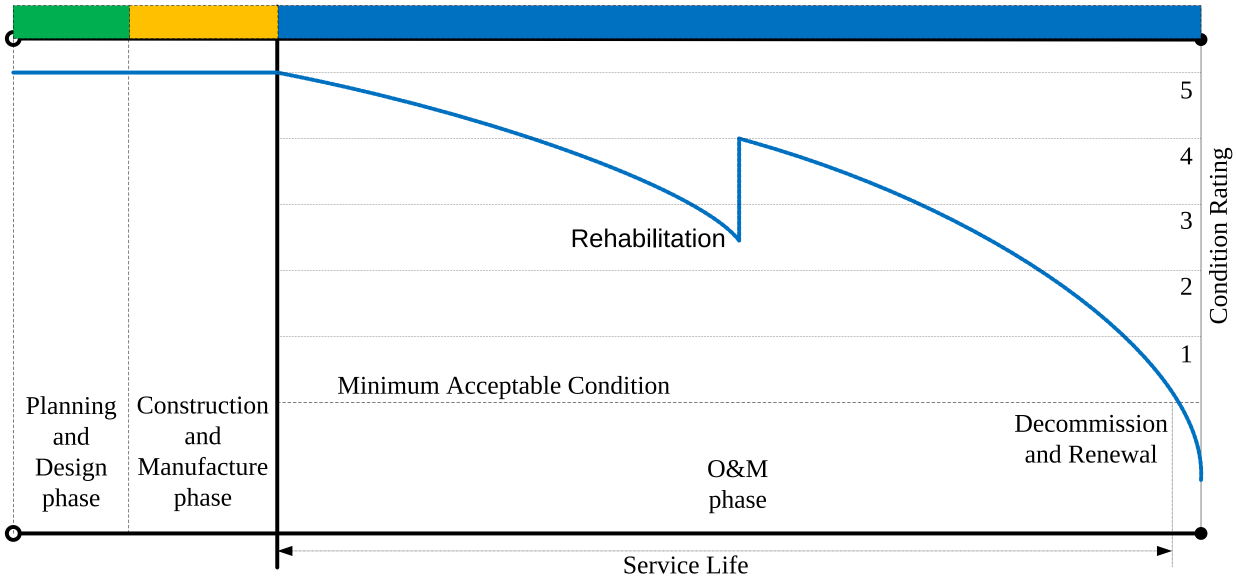


Figure 2-7. Life Cycle Phase Asset Management.

The infrastructure planning and design phase is important because decisions taken here will have long-term consequences. The infrastructure will perform with efficiencies and limitations inherited from the design and planning phase. During the construction and manufacture phase, the design specifications and planned features are constructed as accurately as possible, and equipment is manufactured. The third and longest phase is the operation phase, also known as the service life. Decisions made during the planning and construction phase, as well as the construction and manufacturing characteristics will have a long-lasting impact during the service life of the system.

The curve in Figure 2-7 represents physical condition. The curve is horizontal during the initial phases, when the condition is probably the best. When the operation phase starts, the asset starts deteriorating, until some renewal project takes place (rehabilitation). Because of the rehabilitation, system condition increases instantaneously, but usually not to the new condition level. During its service life, the asset may go through multiple renewal projects, improving after each one until a point where further interventions are no longer feasible from an economic standpoint.

At the beginning of their service life, all assets are expected to be in perfect condition. That is not always the case. If there are undetected defects in the assets or the infrastructure system at the beginning of the operating phase, the service life may be significantly shorter than expected, independently of regular maintenance. Figure 2-7 represents a “bathtub curve” which belongs to the manufactured asset Probability of Failure (PoF) (Sinha and St. Clair, 2008). Notice that a PoF curve (Figure 2-8) is not the same as a performance curve or condition curve (Figure 2-6). These curves are frequently confused in practice.

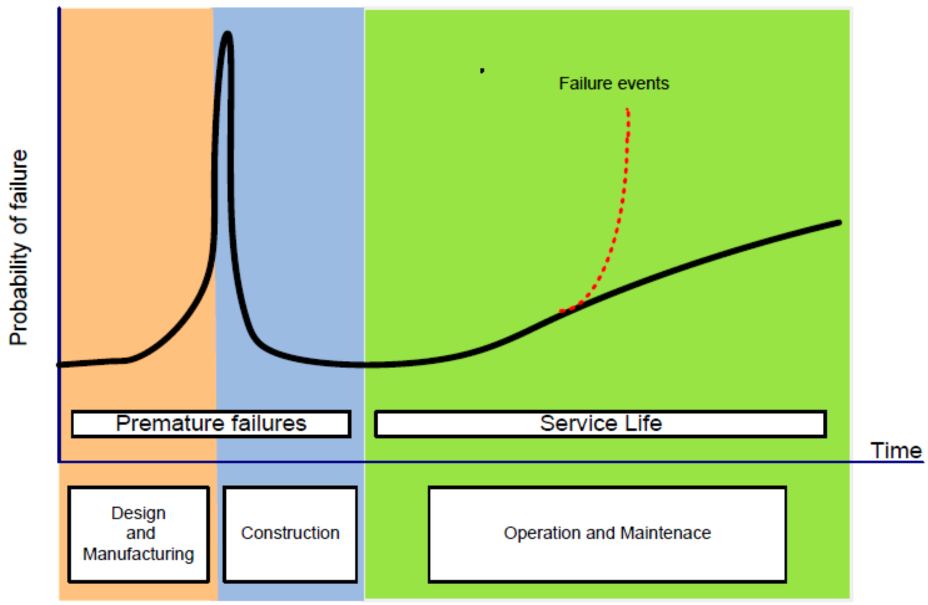


Figure 2-8. Bathtub Curve.

Effective IAM always considers a set of key elements, regardless of the type of infrastructure system managed. Key elements include the following core topics in AM, as identified by U.S. EPA:

LoS: This represents the required level of asset performance. LoS includes expectations about service quantity, quality, frequency, and reliability.

Performance Goals: While the LoS defines a minimum standard to maintain in the operation of the infrastructure system, it is also necessary to define performance goals for the system that may or may not be included in the LoS and contribute to sustaining it.

Information System: AM is information intensive. Information and data management systems need to be established in order to support the collection, storage, and analysis of information on the managed infrastructure system.

Asset Identification and Valuation: It is necessary to inventory all assets in the infrastructure system. Since evaluation of the financial implications of management decisions is required in AM, the value of all assets needs to be estimated and recorded.

Risk Management: An essential feature of AM is that allows the development of systematic approaches for assessing risk on infrastructure. Varied types of risk exist, such as financial, environmental, or social. Risk management includes the consideration of failure modes and impacts, Likelihood of Failure (LoF), and Consequence of Failure (CoF). Risk is addressed separately later.

Condition Assessment: For effective AM, is fundamental to have knowledge of asset condition. A variety of methods and technologies have been developed to assist infrastructure owners and operators in determining or estimating the condition of their assets.

Rehabilitation and Replacement Planning: As it is suggested by the condition curve in Figure 2-8, the timing of intervention (maintenance, repair, rehabilitation, replacement) on assets is important to achieve optimal life cycle costs. While early interventions may waste resources, late interventions risk higher costs, possibly including dealing with costly failure consequences.

Capacity Assessment and Assurance: Capacity assessment indicates the ability of the system to meet present demands, while capacity assurance enables adequate capacity for the future. The long-term scope of strategic AM requires forecasting of future demand, and therefore enables the selection of future near-optimal alternatives.

Financial Management: Optimal financial management of infrastructure is a core aspect of AM. Specific financial management strategies reflect the preferences of the infrastructure owner or operator, and its risk tolerance. AM financial objectives include achieving minimum life cycle cost and minimizing risk costs.

Continuous Improvement: AM is not a static process. Optimal decisions made today are not likely to be optimal in the future, when the context will be likely different. AM is a continuous process that includes a permanent search for improvement.

2.4 AM Frameworks

Although there is general agreement on the scope of AM, a variety of frameworks have been developed. This section describes some of the most frequently used frameworks.

An IAM framework that has acceptance in the water sector contains seven steps (Figure 2-9). The seven steps in this framework represent a continuous process for managing the infrastructure assets in a more effective and efficient way. The seven steps shown in Figure 2-9 start from inspection and data collection, and advance counterclockwise. (*Bridging the Gap: An Educational Primer on Sustainable Water IAM*, n.d.):

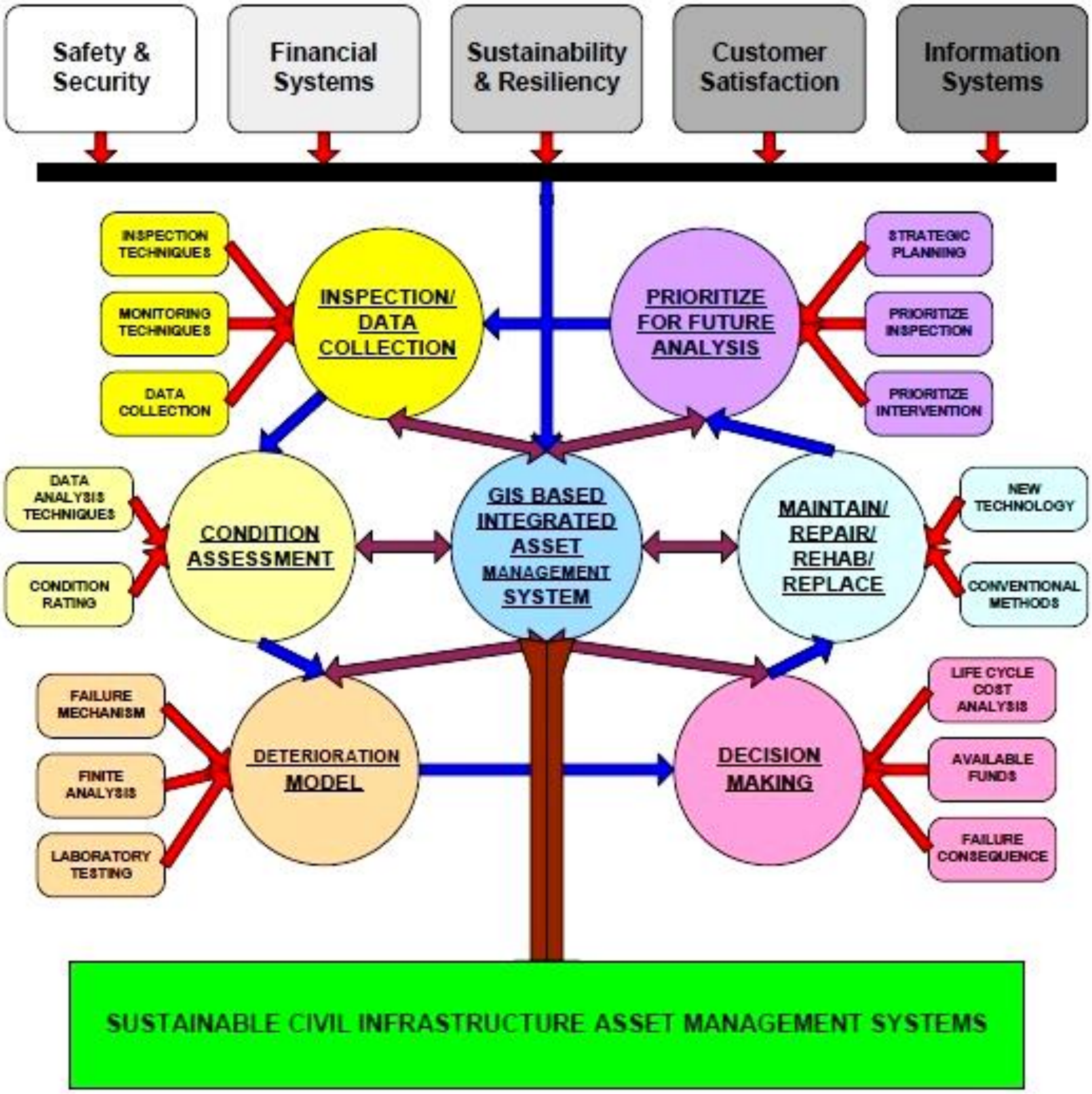


Figure 2-9. Infrastructure Asset Management Framework.

In this framework, the IAM process starts with data collection. A wide array of options and depth levels exist for data collection, from visual inspection, measurements, sensors, to real-time monitoring technologies. Selection of an adequate data collection scope, methodology, and tools depends mostly on financial cost-benefit considerations. Basic methods such as visual inspection might be affordable, but the information that can be extracted will be limited. In contrast, a sophisticated data collection method such as real-time monitoring may produce significant amounts of high-quality and detailed information, but it also requires higher financial investments for its collection and analysis, and might not be justified.

WATER*i*D contains information on numerous inspection and data collection technologies, including the following examples:

Closed Circuit Television (CCTV): This technology is routinely used by many utilities, mostly for sewer pipes. A robotic camera is introduced in the pipeline and an operator in the surface records video and identifies defects, blockages, or other issues. The video tapes and operator logs are used to assess the overall condition of pipeline inspected.

Acoustic Technologies: These include sounding, sonar, noise correlators, and others. The objective is either to capture sounds (for example, to detect leaks) or to use sound waves to assemble a surface profile of the pipe interior, frequently of the wall below water level (as in the case of sonar).

Laser Profiling: This technology uses a robotic CCTV camera that projects a circumferential laser. As the robot moves through the pipe, the laser shape changes reveal the pipe interior surface in video.

Electromagnetic Technologies: These are used mainly for prestressed concrete cylinder pipe (PCCP) and metallic pipes, although not exclusively. The electromagnetic equipment detects possible wire breaks in a non-destructive fashion. Other electromagnetic technologies are used for estimating the remaining wall thickness in metallic pipes.

Combined Technologies: Sometimes these technologies are combined for achieving a more accurate assessment. For example, CCTV and Sonar can be combined to inspect a sewer in service, which would impede CCTV to get a view of the pipe bottom. Combined technologies are frequently used also for cross verification and to obtain more complete inspection results in a cost effective way.

Once data have been collected, it is necessary to extract the information contained in it. The objective of the condition assessment step is to estimate as accurately as possible, based on the data and extracted information, the specific condition of each asset in the system. While in some cases asset age can be used as a proxy for asset condition, in many cases the correlation between age and condition is not high enough to ensure reliability of a condition assessment based solely on age. As a result, condition assessment requires significant amounts of reliable information from a variety of parameters. Notice that although the inspection technologies described above are also known as condition assessment technologies, these technologies only provide the information required to perform condition assessment. Those are rather inspection technologies.

If there are sufficient data points in a time series of asset condition, it is theoretically possible to assemble a deterioration model. The deterioration model is useful for planning purposes and to generate curves for asset condition forecasting. The ability to forecast asset condition at any future time would enable more efficient asset renewal interventions. Nevertheless, obtaining a reliable deterioration model is challenging, because the deterioration process of any given asset is a complex process and depends on multiple factors with significant uncertainties and random variables. For example, a buried water main will deteriorate in a particular way depending on pipe material, age, manufacturing quality, installation quality, soil conditions, external loads, and water quality, amongst other factors.

Based on condition assessment, Business Risk Exposure (BRE) score, and the available information on asset deterioration, a decision is made whether the asset requires routine maintenance or a renewal intervention. Renewal includes asset repair, rehabilitation, and replacement activities. Decision making is based on techniques such as life cycle analysis, financial methods, or risk-based methodologies. Good asset maintenance contributes to maintain an acceptable asset deterioration rate and is expected to extend service life as shown in Figure 2-2 (Service Life Gap), but it is no substitute for renewal activities. At some point in time, every asset will require some kind of renewal, regardless of the maintenance performed.

When a decision has been made regarding the type of intervention required for an asset, asset maintenance or renewal can be performed using different technologies and methods. It is important to notice that the "do nothing" alternative is usually a valid option for analysis. An asset may not require immediate attention, or it may be more convenient to adopt a "run to failure" strategy where the asset is allowed to fail before replacing it. In the case of assets that are critical for sustaining system performance or whose failure implies unacceptably high risks, it is necessary to intervene before physical asset failure. The selection of a renewal method is currently based on financial, risk, and, when practical, TBL (economic, social, and environmental considerations.

Some examples of information on renewal trenchless technologies included in the WATER*i*D database are:

Cured-in-Place Pipe (CIPP): There are many varieties of CIPP. In general, the process includes the introduction of a liner, which is then internally pressurized to take the shape of the pipe interior, and cured in place. The liner becomes the internal pipe wall. There are liners with or without structural capacity depending on the intended application.

Pipe Bursting: In pipe bursting, a new pipe is introduced in the deteriorated pipe, using a pneumatic or hydraulic head to break the host pipe and allow the new one in. Only two pit excavations are required, which is very convenient for busy areas or for working under traffic. Pipe bursting can be used for upsizing a deteriorated pipe.

Grout Injection: In some fractured pipes, an option is to inject grout to fill external cavities formed by the water leak or break. The grout fills the cavity, and also provides the pipe with extra structural integrity by closing fractures and providing better external support.

In every civil infrastructure system there is usually limited resources for maintenance and renewal activities. Sustaining the infrastructure system LoS with limited resources requires prioritization of asset interventions, in order to address asset issues over many months or years. Prioritization is based on a set of criteria, including asset criticality for overall system performance, asset risk, TBL considerations, cost effectiveness, and available resources. Prioritization is applied not only to maintenance and renewal activities, it can be applied also to other steps of the AM process such as data collection and analysis.

One of the last steps in the IAM framework shown in Figure 2-9 is about system security. System security and resiliency are important to ensure public safety and near continuous system operation. While some assets do not require specific security measures, the investment required in critical assets may include some kind of security system.

The seven circles shown in Figure 2-10 represent steps of a continuous process. Ideally, all the seven steps are being performed continuously, and thus the infrastructure system can sustain an acceptable LoS in a very cost effective way. Additionally, an AM system demonstrates responsible stewardship of a public system, which is fundamental to make a strong business case and ensure continued public funding.

Figure 2-10 represents the Synthesis Reports generated as part of the WATER*i*D project, and their relationship with the AM framework in Figure 2-10. For more detailed information on any of the AM steps, please consult the appropriate report. The WATER*i*D reports are organized as follows, from left to right (Figure 2-12):

Condition Assessment Technologies and Utility Engineering Technologies contain extensive information on WATER*i*D contents related to the two first steps of the AM framework: inspection, data collection, and condition assessment. These are covered in three reports:

a. Condition Assessment for Wastewater Pipeline Synthesis Report (IN9SG09caww)

b. Condition Assessment for Drinking Water Pipeline Synthesis Report (IN9SG09cadw)

c. Underground Utility Locating Technology Synthesis Report (IN9SG09uult)

Benchmarking Studies for Water and Wastewater. Benchmarking is a useful management tool for continuous improvement processes such as AM. This is covered in two reports:

a. Utility Benchmarking for Wastewater Synthesis Report (IN9SG09ubww)

b. Utility Benchmarking for Drinking Water Synthesis Report (IN9SG09ubdw)

Management Practice Report and Cost Information for Condition Assessment and Renewal Engineering. The report on management practice contains important information regarding the state of the practice in water and wastewater utilities, mainly in decision making. These steps are covered by four reports:

a. Management Practice for Wastewater Pipelines Synthesis Report (IN9SG09mpww)

b. Management Practice for Drinking Water Pipelines Synthesis Report (IN9SG09mpdw)

c. Cost Information for Wastewater Pipelines Synthesis Report (IN9SG09ciww)

d. Cost Information for Drinking Water Pipelines Synthesis Report (IN9SG09cidw)

Renewal Engineering Technologies. In WATER*i*D, renewal engineering includes repair, rehabilitation, and replacement of infrastructure assets. Two reports on renewal engineering cover two steps of the AM framework, as indicated in Figure 2-10. These by two reports are:

a. Renewal Engineering for Wastewater Pipelines Synthesis Report (IN9SG09reww)

b. Renewal Engineering for Drinking Water Pipelines Synthesis Report (IN9SG09rdww)

Technology Qualification Evaluation and Verification of Condition Assessment and Renewal Engineering Technologies Report is focused on Quality Assurance and Control evaluations and procedures for the technologies in WATER*i*D.

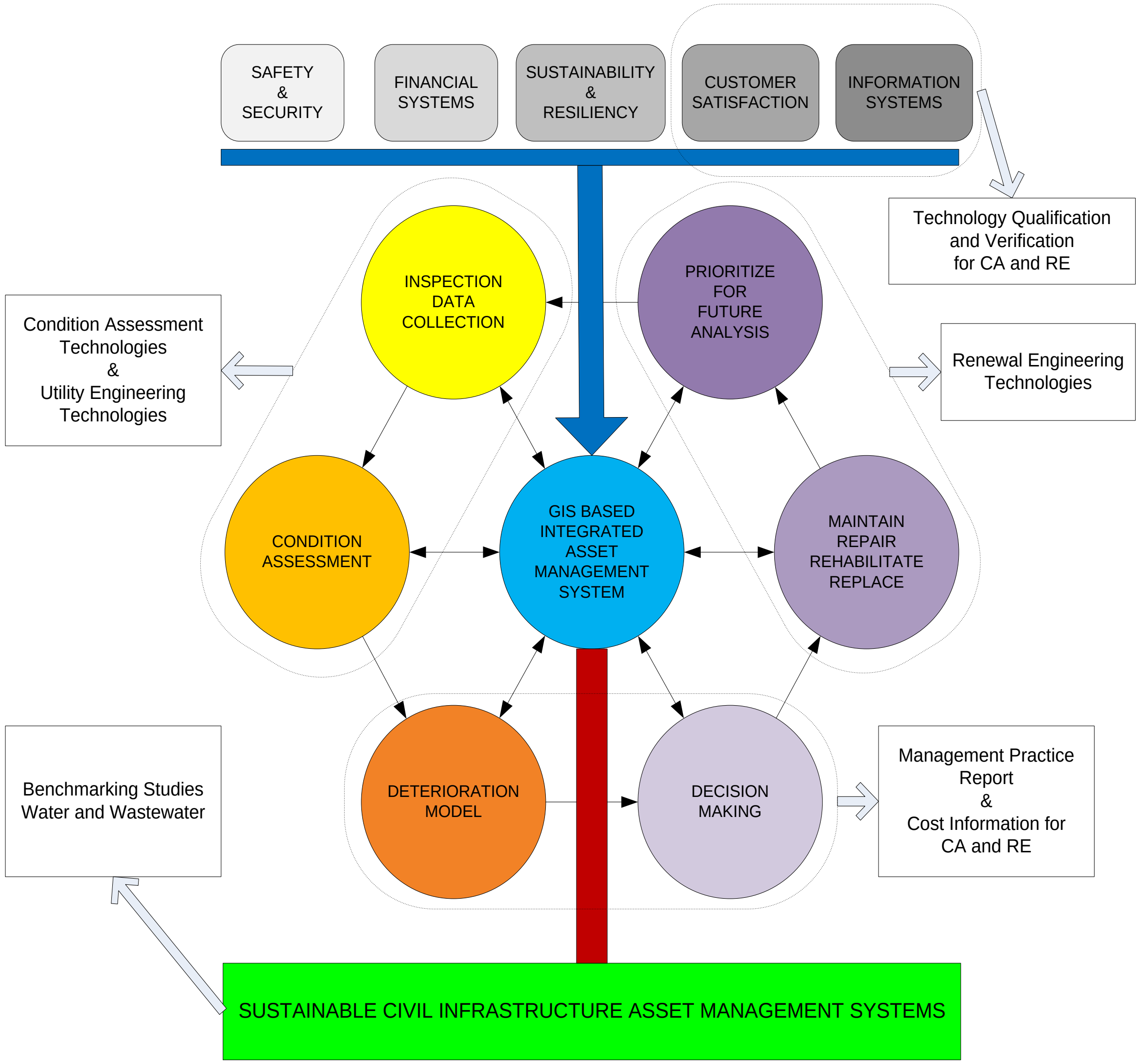


Figure 2-10. WATER*i*D Reports and Asset Management Framework.

Finally, this primer on AM for performance, sustainability, and resiliency is intended as a higher level overview of the three areas, in order to compare the state of the art in them with the current state of the practice and therefore identify gaps and challenges for advancing the practice.

The five core questions previously discussed can be developed in 10 steps for applying the AM process in water and wastewater utilities following a structured approach, as shown in Figure 2-11 (U.S. EPA, 2002).

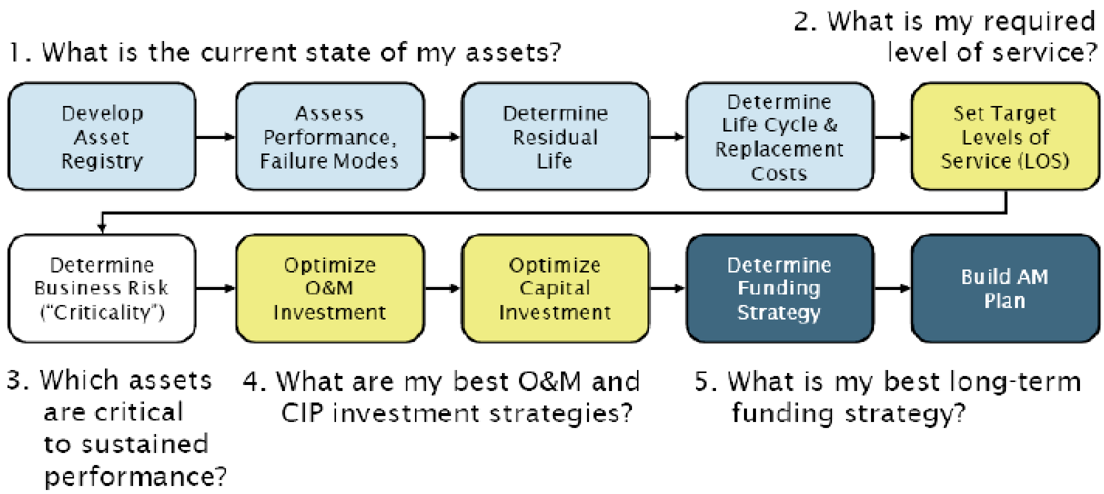


Figure 2-11. Ten-Step Asset Management Process Utilized in SIMPLE.
(U.S. EPA, 2002)

As the previous framework, the ten-step AM process shown in Figure 2-11 is designed for practical application in water and wastewater utilities. However, these frameworks are general enough that they can be applied to most civil infrastructure systems. All infrastructure systems require methodologies for minimizing life cycle cost of system operation while maintaining an adequate LoS. For detailed information on the SIMPLE AM Framework, please refer to the SIMPLE knowledge base.

2.5 Implementation of AM

The implementation of AM is tailored to each particular infrastructure system. Although in theory IAM has a defined set of steps and characteristics, in practice many organizations responsible for infrastructure O&M do not have the resources to implement a full AM program from the start, nor should they wait until they do. A common approach is to start step by step, building an Asset inventory, establishing procedures for condition assessment, a basic prioritization method, and so forth.

In addition, the depth and extent of AM required by different utilities is not the same. While a medium or large utility may require a sophisticated AM, a community or small utility benefit from a more basic form. The key point is to get started.

As part of the WATER*i*D project, the research team observed applications of AM in practice directly from water and wastewater utilities. This primer is intended to improve AM practices.

2.6 AM Resources

This section provides an overview of key organizations and documents on IAM across a variety of sectors. For the water sector, extensive information on AM is contained in the SIMPLE knowledge base. In addition, IAM primers have been developed across many of those sectors, and are important to review so water and wastewater utilities may benefit and learn from other AM practices. In this section, some of the most important AM primers are introduced, and their key features discussed.

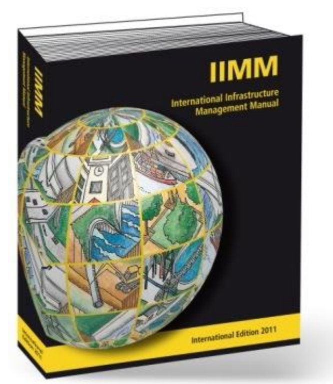
2.6.1 SIMPLE

WERF's online knowledge base SIMPLE, is designed specifically for the water quality and drinking industry. It incorporates industry- specific tools, graphics, guidelines, templates, AM plans, interactive training aids, glossary of terms, web links, and general wastewater references. SIMPLE breaks AM into seven concepts; asset inventory, data standards, LoS, risk/failure analyses, capital improvement plans, life cycle costs, and maintenance programs. The content is tailored to the U.S. wastewater industry yet is mostly based on international AM experience from countries like Australia and New Zealand.

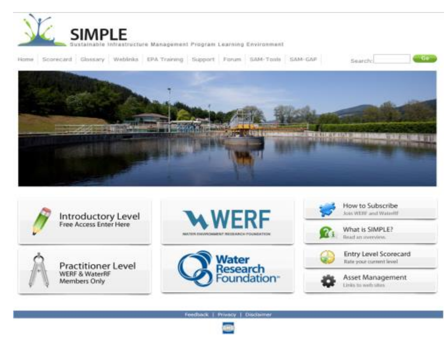
SIMPLE contains over 16,000 pages of best practices developed over a 20-year period and from extensive international experience and collaboration with AM practitioners and includes decision support tools for every aspect of an AM program. The purpose of the knowledge management system is two-fold: to make AM comprehensible and to promote information exchange among practitioners with varying needs and experience levels.

2.6.2 IIMM

The IIMM is a leading document on IAM, published by the non-profit organization National Asset Management Steering Group (NAMS) of New Zealand (NAMS, 2011). In addition to updating the manual periodically (traditionally every five years), NAMS produces other IAM publications, and sponsors workshops and conferences.



By the end of the twentieth century, it was clear that civil infrastructure systems required a long-term management approach for sustaining performance. Although the capital investment of constructing a new infrastructure system is considerable, costs and impacts associated with the construction stage are relatively low compared with those required for the operation of the system over its entire service life. As a consequence, effective and efficient management of infrastructure systems during their full life cycle is critical, from design to decommissioning.



The IIMM covers most AM topics, from the basic issues to advanced considerations. The manual also includes the current situation of IAM practice in Australia, New Zealand, Canada, South Africa, United Kingdom, and the U.S. The main sections of the 2011 version of the IIMM are:

Section 1. Introduction to IAM. This section introduces the basic concepts of AM, drivers, objectives, and overall philosophy.

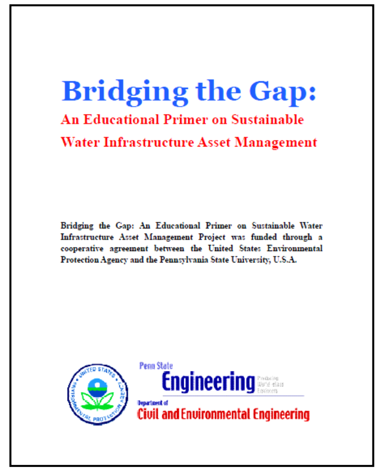
Section 2. Understanding and Defining Requirements. Here, the steps contained in AM frameworks are explained and developed, including condition assessment, asset risk, and others.

Section 3. Developing AM Lifecycle Strategies. Strategies for decision making, optimum maintenance, project funding, and capital improvement programs are discussed in this section.

Section 4. AM Enablers. This section deals with AM teams, plans, information systems, and other topics related with AM as a continuous improvement process.

Section 5. Country Specific Issues. Discusses the situation of AM in individual countries.

The IIMM is a necessary referent for AM practitioners, Infrastructure owners and operators, and Public officials worldwide.


Bridging the Gap:
An Educational Primer on Sustainable Water Infrastructure Asset Management

Bridging the Gap: An Educational Primer on Sustainable Water Infrastructure Asset Management Project was funded through a cooperative agreement between the United States Environmental Protection Agency and the Pennsylvania State University, U.S.A.

2.6.3 Bridging the Gap: An Educational Primer

The title of this primer makes reference to an EPA report containing a comparison between the financial needs and resources of water infrastructure in the U.S., known as "The Gap Analysis" (*The Clean Water and Drinking Water Infrastructure Gap Analysis*, 2002).

This educational primer is part of a research project sponsored by the U.S. EPA and developed by the Pennsylvania State University. This primer is complemented by a series of educational modules on-line, from the basics of IAM, to advanced issues facing municipal water systems. The modules are:

1. Key Principles of AM and its Components.
2. Current and Best Practices for Water and Wastewater IAM.
3. International Perspectives on IAM.

The "Bridging the Gap" primer introduced an earlier version of the seven step IAM framework shown in Figure 2-9. The body of this primer is comprised of the following chapters:

1. What is AM?
2. Why AM?
3. AM Framework and Processes.
4. Asset Data and Information Management.
5. Perspective on AM.
6. Implementing AM.
7. Research and Education in AM.

2.6.4 AM Primers, USDOT

The U.S. Department of Transportation (USDOT), through the Office of Asset Management in the FHWA produced their first AM primer in 1999.

This AM primer for transportation Infrastructure is another important reference document for AM practitioners, even outside the transportation sector. The primer body contains the following chapters:

1. What is AM?
2. Why AM?
3. Current Paradigm for Decision Making (What do they have?)
4. Current Practice (How is it working?)

5. Improving the Process (What is needed?)
6. Strategies for Implementation (How do they get there?)

Among other features, this primer compiled some definitions of IAM at a strategic level for the transportation sector (Table 2-1).

Table 2-1. Asset Management Definitions in Transportation.

Organization	Year	Asset Management Definition
American Public Works Association		"…a methodology needed by those who are responsible for efficiently allocating generally insufficient funds amongst valid and competing needs."
AUSTROADS	1997	"…a comprehensive and structured approach to the long-term management of assets as tools for the efficient and effective delivery of community benefits"
Organization for European Cooperation and Development	1999	"Asset Management…goes beyond the traditional management practice of examining singular systems within the road networks, i.e., pavements, bridges, etc., and looks at the universal system of a network of roads and all of its components to allow comprehensive management of limited resources. Through proper asset management, governments can improve program and infrastructure quality, increase information accessibility and use, enhance and sharpen decision-making, make more effective investments and decrease overall costs, including the social and economic impacts of road crashes."
New York Department of Transportation	1998	"In the transportation world, asset management is defined as a systematic process of operating, maintaining, and upgrading transportation assets cost-effectively. It combines engineering and mathematical analyses with sound business practice and economic theory. The total asset management concept expands the scope of conventional infrastructure management systems by addressing the human element and other support assets as well as the physical plant (e.g., highway, transit systems, airports, etc.). Asset management systems are goaldriven and, like the traditional planning process, include components for data collection, strategy evaluation, program development, and feedback. The asset management model explicitly addresses integration of decisions made across all program areas. Its purpose is simple—to maximize benefits of a transportation program to its customers and users, based on well-defined goals and with available resources."

The FHWA AM Primer also established a Generic AM System. The components of such system are shown in Figure 2-12. Notice that the general sequence of steps in the Generic AM System is very similar to other AM frameworks discussed in previous sections.

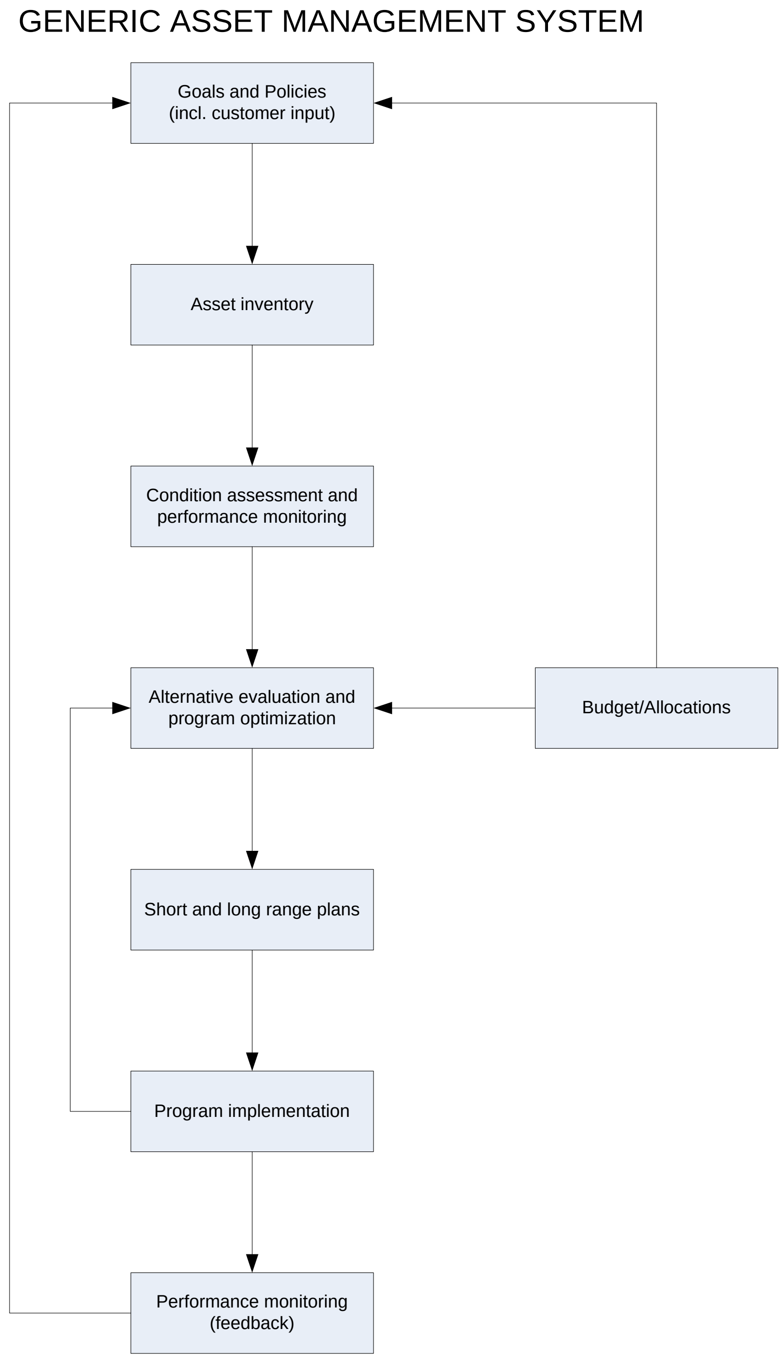


Figure 2-12. Components of the Generic Asset Management System.
(FHWA, 1999)

In this AM primer, AM is defined as:

"Asset management is a business process and a decision-making framework that covers an extended time horizon, draws from economics as well as engineering, and considers a broad range of assets. The asset management approach incorporates the economic assessment of trade-offs among alternative investment options and uses this information to help make cost-effective investment decisions." (FHWA, 1999).

2.6.5 FHWA Primer on GASB-34

The GASB is the source of GAAP that apply for financial reporting by all state and local governments in the U.S. In 1999, GASB issued statement 34 that required civil infrastructure systems to be considered as investments, instead of expenses. By doing so, the GASB-34 encourages the application of AM principles by the infrastructure owner and operator organizations.

The FHWA issued a primer on the GASB-34 Statement, because of its importance for IAM.

As part of GASB-34, a new depreciation method was introduced that acknowledges the fact that infrastructure systems can operate indefinitely. For example, while the design life of a water distribution system may be 50 years, in practice water systems are maintained, expanded, and operated indefinitely. Although all system assets are repaired, rehabilitated, and replaced at different times and therefore they have traditional depreciations, the system as a whole continues operating.

Figure 2-13 contains a comparison of different management models applicable at different stages during the infrastructure system life cycle.

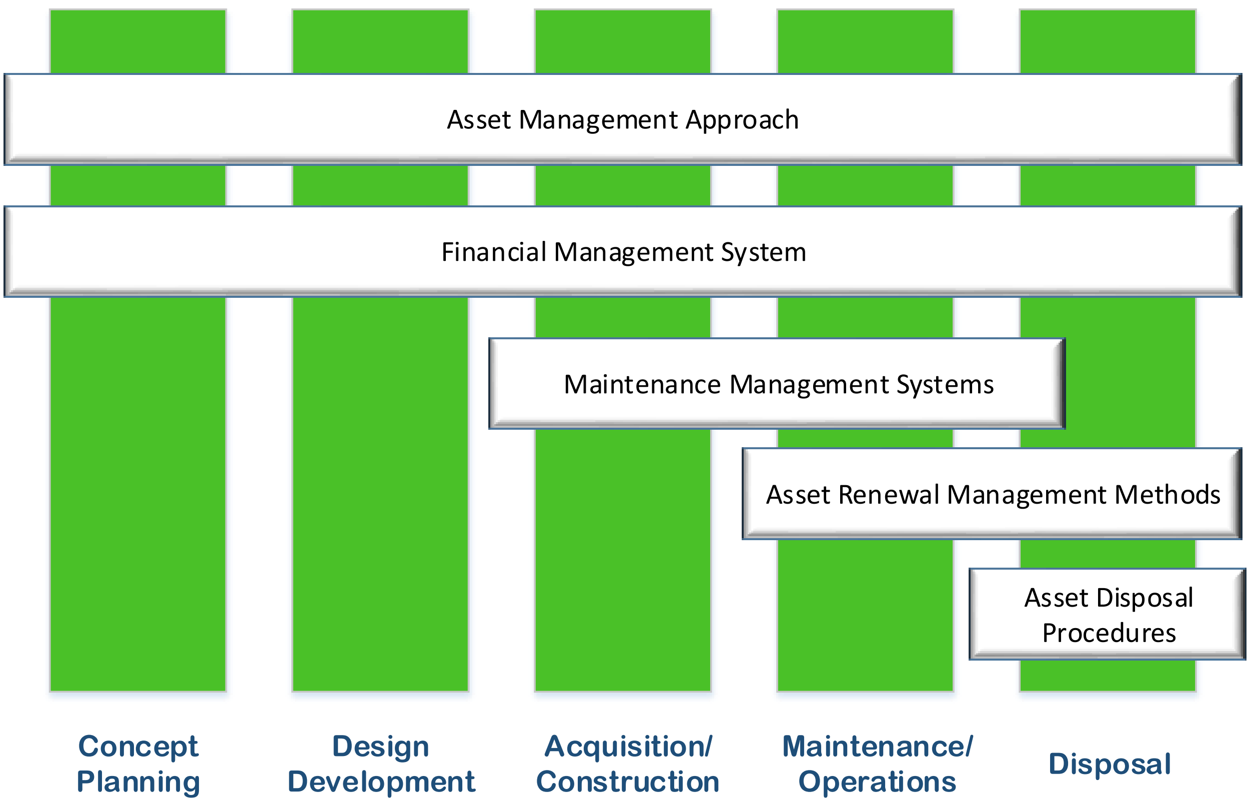


Figure 2-13. Comparison of Management Models.

CHAPTER 3.0

RISK MANAGEMENT

Risk management is a key component of AM. All AM programs use risk as the primary driver for decision making. Strategic AM decisions are risk-driven. All the AM steps use risk considerations, including data collection, condition assessment, deterioration models, and prioritization tasks.

Risk is defined in terms of LoF and CoF. For example, in the Australia/New Zealand Risk Management Standard AS/NZS 4360 Risk is defined as *"the chance of something happening that will impact upon objectives, and is measured in terms of consequences and likelihood"* (Brennan et al., 2004). The SIMPLE definition BRE adds a risk mitigation factor to the core risk definition (Figure 3-1).

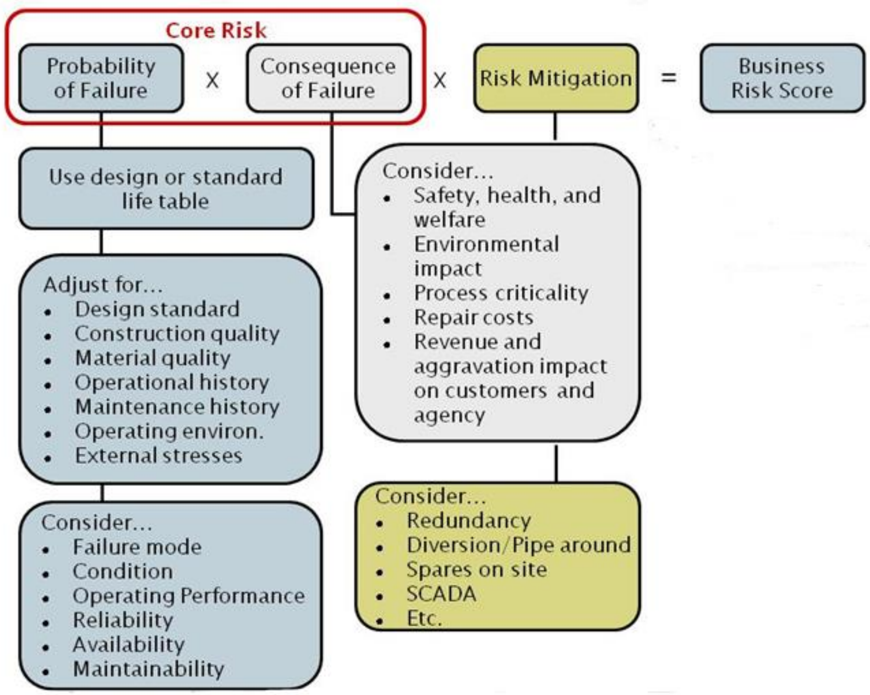


Figure 3-1. Steps for Business Risk Management (SIMPLE).

As observed in Figure 3-1, risk assessment is part of the risk management process and includes the three central concepts: likelihood of failure, CoF, and an optional mitigation factor. Risk expressed as LoF times CoF is sometimes known as Raw Risk. Raw risk is frequently modified using a factor that takes into consideration possible mitigation or adaptation options the utility is taking to reduce such risk.

Although the quantification of CoF may be challenging, LoF is probably more difficult to quantify. Estimations of LoF tend to have significant uncertainty, and are often based on heuristics.

3.1 Likelihood of Failure (LoF)

There is an important amount of information and research on the LoF side of risk. LoF has been estimated in a variety of ways, including statistical analysis of historical data, expert opinion, and others. Condition assessment of infrastructure assets is frequently related to LoF, assuming that condition and PoF are strongly related. This is one of the reasons why asset age is not generally a good indicator of LoF. Research has shown that the relationship between asset condition and asset age is not very strong. Therefore, it is necessary to distinguish between a PoF curve and other curves based on performance or condition. Table 3-1 contains an example of a LoF matrix.

Table 3-1. Likelihood of Failure.

Rating	Description	Probability	Frequency
5 Certain	Imminent Failure	0.99	1 per year
4 Likely	Failure likely to occur during the period	0.50	1 in 1-4 years
3 Possible	Failure may occur during the period	0.20	1 in 5-19 years
2 Unlikely	Failure not likely to occur during the period	0.05	1 in 20-49 years
1 Rare	Failure will occur under exceptional circumstance	0.02	1 in 50 years or more

The LoF values shown in Table 3-1 vary according to the type of asset under consideration, and the specific utility. Although useful, those values tend to have a high level of uncertainty.

3.2 Consequence of Failure (CoF)

LoF and CoF are challenging to quantify, particularly when including aspects difficult to monetize. In general, CoF is estimated using financial metrics, such as cost of repair, cost of damage caused to third parties, business lost, and others.

Despite the convenience of using financial metrics for estimating CoF, there are failure impacts that are hard to measure by economic means, such as social consequences and impacts to the natural environment. For this reason, an approach gaining acceptance is the TBL. The TBL approach considers the consequences of failure in three dimensions, social, economic, and environmental (Figure 3-2).

The TBL approach establishes a departing point for improving the CoF identification process and includes impacts that are challenging to measure in terms of dollars. Despite these advances, CoF within a TBL framework must be monetized to allow comparison of alternatives. In addition, using financial measures in the TBL approach enable easier evaluation of costs and benefits of alternatives.

Figure 3-2. TBL Approach to CoF.

Figure 3-2 contains a list of key costs that may be considered within a TBL analysis. Some costs in the social and environmental dimensions of a project are difficult to quantify. However, advances have been made in monetizing such costs. Expressing all costs and benefits in financial terms will facilitate decision making in the utility.

3.3 Risk Analysis

Risk analysis is the process of taking the estimated LoF and CoF to evaluate risk by multiplying LoF x CoF. This process generally is better represented by a risk matrix such as the one shown in Table 3-2.

Table 3-2. Standard Risk Matrix.

	Likelihood of Failure				
Consequence of Failure	1	2	3	4	5
5	Medium	Medium	High	Extreme	Extreme
4	Medium	Medium	High	Extreme	Extreme
3	Medium	Medium	High	High	High
2	Low	Low	Medium	Medium	Medium
1	Low	Low	Medium	Medium	Medium

The matrix in Table 3-2 is color-coded according to the risk level resulting from different combinations of LoF and CoF. The descriptions can be associated with more usable terms, such as sample monitoring, aggressive monitoring, and immediate work.

CHAPTER 4.0

DATA AND INFORMATION MANAGEMENT

4.1 The Importance of Data

IAM is an information-intensive process. The first step in most AM frameworks is frequently related to data collection. This is because all steps afterwards rely on information about the infrastructure system, such as asset registry, asset condition assessment, deterioration rates, cost information, and others. Data can be gathered from a variety of sources, including historical records, as-built drawings, field data, and experienced staff.

The WATER*i*D project was developed as a means to capture valuable data that otherwise may be lost. For example, experienced employees have developed valuable knowledge, information, and even mental models about the infrastructure system and its performance. When such an experienced person retires, all or much of that valuable knowledge may be lost. In addition, WATER*i*D enables data and information sharing among peer utilities. This is helpful because they tend to be isolated in regards to knowledge sharing.

Data management considers all aspects of data processes, such as data collection, data storage and retrieval, and data analysis. Each of these aspects is vital for implementing a successful AM program. Yet, there are significant challenges associated with data management.

Data is Expensive: Gathering the required amount of data may be expensive. The more detailed required, the more costly it is. It is important to gather pertinent data to achieve cost effectiveness, with an adequate trade off balance between detail and cost, considering the intended application.

Data Storage: Significant amounts of data are required, and therefore storage is an important consideration. Stored data has to be safe and easily accessible, preferably in a standard format. Media obsolescence may also be an issue. For example, data stored in floppy disks may be inaccessible in the future unless its format is updated periodically.

Data Has to be Analyzed: Gathering data is not beneficial unless valuable information is extracted. Analyzing significant amounts of data is not the only challenge, since such analysis has to be done in a timely manner. For example, data indicating an imminent failure needs to be known before the actual failure occurs, in order to be useful.

Figure 4-1 represents the data and information flow evolution for IAM. The first step involves collecting data and extracting information. Operational and tactical level AM are strongly related to these activities since significant amounts of data are collected at the operational level, and basic research uses information extracted from such data. Moreover, tactical and strategic level AM decisions often require transforming information into knowledge by contrasting such information with experience, considering the context, formulating and testing hypothesis, and applying adequate generalizations. At the final stage, knowledge is transformed into wisdom. This happens mainly at the strategic level after knowledge has been slowly decanted with experience and a variety of decision contexts taken into account. However, information and knowledge flow in both directions, top down and bottom up, at some degree in a continuous cycle. Meaningful data collection has to be paired with a management strategy.

The WATER*i*D project is intended to capture the knowledge and wisdom of experienced utility staff, and enable knowledge and experience sharing among utilities. The water sector is highly fragmented, with nearly 90,000 water and wastewater utilities in the U.S. alone. Due to this fragmentation, information sharing is challenging but also highly beneficial.

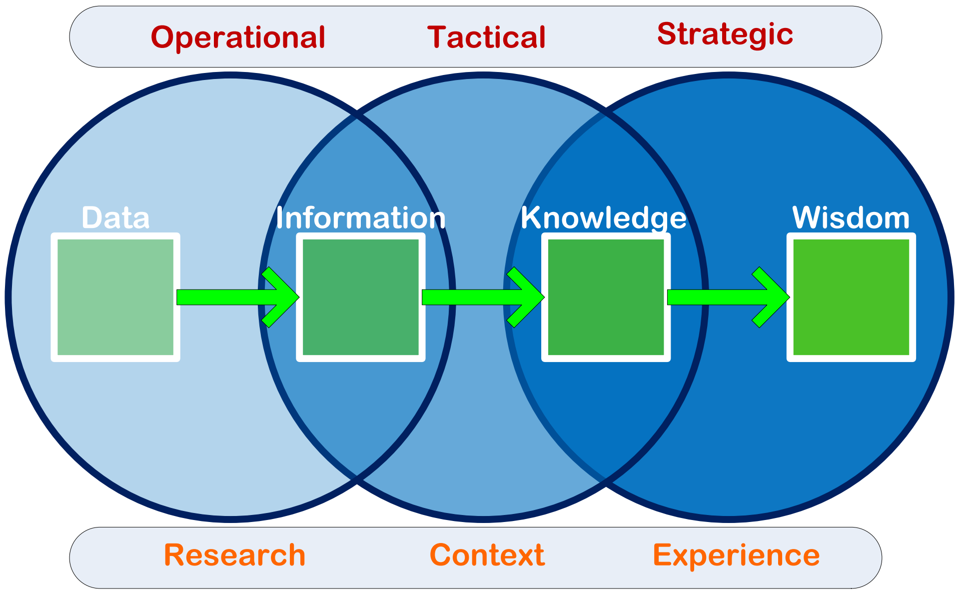


Figure 4-1. Data Transformation Into Information, Knowledge, and Wisdom.

4.2 Data Integration

The FHWA published a *Data Integration Primer* in 2010 (FHWA, 2010). The primer addresses the importance of data for AM. An organization may have significant amounts of data, and still not enough information. Data integration is intended to maximize the benefits from data collection, storage, and management activities.

Data integration is required in addition to data management. Traditionally, data has been managed in separate units. For example, each business unit within a water sector utility may have a specific data collection and storage system. Frequently, those separate data management units cannot communicate with each other because of different formats and standards. This problem is even more evident when trying to compare data between different utilities. Data integration addresses this problem. Using the currently available information technology tools, it is possible to manage all data in a standard consistent manner. Data integration enables cost effectiveness, interoperability, and other benefits.

Table 4-1 contains a list of potential benefits of data integration for five key components of any IAM system.

Table 4-1. Potential Benefits of Data Integration.

Asset Inventory	• Acquire and upload data from a single source just once • Update and process inventory records • Reduce data handling and processing time
Assessing current conditions and performance	• Analyze historical and spatial conditions more conveniently • Quickly identify assets requiring immediate attention • Standardize condition rating procedures and evaluation criteria • Store condition/investment analysis data and results • Support collective decision making
Determining and evaluating future system needs	• Facilitate integrated decision making • Support investment trade-off analysis • Determine future funding needs • Enhance communication and improve overall alignment of investment programs
Evaluating and selecting strategies for current and future needs	• Develop more effective management strategies combining data • Reduce the risk of taking ineffective action • Prevent development of multiple strategies for a single asset • Store and retrieve results of analyses • Support fact-based strategies
Evaluating the effectiveness of strategies	• Improve performance through immediate feedback • calculate performance measures and indicators • Promote consistency and standardization • Conduct different types of analysis

The implementation of data integration for IAM may require overcoming a series of potential challenges, including heterogeneous data, bad data (data quality issues), lack of storage capacity, unanticipated costs, lack of data management expertise, and perception of data integration as an overwhelming effort.

The primer on data integration contains specific suggestions for overcoming data integration challenges. Although the implementation of data integration may represent high upfront costs, the benefits in the long term outweigh those costs.

What is Data Integration?

According to the FHWA, data integration is defined for transportation infrastructure as a method of combined data from a variety of sources to inform improved decision making for infrastructure assets. Data integration takes advantage of current information technologies and standardization to improve data management for AM.

Why Integrate Data?

IAM is based on data. Significant amounts of reliable data are required to achieve efficient and effective decision making. Although high-quality data is a first step, it may not be enough. Frequently data is collected and stored in a variety of non-compatible formats. Data integration enables increased infrastructure system stewardship and more cost-effective decision making by combining disparate data sets. Data standards that enable data integration are required in order to achieve data interoperability across different platforms and interfaces. Data integration benefits include:

Integrated Decision Making: Decisions made by different business units in a single infrastructure agency can be more effective if they are based on integrated data, allowing public funds to be used more efficiently.

Proactive Analysis: Many decisions are still reactive. Data standardization and integration enable proactive data analysis for predictive purposes. Since standard data can be integrated and shared among a variety of platforms, its predictive potential increases.

Other Benefits: Other benefits of data integration include improved: Data availability and accessibility, timeliness, accuracy, consistency, and completeness. Data integration enables reduction of duplications, and facilitates faster data analysis. Other benefits of data integration are shown in Table 4-1.

How to Integrate Data

Data integration can be a challenging and complex task. A good start in any infrastructure agency may be to analyze the current AM process, identifying opportunities and needs for data integration. It is also recommended to establish a data integration team. As a summary, data integration can be achieved considering the following general steps:

1. Develop a data integration requirements analysis.
2. Perform data and processes flow modeling.
3. Analyze data integration alternatives, mainly between fused or interoperable databases.
4. Develop database design and specifications.
5. Develop, test, train, and implement.

An incremental approach may be a good way to start data integration. The incremental approach will provide flexibility to the process and allow time for evolution of the organizational processes. It will also give time for system testing and upgrading, as required.

Challenges to Data Integration

Data integration will not solve every data management challenge. However, if realistic expectations are set, the integration and standardization of data across the organization can significantly reduce the most common problems in effective AM.

The first stage of data integration – the requirements analysis – is particularly important. It provides a unique opportunity to set realistic expectations and minimize possible data integration challenges further in the implementation process. Some of the most common challenges to data integration include the following:

1. Heterogeneous data from different sources or in varying formats.
2. Low quality data.
3. Lack of storage capacity.
4. Unanticipated data management costs.
5. Lack of staff cooperation.
6. Lack of data management expertise.
7. Perception of data integration as an overwhelming effort.

Data management and integration can have a significant impact on any AM program success. The quantity and quality of available data determines what AM practice to follow.

CHAPTER 5.0

PERFORMANCE MANAGEMENT

5.1 Performance

Performance is an essential concept for IAM. Sustaining an adequate LoS while minimizing life cycle cost, implies the existence and usage of a set of performance measures. Those measures include technical, financial, social, organizational, and environmental aspects. Since performance is a core consideration when managing infrastructure assets, is important to explore the concept of performance management in this primer.

Performance management is the process of developing a set of performance measures for an organization, setting goals for such performance, and monitoring organizational progress towards them (TRB, 2009). Performance management contributes to AM in a variety of ways, including:

- Quantification of policy goals and objectives.
- Evaluation of resource allocation options.
- Comments on the effectiveness of a program.

A key step in achieving effective performance management is developing the performance measures set. According to the Transportation Research Board (TRB) (TRB, 2009), the selection of adequate performance measures comprises five basic steps. These steps are relevant to water IAM.

Step 1: Review Existing Measures

This includes a comprehensive literature review for performance measures used in the industry and in other industries as well. Major reports from governmental agencies or other organizations provide important references. Given that the performance measures have to be multi-dimensional (technical, organizational, economic, etc.) the literature review includes publications from diverse backgrounds. This provides a broad overview and promotes innovative approaches.

Step 2: Assess Needs

This step considers how and why performance measures should be utilized, to make sure the proposed set of measures is right for the needs of the AM being implemented. For example, the TRB uses five categories of performance measures:

a. Preservation, for characterizing the physical condition of assets.
b. Mobility, to measure how well the transportation infrastructure fulfills its mission of supporting transport.
c. Safety, encompassing measures of how safe is the transportation system.

d. Environment, to measure the environmental impacts of the infrastructure system.

e. Project delivery, to measure progress towards objectives of the capital plan.

Step 3: Define Selection Criteria

A set of criteria was established to select adequate performance measures. Criteria include feasibility, policy sensitiveness (whether the performance measure is useful for measuring the impact and effects of policies), strategic value, (whether the set of performance measures is useful for decision support), and usefulness across the organization.

Step 4: Apply Selection Criteria

The set of criteria is applied to performance measures identified in step 1 or in the needs assessment in step 2. In general, similar performance measures are grouped together and their variations are characterized descriptively.

Step 5: Finalize Set of Measures

The set of measures is finalized by achieving the shortest possible set with full coverage of the categories and addressing all needs. In transportation, a workshop was held with elected officials, personnel from different departments of transportation, and other stakeholders to review the set of performance measures and ensure their completeness and relevance.

Figure 5-1 represents a continuous cycle or feedback loop of performance measures. It is used for assessing the effectiveness of policies and plans. The performance measures are also updated and improved. This suggests that AM is a continuous improvement process.

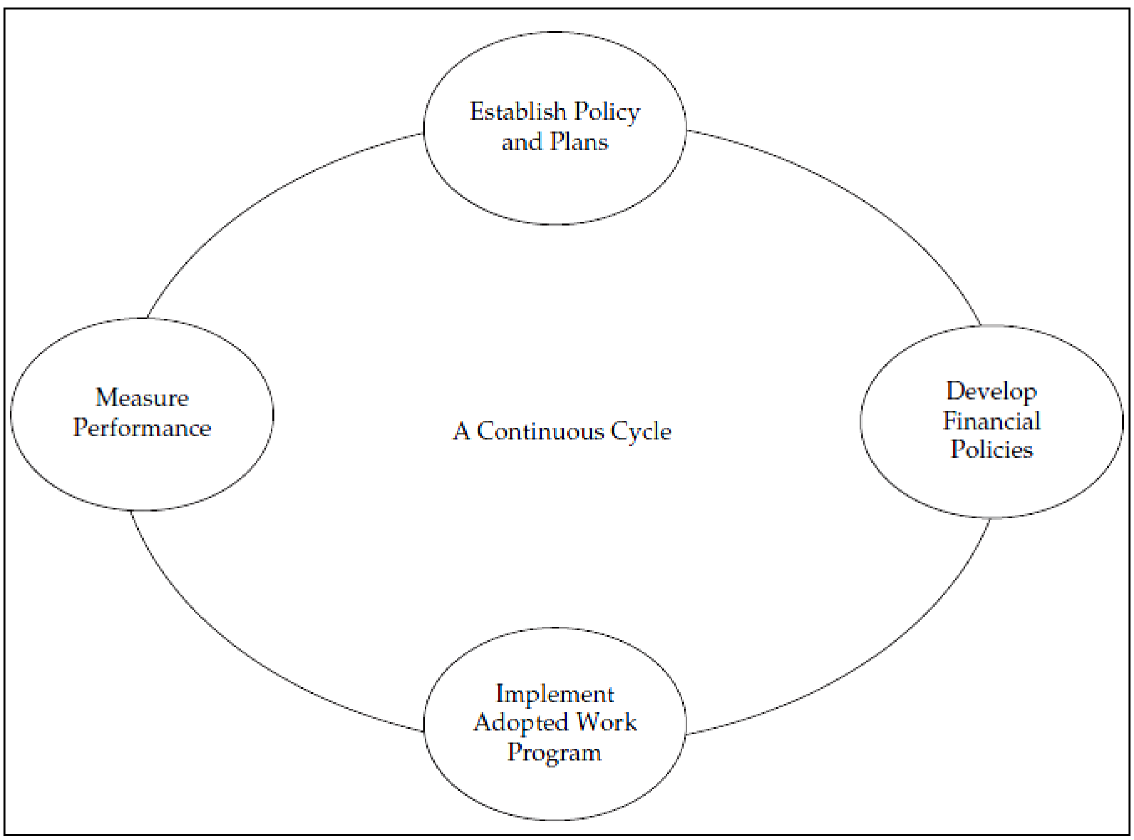


Figure 5-1. Florida DOT Asset Management Feedback Loop.

5.2 Gap Assessment

WATER*i*D currently contains nearly 300 case studies, all related diverse aspects of IAM at water and wastewater utilities. Most of the case studies refer to U.S. water sector utilities. Also, AM practice in systems in the UK, Canada, Australia, and South Korea are included. Topics covered in these case studies include condition assessment, renewal engineering (which includes maintenance, repair, rehabilitation, and replacement), and management practices. Current AM programs address performance of the infrastructure system.

The case studies were written using information obtained by directly contacting each participating utility. They shared their experiences and information with the researchers. As a result, the research team accumulated significant knowledge regarding the current state of the practice in the U.S. for a variety of AM topics. The previous section presented the state of the art on IAM at a theoretical level. However, frequently there is a gap between theory (what should be) and practice (what actually is), and IAM is not an exception. Gaps exist between the AM in theory and its practice. This section describes the main findings of the WATER*i*D research team regarding the state of the practice in AM in participating utilities, and contrasting it with the introduced IAM frameworks.

Each one of the 10 steps of IAM considered in SIMPLE (Figure 2-11) is discussed with the state of the practice observed for that step.

1. Develop Asset Registry

An asset registry is constituted by the systematic recording of all assets owned or operated by the organization. The asset registry uses asset identification numbers to link all asset attributes with the rest of the AM process. An asset registry can have a variety of structures, depending on the utility preference or needs. In addition, the asset registry requires the establishment of a data standard to record and utilize the information in a consistent way.

Most participating utilities have an asset registry (also called asset inventory) or are in the process of assembling it, because this is a necessary first step in any AM program. However, water and wastewater systems are comprised of many assets and assembling an asset registry takes time and also may be expensive. Medium or large utilities tend to have better asset registries than small systems, likely because they can assign more resources to the task.

2. Assess Performance and Failure Modes

In addition to having the asset registry, it is necessary to assess the performance of each asset. Performance can refer to measures such as asset function, LoS, availability, or reliability, among others. When there is no data, some performance proxies are used such as condition, age, or usage. There are also different types of failure modes. Failure can refer to physical failure, capacity failure, or a LoS failure. A variety of condition assessment techniques and rating systems exist, and are used to assess asset performance.

Most participant utilities have condition assessment processes in place, and basic condition assessment systems such as simple scales are more common than sophisticated systems requiring significant amounts of data. Although there is a wide array of technologies for asset inspection and data collection, the most used are those technologies that are less expensive.

Condition assessment technologies that produce more accurate information at a higher cost are mostly used only in particular high-risk assets.

3. Determine Residual Life

It is important to distinguish between asset physical life and economic life. Economic life is usually shorter, ending when the asset is no longer the most cost-effective option to serve its intended purpose, even if it is still working. The determination of residual life is probably one of the most important tasks in AM. Knowledge of remaining asset life would allow the utility to optimize the timing of renewal activities in order to minimize total life cycle costs. Unfortunately, determination of the asset's residual life is also one of the most challenging tasks, since factors involved in remaining asset life are highly uncertain.

In the participant utilities, in general residual asset life is estimated using basic proxies such as comparing asset age with expected design life, or based on subjective assessments from staff experience (which can be accurate in some cases). In general, there is no use of advanced methods for determining remaining asset life.

4. Determine Life Cycle and Replacement Costs

There are different types of costs related with AM. Two of the most important costs are life cycle costs and replacement costs. Life cycle cost is the total cost of an asset, including design, construction, operation, maintenance, renewal, and decommissioning. Any salvage value is subtracted from the total life cycle cost. Understanding costs associated with the assets is important because one of the key benefits of AM is an improved financial management of the system.

Most of the participating utilities routinely track a variety of costs. However, this is a historical record with relatively low forecast value because costs are highly dependent on the particular conditions in each project. Historical costs from similar assets can provide a ballpark estimate only, but a comprehensive cost study on AM appears to be lacking in practice.

5. Set Target LoS

Setting target LoS is fundamental to AM. As it was explained before, LoS are standards set for minimum expected system performance. LoS are customer driven. They specify service expectations about how much, of what nature, and how frequently are they provided by the infrastructure (U.S. EPA, 2002).

In general, LoS is defined in the participant utilities, although in some cases they may not be explicitly stated. In some small utilities that may not have an established formal AM system, the LoS is implicit.

6. Determine Business Risk ("Criticality")

Risk is at the core of AM. A traditional measure of risk (raw risk) results from the multiplication of PoF and CoF. BRE is an AM term that is measured as raw risk x a 'risk mitigation' factor. The risk mitigation factor takes into consideration actions that the utility may have taken to reduce raw risk. BRE is commonly used to prioritize assets based on their risk degree.

Larger participant utilities appeared to have a more structured and explicit approach to risk, including established procedures for estimation of BRE. However, almost all utilities used some measure of risk for decision making, even when in some cases it was not a sophisticated one.

7. Optimize O&M Investment

Maintenance is those periodic and minor activities required to support performance and reliability of an asset according to design and manufacturing standards. The operations and maintenance investments are optimized when the strategy used produces the minimum cost for these activities. Planned maintenance is in general more cost effective than unplanned maintenance required after there is a failure.

The concept of optimizing O&M investments is widespread in the participant utilities, with varying degrees of success. Nevertheless, O&M investments appear to be currently more cost effective than in the past, due in part to better knowledge of IAM objectives and techniques. Some utilities struggle to optimize investments because of resource constraints or budgetary considerations.

8. Optimize Capital Investment

While O&M investments only sustain the expected asset performance, Capital Investments are required for replacement of assets or to expand system capacity. Capital investment optimization is important because a significant part of the life cycle costs of a given infrastructure system are determined by decisions taken in the initial stages, from design to the end of construction.

In the participant utilities there is a clear understanding of the importance of optimizing capital investments. Most utilities performed some kind of optimization, although degrees of success vary due to several factors such as available resources, political issues, and the development achieved in implementing AM processes. It was observed that those utilities with established AM systems have better access to funding opportunities.

9. Determine Funding Strategy

The funding strategy applied has significant financial implications. There are two main strategies for funding O&M and capital investments. One is to have a separate dedicated fund for these activities. The other one is to use debt. Although the first option is in general financially preferable, it is not always possible. In fact, the rates of most water and wastewater utilities only are enough for O&M, leaving no funding for capital investments.

As previously mentioned, one of the benefits of implementing an AM program in an infrastructure system is improved access to funding. A utility's AM program can provide important information that can help lending agencies understand the financial condition of the utility.

10. Build Asset Management Plan (AMP)

The AMP brings together the previous nine steps. The key point in the AMP is to financially balance costs and income in such a way that the utility is prepared with adequate funding for present and future needs. In some cases, the required LoS is unrealistic given the available funding, and might be necessary to increase rates or reduce the LoS.

Some utilities already had complete AM programs in place, while others were in the process of building an AM program. Designing and implementing an AM program takes considerable time and resources given the data required. Some utilities, particularly smaller ones, are still building asset registries and have informal processes in place for condition assessment, prioritization, and other AM aspects.

The water sector is comprised by thousands of utilities and community water systems, most of them small or very small. Key IAM concepts and principles are known in the participant utilities, although applied at diverse degrees. This section identifies the main gaps and challenges observed in the participant utilities regarding AM. However, it is important to notice that the participant utilities are very few compared with the total number of water systems in the U.S. and therefore it is not possible to generalize the conclusions as statistically significant. The information provided applies only to the participant utilities. Final considerations for the gap analysis are included below.

Education on IAM is an ongoing process. Although the basics of IAM are well known, the efforts of WERF, EPA, and other agencies and organizations toward continuing education of water and wastewater system administrators on advanced AM are still necessary, for the following reasons:

IAM is a continuous improvement process. The concept of IAM as well as its techniques, methodologies, and tools are always improving. The IAM process from years past is not necessarily the same as today.

Small utilities are in early stages of developing an AM approach. The largest participant utilities had more established AM processes, because they tend to have more resources and also own and operate assets that imply higher risks. Most water and wastewater utilities are very small systems that require continuing support on AM from initiatives like SIMPLE and others.

Most water sector utilities do not apply all of the AM framework components. While most utilities have the basic building blocks of an AM program such as an asset registry, not all of them apply more advanced techniques such as prioritization, investment optimization, and others. AM is generally applied as needs arise and resources allow. In some cases, there might not be incentive to apply some of the most advanced AM concepts.

Also, small utilities tend not to have the largest assets that are frequently associated with higher risks, such as large diameter prestressed concrete cylinder pipes (PCCPs). For smaller risk levels, a less-developed AM framework may be enough. AM programs are built over time and the universes of practices are such that not every practice is appropriate in every instance.

5.3 Conclusions and Recommendations

Comparing the observed state of the practice on IAM and performance in the participant utilities with the state of the art in AM, it is possible to formulate some basic recommendations for advancing AM in water and wastewater utilities and addressing the identified gaps.

Continue the educational and training efforts on AM. Continuation of the educational efforts on AM is required to keep utilities up to date, as well as ensure every utility has basic knowledge of core concepts and contact with AM practices. In addition, WATER*i*D provides an easy access platform for all registered utilities.

Focus on small systems. Small water and wastewater systems comprise the majority of the water sector utilities, and have some of the clear gaps in AM. It is necessary to develop AM strategies, tools, and training programs specifically designed for small systems. The U.S. EPA has developed some products and training materials specifically directed to small systems, but more efforts are required in this direction. Small systems face challenges such as AM knowledge, funding, staff shortages, and others.

Strengthen a life cycle, long-term approach across the water sector. IAM is intended for minimizing infrastructure life cycle costs, while maintaining an adequate LoS. However, many utilities still inadvertently incur higher life cycle costs than they could. Reasons are the industry standards and regulations.

Figure 5-2 represents this decision problem. The red curve represents what happens when a low initial investment is chosen, which causes in the long-term rising costs due to more frequent and extensive repairs, rehabilitation, and replacement needs. In the other hand, the blue curve represents a higher initial price, but such alternative may produce the lowest life cycle cost in the long term.

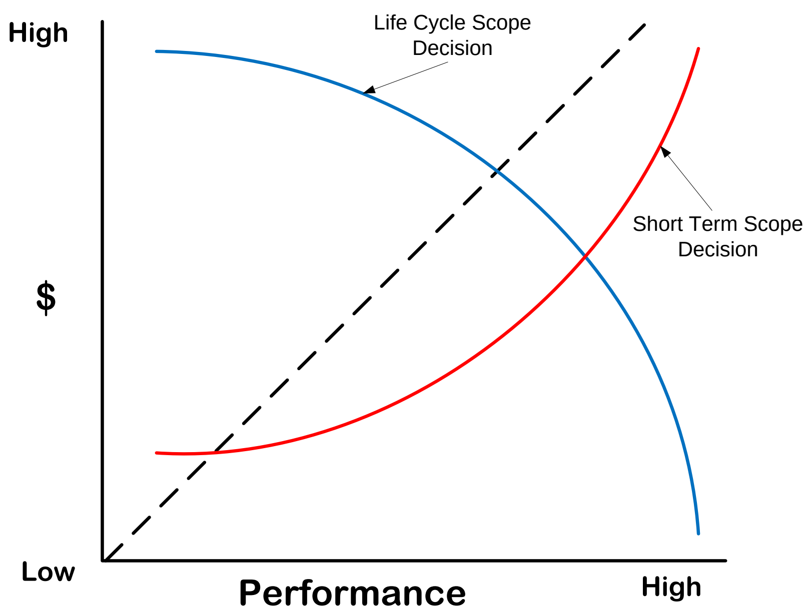


Figure 5-2. Decision and Life Cycle Costs.

An important aspect of strengthening a long-term scope is providing the infrastructure owners and operators with adequate financial resources to afford a minimum life cycle cost. Those resources will enable the utilities to make better decisions.

CHAPTER 6.0

SUSTAINABILITY MANAGEMENT

6.1 Sustainability

Sustainability in general is the capacity to persist. Therefore, a sustainable system or process is expected to have the capacity to continue for indefinite time. In the case of civil infrastructure systems, sustainability implies the capacity of the system to perform as expected without generating adverse impacts on different dimensions of its context. Specifically, sustainable development is understood as a development that does not compromise non-renewable resources and does not cause undesirable direct or indirect impacts. One of the first widespread definitions of sustainable development was put forth by the U.N. Sustainable development is to satisfy our needs without compromising the ability of future generations to satisfy their own needs (Brundtland, 1987).

Currently, sustainability is frequently addressed using the TBL approach. Although not a new concept in AM practice, the TBL approach balances economic, social, and environmental implications of business decisions. These three dimensions are not independent, as shown in Figure 6-1. The environment imposes constraints to social and economic developments, while society drives economics.

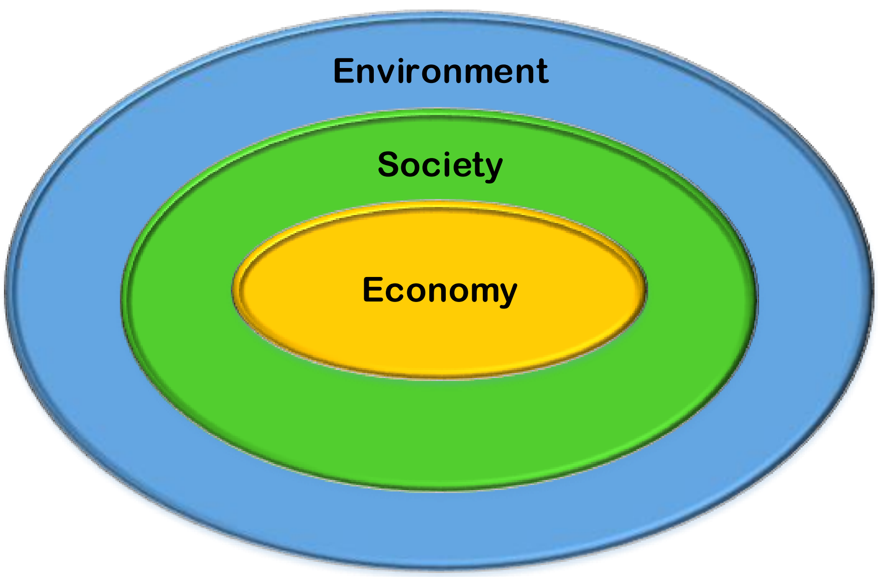


Figure 6-1. Sustainability.

Although sustainability shares concerns with the “Green Movement” regarding stewardship of the natural environment, sustainability is a much broader and deep concept.

Achievement of complete sustainability is a daunting challenge. However, advancing in small steps, some gains have been obtained already, such as the consideration of a TBL evaluation approach in many infrastructure systems.

A definition of sustainability that can be applied in the water sector has previously been proposed by ASCE/UNESCO (1998), who defined a sustainable water system as:

> *…one that is designed and managed to contribute fully to objectives of society, now and in the future, while maintaining ecological, environmental and hydrological integrity.*

This definition integrates the concept of sustainable development with issues that are specific to the use of water resources, and also explicitly reflects the TBL focus of the water industry. As such, the ASCE/UNESCO definition provides a reasonable basis from which to assess the sustainability of a water utility, especially from the perspective of its management of water resources.

The U.S. EPA considers that a sustainable water sector will rest on four main pillars (Crossland, 2006):

Better Management. Better management is necessary to move water infrastructure systems operation above minimum compliance levels, in order to achieve real sustainability. The promotion of advanced formal management systems is part of this pillar, such as Environmental Management Systems (EMS) and IAM. However, better management is not limited to the use of these management systems; it also includes the use of cost-effective and environmentally friendly technologies, innovative approaches, and other strategies.

Full-Cost Pricing. Currently, the price most people pay for water and sanitation services is unsustainably low. Water sector prices should be higher, considering the capital investment required for infrastructure renewal, expansions, and technology upgrades. In fact, water and sanitation rates usually cover only basic O&M costs, leaving utilities without financial resources to address long-term infrastructure deterioration and encouraging wasteful usage by customers.

Water Efficiency. Water efficiency measures allow better use of water resources. Given the significant amount of energy required to extract, convey, and treat water, water efficiency also saves energy. Moreover, energy savings represent fewer emissions into the atmosphere and less resource usage for more energy generation or other activities.

The Watershed Approach. A significant part of possible capital investments required for water treatment can be avoided by taking a watershed approach, where water quality is protected from the source. Instead of investing heavily in treatment systems, it is preferable and more sustainable to avoid water pollution in the first place, so that only a lighter and cheaper treatment is required.

The four pillars are keys for improved water and wastewater system sustainability. The transportation sector also has a set of sustainability pillars.

6.1.1 Sustainability Definitions

Table 6-1 contains a compilation of some of the most important definitions of Sustainability and Sustainable Development (Umapathy, 2011).

Table 6-1. Sustainability Definitions.

Organization	Definitions of Sustainability	Description of Organization
National Environmental Policy Act (NEPA) 1970	The creation and maintenance of conditions under which humans and nature "can exist in productive harmony, and fulfill the social, economic and other requirements of *present and future generations of Americans"*	EPA's mission is to protect human health and the environment.
Brundtland Commission, UN 1987	Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.	To address growing concern "about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development."
The Johannesburg Declaration 2002	A collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development – economic development, social development and environmental protection – at local, national, regional and global levels."	The Johannesburg Declaration builds on earlier declarations made at the United Nations Conference on the Human Environment at Stockholm in 1972, and the Earth Summit in Rio de Janeiro in 1992.
IUCN - The World Conservation Union, UNEP - United Nations Environment Programme, WWF - World Wide Fund for Nature 1991	Improving the quality of human life while living within the carrying capacity of supporting eco-systems."	All these organizations focus on protecting the eco-system.
Interfaith Center on Corporate Responsibility (ICCR)	"Sustainable development...[is] the process of building equitable, productive and participatory structures to increase the economic empowerment of communities and their surrounding regions.	ICCR seeks a global community built on justice and sustainability through transformation of the corporate world by integrating social values into corporate and investor actions. We invite you to join us in our mission.
World Business Council	"Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Companies aiming for sustainability need to perform not against a single, financial bottom line but against the TBL."	It is a global association of some 200 international companies dealing exclusively with business and sustainable development.

Organization	Definitions of Sustainability	Description of Organization
Thomas Jefferson Planning District Commission, Sustainability Council	"Sustainability may be described as our responsibility to proceed in a way that will sustain life that will allow our children, grandchildren and great-grandchildren to live comfortably in a friendly, clean, and healthy world. that people: o Take responsibility for life in all its forms as well as respect human work and aspirations; o Respect individual rights and community responsibilities; o Recognize social, environmental, economic, and political systems to be inter-dependent; o Weigh costs and benefits of decisions fully, including long-term costs and benefits to future generations; o Acknowledge that resources are finite and that there are limits to growth; o Assume control of their destinies; o Recognize that our ability to see the needs of the future is limited, and any attempt to define sustainability should remain as open and flexible as possible."	The purpose of the Planning District Commissions is to encourage and facilitate regional solutions to problems of area-wide significance. This cooperation recognizes regional opportunities and the importance of regional influences in planning and implementing public policies and services.
American Society of Civil Engineers	A set of environmental, economic and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or the availability of natural, economic and social resources.	The American Society of Civil Engineers (ASCE) represents more than 140,000 members of the civil engineering profession worldwide and is America's oldest national engineering society.
FHWA	It relates primarily to achieving a satisfying life for all while staying within the limits of nature. To achieve sustainability, we need to balance the basic conflict between the two competing goals of ensuring an acceptable quality of life (QOL) and living within the limits of nature. If either of these elements is not achieved, we will fail in our efforts to reach sustainability.	FHWA is a division of the United States Department of Transportation that specializes in highway transportation. The agency's major activities are grouped into two "programs," the Federal-aid Highway Program and the Federal Lands Highway Program.

6.1.2 The Water – Energy – Climate Nexus

Significant gains on infrastructure sustainability can be achieved by addressing the interdependencies existing among different systems. Infrastructure systems are not isolated; they all function integrated into a higher level meta-system or "system of systems." Cities are examples of such meta-systems. An important consequence of the interdependency of infrastructure systems is that sustainable development needs to be achieved at the meta-system level. Not only does each infrastructure system needs to be sustainable, but the meta-system itself, which includes the individual systems and their relationships, needs to as well.

One of the most pressing interdependencies is the one between water and energy. The water sector infrastructure is highly dependent on power generation, while power generation plants require significant amounts of water to produce energy (USDOE, 2006). As a result, regions with water scarcity also struggle to produce enough power to sustain economic development and quality of life, which compounds the water problem. Limited water resources need to be allocated among competing needs, including power generation, agriculture, potable water, and others (Figure 6-2).

Given the drought patterns observed in some regions, a possible solution to water scarcity is desalination. Desalination is currently energy intensive, while some major cities are not close to shores. For these reasons, the cost of providing safe drinking water to the population is expected to increase, while the water-energy nexus will continue as a significant interdependency.

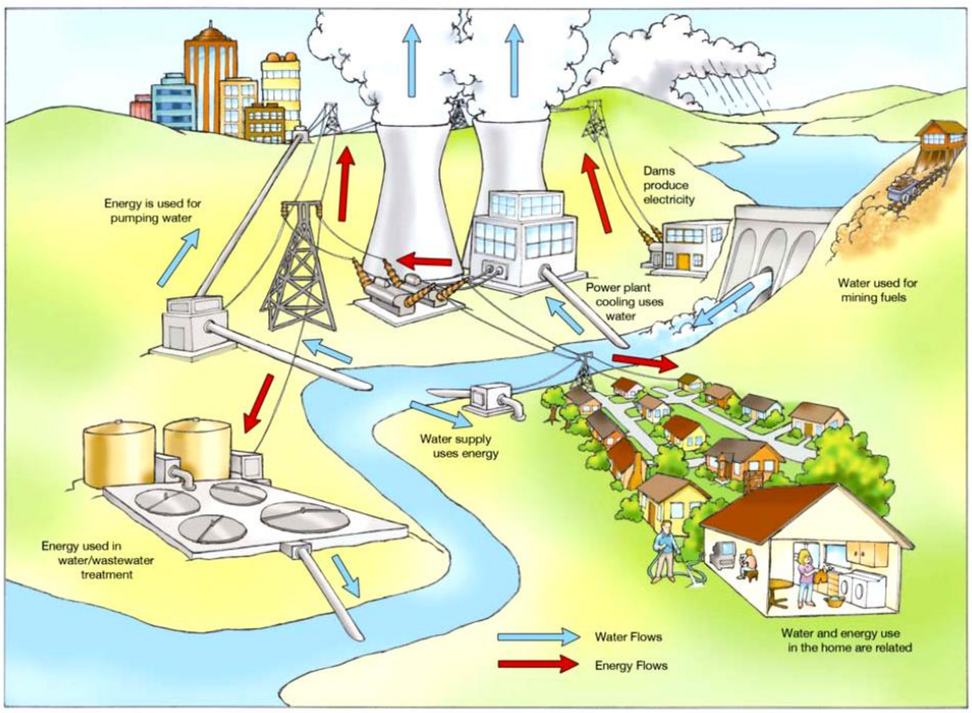


Figure 6-2. Examples of Water-Energy Nexus.
(USDOE, 2006)

Figure 6-2 represents some examples of the water-energy nexus. Sustainability of the water and the energy sector are tightly interlinked, and water shortages are expected in many states across the U.S. (Figure 6-3). A water shortage is defined by the ratio of freshwater withdrawal to available precipitation

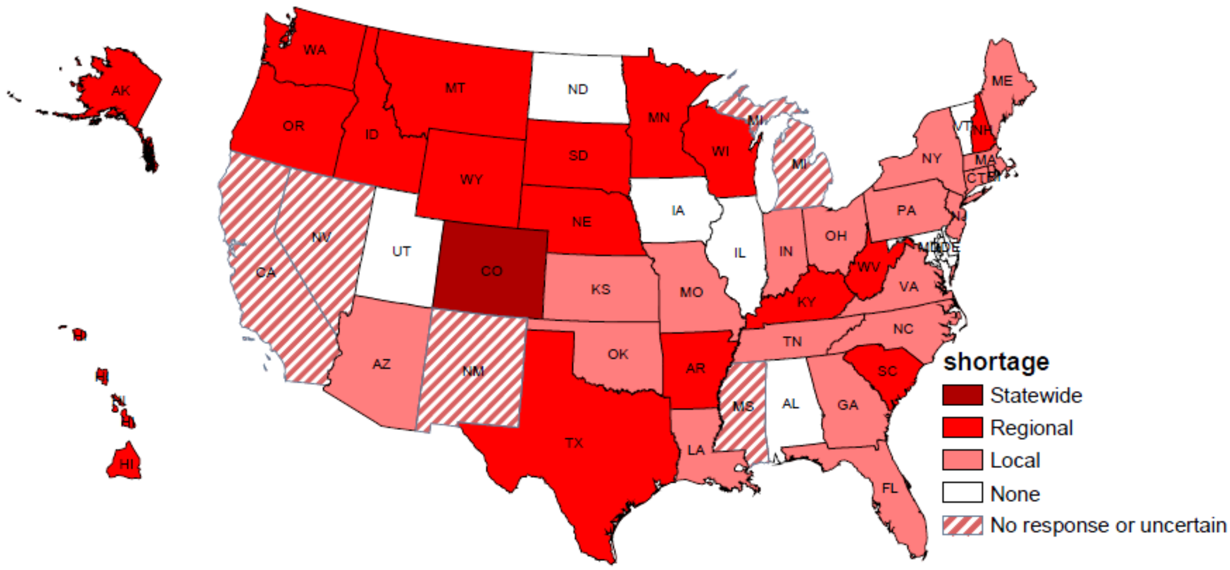


Figure 6-3. Likely Water Shortages This Decade in the U.S.
(USDOE, 2006)

To investigate and examine the water-energy-climate change nexus, there are the following most pressing issues:

Understanding Water-Environment-Climate Equilibrium

This natural cycle has a dynamic equilibrium, in which the status of the system is always changing, but at pseudo equilibrium conditions. Severe disruptions of water quality and quantity can impact the system through feedback loops, often with unpleasant or even devastating consequences (Brule and McCormick, 2005). Fundamental research is needed to understand this complex interaction.

Understanding Energy-Environment-Climate Relationship

This relationship is important because energy generation and use are the predominant man-made sources of gas emissions. Fundamental research is needed on how to reduce gas emissions that may cause climate change and on how to adapt to carbon-constrained environments and a more active climate.

Understanding Energy-Water Linkage

Water and energy have much in common – each is an essential input for productive, comfortable, and healthy human societies (USAID). There has been a steady decline in the state of our water and energy infrastructure over the past two decades and there is a growing realization that these facilities may be inadequate for current requirements or projected future growth (Wilkinson, 2000, 2007).

Understanding Water-Energy-Ecological-Carbon Footprint

The energy-water-environment-climate link makes it imperative to consider the water footprints in energy production, as well as the energy footprints for water development. The ecosystem and carbon footprints affect our climate and water. The basic premise is that mitigation measures may have serious water resources implications, expressed in the form of water footprints, and conversely water development may leave serious energy footprints (U.N. High Level Panel on Global Sustainability, 2012).

Understanding Water-Energy-Environment-Climate

It is critical to understand the complexity of the entire system holistically, in order to be able to improve the sustainability and resiliency of water-energy infrastructure. The strong interdependency between energy, water, environment, and climate change makes it imperative that policy formulation be coordinated, particularly with respect to mitigation and adaptation to climate change effects. Traditionally, energy and water policies are developed within each sector with little coordination and no global consideration.

Development of Sustainable and Resilient Systems

While there is increased concern about the sustainability and resiliency of energy and water systems, very few concrete actions have been taken (Ashley et al., 2008). Although the TBL or other approaches provide a framework, numerous obstacles must be overcome to bring these visions to reality. The NTSC Committee on Environment and Natural Resources issued a Grand Challenge that mandates to "recognize and reduce vulnerability of critical infrastructures" by using integrated models of interdependent systems, so that vulnerabilities can be identified and addressed for sustainability.

Development of Potential Mitigation and Adaptation Strategies

Over the past decade or more, the national and international focus has predominantly been on strategies to reduce gas emissions. In the international negotiations on climate change, there has been an unwillingness to devote serious attention to mitigation and adaptation strategies. Adaptation options for urban water and dams could include systematic inclusion of climate risk – on both the supply and demand side – in all catchments. Adaptation options for energy could include a program studying energy systems' sensitivity to climate events – in particular severe weather events – as an additional risk factor to those already facing the system.

Sustainability considerations are already integrated into various methodologies for prioritization of renewal projects in water and wastewater utilities. For example, the TBL approach is used by some utilities to determine which maintenance, repair, rehabilitation, or replacement projects have priority, as well as capital investments.

Different rating systems for measuring building "sustainability" have been developed worldwide. Table 6-2 contains some of the most important rating systems (Umapathy, 2011)

Table 6-2. Sustainability Rating Systems for Buildings Worldwide.

Building Rating systems	Energy	Water	Site	Indoor Environment	Management	Material	Emissions	Health
BREEAM (UK)	✓	✓	✓	✓	✓	✓	✓	✓
LEED(US)	✓	✓	✓	✓	✓	✓	✓	
CASBEE(JPN)	✓	✓	✓	✓	✓	✓	✓	
Green Globes(US/CAN)	✓	✓	✓	✓	✓		✓	
SBTool(CAN)	✓	✓	✓	✓	✓		✓	
Green Mark(CAN)	✓	✓		✓				
ESGB(PRC)	✓	✓	✓	✓	✓	✓		
GRIHA(IND)	✓	✓	✓		✓			
ICC 700(US)	✓	✓	✓	✓	✓	✓	✓	
BASIX(AUS)	✓	✓		✓			✓	
NABEERS(AUS)	✓	✓		✓				
NatHERS(AUS)	✓		✓	✓		✓		
Green Star(NZ)	✓	✓		✓	✓	✓		
PromisE(FIN)	✓	✓					✓	✓
HQE(FRA)	✓	✓	✓	✓	✓	✓	✓	✓
HKBEAM(HK)	✓	✓	✓	✓		✓		

The columns in Table 6-2 indicate key factors included in any given rating system. Energy and Water use are of utmost importance. In the case of the U.S., the leading rating system is Leadership in Engineering and Environmental Design (LEED) from the U.S. Green Building Council (USGBC). According to LEED, a green building is defined by a series of attributes (Figure 6-4). Another relevant rating system is “Envision,” by the Institute for Sustainable Infrastructure (ISI).

The Water-Energy-Climate nexus is important because infrastructure systems are increasingly interconnected and interdependent, and together they constitute infrastructure meta-systems that generate significant impacts on the environment, including the climate. As a feedback loop, climate changes impact infrastructure. In the case of water and wastewater utilities, climate impacts include drought, storm events causing combined sewer overflows (CSO), sanitary sewer overflows (SSO), flooding, and potentially compromised water quality at the watershed level.

According to the USGBC, different topics that must be considered in order to label a building as “green” are represented in Figure 6-4.

Figure 6-4. Green Building as Defined by LEED.

Despite the benefits of rating systems for buildings, some caution is necessary. A green building is not necessarily a sustainable building. Although a "green building" is expected to have reduced impacts on the natural environment, expanding the constructed land may actually reduce overall sustainability. Sustainability is a significantly deeper concept than mere "greenness."

6.1.3 Sustainability Implementation

As it was explained in the AM section, the WATER*i*D research team produced approximately 300 case studies on diverse AM topics with information obtained directly and individually from participant water and wastewater utilities in the U.S. and abroad. From this experience, it is also possible to summarize some general observations regarding the state of practicing sustainability in the participating utilities.

Most utilities are aware of the importance of sustainability. Since sustainability arose as a fundamental consideration for future social and economic development, significant advances in public education have been made. Currently, every utility has a fair understanding of sustainability, and this knowledge is reflected in how frequency those concerns are included in business decisions. Most water and wastewater utilities that are part of WATER*i*D include sustainability considerations in their decision-making processes, with varying degrees of sophistication.

Sustainability in the water sector has a predominantly financial meaning. Among participant water and wastewater utilities, sustainability is mainly about business financial viability. Even when economic considerations are a key part of the theoretical background of sustainability, there are other equally important factors such as social and environmental aspects. In a few of the participant utility cases, environmental sustainability is seen mostly as a compliance-oriented task. Despite this, most utilities have good understanding and strong commitment to sustainability.

Some utilities use a TBL approach as part of their project evaluation. The TBL sustainability framework considers that there are three basic areas required to measure sustainability efforts: economic, social, and environmental. Some of the participant utilities, mostly (but not only) the largest ones, have established procedures in place to evaluate their projects using a TBL approach. TBL was observed to be widespread among participant water and wastewater utilities.

6.2 Gap Assessment

Comparing the theoretical background on sustainability with the state of the practice observed in participating utilities, a few key gaps have been identified. This is not intended as a comprehensive list of sustainability gaps for the U.S. water sector. Since the number of participant utilities has no statistical significance when compared with the thousands of water and wastewater utilities in the U.S., these gaps are not to be generalized or utilized to draw nationwide conclusions. However, the research team considers that these gaps capture key elements of the sustainability experiences and practices in the participant utilities.

Sustainability applications tend to be narrow. The application and use of sustainability concepts and methods in some of the participant utilities tend to be narrow, focusing strongly on financial aspects in detriment to other types of considerations. The financial aspects are important because they are the basis for constructing a strong business case for sustainability measures, enabling support from customers, regulators, and other agents. Advancement of sustainable practices and the achievement of sustainable development require a holistic view of sustainability across all utility processes. It is also important to distinguish between green initiatives and true sustainability.

There are other methods besides TBL. The TBL approach is probably the most used method for considering sustainability in business decisions in the participant utilities. Although the TBL approach is useful and certainly advances sustainability, an associated risk is that TBL may become more of a checklist than a comprehensive approach for integrating sustainability considerations into project evaluation protocols. Achieving sustainability requires consideration of a variety of processes across the utility, and searching for sustainable practices beyond compliance levels.

6.3 Conclusions and Recommendations

The recommendations for advancing sustainability in water and wastewater utilities include the following statements:

Encourage utilities to search for other sustainability enhancing actions. Each utility is unique. Therefore, each utility may be able to implement sustainability enhancing actions that cannot be prescribed for all. In other words, although TBL or other sustainability assessment methods can provide general guidelines, each utility can identify possible sustainable practices beyond compliance. Some options might be inexpensive or support the utility's business case for sustainability. This recommendation rests on the following one.

Strengthen the education and training efforts on sustainability. Sustainability training for water and wastewater utilities can address two main parts. One is the more practical part, focused mostly on compliance issues regarding sustainability methods and tools. The other part is directed toward promoting organizational flexibility and creativity towards identification and implementation of sustainable practices across the utility. It is also important to clarify the differences between eco-friendly or "green" activities (which are an important part of sustainability) and sustainability itself. Green practices by themselves do not guarantee sustainability.

CHAPTER 7.0

RESILIENCY MANAGEMENT

7.1 Resilience of Infrastructure Systems

Civil infrastructure systems are essential for sustaining our quality of life. Therefore, ensuring near continuous performance of infrastructure systems is critical. Such a continuous performance is the promise of infrastructure resilience.

In general, resilience is the ability to recover from disruption. Resilience is closely related to sustainability. A sustainable system or process is necessarily resilient, although not every resilient system or process is sustainable. As a consequence of this asymmetry, while sustainable development is desirable as a societal objective, resilient development may or may not be desirable. Currently, there are many examples of undesirable processes that are very resilient, such as the widespread human reliance on finite fossil fuel resources or high unemployment.

Resilience can be conceptualized as an outcome or as a process. Resilience as an outcome is mostly observed in engineering applications, where a system is expected to recover a defined pre-disruption performance level after a failure. Resilience as a process is observed in social or ecosystem contexts, where the post-disruption state can be different than the pre-disruption state, but the whole recovery process is resilient.

Applied to civil infrastructure systems, resilience is the ability of a system to minimize loss of performance in case of disruption, and to recover within acceptable time and cost limits. Resilience is mostly defined by the recovery characteristics of the system after disruption. Nevertheless, the pre-disruption phase is important for achieving adequate emergency preparation because a well prepared system is more likely to be resilient than an unprepared one.

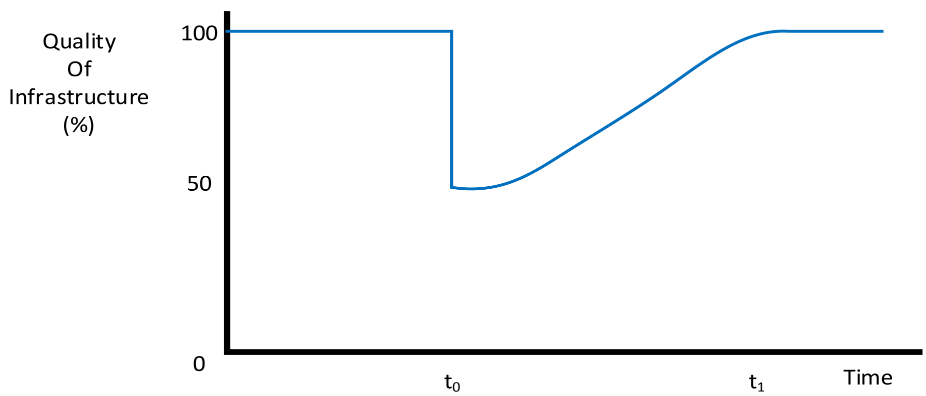


Figure 7-1. Quality of Infrastructure Performance.

Figure 7-1 represents an early resilience curve, which illustrates the loss of infrastructural services from an unforeseen disruption, and the recovery period afterwards. The vertical axis represents “Quality of infrastructure” in percentage. Quality of infrastructure can be measured in terms of LoS, system performance, or other metrics.

The horizontal axis represents time in Figure 7-1, and it is assumed that the quality of infrastructure is constant until a disruption happens at time t_0. The system recovers from t_0 to t_1. Due to the disruptive event, the quality of infrastructure drops significantly and then bounces back after a given period of time.

Disruptive events can be natural or man-made. Examples of natural disruptive events are hurricane, flood, earthquake, blizzard, or tornado. Man-made disruptions can be further classified into deliberate attack or accidental.

Disruptive events may also have different time domains. For example, while damage caused by an earthquake may take only some minutes to occur, slow occurring processes such as drought or system aging deteriorate infrastructure performance over long periods of time.

Currently, given that the term “Quality of Infrastructure” is rather vague, it is more common to use a performance-based functionality curve (Bruneau et al., 2003; Cimellaro et al., 2006), sometimes also known as a resilience triangle (Zobel, 2010). Functionality curves evolved from the “Quality of Infrastructure” curve.

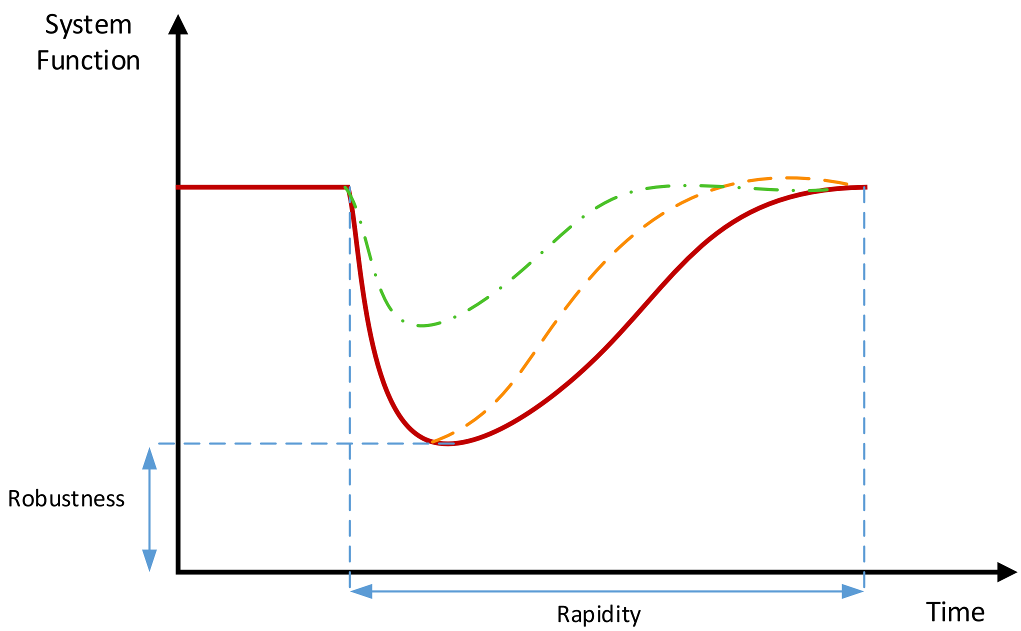


Figure 7-2. Functionality Curve.

The functionality curve shown in Figure 7-2 has a vertical axis that represents system performance. In the case of a water infrastructure system, such performance can be measured in diverse ways, like quantity of water delivered, water treated, or water quality standards met. The horizontal axis represents time. The first section of the curve is a horizontal line because that is the assumed pre-disruption performance level. When a disruption occurs, system performance falls to the lowest point in the curve. In some cases, the residual performance is associated with system robustness as shown in Figure 7-2. After disruption, the curve recovers the original performance level in certain time. Figure 7-2 also shows that mitigation measures (preparedness) are expected to reduce performance loss (and therefore, increase system robustness). Adaptation measures do not reduce the impact of disruption, but reduce the required recovery time.

7.1.1 The R4 Framework

One of the most frequently used resilience frameworks was developed in the Multidisciplinary Center for Extreme Event Research (MCEER). The framework is known as the R4 (Chang and Shinozuka, 2004; Cimellaro et al., 2007; MCEER, 2005). According to the R4 framework, a resilient system has four attributes:

1. **Robustness.** The system capacity to withstand damage without catastrophic loss of performance. For example, stringent building codes contribute to enhance the robustness of buildings against earthquakes.
2. **Redundancy.** The availability of alternate resources and assets to quickly substitute those that have been damaged. For example, in a looped water system the pipes have significant redundancy, and a break in a pipeline will not usually impact system performance in the short term.
3. **Resourcefulness.** Refers to the ability of the system to adapt to changing conditions making use of the available resources, a form of ingenuity. It also refers to the stock of resources available for responding to unforeseen circumstances or disruptive events.
4. **Rapidity**. The rate at which recovery occurs. A well-prepared system with enough resources is expected to recover quickly. Rapidity can be interpreted as the slope of the recovery section of the functionality curve in Figure 7-2.

The R4 framework also takes into consideration that civil infrastructure systems have four dimensions: technical, organizational, social, and economical. The R4 framework is very clear and had a significant influence over the development of the concept of infrastructure resilience. However, it is a challenging framework to develop into practical applications of resilience for infrastructure systems.

7.1.2 An Economic Framework

The functionality curve shown in Figure 7-2 does not take into account explicitly the costs of resilience. Two systems may recover at the same time and appear to be equally resilient, but probably one will require significantly more economic resources for recovery than the other.

There is an economic measure of resilience that considers two curves instead of one. The first curve is a functionality curve (Figure 7-2) in this case called “systemic impact.” The other curve is known as “restoration effort” (Vugrin et al., 2010). The restoration effort curve measures the economic resources required for recovery. From two systems that recover at the same rate, the one requiring fewer resources is considered more resilient. A restoration effort curve is shown in Figure 7-3.

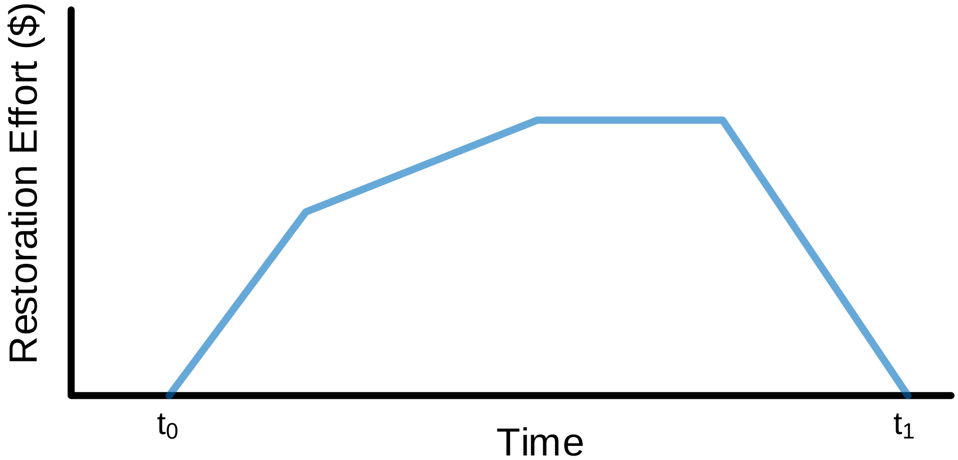


Figure 7-3. Restoration Effort Curve.

In Figure 7-3 the total resources utilized for system recovery (effort) are represented by the area under the curve. This curve is important because infrastructure resilience is not only about system recovery time. Given the always present economic resource constraints, resources required to achieve a proper system recovery are an essential consideration for defining a resilient infrastructure.

7.1.3 Why Resilience is Important

Many of the components of infrastructure resilience are not new. For example, emergency preparedness, disruptive events, emergency response, restoration, and recovery alternatives have been practiced for decades as a part of disaster management and other disciplines. Infrastructure system reliability and vulnerability assessments are conducted on critical infrastructure systems without reference to resilience. However, the integration of those components into a resilience framework allows more complete and holistic methodology.

The concept of infrastructure resilience is mostly a result of the current world conditions, and is a response to augmented risks. Higher risk of infrastructure failure can be explained using the traditional risk factors: PoF and CoF. The PoF of infrastructure systems has significantly increased. Civil infrastructures built 50 or 100 years ago are aging and nearing the end of their design service lives. Some systems already exceeded their service life, but they are being sustained with extensive rehabilitation and replacement programs. Natural events such as hurricanes, severe thunderstorms, blizzards, and tornadoes are unpredictable and can vary in frequency from year to year. Additionally, the risk of terrorism was evident after 9/11. All these factors contribute to create a more hazardous environment for communities and their supporting infrastructure. The consequences of infrastructure failure have increased as well. The tight interdependency and dependency relationships of infrastructure systems make the whole urban system vulnerable to escalating or cascading failure. If an infrastructure system fails, many other systems down the line may fail as well. In addition, the population size dependent on such infrastructures is growing due to the ongoing worldwide urbanization trend. Higher risk of infrastructure failure caused existing approaches for emergency preparedness and infrastructure protection to be insufficient. The concept of resilience has been applied in many different fields to study the recovery capacity of systems. Infrastructure resilience is a promising approach for quickly and efficiently recovering lost infrastructure performance.

There are some specific advances towards an applicable methodology for taking advantage of the concept of infrastructure resilience. Although mostly an academic term, resilience can be used to enhance utility AM. A first step is resilience measurement. Assessing the resilience of a system would allow a utility to enhance its emergency preparedness in a cost effective way. Coupled with vulnerability analyses, resilience assessment can contribute to achieving shorter recovery times while minimizing negative impacts to service area customers.

A resilience assessment methodology is under development that can provide water utilities with pre-disruption information about their ability to efficiently recover performance lost. Such knowledge provides opportunities for strengthening identified weaknesses in the system and improving emergency preparedness.

The resilience assessment methodology is based on stochastic simulation. The performance metric is system serviceability in terms of the water quantity delivered to demand nodes. Utilizing this performance metric, three resilience parameters of the system are estimated for each one of a set of possible failure scenarios: Damaged system performance, recovery time, and recovery cost. These parameters are finally compared with certain acceptable limit values for them, in order to estimate the system's degree of resiliency.

A set of failure scenarios is randomly generated. Each scenario is a combination of asset failures in the network. For example, if some pipes and a pump fail simultaneously, this constitutes a scenario; if a tank fails, that is another scenario, and so on. Since water infrastructure networks have a significant number of assets, there are many more possible failure scenarios than it is practical to analyze. Figure 7-4 provides a conceptual model for this methodology.

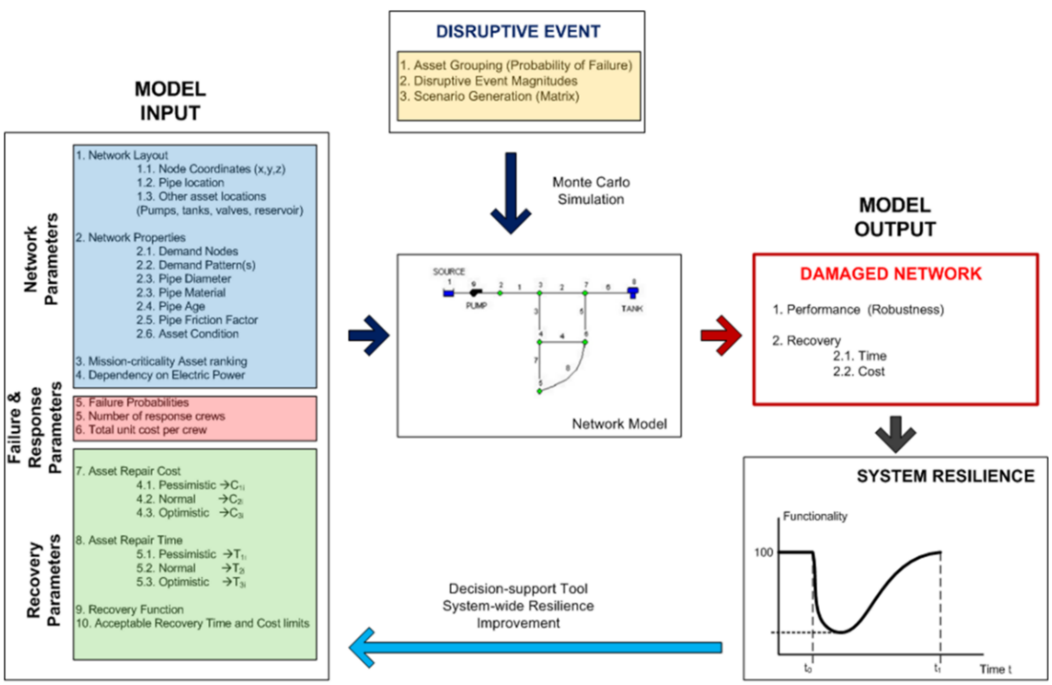


Figure 7-4. Conceptual Model for ERASMUS.

A network model of the real system is assembled (Figure 7-4, center) and subject to many failure scenarios (disruptive events). Information on the damaged network is recorded (right side) and aggregated for obtaining information on the system resilience. The process is repeated multiple times (1,500 scenarios for WDN-1, and 3,000 scenarios for WDN-2) to achieve enough information for statistical analysis.

Limits for acceptable damaged system performance, recovery time, and recovery cost are necessary in order to estimate the degree of resiliency of a water network. Without limits, every system could be considered resilient, independently of how much time or money is required for recovery.

This methodology was applied to two water distribution networks for piloting. The first one (WDN-1) had approx. 2,800 assets, and the second (WDN-2) had 10,200 assets. Resilience assessments were performed for flash flooding and earthquake, respectively. The results of these analyses indicated that WDN-1 has an expected post-disruption performance of 0.905, while WDN-2 had 0.55. This means that, in case of flooding, WDN-1 is expected in general to be able to deliver 90% of the normal water volume. For WDN-2 under earthquake, the expected system performance is 55% on average.

The methodology is called Effective Resilience Assessment Methodology for Water Utilities (ERASMUS) developed at Virginia Tech. Although the methodology and its associated computerized tool are in an early development stage, they provide a promising approach for integrating more practical resilience measures into current AM frameworks.

7.2 Gap Assessment

Infrastructure resilience is a relatively new term, and therefore the practice of resilience is not expected to be abundant. However, there are some practices in participating utilities that can increase system resilience. The main findings of the research team regarding practice of resilience are as follows:

The concept of infrastructure resilience is spreading, but remains a highly academic topic. Resilience is still an alien term for most participating water and wastewater utilities. Most utilities know what resilience is about, but are perceived as a mostly academic exercise. Such perception is not entirely wrong; Infrastructure resilience is still significantly undeveloped in terms of practical applications, methodologies, and tools.

Resilience is known mostly because of the Department of Homeland Security (DHS). The National Infrastructure Protection Plan (NIPP) uses a dual-protection and resilience approach for critical infrastructure (DHS, 2009). The U.S. EPA oversees the advancement of security and resilience measures in the water sector and it is also promoting the concept.

7.3 Conclusions and Recommendations

Since infrastructure resilience is a novel concept and practical applications are still being developed, there is a significant amount of work to do with the utilities in this area. In fact, most resilience practices are lacking for obvious reasons. The main gaps identified are:

More information is needed regarding the importance and methods of resilience. As an emerging concept, resilience is not fully known by the participant utilities. Although most of them have heard about it, few actually know more. An effort is required from academia to give resilience practical meaning, and from public officials to educate the owners and operators of infrastructure systems.

Infrastructure resilience integration with IAM frameworks. Resilience is generally perceived as something separate from AM, even though it is not. The objective of AM is to sustain cost-effective system performance, and this objective can be maintained either under normal or disruptive event conditions. If done during exceptional disrupted conditions, may be called Resilience.

Practical tools for resilience need to be developed. There is a real lack of practical methodologies and tools for the practice of resilience in infrastructure systems. A renewed effort for the operationalization of resilience concepts is required, including their linkages to the better known AM practices.

The recommendations for advancing infrastructure resilience are directly related with the gaps described in the previous section. Key recommendations are:

To develop an educational program directed to water and wastewater utilities on infrastructure resilience. Educational and training programs are required to promote resilience awareness, as well as for establishing outreach efforts for spreading practical methodologies and tools for system resilience. The U.S. DHS has developed a series of web seminars and other events to promote resilience. Additionally, WERF's extensive project, *Water/Wastewater Utilities and Extreme Climate and Weather Events* (Project No. CC7C11), gathered and synthesized resiliency practices in six communities. However, more educational and outreach events are required.

To integrate infrastructure resilience as an essential part of risk management in IAM, to bring the topic to the mainstream. Water and wastewater utilities are familiar with risk management processes and methods. Linking resilience with risk management may contribute to disseminate the concepts and translate resilience into a more familiar environment.

Continue developing research projects on achieving infrastructure resilience. Research is an essential requirement for advancing resilience concepts and their application to infrastructure systems. Infrastructure resilience as an academic discipline is in its infancy.

CHAPTER 8.0

HOLISTIC INFRASTRUCTURE ASSET MANAGEMENT

In their Report card for America's Infrastructure 2013 (ASCE, 2013), the American Society of Civil Engineers assigned a grade of D for both drinking water and wastewater infrastructure systems. The overall "GPA" of America's infrastructure is D. An estimated investment of USD 2.2 trillion is required over a period of five years to significantly improve these grades. Given the importance of civil infrastructure systems for sustaining quality of life, ASCE grades are concerning, and the required investment for improving infrastructure systems is only expected to rise as time runs out.

Advanced AM is improving the condition, financial situation, and sustainability of civil infrastructure systems worldwide. Although IAM alone is not the solution to deteriorating infrastructure, the responsible and comprehensive management of infrastructure systems has positive impacts and contributes significantly to sustain and improve system condition and performance. IAM is constantly undergoing continuous improvements and upgrades.

Sustainability is by definition addressed in AM frameworks, a significant advance compared with decision-making processes used decades or even years ago. However, in practice the application of sustainability-based decision-making tools still face challenges. For example, most sustainability assessments tend to consist mostly on checklists, and opportunities to tap on unique increased sustainability features of particular infrastructure systems are frequently unknown or ignored.

Infrastructure resilience is almost non-existent in current AM frameworks, mostly because it is still a predominantly academic field. The need for addressing infrastructure resilience may not be clear enough for water and wastewater utilities yet. At a first glance, it may seem like risk management strategies, emergency response plans, and the vulnerability analysis periodically required by U.S. EPA, already cover all aspects of infrastructure resilience and therefore the field is redundant. Nevertheless, that is not the case. Risk management strategies are mainly used for prioritization of infrastructure maintenance and renewal, not for considering a possible system-wide disruption scenario. Vulnerability analyses are designed to detect system weaknesses, but do not provide strategies for coping with a disrupted system. Emergency response plans tend to have a narrow focus and disruptive events rarely develop as expected.

Infrastructure resilience is required to link with IAM because it addresses the possibility of system-wide disruption, and has a broad scope integrating vulnerability, reliability, preparedness, and recovery strategies. A resilient system would be able to recover full performance faster and at a lower cost than a non-resilient system. Given the tight interdependencies among civil infrastructure systems constituting the urban meta-system, a resilient system will also enable the resilience of dependent infrastructures and thus increase resilience of the whole community. AM and resilience are both concerned with sustaining infrastructure performance.

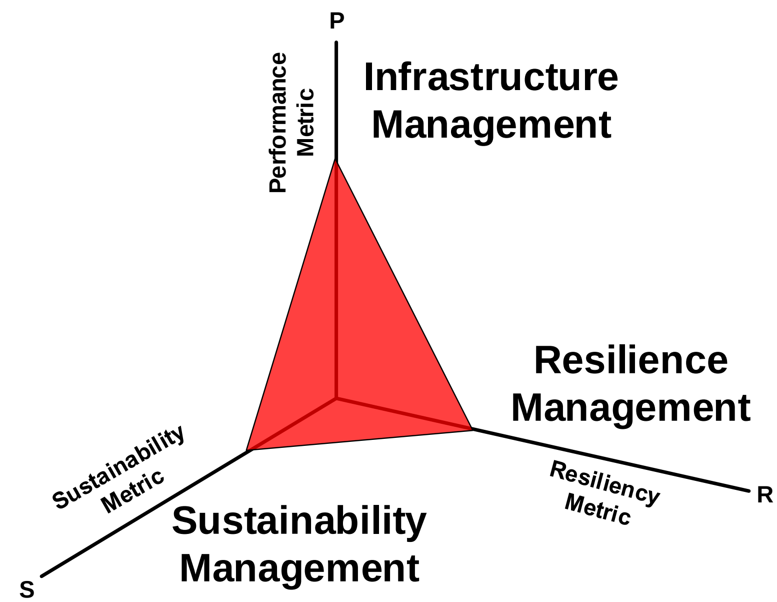


Figure 8-1. Integration of Performance, Sustainability, and Resiliency Management.

Figure 8-1 represents the integration of performance, sustainability, and resiliency managements into a holistic approach. Owners and operators of an infrastructure system make decisions on long-term system performance through the design and implementation of AM. However, such performance is interrelated with sustainability and resiliency aspects, because in addition to having an acceptable performance, an infrastructure system has to operate sustainably and be resilient.

This document is an important step towards higher integration of sustainability and resilience with current IAM frameworks. Methodologies and tools developed for infrastructure sustainability and resilience need to be practical in scope and application to integrate into an AM framework, IAM has to evolve to integrate with sustainability and resiliency management of infrastructure systems.

Resilience of infrastructure systems implies an advanced risk management process. In addition, ensuring proper system performance and sustained LoS even in the face of disruptive events relates to a goal of AM of sustaining cost effective system performance. However, emerging research in the area of tolerable risk can help determine what level of risk is acceptable to the utility and its stakeholders.

Entire infrastructure systems are rarely decommissioned. Their service life may continue indefinitely, in a cycle of deterioration-renewal and disruption-recovery processes. Infrastructure assets are maintained, repaired, rehabilitated, and eventually replaced, with the system itself being operated into the future.

CHAPTER 9.0

MANAGEMENT CASE STUDIES

This chapter presents extracts of some case studies contained in the WATER*i*D database, which illustrate the main topics covered in this infrastructure management primer. For the complete case studies, please refer to the WATER*i*D website.

9.1 Case Study on AM

In addition to exploring the AMP development process, this case study provides tips for approaching the task of elaborating an AMP for each significant system asset.

9.1.1 Portland Water Bureau (PWB) Case Study Summary

PWB provides drinking water to the Portland, OR region producing more than 100 million gallons per day of finished water mainly from the Bull Run watershed. IAM practices can contribute significantly to the achievement of strategic goals of PWB. An AMP is being developed for each asset in the system. In order to facilitate the development of AMPs and maximize their benefits to the utility, PWB developed a guidance document for elaborating such AMPs. The guidance document provides step-by-step recommendations and many examples in developing AMPs.

9.1.2 Key Program Features

The PWB guidelines for developing AMPs include key features such as:

- A step-by-step process for developing AMPs for every type of asset within PWB system.
- Additional supporting information for developing the AMP. Such information includes resources within PWB such as databases and reports as well as examples on how other utilities approach challenging issues.
- Contains many examples on each step of the AMP development. Those examples are useful for visualizing key aspects on each step of the AMP development process.

In order to maximize the benefits from AM, it is necessary to coordinate and align all business units, and develop a consistent approach to AM planning. The PWB guidelines for developing AMPs provide an integrated and comprehensive framework for implementing such utility-wide AM. In addition, those guidelines enable future improvements of the AM system in the PWB.

9.2 Case Studies on Multi-Sector AM

Multi-sector AM enables the integration of AM features from different governmental agencies and business units into an integrated approach. For example, a municipality may want to align and integrate all of its AM programs across departments. Utilizing multi-sector AM, a municipality can implement a single AM framework for transportation, utilities, and other departments. Implementing multi-sector AM may provide significant benefits in terms of data interoperability, scale economies, and consistent decision making.

9.2.1 Calgary, Alberta Case Study Summary

The City of Calgary is the largest city in the province of Alberta, Canada. It had a population of 1,019,942 inhabitants as of 2007. Population growth is down from 55,000 persons per year to 35,000 in the past few years. The main economic activities are those related with oil and gas industries.

In 1999, the city recognized addressing its infrastructure needs, including the addition of new assets and the improvement of the existing systems. A Corporate Asset Management (CAM) group was constituted and formalized in 2004 within the infrastructure services group. The CAM team responsibilities include the following:

- Develop the City's CAM strategy.
- Prepare annual Infrastructure Status Reports (ISR's).
- Assist business units with implementing AM principles.
- Help develop business unit's AM plans.
- Develop and implement a city-wide AMP.

One significant feature of the Calgary's CAM group is that it is independent from the Finance Department. Such independence allows CAM team to have a broader view of AM, beyond a purely accountancy perspective, and interact more freely with different business units and stakeholders. The CAM has a multi-sector scope, integrating water and wastewater services, roads, and information technology into an integrated approach for AM.

Benefits obtained by the City of Calgary from the application of a multi-sector AM approach through CAM include the following:

- Improved decision making. Information coming from AM practices supports better resource allocation and project prioritization.
- Better justification of capital and maintenance expenses to the public.
- Increasing confidence in the information provided by the AM Plan.
- Financial savings on capital investment and system repairs.

The annual ISR is aligned with the National Research Council of Canada's recommendation for every municipality in terms of being able to answer the following six key questions:

- What do we own?
- What it is worth?
- What is its remaining service life?
- What condition is it in?
- What do we spend and what should we spend?
- What is the gap?

9.2.2 Hamilton, Ontario Case Study Summary

The city of Hamilton has an approximate population of 500,000 inhabitants. Located between Buffalo, NY and Toronto, ON, the city resulted from the amalgamation of Hamilton-Wentworth and six other municipalities into one single city in the year 2000: Hamilton, Ancaster, Dundas, Flamborough, Glanbrook, and Stoney Creek. Although the city managers have been working with AM since 1998, the reorganization caused by amalgamation two years later brought renewed impetus for creating and funding an AM group.

The AM group has a multi-sector scope that includes roads, water, and wastewater systems. The AM group is managed by two senior staff. One is in charge of surface assets and finance, while the other is in charge of subsurface assets and information technology. The responsibilities of the AM group include:

- Condition assessment of city-wide surface and subsurface assets.
- Monitoring current levels of service.
- Monitoring life cycle trends and deterioration models.
- Developing a three- to five-year span detailed budget.
- Developing a 20-year long-range capital budget.
- Developing a 100-year financial forecast to predict the city's infrastructure investments.

The creation of the AM group addressed relevant concerns of the city managers, including: The need to move beyond the "silo mentality" of keeping different assets separate, and to promote an integrated approach to deal with the challenges of economic and geographic diversity that were joined through the amalgamation in 2000.

Information provided by the AM group allows them to maintain an adequate LoS at the lowest possible tax structure, while also addressing infrastructures' needs and required funding. In addition, AM helps the council make a business case for the required projects.

The AM group in Hamilton was very successful and soon they were attending many inquiries about AM from municipalities all over Canada. In the light of these consultations, Hamilton started the Canadian Network of Asset Managers (CNAM) with a board of 14 people representing seven major cities across Canada. CNAM has successfully run two sessions with participation of over 120 people from 30 municipalities across Canada. Other benefits from multi-sector AM for the city of Hamilton are:

- Staff can demonstrate to the city management and the public that resources are being used cost effectively (stewardship).
- The AM process and information has sped up the capital budget development process.
- The AM process has taught everybody to see the community as a whole and how the assets function together to deliver high-quality life.

9.2.3 Portland, Oregon Case Study Summary

Portland is the largest city in Oregon and the second largest city in the Pacific Northwest. Portland has 568,000 inhabitants over an area of 145 square miles, and its population is expected to increase by 1,000,000 people within 20-30 years. The city has been applying AM for many years (20+) in some sectors (transportation), while it is just beginning to apply it in other sectors such as water and wastewater (5+ years). Portland's AM programs now span transportation, water, wastewater, parks, affordable housing, civic facilities, parking garages, and sports venues.

Currently, all of these sectors apply different AM frameworks. They use common terminology and definitions, but different processes. The implementation effort for a city-wide multi-sector AM program is ongoing. The Bureau of Planning has generated annual reports since 2005 on the status and condition of physical infrastructure. These reports provide essential information to the city regarding current levels of service, and to ensure infrastructure is in good condition and maintenance programs are as effective and efficient as possible.

The annual reports include number of assets, condition, replacement value, current levels of service, cost of unmet needs, and BRE as defined by U.S. EPA's AM framework. These reports are intended as decision support for the city to ensure that infrastructure is in good condition and their performance is adequate. The reports also include confidence level data to reflect the quality of data presented. Portland is advancing towards an integrated AM framework based on New Zealand's *IIMM* (NAMS, 2011).

Although Portland is in the process of integrating a single city-wide AM framework, the efforts to achieve such integration and its previous experience with AM have taught Portland important lessons:

- Engage the support of top management to enable required decisions.
- Recognize the varied business needs of each sector.
- Allocate resources to collect and maintain reliable asset data.

Portland is committed to integrating all different AM frameworks into a single multi-sector city-wide AM process. Integration would have advantages such as a common terminology, standard procedures, and delivery of more efficient and cost-effective services. A city-wide report on the state of the assets is prepared every year.

9.3 Case Study on Risk Management

This case study provides an overview of guidelines for estimating BRE at two levels, basic and advanced. It also contains some policies for BRE estimation and application.

9.3.1 Washington Suburban Sanitary Commission (WSSC) Case Study Summary

The WSSC operates water and sewer systems in the Montgomery and Prince George counties of Maryland. Currently, WSSC owns more than 5,300 miles of pipe and has more than 434,000 customer accounts. Risk assessment is an important part of IAM for WSSC. In order to assess risks, WSSC uses the concept of BRE which evaluates risk as a function of three parameters: PoF, CoF and risk mitigation.

PoF is estimated based on remaining asset life. The accuracy of such estimation depends on the type of BRE being evaluated, basic or advanced. CoF is estimated with support of tables developed by WSSC using a Delphi method. Risk mitigation options are included in a "resiliency factor" which measures how many resources and what plans are ready in place in anticipation of asset failure. BRE scores and costs are used as decision-support tools.

9.3.2 Key Features

BRE is estimated as a function of PoF, CoF, and risk mitigation. The product of PoF and CoF is called "raw risk". Raw risk is compensated by risk mitigation measures, after which it becomes "BRE". Each factor is briefly explained as follows.

9.3.3 Probability of Failure (PoF)

PoF is probably one of the most difficult factors to assess. As shown by many authors including Kahneman et al. (1982), subjective estimation of quantitative probabilities is biased and unreliable at best.

In water systems, PoF is measured in terms of asset performance and is related to a primary failure mode. PoF can be estimated in two ways, qualitative and a more advanced quantitative estimation. Qualitative estimation of PoF indicates the likelihood of an asset failure during certain period of time, typically one year. Advanced estimation of quantitative PoF requires the use of models such as Fault-event Tree Analysis (FTA), or other more sophisticated modeling techniques.

For asset failures due to aging, the most frequently used indicator of PoF is remaining asset life. Remaining asset life can be estimated using methods of varying degrees of complexity, depending on desired accuracy of results. For simple assessments of remaining asset life, a frequent methodology is to subtract asset age from total expected service life. This method is not very accurate, since it is known that asset age alone is not a good indicator of asset condition and therefore of PoF. However, this method is acceptable for applications requiring a simple assessment, or when no other information on assets is available. This simple method for assessing remaining useful life for assets is shown in Table 9-1.

Table 9-1. Probability of Failure and Asset Age.

Linking Probability of Failure (PoF) to Age of Asset	
% of Effective Life Consumed	PoF Rating (%)
0	0%
10	10%
20	20%
30	30%
40	40%
50	50%
60	60%
70	70%
80	80%
90	90%
100	100%

9.3.4 Consequence of Failure (CoF)

CoF is a measure of the impact on WSSC from asset failure. CoF implies costs to the utility, in terms of lost business, repairs, injury, or disadvantages in TBL terms. CoF includes both direct and indirect costs. Direct cost includes repairs, legal fees, and fines, while indirect costs are intangible and include image loss, social impacts, and environmental damage.

The CoF is estimated using standard tables developed by WSSC using a Delphi process. The tables use a TBL approach to classify CoF, and assign weights to each factor for use when estimating CoF. The tables also provide links to other sources with additional information, such as GIS data. A detailed assessment of CoF is case-specific.

As it was mentioned, for WSSC raw risk is the result of multiplying PoF and CoF. But obtaining BRE requires also the use of a risk mitigation factor. Mitigation is represented by a "resiliency factor." The resiliency factor has three possible values that represent the availability of mitigation measures to reduce the consequence of asset failure. The three values correspond to "full," "partial," and "none" mitigation options. CoF reductions are 90% for full resiliency factor, 50% for partial, and 0% for "none."

9.3.5 Risk Classification

By using estimated BRE scores, it is possible to prioritize management interventions on WSSC assets. Assets with highest BRE scores should be addressed first. Possible interventions are the development of a Capital Investment Program (CIP) project, increased maintenance, or developing appropriate response plans anticipating asset failure. Other possible standard approaches to management interventions are:

- Status Quo (continue current strategy).
- Do nothing (stop everything).
- Renew (repair/rehabilitate/replace).
- Change maintenance/operations level (run to failure).
- Upgrade.
- Schedule regular condition assessment (monitoring).
- Mothball (stop operation and protect asset).
- Remove (unnecessary).
- Non-Asset solution (provide same LoS by other means).

The high risk assets are managed according to the organization's management objectives. These objectives usually result in allocating resources to reducing asset failure risk, without losing sight of the need for sustainable service delivery.

9.3.6 BRE-Related Policies in WSSC

The main WSSC policies regarding BRE include:

- BRE scores are developed for assets so capital projects can be prioritized.
- BRE costs are evaluated to allow benefit/cost ratios of different mitigation options to be estimated.
- CoF scores consider a TBL approach (economic, social, and environmental) and should be periodically updated to reflect current conditions.
- High-, medium-, or low-risk classifications are based on the amount of risk the organization is able to bear. Therefore, the definition of risk levels is organization specific.
- BRE scores will support application of Reliability-Centered Maintenance (RCM) and condition assessment decisions.

9.4 Case Study on Data Management

This case study presents a comprehensive review of The City of Atlanta's approach to sewer system data collection, condition assessment, system modeling, enterprise database system, system prioritization, and rehabilitation design.

9.4.1 The City of Atlanta's Case Study Summary

The Clean Water Atlanta Sewer system improvement program is one of the most comprehensive programs in the United States, where the entire public sewer system with diameters 6" and larger is evaluated and renewed. The program received its first mandate from the Consent Decree which requires the City of Atlanta to perform significant improvements to its approximately 1,900 miles of sanitary and combined sewer collection system.

9.5 Case Study on Sustainability Management

This case study contains an overview of TBL analysis performed in Seattle Public Utilities (SPU) for evaluation, and eventual approval of projects by the AM committee.

9.5.1 SPU Case Study Summary

SPU is a public utility based in Seattle that provides water, sewer, drainage, and garbage services for near 1.3 million people in King County, Washington. SPU has developed standard procedures for improving project evaluation. As an important part of such procedures, most projects require being evaluated in terms of a TBL analysis. The TBL provides a basis for reducing SPU risk in new projects, increasing project cost-effectiveness, and ensuring enhanced social and environmental stewardship.

9.5.2 Key Lessons Learned

- SPU has developed organizational structures to deal with improved project review and decision making. An AMC reviews standardized Stage Gate business case documents, which include a TBL analysis. This structure is intended to produce near-optimal project decisions.
- A TBL analysis considers the economic, social, and environmental impacts of a project. Those impacts include positive and negative effects.
- As sustainability concerns become widespread, TBL analyses depth and breadth also increases.
- An adequate TBL project analysis should consider quantitative and qualitative effects, and include reasonable and well-supported assumptions and metrics. Some metrics are more challenging to develop than others.

CHAPTER 10.0

GUIDANCE FOR IMPLEMENTATION

10.1 Why Infrastructure Management?

The United States has a decentralized water network of nearly 170,000 public drinking water systems, with 54,000 community water systems serving more than 264 million people and the remaining 114,000 non-community water systems serving facilities like campgrounds and schools. There are more than 14,700 wastewater treatment facilities and 19,700 sewer collection systems, which are also decentralized nationally (ASCE, 2013). A water infrastructure system provides a critical public health function and is essential to life, economic development, and growth. Water infrastructure is widely considered as a platform for economic growth. Disruptions in water service can slow down disaster response and recovery efforts, expose the public to water-borne contaminants, and cause damage to other infrastructures. For example, the total number of pipe breaks or leaks in Maryland has peaked to 2,129 in 2008, while the total number of reported incident of breakages and leakages across the U.S. is 240,000 (ASCE, 2013).

10.2 System Demands

Our water infrastructure assets are deteriorating because of increasing usage of the system, environmental impacts on the system, and sheer aging of the system. Simply put, our physical water infrastructure assets will not last forever. Being citizens of a highly developed and industrialized nation, we expect safe drinking water and a basic sanitation system. However, pipeline infrastructure in North America has become inadequate to sustain a growing economy, and many haven't received adequate maintenance, repair and rehabilitation over the time (ASCE, 2013).The result is a crumbling infrastructure which recently earned on average D grade according to the ASCE report card of U.S. infrastructure (ASCE, 2013). Huge expenditures are needed to repair, rehabilitate, and replace public facilities (ASCE, 2000a). If the deterioration of water infrastructure is allowed to continue, local governments will suffer severe economic consequences. For example, it is estimated that the cost of replacing all water mains in the United States would run to $348 billion (ASCE, 2000b). The estimated cost to upgrade the water transmission and distribution systems is $77 billion. The enormity of the problem of deteriorating pipeline infrastructure is apparent. Since rebuilding the water infrastructure system is not financially realistic, municipal and utility asset managers are left with no choice but to maximize the life of their assets, and avoid failures which had enormous consequences with their limited budgets.

10.3 Personnel Constraints

Utilities are facing a number of personnel-related issues. First, some utilities have lost significant numbers of staff in recent years as a result of government reinvention and accompanying downsizing. This trend is likely to continue. Second, utilities are finding it difficult to attract and retain capable professional staff to manage a varied and complex array of program areas, primarily because of the competitive nature of today’s economic environment and employment market. As a result, utilities are forced to prioritize their work functions , i.e., to determine which among many valid needs will be addressed. Water utility managers are likely to concentrate more on management functions and less on day-to-day technical functions, which are increasingly being performed by technology and service providers.

10.4 Increased Budget Demands

Budget pressures arise from constraints on the availability of funds, as well as from the demand for funds. On the supply side, utility officials may need to compete for funding with other publicly supported programs. On the demand side, increased usage, costs, and needed rehabilitation and replacement requirements strain limited budgets.

10.5 Accountability to the Public

Public skepticism of government combined with an increasing preference in recent years for using private-sector management approaches in the public sector has led to demands that government be more accountable and operate more like a private business. Utilities are increasingly measuring and reporting on their performance in terms of outcomes, outputs, and economic value added. A major initiative undertaken by GASB, which establishes requirements for the annual financial reports of state and local governments, may provide a significant impetus for drinking water and wastewater utilities to deploy an AM program.

10.6 Current Paradigm for Decision Making (What Do We Have?)

Most water utilities do not currently have common elements that provide data and/or information into the AM process. The advanced AM systems are only employed by very few big utilities in the United States. These systems are intended to cyclically monitor the condition, measure the real-life performance, predict future trends, and recommend candidate projects for repair, rehabilitation, and replacement. In addition, some include analytical tools such as deterioration models and optimization algorithms designed to evaluate the impacts and trade-offs of current and future alternative policies, programs, and projects. All of these features are not, however, necessarily used by most of the drinking water and wastewater utilities in the United States. In summary, although each water utility has a unique approach to making infrastructure investment decisions, three primary functions are common to major water utilities. First, each utility has a long-term strategic planning element that is intended to provide guiding policies and objectives. Second, each utility has a requirement to produce a short-term program of projects intended for funding. Finally, each utility has mechanisms for evaluating and selecting projects for actual implementation.

10.7 Current Practice (How is it Working?)

During the 1960s, 1970s, 1980s, and into the 1990s, infrastructure preservation projects were selected and developed without the benefit of today’s advanced technology and the information systems made possible by the technical revolution in computers, automated data collection, sensor technology, advanced mathematical models, analytical tools, etc. Investment decisions were project driven, and asset repair, rehabilitation, and replacement were frequently byproducts of demand, expansion, and new construction. Over the past two decades, progress in the planning and programming taking holistic system approach, upgrading, and operation has been considerable, with IAM becoming a more important element in the utilities’ overarching plan and program development.

Currently, major utilities are developing performance measures and target LoS to guide the overall decision-making process. Achieving the situation where programs and plans reflect predetermined goals and objectives is difficult for a number of reasons. First, available tools and methods are subject to technical constraints related to data, assumptions, and theoretical understanding of the performance parameters. Second, practical realities related to organizational considerations, social objectives, and political goals may circumvent the process. And third, the planning, programming, and project development processes in many utilities must deal with antiquated data systems, disparate software systems (such as GIS, Oracle, SCADA, Infonet, etc.), and limited communication, especially along horizontal lines.

10.8 Improving the Process (What Do We Need?)

What is needed to support the IAM approach is a logical sequence of decision steps, constituting a decision framework. The framework is supported by 1) information regarding organizational goals, policies, and budgets; 2) horizontal and vertical organizational integration to implement the decision steps in practice; and 3) technical data and information to support the decision-making process.

The trend is for utilities to be required to do more with less. Since a large part of a water utility's expenditure relates to assets that deliver core services, it is essential to manage this expenditure more effectively by using Best Appropriate Practice (BAP) in portfolio AM. This will ensure that customers and stakeholders are getting the LoS required, at the lowest sustainable life cycle cost or "best value".

Advanced IAM practices, combined with technology, can greatly benefit utilities that embrace performance measures. For most municipal utilities, performance measures may be akin to management goals or service levels without a penalty if a target is missed. However, privately run or contracted water and wastewater firms may see this differently. "Infrastructure asset management linked to performance measures and tied to penalties or payments creates a new water business model of the future," said Susan Ancel, director of water distribution and transmission for EPCOR, which currently owns and/or operates facilities in more than 75 communities and industrial sites in Canada and the United States. Many water utilities could find their issues addressed in an advanced IAM process, in which technology and performance measurements provide a higher degree of transparency, customer responsiveness, environmental stewardship, and financial accountability than existing fix when fail approach or crisis management approach (Baird, 2012).

10.9 Strategies for Implementation (How Do We Get There?)

The U.S. EPA, WERF, and the Water Research Foundation have made AM a national priority and providing national leadership and guidance to water utilities as they work to incorporate AM principles and practices into their business process. The goal is to supply generic AM approaches to organizational integration, performance-measure development, application of analytical tools, and information management. These generic processes and tools may then be directly used as is or applied after in-house and/or customized revisions. The potential advantage of adopting the generic approach is cost effectiveness, as well as the opportunity to share technical expertise and experience with other utilities.

The U.S. EPA – through its Aging Water Infrastructure Research Program – and WERF teamed up to fund the Water*i*D. The database was created and made available to ensure a single-point information center for utilities to find relevant information that will aid in decision making for the selection of appropriate condition assessment and renewal technique technologies and cost information. WATER*i*D (www.WATER*i*D.org) is structured to help bridge the product and service knowledge gap in order for AM benefits to be actualized. The types of data available include unbiased information about condition assessment, renewal engineering, pipe-locating technologies, and access to other utilities' experiences with various technologies and processes. These data also include best practices and cost drivers that are available by region. WATER*i*D is the central knowledge database through which water and wastewater utilities and the rest of the industry share information and knowledge pertaining to the application of pipeline AM. The database is structured to perpetually include industry knowledge in all of these associated areas, ensuring that the next generation of water utility professionals has access to the wealth of knowledge that can be recorded from retiring experts and that the data are easily retrieved. As a result of the success of the WATER*i*D program – measured by the participation of hundreds of utilities – plans for WATER*i*D+ are underway to further develop integrated technology design tutorials, decision support tools for technology selection, performance prediction, modeling of data trends to determine technology cost drivers, and other academic research.

An online water IAM certification program supports efforts. The Department of Civil and Environmental Engineering at Virginia Tech, in partnership with the U.S. EPA, GHD Consulting, and WERF, is also offering an online certificate program for individuals interested in learning the fundamentals of sustainable water IAM. A water infrastructure expert, Steve Allbee, the recipient of the first Utility Infrastructure Management Award, U.S. EPA project director, and primary author of The Clean Water and Drinking Water Infrastructure Gap Analysis (U.S. EPA, 2002), is one of the key instructors. According to the program's website (www.cpe.vt.edu/swim/index.html), "Students have the opportunity to learn the methodologies and tools that use knowledge of these fundamental processes for infrastructure engineering and management." The program's objective is to broaden and deepen the body of knowledge for AM practitioners, and it was developed "to improve the practice, elevate the standards, and advance the profession of water infrastructure management."

CHAPTER 11.0

CONCLUSIONS AND RECOMMENDATIONS

This primer contains a qualitative analysis of the state of the practice regarding infrastructure management in terms of performance management, sustainability management, and resiliency management, in the water infrastructure sector. Such analysis is based upon observations obtained during the development of the WATER*i*D National Knowledge Database.

Key conclusions and recommendations are the following:

- Efforts for promoting IAM by WERF and U.S. EPA in water and wastewater utilities through SIMPLE, training workshops, and other means appears to be having a significant impact in the sector. Virtually all participating utilities are aware of decision guidance tools and have at least basic knowledge of AM principles and practices, and their importance in managing their infrastructure performance.

- Most utilities acknowledge sustainability concerns in developing their capital improvement plans and advanced AM programs. The educational efforts (workshops, certificate program, etc.), SIMPLE, and U.S. EPA's four pillars of sustainable infrastructure are also producing visible results. Despite these advances, it is necessary to improve sustainability understanding among water sector utilities and develop robust sustainability metrics for better AM.

- The importance of enhancing infrastructure resilience is not clear enough for most water utilities. Furthermore, there is a lack of practical methods and tools for designing and implementing infrastructure resilience. The term is still seen as an academic exercise. Those utilities that know the term tend to think of it as emergency protocol with no practical implementation plan. Part of such perception is justified, since researchers are still discussing exactly what resilience means for water utilities and how to achieve it in daily infrastructure operation. However, there is enough resilience knowledge to start translating it into basic practical applications and metrics.

- The integration of performance management, sustainability management, and resiliency management into a truly advanced holistic IAM framework is desired. Water and wastewater infrastructure represent significant investments that can have indefinite service lives if managed properly.

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Phoenix Water Services Department
Pima County Wastewater Reclamation Department
Tempe, City of

Arkansas
Little Rock Wastewater

California
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Corona, City of
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Novato Sanitary District
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Sanitation Districts of Los Angeles County
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Florida

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