Integrating Water Infrastructure for Sustainable, Resilient Communities

Trevor Clements and Vic D’Amato, Tetra Tech
Tina Taylor, Electric Power Research Institute
Tetra Tech, P.O. Box 14409, 3200 Chapel Hill – Nelson Highway
Research Triangle Park, North Carolina 27709

ABSTRACT

The advancement toward more sustainable communities continues to gather strength as business and government plan for continued CO_2 reduction, designers and developers embrace green building principles, reclaimed water use increases, and green infrastructure gains favor particularly in urban areas seeking to reduce wet weather flows. With green building in particular, the development industry already appears to be making the transition to a new paradigm of sustainable practices. However, the current emphasis is generally on green building rating systems – achieving LEED certification, in particular – and may be problematic from a water management perspective. Because green building rating systems focus on prescribed design features and practices, priority sustainability needs for the watershed may go unaddressed despite achieving LEED certification. Without a paradigm that places land and water infrastructure development design in the context of sustainable community and watershed needs, the nation risks moving further away from its sustainability goals.

Research conducted for the Electric Power Research Institute (EPRI) under a grant from the Water Environment Research Foundation (WERF) is aimed at identifying the foundation and support structure for sustainable water infrastructure at the community and watershed scale. For this project, the communities of Tucson-Pima County AZ and Northern Kentucky along with an expert advisory panel were recruited to participate in a retreat to flesh out ideas for a new water infrastructure paradigm.

The research team and its community and expert advisory panel representatives identified key principles that provide a foundation for a new paradigm for sustainable water infrastructure. The principles contrast with past and current practices and include: valuing all water as a resource, moving toward a performance-based regulatory framework, aspiring toward better outcomes, and recognizing true costs while maximizing the value of action. A framework for supporting this new sustainable water infrastructure paradigm has been developed and includes as core elements an integrated planning structure that connects institutional entities that are currently often siloed, a technical toolbox to use in the context of performance-based requirements at the watershed and community scale, regulatory flexibility to encourage innovation and affect better outcomes, research and demonstration to build knowledge and capacity, new partnerships and funding mechanisms, and a variety of means for engaging the community stakeholders to broaden support and affect better outcomes.

This paper presents a summary of the results of this research and shares recommendations for advancing a sustainable water infrastructure paradigm. Community case studies are used as examples to illustrate the principles and supportive framework.

KEYWORDS

sustainable water infrastructure; new paradigm; sustainability principles; framework for supporting sustainable communities; integrated technological architectures

INTRODUCTION

Growing demands on resources and increasing management challenges are driving communities throughout the nation to become more sustainable. For example, greenhouse gas (climate change) concerns are driving demand for carbon (CO_2) reduction, energy conservation, and reduction in urban heat island effects. Changes in flooding and drought patterns (for example, the 2009 flooding in Minnesota and the 2007 drought in Atlanta, Georgia) are pushing communities to assess vulnerabilities and take action to become more resilient. Water scarcity and water quality concerns caused by changing population and land use pressures are forcing communities to think beyond traditional water management approaches. The high cost of aging infrastructure maintenance and replacement has many communities seeking alternatives. Increasing concern over energy cost and energy security (e.g., vulnerability from excessive reliance on foreign energy sources) and reliability has increased the public pressure for sustainability. Additionally, the increase in public preference for sustainable agriculture is leading to revised field practices and local food markets and entrepreneurial partnerships. Overall, the increase in concern for public health, the environment, economy, and social fabric of society is pushing communities to seek balance to provide for a higher quality of life and sustainability.

Water and water management are integral to this overall trend. New models for more efficient and holistic water management and infrastructure development that integrate sustainable site-scale to watershed-scale strategies are beginning to evolve (e.g., the 2007 Baltimore Charter for Sustainable Water Systems (Nelson et al. 2007)). Despite the good work that is emerging, most communities and technical professionals have difficulty in moving from traditional water management concepts toward tangible sustainable water management policy and practice. The green building sector, by contrast, has been relatively quick to embrace innovative onsite water reclamation, rainwater harvesting, and water reuse. However, most green building projects (and the programs that support them, such as LEED) focus exclusively on site-scale water management, sometimes at the expense of community-wide and watershed-scale concerns.

There is a great need to bring together the site-scale innovation being driven by the green building movement with the watershed management and integrated infrastructure planning being increasingly promoted and implemented by communities. Without this connection, it is unlikely that green building will be successful in helping our communities address common water quality problems. For example, despite our intense connection to water and our detailed scientific understanding of the hydrologic cycle, USEPA indicates that 45 percent of assessed rivers and streams, 47 percent of assessed lake acres, and 32 percent of assessed bay and estuarine square miles are listed as pollutant impaired, with the chief causes being nutrients, pathogens, and sediment from nonpoint sources including that from onsite wastewater systems and polluted stormwater runoff (USEPA 2007). These impairments impact our water supplies, public health, fishing and shellfishing, recreation, aesthetics, and ecological resources. To truly be successful, green building decisions must be linked to the specific human and ecological needs of a community. Rather than having green building rating systems based on prescriptive menus, designs need to be performance-based (i.e., rated in the context of how well they address the specific environmental issues in watersheds in which they reside), and adaptable to the changes that occur within the community.

Water infrastructure also needs to be connected to other aspects of the community, including transportation, energy and other public services and amenities. The water-energy connection provides a good example. The existing water infrastructure management paradigm is not addressing the interdependency of energy and water, and the threats to national energy production resulting from limited water supplies. In a report to Congress, the US Department of Energy (2006) identifies concerns regarding water demands of energy production and discusses science and technologies to address water use and management in the context of energy production and use. For example, in calendar year 2000, thermoelectric power generation accounted for 39 percent of all freshwater withdrawals in the US, roughly equivalent to water withdrawals for irrigated agriculture. The River Network (Griffiths-Sattenspiel et al. 2009) estimates that U.S. water-related energy use is at least 521 million MWh per year (including embedded energy and end uses)—equivalent to 13 percent of the nation's electricity consumption. They also report that the carbon footprint associated with moving, treating and heating water in the U.S. is at least 290 metric tons per year, representing 5 percent of all U.S. carbon emissions (equivalent to the emissions of over 62 coal-fired power plants). Thus, sustainable practices that accomplish water conservation, efficiency and reuse and that support maintenance of the hydrologic cycle, in turn reduce energy demand and greenhouse gas emissions. The main point is that energy and water are essential, interdependent resources and that through science- and systems-based natural resource management, energy-water infrastructure synergies will likely constitute a critical portion of our communities' sustainable solutions.

So why aren't all communities simply opting for sustainable approaches? The reality is that it takes time for a paradigm shift. Mindsets have to shift. The way we make decisions has to shift to include more criteria than is typically considered. Additionally the institutions and regulatory frameworks that govern our current water infrastructure practices will need to adapt to facilitate the planning and implementation of more integrated approaches. There is considerable momentum nationwide for simply repeating past practices and following current water infrastructure management based on policies and regulations set forth under the Clean Water Act and Safe Drinking Water Act. Existing institutions established under the current water management paradigm have inadvertently created obstacles to innovative new infrastructure approaches that have the potential to help address many of today's complex challenges. As a society, we need to adapt and apply new ways of thinking.

While the existing paradigm has gotten us to where we are today in addressing many past issues such as widespread waterborne disease outbreaks and gross surface water pollution problems, it does not appear that it can adequately address many of today's emerging problems. In addition to the existing water quality impairments mentioned above, we are reminded almost every day that the nation's water infrastructure is aging, with some piping networks being more than 100-years-old. As indicated by USEPA (2003), collection system failures have been reported to increase at a rate of approximately 3 percent per year, while another study indicated that approximately 50 major main breaks and 500 stoppages occur per 1,000 miles of pipe per year, amounting to an estimated 50,000 breaks and 500,000 stoppages annually in the U.S. Based on the USEPA's Clean Water Needs Survey (2003), replacement costs for the nation's sanitary collection systems alone are estimated to be from $1 trillion to $2 trillion. The national cost to mitigate Sanitary Sewer Overflows (SSOs) over the next 20 years has been estimated at $155 billion. Despite tens of billions of dollars currently being spent each year, the U.S. Government Accountability Office (GAO) reported the gap in water infrastructure funding needed over the next decade to be in the $150 - $400 billion range (GAO 2009).

Part of the reason for this gap can be attributed to the current paradigm, whereby water provision and waste management are generally viewed as extractive, linear processes where:

- Water is extracted, treated to potable standards, conveyed to numerous consumers, used once and disposed as wastewater.
- Wastewater is collected, conveyed to a central out-of-the-way location, and treated to remove pollutants, with relatively clean water and residuals disposed.
- Stormwater is managed primarily for flood control through rapid conveyance and discharge.

Such thinking adds to societal cost (e.g., for infrastructure, pumping, treatment, and environmental impacts) rather than using more integrated approaches that incorporate concepts of efficiency, recovery and reuse, potentially reducing full life-cycle costs. Given the magnitude of existing problems and challenges, extensive discussion has taken place over the past decade or so about the need for a change in direction—or a new paradigm—for water infrastructure planning and resource management. Under EPRI Project Number 068143-01, a research team led by Tetra Tech was contracted to organize and hold a retreat where diverse teams of experts work through two or more case studies to help elicit ideas for effectively describing and advancing the new paradigm for water infrastructure management. The complete report on this research can be reviewed for more detail (EPRI and Tetra Tech, 2009); highlights are provided in this paper.

Methodology

Two communities endeavoring toward sustainable water management were recruited to use as retreat case studies: Tuscon-Pima County Arizona and Northern Kentucky. The City of Tucson and Pima County are located in the arid southwest where water supply is scarce, precipitation is low and typically comes in a few large events, perennial streams are rare, wastewater reclamation is prevalent, and large swaths of land are under federal government and Native American tribal ownership. The Northern Kentucky community, on the other hand, is located east of the Mississippi River where precipitation is considerably higher, precipitation events are spread throughout the year, perennial stream flow is abundant, and most of the land is under local jurisdiction. The two communities offer a broad spectrum of physical and cultural differences for consideration of concepts to be applied to a new paradigm.

Experts in a variety of disciplines and organizations related to water infrastructure were recruited to form an advisory panel (engineers, planners, scientists, sustainability consultants, governmental agency representatives and non-governmental agency representatives). Community representatives and advisory panelists were oriented to the project purpose and engaged in a dialog regarding a conceptual approach for the new paradigm via a teleconference held on April 30, 2009. Based on the teleconference discussion, the Tetra Tech team established the following definitions for “Sustainability” and “Water Infrastructure” that were used for this research:

Sustainability (General Definition):

Sustainability refers to community development that meets the needs of the present without compromising the ability of future generations to meet their own needs. As a part of this characteristic, communities must demonstrate their resiliency or robustness to adapt to and thrive in the face of change. The degree to which community needs are met sustainably is evaluated using a “triple bottom line” of environmental, societal, and economic considerations.

Water Infrastructure (General Definition):

Water Infrastructure refers to the basic physical and organizational water-related structures needed for the functional operation of society. These include both built (e.g., reservoirs and retention systems, piped collection and distribution systems, treatment systems) and natural infrastructure (e.g., forested land, stream buffers, flood plains and hydrologic networks, wetlands).

Following the teleconference and in preparation for the retreat, the research team offered five components to organize conceptual thinking for the new paradigm:

1. Technological Approaches: System Architecture
2. Integrated Planning
3. Regulatory and Programmatic Change
4. Community Engagement
5. Management and Financing

It was generally agreed that discussion of system architectures and technologies for each of the two communities would help establish a vision of what the future might look like in the context of sustainable water infrastructure. The other four components would essentially describe the supporting structure for how each community could achieve its vision for sustainable infrastructure.

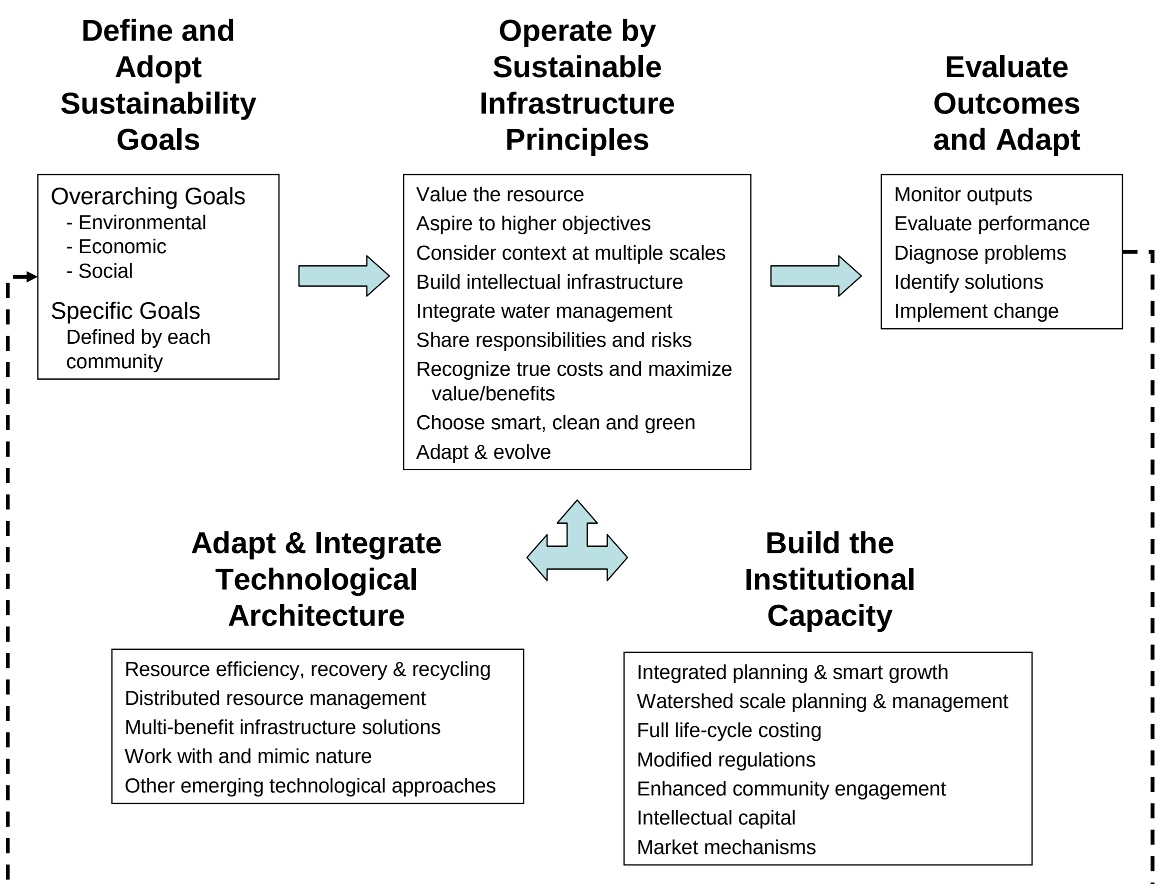
In preparation for the retreat, the two case study communities were asked to prepare background papers that described their sustainability goals and objectives, existing efforts and building blocks, challenges to achieving their objectives, and opportunities and potential solutions for moving forward for each of the five organizational components. The background papers were distributed to invitees approximately 10 days prior to the start of the retreat. Additionally, the two communities were asked to prepare presentations to use at the beginning of the retreat to orient the participants to their local environment and water infrastructure.

The retreat was conducted in Hebron, Kentucky from June 1 – June 3, 2009. Thirty-five people comprised of research team members, case study community representatives and advisory panelists attended.

RESULTS

The real-life circumstances for each of the two case study communities provided the retreat participants a basis for dialogue to define the new paradigm. Retreat participants first discussed the five conceptual model components listed above in the context of each community, and then the entire group worked together to generate ideas for a refined model for the new paradigm in light of the community dialogues. Based on input received at the retreat and from follow-up discussion, the research team then defined the new paradigm as a composite of five integrated components (Figure 1).

Figure 1 - Overview of New Paradigm



Each component is touched upon briefly below.

New Paradigm Component 1 – Define and Adopt Sustainability Goals

Far-reaching community sustainability goals provide something for communities to aim toward. They reflect the concept of the "triple bottom line" and integrate the collective thinking of many of the professional disciplines working to define sustainability in practical terms for communities. The term is used to refer to three key attributes associated with sustainable systems —environmental performance, economic benefit and social equity/acceptance.

Environmental Goals

The primary environmental goal is to be ecologically “neutral,” by which we mean not upsetting the natural balance. This concept carries forth to ecological components, i.e., being carbon neutral, hydrologically neutral, nutrient neutral, air quality neutral, etc. For example, as a community increases development (and thus increases it’s built upon area), it must manage stormwater to support the local hydrologic cycle. This can mean adopting policies and implementing practices that support local (close to the source) capture of runoff from impervious surfaces (e.g., rooftops, driveways, streets, and parking lots), natural rates of infiltration to groundwater, evapotranspiration to the atmosphere, and runoff to the down-slope hydrologic network of wetlands, streams, rivers, etc. Where impacts and imbalances already exist, communities can set goals to restore elements to functioning levels associated with a healthy environment (i.e., the “be restorative” or “have positive benefits” portion of some of the overarching environmental goals).

Although overarching, these environmental goals are all context-based. In other words, what it takes to be hydrologically or ecologically neutral or restorative in one community may be very different from that for another. For example, the infrequent but relatively extreme rainfall events in the Tucson-Pima County region require greater consideration of “flashy” (from no volume to large volume) runoff conditions, intermittent stream conditions, and groundwater recharge processes. Thus, what it takes to be hydrologically or ecologically neutral in that part of the country is very different from the context for Northern Kentucky, where rainfall events are more evenly distributed, and a significant portion of the streams flow perennially. Consequently, even with the broad overarching goals, communities need to develop knowledge of what this means for them so they can act sustainably.

Social Goals

Social goals in the context of sustainable water infrastructure include things like maintaining a clean and abundant water supply, safe and secure food supply, clean and stable energy supply, healthy and enjoyable living (including working and recreational) space, social connectedness, and environmental justice. Many communities likely would say that they traditionally support goals such as providing clean and abundant water supply, and a safe and secure food supply. What is different, however, is considering them simultaneously with the other goals to try to accomplish the environmental, social and economic goals collectively. Additionally, water infrastructure management decision-making has not always prioritized goals involving enjoyable living, social connectedness and environmental justice. These are part of the new way of thinking to support sustainable communities.

Economic Goals

From an economic standpoint, the existing paradigm typically looks for low cost alternatives without considering the value of the services offered and other community objectives. The goals recommended under the new paradigm include some other economic considerations. For example, having water systems that are self-supporting (i.e., customers pay the full cost), and ensuring that the value of water infrastructure services exceeds the monetary cost. Another new paradigm economic goal is building in resilience; for example, to avoid potential future high cost of infrastructure repair/replacement following extreme events and the cost to the community when services are disrupted due to damage. Additionally, facilitating economic growth through the promotion of clean and green industry both helps provide local solutions to environmental challenges while providing economic benefits across the workforce.

Communities can use the overarching goals listed above as a starting point in setting local water sustainability goals. Ideally, this would be done in conjunction with local comprehensive planning efforts and accompanying land use planning as these can provide excellent vehicles for communities to define and coordinate policy on a range of long-term issues affecting water such as land use, transportation, environment, housing, water and sewer infrastructure, parks, waste disposal, etc. Alternatively, a local sustainability task force might be appointed to establish sustainability goals (including but not limited to water), which can later be incorporated into comprehensive planning efforts and other more specific infrastructure and land use plans.

New Paradigm Component 2 – Operate by Sustainable Infrastructure Principles

A considerable amount of time was spent by the research team and retreat participants to identify the core principles that constitute this new way of thinking. Many of the project's advisory panelists said that these thoughts are among the most important outcomes of the retreat to communicate because they reflect the type of thinking and action that communities need to follow to successfully achieve a strong triple bottom line (i.e., the environmental, social and economic goals listed above). For example, valuing the resource (the first principle that will be discussed below), should lead to decisions and actions that are environmentally neutral or restorative. Actions that have this outcome are also likely to help in supporting clean and abundant water supply, healthy living, and economic value (e.g., associated with recreational amenities in areas with healthy ecosystems).

While the principles were derived from discussion involving the two case study communities, they are recommended for any community striving for sustainability and as such they constitute the second component of the research team's definition of the new paradigm. Like the example provided in the previous paragraph, each of these principles can be linked to multiple goals. There are too many connections to list them all, so just a few will be discussed to provide illustration.

1. Value the resource.

   A core principal for the new paradigm is to recognize all water as a valuable resource including stormwater and wastewater. Water is vital for life, and water in its various forms contains valuable resources such as nutrients, energy and carbon. From an environmental perspective we need to value the entire water cycle, recognizing the importance of precipitation, interception, storage, infiltration, runoff and evapotranspiration processes to sustaining a strong triple bottom line. There is also social and economic value to the beauty and community that water can create (e.g., parks, beaches, hiking and boating areas).

2. Aspire to higher objectives that spawn better outcomes.

   The core of this principle with regard to water infrastructure is that designs should add value and provide multiple benefits (for example, natural treatment systems that double as recreational spaces or bioretention areas that serve as public art for the community). A key part of this higher objective is integrating the built environment with the natural environment (for example, using native soils and vegetation as green infrastructure to capture and treat stormwater runoff from the built environment). Under this principle, communities should consider life cycle impacts of actions beyond their local boundaries (for example, looking at impacts of local water infrastructure decisions on global climate change, or controlling water quality in the Ohio River to minimize the hypoxic zone in the Gulf of Mexico).

3. Consider context at multiple scales.

   Local actions can have implications at every scale; some impacts occur on site, some at the watershed scale, some regionally and some globally. For example, excess runoff from a developed site can erode soil on site, the excess runoff in turn destabilizes downstream channels adding further sediment to the water column at the small watershed scale, and the pollutants associated with the sediment combine with other runoff to impact water quality at the regional scale (for example, nutrients in the Mississippi Basin feed algae in the Gulf of Mexico leading to large segments of the Gulf that are devoid of aquatic life). This principle brings us back to the green building issue raised in the Introduction. Building design decisions (including water infrastructure) need to be made in the context of critical concerns for a given community. Watershed-based assessments are needed to identify thresholds for variables such as pollutant loads so that performance standards can be established locally, and building decisions are made to support neutral or restorative measures. Decision-makers need to avoid “one size fits all” solutions, instead staying attuned to ecological, social and economic opportunities, issues and constraints associated with their community.

4. Build intellectual infrastructure.

   To support new paradigm approaches, communities need to foster and support research, development and new ideas for water infrastructure management. Finding good triple bottom line solutions will often be challenging, and use of research and demonstration projects, and the compiling of a knowledge base of new technological approaches will facilitate success. Additionally, communities need to build knowledge about their specific water resource issues. This means investing in maintenance of watershed characterization decision support tools. Monitoring and modeling systems (that can predict future conditions, support performance standard development, and help evaluate alternative water infrastructure management options) are both important in this regard.

5. Integrate water management decisions with all aspects of community planning and development.

   Under the new paradigm, all community decision-making must consider water. This is different from most community projects that currently do not consider water directly or treat it as an afterthought when issues arise. Valuing water and understanding that most infrastructure projects will affect the natural hydrologic cycle means addressing these issues up front in the planning and design phases. In particular, land use planning and water resource management must be coordinated.

6. Share responsibility and risk throughout the community.

   Under the new paradigm, the process of informing and engaging stakeholders regarding water infrastructure management should be transparent and inclusive. Too often under the existing paradigm, stakeholders are only informed when approval of pre-chosen solutions is required. Under the new paradigm, stakeholders are engaged in the decision-making process from the beginning. The open process is more likely to result in shared responsibility and risk, which helps the community move more as a whole toward sustainability goals. A part of sharing responsibility and risk involves building and relying on local capital for creative and science-based decision making. This also creates a greater "stake" in the outcome, which helps to focus efforts. Additionally, the inclusive and transparent approach is more likely to serve the overarching economic justice goal, deriving solutions that share cost across the community.

7. Recognize true costs and maximize value/benefits.

   Under the new paradigm, communities use triple bottom line principles to plan, design and manage water systems. Current infrastructure management decision-making often relies heavily on capital and recurring (e.g., operation & maintenance) cost as the primary quantitative factor for cost-benefit analysis. The new way of thinking incorporates use of full life cycle costs over a long-range (e.g., 100-year) life cycle to evaluate water resource management decisions. This information takes into consideration the external social and environmental impacts. Through this approach communities are more likely to be able to adequately assess whether they are meeting their overarching goal of having the value of services exceed the monetary cost of alternatives.

8. Choose Smart, Clean and Green

   "Smart" infrastructure uses information and signaling (e.g., real-time meters) to modify water use behavior and treatment supporting efficient use of resources. "Clean" infrastructure uses resources and methods that are resource efficient and avoid use of harmful substances. "Green" infrastructure learns from and works with nature and uses soil and vegetation to manage water and restore natural ecosystems. Again, these new paradigm approaches differ from the existing paradigm approaches that tend to favor gray infrastructure approaches (linear, single-pass, centralized systems). Smart, clean, and green approaches are directly linked to the overarching environmental, social and economic goals because they emphasize efficiency, conservation, low environmental impact, healthy living, and an economy with more emphasis on clean industry.

9. Adapt and evolve.

   Change is inevitable. Even though the perceived risk of change is often high, continuing under the current water management paradigm may be riskier as waterbodies become more polluted, the cost of infrastructure management increases, and resources are depleted. The new paradigm recognizes this by emphasizing flexible systems that can adapt and evolve over time. Communities need to implement management approaches that monitor performance so that progress toward goals can be assessed and corrections to plans, designs and operations can be made as needed.

New Paradigm Component 3 – Adapt and Integrate Technological Architecture

The new paradigm goals and the operating principles both represent a new way of thinking and thus change. Most communities know from experience that change is difficult. A key component for facilitating such change in communities involves adapting and integrating the technological architecture for our water infrastructure systems. Just as conventional architecture revolves around laying out buildings and living spaces and landscape architecture revolves around laying out and designing landscapes, technological architecture revolves around the placement and design of various components of our water infrastructure systems – where should treatment systems be located and how big should they big, how do system integrate with the natural work and other built environments, and what is the role of controls and monitoring systems in this architecture?

A fundamental theme coming out of the retreat sessions associated with new paradigm technologies revolves around integration—integration of resource management technologies and strategies as well as integration of technological approaches and architectures. Integrated resource management describes the coordinated development and management of water, land, and related resources to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Water (and other resources—nutrients, carbon, energy, etc.) can be more sustainably managed by considering the system holistically, rather than separately as specialized elements (e.g., water supply versus stormwater versus wastewater versus aquatic ecosystems) with limited interrelationship.

Under a new technological framework rooted in integrated management, a number of movements or fields of study and practice continue to develop. These movements are not mutually exclusive—applied collectively, they support new and exciting infrastructure system architectures that combine closed loop resource recovery at localized scales with centralized management and oversight informed by smart and responsive monitoring and control systems. Existing infrastructure may be repurposed for new functions, such as the case with a wastewater collection and treatment system managing residuals and providing backup for satellite water reuse. Likewise, institutional structures may change; traditional municipal utilities may be adapted to take on roles with higher purposes and improved community outcomes as goals.

For the purposes of this project, the research team organized the new technological approaches into the following four categories:

1. *Resource efficiency, recovery and recycling*—in addition to water, other waste-related resources should be used as efficiently as possible, while resources in waste should be recovered and recycled.

2. *Distributed resource management*—a combination of infrastructure scales, from decentralized to centralized, should be used as appropriate; managing resources closer to the source of generation and reuse opportunity is often more efficient.

3. *Multi-benefit infrastructure solutions*—infrastructure solutions can and should provide a multitude of benefits spanning the triple bottom line of environmental, societal and economic attributes.

4. *Design new water systems that mimic and work with nature*—these systems will both protect public health and safety and will restore natural and human landscapes. Nature and man can cooperate to rebuild healthy communities and restore natural ecologies through incorporation over time of sustainable infrastructure designs and principles, with water at the center of these designs.

While each approach has merit on its own, the new paradigm emphasizes integration across the spectrum of approaches as appropriate for the context within each community. Additionally, since technological approaches are applied with the objective of attaining certain levels of performance to achieve triple bottom line goals, the new paradigm emphasizes monitoring outcomes and adapting the technological approaches used to enhance performance over time.

New Paradigm Component 4 – Build the Institutional Capacity

Although there are innovative and effective technologies available that recover and reuse water, mimic and preserve ecological functions and services, and holistically integrate water, stormwater, and wastewater management, most utilities still rely on conventional technologies. To shift to the new water infrastructure management paradigm, the site-scale innovation being driven by the green building movement needs to be brought together with integrated infrastructure and watershed management planning. This shift will depend, in great part, on institutional changes that help build the capacity to support sustainable operations at the community scale.

During the project retreat, a significant portion of time was spent on discussing various aspects of institutional factors that play an important role in water infrastructure management decision-making including: integrated planning, community engagement, regulatory and programmatic change, and management and financing. For each of these factors, breakout groups for Northern Kentucky and Tucson-Pima County identified opportunities and challenges for each case study community building off of their existing management foundations to help them achieve triple bottom line goals. The results of these discussions and follow up by the research team led to defining and developing several key areas where communities in general can focus on building their institutional capacity, including:

- Integrated Planning and Smart Growth
- Watershed Scale Planning and Management
- Full Life-Cycle Costing
- Improved Regulations
- Enhanced Community Engagement
- Investment in Intellectual Capital
- Market Mechanisms

New Paradigm Component 5 – Evaluate Outcomes and Adapt

The fifth and final component defined by the research team for the new paradigm involves evaluating the outcomes of a community's water infrastructure management approach and adapting goals, policies, tools, methods and/or operations as needed where performance assessments indicate an unacceptable shortfall from established goals and objectives. Outcomes are often uncertain when charting new waters, so monitoring results iteratively allows decisions to be optimized over time to reduce uncertainty and improve the outcome. Those decisions/projects are evaluated against the triple-bottom line objectives, which requires selecting indicators for each or representative objectives.

Targets or performance standards that have been set for the indicators provide the basis for evaluation. If targets or performance standards are not met, evaluators move into a diagnostic phase (where does the problem lie?—goals? technologies? application? policies? operations?). Based on the lessons learned from this diagnostic review, and any new information (e.g., related new research), stakeholders identify solutions or new approaches to take for the next iteration. Selecting the refined or new approaches will likely involve using the support tools (e.g., watershed models, full life-cycle costing) for infrastructure projects to provide triple bottom line justification. The community then moves forward to implement those changes, and the evaluation process cycles through another iteration.

DISCUSSION

So how is the new water paradigm different from current practices? Table 1 provides several examples of how various practices are carried out differently under the new paradigm principles using an integrated management framework.

Table 1 – Summary of What's Different Under the New Water Paradigm (Adapted from the Rocky Mountain Institute, 1999)

Topic	Current Practice	New Paradigm
Water Use	Single use—water is used only once before treatment and disposal.	Greater emphasis is placed on water reuse and reclamation, use water multiple times (e.g., household graywater for irrigation), and reclaim treated water for the supply side of the infrastructure.
Water Quality (supplied)	Treat all supply-side water to potable standards.	Apply "right water for right use"—level of water quality supplied is based on the intended use.
Wastewater	After one-pass use, treat the resulting "waste" water, and return it to the environment.	Cyclical/"Close the Loop" —recognize the value in "wastes"; recover resources (reclaimed water, nutrients, carbon, metals and biosolids) for beneficial uses including potable water offsets, fertilizers, and generating power.
Stormwater	Convey stormwater offsite as quickly as possible with no regard for maintaining hydrological integrity of ecosystem.	Harvest stormwater for water supply, irrigation, and/or infiltration benefits.
Increase System Capacity	Add capacity to water and wastewater facilities and collection/distribution systems as water demand increases.	Implement cost-effective demand side and green infrastructure before increasing gray infrastructure.
Type of Water Infrastructure	Primarily use gray infrastructure—engineered and constructed materials (pipes and treatment facilities and pumps).	Integrate the natural capacities of soil and vegetation to capture, infiltrate and treat water (green infrastructure) with gray infrastructure.
Centralized Infrastructure	Preference for large, centralized treatment and distribution systems that focus on economies of scale at the treatment facility without considering the whole system, which includes collections and distribution systems as well.	Favor distributed approach evaluating the spectrum from small decentralized systems to larger centralized systems, including combinations, based on local needs and the triple bottom line.
Complex Design	Administrative programs tend to favor more well-known (established), less complex, standard	Since today's problems cannot always be solved with today's standard solutions; new technologies

Topic	Current Practice	New Paradigm
	infrastructure designs and technologies.	and strategies are encouraged (tested at demonstration scale as appropriate).
Infrastructure Integration	Water, stormwater and wastewater are typically managed as separate systems (creating management "silos").	Water is water—integrate infrastructure and management of all types of water regionally, as appropriate.
Public Involvement	Stakeholders are informed when approval of pre-chosen solutions is required.	Stakeholders are engaged in the decision-making system from the beginning.
Monitoring and Maintenance	Water and wastewater facilities use computerized Supervisory Control and Data Acquisition (SCADA) to monitor and control processes.	Moves smart systems out to end users to provide real-time feedback regarding energy use and water use rates to build understanding, modify behavior for higher efficiencies, and notify for maintenance.
Cost-benefit Analyses	Use estimates of capital and recurring costs as the primary quantitative factor for cost-benefit analyses.	Develop an understanding of the full cost and benefits of infrastructure, including externalities.

Importantly the new paradigm recognizes that water sustainability cannot be accomplished by adding up the excellent results of separate institutions – an integrated plan where resources are pooled and challenges and opportunities are explored will yield more sustainable solutions in many cases. Likewise water sustainability cannot always be accomplished by perfect compliance with a list of one-by-one rules. Principally the new paradigm recognizes the value of water and institutes an integrated management framework to facilitate meaningful implementation of sustainable measures.

To illustrate these points, a synopsis of the opportunities identified by the research team and retreat participants for application of new paradigm principles to the two case study communities is presented.

New Paradigm Opportunities in Tucson-Pima County

Pima County covers 9,200 square miles (an area roughly the size of the State of Massachusetts) of arid western land in Arizona. Approximately 42 percent of the county is Native American land, 44 percent is public land, and only 14 percent of the land is in private ownership. The population in the county is roughly one million, with 742,000 living in the City of Tucson. There is rapid growth around Tucson, including satellite areas that pose special problems for utilities.

The arid west is defined by rainfall. Annual rainfall recorded in the metropolitan area averages about 12 inches, coming in three distinct rainfall seasons: June to September is characterized by intense thunderstorms; October to November has occasional storms from Pacific hurricanes; and December to March can have large slow-moving storm fronts. There are significant water regulatory challenges associated with arid Arizona land. All of the water is allocated or owned through water rights. This includes groundwater rights and effluent entitlements.

Technological Approaches/Architectures in Tucson-Pima County

Currently, the large majority of the total water used in Tucson-Pima County comes from the Central Arizona Project (CAP), where Colorado River water is diverted to groundwater storage facilities for future use. Supply is augmented by groundwater withdrawals and regional water reclamation systems. The community is quite concerned about reliability of water supplies due to the uncertainties of drought and climate change. Additional objectives include greater integration between the built and natural environments, and greater integration of water management with energy management and other resource management initiatives.

The community representatives and advisory panelists discussed numerous technological architecture opportunities. The region is fortunate to have a relatively engaged and active community which appreciates and supports the unique and sensitive indigenous environment. This support can be used to link land use planning with system architecture to be more water-centric (i.e., mixing natural and physical infrastructure, and bringing demand closer to local supply of water, and accomplishing closed loop greenfield development). Energy-water connections can be increased integrating solar and co-generation options with water and wastewater facilities. Additionally, the community can integrate smart systems in homes and business to take advantage of the conservation ethic in the region. Community representatives also see an opportunity to develop greater understanding of arid hydrology and ecology to support increased use of effluent, reclaimed water, stormwater and rainwater. One example of this already occurring is the recently completed Kina Environmental Restoration Project where Pima County has integrated stormwater capture, wastewater reclamation, wetland restoration and natural resource amenities as a part of its water infrastructure management approach (Figure 2).

Figure 2 – Kina Environmental Restoration Project in Pima County, AZ
(*photo courtesy of Pima County Regional Wastewater Reclamation Department*)

Integrated Planning in Tucson-Pima County

Regional planning and management of water resources are essential in the rapidly growing arid southwest since balancing economic growth and preservation and protection of environmental and cultural resources is dependent on a sustainable water future. City and County representatives would like to improve overall community ability to work collaboratively within the dynamic, complex circumstances, and sometimes conflicting interests among diverse stakeholders, to achieve comprehensive integrated planning. The community wants to find tools and incentives that achieve the performance-based planning outcomes of sustainable urban forms, stronger links between land use planning, water resources and infrastructure planning, and growth that is directed to suitable areas and is financially sustainable.

Tucson and Pima County face several challenges in trying to achieve these outcomes. In the past, water and wastewater services were extended throughout the region based on demand. This approach has led to continual expansion of the service areas without regard to sustainability criteria. There are also regulatory and institutional barriers to comprehensive integrated planning such as multiple jurisdictions with distinct land use plans, and multiple water providers, both public and private, with numerous service area boundaries that are not aligned with jurisdictional land use boundaries. Additionally, a lack of defined performance standards for the arid southwest, and the lack of technically-based tools can stymie regional planning due to insufficient backup. The cost of comprehensive planning is extensive, and local capacity may not always be sufficient with regard to infrastructure management.

Given these challenges and objectives, community representatives and advisory panelists identified potential opportunities for Tucson-Pima County. The community can build on existing regional planning efforts such as the Sonoran Desert Conservation Plan and joint Water and Wastewater Infrastructure, Supply and Planning Study. Key City and County opportunities include directing growth to suitable areas through joint land use and capital investment planning efforts, acquisition of open space, new policies for integrated planning embedded in updated long range planning documents, conducting advance planning of water resources for the future growth areas, and identifying mechanisms for providing renewable water resources to these areas. The existing reclaimed water system can be further developed along with graywater and rainwater harvesting, and linked to land use planning. This will require a new platform for planning across different departments and community programs. Using this platform, the City and County could develop shared water efficiency goals and strategies at the sub-regional and neighborhood scales.

Regulatory and Programmatic Change in Tucson-Pima County

The City and County assume the trend of more stringent regulation will continue. Their objectives as the regulatory framework evolves include:

- Improve understanding of arid western ecology, research arid west water quality criteria, and establish appropriate regulatory standards for arid conditions.
- Move from a prescriptive-based approach to a performance-based approach; accomplish this in a more holistic manner than current separated programs (silos) approach.
- Move away from risk averse regulation toward support for innovation and adaptive approach.

A big challenge to the community is that western water rights do not necessarily support water conservation (e.g., sometimes preventing stormwater capture, use and recharge) and a performance-based approach. Additionally, Arizona regulations have prescriptive processes that are not flexible which is an impediment to innovation (e.g., method for classifying reuse water).

Some near-term opportunities identified included mandating performance standards for new development, and reviewing current codes for impediments and developing model codes that support the sustainable water infrastructure approach. Training of regulatory staff is necessary to increase understanding of sustainable water infrastructure technologies and architectures and how to implement a performance-based process. The community will need to incorporate faster verification measures for new technologies into the more flexible regulatory process. Additionally, the City and County can jointly advocate for policy and rule changes to overcome barriers to maximizing use of reclaimed water and to dissuade the use of groundwater when other renewable sources are available.

Enhanced Community Engagement in Tucson-Pima County

The City and County want to assure effective community participation in determining and realizing a sustainable water future in the region. Diverse participation, two-way dialogue and response to public input are key facets of effective public participation. Diverse participation means inclusion of non-expert community members in water and wastewater management allocations, policy, and planning decisions. Non-expert participation requires that they acquire a basic understanding of issues, options, and decision tools. In addition, they need to understand the science, the areas of uncertainty, the areas of disagreement, and needs for additional information without delaying decisions that must occur in the absence of perfect information.

Opportunities to expand public participation in water resource management decision making include the upcoming regional visioning process, and the updates of the Pima County Comprehensive Plan and the City of Tucson General Plan. Successful methods that have been used in the past that are being considered include training of community leaders to conduct round table dialogues within existing forums and organizations to obtain broad and substantive input across a diverse cross section of the community.

New Paradigm Opportunities in Northern Kentucky

The area referred to as Northern Kentucky in this case study is approximately 229 square miles and is comprised of three counties: Boone, Kenton, and Campbell. The current population of these counties is approximately 350,000 with the City of Covington being the largest municipality at 40,000 people. The region is part of the growing Cincinnati metropolitan area; the overall growth rate for Northern Kentucky was 27 percent between 1990 and 2008, with Boone County experiencing 100 percent growth during that period.

Sanitation District No. 1 of Northern Kentucky (SD1) was established as a special district in Kentucky and has been in existence for over 60 years. It is responsible for providing sewer services to most of the Northern Kentucky region, and it also oversees stormwater management for the region. Water infrastructure is managed by the Northern Kentucky Water District (NKWD), which operates three water treatment plants and oversees 20 storage tanks, 15 pump stations and 1,192 miles of water main pipes. The plants draw their water out of the Ohio and Licking rivers, and water is provided for about 300,000 people.

Technological Approaches/Architectures in Northern Kentucky

Northern Kentucky is challenged by extreme wet weather flows in both its combined and separated sewer systems that impact water quality in the region. Suburban growth presents another challenge with respect to sewer service and nonpoint source water quality. Community objectives expressed at the retreat revolve around improving water quality in the region, keeping water and sewer rates reasonable, and improving energy performance. Engaging the local community is a key goal that will help build support and capacity for more ambitious sustainability initiatives in the area.

Given these challenges and objectives, community representatives and advisory panelists identified potential promising technologies/architectures for Northern Kentucky. These included green infrastructure, water conservation, high efficiency pumps, increased use of decentralized water and wastewater systems outside of the core urban areas served by centralized systems, and resource recovery for such current wastes as biosolids, fats, oil and grease. SD1 is leading by example. While working with the local communities in Northern Kentucky to adopt and implement low impact development (LID) approaches, SD1 has incorporated green infrastructure into its own campus. Demonstrations include a greenroof (Figure 3), cistern and constructed wetland.

Figure 3 – Green Roof for Sanitation District No. 1 of Northern Kentucky (part of onsite demonstration of green infrastructure)
(*photo courtesy of SD1)*

Integrated Planning in Northern Kentucky

Northern Kentucky's community objective is to achieve a more regional approach to sustainability, with better recognition of the interaction between different types of infrastructure (water, sewer, stormwater, power, transportation, etc.). SD1 and NKWD have good working relationships with local jurisdictions, planning and zoning agencies, community groups, and other utility service providers in the region providing a reasonable foundation upon which to build a more integrated planning framework. Nonetheless, community representatives see several challenges to accomplishing this integration. Leadership (a local champion) is needed, along with stronger coordination between SD1 and NKWD regarding sustainability policy and infrastructure planning/ investment. Community representatives are also concerned that corresponding state and federal oversight agencies for water, wastewater and stormwater are not currently positioned to coordinate well among themselves and with local institutions.

Given these challenges and objectives, community representatives and advisory panelists identified potential opportunities for Northern Kentucky. In addition to SD1 providing sewer and stormwater services and NKWD providing water services, the region has the Northern Kentucky Area Planning Commission (NKAPC) which coordinates planning with individual local governments and among governments of the region, including developing model ordinances and land use policies. NKAPC is leading the forthcoming update of the Kenton County

Comprehensive Plan that will include sustainability planning. NKWD and SD1 will be participating in the Plan development as well as the State Department of Water representatives. The regional agencies can offer the Kenton County sustainability planning as a model for other local governments in the region. Additionally, upcoming rate increases anticipated if conventional practices are used in the future for compliance with SD1's consent decree may provide an impetus for seeking greater efficiency through integrated system architectures organized regionally.

Regulatory and Programmatic Change in Northern Kentucky

Planning in Northern Kentucky is managed through a relatively large number of planning and zoning entities. Ideally, local regulations that affect water quality would be developed with the input of all necessary parties, with everyone operating from a basis of clear understanding of the issues.

From SD1's and NKWD's perspective, the federal and state regulations related to water and sanitary sewer service are sometimes overly restrictive and lead to the allocation of funds towards projects that yield minimal results. For example, all sanitary sewer overflows are deemed "illegal" by the USEPA with little recognition of the complexity of those problems. Many of SD1's SSOs are small volume overflows that occur during relatively large rainfall events and represent a minimal source of pollution into streams that are impacted by many other sources of water quality impairment (failing septic systems, urban runoff, loss of riparian corridor, etc.). The elimination of such SSOs often requires the use of funds that could provide more benefits if they were directed toward other water quality improvement projects. For SD1 and NKWD, an ideal regulatory / programmatic paradigm would be based on reasonable, flexible, and scientifically-based federal regulations affecting water, sewer and stormwater utilities.

One opportunity that the community can act on in the near term involves using the forthcoming Kenton County comprehensive plan update to identify and address barriers in local ordinances to better support sustainable approaches such as green infrastructure. Longer term, the Northern Kentucky representatives would like to work with state and federal agencies to establish context-based regulations. This could include looking at all sources of pollution in the watershed and determining where proper management will result in the best bang for the buck.

Enhanced Community Engagement in Northern Kentucky

SD1 manages the stormwater program on behalf of 31 cities and 3 counties. It developed interlocal agreements with all of these jurisdictions and worked with them to come up with the stormwater requirements. Through its stormwater permit compliance program, SD1 has an award winning public education program. Public Education and Outreach weaves throughout everything that they do. The program includes:

- An interactive outdoor learning center called Public Service Park that features environmental best management practices. The park was built with contractors and developers in mind but turned into an extensive education and outreach project. SD1 hosts tours for engineers, schools kids, community groups, etc.

- An educational program taught in over 60 elementary schools (4th and 5th graders). The program has been successful at the elementary level. Therefore, programming for middle and high school students is currently being developed. A 200 level college course titled “Protecting Water Resources” began at NKU in fall 2009.

- Waterific, a hands on science fair all about water tailored for sixth graders. Students are given the opportunity to interact with many local environmental agencies and learn how these organizations work to better the water resources and quality of life in Northern Kentucky. Typically about 300 kids attend.

- A protecting the environment award program in which schools apply for funds to help complete a stormwater related project. Applications are reviewed by outside agencies and the money awarded to the winners is supplied through a Wal-Mart grant.

- Adult Education: workshops, seminars, educational resources and media outreach. All programs and resources are developed with the intent to encourage a change in behavior.

- Contractor and Developer Awards Program recognizes one contractor and developer for bettering the community through employment of erosion and sediment control BMPs.

Northern Kentucky can build on this existing foundation to further implement the new paradigm incorporating stakeholders more effectively into the design and implementation of its water technological architectures and infrastructure management.

CONCLUSIONS

Many factors are driving communities to become more sustainable. Current water infrastructure management practices, while helping to build our communities and improve environmental and social conditions, are not capable of achieving our environmental, economic and social goals. Communities that embrace sustainability goals will need to operate under a new set of principles, anchored in recognizing the value of water and integrating planning, design, and implementation across multiple institutions and programs. An initial set of these principles have been defined for communities to adopt and adapt as they move forward.

Despite the challenges that have been identified by the research team and retreat participants, there are important actions that can be taken in every community to start building the foundation and architecture for new paradigm sustainable water infrastructure management. Implementing near-term opportunities can have immediate results. However, a number of challenges and actions will take longer to address, and require leadership, capacity-building, and persistence. Recommended steps for moving forward are summarized below.

Near-Term Opportunities

Coordinate Water Master Planning to Realize Synergistic Benefits. Most communities currently conduct master planning for water and wastewater separately in different departments or utilities such as water, wastewater, and stormwater. At a minimum, these plans, which look 20 to 30 years into the future (sometimes even 50 years), should be coordinated with each other and with local comprehensive plan updates, which usually occur every 10 to 15 years. This is important because the Comprehensive Plan is where the local land use plan is developed and resides, and where transportation, open space, recreation, and other long-range planning efforts can come together.

Revise Building and Zoning Codes to Remove Barriers to Sustainable Practices. Find the barriers to sustainable water practices that exist in most state and local building codes and local zoning and subdivision ordinances. This will likely involve the local planning and zoning, public works, engineering, and health departments, as well as state departments of health and environment, insurance and plumbing commissions, etc. Ultimately, we recommend that local codes have green building requirements tailored to meet the local context and needs. Communities do not have to wait for the grand plan; we know enough about green building technologies to start incorporating them now.

Build Local Demonstration Projects to Lead by Example. Individual demonstration projects can be the foundation and the early bricks for the sustainable water system architecture. Government entities can require that all new public buildings incorporate multiple sustainable water features, and support private, incubator demonstration projects. Local examples are essential; communities need to demonstrate success to increase public awareness and support and to help develop the local context for sustainable water management practices.

Use Social Marketing Techniques to Increase Awareness and Support for Sustainable Water Practice. Non-governmental organizations should develop social marketing tools to advance sustainable water practices. Focus on getting people to do something specific. Gather the information that will enable a community to tap into its values and motivate its citizens to take action. Consider which market forces affect the likelihood of taking action, and partner around mutual benefits. Show how sustainable water practices improve peoples' lives and pocketbooks, and then stress the environmental benefits.

Use Stimulus Dollars and Federal Infrastructure Grants and Loans to Jumpstart Efforts. Through 2010—and perhaps beyond—there are federal dollars allocated specifically for sustainable, green water management practices. This includes money for states to set up rebates for water efficiency and water reuse systems, green stormwater infrastructure, decentralized wastewater systems, and others. Local utilities, affordable housing agencies, and local and state economic development agencies can take advantage of federal stimulus grants and loans to create local green industries and jobs, retrofit existing homes and treatment facilities, and build demonstration projects.

Enhance Training and Certification to Build Intellectual Capital. Some state universities and extension agencies, such as North Carolina State University (NCSU), have LID training and certification programs that address stormwater management. The opportunity is there to begin redefining "low impact development" beyond stormwater to include water and wastewater management in a more holistic way. This will require integration of training from various disciplines.

Longer-Term Opportunities

Develop Water Performance Standards to Provide Context. Critical to spending public and private water dollars most effectively is reorienting the siloed-, prescriptive-based standards to performance standards linked to preserving watershed functions and services, and protecting human and ecological health. The standards must be based on context, relative risks, and outcomes, and they must provide flexibility. Importantly, they must be able to target public and private water dollars to those sustainable practices that are most effective across water, wastewater, and stormwater management. The context based performance standards would include large river basin standards, watershed standards, and local green building standards all linked to meet multiple sustainability goals. This will require watershed, risk management and economic tools, all of which are available. More importantly, it will require a shift in thinking from federal, state, and local governments. It will require changes in federal, state, and local laws from the Clean Water Act and Safe Drinking Water Act to local land development codes. It may require an overarching Sustainability Act. And it will require dedicated funding. One relevant example would be performance-based standards for fit-for-purpose water quality. In other words, the water quality required to irrigate plants or flush toilets could be lower than that required for potable consumption. Moving toward these types of flexible standards has the potential to drastically improve water service delivery efficiencies, while sparking water sector cleantech innovation.

Establish New Ownership and Maintenance Models to Address Past Shortfalls. As we move to a combination of distributed and centralized water infrastructure, we are faced with the thorny issue of who is responsible for the distributed systems. Who builds, owns, operates, and maintains them? For distributed wastewater systems, the USEPA has developed guidelines on responsible management (http://www.epa.gov/owm/septic/pubs/septic_guidelines.pdf) and WERF recently released guidance for successfully establishing and running Responsible Management Entities (www.werf.org/rme). However, for some distributed systems—from community wastewater systems and septic systems, to stormwater detention ponds and bioretention areas, to community wells—homeowners and homeowner associations have been put in charge after development is completed. This model has not worked well. We have to come up with new models of ownership and maintenance that work. This could range from local government/utility ownership and maintenance, cooperatives, or water districts. In any case, the entity will need to be a multi-purpose RME, so building on the EPA guidance for distributed wastewater systems is a good starting point. In some states, this may require revisions in state enabling legislation.

Develop Funding and Market Mechanisms to Leverage and Expand Capacity. We need to change local rate structures and state regulations that govern how infrastructure is funded or financed. As previously discussed, the new rate structures should encourage conservation and account for the true costs of providing sanitary sewer and stormwater utility services, including externalities and ecosystem services. Again, models need to be developed and tested that can provide a reliable stream of revenues which cover these full costs—and which are affordable to all customers. While we can glean ideas from the energy sector regarding setting rates and the use of smart monitoring and control technology, affordability must be addressed. Clearly, affordability is an issue now with the silo approach to regulatory requirements. As we look for cost-effective, cross cutting water solutions, customer affordability is part of the bottom line.

REFERENCES

EPRI and Tetra Tech. 2009. Final Report: Case Studies on New Water Paradigm. EPRI, Palo Alto, CA and Tetra Tech: 2009. 068143.

GAO. 2009. *Clean Water Infrastructure: A Variety of Issues Need to Be Considered When Designing a Clean Water Trust Fund*. Government Accounting Office report to congressional requestors, May 2009, GAO-09-657.

Griffiths-Sattenspiel, B. and W. Wilson. 2009. *The Carbon Footprint of Water*. The River Network.

Nelson, V., S. Moddemeyer, and P. Schwartz. 2007. The Baltimore Charter for Sustainable Water Systems. *Hosted by the Coalition for Alternative Wastewater Treatment for Water Environment Research Foundation.* http://sustainablewaterforum.org/baltimore.html.

US Department of Energy. 2006. *Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water.*

USEPA. 2003. *Clean Watersheds Needs Survey 2000.* Report to Congress, EPA-832-R-03-001; U.S. Environmental Protection Agency, Washington, DC.

USEPA. 2007. *National Water Quality Inventory: Report to Congress*. 2002 Reporting Cycle, EPA 841-R-07-001, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/305b/2002report/.