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INSTITUTIONAL CHALLENGES AND OPPORTUNITIES: DECENTRALIZED AND INTEGRATED WATER RESOURCE INFRASTRUCTURE

by

Valerie I. Nelson, Ph.D.
Coalition for Alternative Wastewater Treatment

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ABSTRACT AND BENEFITS

Advocates of decentralized technologies and designs have argued that small-scale, integrated technologies work and are more sustainable in the environment. The failure of mainstream institutions to adopt these technologies is increasingly attributed to institutional and market barriers. The framework of institutions needs to be altered and expanded in the following key respects if decentralized and closed-loop systems are to be adopted over time:

- **Integrated water resource management**–management and regulations need to be integrated across the water chain. Much of the demand for closed-loop reuse of treated effluent, for example, will stem from reducing demand for new water supplies and the avoided cost of loadings to wastewater conveyance and treatment
- **Enhanced role of the private sector**–since most decentralized systems are on private property, the role for the private sector can be much enhanced. Private property owners generally prefer to choose a private contractor to construct and manage their system, rather than a public utility. So, the market model for decentralized systems will likely involve myriad small companies or utilities regulated by public authorities, greater involvement of homebuilders and developers in adopting new approaches, and leadership from Cleantech investors and companies
- **Multiple community benefits and stakeholders**–many of the benefits of decentralized systems are outside the water field, and include recapture of energy from wastewater, recapture of nutrients for agriculture, creation of parks and green space, and regeneration of neighborhoods and local jobs. Engineers and communities need to develop "systems engineering" approaches to "triple bottom line" planning, capital budgeting needs to be integrated across all municipal infrastructure, and multiple constituencies need to be involved in decisions.
- **Continuous innovation**–as in all transitions to a new paradigm, the precise technologies and applications are still evolving and often higher in price than they can eventually be. All parties need to incorporate greater experimentation and innovation in their practice, including government funding of demonstration projects, municipal funding of pilot programs as part of responsible asset management, and early adoption by "green" customers of technologies that are new and more expensive.
- **Streamlined institutional tools**–new, robust models need to be developed, where a package of installation, maintenance, financing, regulatory oversight, and customer acceptance have been shown to work for a given technology. For example, green roofs can be installed, managed, and financed by the private developer, and the municipality can provide financial incentives, "social marketing," and oversight inspections. Cluster wastewater systems can be managed by private utilities. Water-efficiency appliances can be sold directly to homeowners, and developed and marketed by large corporations. These demonstrated "packages" then need to be broadly disseminated in the field.

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Chapter 1

NEW PARADIGM OF DECENTRALIZED WATER RESOURCE INFRASTRUCTURE

A more sustainable water infrastructure will be developed when decentralized technologies are blended into the current, highly centralized network of water and sewer lines and treatment plants. Scattered communities across the US that are facing water shortages, wet weather runoff, sprawl development, and escalating costs of repairing the aging centralized infrastructure are beginning to incorporate one or more of the following trio of decentralized approaches:

- Water-efficient appliances
- Stormwater retention and use
- Decentralized wastewater treatment, reuse, and resource recovery

This trio can reduce per capita consumption of water, restore ecosystem functions, and enhance the larger community benefits of the infrastructure.

Nationwide, great institutional impediments are still in the way of blending decentralized technologies into the mainstream of central system design and practice. A workshop of experts and advocates identified barriers such as:

- Government funding and regulations that have been built up to support the traditional infrastructure
- Distorted pricing of water
- Risk aversion
- Conventional attitudes and expectations of the public
- Management utilities that are oriented around big-pipe infrastructure in public rights-of-way

Four major structural changes in how water is managed need to be made, including:

- Integrating planning, funding, regulations, and design across the currently segmented fields of water, stormwater, and wastewater
- Expanding the role of the private sector in technology development, systems management, and finance
- Creating a closer link between professional practice and community participation
- Carefully managing and stimulating continuous innovation and reform

Robust packages or patterns that combine the use of decentralized technologies with new institutions need to be demonstrated in new Green Building developments and community pilot projects, as well.

Each of these structural changes represents both a significant challenge and a significant opportunity for the field. The current infrastructure model resists large-scale reform, as does any major paradigm of design and practice. But making these changes is more than warranted by the substantial new values and benefits that will result.

Integrated Water Resource Management

Traditionally, water legislation and utility services have been siloed into:

- Water supply
- Stormwater management and flood control
- Wastewater treatment and disposal

Projects were designed, funded, built, and managed separately with little attention to the interrelationships among projects or to the larger point that taking water out or putting treated effluent back into the system affects the whole water system and ecosystem in the watershed.

This siloing of functions has perpetuated the use of big-pipe centralized systems. When a utility is tasked to provide a single service, such as supplying water or disposing of wastewater, the economies of scale in centralizing the infrastructure are the dominant factor. Adding another customer to the piping network or treatment plant costs less than the revenue that customer can provide to the system (water rates are based on average costs across the system). Externalities of environmental harm or disruptions of broader water hydrologies are not considered. In the aggregate, however, as population increases, more land is developed, and climate change exacerbates droughts and heavy rainfalls, this siloed and specialized infrastructure takes, moves, and pollutes too much water in the ecosystem and is not sustainable.

An integrated water resource management perspective starts with the goals of:

- Minimizing waste
- Lightening the environmental footprint
- Maximizing community benefits of the infrastructure

Figuring out what this new integrated system would look like is not obvious. The following five scales and perspectives of integration are a start:

1 **At the “appliance” or technology level, the trio of decentralized water-efficiency, stormwater retention, and wastewater treatment and reuse should be blended into common programs.**

The Environmental Protection Agency (EPA) continues to have separate policies and programs in each of these sectors, rather than an integrated decentralized systems approach. For example:

- WaterSense is a program that promotes water-efficient appliances and landscaping
- The new Green Infrastructure initiative promotes low-impact development and natural stormwater systems, such as green roofs
- The decentralized wastewater management program promotes onsite and decentralized wastewater systems, particularly in rural and suburban areas

What neither the EPA nor program advocates have yet recognized, however, is that these "appliances" have already begun to emerge together in scattered discussions about sustainability in the water system. The rank order may vary depending on the issue at hand. For example:

- In Georgia or Australia, where drought and water supply shortages are a major concern, analysts and advocates are looking to reduce per capita use of the water by installing water-efficiency appliances, harvesting rainwater, and reusing wastewater in that order of cost-effectiveness (Vinson 2006; Commonwealth Scientific Industrial Research Organisation 2007.)
- In cities such as Seattle and New York, where stormwater runoff and combined sewer overflows are a problem, stormwater retention rain and roof gardens have been promoted, along with water-efficiencies, and recently, a demonstration project for wastewater reuse (Seattle Public Utilities 2003; Clerico 2007)

The EPA and decentralized advocates should merge the three programs—WaterSense, Green Infrastructure, and decentralized wastewater management—into a common program, where strategies such as product labeling, incentives, social marketing, and cumulative impacts can be jointly addressed.

2 At the site or neighborhood level, the Green Building movement should take an integrated approach to water conservation, reuse, and resource recovery.

The highly successful Green Building movement in the US has yet to take a comprehensive approach to sustainable water management. Australia has been developing a ratings system that assigns higher points for localized capture and disposal, as well as reuse of both water and nutrients in landscaping.

In the US, however, only modest numbers of points in Leadership in Energy and Environmental Design (LEED) are assigned for water-efficiencies, and onsite stormwater management.

Design and management at the site or subdivision level is ripe for achieving efficiencies and synergies in the whole water cycle. For example:

- At the Solaire in New York City, stormwater and wastewater are blended in the membrane treatment system in the basement, and the combined effluent is used for toilet flushing, landscaping, cooling towers, and laundry (Clerico 2007)
- In Texas, companies formed for onsite wastewater system management are discovering that they are highly qualified to meet new requirements for onsite stormwater system management
- UC-Berkeley is designing "eco-blocks" (urban infill developments), which use organics in wastewater as a source of energy to complement wind and solar power (Fraker 2007)

Water and wastewater engineers involved with the Green Building movement have just begun to scratch the surface in developing "off-the-grid" water and energy systems. Over time, integrating these systems into the practices of developers and builders could dramatically reduce the impact of new development on ecosystems and hydrologies. Through infill developments, they could begin to reduce the adverse impacts of existing urban areas as well. Water-centric designs of new and infill developments can also create green spaces and improve air quality.

3 At the municipal level, asset management and facilities plans should be based on full benefit and cost comparisons of the centralized and decentralized options.

As described in the preceding paragraphs, the critical driver for centralized infrastructure has been the economies of scale in big-pipe construction and management projects and treatment plants. However, these systems are generally wasteful of water, disrupt ecosystems, and miss opportunities for community benefits.

Multiple-benefit analysis and true cost pricing will drive municipalities toward adopting localized and closed-loop systems within their boundaries. Advancements in technologies, such as membranes, have also increased confidence that small-scale treatment units can adequately protect public health.

Municipalities with aging water and sewer systems will need to consider whether decentralized systems can help them avoid large new capacity projects, and alternatively, avoid or delay major repair and replacement projects. Communities without public water and sewer can avoid centralized systems entirely.

Decentralized systems will begin to challenge continued investments in centralized approaches for several reasons:

- Water conservation is primarily achieved through onsite water-efficient appliances and reuse
- Treatment and reuse is more efficient at the local level, since pumping water in, wastewater or stormwater out, and reuse water back in is expensive
- Other benefits are also local by definition—such as tree-plantings, green roofs, and stream restoration—and are dispersed across the municipality

A municipality could adopt two approaches to incorporate decentralized systems:

- Developing appliance promotion programs, which would be installed at scattered sites throughout the area
- Creating closed-loop designs for new construction and infill development

The first choice could involve social marketing and incentive programs for homeowners and businesses to purchase water-efficiency and reuse technologies, plant trees, and other such efforts.

The second option could involve encouraging developers and builders to implement off-the-grid designs, or utilities could build and manage decentralized, or satellite, treatment systems on public property.

4 At the watershed level, assessment and planning should be integrated across the water cycle.

Recently, on the water quality side, there has been interest in combining stormwater and wastewater management in a larger “watershed” perspective of surface water quality concerns. The Clean Water Act established a Total Maximum Daily Load calculation that required an analysis of all point and non-point sources—including agricultural runoff—for stream segments. This provision is being more rigorously enforced by the EPA and advocacy groups.

On the water quantity side, there have also been conferences and reports by groups such as the Awwa Research Foundation (AwwaRF), which has urged an integrated water quantity/quality approach. (Commonwealth Scientific Industrial Research Organisation 2007) None of these arguments and initiatives has penetrated more than superficially into the practice of utility management at the local level.

Watershed organizations need to be pushed further to integrate both water quantity and water quality considerations, and ultimately to incorporate resource considerations, such as energy use, and principles of sustainable community design.

In Tennessee, for example, university faculty are trying to help communities identify development and infrastructure patterns for new development in rural areas that maintain ecosystem functions, while also building livable communities (Moir-McClean and DeKay 2006).

5 At the federal and state levels, policy, funding, and regulatory structures need to be integrated across the water cycle.

Several politically difficult, but essential, steps should be taken at the federal level:

- All federal funding programs should require integrated water management analysis for individual projects
- Incremental steps should be taken to incorporate decentralized water-efficiency, stormwater retention, and wastewater treatment and reuse systems in a variety of federal permits and regulations, including Army Corps, Drinking Water, National Pollutant Discharge Elimination System (NPDES), and others
- A major overhaul of federal regulatory structures in water should be studied so that water sustainability becomes the performance objective
- Consideration should be given for greater inter-agency coordination and eventually the establishment of a new Department of Water modeled on the Department of Energy

Chapter 2

PRIVATE AND PUBLIC SECTOR INVOLVEMENT

Enhanced Role of the Private Sector

While private wells and septic systems in rural areas have generally been managed by homeowners, the "permanent" water and sewer lines and treatment plants built in urban and suburban areas have been the responsibility of public utilities. "Privatization" of these large utilities has been relatively rare in the US, in contrast to Europe and Australia, in particular. Integrating the "trio" of decentralized systems into this mainstream public infrastructure will largely be through private sector activity, but municipalities will have to oversee this process and ensure that the public is well served.

The likely private sector dominance of the decentralized water field is a challenge to conventional thinking and practice, but it can be a tremendous opportunity for leveraging the creativity and dynamism of entrepreneurs and inventors and for shifting some of the financial burden of infrastructure installation and maintenance onto private transactions.

The EPA has taken a strong stance for utility management, and even outright public ownership, of decentralized wastewater systems, in particular (EPA 2004), but that approach needs to be reconsidered. In spite of EPA advocacy, few public utility management models for decentralized systems have emerged, and that is largely explained by the unsuitability of market conditions for this role.

The basic reasons for an enhanced role of the private sector, and conversely, a minimized role of the public sector, is that decentralized infrastructure is usually on private property, and services are customized for each buyer, whether at an individual home, subdivision development, or commercial property. Generally, neither the customer nor the municipality is interested in direct utility management of this work.

Homeowners and builders are used to hiring their own contractors and subcontractors, such as electricians and plumbers, and they prefer being able to choose their own contractor in water, stormwater, and wastewater as well. Additionally, municipal utilities are used to managing large treatment plants and pipes, and are quite nervous about trying to work with and control thousands of quirky and demanding homeowners and businesses. Therefore, it is not surprising that most water-efficient appliances, green roofs, and advanced onsite treatment units are being purchased, installed, and managed by private customers and contractors.

The cluster system that mimics the conventional sewer, but on a smaller scale, is a more market-friendly fit with conventional utility management, because management of the advanced treatment unit is controlled by individual homeowners. Case studies show that cluster system management is being more readily adopted by both existing municipal and new private utilities.

Disinterest, doubts, and unease by municipal utilities about managing decentralized units on private property have a lot to do with their relative lack of use so far. Also, federal and state enforcement officers and permit writers are more comfortable with municipal responsibility for centralized systems than private management of multiple, dispersed treatment units. Past poor homeowner association management of package treatment plants, in particular, has led government agencies to be cautious. However, utilities and government agencies alike will have to bend in the face of the significant benefits that decentralized units can bring to the water field, and will have to develop the oversight mechanisms to assure accountability and compatibility with their larger objectives in water services, ecosystem protection, and community benefits.

Creativity and Innovation in the Private Sector

Part of the advantage of a private sector model is the creativity and innovation that entrepreneurs can bring to the field. The decentralized private sector model offers a number of opportunities:

- **Private sector companies install and manage decentralized technologies**—This is a natural fit for the private buyer and a competitive choice among small service providers in the community
- **Private companies invent and manufacture decentralized equipment**—If use of decentralized systems were to expand, private companies could become more involved in the invention and manufacture of equipment. The current market is mixed. Large corporations are involved in water-efficiency appliances, such as washing machines. However, most of the decentralized wastewater system manufacturers are still relatively small due to great fragmentation in local regulations and systems that are permitted across the country. The larger companies look at the field and back away. Companies do not want to have to redesign a new system for each different set of local regulations, nor go through the expense of getting their systems permitted in one locale after another. An important way to break down this fragmentation is the development of "voluntary national standards" that could be adopted by more and more municipalities, counties, and states over time. These standards, along with expanded use of decentralized systems, would encourage corporations like General Electric (GE) to invest in the decentralized field and bring in its creativity, marketing skills, and general knowledge. These standards would also increase venture capital investments in new Cleantech equipment, which includes knowledge-based products or services that improve operational performance, productivity, or efficiency while reducing costs, inputs, energy consumption, waste, or pollution
- **Green Building adoption of decentralized systems—**Developers and builders search for niche markets of early adopters, and currently there is much interest by homebuyers in green building and infrastructure. New subdivision and infill developments are a key arena for introducing decentralized, closed-loop systems into the infrastructure. Private management companies and manufacturers can also collaborate with developers and builders to advance innovative, leading-edge approaches

- **Private capital investments in sustainable infrastructure—**The Vancouver Valuation Accord is a major example of an effort to build triple-bottom line analysis into investments such as in real estate, pension, World Bank, and insurance (Vancouver Valuation Accord 2007; Freshfields Bruckhaus Deringer 2005). For example, municipalities will not get an automatic pass on bonding for traditional sewers. Big real estate companies will need to show that their approaches reduce risk. The UN Freshfields report out of the UK says this practice will be necessary in the future. Because decentralized technologies can enhance the long-term sustainability of the infrastructure, this review of investments can be a major incentive of their use

Aligning Private and Public Sector Interests

The key to an appropriate and successful role of the private sector in decentralized systems will be in aligning the private and public interests. Case studies have shown that new private companies are doing important work in establishing models for installation and management of small-scale treatment units. But, the larger and longer-term interests of the public are not yet being protected. Over time, the following issues were identified that will need to be addressed:

- **Accountability and control—**Private companies have not always advocated the intensity of maintenance and repair needed for systems to function properly. Public agencies will need to develop effective inspection and oversight programs, certification systems, and fines so that this maintenance is assured
- **Equity—**Many of the new installations are in up-scale new subdivisions. Public agencies will need to provide subsidies, and eventually, mandates for decentralized treatment installations regardless customer income
- **Land use—**Developers are discovering that cluster wastewater systems and low impact development practices can lower the price of water services in new subdivisions, but these developments are not always consistent with broader community or watershed land use needs

Developing Public Policies and Managing the Private Sector

Municipal utilities will need to explore and ultimately feel more comfortable with a set of new tools to manage decentralized infrastructure. Instead of directly installing, maintaining, and owning the infrastructure, they will need to provide incentives and oversight of the infrastructure. Like the transition energy utilities made to encouraging solar panels on private property, utilities will need to institute:

- Financial incentives to the homeowner or business, including tax incentives, rate incentives, or rebates
- Social marketing programs to encourage the purchase of decentralized units
- Possible ordinances or mandates for decentralized systems, if voluntary use is not high enough
- Inspection programs to assure compliance
- Planning procedures for understanding the role of decentralization in the broader infrastructure mix, patterns of siting the infrastructure appropriately, and others

Federal and state governments will also need to adapt to, and provide incentives for, an enhanced role of the private sector.

- Grants and loans made available to communities should be flexible, so that communities can use the funds to set up homeowner revolving loan funds or grants
- Tax incentives directly for the customer should be considered
- Efforts should be made to establish national standards in management, technology performance, certification and training of installers, and green building ratings

Federal research and development investments can be made in partnerships with the private sector to pilot test new inventions and to commercialize and disseminate their use. Finally, federal "champions" can provide signals to the private sector that decentralization is a key to future sustainability in the infrastructure, and Cleantech investors and others will likely follow.

Chapter 3

INNOVATION IN COMMUNITIES

Multiple Community Benefits and Stakeholders

In the past, most of the heavy lifting in the provision of water, stormwater, and wastewater infrastructure has been provided by engineers, managers, and staff trained in big-pipe systems and treatment plants. Public regulators and funders have overseen and supported this infrastructure, as have non-governmental organizations (NGOs), which have seen water and sewer systems as the best means to protect public health and surface water quality where treatment plant effluent is released. Economic development advocates have also seen public infrastructure as an underpinning for growth.

Nesting decentralized systems in this centralized grid will require a refashioning of the goals and objectives of these traditional participants, as well as an involvement of a host of other stakeholders and disciplines, particularly in the early stages of invention.

These changes, which require an increasing complexity of the work, will be a challenge for the field. They also constitute a significant opportunity to increase the sustainability of the infrastructure and enhance the values produced by the infrastructure. In scattered projects around the country, collaboration and non-traditional alliances are the foundation for new and higher-value initiatives.

Expanding the Objectives for the Infrastructure

As mentioned earlier, an integrated water resource management perspective starts with the goals of sustainability, lightening the environmental footprint, and community benefits. However, scattered communities and entrepreneurs across the country are discovering that water, stormwater, and wastewater infrastructure can create significantly more value in communities than the traditional centralized provision of clean water and sanitation services have been delivering.

The trio of decentralized technologies, in particular, can reduce overall water usage and be used to:

- Restore and maintain ecosystem services
- Save energy
- Produce energy and nutrients
- Create green spaces
- Improve air quality
- Restore urban streams and ecosystems
- Create green companies and jobs

These benefits will be realized when management of the infrastructure is significantly more integrated and when the private sector has an enhanced role. This will require

- Familiarity with more complex "systems engineering" for environmental, social, and economic benefits
- Natural system functions provided by soils, trees, etc., and by new engineered technologies
- Complex watershed processes and functions
- Social marketing and incentive financing
- Community revitalization

Expanding Participation in Infrastructure Design

Significantly more diverse constituencies, professions, and bureaucracies will be required to make decisions about water infrastructure, particularly during phases of invention and experimentation. From the start, a broad range of municipal bureaucracies will need to participate in asset management and facilities plans.

How can the existing centralized and new decentralized infrastructure maximize environmental, energy, and other community benefits? Professionals in water, energy, and transportation engineering, architecture and landscaping, ecosystem functions, community development, and economic development will need to collaborate. In the process, the efficiency of city services will be improved and the benefits will be increased.

Municipal staff will also need to collaborate with both private and nonprofit sector groups. Traditionally, municipalities have presented citizens and stakeholder groups with a set of options and requested public input. In the future, the public and stakeholder groups need to be involved from the start in the generation of options.

The role of the voluntary nonprofit sector, in particular, needs to be enhanced. Environmental NGOs have been creating non-traditional alliances around the country in recent years, in such areas as ranch management, dam removal, and urban environmental justice. These alliances with the private sector and city officials have generated creative new solutions, including in the use of decentralized technologies in cities. The Green Building movement, based on the alignment of interests of builders, manufacturers, environmental NGOs, and public agencies, is another example of the synergies of expanding the conversation.

NGOs need to broaden their understanding of centralized and decentralized water infrastructure and their long-term sustainability, impacts on ecosystems, and community benefits. The environmental and social justice organizations in the past have supported funding and enforcement of traditional centralized projects. It is important for these groups to rethink the broader implications of this support and to research and reconstruct a new and broader set of objectives for the infrastructure. It is also important for NGOs at federal, state, and local levels to participate in the generation of new policies and institutions.

Continuous Innovation

The decentralized water field is still in an early stage of development and support needs to be provided for innovation. This way of looking at the field is very important because the market organization literature suggests:

- **New products tend to be more expensive.** Costs fall as the market matures. Decentralized systems may be more expensive at this early stage in the development of the field and should not be held to a strict cost-effectiveness standard. Demonstration project funding is useful to cover these additional costs
- **Without public funding, markets will under-invest in research and innovation—** The decentralized field is suffering from insufficient investments in research and demonstration projects—practitioners and advocates have sub-optimal choices and lack performance data and good examples for robust systems
- **The early adopters tend to be visionaries with willingness to try out and customize products to their needs—**Pragmatists, on the other hand, in later diffusion stages are often more concerned about cost-effectiveness and comparative performance of systems. The decentralized field should support early adopters and look to their experiences for lessons on what works
- **Avoidance of risk is a key factor in conservative choices among technology options—**The Government should seek ways to help communities by absorbing risk through financial support and regulatory/enforcement flexibility
- **Government regulations are the most potent driver of innovation in a public-private market—**The regulations need to incorporate principles of "adaptive management," so they do not block innovation.

Without serious consideration of these factors, the decentralized field remains caught in a self-reinforcing trap. Existing technologies and institutions may have high costs and unknown performance, but without government engagement, there are few openings for new systems to be tried and to mature.

Development, Piloting, and Early Adoption

Students of innovation and market change generally separate the process into phases: development, piloting, early adoption, and dissemination. The EPA and industry experts in the decentralized field have developed strategies designed primarily to promote the dissemination of existing practice and knowledge, arguing, in effect, that enough is already known. A more accurate portrait of the field is to see it as still being in the development, piloting, and early adoption phases and to build strategies appropriately.

The EPA's 1997 *Response to Congress on the use of Decentralized Wastewater Treatment Systems* (EPA 1997) is an example of the following assumptions:

- Technology is available to treat wastewater onsite
- The key to permanence is adequate long-term, professional maintenance and management
- Decentralized systems will be adopted once barriers are identified and removed
- Mainstream institutions (engineers and utilities) are the primary audience for information on decentralized alternatives

- Small communities and homeowners, as the ultimate customers of systems, should be educated on the cost-advantages, in particular, of these approaches and persuaded of the need for management

Recent history suggests the field is at a much earlier phase of development, piloting, and early adoption. Several indicators of this high level of innovation and uncertainty are:

- New markets are opening up that were not widely foreseen in 1997 (cluster systems, urban use)
- New demands for energy and nutrient recovery and reuse are emerging
- The benefits and costs of decentralization are not well understood
- Failures of technology and management are common
- Adopters of decentralization are not mainstream institutions, but rather outliers, such as developers and environmental advocates
- Models for management, regulations, and decisionmaking still need to be developed

Strategies to Promote Innovation

Starting in the 1980s, the federal government began cutting back on water-related research, with the assumption that states and the private sector would pick up the slack. That shift has not occurred. Private investments in water technology research and development have also fallen in recent decades (U.S. General Accounting Office 1994).

The federal government needs to restore a significant research and development and demonstration project program. Basic research in biotechnology and nano-technology will generate breakthrough treatment and telemetry technologies. Watershed and climate research will help in predicting the differential impacts of the water infrastructure. Demonstration project funding will help absorb the risks for local communities in piloting new technologies and developing new institutions.

The federal government can also encourage innovation by water, stormwater, and wastewater utilities by revising permitting and enforcement practices to encourage “adaptive management.” Existing permits and consent decrees lock in conventionally-engineered approaches, and minimal time or space is provided for municipalities to explore innovative, decentralized solutions. There is a Catch-22, in effect. Regulators do not encourage pilot projects that would provide performance data but, without performance data, regulators will not allow new systems to be used. In the long-term, integrated and performance-based reform of federal statutes in water should be pursued.

Finally, the federal government can provide leadership to stimulate both private and nonprofit funding of research. National challenges to set water infrastructure on a more sustainable path, help with commercialization and exporting of new products, development of voluntary national standards, and piloting of new technologies in federal facilities can all be signals to corporations and foundations that there will be wide openings in the future for new decentralized technologies and institutions. Corporations can invest in future profits and foundations can invest in solutions that enhance ecosystems and bring other benefits to communities as well. Federal support for Green Building is an example of this assistance and “signaling” by the federal government.

Streamlined Institutional Tools

As the preceding recommendations suggest, substantial institutional innovation and reform is needed if decentralized infrastructure is to be used appropriately. In summary:

- Integrated designs, planning, funding, regulations, and management are needed
- The private sector role needs to be expanded and governments need to develop mechanisms to assure that private and public interests are aligned
- The objectives of the infrastructure need to be expanded, and nonprofit organizations need to play a leadership role in creating new models and alliances among non-traditional stakeholders
- The water field needs to adopt a strategy to promote research and innovation

These institutional changes suggest the need for a complex paradigm shift. Little is known about the precise shape or structure that will emerge in each of these areas. In general, an unacceptable level of complexity and uncertainty exists, and communities are left to invent and pilot approaches largely on their own.

Ultimately, as in any new field, robust models need to be developed that incorporate the suggested technology and institutional changes. These models need to include a comprehensive package of installation, maintenance, financing, regulatory oversight, and customer acceptance. Case studies will have to show that these packages work for a given technology. For example:

- Green roofs can be installed, managed, and financed by the private developer, and the municipality can provide financial incentives, "social marketing," and oversight inspections
- Private utilities can manage cluster wastewater systems
- Water-efficiency appliances can be sold directly to homeowners, and developed and marketed by large corporations

These demonstrated "packages" need to be broadly disseminated in the field.

Chapter 4

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