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**FINAL
REPORT**

Long-Range Planning for Decentralized Wastewater and Stormwater Treatment Research: Workshop Summary

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LONG-RANGE PLANNING FOR DECENTRALIZED WASTEWATER AND STORMWATER TREATMENT RESEARCH: WORKSHOP SUMMARY

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2007



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ABSTRACT AND BENEFITS

Abstract:

A two-day workshop was conducted in March 2007, immediately following the National Onsite Wastewater Recycling Association's *First US International Program on Decentralized Systems*, to begin charting an international research agenda in support of an integrated and sustainable water infrastructure in the U.S. The workshop participants included scientists, teachers, engineers, regulators, manufacturers, and others from around the world in an effort to gain the broadest possible perspective on current and future environmental science and engineering research needs.

The workshop participants formulated a consensus vision, called *The Baltimore Charter for Sustainable Water Systems*. Smaller working groups of participants working independently formulated 11 research challenges in the areas of regulations, policy, and economics; public involvement, education, and demonstrations; and natural systems, technology, and decision or social science.

Benefits:

- ◆ Provides a summary of priorities for future research projects in the area of distributed wastewater and stormwater infrastructure.
- ◆ Proposes a vision for sustainable, decentralized water infrastructure.
- ◆ Brings an international perspective to identifying research priorities.
- ◆ Identifies key ideas and messages necessary to create a new thinking around a sustainable water infrastructure.
- ◆ Creates a worldwide network of leading thinkers on distributed wastewater and stormwater infrastructure.

Keywords: Onsite wastewater treatment, soft paths, integrated water infrastructure, decentralized wastewater, decentralized stormwater; distributed infrastructure

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LIST OF ACRONYMS

CAWT	Coalition for Alternative Wastewater Treatment
EPRI	Electric Power Research Institute
ES&E	Environmental science and engineering
IWA	International Water Association
MBR	Membrane bioreactor
NASA	National Aeronautics and Space Administration
NDWRCDP	National Decentralized Water Resources Capacity Development Project
NOWRA	National Onsite Wastewater Recycling Association
NRECA	National Rural Electric Cooperative Association
U.S.	United States
WERF	Water Environment Research Foundation

EXECUTIVE SUMMARY

The *Workshop on Research Needs in Decentralized Wastewater, Stormwater, and Related Fields* was co-sponsored by the Water Environment Research Foundation (WERF) and by the National Onsite Wastewater Recycling Association (NOWRA), and was held on March 14-15, 2007 in Baltimore Maryland, immediately following the First U.S. International Program on Decentralized Systems.

The purpose of the workshop was to build future visions, identify research gaps, gain guidance on promising avenues for investment, and begin collaboration discussions on a sustainable water future among various sectors within the United States and with the global community. Workshop participants included U.S. and international professionals and policy makers in decentralized wastewater, storm water, and related fields like green building and water reuse.

The products of the workshop were a consensus vision statement, called *The Baltimore Charter for Sustainable Water Systems*, and 11 research challenges developed by smaller, independent groups of participants:

- ◆ Develop and implement a unified regulation and compliance structure for distributed systems.
- ◆ Define an effective integrated water management strategy, and provide tools, policies, and regulations that allow communities to achieve a local vision of sustainability. To that end, invest in data collection, analysis, monitoring, economic analysis, and risk analysis, and risk analysis to support integrated water management infrastructure.
- ◆ Develop new economic methods, translatable into practical tools, that sufficiently address full cost integrated water pricing, including secondary economic benefits and consequences, community values, and local priorities.
- ◆ Demonstrate the possibilities and benefits of integrated water infrastructure in a way that is meaningful, useful, and desirable to the public. These demonstration projects should encompass other sectors that affect water (such as transportation and energy).
- ◆ Conduct market research and create social marketing initiatives about a sustainable water infrastructure to reach target audiences and define successful outcomes, and provide for the training of community assistance providers to effectively convey these principles and facilitate implementation.
- ◆ Identify products and practices leading to ‘conspicuous conservation’ and effective pollutant elimination by consumers and consumer services.
- ◆ Improve water literacy in the general public by developing and delivering effective and scientifically accurate messages in a simple and readily absorbed manner.
- ◆ Understand the ecological switches controlling the water cycle; define criteria for ecosystem health; and use integrated tools to understand the network of interactions between our water systems and the environment and implications to human health.
- ◆ Understand the impacts of all types of water and wastewater systems on human health, while documenting the fate and transport of constituents (chemical and biological) in water and ultimately to the point of human exposure.
- ◆ Minimize resource utilization and maximize resource recovery by using intelligent, efficient, adaptable, sustainable technologies.

- ◆ Use social and decision science to engage communities in integrated design and planning for water sustainability which will result in cost savings, water protection and healthier communities.

CHAPTER 1.0

INTRODUCTION

The synthesis report and workshop completed through this project continued work started in the mid-1990s by the National Decentralized Water Resources Capacity Development Project (NDWRCDP). The NDWRCDP is a collaborative effort of the Coalition for Alternative Wastewater Treatment (CAWT), the Consortium of Institutes for Decentralized Wastewater Treatment (Onsite Consortium), the Electric Power Research Institute (EPRI), the National Rural Electric Cooperative Association (NRECA), and the Water Environment Research Foundation (WERF). The NDWRCDP's purpose is to coordinate and implement a national training, research, and development agenda in decentralized water resources.

At a research needs conference held in 2000, papers were presented on gaps in the science of treatment in soil absorption systems and of fate and transport of nutrients and pathogens. A 2001 strategic retreat, with input from a wide range of policy and industry experts, helped to further prioritize these topics, and a research plan was published in 2003 that identified 22 research priorities within the field of decentralized wastewater environmental science and engineering (ES&E).

In 2006, a literature review was conducted to provide an overview of some of the research completed since 2002 related to decentralized wastewater ES&E priorities and to summarize current research in ES&E related to decentralized stormwater (Appendix G). This review became part of the background material distributed to participants prior to the workshop.

The Workshop on Research Needs in Decentralized Wastewater, Stormwater, and Related Fields was co-sponsored by WERF and NOWRA, and was held on March 14-15, 2007 in Baltimore Maryland, immediately following the First U.S. International Program on Decentralized Systems.

The purpose of the workshop was to build future visions, identify research gaps, gain guidance on promising avenues for investment, and begin collaboration discussions among various sectors within the United States and with the global community. Workshop participants included U.S. and international professionals and policy makers in decentralized wastewater, storm water, and related fields like green building and water reuse.

1.1 How to Use This Report and Summary of Activities

Chapter 2.0 contains a summary of the activities conducted during and the final products of the workshop. Additional workshop documentation, including the attendee list with contact information, background information, and materials produced during the workshop, is included as Appendices to this report.

On the first day of the workshop, after an introduction and discussion of background information (Section 2.1), three smaller working groups of participants formulated research challenges at the individual site scale, the community scale, and the municipal (urban) scale

(Section 2.2). The three groups came back together at the end of the first day to hear each group's challenges and to provide feedback (Section 2.3).

After the first day's workshop session was complete, the steering committee met to determine the agenda and focus for the second day of the workshop. The focus of the second day was changed from working at the site, neighborhood, and municipal levels envisioned in the original agenda to encompass a total of four working groups. One group would create a vision or values statement to articulate elements of an integrated and sustainable water infrastructure, using the information from the Wednesday session and additionally informed by discussion at an initial plenary on Thursday morning. Three additional working groups would formulate and prioritize research challenges that, if completed, would most aid in achieving the group's vision for a sustainable water infrastructure.

At the beginning of the second day of the workshop, participants were asked to brainstorm on the kinds of key elements that should be included in a similar vision statement from this workshop (Section 2.4), and then to vote on prioritizing the key elements. Based on the results of Wednesday's work and the Thursday morning plenary, new small groups were assembled. Each working group was asked to either formulate the vision statement or to identify the top 4-5 research challenges that, if accomplished, would most influence the future (Section 2.5). The working groups then re-convened in plenary session to hear short reports on the research challenges and to accept feedback from the other workshop participants. The feedback for each group of research challenges is included after the summary of each working session in Section 2.5.

After all breakout groups had presented their research challenges and received feedback from the conference participants, the breakout groups reconvened to refine the research challenges and to produce a 60-second summary of their work (Section 2.6).

In the period following the workshop, the vision statement breakout group made additional revisions to the statement presented at the final plenary session (Section 2.7). While the vision statement is a consensus document that was generally agreed upon by the participants in the workshop, the research challenges developed by the independent working groups during the workshop (Section 2.8) were not always discussed to consensus by the participants.

CHAPTER 2.0

WORKSHOP DOCUMENTATION

The following summary of the activities during and products of the long-range planning workshop roughly follows the format of the workshop's agenda (Appendix C).

2.1 Introductions, Overview, and Background

After a brief welcome statement from Doug Sarno, all participants in the workshop introduced themselves and gave a brief explanation of their own experience and expertise (a complete list of participants is included in Appendix A).

Valerie Nelson (CAWT) gave a short presentation about the motivation for the workshop (Appendix B). The workshop's goal was to set a new agenda for research and development and demonstration projects to promote a sustainable water resource infrastructure. Ms. Nelson's presentation highlighted the history of decentralized wastewater research and demonstration projects funded by Congress and others and summarized the discussions about future funding that are happening now at the federal level. She also emphasized the opportunities for international collaboration that were personified in the diverse attendance at the workshop.

Glenn Daigger, representing the International Water Association, gave his perspective on leading edge activities, opportunities, and needs for water resources research. His main question to the participants was "How do we combine the best of all available solutions to find the right one—how do we change *either/or* to *and*?" Mr. Daigger's challenge to the participants was to articulate the value of a new water resource paradigm through research dealing with the 'how' and the 'what' of that paradigm.

Scott Johnstone (Stone Environmental, Inc.) presented a summary of the key themes identified during the international session of the preceding NOWRA/IWA conference (Appendix B). Mr. Johnstone's presentation summarized the international session by using two reflections on leadership from Dr. Bill Grace: one, tell the truth; two, provide hope and inspiration. The truth spoken by many of the international presenters was that we have a moral and humanitarian obligation to address problems relating to water at a human scale. For example, despite recent progress in the developed world, billions of people worldwide do not have access to sanitation. Closer to home, in the U.S., we find that our water infrastructure is not sustainable financially and that our consumptive relationship to water is already causing scarcity in some areas.

There is ample room for hope and inspiration too, but as one of the presenters from the international session said, "We must figure out how to articulate this new vision with clarity if the new paradigm is to gain traction". Some of the broad concepts and ideas discussed during the international session included:

- ◆ Integrated water resource management
- ◆ Sustainability

- ◆ New models of partnership
- ◆ The role of people

After these presentations, a question and answer session was held to hear about the participants' perspectives. Comments received included:

- ◆ People and their institutions are a necessary part of the discussion
- ◆ What would the international guests like to see out of this workshop?
- ◆ We have not, in the past, been thinking about sustainability.
- ◆ We need to link in energy, transportation, jobs, etc.

2.2 Small Group Work Session 1: Identify Research Challenges

At the end of the introductory plenary session, three breakout groups were tasked with identifying current gaps in knowledge and research challenges were convened at three scales: site, community, and municipal (larger urban areas). Each of the breakout groups began with a general discussion of the issues introduced during the plenary that were relevant to their scale, including anything that was missed by the introductory presentations. The initial discussions were then refined to no more than five research challenges per breakout group. The results from these breakout sessions are summarized below.

2.2.1 Individual Site Level Breakout

The onsite breakout group initially developed a total of four research challenges.

Regulatory Reform: Integrated Regulatory Reform Leading to Sustainability

The first research challenge was centered around regulatory reform: to inspire useful regulation development, be it prescriptive, performance-based, or both, ensuring efficient, effective regulation that protects public health and the environment while welcoming innovation. Research to meet this challenge includes developing intelligent performance standards or evaluation processes for wastewater systems and funding demonstrations of the new standards or processes. Developing approval processes for small-scale reuse technologies could be part of this effort, or a separate effort. Finally, to meet this challenge, there is a need to force consideration of integrated (or at least mixed) centralized and decentralized solutions for new development and retrofit development. There is a real need to include *values*, not just costs, in feasibility-level calculations and analyses.

Research: Improve Quality and Dissemination of Basic and Applied Research

In the U.S. decentralized wastewater industry, a real challenge is to inspire the industry to align claims of performance with reality. When research is accomplished it should be defensible and reproducible, published in appropriate journals, and communicated adequately to regulators and practitioners.

Specific needs for research at the individual site level include:

- ◆ Continued and sustained efforts to facilitate comparison of available technologies.
- ◆ An assessment on the “triple bottom line” based on sufficient performance research.

- ◆ Accurate, impartial analysis of both current and future treatment processes is essential.
- ◆ Simple ways to share basic information on complex topics such as economics, human health impacts, the performance of onsite systems in specific environments, and onsite approaches to watershed health.
- ◆ Standardized protocols for assessing alternative technologies.
- ◆ Better characterization of trace contaminants in water systems to determine their impacts on people and ecosystems.
- ◆ Methods for recovering wastewater constituents for reuse at the individual system scale.

Resources: Integrate Resource Pool of Centralized and Decentralized Knowledge with Broader Values

One way to start moving from the centralized/decentralized dichotomy to an integrated water infrastructure is to critically evaluate current funding structures for wastewater projects—and to make changes to those funding structures so that integrated, sustainable projects have higher priority. In order for this sort of change to be feasible, accurate and impartial analysis of current treatment options is needed at all scales, not just the site scale.

Other specific needs at the individual site level include both human and monetary resources, such as:

- ◆ Tax or financing incentives for developing business models that promote water reuse at the site level
- ◆ Monetary incentives for education and research and development
- ◆ Developing methods to recover waste water constituents for reuse at small scales, as well as and developing markets for the recovered resources
- ◆ Identify and build a coalition of winners for a new paradigm that includes decentralized systems

Education and Capacity Building: Develop a Common Base of Understanding to Enhance Public Awareness and Education

The focus of this research challenge is to develop capacity to implement integrated water management at an individual site in a sustainable manner. Models and decision support tools are needed that are capable of quantifying processes, systems, and benefits in a way that shows the real consequences of each possible option. Another challenge is to use the results of both modeling efforts and real projects that have already been implemented to inform more sustainable management of systems at the site level, through such means as updating regulations or integrating new information into practitioner training.

2.2.2 Community Breakout

The community level breakout group started by defining “community scale” as greater than 10 homes, but less than an urban area or single-purpose municipal jurisdiction. This group developed a total of five research challenges.

Research and Demonstration Projects

Basic research and demonstration projects are needed that implement sustainable community design, based on both dollar costs and the value of ecological services and other

intangibles. There is a need for objective evaluation of the operational sustainability and total value of a range of systems for community applications in a variety of natural settings. The range of technologies may include existing “off-the-shelf” systems, retrofits, hybrid systems, and new or experimental technologies.

Matching Systems with Problems and Communicating Solutions

This challenge is twofold: first, to build on existing work and develop guidance for matching community water and wastewater problems with technology options; and second, to communicate these options in plain language to decision-makers and citizens and to better understand how to engage communities in the decision making process. The decision making process must include ecological impacts as well as costs and management needs—and it must include costs and impacts over a longer planning period than is currently employed. This process should also lay out successful approaches to getting the buy-in not only of a community, but that of regulators, developers, lenders, and other stakeholders.

Science

A major challenge is that we need better science, particularly with regard to human health, to inform the need for change in beliefs and behaviors. We must better quantify actual human health and ecological risks from all types of water infrastructure. When we begin to meet this challenge, we should be careful to communicate actual risks, keeping in mind that perceived risk equals actual hazard multiplied by public outrage or fear. To be successful, we need to develop and support proactive science-based policy, rather than reactive policy based on unfounded or misguided public outrage or other factors.

Understanding Community Behavior to Address Local Needs and Desires

There is a need to identify strategically and work with communities towards a sustainable water future within the next 10 years. This work will require experts in social marketing and decision science, who can identify and understand community values and who can combine those values with available science and financial resources to define an appropriate path to success in water resource management. The workers will communicate a new paradigm in clear language that is understandable and appropriate to the audience, will present options and engage the community to honestly assess choices, and will keep the community engaged by assessing and applying lessons learned.

Management and Planning

This challenge, for research and demonstration in planning for and managing decentralized systems, was two-fold:

- ◆ Develop tools and processes to define and articulate a holistic community vision for water that balances the ecological, economic, and social impacts of water use; and
- ◆ Identify planning processes, management structures, and tools to realize and implement that vision.

2.2.3 Municipal Breakout

The municipal breakout group formulated three interrelated research challenges.

Integrated Sustainable Infrastructure Theory

A sustainable municipal water infrastructure is, essentially, invisible in an ecological sense. The challenge is to go beyond mimicking predevelopment hydrology and towards making infrastructure compatible with local ecologies and environments. In doing so, we must maintain or enhance public space and quality of life in our cities, while also acknowledging that water may not yet be the central issue of public concern (as compared to air quality, transportation, or energy issues).

Water Centric Discipline and Planning

To support the theory of sustainable water infrastructure at the municipal level, a number of initiatives will be necessary:

- ◆ Develop policy tools, built on solid science
- ◆ Explore and implement the “triple bottom line” philosophy of business as it relates to municipal water infrastructure
- ◆ Work at the municipal, state, and federal levels to change the “siloed” or point-source nature of regulation related to water resources
- ◆ Conduct outreach and training to help build trust, including joint initiatives with other groups. For example, landscape ecology and horticulture, fields not traditionally included in water infrastructure planning, can play an essential role in creating a sustainable infrastructure.

Implementation and Practice

The implementation of a sustainable municipal water infrastructure should begin now through demonstration projects that include the environmental, ecological, regulatory, and policy aspects discussed above. Financial models and tools that allow for the true cost of water resources must be put into practice to support and sustain this infrastructure.

2.3 Presentations and Feedback from Work Session 1

At the close of the first work session, each breakout group was given 15 minutes to present summarized results and get feedback from the group. All participants discussed and suggested modifications to research challenges from all three groups. Comments received during this discussion included:

- ◆ There were many similar conversations between groups.
- ◆ In Germany, incentive programs are being stopped instead of expanded—removing subsidies allows more equitable comparisons.
- ◆ The value of water and sustainability are common themes between groups.
- ◆ We need to look long-term for sustainable solutions. Consider materials efficiency and long-term research projects—there is a need for research that far outspans our current funding planning periods.
- ◆ Integrated sustainable infrastructure gives a broad systems perspective...but how to define what sustainable infrastructure is?
- ◆ NASA is looking for life on other planets by looking for water as basis for life, not platinum or other compounds

After the first day's workshop session was complete, the steering committee met to determine the agenda and focus for the second day of the workshop. The focus of the second day was changed from working at the site, neighborhood, and municipal levels envisioned in the original agenda (Appendix C) to encompass a total of four working groups. One group would create a vision or values statement to articulate elements of an integrated and sustainable water infrastructure, using the information from the Wednesday session and additionally informed by discussion at an initial plenary on Thursday morning. Three additional working groups would formulate and prioritize research challenges that, if completed, would most aid in achieving the group's vision for a sustainable water infrastructure.

The goals for the second day of the workshop were to brainstorm and then prioritize elements of an integrated sustainable water infrastructure in order to develop a consensus vision statement. Given that vision, research challenges would be developed to address the following general questions:

- ◆ What do we need to demonstrate to the public and to consumers?
- ◆ How do we get there from a regulatory/policy/economic standpoint?
- ◆ How do we 'close the loop' on water systems in the next 25 years? What are the technical challenges we need to overcome?

2.4 Second Day Introductory Plenary

The second day of the workshop began with an example, presented by Glenn Daigger, of a vision statement produced during a conference about membrane bioreactors (MBRs) in 2003. The focus of this statement was on how MBRs can solve water treatment problems and help to achieve water sustainability. The statement was widely distributed, and an accompanying article was published in several journals and organizational publications. Many papers written on MBRs today reference the "Bellagio paper".

The participants were then asked to brainstorm on the kinds of key elements that should be included in a similar vision statement from this workshop. A selection of the ideas from the brainstorming session includes:

- ◆ Optimized systems should protect public health at all levels.
- ◆ Our technology currently can produce any quality of water. Given that, what's our vision for how these systems will look in 100 years? How are we going to apply this technology and in what contexts?
- ◆ Holding conflicting ideas is essential as we move towards sustainability: "look, all these important people overseas say this is important", a really important piece of paper we can wave around. Also, program in Netherlands to co-evolve technology, social conditions, and physical conditions.
- ◆ Use "infrastructure" as a defining concept—a whole system infrastructure for water with local collection, use, and reuse, and closed loop systems.
- ◆ Distributed systems meet a real need and are not optional going forward, but need to provide a good value for the consuming public
- ◆ Management institutions need to be in place.
- ◆ There is a tremendous opportunity to involve businesses in what needs to be done; large corporations with R&D budgets, smaller private businesses, and public entities can compete in making vision successful.

- ◆ We need to do what's necessary so that the public values water, and so that we understand what the public values.
- ◆ Make the link between water and global climate change.
- ◆ The first environmental problem was the 'tragedy of the commons', where grazing on common land moved to grazing on private land. We need to reinvigorate the concept of the commons by taking individual responsibility for water. People must be accountable for their roles.
- ◆ If vision refers to boldly enabling technology, then entrepreneurs will find things to represent what we want that to be—but we should enable what that is rather than having a roomful of scientists tell entrepreneurs what the future should look like.
- ◆ Use technology and systems, etc. to further environmental and social justice.
- ◆ Public will have to 'feel in their belly' that this is right; we need to articulate our vision in words they can understand.
- ◆ We have lots of "education" but what we need is *learning*.
- ◆ A one-pager is too long—the 'marketing' is one word, one sentence, one paragraph.
- ◆ In the 1970s, pictures of smokestacks communicated the problem clearly. Today, people don't yet connect with what we're doing that negatively impacts our water.
- ◆ This is NOT an optional thing. It must happen. In selling, we need to articulate this—it is not optional to be sustainable. This is water.
- ◆ This is a piece of a process, a beginning...a step, not the end.
- ◆ We're talking about the value of water; it forms the basis for our long-term ideas.

All of the ideas discussed during this brainstorming session were posted and participants were given the opportunity to prioritize the ideas through dot voting, with six "votes" given to each participant. The complete results for the dot voting exercise are included in Appendix D. The ideas with the highest number of votes included:

- ◆ Value of water is basis of long-term vision
- ◆ Protect public health at all levels
- ◆ Link to global climate change
- ◆ Design with nature to restore natural cycles
- ◆ Create personal responsibility for resources
- ◆ Stop creating unsustainable cities
- ◆ Call to action is not optional, it's necessary
- ◆ Closing loops
- ◆ Restoring hydrologic balance
- ◆ Decentralized and centralized => optimized systems

2.5 Small Group Work Session 2: Frame Major Research Challenges

Based on the results of Wednesday's work and the Thursday morning plenary, new small groups were assembled to examine priorities and frame research challenges by describing the following aspects of the challenges using a form provided by the facilitators:

- ◆ Description/explanation of the research challenge
- ◆ Identification of key technical, regulatory, managerial, financial, organizational, and community issues as appropriate

- ◆ Explanation of why addressing this challenge is important
- ◆ Desired outcomes of research at the basic, applied, and demonstration levels as appropriate
- ◆ Identification of who is best suited to conduct the research
- ◆ Level of investment/effort warranted

Each breakout group was asked to either formulate the vision statement or to identify the top 4-5 research challenges that, if accomplished, would most influence the future.

- ◆ What work needs to be done with the public in next five years?
- ◆ What regulatory/policy/economic changes and challenges need to be addressed in next 5-15 years?
- ◆ What science needs to be developed by 2025?

2.5.1 Vision Statement (“Baltimore Charter”) Group Breakout

The results of the dot voting exercise indicated that workshop participants were interested in a statement with a strong ethical foundation. The vision drafting group acknowledged that their task was to take the ideas and spirit of the participants and condense it into a short and accessible statement. The international presentations at the preceding conference reflected a core realization that the way we have treated water in the past is no longer acceptable—yet our culture is still in denial. A basic shift in perception is beginning—and is needed.

An extensive and animated discussion evolved about what transformations the group wanted to express in the vision:

- ◆ Transform water not valued to water valued
- ◆ Transform water as separate issue to water as connected to all other issues
- ◆ Transform water removed from urban and rural landscapes to water returned to soil and air
- ◆ Exploitative/gray infrastructure to restorative/green infrastructure
- ◆ Reconnect water to our central struggle for food, jobs, health, and spiritual life

The group eventually divided into sub-groups to write three parts of the vision:

- ◆ The Problem (truth)
- ◆ The Solution (hope)
- ◆ A Strategy (people are all parts of this solution)

Discussion of the “problem” and “solution” draft statements reported back to the full vision group took the remaining time available in the morning breakout session. Several examples of the “solution” at the parcel, neighborhood, and municipal scales were brought forward, including the Solaire in Manhattan and neighborhoods with lighter, greener, cheaper, smarter infrastructure, cognizant of natural cycles and with opportunities for water reuse.

The group acknowledged that additional work would be needed after the workshop to include the “strategy” and to refine and expand other aspects of the vision. The statement produced at the end of the initial breakout session is provided here:

In the past, we built water systems to protect ourselves from diseases, floods, and droughts. Now we see that fundamental life systems are in danger of collapse. Water is at the heart of these life systems. New and evolving water systems that mimic and work with nature will protect us and restore our human and natural ecology across lots, neighborhoods, cities, and watersheds. We need to work together in our homes, communities, workplaces, and governance to seize the opportunity to put these new systems in place. Our group of scientists, engineers, environmentalists, government officials, manufacturers, and members of the private sector are part of the solution. We have both the opportunity and obligation to participate with others on this task.

Vision Group Feedback

Feedback on the vision from the plenary session following the breakouts included:

- ◆ There is talk about the future, but what about the current generation?
- ◆ The statement is not linked to distributed or optimized systems.
- ◆ The “Freshwater Imperative” we’re stating needs to be a “water imperative”.
- ◆ We are way high, need to get back to water infrastructure.
- ◆ The statement could use a bit more hope and inspiration.

2.5.2 Public Challenges Group Breakout

The public breakout group sought to create research challenges that addressed the work needed, involving the general public, in terms of research, education, or demonstration projects in the next five years. Each member of the group wrote down two challenges about what it would take to get the public engaged and involved. A selection of these challenges is included below:

- ◆ How do we create a better understanding of water issues at a basic level?
- ◆ We need to identify the true costs of providing clean, safe water to the public.
- ◆ We need to define an effective public education process, and to teach the hydrologic cycle, basic infrastructure, and how services are provided.
- ◆ We need to move from conspicuous consumption to conspicuous conservation.
- ◆ What are the products/home improvements that will enable/encourage consumers to change their consumption practices?
- ◆ What are the products/practices that will make the biggest difference if introduced or removed?
- ◆ How do we identify products/data that can be sold and how to make them marketable?
- ◆ How do we get scientists/engineers to think about a sustainable water future as a product?
- ◆ Market research is valid research—you can’t market until you know who the audience is. We need to realize that outreach is different with differing audiences, need to speak to public’s values and look for or create teachable moments.
- ◆ How do you make it relevant and feasible to deliver decentralized systems to people? How do we engage local government officials to explore and adopt these systems? How do we convince trendsetters?

- ◆ How do we demonstrate the possibilities and benefits of an integrated water infrastructure (urban, suburban, and onsite contexts) in a way that is meaningful and useful, and desirable to locals, yet transferable to other localities?

These ideas and challenges were then narrowed down to four research challenges (Appendix E.2):

- ◆ **Demonstration Projects:** Demonstrate the integrated water systems vision.
- ◆ **Market Research:** Conduct market research designed to deliver statistically valid information to be used in the informed development of effective tools for implementing sustainable integrated water infrastructure goals.
- ◆ **Products:** Identify products and practices leading to ‘conspicuous conservation’ and effective pollutant elimination by consumers and consumer services.
- ◆ **Water Literacy:** Improve water literacy by delivering effective and scientifically accurate messages through trusted community partners, communicating science to people, and conducting research to answer basic public questions.

Demonstration Projects Feedback

Feedback on the demonstration project challenge from the plenary session following the breakouts included:

- ◆ We need to also demonstrate cross-industry projects.
- ◆ Water may not be the “door” into a community; there may be race or class issues that must also be addressed.
- ◆ Need to consider decision makers/funders in addition to communities.
- ◆ Demonstrations need to be replicated—how do you bring the next round of communities in so that demos are widely implemented?

Consumer Products and Practices Feedback

Feedback on the challenges related to consumer products and practices from the plenary session following the breakouts included:

- ◆ Strong assumptions: full value, not just full cost pricing
- ◆ If we’re using cost then we need to consider equal equity and access
- ◆ Elaborate on public health moving away from exposure? To many, the overarching theme has been exposure to the end of the waste stream rather than on the cumulative effects of wastewater systems’ potential impacts.
- ◆ Incorporate landscape that green buildings are in and the inhabitants of green structures.
- ◆ Not hearing aggressive attitudes that suggest our change in 25 years is as drastic as may be needed.
- ◆ Remember that we’re talking about settled and redevelopment in Europe/US, while new development is happening in India, etc.
- ◆ Existing streams of funding are committed for the next generation. How do we change that to redirect money now?

2.5.3 Regulatory, Policy, and Economic Challenges Group Breakout

Regulatory Challenges and Feedback

Discussion about regulatory research challenges centered around the need for complete water accountability at all levels (site, community, regional/basin, state, and federal). The fragmentation inherent in the current regulatory framework, coupled with a lack of federal direction regarding distributed systems, constitutes a major impediment to performance-based standards and approaches and to accountability at a broad system or watershed level. Several different ideas were discussed, including instituting requirements for making service and management of decentralized systems mandatory and for training of decentralized system operators similar to those that already exist for the operators of centralized wastewater facilities. Ultimately, the discussion was narrowed to two research challenges (Appendix E.1.1): defining a unified regulatory structure for decentralized systems, and developing more accurate cost/benefit analyses in facilities engineering that include all possible alternatives and evaluate these fairly.

Feedback on the regulatory challenges from the plenary session included:

- ◆ Like concept of paying for abuse. What about carbon offsets?
- ◆ In US, regulatory structure fragmented. What about a better way for regulators to share information and facilitate change?
- ◆ We currently have a technical lock-in that comes from regulatory structure and siloed nature. Modify federal regulations to allow other structures.
- ◆ Regulations are often based on past regulations...what about a clean slate?
- ◆ Two metrics: green buildings, and water balance model at the lot level.

Policy Challenges and Feedback

Initially, the Policy breakout group conducted a wide-ranging discussion about what kinds of policy efforts were needed in the future and the necessary characteristics of those initiatives. Policy initiatives should be science based, enhance protection of public health and environmental quality, emphasize performance and accountability while enabling innovation, and be implementable. Planning and implementing water policy on a regional scale, based on regional hydrology and water budgets should be encouraged, and local or regional management entities doing planning this way should be supported. Further, while the perception of water systems is shifting in the engineering community, more openness about integrated approaches is still needed. For instance, it is still policy in many areas to require connection to centralized sanitary and storm sewer systems regardless of the condition of the onsite systems.

This breakout group also discussed the challenges and opportunities around linking water resource use and policy with other areas such as air quality, energy, climate science, and land use planning. In order for such approaches to succeed, new tools and strategies will be needed both for risk-based decision making and for quantifying the consequences of increasingly diverse choices. The group ultimately formulated two research challenges: to develop a decision making framework to implement sustainable water resource management programs, and to develop research and funding programs that promote sustainable, integrated water management infrastructure (Appendix E.1.2)

The plenary session did not have any specific feedback on these challenges.

Economic Challenges and Feedback

Discussion of economics-related research challenges centered on the idea of full cost pricing for water, and on the practical tools needed to determine what the full cost of water is (Appendix E.1.3). In order for consumers to pay the full costs of water infrastructure, a better understanding is needed of what all the costs are—including “externalities” like the environmental consequences of water extraction and the monetary value of ecosystem services. The group acknowledged that by placing a more realistic economic value on natural resources, systems, and services, a system might be created where sustainable solutions become the most affordable solutions. One example discussed was New York City’s water filtration avoidance program, where protecting water quality in reservoir watersheds has thus far resulted in lower costs than would be incurred through building a new filtration plant for the City’s water supply.

Feedback on the economic challenges from the plenary session included:

- ◆ Ecosystem valuation is not speaking to people. Bring it down to people-scale.
- ◆ Outcomes-based public budgeting (rather than building around existing structures)
- ◆ Green infrastructure MAY also result in lower costs
- ◆ Significant work on whole systems accounting is being done in Australia; book coming soon
- ◆ If we got a good handle on real and existing costs, may not need to concentrate on externalities

2.5.4 Science Challenges Group Breakout

The science breakout group’s goal was to come up with three to five research questions, to be answered over the next 20 years, which are critical to implementing an integrated and sustainable infrastructure. There was discussion and some disagreement on what the next 20 years might allow. Each member of the group wrote out their own primary research questions for further discussion, and these questions were then shared in the breakout group. A selection of these ideas and questions is included below:

- ◆ How do we create an aesthetic, efficient, low cost toilet?
- ◆ We need to investigate single bacteria, not just microbial communities, to do a better job of harnessing these unseen powers.
- ◆ What are the actual public health risks of centralized and decentralized systems?
- ◆ We must better understand the impacts of trace chemicals; we need to outlaw chemicals that can’t be treated by physical, chemical or biological means
- ◆ How can we use water more efficiently, particularly so it doesn’t look like a downgrade to consumers (e.g., composting toilets)?
- ◆ In the future, there should not be “wastewater” because the concept creates fear and aversion. We are *regenerating* water, transforming it, not “treating” it.
- ◆ We need: distributed energy for distributed water; sensors so we understand what’s going on; source manipulation methods e.g. eco plumbing; modeling to inform and enable decision making; and a better understanding of the form and function of natural systems.
- ◆ How do we keep water on the land as long as possible?
- ◆ How can we restore natural hydrologic pathways and get the public to understand these pathways?

- ◆ What role does water play in global climate change? All the work now is on carbon, but water may be a bigger player.

These research questions and ideas were re-organized by the group into four research challenges (Appendix E.3):

- ◆ Natural Systems: Better understand the major natural elements and switches controlling the water cycle, and define criteria for ecosystem health.
- ◆ Human Health: Understand the impacts of the artifacts of modern life on human health, especially the use of decentralized wastewater systems.
- ◆ Technology: Minimize resource utilization and maximize resource recovery through intelligent, efficient, adaptable, sustainable technologies.
- ◆ Social and Decision Sciences: Determine appropriate methods to link research, management, and policy.

Science Challenges Feedback

No feedback was recorded for these challenges.

2.6 Refine Content of Research Challenges and Present Summaries

After all breakout groups had presented their research challenges and received feedback from the conference participants, the breakout groups reconvened to refine the research challenges and to produce a 60-second summary of their work. Each summary highlighted what was most important about the challenge and made a case for why the research challenge should be funded. At the end of the workshop, each breakout group presented their short statements to all workshop participants. These statements are included in Appendix F.

2.7 Final Baltimore Charter

In the period following the workshop, the vision statement breakout group made additional revisions to the statement presented at the final plenary session. The final version of the *Baltimore Charter for Sustainable Water Systems* is:

Water is at the heart of all life. In the past, we built water and wastewater infrastructure to protect ourselves from diseases, floods, and droughts. Now we see that fundamental life systems are in danger of collapsing from the disruptions and stresses caused by this infrastructure.

New and evolving water technologies and institutions that mimic and work with nature will restore our human and natural ecology across lots, neighborhoods, cities, and watersheds. We need to work together in our homes, our communities, our workplaces, and our governments to seize the opportunities to put these new designs in place.

Our group of scientists, engineers, environmentalists, government officials, manufacturers, and members of the private sector are part of the solution. We have both the opportunity and obligation to participate with others on this task of transforming how we think and act in relation to water.

We commit to implementing more sustainable water systems by expanding uses and opening new markets for small-scale treatment processes, advancing research on micro-biological and macro-ecological scales, inventing new technologies based on nature's lessons, creating new management and financial institutions, reforming government policies and regulations, and elevating water literacy and appreciation in the public.

2.8 Summary of Research Challenges

In the weeks following the workshop, Valerie Nelson and others from the vision breakout group worked to summarize the research challenges from the workshop to use in future funding discussions in Washington, D.C. That summary, as of March 30, 2007, is included on the following pages. The version presented here has been modified only to improve grammar and readability.

DEMONSTRATION PROJECTS, MARKET STUDIES, AND EDUCATION

Demonstrate the Integrated Water Systems Vision

Define multiple approaches to a sustainable water system in social, cultural, and environmental contexts as well as at a variety of scales and in both retrofit and new construction situations.

- ◆ Demonstrate the possibilities and benefits of integrated water infrastructure in a way that is meaningful, useful, and desirable to the public.
- ◆ Complete cross-sector demonstration projects that include other sectors which impact water, such as transportation and energy.
- ◆ Address national and regional needs to improve transferability.
- ◆ Engage the “public”, including decision-makers, practitioners, trendsetters, communities, and local government officials, in exploring and adopting these systems.

Market Research

Conduct basic market research across the country to assist in the implementation of cost-effective and sustainable water infrastructure.

- ◆ Identify target audience sectors, including societal and employment roles, age groups, socioeconomic status, and subject informational knowledge levels.
- ◆ Develop target-specific research tools and informational packets that include issues, questions, and focus group formulas meaningful to each target sector.
- ◆ Prioritize targets for effectiveness, determine feedback and accountability metrics, and define outcomes to ensure research is useful and meaningful.

Water Literacy

Develop effective and scientifically accurate messages in a simple and enjoyable (humorous) manner for delivery via trusted community partners.

- ◆ Improve communication of research and science to people.
- ◆ Conduct supporting hydrologic (climate change) research, including demonstrations of actual change, that answers basic public questions.
- ◆ Emphasize public health and total ecosystem exposure (for example, “would you let your 6-year-old drink estrogen?”)

POLICIES, REGULATIONS, AND ECONOMICS

Policies

Create an effective integrated water management strategy and associated policies.

- ◆ Define sustainable, integrated water resource management.
- ◆ Provide tools, policies, and regulations that allow communities to achieve their own local visions of sustainability.
- ◆ Quantify economic, environmental, and societal consequences of integrated water management strategies.
- ◆ Invest in data collection, analysis, monitoring, economic analysis, and risk analysis to support an integrated water management infrastructure.

Regulations

Articulate and implement a unified regulatory methodology.

- ◆ Craft a methodology of analysis and benefit/cost for water, people, and nature
- ◆ Quantify performance- and risk-associated management systems.
- ◆ Integrate the importance of water into LEED® and other ‘green building’ initiatives.
- ◆ A unified regulation and compliance structure for distributed systems

Economics

Define new economic methods that sufficiently address full cost integrated water pricing

- ◆ Account for secondary economic benefits and consequences, including community values and priorities, in cost-benefit analyses.
- ◆ Enable communities to use limited resources more efficiently by translating new economic methods into practical, implementable tools.

SCIENCE, ENGINEERING, AND TECHNOLOGY

Integrated Sustainable Water Infrastructure

Minimize resource utilization and maximize resource recovery through intelligent, efficient, adaptable, sustainable technologies.

- ◆ Research and implement new sensing and monitoring control technologies that connect scientists, managers, customers and the community with water infrastructure and ecosystems.
- ◆ Create new technologies, systems, and materials for the sustainable infrastructure including water efficient devices and cascading systems (from high to low quality).
- ◆ Investigate harvesting, storage, and reuse technologies at various infrastructure scales (including within building envelopes).
- ◆ Minimize or eliminate chemical usage and chemical conveyance in water treatment.

Natural Systems and Water Cycling

Understand the major natural elements and switches controlling the water cycle.

- ◆ Define criteria for ecosystem health.
- ◆ Understand the structure and function of unseen biological elements and their interactions with the environment.
- ◆ Integrate tools to understand systems biology, its network of interactions with the environment, and implications for human health.
- ◆ Conduct basic micro-biological and macro-ecological research.

Social Institutions and Decision Making

- ◆ Engage communities in integrated design and planning for water sustainability which will result in cost savings, water protection, and healthier people.
- ◆ Develop local government management tools, design guidelines, model bylaws, and community education modules.
- ◆ Implement simple, practical management tools and design guidelines.

Public Health

- ◆ Understand the impacts of all types of water and wastewater systems on human health.
- ◆ Document the fate and transport of chemical and biological constituents in water, ultimately to the point of human exposure.

APPENDIX A

ATTENDEE LIST AND CONTACT INFORMATION

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Baltimore, Maryland • March 14-15, 2007

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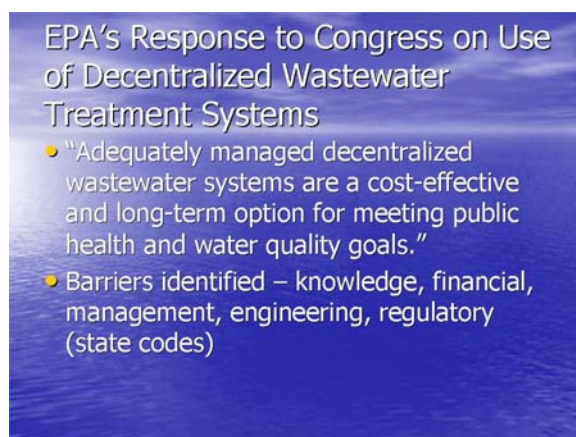
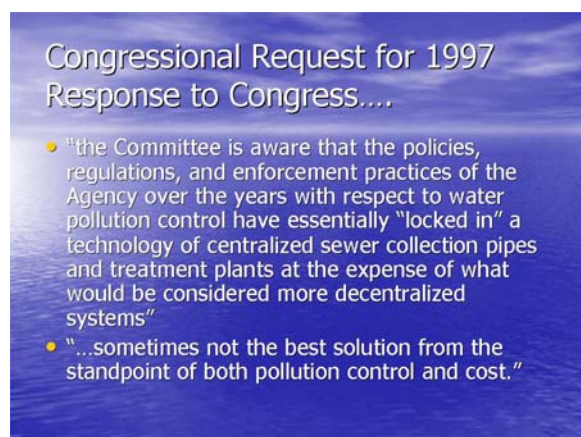
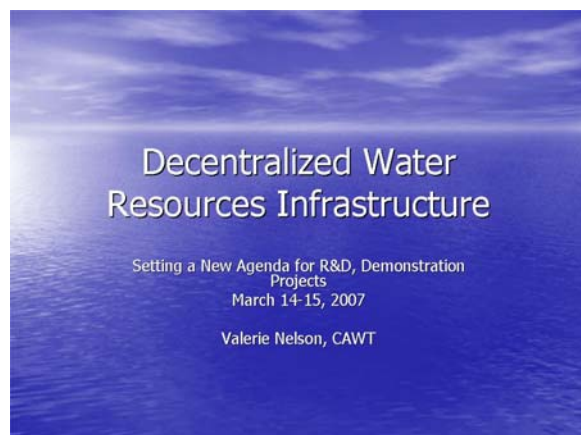
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APPENDIX B

INTRODUCTORY POWERPOINT PRESENTATIONS



EPA response:

- Focused on “barriers” to use of systems Near-term actions (design manual, outreach)
- Particular emphasis on “management” models, in particular “Responsible Management Entities”
- Avoided answering question of technology “lock-in” at federal level
- Established decentralized wastewater program separate from stormwater, LID, etc.

Congressional initiatives in other directions

- Research and development – National Decentralized Water Resources Capacity Development Project – WERF, Coalition for Alternative Wastewater Treatment, EPRI, NRECA, Consortium of Institutes for Decentralized Treatment – which is funding this workshop
- Demonstration projects to “jump start” technologies, approaches – 25 projects and \$30-40 million in funding (Block Island/Green Hill Pond, RI; LaPine, Oregon; Table Rock Lake, MO, etc) – in particular to nudge state regulators
- Integration of wastewater with other “soft path” sectors – decentralized stormwater, green infrastructure, reuse, efficiency, etc.

Current discussions in Congress – CWSRF reauthorization

- Decentralized, “closed loop”, and multiple-benefit systems are a big part of a sustainable future
- Allies -- environmental organizations, NACWA (National Association of Clean Water Agencies), NOWRA
- \$250 million in research and development
- Additional subsidization for CWSRF projects
- National Academy of Sciences study on “soft path” water in international context
- Integrated water resource management

Opportunity for more seats at the table

- New Strategies/New Alliances Workshops --
- Natural Resources Defense Council
- American Rivers
- Clean Water Action
- National Association of Home Builders Research Center
- Taxpayers for Common Sense
- As well as WERF, WEF, EPRI, EPA

Recommendations from “Strategy” Workshops

- Research and Demonstration Phase needed – before major changes in federal policies and regulations
- Demonstration Projects – piloting of technologies, community institutions, etc.
- Understanding of full range of benefits and costs, “value proposition”
- Green Building approach as model for “market transformation” opportunity
- Integrated water resource plans as condition of funding
- Networks of advocates and experts, “champions”

Research dimensions

- Integrating the water “chain”
- Solutions at multiple “scales”
- Blending centralized and decentralized
- Understanding the multiple benefits of infrastructure
- Innovations in technology, management, regulations, financing, private behavior
- Engaging multiple players and stakeholders – new alignments of interests and needs
- Supporting multiple soft paths – learn what works

Opportunity for International Collaboration

- Wealth of ideas and demonstrations across countries
- International Water Association
- SWITCH model of demonstration projects and learning alliances
- Institution to Institution collaboration – Beijing Institute, Murdoch, Hebrew University
- Others



Summary of Key Themes from the NOWRA / IWA Conference

Scott Johnstone

March 14, 2007

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Themes – Telling the Truth

Data Driven Truth – Human Scale

- 50 yrs = massive desertification
- 50 yrs = 1 billion people living with water shortage
- 3 million living under water stress by 2025
- 1/2 without safe water by 2050
- 1/2 without proper sanitation by 2050
- 2.6 billion without access to sanitation at all

P2-S102006

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Themes – Telling the Truth (cont.)

Fact Driven Truth – Issue Scale

- Gap Analysis in US
- Current model is not sustainable financially
- US has water scarcity now in areas

P3-S102006

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Themes – Telling the Truth (cont.)

Competition for attention – Issue Scale

- Climate Change
 - Peak Oil
 - Peak Phosphorous
 - Peak Oil
 - Defense Spending
- so:
- Can we get to creating political will?

P7-S102006

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Introduction to Themes



Reflections on Leadership:

- Tell the Truth
 - Provide Hope & Inspiration
- ~ Dr. Bill Grace

P2-S102006

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Themes – Telling the Truth (cont.)

Response Driven Truth – Human Scale

- We have a moral obligation
- We have a humanitarian obligation

P3-S102006

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Themes – Telling the Truth (cont.)

Response Driven Truth (&/or belief) – Issue Scale

- Command & Control won't work
- Silo's won't work
- Time has passed the current model by

P3-S102006

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Themes – Telling the Truth (cont.)

Competition for attention – Issue Scale

- Research behind Centralized in many cases
- Good progress, but much more to do
- Decentralized infrastructure still viewed as a temporary solution by many

so:

- How can decentralized solutions garner the same respect as centralized?

P8-S102006

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Themes – A word of early caution

"We must figure out how to articulate this new vision with clarity if the new paradigm is to gain traction"

~Unknown

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PS-1/12/2004



Themes – The Path to Hope & Inspiration

Broad Concepts and Ideas (BHAG's)

- Integrated Water Resource Management
- Sustainability
- New Models of Partnership
- The Role of People

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PS-1/12/2004



Themes – The Path to Hope & Inspiration

Integrated Water Resource Management

- Ecosan
- Water Reuse
- Ecology used as primary treatment device
- Integrate rainwater, green buildings into reuse strategies
- Use watershed or river basins as mgmt tool
- Consider wastewater as a resource
- Treatment linked to (re)use
- Hydrologic Invisibility

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PS-1/12/2004



Themes – The Path to Hope & Inspiration

Sustainability

- Link water decisions to land use choices
- Ecology, Economy, Tourism, Water all linked
- Include energy needs as part of analysis
- Incorporate Life Cycle Costing analysis
- Link to Global Warming
- Link Social, Environmental, and Economic factors
- Include the voice of people & stakeholders
- Not Centralized or Decentralized, but right mix
- Consider landscapes, not leachfields
- Longer view required – 50 years +

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PS-1/12/2004



Themes – The Path to Hope & Inspiration

New Models of Partnership

- Intellectual Property rights
- Socially Responsible Investing as a financial tool
- Engineers working with affected interests
- Interdisciplinary Teams
 - Engineers
 - Microbiologists
 - Planners
 - Architects
 - Financial Sector
 - Politicians and Press

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PS-1/12/2004



Themes – The Path to Hope & Inspiration

The Role of People

- Need stake in ecological future
- Remind that sustainability is a trip home
- People make lifestyle choices
- People, politics and process
 - Need to be called to be involved
 - Celebrate role of water in our lives
- Focus on people's values as important as science and technology
- Socio-cultural issues can make or break progress
- Disruptive technology as way to empower

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PS-1/12/2004



Themes – Hope

- So many Cities moving towards sustainability
- So much great research being done
- So many ideas on how to proceed
- So many champions to work on the cause

"Decentralized systems are a fundamental element of an emerging paradigm of urban sustainability - at every scale"

~Paul Brown, CDM

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PS-1/12/2004



Themes – Inspiration

Quotes...

"The future will do economically well by doing ecological good." Futurist

"To deliver a preferred future, we must first imagine it." Futurist

Concepts...

Why not call for an Eco-innovation revolution built on the premise of Congressman Inslee's Apollo Energy Act

Why not call for a pact similar to the EU's Lisbon strategy focused on the premise of sustainability, integrated water management, the need for new partnerships and, the real needs of people and the planet

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PS-1/12/2004

APPENDIX C

FINAL WORKSHOP AGENDA AND PARTICIPANT HANDOUTS

Research Needs Workshop in Decentralized Wastewater, Stormwater, and Related Fields

Wednesday March 14, 2007

1:00 PM – 5:15 PM

1:00 Welcome and Introductions (WERF staff)

1:25 Overview of workshop goals, agenda, and final products (Doug Sarno)

1:30 Background

- Motivation for workshop (Valerie Nelson, CIDWT)
- A look at leading edge activities, opportunities, and needs (Paul Reiter, IWA)
- Summary of key themes identified at the NOWRA/IWA conference (Scott Johnstone)
- Q&A and participant perspectives

2:30 Small Group Work Session 1: Identify Research Challenges

Participants will be organized into three groups to identify research challenges from three perspectives of scale:

1. On-site
2. Community
3. Municipal

4:45 Presentations and Feedback on Work Session 1

- Each group will be given 15 minutes to present summarized results and get feedback from the group
- All participants will discuss and suggest modifications to research challenges from all three groups

5:30 Adjourn Day 1

(One Hour Informal Mixer Planned at End of the Session)

Thursday March 15, 2007

8:30 AM – 12:00 PM

8:30 Introduce Topics for Work Session 2 and Identify Priorities (Doug Sarno)

- Research challenges will be organized by steering committee into three groupings for small group discussions
- All participants will provide input to prioritization of these research challenges for consideration in work session 2.

9:00 Small Group Work Session 2: Framing Major Research Challenges

Based on the results of Work Session 1 and plenary session input, new small groups will be assembled to examine the highest priority and frame the associated research challenges by describing the following:

- Description/explanation of the research challenge
- Identification of key technical, regulatory, managerial, financial, organizational, and community issues as appropriate
- Explanation of why addressing this challenge is important
- Desired outcomes of research at the basic, applied, and demonstration levels as appropriate
- Identification of who is best suited to conduct the research
- Level of investment/effort warranted

Lunch: 12:00 PM – 12:30 PM (To be provided in the room)

12:30 Results of Work Session 2

Each group will have 20 minutes to present their draft research challenge descriptions and receive feedback from all participants

1:30 Identification of Key Integration Issues (Doug Sarno)

Facilitated discussion of how challenges interrelate, and how research should be approached in the big picture

2:00 Work Session 3: Refine Content of Research Challenges

Groups will use feedback from plenary session to refine challenges and create 20 minute presentations of how research monies should be spent to achieve the best outcomes for their research challenges.

3:15 Break

3:30 Presentation of Revised Research Challenges

Each group will have 20 minutes to present a case for the research and why it should be funded

4:30 Closing Remarks and Discussion (Doug Sarno, Valerie Nelson)

5:00 Adjourn

APPENDIX D

RESULTS OF VISION PLENARY BRAINSTORM SESSION

Brainstorm Idea	Number of Votes
Value of water is basis of long-term vision	28
Protect public health at all levels	20
Link to global climate change	18
Design with nature to restore natural cycles	15
Create personal responsibility for resources	14
Stop creating unsustainable cities	13
Call to action is not optional, it's necessary	12
Closing loops	12
Restoring hydrologic balance	11
Decentralized vs. Centralized => optimized systems	11
Enabling market to respond	9
Accountability	9
Social and Environmental justice	8
How do we define sustainability?	7
How do we use/apply/enable technologies?	6
Stop destroying and start restoring	6
Synergy between energy and water	5
Infrastructure: close loop water	4
Marketing	4
Co-evolution of structural conclusion, technology culture, \$	4
Define audience	3
Microbiology	3
Good value for public	2
Biomimicry	2
Learning	2
Involve business	2
Time scale to alt/accomplish	2
Vision has clear targets and goals	2
Articulate problem	2
Feedback loops	1
Learn from past	1
Create environment to compete	1
Systems are necessary and good value	1
Bioreactors	1
Competition	1
Problem statement call to action	
Water is life	
Optimal system focus	
Diversity and abundance in natural systems	
Water is the center of our problem	
Clarify intent for the water industry/sector	
Energy sufficiency re: natural currency	
Resource efficiency	
Management and institutions in place	

APPENDIX E

RESEARCH CHALLENGE WORKSHEETS

E.1 Public Challenge Sheets

E.1.1 Demonstration Projects

Descriptive Title of Research Challenge:
Demonstrating the Integrated Water Systems Vision
Bullet points explaining details of the research challenge:
◆ Define multiple approaches (visions) to a sustainable water system in social, cultural, and environmental contexts as well as a variety of scales (urban, suburban, on-site) ◆ Demonstrate the possibilities and benefits of integrated water infrastructure in a way that is meaningful, useful, and desirable to the public. Cross-sector demonstration projects are also important (transportation, energy, water, etc.). Demonstrations need to address national and regional needs such that they may be transferable. ◆ Engage the “public” (decision-makers, practitioners, trendsetters, community, local government officials, etc.) to explore and adopt these systems. Demonstrate in a way to replicate and bring next 20 groups along.
Bullet points explaining key technical issues
◆ Uniformity of data for direct comparison of technology approaches with respect to the values of importance by the consumer ◆ Reliability ◆ Maintainability ◆ Long-term O&M ◆ Design guidance
Bullet points explaining key regulatory issues
◆ Current codes may prevent implementation. ◆ Plumbing. ◆ Onsite wastewater. ◆ Building codes. ◆ Green building. ◆ Pipe color codes. ◆ Enforcement. ◆ Knowledge. ◆ Public will. ◆ Water rights laws.
Bullet points explaining key managerial issues
◆ Knowledge of practitioner. ◆ Distributed management.

◆ O&M of water system components. ◆ Responsible management entities ○ owner ◆ entity: public, private
Bullet points explaining key financial issues
◆ Current subsidies ◆ Capital ◆ O&M ◆ Energy ◆ Environmental ◆ Ability to pay
Bullet points explaining key organizational issues
Consider decision-makers and their relationship to the process.
Bullet points explaining key community issues
◆ Water literacy. ◆ Development/acceptance of vision. ◆ What are their values? ◆ Social justice. ◆ Engage the community: ready to accept, select vision (approaches) appropriate for the community, incorporate community in every step of process, and demonstrate community involvement. ◆ Reach out to communities via their issues vs. just water; race, class, and other challenges to community integration.
Explanation of why addressing this challenge is important
◆ Water availability in some areas. ◆ Environmental concerns. ◆ Data addressing the technical, regulatory, management, financial, & community issues. ◆ Lessons learned during demonstrations. ◆ Marketing approaches.
Desired outcomes of research at the basic level
Data on energy, water (input gall./cap./day), O&M, triple-bottom line costs
Desired outcomes of research at the applied level
◆ Define potential approaches to management ◆ Capacity to implement issues. ◆ Knowledge gained with respect to “issues”.
Desired outcomes of research at the demonstration level
◆ Community acceptance (willingness to adopt). ◆ Feasibility based on implementation. ◆ Elements of successful demonstrations could serve as models that may be transferred to other communities. ◆ Example of watershed protection.
Identification of who is best suited to conduct the research
Depends on the scale of demonstration – smaller on-site or community systems could be universities, non-profits, vendors (w/third party results), consulting firms and others; larger projects may require large consulting firms or multi-disciplinary teams.

Level of investment/effort warranted
◆ Critical: 40-50% of overall funds for decentralized research ◆ \$30-\$50 million year ◆ Enable creativity. ◆ How: EPA, Federal and local govt., non-profits, and private companies (could be enabled).

E.1.2 Market Research

Descriptive Title of Research Challenge:
Market Research designed to deliver statistically valid information to be used in the informed development of effective tools for implementing sustainable integrated water infrastructure goals.
Bullet points explaining details of the research challenge:
◆ Effective Market Research is necessary to develop successful target messages and tools to create, advance and capitalize public awareness and action. ◆ What are the current and potential opinions of each target population segment on these critical water infrastructure issues? ◆ What are the cross-comparisons between segments and issues?
Bullet points explaining key technical issues
◆ Identify target audience sectors (societal/employment role (e.g.: public officials, schoolchildren, developers, etc.), age groups, socioeconomic status, subject informational knowledge level, etc.) ◆ Develop target specific research tools and informational packets ○ What issues, questions and focus group formularies will be meaningful to each target sector? ○ To all target sectors? ◆ Prioritize targets for effectiveness (ability to make an impact) ◆ Feedback and accountability metrics (ensures validity and rigor to deliverables) ◆ Define successful outcome (useful and meaningful)
Bullet points explaining key regulatory issues
Regulatory target sector available as potential target audience (likely low priority). We suggest developing research mechanisms without using pre-determined assumptions of current regulatory obstacles to the extent possible).
Bullet points explaining key managerial issues (for the project itself)
◆ Real market research firm ◆ Assuring valid target audience representation ◆ Experience with diverse audience messages ◆ History of success with grant management or similar ◆ Building the right project subcommittee to: ○ develop the RFP ○ select correct researcher ◆ Ensure high quality deliverables.
Bullet points explaining key financial issues
Project management: budget preparation and accountability

Project outcome: developing meaningful value propositions for each target stakeholder group.
Bullet points explaining key organizational issues
Meaningful matrix development as part of research outcome data statistical evaluation to include: ◆ Target stakeholders focus groups (data within specific target) ◆ Target specific relevant issues (data within specific issues) ◆ Common – and opposing – values and “calls to action” (cross comparison between target audiences and target-framed issues to find both ‘things in common’ and ‘things in opposition’.)
Bullet points explaining key community issues
◆ Implementing community action plans using benefit statements and outcomes of the research. (the “buy ins” and “give a darns”). ◆ Well-constructed and conducted research would give valid practical data to all practitioners and otherwise interested parties from which could be developed target specific messages and tools.
Explanation of why addressing this challenge is important
Effective and meaningful Market Research is key first step to gain stakeholder buy in and sustained support towards mission completion. Market research sometimes confirms instincts, sometimes offers startling surprises. Which will this research show?
Desired outcomes of research at the basic level
◆ Identify targets and their characteristic behaviors and opinions relative to sustainable integrated water infrastructure. ◆ Prioritize future efforts for maximum effect. ◆ Basic market research needed to develop potentially effective marketing strategy (public outreach campaign) for all interested parties – including the studied target audiences themselves – to use towards the development of a sustainable integrated water infrastructure.
Desired outcomes of research at the applied level
Develop targeted messages and tools for use with stakeholder audiences. Without valid basic market research, it can be ‘dangerous’ (wasteful and ineffective) to march boldly into future operational tactics based on instincts of a disconnected albeit well-intentioned public.
Desired outcomes of research at the demonstration level
Once basic research and associated analyses is completed, and effective strategy and tools developed to help lessen burdens of implementation, then: Case studies involving specific community implementation and success stories.
Identification of who is best suited to conduct the research
A real marketing and public relations firm experienced with projects involving multiple target audience and message analysis. Although the initial focus of the basic market research will involve mostly data analysis (including the key components of target audience identification, research tools and analysis matrix development), the data are likely to be extremely informative towards the development of a successful marketing/public outreach strategy. The informed strategy will then make it much more likely to develop persuasive and meaningful messages as part of an overarching effort to develop a sustainable integrated water infrastructure.

Note: Remember, it is also possible for the basic research to reveal information in direct conflict with historical “instincts” under which various interested parties and agencies have been operating.

Level of investment/effort warranted

Mission critical! Preliminary Funding level suggested: 0.5M – 1.0M USD for basic research development and analysis.

E.1.3 Products

Descriptive Title of Research Challenge:

Identification of products and practices leading to ‘conspicuous conservation’ and effective pollutant elimination by consumers and consumer services.

Bullet points explaining details of the research challenge:

- ◆ What are the products and practices which, if adopted by consumers and consumer services, will create the greatest impacts for water conservation, restoration and sustainability?
- ◆ What are the products, systems and practices that will make water recycling, constituent reduction/elimination, conservation, and closed-loop systems acceptable in American consumer markets?

Bullet points explaining key technical issues

- ◆ Constituents to be introduced to or removed from the water cycle must be identified and justified (scientifically and financially) as targets of behavior and product change.
- ◆ Dangerous products or constituents affecting water quality and public health, equivalent to trans fat in food, should be identified and vilified.
- ◆ A standard for products equivalent to ‘organic’ for food, ‘energy star’ or ‘sustainable’ for forestry products may be effective.
- ◆ Product and market uses of treated water must be defined, proved and accepted – a zero waste or closed-loop context.

Bullet points explaining key regulatory issues

- ◆ Statutory or regulatory prohibitions on waste constituents and quantities may be involved in implementation (e.g. phosphate detergents, triclosan, other PCPPs)
- ◆ Regulations regarding public health may be necessary, along with creating social disapproval of poor practices and products/constituents.
- ◆ Regulatory practices reflecting full cost, supply limitations, and scientific evidence regarding constituents are critical.
- ◆ Regulations, notably plumbing and building codes but also green building standards and checklists, will affect implementation.
- ◆ Consumer product safety and FDA regulations may be involved.

Bullet points explaining key managerial issues

Management and financial practices reflecting full cost and value of water are essential.

Bullet points explaining key financial issues

Management and financial practices reflecting full cost are essential. Continued subsidization of water cost, especially as infrastructure is renovated in urbanized areas, will continue to delay broad acceptance of water-smart products and practices.

Bullet points explaining key organizational issues
Bullet points explaining key community issues
Consumers and consumer services must accept the potential harm of poor practices and products – along with readily adopted and acceptable alternatives.
Explanation of why addressing this challenge is important
Larger-scale societal change on recycling/solid waste and recently carbon emissions demonstrate the importance and potential for widespread consumer adoption of better practices. Moving to or towards a closed-loop water cycle and water restoration (pollutant elimination) will require significant changes in the consumer practices and products that generate the volume and characteristics of the waste stream.
Desired outcomes of research at the basic level
◆ Microbiology and chemistry (including PCPPs) of consumer water-related products (durable and non-durable) ◆ PCPP impacts on soil, biological, mechanical treatment processes ◆ Basic science and modeling must tell us what we have to do for our water!
Desired outcomes of research at the applied level
◆ What are the durable and non-durable consumer products that affect our outcome? What needs to be eliminated? Modified? Developed? ◆ Best practices for segregating/minimizing PCPPs (and other scary, consumer-based constituents) in water ◆ What are the overall household/business economics of water-product choices? Do we help or hurt the overall market and success rate by subsidizing or giving away best-practice features (e.g. rain barrels, non-toxic products, etc.)? Relationship to stormwater BMP programs such as Lake Tahoe, 10,000 rain gardens, etc.
Desired outcomes of research at the demonstration level
◆ MUST get the closed-loop water cycle into the essential features of green building. ◆ Products and closed loop cycles in essential and visible public facilities – how about a zero-waste closed loop correctional facility? School? Library? ◆ Consumer-acceptable and realistically priced water-related products: filtration units, greywater recycling, certification for products equivalent to ‘organic’ food or ‘certified sustainable’ wood products
Identification of who is best suited to conduct the research
◆ Needs input from consumer product researchers/marketers ◆ Needs strong relationship to green building and homebuilding industries, and energy conservation practices ◆ Needs strong basis in essential microbiology of water processes & treatment
Level of investment/effort warranted
This has to become the “new big job” for the consumer products market. Science and public health first must inform the critical focus for altering consumer practices and goods.

E.1.4 Water Literacy

Descriptive Title of Research Challenge:
Improve water literacy
Bullet points explaining details of the research challenge:
◆ Develop effective and scientifically accurate messages in simple and enjoyable (humorous) manner for delivery via a trusted community partner ◆ Communication research (science to people) ◆ Hydrologic (climate change)/research (incl. demonstrated changes) that answers basic public questions
Bullet points explaining key technical issues
◆ Effective communication techniques and development/improvements ◆ R&D to define hydrologic impacts of climate change for future programs
Bullet points explaining key regulatory issues
◆ Message must be consistent with law ◆ Cause regulators to revisit regulations
Bullet points explaining key managerial issues
◆ Managers, regulators, decision makers must be on-board ◆ Must have open program with maximum community involvement
Bullet points explaining key financial issues
Cost of training, textbooks, electronic products, courses, games, etc. to effectively message
Bullet points explaining key organizational issues
◆ Organization strategy to reach key stakeholders, e.g., students, decision-makers, churches, NGOs, builders, lenders, planners, etc. ◆ The message delivery organizations need to be trained and otherwise enabled
Bullet points explaining key community issues
◆ Community/audiences enabled to determine what role they play in water cycle & responsibility and costs that they may incur ◆ To accomplish changes required or desired
Explanation of why addressing this challenge is important
◆ Compliance ◆ Making people see how they relate to watershed ◆ Serve as example for others
Desired outcomes of research at the basic level
Better issue/options grasp by community, local decision makers, and regulators of the issues
Desired outcomes of research at the applied level
◆ -To grasp existing water problems ◆ -To use as base to make decisions ◆ -Products and processes for use by community and others in future
Desired outcomes of research at the demonstration level
Potential broad use of products elsewhere
Identification of who is best suited to conduct the research
◆ Communications – universities, private marketing organizations ◆ Technical-R/D universities ◆ Products publication/producers – commercial, professional media contractors

Level of investment/effort warranted
◆ Federal funding - \$1million US/year (EPA, USDA, DOD, CDC) ◆ International marketing possibilities ◆ News releases, marketing of products, public relations opportunities

E.2 Regulatory, Policy, and Economic Challenge Sheets

E.2.1 Regulatory: Unified Regulatory Structure

Descriptive Title of Research Challenge:
Define success in a unified regulatory compliance structure for distributed systems
Bullet points explaining details of the research challenge:
Pull existing pieces together (recycle manual, land application manual, on-site manual) then set performance goals and outcomes that are measurable.
Bullet points explaining key technical issues
Set, test, evaluate, and verify to build confidence throughout the industry.
Bullet points explaining key regulatory issues
Gain support for EPA, model code and also national goals.
Bullet points explaining key managerial issues
Cull good, better, best, technology based on performance.
Bullet points explaining key financial issues
This sets a basis for real cost analysis
Bullet points explaining key organizational issues
Bullet points explaining key community issues
They will know what to expect and can choose better
Explanation of why addressing this challenge is important
No rules lead to chaos.
Desired outcomes of research at the basic level
What is the measure of success for all systems and alternatives.
Desired outcomes of research at the applied level
More states acting in similar ways.
More collectives or regional compacts.
More market opportunities.
Desired outcomes of research at the demonstration level
Database on performance for comparison
Identification of who is best suited to conduct the research
NEIWPCC – Variability team and industry
SORA
NOWRA
EPA
Level of investment/effort warranted
\$450,000

E.2.2 Regulatory: New Analysis Methodology

Descriptive Title of Research Challenge:
Develop new methodology of analysis and benefit for water, people, and nature.
Bullet points explaining details of the research challenge:
Quantify and distinguish between positive and negative effects, both primary and secondary.
Bullet points explaining key technical issues
Specific agreed upon performance watched to technology and system management.
Bullet points explaining key regulatory issues
Needs to provide both incentives and regulatory compliance.
Bullet points explaining key managerial issues
Who will take ownership of analysis and how will they decide. Suggest use a water LEED approach.
Bullet points explaining key financial issues
Develop cost and benefit for all water non-monitory, ecological and sociological.
Bullet points explaining key organizational issues
Cross water coordination and pollination between water programs. Promote and tie to national security and public health
Bullet points explaining key community issues
More and better analysis and better choice and better fit for community.
Explanation of why addressing this challenge is important
No fairness in the market without honest and complete analysis of alternatives. Current system is missing transparency.
Desired outcomes of research at the basic level
Common language between water projects.
Tool for communities, engineers and innovators.
Desired outcomes of research at the applied level
Connector between land use and water use/reuse.
Promotes market opportunities that can be measured.
No analysis means no competitive choice.
Desired outcomes of research at the demonstration level
Regional and state design competition for on-site, recycle and pipe.
Identification of who is best suited to conduct the research
Planners, building code, architects, hydrologists, industry, regulators, special scientist.
Level of investment/effort warranted
\$450,000

E.2.3 Policy: Decision Framework

Descriptive Title of Research Challenge:
Develop decision making framework that policy-makers/local elected and appointed officials can use to develop and implement sustainable water resource management programs
Bullet points explaining details of the research challenge:
Would include: risk analysis, cost analysis, performance analysis, full cost accounting, system specification, policy implications
Bullet points explaining key technical issues
Need adequate cost and performance data on multiple scales and from diverse regions

Bullet points explaining key regulatory issues
Framework/process tool can be used to drive change/revise regulatory and policy approaches
Need to build model so outputs are useful for policy development
Bullet points explaining key managerial issues
Concerns: complexity of model, data gaps
Simple
Does not require expensive investment (time, \$, expertise)
Can be used to analyze scenarios and options
System evaluation and selection
Data collection and input
Bullet points explaining key financial issues
Costs of decentralized approaches, US cost of conventional or hybrid approaches
Lack of adequate operation and maintenance data
Bullet points explaining key organizational issues
Adoption of sustainability as an organizational mandate
Bullet points explaining key community issues
Garnering public input in decision-making process
Explanation of why addressing this challenge is important
Federal/state/local governments lack systematic approach to making infrastructure decisions and understanding the consequences of a set of choices.
Desired outcomes of research at the basic level
Identify research gaps necessary to build model
Risk and uncertainty modules for model or decision-making framework
Apply framework and test in local context
Desired outcomes of research at the applied level
Validate methodology
Desired outcomes of research at the demonstration level
Validate methodology
Identification of who is best suited to conduct the research
Academic institution-partnership with local government (state?)
Coordination of existing research efforts, e.g. WERF
Level of investment/effort warranted
Significant

E.2.4 Policy: Integrated Water Resource Policy

Descriptive Title of Research Challenge:
Develop research and funding programs that promote sustainable, integrated water management infrastructure and uniform water management policies that reinvigorate concept of commons and redefine infrastructure.
Bullet points explaining details of the research challenge:
Extend planning period
Cross traditional media and academic boundaries
Incorporates risk and performance base
Assures assets required are available
Bullet points explaining key technical issues
Lack of mutually agreeable definition of/for sustainability

Expectation that technology will solve problem
Bullet points explaining key regulatory issues
Lack of cogent, integrated water/environmental management strategy at all levels of government and in watersheds
Bullet points explaining key managerial issues
Trained personnel at all levels providing funding Scheduling required operations
Bullet points explaining key financial issues
Funding too short term, ecosystem studies will require long-term, reliable funding
Bullet points explaining key organizational issues
Organizational sustainability critical to protect resources
Bullet points explaining key community issues
Communities mistrust of scientists, regulators as sources of information Community ability to pay/willingness to pay
Explanation of why addressing this challenge is important
Without comprehensive approach to research, little change to current practice
Desired outcomes of research at the basic level
Development of cogent, uniform, science based water/land use/environmental policy Comparison of water/environmental management mandates of assessment of effectiveness
Desired outcomes of research at the applied level
Statewide/region/watershed wide measures of consequence
Desired outcomes of research at the demonstration level
Measure of effects (social/environmental/economic) of implementation of a specific/targeted rule/ordinance
Identification of who is best suited to conduct the research
University research Public interest groups/NGOs
Level of investment/effort warranted
\$20M 10 years

E.2.5 Economics: Full Cost Pricing

Descriptive Title of Research Challenge:
Quantifying and characterizing full cost integrated water pricing, including secondary economic benefits and consequences
Bullet points explaining details of the research challenge:
◆ Challenge: How to determine full cost pricing ◆ Challenge: Categorize and quantify benefits and consequences (+/-) of total water to arrive at economic measures of total pricing (including avoided costs & opportunity costs; & cost and value of natural systems) ◆ Challenge: Put a dollar figure on secondary impacts (real benefits & costs) ◆ Develop science based Ecological economics ◆ Bob's example: City of NY water filtration avoidance program – able to protect quality of water at less cost than building filtration plan. ◆ Challenge: Practical economic tools for comparing centralized to distributed systems

◆ Economic analyses should focus on desired water quality outcomes ◆ Identify existing sources of information & methodologies ○ Sydney Technical University costing for sustainable urban sustainable water outcomes and externalities ○ University of VT has done work in ecological valuation
Bullet points explaining key technical issues
◆ What is cost of environmental degradation ◆ What is the value of natural functions (environmental services) ◆ What is value of existing infrastructure ◆ How to determine value of ongoing operation and maintenance (asset management) ◆ Focus on avoided costs and benefits gained by sustainable approaches ◆ Quantify value of costs & benefits as a spectrum focusing on available data, methods and metrics.
Bullet points explaining key regulatory issues
Currently no regulatory driver to conduct holistic economic analysis
Bullet points explaining key managerial issues
No consistency on how responsible management entities function.
Bullet points explaining key financial issues
How to overcome personal willingness to pay
Lack of funding in planning phases
Funding programs should be focused on water quality outcomes
Bullet points explaining key organizational issues
Need to integrate water economic analysis with other media and infrastructure system (e.g., transportation or energy)
Bullet points explaining key community issues
Determination of local community's perception of resource value - Need tools to incorporate this value based data (book: <i>Restoration Economy</i>)
Explanation of why addressing this challenge is important
Because full cost pricing will provide incentive for integrated water management and avoid future costs.
In the long term sustainable solutions should be most cost effective in the long term.
Desired outcomes of research at the basic level
Desired outcomes of research at the applied level
◆ If the full costs can be characterized at a community level then they can be input into tools for economic analysis ◆ Need new economic models to evaluate performance of infrastructure projects at an existing new community level (existing urban, existing suburban, existing rural, and new urban, suburban and rural settings)
Desired outcomes of research at the demonstration level
Take a community through the process of full costing economic analysis for water infrastructure
Identification of who is best suited to conduct the research
Level of investment/effort warranted
\$250,000 per year for five years

E.2.6 Economics: Practical Tools

Descriptive Title of Research Challenge:
Develop practical economic tools for accurate full – cost pricing for planning and implementation of integrated water systems
Bullet points explaining details of the research challenge:
◆ Tools how to determine full cost pricing ◆ Provide economic incentives for sustainable water infrastructure ◆ Development of tools to quantify the cost of distributed treatment systems ◆ Need tools to analyze cost of existing infrastructure ◆ Need to utilize science-based ecological economics (triple bottom line – financial, social and environmental) ◆ Practical economic tools for consultants to comparing centralized to distributed systems
Bullet points explaining key technical issues
What is the value of water?
Bullet points explaining key regulatory issues
Regulations can influence economic feasibility - example City of NY water filtration avoidance program – able to protect quality of water at less cost than building filtration plan.
Bullet points explaining key managerial issues
What is perceived value of water?
Bullet points explaining key financial issues
Full value water costing should result in a change in rate payer fees. Therefore financial tools are needed to justify fees
Bullet points explaining key organizational issues
Getting different agencies to work together Interagency cooperation is essential
Bullet points explaining key community issues
Communities do not currently pay for some water services (e.g. stormwater) Therefore tools must be available to characterize avoided costs
Explanation of why addressing this challenge is important
These tools are needed to overcome bias inherent in existing cost benefit analysis methods
Desired outcomes of research at the basic level
Elements of sophisticated tools should be assessed and prioritized to enable economic analysis at community level
Desired outcomes of research at the applied level
Use new economic tools to optimize performance of existing centralized infrastructure by incorporating centralized approaches
Desired outcomes of research at the demonstration level
Demonstrate these tools in real communities to determine effectiveness and outcomes
Identification of who is best suited to conduct the research
Economists, policy makers, and engineers
Level of investment/effort warranted
\$250,000/year over 5 year period

E.3 Science Challenge Sheets

E.3.1 Natural Systems

Descriptive Title of Research Challenge:
Water cycling – the major natural elements and switches controlling the water cycle Defining criteria for ecosystem health
Bullet points explaining details of the research challenge:
Structure and function of the unseen biological elements and their interactions with the environment
Bullet points explaining key technical issues
Integrating tools to understand system biology and network of interactions with the environment and implications to human health.
Bullet points explaining key regulatory issues
Bullet points explaining key managerial issues
◆ Define converging technologies – modeling ◆ Need of bioinformatics – computational artificial ◆ Intelligence technology – making sense of it all
Bullet points explaining key financial issues
The value of ecosystem health for the quality of life
Bullet points explaining key organizational issues
Interdisciplinary approach of research
Bullet points explaining key community issues
◆ Ecosystem health = life quality ◆ Ecosystem health knows no boundary yet ◆ Cumulative effect of individual/community responsibility
Explanation of why addressing this challenge is important
Global habitability emerging from space imaging. Need to understand the switches controlling health of the ecosystem.
Desired outcomes of research at the basic level
Understanding of the major elements of the ecosystem – the controlling switches
Desired outcomes of research at the applied level
Harnessing of the “unseen powers” controlling the health of the ecosystem
Desired outcomes of research at the demonstration level
Define a suitable “pilot site”
Identification of who is best suited to conduct the research
Converging effort of academia/industry/governments
Level of investment/effort warranted
Need for long-term research platforms

E.3.2 Human Health

Descriptive Title of Research Challenge:
To better understand the impacts of the artifacts of modern life on human health, especially the use of decentralized wastewater systems.
Bullet points explaining details of the research challenge:
◆ Need to better understand fate & transport of constituents (both chemical and biological) in water (including wastewater, stormwater, and septage), and ultimately to point of human exposure and possible human health effects. ◆ Need to understand effectiveness of technological interventions in management/removal of constituents
Bullet points explaining key technical issues
◆ Epidemiologic studies to define exposure and health effects are a start, but new methods are needed, such as active surveillance to find dispersed cases, physician education to increase lab testing and reporting of waterborne disease. ◆ Work needs to be ongoing, not just studied at a point in time. ◆ Need better environmental health related sensors
Bullet points explaining key regulatory issues
◆ Effective regulations need to be based on sound science about movement of water constituents in the environment ◆ Possible removal of non-treatable constituents from market by regulations
Bullet points explaining key managerial issues
◆ Information on fate/transport of constituents in water will impact need for need and type of treatment needed to minimize health effects. ◆ Knowledge of fate/transport leading to exposures, which can then be used in risk assessment ◆ Decentralized wastewater management integrated with other water issues such as stormwater and septage).
Bullet points explaining key financial issues
Enhanced knowledge of fate/transport and exposure (resulting from small research expenditures in short run) will lead to more effective management of much larger infrastructure investments in the long run
Bullet points explaining key organizational issues
Bullet points explaining key community issues
◆ Communicate actual risks to public & policy makers: all water is reused, and public health can be protected ◆ Decentralized systems can be effective in protecting public health and the environment but need to be managed by someone (could be anyone from homeowner to utility)
Explanation of why addressing this challenge is important
Human health is an important area of research based on data from CDC (the federal agency most trusted by the public) showing there is a clear trend toward more outbreaks related to small water and onsite wastewater systems (including temporary use facilities at camps or fairs)
Desired outcomes of research at the basic level
Better understanding of mechanisms and processes involved in fate & transport, including new techniques (QSAR, microbial source tracking)

Desired outcomes of research at the applied level
◆ Enhanced protocols for treating constituents of concern ◆ Better understanding of exposure and illness effects of decentralized systems
Desired outcomes of research at the demonstration level
Demonstration of effectiveness of treatment processes (including soil management systems) in removal or management of constituents
Identification of who is best suited to conduct the research
Universities, public health and environmental agencies (joint projects)
Level of investment/effort warranted
300-500K/year for 3 years (to start anyway...)

E.3.3 Technology

Descriptive Title of Research Challenge:
Integrated Sustainable Water Infrastructure
Minimize resource utilization and maximize resource recovery through intelligent, efficient, adaptable, sustainable technologies
Bullet points explaining details of the research challenge:
◆ new sensing and monitoring control technologies , interact with scientists, managers, customers, and the community with water infrastructure ◆ new technologies and systems (including materials) for the sustainable infrastructure including water efficient devices and cascading systems (from high to low quality) ◆ storage and reuse technologies a various scales of infrastructure (including building envelope) ◆ identifying resource ◆ minimizing chemical usage e.g. biological treatment.
Bullet points explaining key technical issues
◆ Retrofitting – storage, treatment systems, plumbing, sensors at building and infrastructure scale ◆ Sensors – control systems, materials, interfaces
Bullet points explaining key regulatory issues
◆ Lack of decentralized code of practice ◆ Building codes not ready for adaptable water buildings
Bullet points explaining key managerial issues
Institutional structures not in place for decentralized ownership and maintenance.
Bullet points explaining key financial issues
◆ Who pays for what – who receives revenue for what ◆ Upfront financiers to create critical mass ◆ Retrofitting expensive
Bullet points explaining key organizational issues
Fragmented
Bullet points explaining key community issues
◆ Ethics of sensor intrusion ◆ Management and ownership, access, accountability on private property ◆ Aesthetics perception – toilets, local treatment plants

♦ Willingness to pay for future maintenance or upgrade ♦ Education needs and costs
Explanation of why addressing this challenge is important
Desired outcomes of research at the basic level
Improved system performance – sensors
Resource minimization -
Desired outcomes of research at the applied level
Desired outcomes of research at the demonstration level
♦ Shift from utility system to consumer system (toilets that have multiple functions) ♦ Washing machine treatment system, storage systems w/cooling functions – multi-benefit providers ♦ Aesthetically acceptable water toilet – no water, nutrient recycling, source control of pollutants
Identification of who is best suited to conduct the research
Level of investment/effort warranted

E.3.4 Social and Decision Sciences

Descriptive Title of Research Challenge:
What is the most appropriate method to link research, management, and policy?
Bullet points explaining details of the research challenge:
♦ Governance is not there; amateurs doing decision-making. ♦ Public is lacking in understanding – unable to make informed decisions – engineers/scientists don't have the language to communicate
Bullet points explaining key technical issues
♦ Relationship between urban footprint and individual land use decisions. ♦ Interactions between water and non-water infrastructures.
Bullet points explaining key regulatory issues
♦ Green infrastructure co-equivalencies (code says catch basins, curbs, sidewalks, etc. – need equivalent) ♦ Accelerate sustainable infrastructure permitting process.
Bullet points explaining key managerial issues
♦ Permitting review (overlap with above) ♦ Regulatory staff comprehension, training.
Bullet points explaining key financial issues
♦ Better understanding of appropriate balance of risk (LUST example) ♦ Appropriate valuation of sustainable projects.
Bullet points explaining key organizational issues
♦ Challenge is organizational. ♦ Removing siloing – leverage ideas, funding. ♦ Integrated design and planning teams – governmental and private and public

Bullet points explaining key community issues
◆ Need to make the link between clear water and sustainable civil society ◆ Inclusion of community in decision-making process at the beginning, before the project is framed – leaving them understand the tradeoffs (cheap now may be expensive later)
Explanation of why addressing this challenge is important
Can result in “whole city” change if applied.
Negotiation with community may increase satisfaction.
Desired outcomes of research at the basic level
Consensus building tools.
Desired outcomes of research at the applied level
Develop a common language to frame questions, answers, and implementation.
Desired outcomes of research at the demonstration level
Examples/case studies of situations that worked.
Tools/protocols that are transferable.
Consensus-building process.
Identification of who is best suited to conduct the research
Not just academics – those in the field need to be involved.
Professional facilitators.
Level of investment/effort warranted
Fundamental issue – level of investment/effort should be high.
Timeline and scale and culturally contextual, 1-5 years, 15-25 years

APPENDIX F

RESEARCH CHALLENGE SUMMARIES

F.1 Public Statements

F.1.1 Demonstration Projects

Our future depends on defining multiple approaches to a sustainable water system in respect to social, cultural, environmental context and at appropriate scales. To accomplish this, we must conduct projects demonstrating multiple integrated water management approaches appropriate to a particular scale that address regional and national issues.

We need to engage the “public” (decision-makers, community practitioners, owners, users) to facilitate adoption of appropriate water management strategies.

Demonstrations are critical because:

- ◆ Water supply shortages exist across the globe
- ◆ We want to quantify the impacts on the triple bottom line in a real world situation
- ◆ Seeing is believing
- ◆ Collecting information relative to implementing an integrated water system within our regulatory, managerial, financial, organizational and community frameworks
- ◆ They identify unforeseen consequences of implementing a particular integrated water management strategy
- ◆ Demo projects expedite adoption and transfer

In order to implement demonstration projects, a significant investment is needed (\$30-50 million/year for 10 years). In order for the demonstration projects to be truly implementable, we must also create a safe haven for innovation through a framework of consultant participation, manufacturer innovation, and third party verification.

F.1.2 Market Research

Water, in all its forms and for all its uses—is a critical resource for the United States, our allies and the world. Several factors are at play which could be significantly degrading our precious water—both in quantity and quality.

Our water infrastructure is aging rapidly and if continued to be operated as it has in the last century is at risk of being catastrophically harmed—without a frighteningly huge and unpopular funding initiative. Unfortunately, without change, the health, lives and productivity of our citizenry and the businesses for which they work or own are at risk.

Cross disciplinary partnerships involving private industry, governmental and non-governmental agencies and organizations, including a rapidly growing army from the scientific

community have developed tools to potentially move us into a remarkably effective, low-cost, proven and sustainable integrated water infrastructure—all meeting a good ‘ol “common sense” sniff test.

We need your modest support to enable these efficient and affordable methodologies to gain further momentum. We ask specifically for 2.5 million dollars in the current fiscal year to enable the mission-critical basic market research plan outlined in the submitted documents to take place across the country to assist in the implementation of these cost-effective methodologies.

These methodologies have previously been supported across both sides of the aisle and in various agencies in multiple administrations. We ask now for your support to act quickly in this critical time of need to assist you in your efforts to protect the precious water resources of our nation.

Thank you for the opportunity to bring this important matter to your attention.

F.1.3 Products

Large-scale societal change on recycling, organic food, green building, and carbon emissions demonstrate the importance and potential for consumers to adopt smart water practices. Strategic investments in basic scientific research, team demonstrations, and new products will give our citizens ‘conspicuous conservation’ choices that restore water health.

First, science must define the microbiology and chemistry of appliances and personal products involving water. It is particularly important for the future of water, communities and public health to know how PCPPs and other introduced substances affect soil, biological, mechanical treatment processes, and what we must fix.

Second, sustainable demonstrations done with LEED and green buildings must be done to create truly whole-systems models of ‘conspicuous conservation’ and water health.

We recommend research and demonstration on monetary and whole-cost impacts at the consumer level, including the effectiveness of local water incentive programs like rain barrels. And applied partnership research should support profitable enterprises growing around water-smart consumer solutions.

F.1.4 Water Literacy

A critical way for us to improve our water future is to improve water literacy at the local level. We recommend work with media professionals to develop the message of watershed relationships to human activities in many forms to deliver to multiple audiences. Trusted community organizations, such as NGOs, must be trained to deliver the message with maximum impact using multiple products for multiple audiences.

The products of this work should be disseminated for use by others with necessary support services, as required. These process, product development, and initial training efforts can be supported using federal funding (EPA, USGS, USDA, DOD, CDC, etc.) at a recommended level of \$1-3 million/year for three to four years. Any necessary background research (e.g. global warming impacts on hydrologic cycles), conducted through universities or government offices, is recommended for funding at \$<1million/year for three years.

F.2 Regulatory, Policy, and Economic Statements

F.2.1 Regulatory

To succeed, we need to develop a new methodology of analysis and benefit/cost for water, people, and nature. Performance and risk associated management systems need to be quantified to distinguish the good and better as well as the poor performers. A LEED-type approach for all water could serve as an analysis tool to assess alternatives. For a fair free and open marketplace, a unified regulatory compliance structure should be developed and implemented for distributed systems. Regulatory confusion is costly and could be deadly to ecology, nature, water, and people. Where there is no unified vision, water opportunities perish.

F.2.2 Policy

An effective integrated water management strategy and associated policies must:

- ◆ Define sustainable, integrated water resource management;
- ◆ Provide tools, policies, regulations that allow communities to achieve a local vision of sustainability;
- ◆ Quantify economic, environmental, societal consequences of integrated water management strategies; and
- ◆ Invest in data collection, analysis, monitorial, economic analysis, and risk analysis, and risk analysis to support integrated water management infrastructure.

F.2.3 Economics

Historically, the undervalued cost of water has led to inefficient, unsustainable water infrastructure. Traditional economic methods do not fully quantify or characterize the true costs of impacts on communities and natural systems. New economic methods are needed that sufficiently address full cost integrated water pricing. This includes secondary economic benefits and consequences. It also includes community values and priorities.

These new economic methods must then be translated into practical, implementable tools that enable communities to use limited resources more efficiently.

Full cost accounting and valuation has the potential to make sustainable water resources management acceptable and preferable to the end user.

F.3 Science Statements

F.3.1 Natural Systems

Presently, we have a global view of the role of water cycling in natural ecosystem emerging from ecological research and space imaging—global habitability. We need to define criteria for the state of health of the ecosystem. More importantly, we need to define the switches that control the biological networks and its interactions with the environment. This calls for a multidisciplinary approach using converging technologies and addressing both temporal and spatial dimensions. A multi-strata data acquisition is required to develop feedback model systems using bioinformatics, artificial intelligence, and computational tools in order to make sense out of these huge data bases. A conceptual, dynamic platform can then be used for

developing micro-ecological engineering elements for restoring the state of health of the ecosystem.

This is a long-term goal, requiring a long-term integrated research plan.

A shorter-term strategy is the development of intelligent bioreactors that include necessary feedback loops. These systems can be applied to a spectrum of different scales.

F.3.2 Human Health

The research challenge is to better understand the impacts of the artifacts of modern life on human health, especially the effects of decentralized wastewater systems.

There are two different but complementary ways to approach this research challenge:

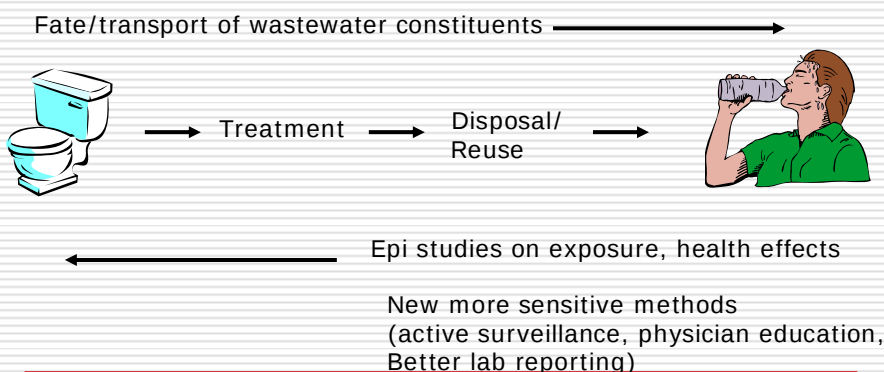
1. Starting from the point of generation: better understanding of fate & transport of constituents (both chemical and biological) in water (including wastewater, stormwater, and septage), and ultimately to point of human exposure.
2. Starting from point of human exposure/illness, trace back through the environment to point of generation to understand why the constituent was present in the environment in such a way that people were exposed.

To meet this objective, epidemiologic studies are a start, but new methods are needed, such as active surveillance to find dispersed cases, physician education to increase lab testing and reporting of waterborne disease.

Human health is an important area of research based on data from CDC (the federal agency most trusted by the public) showing there is a clear trend toward more outbreaks related to small water and onsite wastewater systems.

Human Health

□ 2 ways of approaching:



F.3.3 Technology

We have a legacy system of infrastructure that is a liability to our nation's growth.

We are proposing a technology revolution that changes the paradigm from urban consumption to production of resources. Our houses will be generators of water and energy and our water efficiency measures will create a 20% reduction in the nation's CO₂ production—the single most effective measure we can take.

By moving away from centralized systems, we will create a national system of resilient infrastructure that can cope with climate change, terrorism, and natural disasters.

F.3.4 Social and Decision Sciences

We have shown that engaging the community, from the beginning, in integrated design and planning for water sustainability will result in cost savings, water protection and healthier communities.

We have shown communities how restoring and conserving healthy freshwater ecosystems can save millions of dollars in drinking water and stormwater infrastructure costs by replacing, deferring or eliminating the need for conventional “pipes and valves”.

To do this, we need to work with local people, on their landscape, on their issues.

We need to develop the local government management tools, design guidelines, model bylaws and community education modules they need to capture the savings.

Communities need simple, practical management tools and design guidelines so they can meet the economic needs of their communities and they need them NOW.

APPENDIX G

LONG-RANGE PLANNING FOR DECENTRALIZED WASTEWATER AND STORMWATER TREATMENT RESEARCH: LITERATURE REVIEW

04-DEC-8W

LONG-RANGE PLANNING FOR DECENTRALIZED WASTEWATER AND STORMWATER TREATMENT RESEARCH: LITERATURE REVIEW

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ABSTRACT AND BENEFITS

Abstract:

This document summarizes research related to the environmental science and engineering (ES&E) of decentralized stormwater and wastewater that has taken place since the National Decentralized Water Resources Capacity Development Project's (NDWRCDP's) 2002-2003 Training, Research, and Development Plan (2002) was published. A number of earlier publications were also reviewed to provide context.

The 2002-2003 Plan identified 22 research priorities within the field of wastewater environmental science and engineering. This report provides an overview of research completed in those areas since the Plan's completion, including that published in NDWRCDP research reports, peer-reviewed journals, and conference proceedings. The report also provides a summary of research conducted between 2000 and early 2006 in ES&E related to decentralized stormwater.

Benefits:

- ◆ Provides a summary of ES&E priority research projects completed through the NDWRCDP
- ◆ Sets ES&E research completed through the NDWRCDP in the wider context of current research about decentralized wastewater treatment
- ◆ Summarizes recent research in decentralized stormwater treatment, including the latest on pollutant sources and source control, site-scale controls and best management practices, and watershed-scale assessment of decentralized practices

Keywords: Onsite wastewater treatment, soft paths, integrated water infrastructure, decentralized wastewater, decentralized stormwater.

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LIST OF ACRONYMS

ASABE	American Society of Agricultural and Biological Engineers (formerly known as ASAE)
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
AOCM	Aluminum oxide coated media
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BMP	Best management practice
BOD	Biochemical oxygen demand
C	Carbon
C	Celsius
Ca	Calcium
CAWT	Coalition for Alternative Wastewater Treatment
cBOD	Carbonaceous biological oxygen demand
CDC	Centers for Disease Control and Prevention
CEC	Cation exchange capacity
CFU	Colony-forming unit
Cl	Chloride
cm	Centimeter
COD	Chemical oxygen demand
CSO	Combined sewer overflow
Cu	Copper
d	Day
ES&E	Environmental Science and Engineering
ESP	Exchangeable sodium percentage
EPRI	Electric Power Research Institute
ETV	Environmental technology verification
FAST	Fixed activated sludge treatment (brand name)
FC	Fecal coliforms
Fe	Iron
ft ²	Square foot/feet
g	Gram
gal	Gallon
GIS	Geographic information system
H	Hour
HLR	Hydraulic loading rate
HSPF	Hydrological Simulation Program-Fortran
in	Inch
IR	Infiltration rate
ISMDSF	Integrated Stormwater Management Decision Support Framework
kg	Kilogram
km ²	Square kilometer
L	Liter
LID	Low-Impact Development

LIFE™	Low Impact Feasibility Evaluation™
LTAR	Long-term acceptance rate
MANAGE	Method for Assessment, Nutrient-Loading and Geographic Evaluation
MBR	Membrane bioreactor
m	Meter
m ²	Square meter
Mg	Magnesium
mg	Milligram
mL	Milliliter
mm	Millimeter
Mn	Manganese
MODFLOW	Modular Three-Dimensional Groundwater Flow Model
MRA	Microbial risk assessment
MT3D	Model Transport in 3 Dimensions
MUS	Marshland upwelling system
N	Nitrogen
NDWRCDP	National Decentralized Water Resources Capacity Development Project
NEIWPCC	Northeast Interstate Water Pollution Control Commission
NH ₃	Ammonia
NH ₄ -N	Ammonium nitrogen
NO ₃ ⁻	Nitrate
NO ₃ -N	Nitrate nitrogen
NODP	National Onsite Demonstration Project
NOWRA	National Onsite Wastewater Recycling Association
NPDES	National Pollution Discharge Elimination System
NSQD	National Stormwater Quality Database
NURP	National Urban Runoff Program
NLMM	Nitrate Loading Management Model
NRECA	National Rural Electric Cooperative Association
OWS	Onsite wastewater system
OWTS	Onsite wastewater treatment system
P	Phosphorus
PAH	Polyaromatic hydrocarbon
Pb	Lead
PPCPs	Pharmaceuticals and personal care pollutants
PVC	Polyvinyl chloride
RMFs	Redoximorphic features
RNA	Ribonucleic acid
RSF	Recirculating sand filter
SND	Shallow, narrow drainfield
SPSF	Single pass sand filter
STE	Septic tank effluent
SUDS	Sustainable Urban Drainage System
SWAT	Soil and Water Assessment Tool
SWMM	Stormwater Management Model
TFU	Textile filter unit
TKN	Total Kjeldahl nitrogen

TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
UOP	Unit operating process
URWARE	Urban Water Research Model
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
WARMF	Watershed Analysis Risk Management Tool
WEF	Water Environment Foundation
WERF	Water Environment Research Foundation
WSAS	Wastewater soil absorption systems
WSUD	Water sensitive urban design
WWTP	Wastewater treatment plant

EXECUTIVE SUMMARY

In 2002, the National Decentralized Water Resources Capacity Development Project (NDWRCDP) published a *Training, Research, and Development Plan* that listed 22 research priorities within the field of decentralized wastewater environmental science and engineering (ES&E). This report summarizes research completed through the NDWRCDP since the publication of the *Plan*, setting the NDWRCDP projects in a wider review of recent scientific literature in an effort to understand progress made toward addressing the ES&E research priorities that were established in 2002. In the report, the ES&E research priorities are organized according to whether they apply to the site scale (Chapter 2.0), the watershed scale (Chapter 3.0), or to technology assessment methods (Chapter 4.0). Additional summary information about the NDWRCDP research findings highlighted in this report may be found in Appendix A.

In support of efforts to understand decentralized wastewater and stormwater issues as parts of a wider distributed infrastructure, recent research on ES&E related to decentralized stormwater treatment is also summarized in this report (Chapter 5.0). Since an organizing document summarizing research priorities was not readily available at the outset of the project, this chapter begins by reviewing recent work in pollutant sources and source controls, and then provides an overview of research in both site-scale treatment practices and in assessment of cumulative effects of site-scale decentralized practices at the watershed scale.

CHAPTER 1.0

INTRODUCTION

This document continues work that was begun by the National Decentralized Water Resources Capacity Development Project (NDWRCDP). The NDWRCDP was formed in 1996 to coordinate and implement a national training, research, and development agenda in decentralized water resources. The NDWRCDP is a collaborative effort of the Coalition for Alternative Wastewater Treatment (CAWT), the Consortium of Institutes for Decentralized Wastewater Treatment (Onsite Consortium), the Electric Power Research Institute (EPRI), the National Rural Electric Cooperative Association (NRECA), and the Water Environment Research Foundation (WERF).

In a research needs conference held in 2000, papers were presented on gaps in the science of treatment in soil absorption systems and of fate and transport of nutrients and pathogens. A 2001 strategic retreat, with input from a wide range of policy and industry experts, helped to further prioritize these topics. The *2002-2003 Plan* identified 22 research priorities within the field of decentralized wastewater environmental science and engineering (ES&E).

This publication presents an overview of some of the research completed since 2002 related to the decentralized wastewater ES&E priorities, and also provides a summary of current research in ES&E related to decentralized stormwater.

1.1 Methods

The chapters updating the decentralized wastewater research priorities were developed through a review of literature mostly published since 2002. The project team identified literature to be reviewed, and the WERF Project Subcommittee (PSC) offered additions and clarifications. More relevant literature was identified than could be reviewed within this project. The sources explored most carefully included published NDWRCDP project reports, proceedings from American Society of Agricultural Engineers (ASAE; now ASABE) symposia on individual and small community sewage systems, proceedings of the annual conferences of NOWRA (National Onsite Wastewater Recycling Association), proceedings of the Water Environment Foundation's (WEF's) WEFTEC conferences, proceedings of the annual conferences on onsite systems held at North Carolina State University, issues of *Small Flows Quarterly*, and issues of WEF's *Water Environment Research*.

Contents of these and other sources were scanned and coded according to their relevance to one or more of the 22 ES&E research priorities. The sources that addressed one or more of the research priorities were entered into a bibliographic database (EndNote). More than a thousand publications were scanned, and over 180 publications were entered into the database.

No equivalent of the 22 ES&E research priorities existed for decentralized stormwater. Therefore, the project team conducted a review of recent literature (roughly 2000-2006) in ES&E for decentralized stormwater. The sources explored included published WERF project reports and literature reviews, proceedings from American Society of Agricultural Engineers

(ASAE; now ASABE) and American Society of Civil Engineers (ASCE) conferences and symposia on urban drainage and water resources issues, WEFTEC conference proceedings, and a number of peer-reviewed journals including WEF's *Water Environment Research*.

1.2 Organization

Chapters 2.0 through 4.0 take up the ES&E challenges for decentralized wastewater, focusing on site-specific processes, watershed-scale processes, and technology assessment methods. The 22 ES&E challenges were not arranged in any particular order in the 2002-2003 *Plan*. Through discussion with the PSC, a basic framework for organizing the challenges was developed, and it was modified during the writing process to add greater clarity. The relevant research priorities are listed as bullet points at the beginning of each chapter. Additional detailed information about the NWDRCDP research discussed in this report, often including quoted abstracts or conclusions/research needs sections, is included in Appendix A.

Chapter 5.0 is devoted to recent research in decentralized stormwater. The review of decentralized stormwater literature is organized by research area, but follows a progression similar to that of the decentralized wastewater research (site-scale to watershed-scale).

Wherever possible, hyperlinks to reports, journal articles, and other sources are included in the References section of this report.

CHAPTER 2.0

SITE-SPECIFIC PROCESSES (“MICRO-SCALE”)

Site-specific processes, sometimes called processes at the micro scale, are primarily those biochemical and physical processes which take place in the wastewater treatment train. They can also include processes that take place near an individual system but not necessarily as part of the treatment train, e.g., in groundwater downgradient from a wastewater soil absorption system.

The research priorities identified in the NDWRCDP’s *2002-2003 Training, Research and Development Plan* (NDWRCDP, 2002) related to micro-scale processes include:

- ◆ Develop/evaluate methods for assessing the treatment capacity of a site, including a basis for performance-based standards and the possibility of designing soil-based treatment systems that maximize use of soils and minimize mechanical pretreatment; and develop/evaluate effective methods to assess the hydraulic capacity of a site for use with large/cluster wastewater soil absorption systems (WSAS)
- ◆ Characterize the effect of pretreatment on soil clogging and wastewater soil absorption systems’ hydraulic and purification performance
- ◆ Identify appropriate levels of pretreatment / pretreatment technologies (black boxes) needed to allow minimal reliance on soil treatment.
- ◆ Quantify fate and transport of pathogens in saturated soils; evaluate pathogen containment in cluster systems; and identify and characterize the basic mechanisms by which pathogens are inactivated.
- ◆ Identify/develop appropriate models for predicting treatment efficiency (system performance) as a function of siting, design, and operation; and develop effective models to predict soil treatment (residence time, loading rates, dose frequency, biomat effects, soil profiles)

2.1 Assessing Treatment Capacity of a Site

Tyler et al. (2004) worked with the National Model Code Committee of the National Onsite Wastewater Recycling Association (NOWRA) to estimate the treatment of various wastewater effluents by soil. The project developed a series of matrices showing effluent output concentration vs. the probability of reaching that concentration for a number of system design parameters such as influent wastewater concentration, wastewater loading rate, and depth of application. One set of matrices was developed for each wastewater constituent. The appropriate set of matrices to be used in design was determined by the site’s soil morphological characteristics. The matrices could be used either to estimate expected treatment for selected wastewater inputs by the various soils, or to determine effluent quality needed prior to soil infiltration in order to reach desired performance standards. A draft report was produced, but the project was not completed in the form it began. At least one of the researchers plans to publish results in a number of separate papers (Tyler, personal communication).

Most recent work in this area tended to report on the qualitative importance of various factors rather than providing models. The following sections review recent literature on site evaluation, including:

- ◆ Site infiltration capacity for small and large-scale decentralized systems (Section 2.1.1);
- ◆ Determining depth to water table (Section 2.1.2);
- ◆ Treatment for phosphorus (Section 2.1.3), nitrogen (Section 2.1.4), and pathogens (Section 2.1.5); and
- ◆ Treatment at a number of special sites (Section 2.1.6).

2.1.1 Site Evaluation for Infiltration Capacity

White and West (2003) provided a thorough review of “the science of getting water into the ground” and report on experiments and calculations to further advance that science. They describe how Darcy’s law and hydraulic resistance relate to the infiltration of effluent, and show that restrictive layers like fines or biomat “control infiltration rates and long-term soil acceptance rates of septic tank effluent because of low hydraulic conductivity.”

Wheeler et al. (2005) described what they believe to be the minimum amount of soil information necessary for site evaluation to be accurate and thorough. The geomorphic and surface properties of importance include soil parent material; hill slope position, slope shape, and slope gradient; and soil disturbance. The soil properties of importance are soil texture and soil structure (type and grade) for each horizon; all the components of soil color (both matrix and mottles); and soil consistence. They recommend, “Additional soils information should be sought in areas where known problem soils exist.”

Three-dimensional laboratory studies at the Colorado School of Mines and field studies in nearby areas of Colorado were performed that investigated the effects on infiltration rate of chamber vs. aggregate systems (Siegrist and Van Cuyk, 2001). Their 3-D laboratory experiments, conducted in sand-packed lysimeters, indicated that the chamber systems loaded at 8.4 cm/d performed comparably to aggregate systems loaded at 5.0 cm/d for BOD, TSS, nutrient, and bacteria treatment. Their field investigations, located in coarse and gravelly native materials, showed that the performance of chamber systems was comparable to gravel systems at two paired sets of loading rates, in which the chamber systems received loading rates more than 70% higher than the aggregate systems. The effects of aggregate vs. no aggregate (chambers) on the infiltrative surface architecture and infiltration of effluent were also investigated, and results consistent with these field and laboratory studies were reported (Diaz and Siegrist, 2004).

The effect of soil type on the long term acceptance rate (LTAR) of subtropical soils located in southeast Queensland, Australia was explored, using existing WSAS and column tests on soil samples from those systems (Dawes and Goonetilleke, 2004). Treatment performance, as noted via field observations (including soil water sampling) and reports from system owners, was compared with soil properties that influence the soil’s structure and stability, including soil permeability, clay content, and clay type. The study confirmed that sodium in wastewater can cause soil structural problems and reduce permeability. However, the authors noted that soils like kaolinite and illite clays, with little in the way of shrink-swell characteristics, were more susceptible to reduced permeability than soils with substantial shrink-swell characteristics (smectite clay), where soil properties and porosity can regenerate. Sites with a predominance of smectite clays showed little reduction in permeability even with

moderately high levels of exchangeable sodium. In soils exhibiting the least structural changes with effluent application, the following chemical characteristics were found:

- ◆ Moderate to high cation exchange capacity (CEC) (or effective CEC),
- ◆ Ca:Mg ratios greater than 0.5, and
- ◆ Low exchangeable sodium percentage, with exchangeable Ca or Mg dominating over exchangeable Na concentration.

Many jurisdictions require a “perc test,” a field test of a soil’s initial LTAR. Marquart (2004) critically reviewed the literature on percolation tests, conducted trials, and proposed a standardized design. He concluded, “[M]ore research is needed to find out if the perc test can reliably approximate unsaturated flow in coarse textured soils with fast perc rates, and reliably approximate saturated flow in fine textured soils with slow perc rates.”

Miles and West (2001) compared two states’ approaches to systems for assessing sufficient infiltration capacity. In Georgia, infiltration capacity assessment is based on identification of soil series. While this method makes communication, the production of large-scale soil maps, and the description of properties not reflected in morphological descriptions easier, the lack of soil series for every set of properties identified in the field results in the use of ‘variants’ that may be misinterpreted. In Missouri, assessment is based on soil morphological descriptions that are used to determine loading rates based on texture and structure groupings for each specific horizon; along with redoximorphic features (RMFs) and depths to restrictive layers, these groupings are the basis for the spatial layout of the absorption system. The Missouri system captures descriptions of ‘variants’ within the soil series, but makes communication among non-soil science professionals more difficult.

Research in arid regions showed that a soil’s LTAR may not be the only parameter to consider when calculating design loads in some places. Al-Shiekh Khalil et al. (2004) speculated on the effects of evaporation, and Rainwater et al. (2005) reported on field demonstrations that showed taking evaporation into account could allow loading rates to double compared to the rates allowed under current regulations for some arid soils.

Methods of effluent application may strongly influence a site’s ability to accept effluent (Corwin, 2003). In Williamson County, Tennessee, 50% of onsite systems had failed in 1982, when the County started using low-pressure pipe (LPP) systems. Since then, less than 5% of systems have failed hydraulically.

Effluent dispersal using drip irrigation can also spread effluent application out over time and a greater proportion of the soil absorption system space, potentially enhancing a site’s infiltration capacity. Peer-reviewed guidelines for drip dispersal in various conditions were recently completed (Watson, McEntyre, and Whitehead, 2003). The authors conclude “The success of drip dispersion depends on how successfully the wastewater dose rate and volume is matched to the soil and site characteristics... through teamwork between the professional soils evaluator and the design engineer. The guidelines outline the steps that are needed and provide basic criteria for adapting the various components to site conditions.”

A project funded by the NDWRCDP specifically addressed the potential for groundwater mounding to occur beneath cluster and other high-density WSAS (Poeter et al., 2005; see Appendix A.1) and developed a methodology for:

- ◆ “Evaluation of site-conditions and system-design influences on the potential for groundwater mounding and lateral spreading,
- ◆ “Selection of investigation techniques and modeling approaches based on site conditions, system parameters, and the severity of the consequences of excessive mounding.”

The authors recognized that successful “[e]valuation of the potential for groundwater mounding and break-out on the surface or side slopes requires different levels of effort depending on the characteristics of the subsurface and the consequences of system failure.” Consequently, they developed a phased approach, with more investigation called for as the risk of mounding increases or the consequences of failure due to mounding become more severe. They developed a flowchart to guide preliminary assessment and to show subsequent steps. Investigative tools presented ranged from analytical modeling, which may be done with a calculator or spreadsheets, to more sophisticated numerical modeling.

Amoozegar (2005) described a three-step hydrological analysis used for over 15 years in North Carolina to design large (over 3,000 gpd) wastewater treatment systems. The analysis includes effluent infiltration into the soil, vertical movement of effluent through the unsaturated zone below the trenches, and lateral transport of effluent away from the WSAS. The author recommends “a simple analysis using Darcy's law...to estimate the amount of water that can leave the drainfield area of the proposed system.”

Stephens (2005) advocated low-pressure dosing in large-scale systems. He presented a method for calculating the size and length of the laterals and size and spacing of orifices for a low-pressure system. He also (Stephens, 2005) presented a method for determining design flows for a group of homes, using census data, known differences in lifestyle, and a safety factor.

A study for the NDWRCDP of methods used in designing large WSAS was partially completed, but not published (Wallace and Grubb, 2004). The authors report, “After peer review by internal and external reviewers, it was the decision of NDWRCDP to not publish the detailed results of the study.” Nonetheless, the investigators concluded that the Hantush method and MODFLOW both produced acceptable results, with MODFLOW more accurate but the Hantush method easier to use. Potential errors in field methods that they identified were: 1) sampling only upper soil horizons, not the aquifer material, 2) calculation rather than in-situ measurement of hydraulic conductivity, and 3) the use of split-spoon sampling to characterize subsurface conditions.

2.1.2 Depth to Water Table

Accurately evaluating the depth to seasonal high water table is key to knowing how deep infiltration trenches can be placed—or whether they must be placed at or above the ground surface. Redoximorphic features of the soil profile are often used in evaluating the depth of the seasonal high water table. Owens et al. (2001) used eleven years of data on water table levels in a fine-silty, siliceous, mesic Aquic Hapludult to study the correlation between free-water occurrence and RMFs with chroma ≤ 2 , chroma > 2 , and Fe-Mn nodules. They found that free-water occurred in all soil horizons that contained RMFs, and that frequency and duration of the water table was related to the intensity of the RMF that was expressed.

Three years of unpublished daily water table data from several wells in eastern North Carolina were used to calibrate a DRAINMOD simulation in order to determine correlations between particular RMFs and the length of time seasonal high water table existed at that depth (Lindbo, 2005). Statistical analysis showed that redox depletions “were significantly correlated to periods of >21 days saturation ($r^2 = 0.93$). The actual percentage of redox depletions increased each time the soil was saturated for >21 days.” The findings are preliminary and need to be refined with information from additional sites.

In North Carolina, monitoring may be more reliable than RMFs (Lindbo et al., 2004). North Carolina regulations combine field data of rain and groundwater depth with modeling to establish seasonal high water table in the wettest years; however, sites exist where changes to local or regional hydrology have resulted in actual soil wetness that is shallower than what the morphological indicators suggest. Lindbo et al. found that “all the monitoring methods are more conservative and place the water table as much as 60 cm above the water table depth determined by morphology.”

Additional evidence that RMFs may not be completely reliable as indicators of the high water level was presented by Kertes (2003). Test pits on a 92-acre sod farm were examined and the seasonal high water table was estimated based on mottles at 13-115 inches. However, monitoring of temporary wells showed that the ground water was 19-35 feet below ground surface in late March. Color variations within coarse-textured horizons were misidentified as mottles, but were inherited from geological processes that resulted in textural changes (e.g., interbedded sand and gravels) where the preferential accumulation of iron is occurring that is not due to water saturation during seasonal high water periods.

The effects of groundwater mounding when effluent is applied must be understood when designing WSAS (see Section 2.1.2).

2.1.3 Evaluating Nitrogen Treatment in Soil

Little recent research was found on evaluating a soil’s ability to treat nitrogen (N). The fate and transport of nitrogen in shallow, narrow drainfields (SNDs) loaded with secondary quality effluent in Rhode Island was investigated (Holden et al., 2004). In this study, decreases in nitrogen concentrations as a result of treatment and dispersal by the SND ranged from 30-57%. Comparisons of chloride (Cl) levels and Cl:N ratios between effluent and pore water were inconclusive, suggesting that both denitrification and dilution were responsible for N reductions seen in pore water samples collected below the SND. Nitrogen reductions from SND were not substantially greater than reductions reported in the literature for conventional drainfields.

The chemistry of a site’s water supply may be important to nitrogen treatment at that site, both in pretreatment systems and in the soil (Biesterfeld et al., 2003). Bench-scale nitrate plus nitrite generation rates were measured at various initial carbonate alkalinity concentrations and with four types of available alkalinity: carbonate only, phosphate only, phosphate plus hydroxide, and phosphate plus carbonate. When carbonate alkalinity was less than 45 mg/L, nitrification rates were impaired regardless of the total alkalinity concentration and independent of pH (for the range of 6.92 to 7.99 evaluated in the study). The findings suggest that in addition to neutralizing acid generated during nitrification, a minimum level of carbonate alkalinity is necessary.

2.1.4 Evaluating Phosphorus Treatment in Soil

A literature review of the soil geochemistry of phosphorus funded by the NDWRCDP was performed (Lombardo et al. Submitted; see Appendix A.2). The review describes the various chemical forms of phosphorus in wastewater and how they behave in a septic tank, the biomat of a WSAS, the vadose zone, and ground water. Phosphorus immobilization in all these places is dominated by mineral precipitation and adsorption. The dominant phosphorus minerals in WSAS are iron and aluminum precipitates, and their stability is influenced by pH and redox conditions. How much phosphorus is retained in the vadose zone under WSAS is influenced by the type of soil, the wastewater, and the site, and has been found to vary from 23-99%. Groundwater phosphate concentrations are strongly influenced by reactions in the zone immediately underlying the WSAS distribution pipes. The following research priorities were identified for increased understanding of phosphorus geochemical processes:

- ◆ Further microscale plume assessment
- ◆ Development of standardized methodologies for assessing transport at the microscale
- ◆ Behavior at the ground water-surface water interface and other "hotspots"
- ◆ Site indexing for vulnerability (methods to rate the risk of phosphorus transport from a site)

A field study of shallow, narrow drainfields found phosphorus immobilization beneath the drainfields to be 40-100% (Holden et al., 2004), mostly within the range reported by the literature reviewed by Lombardo et al. (Submitted).

Experiments with temperature profiles of WSAS were conducted at various depths in the climate of Michigan to determine the advantages of shallow placement of WSAS for infiltration and phosphorus immobilization (Mokma, Loudon, and Miller, 2001). The researchers found that frost was unlikely to interfere with performance of an actively used system, and that the best infiltration capacity and phosphorus immobilization occur in the shallower, most reactive part of the soil profile.

The literature of phosphorus management techniques from source reduction to WSAS design was also reviewed in a project for the NDWRCDP (Etnier et al. 2005; see Appendix A.3). A number of recommendations were made for maximizing phosphorus uptake at a site, including the shallow WSAS described above (Mokma, Loudon, and Miller, 2001; Holden et al., 2004) and long, narrow trenches to increase the amount of soil contacted by the effluent. The authors suggested that comprehensive site assessment be developed as a science, so that soil properties observable in the field could be linked with that soil's ability to immobilize phosphorus. They also recommended ways to augment the treatment capacity of a WSAS by using phosphorus-sorbing material (e.g., limestone or tire chips with exposed steel wires) as aggregate.

A different view of phosphorus is presented by McCray et al. (2000; cited in McCray et al., 2002). Using a HYDRUS 2D simulation in sandy materials, the authors concluded that phosphorus "concentrations typical of those observed in the field were adequately explained by transport processes that are relatively easy to quantify."

2.1.5 Evaluating Pathogen Treatment in Soil

Few of the publications reviewed examined how to evaluate pathogen removal in a site. The existing research on fate of pathogens in WSAS in 2001 gave insufficient attention to the role of the biomat, and so the models would not accurately predict performance of mature systems (Van Cuyk and Siegrist, 2001). Even after field studies and modeling exercises were conducted in the following years, many research needs were still reported for virus, along with emerging organic chemicals. (Van Cuyk et al., 2005).

A method for giving soil credit for treatment of pathogens in sandy soil was described by Wespetal and Frekot (2001). For viruses and fecal coliform bacteria, they used data from the literature for reduction in the septic tank, in the clogging mat, and per inch of sandy soil at a given loading rate and dosing frequency. Information on groundwater mounding and height of the capillary fringe is also provided to help estimate the actual unsaturated zone during system use.

2.1.6 Evaluating Treatment at Special Sites

A number of papers give methods for assessing the treatment performance of special types of sites: karst, fractured rock, and salt marshes.

Karst environments, where dissolving carbonate rocks can lead to sinkholes and rapid flows through underground streams, present special challenges for soil-based treatment systems. Flows through conduits can lead to short travel times from WSAS to receiving waters and, therefore, higher impacts on ground water or surface water. The Florida Department of Health (DOH) studied two OWTS in a karst area, using tracers and ten monitoring wells in shallow groundwater at each site (Roeder et al., 2005). The wells were also monitored for total nitrogen, total phosphorus, and fecal coliforms. Estimates of travel velocity from OWTS to wells were on the order of tens of feet/day, and it appeared that little natural nutrient removal was occurring in the ground water at either site. Nitrate concentrations in the wells closest to system were near the levels expected for nitrified septic tank effluent, so little denitrification can be expected in soil treatment in a karst environment. Total phosphorus concentrations were generally below 1.4 mg/L, suggesting that some phosphorus attenuation is occurring in the vadose zone. Additional study is planned to measure effluent concentrations and to investigate the effectiveness of adding nutrient-removing pretreatment.

Colorado regulations usually prescribe 200 feet of horizontal separation between WSAS and wells in mountain aquifers with fractured-rock. The distance may be reduced to 100 feet if it can be shown that the trend of fracture directions is away from the well. The authors of a very short paper without references claim, "Geological analysis of the fracture patterns can estimate the predominant direction of flow leaving on OWS and its probability of intercepting the area of influence of a well within 200 feet" (Church and Dallemand, 2003). The authors also point out that, in Colorado, it is important to know the parent material of soils. Dawson formation (weathered granite) soils have the texture of sand and have fast percolation rates, consistent with that of sand, when soaked for 8 hours. After 48 hours of soaking, however, the percolation rate slows to 60-120 minutes per inch.

In Louisiana, the marshland upwelling system (MUS) has been suggested as a potential wastewater treatment alternative for coastal dwellings (Watson and Rusch, 2001). It can be used in coastal dwellings with high water tables, as it uses injection of effluent into saline

groundwater for treatment. An injection depth of 4.6 m has been determined to provide sufficient treatment volume for the wastewater from a camp, loaded at rates of 45-97 L/day. Injection rates and frequencies were optimized; and effluent counts of 4.6 colonies/100 mL fecal coliforms were achieved at the optimal combination. Further studies on the MUS system are reported by Turriciano (2004), Addo and Rusch (2004), and Kock and Rusch (2004).

2.2 Effects of Pretreatment

A literature review was conducted on how infiltration rate changes when wastewater effluent is treated in soil (Siegrist and McCray, 2002). The review found that soil characteristics have little or no effect on infiltration rate in the long run, but that dramatic reductions of infiltration rates can occur at higher mass loadings of various wastewater constituents. Researchers have not reached consensus about whether a steady-state LTAR is achieved in wastewater treatment systems.

Another literature review by McCray et al. (2002) describes the empirical model by Siegrist and Boyle (1987) which gives the time-dependent infiltration rate as a function of the initial infiltration rate, BOD, TSS, and time. They also describe research using HYDRUS 2D on the hydraulic properties of the biomat, which gives more complex quantitative insight into the biomat's effects.

Tyler (2001) derived a table of design hydraulic loading rates, given soil and site characteristics described in the field, for two ranges of effluent strength: greater than and less than 30 mg/L BOD. Higher infiltration rates are given for the lower-strength effluent. The table is now used in Pennsylvania (Kaintz and Snyder, 2004).

Case studies and demonstration projects showed that clogged soil absorption systems were often restored to proper operation through the addition of pretreatment (Christopherson, Anderson, and Gustafson, 2001; Loomis et al., 2004).

In a project under the auspices of the NDWRCDP, Van Cuyk et al. (2005) completed field experiments on three types of treatment units: a septic tank, a septic tank followed by a textile filter unit (TFU), and a septic tank with a membrane bioreactor (MBR) (see Appendix A.4). Each treatment train ended in a WSAS in Ascalon sandy loam, and effluent was applied to each WSAS at two design hydraulic loading rates (2 and 8 cm/day). After six months of monitoring, performance in the treatment trains that included pretreatment was less affected by hydraulic loading rate (HLR) than in the treatment train based on only septic tank and soil treatment. The overall performance of the treatment trains with a TFU or MBR was better than the septic tank only at shallow soil depths, but increased soil treatment tended to shrink the differences in performance between the three treatment trains. Some degree of soil clogging and biomat formation occurred in the soil during the study, even where higher-quality effluent was applied.

Bohrer and Converse (2001) studied the effects of pretreatment in systems using drip dispersal. They collected soil samples to 105 cm (42 in.) under six drip distribution systems in Wisconsin. The authors say, "Three of the sites received septic tank effluent (STE), one site received recirculating gravel filter (RGF) effluent and two sites received effluent treated by aerobic treatment units (ATU). The soils at these sites ranged from coarse sand to clay loam, and the depth of the driplines ranged from 10-50 cm (4-20 in.) below ground surface. The systems receiving STE showed very low fecal coliforms at 45-60 cm (18-24 in.) below the

dripline with no detects below 60 cm (24 in.). The systems with pretreatment showed even better results, both for the RGF, which was very heavily loaded, and the ATU systems. This could probably allow for a reduction in the separation distance to 45 cm (18 in.) for systems receiving STE and 30 cm (12 in.) if the effluent is aerobically pretreated to a fecal coliform level of <1,000 colonies/100 ml”.

Jantrania (2004) describes the conceptual design of a pre-engineered subsurface dispersal system that can successfully discharge effluent treated to secondary “or better quality” under any soil conditions. The first system to test this concept is permitted and scheduled to be installed in the fall of 2006 (Jantrania, 2006).

2.3 Appropriate Levels of Pretreatment to Minimize Reliance on Soil Treatment

Conventional onsite wastewater treatment systems rely on settling in the septic tank and soil treatment as the sole means of treatment. The availability of more choices for treatment of the septic tank effluent before it is released into the soil opens up the question of how much it is appropriate to treat septic tank effluent before it is applied to the soil. What the *appropriate* level of treatment is depends on a number of factors, including:

- ◆ Appropriate treatment to protect human health and the environment;
- ◆ Appropriate constituents to be treated in the soil; and
- ◆ Whether the groundwater is particularly vulnerable to impacts from OWTS.

Establishing a level of wastewater treatment appropriate to protect human health and the environment raises two questions about the concentration or mass loading of each constituent: 1) How much is too much? 2) What treatment at the site level is necessary to stay below a given threshold at the macro (aquifer or watershed) level?

During the La Pine National Demonstration Project and associated NDWRCDP projects, extensive monitoring and modeling efforts were conducted to determine levels of nitrate from OWTS that were appropriate at the site scale in order to protect regional groundwater and surface water resources (Morgan and Everett, 2005; Hinkle et al., 2005). How treatment levels at individual OWTS affect the mass loading of wastewater constituents at the watershed scale is addressed in the section on watershed-scale processes (Chapter 3). No other publications were discovered that directly addressed appropriate site-scale threshold levels of wastewater constituents.

Otis (2001) asks a third question: Where is the treatment standard applied? He concludes, “Onsite treatment system design has focused on the infiltration design boundary nearly to the exclusion of other important design boundaries. Secondary boundaries that may exist below the infiltration surface and the water table boundary are two other boundaries that must be considered. Not only are they helpful in design, but they also help in failure diagnosis and the design of corrective actions... This boundary design strategy...requires that we begin to gather the appropriate and necessary data to accurately estimate the appropriate mass loadings to each of the boundaries. Having a strategy will help direct the needed research.”

Several wastewater constituents, such as organic matter, solids, and bacteria, are amenable to effective treatment in soil of the right texture, structure, and depth. Nutrients are a different matter; phosphorus treatment varies significantly depending on soil chemistry and pH (Section 2.1.4), and nitrate behaves conservatively in most soil conditions (Section 2.1.3).

Additionally, the fate of viruses in the soil is still not sufficiently understood (Van Cuyk and Siegrist, 2001; Van Cuyk, Siegrist, and Logan, 2001) (Section 2.1.5; Section 2.4).

Nitrate can be a pollutant of concern in ground water even when it is not of concern in nearby surface water. In these cases, the ground water may even be considered a more valuable resource than the surface water, leading people to wish to protect it from all wastewater constituents. For example, the Town of Tisbury, on the island of Martha's Vineyard in Massachusetts, pumps its drinking water from a sole source aquifer. It is surrounded by ocean. When a wastewater risk assessment funded by NDWRCDP was done there, townspeople clearly indicated that their most valuable water resource was the aquifer (Heigis et al., 2002). This information was used as a basis for designing the management program for onsite systems. The value of the groundwater also justified a detailed nitrogen fate and transport modeling study performed in connection with a large cluster system for the village center in Tisbury.

2.4 Pathogen Fate, Transport, and Removal

Much of the recent research addressing pathogen fate and transport in decentralized wastewater treatment systems was presented elsewhere. The fate of bacteria and virus in Ascalon sandy loam following a septic tank alone, a septic tank followed by a textile filter unit, and a septic tank with a membrane bioreactor was discussed in Section 2.2 (Van Cuyk et al., 2005). A number of publications addressing these research priorities or related questions about pathogen fate and transport are described in Section 2.1.5.

The ability of *Cryptosporidium parvum* oocysts to be transported in saturated flows was tracked by Darnault et al. (Darnault et al., 2003). Although these experiments were based on calf feces deposited on column or soil block surfaces during simulated rainfall, the results may be applicable to effluent application. One experiment was carried out in a vertical column filled with glass beads or silica sand under conditions known to foster fingered flow. A second experiment involved undisturbed, macroporous soil columns subjected to macropore flow, while a third examined lateral flow in an undisturbed soil block. Rainfall was applied at rates from 1-2 cm/hr (0.4-0.8 in/hr) in each experiment. The breakthrough of oocysts and chloride through the columns and soil blocks demonstrated the importance of preferential flow on the transport of oocysts. Peak oocyst concentrations were not delayed compared to chloride and in some cases occurred before the chloride peak. Although relatively few oocysts were recovered (0.1 to 10.4% of the oocysts applied) on the columns, the numbers of oocysts present in the column effluents were still orders of magnitude higher than the infectious dose considered sufficient to cause Cryptosporidiosis in healthy adults. Thus, the transport of oocysts via preferential flow may create a significant risk of groundwater contamination.

Unsaturated flows through sand filters can, on the other hand, be very effective in removing *Cryptosporidium* oocysts, according to Logan et al. (2001). They used bench-scale sand columns with intermittent effluent application to simulate sand filters that were dosed at two different loading rates (4 cm/day or 10 cm/day, or 88 or 220 ml/dose). The fine-grained sand columns ($d_{50}=0.31$ mm) effectively removed oocysts under both loading rates with low concentrations of oocysts infrequently detected in the effluent. Coarse-grained media columns ($d_{50}=1.40$ mm) yielded greater numbers of oocysts which were more commonly observed in the effluent, particularly under the 10 cm/day loading rate. Factorial design analysis indicated that grain size was the variable which most affected oocyst effluent concentrations in these intermittent filters. Loading rate had a significant effect when coarse-grained media was used

and lesser effect with fine-grained media. The researchers concluded that “removals exceeding 3 to 4 log can be expected from these systems at loading rates up to 10 cm/day. However, the grain size of the filtration media and the hydraulic loading rate play major roles in determining the oocyst removal potential.”

A study in Jefferson County, Arkansas, was conducted to lower the seasonal water table in a wet soil using gravel filled drain and absorption trenches and to evaluate fecal coliform removal (Goff et al., 2001). The drain trenches and renovation trenches were installed in a fine-silty Aquic Dystric Eutrudept with a 1.5 % slope and redoximorphic features at a depth of 3 centimeters from the soil surface. The septic tank effluent was time dosed from a tank equipped with a screened pump vault to a low-pressure distribution leachfield. Septic tank effluent was applied at an average loading rate of 16 l m²/d. Renovation trenches were 30.5 cm deep, while drainage trenches were 1 m deep. Renovation and drainage trenches were alternated at a lateral distance of 91 cm, and the drainage system discharged by gravity to the ground surface. Water level observations in monitoring wells showed that the drainage system lowered the seasonal water table enough to prevent effluent from surfacing. Though 99.9% of the FC were removed, the discharge from the drainage system did not meet Arkansas Department of Health limits, and the authors recommended disinfection.

Van Cuyk and Siegrist (2001) acknowledged that pretreatment of effluent allows greater infiltration rates, but they cautioned that “purification of contaminants of concern, especially pathogenic bacteria and virus, has not been proven.” Some of their studies quantify the removal of virus and bacteria. For example, microbial surrogates and conservative tracers were used in experiments with 3-D lysimeters in the laboratory and in field tests of mature WSAS (Van Cuyk, Siegrist, and Logan, 2001). They used two viruses (MS-2 and PRD-1 bacteriophages), one bacterium (ice-nucleating active (INA) *Pseudomonas*), and one conservative tracer (bromide ion). They concluded, “The results of the research completed to date have revealed that episodic breakthrough of virus and bacteria does occur in WSAS, particularly during early operation, but that a 3-log removal of virus and near complete removal of fecal bacteria can reasonably be expected in WSAS with 60 to 90 cm of sandy medium.” Work recently completed by the authors at the Mines Park Test Site in Colorado, suggested that “The ability of an Ascalon sandy loam soil to remove viruses was quite high and insensitive to whether the natural soil had received septic tank effluent, textile filter effluent, or membrane bioreactor effluent at either 2 or 8 cm/d. These results refute that virus removal in soils receiving high-quality effluents might be diminished due to the absence of a classic biozone resulting from the low levels of tBOD and TSS applied” (Siegrist et al., 2005).

In an addition to the La Pine National Demonstration Project that was funded by NDWRCDP, 28 traditional and innovative OWTS with downgradient drainfield monitoring wells adjacent to or under the drainfield lines were tested for coliphage (and organic chemicals, see Section 3.2) (Hinkle et al. 2005; see Appendix A.5). A network of 31 wells distributed among three temporary transects along three plumes of onsite wastewater was also monitored. Conclusions from the study included:

- ◆ Coliphage were detected frequently in onsite system effluent and occasionally in lysimeters, but were only sporadically detected in monitoring wells located near or beneath drainfields. The absence of coliphage in confirmatory (replicate and repeat) groundwater samples indicated that the reported detections represented low-level field or

laboratory contamination. Thus, coliphage were attenuated to less than 1 PFU/100 mL over distances of several feet of transport.

- ◆ “If coliphage survival and transport are representative of enteric virus survival and transport, the apparent absence of detectable concentrations of coliphage in the sand aquifer of La Pine might be construed positively by users of that resource. However, broader-based understanding of aquifer vulnerability to virus survival and transport remains elusive. Few plume-scale studies of naturally occurring viruses from onsite wastewater treatment systems in relatively undisturbed, natural settings have been undertaken, and results to date raise questions about factors controlling aquifer vulnerability to virus survival and transport. An understanding of conditions or processes that facilitate coliphage transport in some environments, but attenuation in others, could provide a basis for a more general understanding of field conditions and processes controlling aquifer vulnerability to coliphage” (Hinkle et al., 2005).

Temperature affects pathogen fate and transport, as documented by the tests done with *Salmonella* and fecal coliform by Pundsack et al. (2001) on subsurface-flow constructed wetlands, sand filters, and peat filters. All systems were loaded at or below their design flows of about 950 L/d (250 gal/d). Influent was from “a high-strength septic tank effluent (mean values of 5-day biochemical oxygen demand, total nitrogen, and total phosphorus were 294, 96, and 15 mg/L, respectively) at the Natural Resources Research Institute's alternative treatment system test facility in northern Minnesota. Each treatment system was inoculated with cultures of *Salmonella choleraesuis* (serotype typhimurium) for 5 to 7 consecutive days in summer and winter during 1998 to 1999. After the seeding, outflow samples were taken until *Salmonella* counts were sustained at background levels.” For the pathogens monitored, “peat filters operated most effectively followed by the sand filters and the constructed wetlands.” Their results showed more effective removal during the summer than the winter, and the authors recommended providing additional public health and water resource protection “by discharging the treated effluents to the soil via trenches or other soil-based effluent dispersal systems.”

2.5 Modeling

With the exception of the matrices developed by Tyler et al. (2004) and described in Section 2.1, no models were discovered that predicted the treatment efficiency of a system as a function of its siting, design, or operation.

HYDRUS 2-D was the model most commonly used to predict soil treatment of wastewater at the site scale. Radcliffe and West (2005) reported that HYDRUS 2-D has helped answer a host of questions: “We have shown that borehole measurements of infiltration rates may not reach a steady rate in a layered soil, biomats have an important effect on the rate and pattern of water flow from a trench, trench interactions will depend on soil texture, gravel masking has a negligible effect on flow but embedded gravel does restrict flow, most of the flow out of a trench may be through the sidewall, and there is little consumptive use of water in an on-site system. Computer models seem especially suited to comparing systems with different geometry. They help us to identify research gaps and may be very useful as training and teaching tools.” Some of this work is also described in (Radcliffe, West, and Finch, 2005).

Finch et al. (2005) employed HYDRUS 2-D to model two-dimensional effluent flow from a conventional gravel system in Georgia soils, to understand and extend results from

experiments on infiltration rates through trench bottoms and sidewalls and studies of the thickness and porosity of biomat. They concluded, “model simulations for a soil similar to those evaluated suggested that the trench bottom and sidewall had about equal amounts of wastewater infiltration with a biomat on the lower half of the trench sidewall. Most of the trench sidewall wastewater infiltration was into the upper portion of the sidewall without a biomat. These simulations suggest total wastewater infiltration from the drainfield trench will decrease over time as the sidewall biomat develops more completely, especially in systems or parts of systems that may be hydraulically overloaded.”

HYDRUS 2-D was used to model geometry and transport to understand the soil nitrogen dynamics in drip dispersal systems (Beggs et al., 2004). Modeling results from this study indicated that a system designed for landscape irrigation generally minimized nitrate transport, and that both nitrification and denitrification rates were increased when effluent was applied in a single pulse rather than continuously.

HYDRUS 1-D was used by Doyle et al. (2005) to understand phosphorus transport and attenuation at the Mines Park Test Site in Colorado. HYDRUS 1-D was used to simulate flow and transport in the unsaturated zone and a geochemical model (PHREEQC) was used to determine the saturation indices of phosphorus compounds and thus predict when they might precipitate. They found that choice of a sorption isotherm equation introduced the most variation in model results, and that the Langmuir isotherm most accurately described the results of phosphorus sorption batch tests. Spatial variation in sorption was more important in controlling phosphorus transport than was spatial variation in soil physical parameters.

DRAINMOD was used by Lindbo et al. (2004) to compare soil morphological results and modeling results on soil wetness, as described in Section 2.1.2.

A compartmental analysis model was constructed in the SAS software package to describe and then predict nitrogen transformations and removal in a subsurface-flow constructed wetland, accounting for ammonification, nitrification, denitrification, nitrogen release, and biomass uptake (Liu, Dahab, and Surampalli, 2005). Modeling results led the researchers to conclude “approximately 31.5% of the nitrogen mass was removed through nitrification and denitrification, 31.3% was removed through vegetative assimilation of ammonia and nitrate, and the remainder was left in the wetland effluent.” Although the ammonification, nitrification, and denitrification rates measured in this study were within ranges reported in the literature, the nitrogen removal percentages concluded based on the modeling are higher than can be justified by the study’s analytical results.

Nguyen et al. (2004) applied a model from pharmaceutical chemistry to the movement of 75 organic compounds in soil and sediment. The model applies to non-ionic chemicals, including some solvents, pesticides, and pharmaceuticals. This model consists of simple mathematical equations that are potentially useful as components of software models.

CHAPTER 3.0

WATERSHED-SCALE PROCESSES (“MACRO-SCALE”)

The term “macro-scale” refers to an aquifer or watershed which contains many individual decentralized systems, as well as other point and non-point sources of pollution. The research challenges identified in the NDWRCDP’s 2002-2003 Training, Research and Development Plan (NDWRCDP, 2002) related to decentralized systems at the watershed scale are:

- ◆ Develop/evaluate models designed to reliably predict fate and transport of nutrients for use in assessing risks to watershed water quality
- ◆ Develop/evaluate methods for incorporating centralized, onsite, and storm-water contributions in TMDL calculations
- ◆ Develop/evaluate methods for identifying and quantifying sources of pollutants
- ◆ Develop integrated wastewater risk assessment tools
- ◆ Assess/quantify risks due to microbial pathogens
- ◆ Conduct epidemiological studies to quantify public health risks

3.1 Development and Evaluation of Fate and Transport Models

Significant progress has been made in developing modeling tools that can describe and predict the cumulative effects of multiple systems and pollutant sources on water quality within a watershed. A collaborative team led by the Colorado School of Mines conducted a comprehensive study in the Dillon Reservoir watershed in Summit County, Colorado (Siegrist et al. 2005; see Appendix A.6). An analysis of literature data was used to develop cumulative frequency distributions of pollutant concentrations in domestic septic tank effluent and the parameters governing the fate and transport of those pollutants in the soil and ground water for use in modeling (Siegrist et al., 2005; McCray et al., 2005) (see Section 3.2). Extensive site-scale field and laboratory experiments, as well as significant numerical and analytical modeling efforts, were conducted as part of this project (Chapter 2.0) and were incorporated into an existing watershed model.

The Watershed Analysis Risk Management Framework model (WARMF) was used to simulate the effects of onsite wastewater systems (OWS) relative to other pollutant sources on water quality in the Dillon Reservoir watershed. A water quality monitoring program was concurrently carried out in the watershed to assess the relative impacts of suburban development with OWS compared to urbanized development with a centralized wastewater treatment plant (Bagdol, Siegrist, and Lowe, 2004). The WARMF model was modified to accept OWS effluent to the soil layer below the land surface in order to include OWS in the calculation of nitrogen and phosphorus Total Maximum Daily Loads (Chen et al., 2001). Two other models—Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)/Soil and Water Assessment Tool (SWAT) and Method for Assessment, Nutrient-loading, and Geographic Evaluation (MANAGE)—were also set up for the watershed. Since Dillon

Reservoir supports recreational uses and provides 25% of the drinking water supply for the City of Denver, model simulations were completed to examine both current and future wastewater management scenarios (for example, the connection of properties currently using onsite systems to a centralized wastewater treatment plant).

A NDWRCDP project conducted in partnership with National Onsite Demonstration Project (NODP) in the community of La Pine in southern Deschutes County, Oregon developed and demonstrated a method to estimate the optimal loading of nitrate from decentralized wastewater treatment systems to an aquifer (Morgan and Everett 2005; see Appendix A.7). The La Pine nitrate loading management model (NLMM) was developed by linking the existing MODFLOW-MT3D simulation model to an optimization model. The NLMM was then used to determine the minimum nitrate loading reductions that would be required to meet water-quality constraints in the groundwater and receiving waters. Scenario simulations were compared with an optimal solution to evaluate the relative effectiveness and costs of each. The individual scenarios applied uniform management controls in which all future and existing systems would meet the same performance standard, ranging from 2 mg/L NO_3^- to 46 mg/L NO_3^- , depending on the particular scenario. The results showed that a uniform performance level of 2 to 10 mg/L would have to be imposed to reach the same level of water-quality protection as the optimal solution. The reduction in total loading for the optimal solution was 107 kg/d compared to 192 and 148 kg/d for the 2 and 10 mg/L scenarios. This method enhanced the value of a simulation model as a decision-support tool in developing performance-based standards for onsite systems that protect groundwater quality.

Many methods and models for assessment of risks from OWTS at the watershed scale include a component that accounts for the proximity of an onsite system to a water body of concern (Angenent et al., 2006; Carroll, Goonetilleke, and Hargreaves, 2004; Clark et al., 2001; Douglas, Federico, and Winchell, 2002; Geary and Whitehead, 2001; Heigis et al., 2002; Joubert and Loomis, 2005; Kinsley et al., 2004; Whitehead et al., 2004; Macrellis et al., 2005). The intuitive assumption, borne out in many cases, is that systems that are hydrologically closer to a water body will be greater potential pollutant sources and thus may pose a higher risk. A recent hydrologic analysis of the effects of groundwater travel time on nitrogen reactions and loading to a coastal embayment in Massachusetts suggested that, while in nearshore areas (< 1 year travel time) nitrogen discharge from septic system sources would occur before maximum denitrification occurred in the subsurface, the 0 to 1 year travel time zone represented only a small fraction of the total nitrogen load to the water body (Colman et al., 2004). The authors hypothesized that the embayment under study was exceptionally eutrophic because of near-conservative delivery of nitrogen to the coast from sources in its relatively large zone of short aquifer residence times; however, their research discovered that inputs from zones of longer travel times were substantial (Colman et al., 2004). They suggest that “the interactions of time-varying source loads and aquifer residence times are better investigated with a transient modeling analysis rather than the steady-state approach used” (Colman et al., 2004).

A number of less quantitative approaches to determining risks resulting from the fate and transport of nutrients as a function of land use have been successfully applied at the watershed scale. Many of these methods use geographic information systems (GIS) to spatially categorize risks (Clark et al. 2001; Douglas, Federico, and Winchell 2002; Heigis et al. 2002 (see Appendix A.8); Joubert and Loomis 2005; Macrellis et al. 2005). None of these reports included recommendations for future research.

3.2 Identifying and Quantifying Pollutant Sources

Two literature research efforts successfully quantified pollutants from onsite wastewater treatment systems for use in modeling. A critical review of model input parameters for transport of onsite wastewater treatment system (OWS) pollutants was conducted as part of the NDWRCDP modeling project conducted by the Colorado School of Mines (McCray et al., 2005). The result of the analysis included cumulative frequency distributions for OWS effluent concentrations of nitrogen and phosphorus, nitrification and denitrification rates, and linear sorption isotherm constants for phosphorus. A range of research needs were identified as a result of this review.

A literature review was conducted by workers in Sweden to compile input values for the mass and composition of several wastewater fractions for use in analyses of different wastewater systems using the URWARE model (Jönsson et al., 2005). URWARE describes the composition of each wastewater fraction by a total of 31 parameters, including water volume, total and suspended solids, organic matter, BOD₇, total and fractioned COD, nitrogen, phosphorus, potassium, sulfur, and heavy metals.

Several projects assessed the use of certain water quality characteristics as indicators of potential impacts from septic systems. The La Pine, Oregon NDWRCDP project documented the occurrence of organic wastewater compounds (components of “personal care products” and other household chemicals), pharmaceuticals, and coliphage in septic tank effluent and in a shallow, unconfined, sandy aquifer (Hinkle et al. 2005; see Appendix 1.1.1.1A.5). Coliphage were frequently detected in onsite wastewater, but were attenuated within several feet of transport and thus were not useful indicators of pollutants originating from onsite wastewater treatment systems. A subset of the pharmaceuticals may be useful indicators of the presence of human waste in the environment.

A separate NDWRCDP project conducted in the Table Rock Lake watershed evaluated chemical and biological species as potential indicators of specific phosphorus sources (Angenent et al. 2006; see Appendix 1.1.1.1A.9). Sampling locations were chosen to capture the influence of discharges from centralized wastewater treatment plants, individual septic systems, and runoff from animal feeding operations. Bromide was a unique indicator of large wastewater treatment plants, and nickel and copper can potentially be used as indicators of septic system effluent, but no other chemical species observed were useful as unique source indicators. Coliphages (specifically, F+ RNA phages) were evaluated as potential biological indicators for wastewater input from human and nonhuman origins; however, these phages cannot be used to distinguish between human and nonhuman sources. None of the chemical or biological indicators observed could be used successfully for phosphorus source apportionment (Angenent et al., 2006).

The most prevalent natural and anthropogenic sources of sodium and chloride in groundwater, primarily in Illinois, were characterized and methods of identifying sources were explored (Panno et al., 2006). Seven potential sources were considered, including agricultural chemicals, septic system effluent, animal waste, municipal landfill leachate, and road deicers. Concentrations of sodium and chloride in septic system effluent were found to range from 20-40 mg/L to as great as several thousand mg/L. The ratio of chloride to bromide was most useful as an indicator of halides originating from septic system effluent.

Another study analyzed nitrate concentrations in groundwater on Nantucket Island, Massachusetts to assess the effects of various land uses, including residential development with septic systems, on groundwater quality (Gardner and Vogel, 2005). Statistical analyses of land use within 1,000 feet of each well were used to develop predictive equations for nitrate concentration at 69 wells. The number of septic tanks and the percentages of forest, undeveloped, and high-density residential land within a 1000-foot radius of a well were reliable predictors of nitrate concentration in groundwater.

Finally, two studies demonstrated innovative methods for quantifying pollutant loads from OWS. Potential nitrogen and phosphorus loadings from onsite systems within North Carolina's watersheds and major sub-basins of those watersheds were quantified using an area-weighted GIS procedure (Pradhan et al., 2004). Potential nutrient loading was mainly influenced by density of population using septic systems, density of septic systems, and size of the watershed. The overall potential nutrient loading due to onsite systems was not substantial on a statewide basis when compared to other potential nutrient sources.

A study assessing nitrogen loads to estuaries from wastewater treatment plants with land dispersal was conducted to better understand uncertainties surrounding nitrogen loss during wastewater plume transport through watersheds (Kroeger et al., 2006). A nitrogen loading model was used to estimate land-derived N loads to two Cape Cod estuaries due to all major N sources except the wastewater treatment plants. The modeled loads were then compared to empirically determined total land-derived N loads and the measured/modeled differences were used to calculate the N loads from the WWTPs. The results indicated that nitrogen from the plumes was discharging to the estuaries but that substantial nitrogen loss occurred during transport through the watersheds.

3.3 Integrated Wastewater Risk Assessment Tools

The primary objective of a NDWRCDP project completed by Oak Ridge National Laboratory in 2004 was to develop an approach to risk-based decision making for individual onsite wastewater treatment systems (Jones et al. 2004; see Appendix 1.1.1.1A.10). The three stages of risk assessment were used to structure the framework: problem formulation (a planning process), analysis of site-specific exposure and effects, and risk characterization. The framework of this approach integrated engineering, public health, ecological, and socioeconomic risk analyses. Significant data gaps and opportunities for future research were identified during this project that may be relevant to definition of research needs within ES&E:

For improving assessment of engineering risks:

- ◆ “Failure rates for OWT system components under a wide range of real-world conditions (as opposed to certification test results) over extended periods of operation”
- ◆ “System performance information that has been collected in a way that supports development of continuous failure rates”
- ◆ “Additional relationships between performance of wastewater soil absorption systems and changes in environmental conditions (such as seasonal changes in precipitation and in the separation from the water table)”

For improvement of public health risk assessments:

- ◆ “Dose/response information to support quantitative microbial risk calculations”

- ◆ “Viral dose/response models and rates of human infectivity”
- ◆ “Information on survival of viral particles in the environment”
- ◆ “Environmental fate and transport of microbial pathogens”

For conducting assessments of risks to ecological receptors:

- ◆ “Field studies of amphibians in wet soils, ponds, streams, and other areas around septic tanks versus control areas”
- ◆ “Studies to develop relationships between multiple stressors and effects on various aquatic trophic levels”
- ◆ “Improved technologies for remote sensing of nutrients, phytoplankton, and sea grass area and condition”

Both of the NDWRCDP projects described in Section 3.1 involved a significant integrated risk assessment component. Although much of the effort for the Blue River Basin/Dillon Reservoir NDWRCDP project was focused on refinement, application, and testing of the WARMF watershed-scale model, simulations were conducted to assess the impacts of realistic future scenarios concerning wastewater infrastructure in the watershed and determining the comparative risks of infrastructure changes to water quality (Siegrist et al., 2005). The research gaps identified during this project are summarized in Section 3.1. The groundwater study and model developed for the La Pine area in Oregon were used to identify potential high risk areas, and the optimization model was updated to more accurately identify appropriate treatment standards for the 96 management areas (Morgan and Everett, 2005; La Pine National Demonstration Project Final Report, Submitted). The Draft National Demonstration Project Final Report for the La Pine project highlights the need for development of long-term data on the performance of onsite systems.

3.4 Risks Due to Microbial Pathogens

Little progress has been made in the United States since 2003 in assessing or quantifying risks due to microbial pathogens from onsite systems. However, an analytical tool called the “microbial risk assessment” or MRA tool was recently developed in Sweden (Ashbolt et al., 2005). The tool uses two criteria to assess the risk for infection that may stem from the implementation of differing wastewater treatment options. The first criterion assessed is the ability of a system structure to provide an acceptably low infection level, and the second criterion addressed is system robustness. System alternatives are compared by the MRA tool based on the average infections likely to result per system per year and the number of extreme infection events likely over the life of the system.

3.5 Public Health Risks

No epidemiological studies that specifically quantified the public health risks of decentralized wastewater treatment systems were discovered during the literature review.

A study by Strauss et al. (2001) examined the relationship between bacteriological contamination of drinking water from private wells and acute gastrointestinal illness, using current government standards for safe drinking water, in four rural communities in southern Ontario, Canada. The study found that twenty percent of households sampled had total coliform

or *E. coli* counts above the current Canadian and United States standards for safe drinking water, and “[i]ndividual exposure to contaminated water defined by current standards may be associated with an increased risk of acute gastrointestinal illness”. No attempt was made during this study to determine the source(s) of the indicator bacteria, although a questionnaire was administered to collect “information on demographic factors (age, sex, and number of residents in house), other factors possibly predictive of acute gastrointestinal illness (living on a farm, presence of pets and livestock, recent travel and number of years at current residence), and tap water consumption”.

Borchardt et al. (2003) estimated the incidence of viruses in Wisconsin household wells located near septage land application sites or in rural subdivisions served by septic systems. Fifty wells in seven hydrogeologic districts were sampled four times over a year, once each season. Among those wells, four (8%) were positive for viruses by reverse transcriptase PCR. Contamination was transient, since none of the wells was virus positive for two sequential samples, and no culturable enteroviruses were detected in any of the wells. Other water quality indicators, such as chloride, were not statistically associated with virus occurrence.

Since 1971, the U.S. Centers for Disease Control and Prevention (CDC), the U.S. EPA, and the Council of State and Territorial Epidemiologists have maintained a collaborative surveillance system for collecting and reporting data related to occurrences and causes of waterborne disease and outbreaks. Public health departments are primarily responsible for detecting and investigating waterborne disease and outbreaks and voluntarily reporting them to CDC by using a standard form. The surveillance system includes data on outbreaks associated with drinking water and recreational water, and is the primary source of data concerning the scope and effects of waterborne disease and outbreaks in the United States. A surveillance summary is published approximately every two years; the most recent report covers 2003-2004 and was published in December 2006 (Liang et al. 2006; see also Sherline et al. 2002 and Blackburn et al. 2004). The reports summarize drinking water-associated waterborne disease and outbreaks by etiologic agent (bacterial, parasitic, viral, and/or chemical/toxin poisonings) and, if possible, the source of the outbreak is identified. Although these surveillance summaries do not specifically discuss the public health risks of decentralized wastewater treatment systems, the descriptions of individual outbreaks provided in the report appendices may provide useful information.

CHAPTER 4.0

TECHNOLOGY ASSESSMENT METHODS

Technology assessment methods reported in this section include both studies of long-term performance and failure rates of OWTS infrastructure and methods for monitoring systems' performance over time. The research challenges identified in the NDWRCDP's 2002-2003 Training, Research and Development Plan (NDWRCDP, 2002) related to technology assessment methods are:

- ◆ Evaluate actual life spans and failure rates of onsite and decentralized systems
- ◆ Determine the relationship between system performance and age of operation for similar WSAS in similar environments
- ◆ Quantify the deterioration of centralized and decentralized wastewater infrastructures
- ◆ Evaluate treatment and monitoring technology

The publications in the following sections report studies of particular sets of wastewater treatment systems. A project for the NDWRCDP (Etnier et al., 2004) showed how to put decentralized wastewater treatment systems into the sort of asset management framework that has been used for centralized wastewater treatment. It also identified reliability and costing tools to be used, and gave examples of both.

4.1 Actual Life Spans and Failure Rates

Several researchers analyzed datasets from OWTS permits and management programs to determine actual life spans and failure rates of systems in the field. In Maine, regulatory officials utilized a database of over 145,000 permits to evaluate OWTS performance (Dix and Hoxie, 2001). An average failure rate of less than 0.5% was observed during each of the first 10 years after new system installation, with a noticeable increase in replacements after 15 years. Over 80% of the systems provided more than 20 years of service, with homeowners responsible for system operation and maintenance. An analysis of recent system replacement permits in 19 villages within the City of Ottawa, Canada was conducted as part of validation for a GIS-based risk assessment model (Kinsley et al., 2004). This analysis indicated that 70% of failed conventional septic systems were greater than 25 years old while 65% were in impermeable soils. An initiative for evaluation and management of onsite systems in Washtenaw County, Michigan gathered inspection data from nearly 3,500 private OWTS (Gregory, 2004). Analysis of the data showed strong correlations between permitting practices and OWTS function. The percentage of failures found on permitted systems was less than 10% since 1970, and the percentage dropped below 7% on systems installed since 1975.

In a case study of the Lake Panorama Onsite Wastewater Management District in Guthrie County, Iowa, 1% of the systems failed over the life of the management program based on inspection records, where surfacing effluent was the measure of failure (Mancl and Patterson, 2001). The methodology for determining system performance and failure rates was

not presented, but the data gathered through this management program may be useful to larger studies of system failure.

A methodology for conducting failure rate studies of onsite systems was demonstrated by comparing the field performance of Infiltrator Systems, Inc. EQ24 aggregate-free chamber systems with traditional aggregate laden, rock-filled trench systems in Oregon (King et al., 2002). System populations were studied in two counties with varying climate conditions and soil permeabilities. A field assessment of a random, stratified sample of 389 systems (average age approximately 2-2.5 years old) was conducted to determine failure rates under the same weather conditions for both technologies. Failure was defined as surface discharge of sewage during the field survey. Less than 2% of either type of system had failed, and there were no statistically significant differences in failure rates between the technologies or within any of the strata. The failures that were observed were primarily related to poor site maintenance. The authors recommended that “the study be replicated at the same sample sites periodically over time (perhaps every three to five years) during the next 20 to 30 years and at other locations in the country using similar failure rate research designs” (King et al., 2002).

4.2 System Performance / Deterioration Over Time

In addition to the failure studies described in Section 4.1, significant progress was made in understanding system performance over time. The NODP Phase II Project in Green Hill Pond and Block Island, Rhode Island has collected detailed performance data on six full-scale innovative onsite wastewater treatment systems since their installation in 1999 (Loomis et al., 2004; Loomis et al., 2005). The systems installed consisted of two textile coupon filters; one textile coupon filter followed by a bottomless sand filter; one single pass sand filter; one modular peat filter followed by an ultraviolet light disinfection unit; and one fixed activated sludge treatment system followed by a ultraviolet disinfection unit.

Long-term performance information for a population of 49 conventional and innovative treatment systems was also collected as part of the La Pine, Oregon National Demonstration Project (La Pine National Demonstration Project Final Report, Submitted). The project produced a large amount of information on the field performance of innovative onsite wastewater treatment systems, spanning a period of more than two years for most technologies evaluated. While the primary goal of the study was to identify the best denitrifying technologies and designs, useful information was also collected on the performance of septic tanks, conventional systems, and innovative systems that may be of use for situations with treatment needs other than denitrification (such as BOD₅/TSS or bacteria reduction).

A comprehensive evaluation of the field performance of aeration systems was conducted over a period ranging from 1 to 12 years on a total of 139 sites in Wisconsin (Converse, 2004). Units evaluated were Multi-flo, Norweco, BioMicrobics, Delta Whitewater, Nibbler Jr., Orenco SPSF, Orenco RSF for homes, RSF for commercial units and RSF for homes with filter in a concrete box. Parameters measured included BOD₅, TSS, nitrogen series, alkalinity, pH, TS, VS, COD, fecal coliform, E. coli and enterococcus along with effluent temperature and dissolved oxygen. Data were averaged first by site, and then individual site means were averaged to evaluate the overall performance of each type of unit. No analysis with respect to system age was made; however, the complete data set may allow such an analysis. Comparison of field performance data with test center data for the same system may also give some

indication of the effects of time, if the first six months of operation in the field are similar to test center operation.

A consortium of environmental agencies led by the New England Interstate Water Pollution Control Commission (NEIWPCC) recently completed a NDWRCDP-funded project comparing test center data to real-world field performance data (Groves et al., 2005; see Appendix 1.1.1.1A.11). The goals of this research were:

- ◆ “To develop a statistical and sound scientific relationship between test center data and actual field data of installed alternative technology onsite wastewater treatment systems”
- ◆ “To develop a decision support system to help regulators evaluate the quality and quantity of data submitted for regulatory decisions”

The study evaluated performance data for three different alternative onsite technologies that had ample test center and field data sources. BOD and TSS data from National Sanitation Foundation (NSF) International Standard 40 evaluations, Environmental Technology Verification (ETV) projects, National Onsite Demonstration Projects (NODP), and data collected by regulatory agencies and vendors was assembled and reviewed to eliminate duplicate samples, samples from non-residential facilities, and others. Datasets for each system were analyzed statistically using appropriate models. The researchers concluded that test center data was significantly less variable than real world data; therefore, one data set (such as test or field) cannot be used to accurately predict the other. Since the test data distribution cannot predict the field data distribution, if time or funding is limited it is probably best to sample as many sites as possible on a random basis for a few samples rather than to thoroughly evaluate a small number of locations for an extended period of time. Additionally, a Decision Support System (DSS) tool was developed to help regulators evaluate all sources of data (including test center and field data) to determine the field performance of a technology and guide the regulatory and manufacturing communities on the amount and quality of data needed to accept a technology as “proven.” At the end of the project period, the DSS had not yet been applied to any real world cases.

A WERF-funded project is currently underway that will help to address the limited availability of information on the long-term performance of large-scale decentralized wastewater collection and treatment/disposal systems (Parten, 2006). This project is examining the performance of large-scale decentralized and small community wastewater systems with flows ranging from 5,000 to 50,000 gallons per day with at least five years of operating history. The outcomes of the project should support improved planning and design practices and will provide a factual basis for cost comparisons of wastewater treatment options.

4.3 Evaluate Treatment and Monitoring Technology

As part of an NODP Phase V project, The Conservation Fund’s Freshwater Institute (Shepherdstown, WV) added real-time monitoring technologies to existing recirculating sand and peat filter treatment systems (Tsukuda, Ebeling, and Solomon, 2004). Several water quality parameters were measured every half hour in the influent, denitrification tank, and effluent. Flow meters monitored flow rates throughout the two systems and pressure sensors recorded backpressure on the two low pressure pipe dosing fields. A small weather station monitored ambient air temperature, humidity, solar radiation and rainfall. Data was transmitted to a central

data logger, recorded, and displayed on a computer screen; a subset of the data was displayed on the internet.

CHAPTER 5.0

DECENTRALIZED STORMWATER

5.1 Introduction

Marsalek and Chocat (2002) reported on an international survey of stormwater management practices in which responses were received from 18 countries. Responses made evident the large variations among countries and within countries in the practice of stormwater management. The authors found that stormwater management was widely accepted, in concept or in practice, and that all countries shared a common vision of stormwater management, endorsing a holistic approach promoting sustainable urban drainage systems. Marsalek and Chocat concluded that all responding countries supported:

- ◆ “Developing drainage systems in an environmentally sensitive and sustainable way, by preserving water balance in the affected areas and preventing the entry of sediment and pollutants into stormwater as much as possible.”
- ◆ “Emphasizing source controls in stormwater management, by reducing or even preventing runoff generation and pollution as close to sources as possible. In existing areas, this principle is applied during their redevelopment by disconnecting the runoff-contributing areas from sewers.”
- ◆ “Urban drainage infrastructures are significantly changing from the older systems with pipes only, to new, more environmentally friendly systems (green infrastructures) encompassing attractively landscaped ponds, wetlands, infiltration sites and swales.”

Boller (2004) commented that “New directives for stormwater handling in urban areas will be accompanied by considerable changes of present urban drainage systems. Stormwater will be retained in the urban environment in decentralized form.” The author predicted that beneficial use of stormwater will gain greater importance and water will increasingly be cycled back to nature through retention facilities that are integrated into the developed landscape. Boller concluded that “Renovation of the drainage systems may be considered as part of a more integral concept of a new urban water cycle....The new urban water concepts challenge engineers and scientist to invent, study and introduce innovative technologies and developments to meet the functional, ecological and the socioeconomic requirements for a sustainable urban water cycle of the future.”

The conclusions of Marsalek and Chocat (2002) and Boller (2004) and similar statements made by many resource managers, scientists, engineers, and planners (see for example Shaver and Ridley, 2002; Rahman and Weber, 2003; Nelson, 2003) around the world articulate a trend away from conventional curb and gutter drainage systems towards decentralized stormwater management. Decentralized approaches, including Low-Impact Development (LID), demand the skills and insights of planners and landscape architects in addition to scientists and/or engineers because better site design is at the core of decentralized stormwater management. Many resources related to site design for stormwater management

have been published in recent years, among them the *Handbook of Water Sensitive Planning and Design* (France, 2002); the Bay Area Stormwater Management Agencies Association's *Start at the Source* manual (BASMAA, 1999); and the Department of Environmental Resources of Prince Georges County, Maryland's *Low-Impact Development Design Strategies: An Integrated Design Approach* (1999).

5.1.1 Organization

Marsalek and Chocat (2002) observed that stormwater management is applied at four levels:

1. Policies and source controls,
2. Site best management practices (BMPs)
3. Community BMPs, and
4. Watershed-level measures

The organization of this report roughly follows these four levels or scales. In Section 5.2, recent literature on stormwater pollutant sources and source controls is summarized. Policies are not considered, as this section primarily concerns the environmental science and engineering aspects of stormwater management. Section 5.3 includes references to literature on stormwater controls at the site level, including recent data on BMP performance and guidance on selection. Section 5.4 summarizes recent work on the effectiveness of stormwater management approaches at the development and watershed scales.

5.2 Stormwater Pollutant Sources and Source Control

Sources of stormwater pollution are ubiquitous in developed watersheds. Monitoring of stormwater outfalls has produced valuable data on runoff concentrations and loading of many pollutants from urban areas. The U.S. EPA's Nationwide Urban Runoff Program (NURP) studied 81 outfalls in 28 communities, monitoring approximately 2,300 storm events (U.S. EPA, 1983). These data now serve as a benchmark against which to compare recent data. The most recent effort to develop national stormwater quality data has been undertaken by Pitt and others at the University of Alabama, who are developing a national stormwater quality database (NSQD) from outfall monitoring data collected under the NPDES stormwater program by more than 200 municipalities. Pitt and Maestre (Pitt and Maestre, 2005) describe the data collection effort, which at the time included data from 66 agencies and municipalities from 17 states. According to Pitt and Maestre, preliminary analysis indicates that lead concentrations in urban runoff have dropped by an order of magnitude since the NURP study (presumably due to phase out of leaded gas), sediment and heavy metal concentrations appear to have declined, and nutrients concentrations remain similar.

Metals were the most commonly evaluated group of pollutants in 48 monitoring studies reviewed by Elzufon (1998). Among the 36 studies evaluating metals, copper, mercury, nickel, lead, and zinc were commonly measured at levels of concern. Fourteen of the reviewed studies evaluated pesticides, 13 evaluated organics, 10 evaluated nutrients, and fewer evaluated BOD, TSS, oil and grease, and other constituents. Elzufon (1998) found that few studies were available of specific residential and commercial sources (e.g., types of commercial sites and

residential activities). There are a growing collection of studies, however, on contaminant loads from specific urban surface, particularly roofs.

Several recent papers describe different aspects of contaminant wash off from roofs and building materials. Clark et al. (2003) observed elevated concentrations of phosphate when galvanized metal, pressure treated wood, roofing felt, and tar shingles were exposed to simulated acid rain. The highest levels of phosphate (up to 300 mg/kg) were released from a roof-patching material, Gardner Wet-R-Dri. Leachate from roofing felt had the highest concentration of ammonia (approximately 5-15 mg/kg) followed by galvanized metal. Roofing felt was also a major source of nitrate, although leachate from the patching compound Leak Stopper had the highest nitrate levels. Karlen et al. (2002) found that annual loading rates of copper from naturally patinated copper roofs in Stockholm, Sweden were in the range of 1.0 - 1.5 g/m², increasing slightly with age. Copper concentrations in runoff ranged from 0.9 – 9.7 mg/L. The authors observed that “nearly all copper in runoff water sampled directly after release from the roof, was bioavailable and toxic towards the green alga *Raphidocelis subcapitata*.”

Gromaire et al. (2002) investigated zinc and cadmium runoff from four rolled zinc roofs in Paris, France. Rolled zinc roofs comprise approximately 40% of the roof area in Paris. The estimated loading from zinc roofs in Paris of zinc (34-64 metric tons/year) and cadmium (15-25 kg/year) was approximately half the total runoff load of these metals. Van Metre and Mahler (2003) studied particle associated contaminants in runoff from galvanized metal and asphalt shingle roofs near an expressway. Zinc, lead, pyrene, and chrysene concentrations in particles washed off roofs exceeded sediment quality standards. Yields of all contaminants investigated were greater from rooftops closer to the expressway. The authors distinguished between atmospheric contributions (including fallout from the expressway) and contributions from the roofing materials themselves. Forty-six percent of the watershed load of mercury was attributed to washoff of atmospheric mercury deposition on roofs. Fifty-five percent of the watershed load of zinc was estimated to come from roof washoff; 20% of the total from the roofing materials. Roofing materials were the source of 20% of the watershed lead load.

Polkowska et al. (2002) sampled runoff from eight roofs of varying construction in Gdansk, Poland and found that more than half the samples were toxic using the ToxAlert[®] 10 test. A weak correlation was observed between sample toxicity and concentrations of organonitrogen and organophosphate pesticides. Zobrist et al. (2000) investigated contaminant concentrations and yields in runoff from tile and polyester inclined roofs and from a flat, gravel covered roof. The authors observed a dramatic first flush effect from the inclined roofs. After the first few millimeters of rainfall, contaminant concentrations were similar to levels in rainfall. The gravel roof partially retained water and contaminants.

Zobrist et al. (2000) and Ammann et al. (2003) questioned the assumption (implicit in certain state stormwater regulations) that roof runoff is, in general, sufficiently non-polluted that it may be directed to infiltration practices without pre-treatment. Ammann et al. (2003) conducted an investigation using roof runoff and tracers of varying reactivity to evaluate movement of contaminants through test infiltration practices, concluding that the pollution potential of the roof runoff was sufficiently high that direct infiltration over a vulnerable aquifer was not advisable. Boller and Steiner (2002) tested a copper adsorption layer consisting of a mixture of granulated iron hydroxide and calcium carbonate to control movement of copper in

runoff from a copper facade through an infiltration ditch, finding that passage through the adsorption layer reduced copper concentrations in the percolate by 96-99%.

Lebow et al. (2003) used simulated rainfall to investigate factors affecting leaching of chromium, copper, and arsenic from chromated copper arsenate treated wood. When the wood was finished with water repellant, leaching of the three metals was greatly reduced. UV radiation increased leaching of all three metals. The authors concluded that finishes that prevent UV degradation of wood have great potential for minimizing leaching of the wood preservatives and contamination of stormwater runoff.

Pitt et al. (1995) examined the toxicity of runoff from several urban surfaces: roofs, vehicle service areas, parking lots, storage areas, streets, loading docks, and landscape areas. Nine percent of samples were determined to be extremely toxic to the test organisms. Runoff from roofs, vehicle service areas, and parking lots had the highest detection frequency of organic toxicants. Among metals, zinc concentrations were highest in roof runoff, nickel was highest in runoff from parking and storage areas, and cadmium and lead concentrations were highest from vehicle service areas and streets.

Pitt et al (2004) summarized data from many studies conducted in the U.S. and Canada in the 1970s and 1980s on particulate quality and sheetflow concentrations on stormwater source areas. Nutrient, COD, and metals concentration data in particulates sampled from many residential and commercial land uses are presented, including roofs, paved parking areas, paved and unpaved driveways, footpaths, paved sidewalks, garden soil, and road shoulders. Particles sampled from roofs had the highest concentrations of P, TKN, zinc, and chromium. Particles from paved driveways had the highest COD and copper concentrations, and particles from a paved sidewalk had the highest lead concentration. The authors also provide data on atmospheric wet and dry deposition, and clarify issues related to transfer of material between source areas, which can lead to misinterpretation of deposition data.

Pitt et al. (2004) conducted detailed sheetflow studies in a northern U.S. location (Wisconsin) and a southern location (Birmingham, Alabama). Metals were detected in almost all samples. The most commonly detected organic compounds, 1,3-dichlorobenzene and fluoranthene, were detected in 23% of Birmingham area samples. Concentrations of phosphorus in runoff from Wisconsin lawns were 2 to 10 times higher than for other source areas. The authors estimated that lawns can contribute as much as 50% of the annual P load in residential areas. Concentrations of polyaromatic hydrocarbons (PAHs) were 10 to 100 times higher in sheetflow from commercial parking lots than other source areas.

Boller (2004) suggested that prior to direct infiltration, discharge to surface waters, or beneficial use, runoff from roofs and roads should meet certain quality criteria. Boller stated that there are two ways to ensure runoff quality—through source control and through barrier treatment systems. Street sweeping was cited as an efficient practice to reduce metals and PAHs in runoff, as metals and PAH loads are typically associated with particulates. According to Boller, source control, especially selection of alternate construction materials for buildings, roads, and vehicles, is the most sustainable approach to reducing emissions of hazardous contaminants. Boller cited new guidelines in Switzerland that effectively discourage use of zinc and copper roofing in new construction as well as stakeholder education and “public sensibilisation” programs as examples of source control practices. Given that replacement of existing metal roofing will take decades, Boller suggested that barrier (treatment) systems may be required to remediate roof runoff in the interim.

Pitt and Lawlor (2000) examined the potential of alternate building materials to reduce contamination of stormwater. The authors review a list of commonly used building materials, indicating contaminants the materials have the potential to release when exposed to precipitation or stormwater. Washoff concentrations of selected metals and major ions are presented from plywood, caulk, metal roofs, polyvinyl chloride (PVC), and other materials.

Whereas industrial sources of stormwater contaminants are regulated under U.S. EPA's Multi-Sector General Permit for Storm Water Discharges from Industrial Activities, no comparable regulations address residential and commercial sources in the U.S. Instead, governments at every level are implementing programs to reduce sources of contamination through public education, outreach, and participation. These programs have multiplied since the U.S. EPA's Stormwater Phase II Final Rule went into effect on December 8, 1999, as regulated communities throughout the U.S. are now required to implement stormwater education and outreach measures and involve the public in program development and implementation. Elzufon (2000) reviewed effectiveness measurement tools, discussed reasons why the effectiveness of source control programs is difficult to measure, and provided guidance concerning selecting the most appropriate effectiveness measurement tool for a given situation.

5.3 Site-Level Decentralized Stormwater Controls

Weinstein et al. (2006) identified the three critical rainwater runoff management objectives as: flow rate attenuation, volume reduction, and water quality improvement. The trend towards decentralized stormwater management approaches has been fostered by the recognition that managing rainwater and runoff in dispersed systems integrated in the landscape has the potential to meet these management objectives without many of the disadvantages now recognized as inherent in conventional collection/piped conveyance systems.

A major focus in stormwater management in recent years has been determining how decentralized practices may be combined in systems to meet multiple management objectives on development sites. Low Impact Development (LID) and related strategies such as Water Sensitive Urban Design (WSUD) are attempts to engineer development sites to manage rainfall and runoff close to the source. According to Coffman (2002), "One of the primary goals of LID design for new development (greenfields) is to reduce runoff volume through infiltration, recharge, evaporation and finding beneficial uses for rainwater rather than disposing of it as a waste product into storm sewers. The result is a landscape that is functionally equivalent to predevelopment hydrologic conditions that generates less surface runoff, less pollution, less erosion and damage to lakes, streams, and coastal waters." To approximate pre-development hydrologic conditions, a major focus of LID is in creating opportunities for rainfall and runoff to infiltrate close to the source, thereby reducing runoff volumes, attenuating peak flows, and recharging groundwater. Because accepted watershed models are not adequate to model LID practices and development sites, several investigators have developed simulation models.

Cheng et al. (2004) developed a model for Prince George's County, Maryland to simulate the effects of implementing LID as compared to traditional development. The model contains two basic structural BMP types that the user can adapt (parameterize) to model a range of treatment elements common in LID, such as bioretention cells, rain barrels, roof gardens, vegetated swales, and infiltration chambers. Wetlands and retention and detention ponds may also be modeled. Site design characteristics such as storm drains, building density, road and sidewalk dimensions, and impervious surfaces disconnection may be input. Cheng et al. applied

the model to a hypothetical development and found that in all cases the LID development scenario had substantially lower peak flows than under the existing condition, which was assumed to be completely forested. The peak discharges from the proposed LID development with BMPs were miniscule over five major rain events.

The simulation results obtained by Cheng et al. (2004) (i.e., essentially all precipitation infiltrates) are potentially cause for concern if enhanced infiltration results in an undesirable increase in the local groundwater table. Gobel et al. (2004) discussed the potential for “overcompensation” from intensive infiltration at structural stormwater practices. The authors stressed the need for an understanding of the pre-development hydrogeologic condition, through, for example, creation of a water budget and/or numerical groundwater modeling. With such an analysis, the quantity of stormwater to be infiltrated may be adjusted in the design phase to avoid adverse effects on the groundwater surface.

Medina et al. (2003) and Patwardhan et al. (2004) introduced the Low Impact Feasibility Evaluation (LIFE™) model. The model provides continuous simulation of runoff and infiltration from new and redeveloped areas. Further information on this model, which appears to be still under development, is not available at this time.

Of the many stated benefits of transitioning to decentralized approaches, Weinstein et al. (2006) provided a thorough analysis of the potential for decentralized stormwater management to reduce the frequency and magnitude of combined sewer overflows. Combined sewers are present in 746 municipalities in the United States, discharging an estimated 850 billion gallons of combined sewer overflows every year. Targeting catchments prone to combined sewer overflows (CSOs) for implementation of decentralized stormwater retrofits was discussed.

Loucks et al. (2004) also evaluated the potential for decentralized controls to reducing stormwater runoff and associated combined sewer system impacts. The authors used HSPF to model implementation of decentralized practices at the lot level, and found that downspout disconnection, rain barrels, and rain gardens were all effective in reducing treatment plant load and CSO volume. Green roofs, green parking lots, and bioretention also reduced CSO volumes.

5.3.1 Best Management Practices

“BMPs (and SUDS) represent man-made complex environmental systems (e.g. constructed wetlands), whose performance may be difficult to quantify and sustain without proper support and maintenance. BMPs are management measures, which are expected to produce environmental benefits, but without strict performance targets (defined, e.g. for sewage treatment plants) and full understanding of their long-term operation” (Marsalek and Chocat, 2002). Regarding the long-term performance of BMPs, the authors observed that BMP performance changes over time due to such factors as vegetation growth, species distribution and maturity; reduction of storage volumes/flow areas due to sediment deposition, clogging of the BMP pervious layers, storage of contaminated sediments susceptible to contaminant release, and transfer of contaminants from sediment to the biota. To maintain performance, the authors stressed the need for both “short-term corrective measures” and “long-term preventative maintenance, including rehabilitation of BMP structures.”

There is a substantial and rapidly expanding body of knowledge concerning the treatment performance of stormwater best management practices. Researchers in recent years have been investigating several promising technologies and many variations and combinations

of these technologies to manage rainwater runoff through dispersed systems. Weinstein et al. (2006) identifies 11 main types of decentralized stormwater controls and provides a simple ranking regarding their effectiveness to meet volume control, peak flow attenuation, and water quality improvement objectives. The controls include: downspout disconnection, filter strips, infiltration practices, pocket wetlands, porous pavement, rain barrels/cisterns, rain gardens (bioretention), soil amendments, tree box filters, vegetated roofs, and vegetated swales. Of these, this review identified recent research on decentralized stormwater management practices concentrated in four areas: vegetated (green) roofs, permeable pavements, rain gardens/bioretention/ biofiltration, and vegetated (grass) swales. These are the same four practices reviewed by U.S. EPA and the Low Impact Development Center in a literature review published in 2000 on LID. A section of this report is devoted to each of these practices. There has also been considerable research on various infiltration practices (trenches, basins, seepage pits, the “Mulden-Rigolen-System” used in Germany, et cetera). A few examples are included here, but these systems were judged so variable in their design that they are not considered in detail in this review. Lastly, literature on ponds and wetland systems was not reviewed because these systems are generally considered “end-of-pipe” practices, although distributed runoff storage in ponds and wetlands may have appropriate applications in decentralized stormwater management.

In the U.S., Clary et al. (2002) discussed the creation of the National Stormwater BMP Database, a searchable database of BMP performance data first released in 1999. The goal was to create a “centralized, easy-to-use, scientifically sound tool for assessing the appropriateness of BMPs under a variety of site conditions.” Literature describing BMP performance studies was collected and screened for quality and technical relevance prior to entry into the database. The authors developed BMP data evaluation protocols to encourage use and reporting of more consistent performance measures, demonstrating that the choice of performance evaluation method can dramatically affect the reported pollutant removal efficiencies, complicating selection of appropriate BMPs. Another benefit of the project was to establish a stormwater BMP data clearinghouse to provide long-term maintenance of the database and screen new BMP studies for inclusion in the database. The database now includes data on more than 200 BMPs (<http://www.bmpdatabase.org/>, accessed October 6, 2006).

Jones et al. (2004) presented numerous reasons why it is difficult to obtain good quality BMP performance data and identified problems they encountered in review of BMP performance data for inclusion in the National Stormwater BMP Database. Most of the difficulties the authors cited in obtaining good quality performance data stem from poor study design, technical problems in establishing and maintaining monitoring systems, or financial constraints. The authors noted many reasons why it is expensive and difficult to establish and maintain working monitoring systems to collect representative samples and provide good quality flow measurement.

Barrett (2004) analyzed data in the International (formerly “National”) Stormwater BMP Database on the performance of wet ponds. His discussion highlighted the need to consider differences in facility design and influent characteristics in interpreting performance data. The analysis by Barrett demonstrates the usefulness of the BMP Database in evaluating BMP performance when differences in facility design are taken into account. Barrett identified 11 wet ponds with complete data on facility design and found a “striking correlation between influent and discharge concentrations.”

Lampe et al. (2005) summarized water quality performance data for several classes of BMPs using the International Stormwater BMP Database, supplemented with reports from the literature. The report reviews and compares the performance of major category of BMPs/SUDS and considers the whole life costs of each. An appendix by Michael Barrett summarizes the expected pollutant removal efficiency of retention ponds, extended detention ponds, vegetated swales, bioretention systems, infiltration/filter trenches, and porous pavements. The information contained in this major report cannot be meaningfully summarized in the space of this review.

Barber et al. (2003) discussed field tests and two dimensional groundwater flow modeling of a modified infiltration trench called an ecology ditch. The authors found that the compost/sand media in the ecology ditch retained enough water to reduce peak discharge rates by 50-70% for storm sizes ranging from 0.5 to 2.5 cm. However, the percent peak reduction and the peak delay time declined exponentially as a function of storm size. The authors concluded that the ecology ditch “offers an effective means for the hydraulic treatment of storm water runoff.” No water quality data is presented. Sieker (1998) described a combination grassed swale and infiltration trench system called the Mulden-Rigolen-System that is being used extensively in Germany. This system is designed to allow high rates of infiltration via short term storage in the swale and long-term storage in the trench.

5.3.1.1 Green Roofs

The organization Green Roofs for Healthy Cities prepared a bibliography of green roof articles that provides citations for 82 peer-reviewed journal articles and over 150 books, proceedings from meetings, and reports on the subject of green roofs (Rowe, 2006). A minority of the publications relate to the hydrology and water quality characteristics of green roofs; however, several studies by Scandinavian and U.S. researchers are cited.

Villarreal et al. (2004) modeled an inner city suburb of Malmö, Sweden and found that green roofs reduced total runoff volumes. Van Woert et al. (2005) tested three types of roofs and found that overall extensive green roofs had greater rainfall retention (60.6%) than similarly constructed roofs without vegetation (50.4%) and commercial roofs with gravel ballast (27.2%) over a 14 month period during which 83 rain events were measured. The percent retention was substantially higher on all test roofs for small (<2 mm) and medium (2-6 mm) sized events; for medium sized events, the gravel roofs retained an average of 33.9% and the bare media and vegetated green roofs retained nearly equal amounts, between 82-83%. In a second experiment, the authors monitored green roofs only, determining that slope (2% or 6.5%) and media depth (2.5, 4.0, or 6.0 cm) had minimal effect on overall rainfall retention, which ranged from 65.9-70.7% for all treatments. Peak runoff rates were lower for the green roofs and media only roofs than for the gravel roofs for small, medium, and large storms. Peak runoff from the green roofs was not appreciably lower than from the media only roofs for light and medium storms, but for heavy storms, the green roofs clearly responded more slowly and less dramatically to rainfall.

Bengtsson et al. (2005) related observed runoff rates from extensive green roofs in Sweden to precipitation, potential evaporation, and the storage capacity of the roof. The authors observed that most rain events produced little or no runoff. Runoff began shortly after the roof media reached field capacity (9 mm storage) and quickly equaled precipitation rates. In a related study, roof slope and length did not significantly effect runoff distribution, which result was attributed to the importance of vertical percolation through the vegetation and soil (Bengtsson,

2005). However, peak flows were higher on green roofs with a drainage layer than roofs without a drainage layer.

DeNardo et al. (2005) evaluated small, experimental green roofs during seven rains in October and November 2002. The peak runoff rate was delayed an average of 2 hours for the seven rain events on three replicate roofs with 1:12 slopes, constructed using a conventional covering, a root barrier, a 12 mm thick Enka drainage layer, 89 mm of growth medium, 25 mm of porous expanded polypropylene (PEPP), and *Sedum spurium* plants. The percent of rainfall retained ranged from 19% to 98% and averaged 47% for the seven storms. Roof temperatures were moderated, substantially warmer in the winter and cooler in the summer than conventional roofs, and diurnal temperature variations were dampened.

Jarrett et al. (2006) applied the Annual Model to simulate runoff from green roofs for the period 1976-2003 in two locations, State College, Pennsylvania and Raleigh, North Carolina. The continuous simulation modeling indicated that 45-55% of the annual rainfall volume (depth) can be retained on the green roof. As in Van Woert (2005), increasing the roof media depth did not significantly improve the roofs' ability to retain rain water. Jarrett et al. found that providing only 3 mm of roof storage will still cause 25-40% of the annual rain to be retained. The authors also applied the Storm Model using certain observed storms as well as design storms for Rock Springs, Pennsylvania and found that the model simulated experimental results well. Using the Storm Model, Jarrett et al. demonstrated that the runoff rates from a green roof can approximate the pre-development runoff rate expected from the building footprint.

An ongoing study by Berghage (2006) addresses questions related to evapotranspiration and acid neutralization on green roofs. Berghage reported on this work at the World Green Roof Congress in Basel Switzerland in September 2005. To date the project has developed an "accelerated acid aging test" method to quantify the acid rain buffering capacity of green roofs as well as a model to simulate the hydrology of green roofs, based in part on empirical evapotranspiration data. The authors suggest that green roofs have the potential to neutralize acidic rainfall, which should reduce acid leaching of metals on the roof and downspouts, but that lime or another agent may need to be added periodically to maintain the acid buffering capacity.

Recognizing the energy-saving and environmental benefits of green roofs, the U.S. Department of Energy's Federal Energy Management Program introduced a Federal Technology Alert on Green Roofs with the statement: "Green roofs can improve the energy performance of federal buildings, help manage stormwater, reduce airborne emissions, and mitigate the effects of urban heat islands" (U.S. DOE, 2006). The document reviews basic performance data, construction information, and maintenance requirements, and promotes consideration of green roof systems for new federal facilities.

5.3.1.2 Permeable Pavements

Environmental benefits and limitations of permeable pavement systems (i.e., porous concrete, porous asphalt, and permeable concrete interlocking pavers) as compared to conventional impervious asphalt pavement have been the focus of an increasing research effort in recent years. Numerous studies have concerned the effects of these systems on rainfall-runoff processes and water quality. Work continues to quantify the potential hydrologic and water quality benefits of permeable pavement system strategies and to overcome recognized limitations of these systems.

Smith (2003) describes factors relevant to the siting and design of permeable interlocking concrete pavers. Appropriate siting is discussed, including avoidance of hot spot land uses such as vehicle fueling stations and other sites where the groundwater pollution potential is high, sites with high seasonal water tables, sites near wells or upslope of building foundations without footing drains, and sites receiving substantial run-on.

In Hun-Doris (2005), Sansalone discussed future research needs in the area of permeable pavement, including the need to better characterize the pore structure of porous pavements. Quantifying the distribution of effective porosity could lead to improvements in porous pavements. Another critical avenue of research suggested by Sansalone is development of reactive porous pavements with the ability to immobilize soluble phosphorus and metals. According to Sansalone, “If you take a pavement, which is part of the problem, and modify it to make it part of the solution, that really [is] what’s driving our work on porous pavements.”

In the stormwater arena (note that several benefits of permeable pavement systems, such as improved skid resistance, have little to do with environmental quality), the main research focus in permeable pavements in recent years has been on their infiltration capacity over the long-term, and on cleaning practices to maintain acceptable infiltration rates. Hunt et al. (2002) reported preliminary results of a study comparing two installations in Eastern North Carolina, a permeable paving block system and a porous concrete pavement. The permeable paving block system significantly reduced runoff rates compared with conventional impervious pavement. The runoff coefficients for the block paver system were found to range from 0.20-0.50. Results from the (monolithic) porous concrete installation were not available. Bean et al. (2005) researched three interlocking concrete paver installations in North Carolina. A site in Swainsboro on sandy soils generated no runoff over a 10 month period, illustrating the effectiveness of this system. At a sandy site in Goldsboro, exfiltrate from the permeable interlocking concrete pavement system had significantly lower TP, TKN, $\text{NH}_4\text{-N}$, and Zn concentrations relative to runoff from asphalt pavement. The authors also found that a permeable pavement installation on clay (Cary site) could perform well hydraulically, but observed conversion of $\text{NH}_4\text{-N}$ to $\text{NO}_3\text{-N}$ and increased TP in exfiltrate relative to concentrations in rainfall, which the authors attributed to accumulation of clay fines.

In a parking lot located in Renton, Washington, Brattebo and Booth (2003) examined four types of manufactured permeable pavement systems in adjacent parking stalls plus a conventional asphalt control. None of the four systems showed substantial signs of wear after six years of regular use, although two systems based on a plastic grid had shifted somewhat. Almost no runoff was generated on the four permeable pavements over the 3-4 month monitoring period, during which 15 rain events totaling 570 mm were recorded, while the conventional asphalt control closely followed precipitation rates. The most runoff prone of the four permeable pavements, Grasspave[®], yielded only 4 mm of runoff from a 121 mm, 72 hour storm. The infiltrated water had lower concentrations of copper and zinc than in runoff from the asphalt control, no lead or diesel fuel, and much lower concentrations of motor oil.

Sansalone et al. (2006) analyzed the multi-functionality of pervious pavement systems in the only recent work reviewed in which the pavement and medium were explicitly designed as a treatment system. The authors discussed benefits of permeable concrete pavements over permeable asphalt; permeable concrete increases the alkalinity of percolating water, does not leach PAHs like asphalt, and provides greater skid-resistance under wet conditions. Sansalone et al. quantified reductions in hydraulic conductivity with time at suspended solids loading rates

of 50, 100, and 200 mg/L. At each loading level, hydraulic conductivity decreased by approximately three orders of magnitude over the 250 hour test. Sansalone also investigated two cleaning methods: 1) sonication followed by backwashing and 2) vacuuming the surface. Both methods were found to restore the infiltration rate of clogged pavements to 95% of the initial infiltration rate. In addition to characterizing the hydrologic and particle filtering functions of permeable concrete systems, Sansalone et al. tested aluminum oxide coated media (AOCM) in the base beneath the concrete as a substrate to reduce dissolved phosphorus in the percolate, concluding that AOCM can provide significant adsorption capacity for dissolved phosphorus. The implication is that permeable roadways could be constructed (or reconstructed) in certain settings to serve as sinks for phosphorus in the landscape rather than acting as phosphorus sources.

In East Scotland, Schlüter et al. (2002) evaluated a porous pavement system with a sealed sub-base and perforated drainage pipes, finding that the system attenuated peak flows and pollutant peak concentrations well. Although outflow timing was delayed, on average nearly half the rainfall volume discharged via the perforated pipes, precluding groundwater recharge and other potential benefits cited for permeable pavement systems. The authors also developed a computer model with reportedly excellent prediction of the outflow hydrograph.

Chopra et al (2006) researched the clogging potential of porous concrete pavements and the ability of vacuum sweeping and pressure washing to restore high infiltration capacities. The authors observed average infiltration rates ranging from 1.4 to 627 in/h in 12 concrete cores collected from three parking lots in central Florida, constructed between 1987 and 1991. Average rates exceeded the design rate of 2 in/h in 11 out of 12 cores. Both vacuum sweeping and pressure washing dramatically increased infiltration rates, and combining vacuuming and pressure washing generally improved infiltration rates to the greatest degree. Infiltration rates after vacuuming, pressure washing, or both ranged from 4.1-1,200 in/h, with 5 cores increasing more than 2000%.

Permeable pavement research ongoing at the University of New Hampshire (see Briggs et al., 2005) should provide critical data on application of this technology in cold climates, where freezing conditions and winter road maintenance may be complicating factors. Published results from this study were not available.

5.3.1.3 Bioretention Areas

Field studies of bioretention systems or rain gardens have been initiated in recent years in several states in the U.S., including North Carolina, Maryland, Pennsylvania, New Hampshire, North Dakota, and Connecticut, as well as in Europe (see for example Nordberg and Thorolfsson, 2004; Muthanna, Thorolfsson, and Viklander, 2006). The rapid development of these field studies within the last five years attests to the growing interest in bioretention systems for stormwater management and the need for experimentation to elucidate some basic design principles. Two subjects that received considerable attention in the last several years are cold climate performance of bioretention areas and modifications of the standard design to improve treatment of nitrate.

Christianson et al. (2004) developed a bioretention design model that simulates flow and the fate and transport of nutrients, metals, and organic compounds through a bioretention system. The authors stated that the model is the first to predict chemical fate and transport processes in bioretention systems. Dussaillant et al. (2004) developed a numerical model,

“RECHARGE”, that couples the Richards equation with a surface water balance to simulate recharge, runoff, and evapotranspiration, and applied it to a rain garden in Southern Wisconsin. The model, which can not simulate snowmelt, predicted very high recharge rates for non-snowfall seasons.

Emerson and Traver (2004) reported on a bioretention area at Villanova University in Pennsylvania. In the three years it had been in operation, it had not required any maintenance. Infiltration rates ranged from 0.13 in./h to 0.54 in./h, showing no consistent decreasing trends.

Deitz and Clausen (2005) constructed replicated rain gardens in Connecticut to capture the first 2.54 cm (1 in.) of runoff from a shingled roof. The Connecticut rain gardens had little effect on nutrient concentrations in percolating water other than reduction in ammonia-N in both gardens and total-N in one garden.

Using pilot-plant laboratory bioretention systems and two existing bioretention facilities in Maryland, Davis et al. (2003) documented the effectiveness of bioretention at removing low levels of heavy metals from synthetic stormwater runoff. Average removal rates of lead, copper, and zinc (the most often cited metals of concern in urban runoff) exceeded 95% at one facility (Greenbelt) on both a concentration and a mass basis. Removal was less efficient (average 43% copper, 70% lead, and 64% zinc) at the other facility (Largo), which may be attributable to metal flux from storm drain piping above the effluent sample collection point, differences in the media, or the younger age of the Largo system. In box tests shallower media depth resulted in somewhat lower removal efficiencies. The authors also addressed the question of metal accumulation in the bioretention areas. Based on a 30:1 drainage area to treatment area ratio and typical metals concentrations in runoff, accumulated lead, cadmium, and zinc were predicted to reach or exceed standards set for wastewater biosolids in 15-20 years. A subsequent study using the same pilot (box) and field-scale systems documented 70-85% removal of P and 55-65% removal of TKN from infiltrating runoff (Davis et al., 2006). Nitrate removal was poor (<20%), which result may be due in part to transformation of captured organic-N to nitrate. The authors calculated areal N and P input rates and determined that uptake by vegetation should assimilate substantially more P on an annual basis than would be input to the system. Uptake was estimated to account for approximately 90% of the captured N. Based on these figures, the authors recommend that periodic harvesting and removal of vegetation should prevent build up of N and P in the media.

Kim et al. (2003) focused on optimizing bioretention systems for nitrate removal by incorporating a saturated (anaerobic) zone and evaluating many possible electron donors to reduce nitrate. Among the nine materials the authors tested, newspaper, wood chips, and small sulfur particles (0.6 to 1.18 mm) were the best electron-donors and had among the best TKN and turbidity removal rates. Shredded newspaper was ultimately shown to be the best electron-donor substrate overall of the materials studied. With a submerged anoxic zone and shredded newspaper serving as an electron donor, nitrate and nitrite removal was 70-80% on a mass basis.

Hunt and Jarret (2004) studied the effects of a saturated (anaerobic) zone in field-scale bioretention systems in central North Carolina, without providing an added electron donor source as in Kim et al. (2003). In the two conventionally drained, 1.2 m deep systems, total-N was reduced by 40%, while the results for nitrate were contrasting (75% for Greensboro cell vs. 13% removal for Chapel Hill cell), possibly the result of unintended anaerobic conditions developing in the media of the Greensboro cell. However, influent nitrate loads to the systems

differed by an order of magnitude so that direct comparison of removal rates may be problematic. The systems also differed substantially in their effects on TP and Ortho-P, with the Chapel Hill cell reducing TP by 65% and Ortho-P by 69%, whereas the Greensboro cell was a net exporter of P. The media used at the Greensboro site was enriched with P relative to the media used at Chapel Hill, possibly explaining the observed difference in P processing. The authors attributed significantly reduced TP and Fe outflow concentrations in the Greensboro cell with the modified drainage system relative to the conventionally drained Greensboro cell to the presence of an anaerobic layer in the modified cell; however, the possibility of anaerobic conditions at the conventional cell was previously discussed to explain the high rate of nitrate reduction. As demonstrated by Davis et al. (2003), removal of Zn, Cu, and Pb was substantial. Other conclusions were that the ratio of outflow to inflow was significantly higher during winter than during spring, summer, and fall, resulting in lower mass removal of contaminants in the winter.

There are at least three bioretention experiments implemented in cold climates since 2004 for which no data or limited preliminary data were available. Two small rain gardens were constructed in Trondheim, Norway for which no data could be obtained (Nordberg and Thorolfsson, 2004). Four bioretention areas in North Dakota are currently under study (Davidson, 2006). Double ring infiltrometer tests conducted in the winter and spring of 2006 revealed widely varying infiltration capacity within the same system under different winter conditions, with rates at the Burnsville site differing by more than two orders while rates at the three other sites were zero or near zero on at least one test date. Finally, the bioretention system constructed by the University of New Hampshire in Durham, New Hampshire reportedly produced some favorable results (average peak flow reduction 60%, average lag time 220 min, TSS reduction 81%, NO₃-N reduction 64%, Zn removal 81%); however, insufficient data is available to evaluate this system (Ballesterio, Roseen, and Houle, 2005).

5.3.1.4 Vegetated Swales

Vegetated swales are becoming a common feature of decentralized stormwater design, incorporated into sustainable development design approaches (whether LID, WSUD, Conservation Design, or other). Fletcher et al. (2002) noted a “significant gap in our knowledge” concerning the effect of certain design parameters on pollutant removal in vegetated swales, which leads to uncertainties in their performance and limitations in the ability to optimize performance through design. Fletcher et al. (2002) observed that uncertainty with respect to performance of vegetated swales is also due to the different ways performance has been measured, citing the need for consistent protocols to measure BMP performance (an area of considerable work by the International Stormwater BMP Data Clearinghouse, see Clary et al., 2002) to enable more rapid developments in swale design. Fletcher et al. (2002) compiled monitoring data from multiple sources in a table of summary statistics of swale performance studies. These data indicate that on average TSS removal is superior to TP and TN removal in grass swales. TN removal tends to be lower and more variable than either TSS or TP removal.

To establish empirical relationships between pollutant removal efficiency and hydraulic loading, Fletcher et al. (2002) performed controlled experiments discharging synthetic runoff (TSS = 150 mg/L, TN = 2.6mg/L, TP = 0.3mg/L) at a range of flow rates (2 L/s to 15 L/s) to recently constructed grass swales in Brisbane, Australia. The swales reduced concentrations of TSS in the synthetic runoff by 73-94%, TP by 58-72%, and TN by 44-57%. On a percentage

basis, reductions in TSS loads were consistently lower than reductions in TSS concentrations because treatment performance declined with increasing flow rate. TSS concentrations continued to decline over the full length of the 65 m swale, indicating that increasing swale length promotes greater reductions in TSS. The swale performance data were used in developing the k-C* model, which the authors stated “shows excellent potential for predicting the pollutant removal performance of vegetated swales.”

In Sweden, Backstrom (2002) measured particle trapping in nine grassed swales. Average removal of total suspended solids ranged from 79-98% among the nine swales. Factors promoting particle trapping included high infiltration rates, dense, fully developed turf, and longer swales. Based on the experimental data, the author developed a model of particle trapping efficiency in grassed swales. Backstrom (2003) found that grassed swales retain significant amounts of pollutants at high loading rates, primarily due to sedimentation of suspended particulates. However, swales may release pollutants when pollutant concentrations in influent runoff are low. Backstrom did not observe significant TSS removal when influent concentrations were less than 40 mg/L, which conflicts with the finding of Fletcher et al (2002) who showed progressive TSS removal along a swale to an average of 25 mg/L at the outlet. Backstrom (2003) concluded that grassed swales do not provide consistent pollutant removal but have the effect of evening out peak pollutant concentrations; therefore, swales should be considered as a primary treatment device. In Sweden, grassed swales are important snow storage areas and retain a large percentage of the solids in melting snow. Backstrom’s results from sampling of three swales were very consistent: high concentrations of total suspended solids, copper, lead, and zinc in snow were dramatically reduced in melt water, with removal rates of 96-99% for suspended solids, 93-96% for copper, 96-99% for lead, and 78-94% for zinc. However, concentrations of dissolved metals in melt water were consistently higher than in snow, indicating some desorption from the captured solids.

5.3.2 Treatment and Control Selection

Strecker et al. (2005) discussed the common practice of selecting BMPs/SUDS for stormwater control from a menu of practices. Widely used design manuals (e.g., *Stormwater Management Manual for Western Washington*, (2005); *Maryland Stormwater Design Manual*, (2000); *Vermont Stormwater Management Manual*, (2002)) for permanent (post-construction or operational phase) stormwater management provide various matrices to assist the designer in selecting an appropriate BMP based on their suitability for different types of sites (drainage area, land use, soils, slope, groundwater depth, etc.), ease of maintenance, affordability, and highly generalized pollutant removal specifications. This approach, while appropriate in some cases, does not “adequately build upon more than a century of accumulated experience in the fields of environmental process and wastewater engineering.” The report proposes a comprehensive design framework consisting of the following major steps:

1. problem definition,
2. site characterization,
3. identification of fundamental process categories,
4. selection of treatment system components,
5. practicability assessment,
6. sizing and development of conceptual design, and
7. development of performance monitoring and evaluation plan.

In Steps 3 and 4 of this design framework, Strecker et al. (2005) turn around the conventional practice of selecting BMPs based on their ability to attenuate flows or remove certain pollutants. The authors instead described an approach in which fundamental unit operating processes (UOPs) required to treat the contaminants of concern are identified first (Step 3), and then treatment system components (most of which are recognizable as BMPs) are selected that include the necessary UOPs (Step 4). This conceptual change in the design process has the potential to encourage greater use of wastewater technologies in stormwater management as well as change the stormwater management vocabulary.

Pitt (2006) provided two examples where combinations of unit processes were assembled in treatment trains, one to treat runoff from a critical source area and a second to treat runoff from a new industrial park. The author noted that “In most situations, combinations are needed to meet the broad needs of a comprehensive stormwater management program and receiving water objectives”. The sequencing of stormwater controls is explained in terms of a succession of unit operating processes. The continuous simulation model WinSLAMM was used to project runoff volume and particulate solids reduction through the treatment trains.

Weinstein et al. (2006) provided tools to assist communities addressing combined sewer overflow problems in evaluating the potential for decentralized stormwater management options to reduce the frequency and magnitude of CSOs. The authors demonstrated how simulation and optimization software may be used to evaluate potential impacts of decentralized practices on CSO control. A major component of the analysis involves the prediction of stormwater flows associated with various decentralized management scenarios, which is a critical area of research and model development, apart from its connection with CSO control.

Clark et al. (2006) provided an analysis to support decision making regarding the feasibility of infiltration-based stormwater controls. The report identifies constraints to implementation of infiltration-based practices (technical and institutional) and provides a flowchart to aid regulators, managers, and engineers in determining the applicability of infiltration-based stormwater management systems in meeting their water quality and quantity goals.

Decentralized approaches to stormwater management necessitate consideration of values beyond performance and cost. An ongoing project by the Water Environment Research Foundation, Successful Integration of Stormwater BMPs into the Urban Landscape (Shoemaker, 2006), is reviewing decentralized stormwater projects to gain insight into why some projects succeed while others fail. The project considers factors influencing community acceptance of decentralized controls. No results from this project are available at this time.

5.4 Watershed-Scale Decentralized Stormwater Control Assessment

Quantification at the watershed-scale of the effects of decentralized stormwater controls is a relatively recent area of inquiry. To date, watershed scale effects have been evaluated more often using computer models than through monitoring.

Huber and Cannon (2002) used SWMM to model a 16.9-acre, 115-lot residential neighborhood with a history of flooding problems in Portland, Oregon. The authors compared existing conditions, where much of the watershed impervious area is directly connected to storm

drains, with a hypothetical LID retrofit scenario, and predicted that by draining all parcel imperviousness (roofs, driveways) onto lawns throughout the neighborhood, runoff volumes and peak flows could be reduced more than 50%. Holman-Dodds et al. (2003) compared three hypothetical development scenarios—undeveloped, traditional, and LID, finding that changing the layout in the urban landscape to disconnect impervious surfaces yielded substantially lower flows at the watershed outlet. The authors demonstrated that disconnection of impervious surfaces provided greater reductions in flows over traditional development during smaller storms; the relative difference diminished as the rainfall amount increased. Reininga and MacDonald (2002) described another modeling study comparing a hypothetical LID development with flows from the undeveloped site. The authors concluded that development has adverse impacts that cannot always be mitigated, that site specific conditions largely determine the hydrologic performance of LID developments, and that supplementary practices—identified to include below-grade detention, stream enhancement, and piped bypass—are necessary in some cases to mitigate likely hydrologic impacts of LID developments.

Perez-Pedini et al. (2004) demonstrated an approach to meet peak flow attenuation objectives most efficiently by optimizing the location and number of BMPs in a watershed. The modeled watershed is a 65.5 km² urban watershed of the Aberjona River near Boston, Massachusetts. The goal was to obtain the maximum reduction in peak flows using the minimum number of BMPs, which were generalized in the model as areas (hydrologic response units) assigned low curve numbers. Using a runoff model (SCS curve number method) in combination with a “genetic algorithm,” the authors determined the best placement of BMPs for various levels of BMP implementation (i.e., 25, 50, 100, 150, 200, and 400 BMPs).

Freni et al. (2002) investigated the potential of modeling approaches in characterizing reduction in flooding potential associated with implementation of distributed stormwater management practices. The ability of distributed stormwater management practices to mitigate flooding was not uniform across a test watershed; more efficient mitigation was predicted in upstream locations. The authors found that sensitivity analysis is a useful tool for evaluating stormwater management alternatives. Sensitivity analysis techniques may be applied in model calibration and in uncertainty propagation. The authors also observed that the linearization assumption is justified, that is, that the effects at a larger scale are equal to the sum of the effects at a smaller scale.

Lai et al. (2005) provided an update on U.S. EPA’s Integrated Stormwater Management Decision Support Framework (ISMDSF). The ISMDSF encompasses a range of tools, some still in development, to assist in objective analysis of stormwater management options. BMP/LID assessment tools will assist the engineer/designer in evaluating and selecting BMPs based on performance and cost. GIS-based tools will be developed to aid in visualization and optimization of BMP placement options. The GIS-based tools are scheduled for completion in 2008.

Cheng et al. (2004) is perhaps the first monitoring study comparing runoff quantity and quality between adjacent watersheds, one a LID development and the other a conventional development, each less than 12 acres in size. The developments are new residential subdivisions in Prince George’s County, Maryland. Based on the first two years of data, the LID site had consistently lower event runoff and annual runoff volumes (20% less) and lower peak flows per unit area, despite only partial implementation of LID.

The Jordan Creek watershed in Connecticut (Clausen, 2004) is perhaps the most rigorous investigation available on the effects of decentralized stormwater management on runoff rates, runoff volumes, and pollutant transport. The investigators conducted a paired watershed study, monitoring runoff prior to development (the calibration period), during construction, and after construction of two residential subdivisions, a “traditional watershed” and a “BMP watershed”. An undeveloped watershed served as a control. The traditional watershed includes 18 homes on 10.6 acres. The BMP watershed includes 12 units on 6.9 acres. In the BMP watershed, several LID techniques were applied, including reduced street widths, concrete pavers, grassed bioretention swales along roadways, a bioretention area within a cul-de-sac, rain gardens on house lots for receiving roof and driveway runoff, and others. The investigators found that stormwater runoff during construction of the BMP development decreased by two orders of magnitude, a result attributed to rapid construction of all basements and placement of earthen berms to retain and infiltrate runoff. Concentrations of TSS, nitrogen (NO_3 , NH_3 , and TKN), and total phosphorus increased significantly during construction of the BMP watershed, possibly due to erosion in swales prior to vegetation establishment and fertilizer use by residents. In the traditional watershed, flows increased by a factor of two during construction, but pollutant concentrations did not change, except in the case of TKN which fell significantly. Relative to the undeveloped state, the mass export of sediment, some nutrients, and metals did not change in the BMP watershed during construction and fell following construction. Mass export of sediments, nutrients, and metals all increased from the traditional watershed.

No results are available at present for a LID pilot monitoring project being conducted by Hinman and others at Washington State University for the Water Environment Research Foundation. Hinman (2006) stated that this project “will be one of the first monitoring efforts in the Puget Sound region and one of the few projects nationally to evaluate the performance of individual LID practices and the effectiveness of these tools integrated into a residential stormwater management system.” Given the scarcity of these data, these results will be of great interest to the growing number of professionals involved in decentralized stormwater management.

APPENDIX A

DETAILED INFORMATION ON NDWRCDP PROJECTS

The initial intent of this research effort was to focus primarily upon the results of research conducted under the auspices of the NDWRCDP. The final report, however, includes a significant portion of research that helps to address the research priorities but was not conducted through the NDWRCDP. This appendix contains additional findings and summary information about the ES&E research projects, listed in the order in which they appear in the main body of the report. The full project reports may be downloaded over the Internet at <http://www.ndwrcdp.org/publications.cfm>.

A.1 Guidance for Evaluation of Potential Groundwater Mounding Associated with Cluster and High-Density Wastewater Soil Absorption Systems

Authors: Poeter, E.; McCray, J.; Thyne, G.; Siegrist, R.
Year: 2005

Abstract: “Hydrologic evaluation of cluster and high-density wastewater soil absorption systems (WSAS) is important because it can help ensure that a site has sufficient capacity to assimilate water in excess of natural infiltration. Insufficient capacity may result in significant groundwater mounding on low hydraulic conductivity lenses or elevate the water table, which may alter saturated flow direction or reach the surface. Insufficient capacity can also cause lateral movement of water, which may affect nearby water supplies or water bodies or cause effluent breakout on slopes in the vicinity. Practitioners and stakeholders must be informed of the issues so they will be able to complete the proper investigations and evaluations. Most critical is evaluation of the potential for reduction of the vadose zone thickness, which could result in inadequate retention times and conditions for treatment of wastewater pollutants.”

“This report presents a methodology for:

- ◆ “Evaluation of site-conditions and system-design influences on the potential for groundwater mounding and lateral spreading”
- ◆ “Selection of investigation techniques and modeling approaches based on site conditions, system parameters, and the severity of the consequences of excessive mounding”

“A flow chart and decision-support tool are provided to determine the strategy-level for site investigation and model evaluation depending on the potential for groundwater mounding and the consequences should it occur. Characterization activities and modeling approaches appropriate for each level of assessment are delineated.”

A.2 Phosphorus Geochemistry in Septic Tanks, Soil Absorption Systems, and Groundwater

Authors: Lombardo, P.; Robertson, W.; Mehrotra, A.; Ptacek, C.; Blowes, D.

Year: Submitted

Abstract: “Although phosphorus is an essential nutrient for plant growth, excess phosphorus in aquatic ecosystems may result in water quality degradation due to excessive algae growth. Whereas there exists a substantial body of knowledge with respect to phosphorus removal in subsurface wastewater soil absorption systems, there are gaps in understanding and applying this knowledge to actual situations. The objective of this handbook is to document the current understanding of phosphorus geochemistry. Specifically, the handbook details phosphorus chemistry and removal in septic tanks and soil absorption systems (SAS). In addition, the fate of phosphorus in the groundwater below soil absorption systems is addressed. The information in this handbook is designed to provide guidance on phosphorus removal processes in the subsurface to professionals involved in planning, design, construction, management, and regulation of decentralized wastewater management systems.”

“Wastewater phosphorus is present in various forms, each of which behaves differently in septic tanks, the biomat portion of soil absorption systems, the vadose zone, and the groundwater zone. In order to understand phosphorus removal in these systems and in the subsurface environment, basic phosphorus geochemistry must be understood. Phosphorus chemistry in wastewater treatment systems is governed by physical, chemical and/or biological processes. Mineral precipitation and adsorption mechanisms dominate phosphorus removal in septic tanks, soil adsorption zones, and the subsurface environment.”

“Phosphorus removal in septic tanks is largely due to particle settling, although some chemical precipitation also occurs. Approximately 20-30% of wastewater phosphorus is removed in septic tanks. Phosphorus removal in SAS is primarily achieved by mineral precipitation. Research suggests that the dominant phosphorus minerals in SAS are iron and aluminum precipitates, the stability of which is influenced by pH, redox conditions, and the chemistry of aluminum and iron. The vadose zone in soil absorption systems retains a variable amount of phosphorus (23-99%). The characteristics of the soil, wastewater, and site influence the degree to which phosphate is retained in the vadose zone. The phosphate concentrations that occur in groundwater appear to be strongly affected by attenuation reactions that are focused in the "rapid transformation zone" immediately underlying the SAS infiltration pipes. Further, adsorption processes are important for determining the rate at which phosphorus migrates through groundwater. “

“Research priorities to further the understanding of phosphorus geochemical processes are presented and consist of:

- ◆ “Further microscale plume assessment
- ◆ “Development of standardized methodologies for assessing transport at the microscale
- ◆ “Behavior at the groundwater-surface water interface and other "hotspots"
- ◆ “Site indexing for vulnerability”

A.3 Micro-Scale Evaluation of Phosphorus Management: Alternative Wastewater System Evaluation

Author: Etnier, C.; Braun, D.; Grenier, A.; Macrellis, A.; Miles, R.J.; White, T.C.

Year: 2005

Abstract: “Nutrient enrichment is a leading cause of water quality impairment in the waters of the United States, and wastewater inputs are a source of phosphorus pollution in aquatic ecosystems. Although there has been considerable focus on reduction of phosphorus in effluent from public wastewater treatment plants in the U.S., the environmental impacts of onsite wastewater treatment systems have received much less attention.”

“Understanding and managing sources of phosphorus pollution in the landscape necessitates evaluating and minimizing the phosphorus contribution from onsite systems to surface waters. Many phosphorus management methods have been proposed and/or tested for use in decentralized wastewater treatment. This handbook includes information about the application, performance, cost-effectiveness, and other factors associated with each technology. In keeping with the "soft path" approach to wastewater treatment, a range of phosphorus management technologies was investigated, including source reduction, source diversion, septic tank treatment, secondary treatment technologies, and soil absorption system design. Each alternative was evaluated using a set of criteria including removal capability, cost, system robustness, secondary benefits, maintenance requirements, and familiarity to the user.”

“Methods that improve the soil absorption system's ability to remove phosphorus were the top three methods evaluated, and five of the most promising methods involved the soil absorption system. Microflush toilets also scored high in the evaluation. These toilets can divert a significant percentage of the phosphorus in domestic wastewater, and also greatly reduce the nitrogen and organic matter content of the remaining wastewater. Their high life-cycle cost, however, may be a significant barrier in some areas. Source reduction strategies, including use of low-phosphorus detergents and elimination of in-sink garbage disposals, were also among the top methods evaluated. Only one post-septic tank medium (Filtralite[®]) was ranked among the most promising phosphorus management methods, although two other methods (Phosphex[™] and PhosRID[™]) show excellent potential in pre-commercial development and testing.”

“Ten research and demonstration needs were identified and prioritized, building on the most promising methods identified and on those methods identified as having the greatest potential to manage phosphorus, regardless of other factors.”

A.4 Performance of Engineered Treatment Units and their Effects on Biozone Formation in Soil and System Purification Efficiency

Authors: Van Cuyk, S.; Siegrist, R.; Lowe, K.; Drewes, J.; Munakata-Marr, J.; Figueroa, L.

Year: 2005

Condensed abstract: “The research described in this report investigated the field performance of onsite wastewater systems (OWSs) using engineered treatment units followed by soil treatment. The goal of this type of OWS is to enable higher—or equivalent—performance at higher hydraulic loading rates (HLRs) and/or less unsaturated soil depth. Field experiments were completed on three types of treatment units: a septic tank alone, a septic tank followed by a textile filter unit (TFU), and a septic tank with a membrane bioreactor (MBR). Each treatment train ended in a WSAS in Ascalon sandy loam.”

Among the conclusions from the research:

- ◆ “The effluents generated by the septic tank, TFU, and MBR units, after a period of start-up operations, were consistent in quality for each unit.
- ◆ “As expected, the three treatment units achieved different treatment efficiencies for organic matter, solids, nutrients, and bacteria. The relative efficiency ranking shows: septic tank effluent (STE) << TFU << MBR.
- ◆ “The relative ranking for operational complexity, operation and maintenance requirements, energy use, and cost, followed a similar pattern: STE << TFU << MBR.
- ◆ “The treatment trains including a TFU or MBR...are less affected by HLR than the treatment train based on only STE and soil treatment. The overall performance of the treatment trains with a TFU or MBR is relatively better with 60 cm of soil. Increasing the vadose zone soil depth (for example, from 60 cm to 120 cm) tends to shrink the differences in performance between the three treatment trains.
- ◆ “The results of bromide tracer tests and infiltration rate measurements and modeling reveal that some degree of soil clogging and biozone formation is occurring in the Ascalon sandy loam soil, even with higher-quality effluents applied.
- ◆ “The ability of an Ascalon sandy loam soil to remove viruses was quite high and insensitive to whether the natural soil had received STE, TFU effluent, or MBR effluent at either 2 or 8 cm/d. The results of bromide tracer tests, infiltration rate measurements, and modeling reveal that some degree of soil clogging and biozone formation is occurring in the soil, even with higher quality effluents applied. In addition, viruses are effectively removed (removal in soil of about 6-logs). These results refute that virus removal in soils receiving high-quality effluents might be diminished due to the absence of a classic biozone resulting from the low levels of tBOD and TSS applied.
- ◆ “During this project, a major field experiment was established and operations were initiated, yielding an array of treatment unit operations and performance data over a period of approximately six months (April to October 2004). This research duration has provided valuable insight concerning the startup and early operation and performance of an OWS, but a longer period of monitoring and assessment is needed to develop long-term data and provide greater insight relevant to full-scale system operation.”

A.5 Organic Wastewater Compounds, Pharmaceuticals, and Coliphage in Groundwater Receiving Discharge from Onsite Wastewater Treatment Systems near La Pine, Oregon: Occurrence and Implications for Transport

Authors: Hinkle, S.R.; Weick, R.J.; Johnson, J.M.; Cahill, J.D.; G. Smith, S.; Rich, B.J.

Year: 2005

Abstract: “This project involved documenting the occurrence of organic wastewater compounds (components of ‘personal care products’ and other common household chemicals), pharmaceuticals (human prescription and nonprescription medical drugs), and coliphage (viruses that infect coliform bacteria and that are found in high concentrations in municipal wastewater) in onsite wastewater (septic tank effluent). These contaminants were also documented in a shallow, unconfined, sandy aquifer that serves as the primary source of drinking water for most residents near La Pine, Oregon. Samples from two types of observation networks provided basic occurrence data for onsite wastewater and downgradient groundwater. One observation network was a group of 28 traditional and innovative (advanced treatment) onsite wastewater treatment systems and associated downgradient drainfield monitoring wells,

referred to as the innovative systems network. The drainfield monitoring wells were located adjacent to or under onsite wastewater treatment system drainfield lines. Another observation network, termed the transect network, consisted of 31 wells distributed among three transects of temporary, stainless-steel screened, direct-push monitoring wells installed along three plumes of onsite wastewater. The transect network, by virtue of its design, also provided a basis for increased understanding of the transport of analytes in natural systems.”

“Coliphage were frequently detected in onsite wastewater. Coliphage concentrations in 101 samples of raw and treated onsite wastewater were highly variable, and ranged from less than 1 to 3,000,000 plaque forming units per 100 milliliters (PFU/100 mL). Coliphage were occasionally detected at low concentrations in samples from wells located downgradient from onsite wastewater treatment system drainfield lines (eight occurrences among 110 samples). However, coliphage concentrations were below method detection limits in replicate or repeat samples collected from the eight sites. The consistent absence of coliphage detections in the replicate or repeat samples is interpreted to indicate that the detections reported for groundwater samples represented low-level field or laboratory contamination, and it would appear that coliphage were effectively attenuated to less than 1 PFU/100 mL over distances of several feet of transport in the La Pine aquifer and (or) overlying unsaturated zone.”

“Organic wastewater compounds were frequently detected in onsite wastewater. Of the 63 organic wastewater compounds in the analytical schedule, 45 were detected in the 21 samples of onsite wastewater. Concentrations of organic wastewater compounds reached a maximum of 1,300 µg/L (p-cresol). Caffeine was detected at concentrations as high as 320 µg/L. Fourteen of the 45 compounds were detected in more than 90% of onsite wastewater samples. Fewer (nine) organic wastewater compounds were detected in 51 groundwater samples, despite the presence of nitrate and chloride likely from onsite wastewater sources. The nine organic wastewater compounds that were detected in groundwater samples were:

- ◆ Acetyl-hexamethyl-tetrahydro-naphthalene (AHTN)
- ◆ Caffeine
- ◆ Cholesterol
- ◆ Hexahydrohexamethyl-cyclopentabenzopyran
- ◆ N,N-diethyl-meta-toluamide (DEET)
- ◆ Tetrachloroethene
- ◆ Tris (2-chloroethyl) phosphate
- ◆ Tris (dichloroisopropyl) phosphate
- ◆ Tributyl phosphate”

“Frequent detection of household-chemical type organic wastewater compounds in onsite wastewater provides evidence that some of these organic wastewater compounds may be useful indicators of human waste effluent dispersal in some hydrologic environments. The occurrence of organic wastewater compounds in groundwater downgradient from onsite wastewater treatment systems demonstrates that a subgroup of organic wastewater compounds is transported in the La Pine aquifer. The consistently low concentrations (generally less than 1 µg/L) of organic wastewater compounds in water samples collected from wells located no more than 19 feet from drainfield lines indicates that the reactivity (sorption, degradation) of this suite of organic wastewater compounds may limit their usefulness as tracers of onsite wastewater discharged into aquifers.”

“Groundwater samples from one of the three groundwater transects, along with one sample from the onsite wastewater treatment system associated with that transect, were analyzed for a suite of 18 pharmaceuticals. Eight pharmaceuticals were detected in the onsite wastewater at concentrations up to about 120 µg/L (acetaminophen). In downgradient groundwater samples, sulfamethoxazole (an antibacterial), acetaminophen (an analgesic), and caffeine (a stimulant, and not a medical drug) each were detected once, at concentrations between 0.10 µg/L and 0.18 µg/L—typical of the range of concentrations observed in other studies of wastewater-impacted groundwater. In addition to the readily identified pharmaceuticals, two pharmaceuticals—the anticonvulsant drugs primidone and phenobarbital—were tentatively identified in three groundwater samples from one nest of wells at another transect. Tentative identification of primidone and phenobarbital occurred during analysis of groundwater samples for organic wastewater compounds; chromatogram peaks not associated with the target organic wastewater compounds were observed and the mass spectra of the unidentified compounds were matched to known mass spectra in a mass spectral reference library. Estimated concentrations reached as high as 12 µg/L (primidone). As was the case with organic wastewater compounds, the pharmaceutical occurrence data indicate that some pharmaceuticals may be useful indicators of the presence of human waste in the environment, and a subset of pharmaceuticals is transported to groundwater from onsite wastewater treatment systems.”

A.6 Quantifying Site-Scale Processes and Watershed-Scale Cumulative Effects of Decentralized Wastewater Systems

Authors: Siegrist, R.L.; McCray, J.; Weintraub, L.; Chen, C.; Bagdol, J.; Lemonds, P.; Cuyk, S. Van; Lowe, K.; Goldstein, R.; Rada, J.

Year: 2005

Abstract: “The research described in this report was undertaken to enhance the quantitative understanding of site-scale processes affecting the performance of onsite wastewater systems (OWS) and to develop modeling tools that can describe and predict individual system performance and the cumulative effects of multiple systems on water quality within a watershed.”

“A major focus of this project was on refinement, application, and testing of an existing watershed-scale model, Watershed Analysis Risk Management Framework (WARMF), which has been modified to include explicit representation of OWS of different performance features, an integrated Biozone Algorithm, and cumulative frequency distributions for source concentrations and transport/fate parameters.”

“In addition to the work with WARMF, the BASINS/SWAT model was setup, calibrated and applied to the Dillon Reservoir watershed. Compared to WARMF, the BASINS/SWAT model does not explicitly account for OWS, is less efficient in running scenario analyses, and does not include modules for TMDL analysis and stakeholder consensus building. In terms of setup and application to a given watershed, both models require considerable resources either in the form of the upfront purchase price for a setup and calibrated model (WARMF) or for the consultant or in-house labor costs to setup, calibrate, and run a public domain model (BASINS/SWAT).”

“The environmental monitoring and subsurface characterization efforts of this project were focused on developing sufficient understanding of the Dillon Reservoir watershed to

enable model setup and initial calibration. The water quality monitoring was focused on surface water flow and quality at up to 20 monitoring locations in the watershed. Quality data include routine water quality parameters, wastewater-related pollutants, and some chemical and biological tracers. In performing the characterization work we attempted to use limited and potentially uncertain data and to assess the reliability of that approach.”

“At the watershed-scale in the Dillon Reservoir watershed, compared to urbanized development and WWTP discharges, OWS are not a principal source of water pollutants as evidenced by:

- ◆ “Source load mass balance calculations”
- ◆ “WARMF and BASINS/SWAT model simulation results”
- ◆ “Water-quality monitoring and analysis of spatial and temporal trends”

“Application of a watershed-scale decision-support tool such as WARMF can enable analysis of wastewater management scenarios and provide critical insight into the water-quality benefits of one management option compared to another. Based on WARMF simulations of different wastewater management scenarios in the Blue River basin, extending central sewers and conversion of OWS to a central WWTP appears to offer little or no benefit in terms of water-quality protection, and in some cases may lead to water-quality degradation.”

Recommendations:

- ◆ “A need remains for quantitative understanding to enable proper OWS design to yield a desired performance level. Such understanding also enables the design and implementation of monitoring devices and methodologies for process control and performance assurance.”
- ◆ “The biozone algorithm developed for WARMF is recommended to be further tested and refined.”
- ◆ “Incorporation of a virus constituent into WARMF based on the knowledge gained during this study with respect to reaction rates and transport mechanisms would be valuable.”
- ◆ “The benefits gained from this project’s decision support should be documented and used to assess the benefit/cost of quantitative decision-support such as reported herein.”
- ◆ “The methods and tools developed in this project should be applied and tested for other situations and environmental conditions to determine the extent of extrapolation possible. The components of the work most valuable to enabling application to another geographic region of the U.S. for watershed-scale management would include WARMF model refinement, setup, calibration and simulations, and environmental characterization and watershed monitoring.”
- ◆ “Depending on the goals of the research during a similar project in another region of the U.S., additional site-scale testing and experimentation (to generate site-specific input data and algorithms for modeling) might also be warranted.”

A.7 Application of Simulation-Optimization Methods for Management of Nitrate Loading to Groundwater from Decentralized Wastewater Treatment Systems near La Pine, Oregon

Authors: Morgan, D.S. and Everett, R.

Year: 2005

Abstract: “The objective of this project was to develop and demonstrate a method to estimate the optimal loading of nitrate from decentralized wastewater treatment systems to an aquifer. The method utilizes a simulation-optimization approach in which a nitrate fate and transport simulation model is linked to an optimization model. Using this method, maximum (optimal) sustainable loading rates that meet constraints on groundwater quality and nitrate loading to streams via groundwater discharge can be determined. This method enhances the value of a simulation model as a decision-support tool in developing performance-based standards for onsite systems that will protect the quality of groundwater resources.”

“The method was demonstrated in conjunction with the National Onsite Demonstration Project (NODP) in the community of La Pine in southern Deschutes County, Oregon. The La Pine NODP has developed an extensive knowledge base on the hydrogeology of the shallow groundwater system, dynamics of nitrogen fate and transport, and performance of standard and new technologies for onsite wastewater treatment in this setting. One of the many products of the NODP was a nitrate fate and transport simulation model that could be used to test the optimization approach.”

“The La Pine nitrate loading management model (NLMM) was developed by linking the simulation model to an optimization model using the response-matrix technique. The NLMM was used to determine the minimum nitrate loading reductions that would be required in 97 management areas to meet specified water-quality constraints. Constraints can be set on groundwater nitrate concentration, discharge of nitrate to streams, and maximum or minimum loading reductions in management areas. Minimum loading reductions are determined for existing and future onsite systems. Cost factors can be applied to the optimization if the cost of reducing loading favors reductions for existing or future homes. The NLMM was used to perform trade-off analyses on the cost in terms of increased loading reductions required to meet more stringent water quality criteria. The role of the NLMM in the planning process for La Pine, Oregon, as well as considerations for application of the optimization method to other areas are described.”

A.8 Application of a Risk-Based Approach to Community Wastewater Management: Tisbury, Massachusetts

Authors: Heigis, W.S.; Douglas, B.; Hoover, M.; Luttrell, D.; and Etnier, C.

Year: 2002

Project Summary: “Tisbury is located on the northwestern tip of the island and is largely rural with a population center in the village of Vineyard Haven. Wastewater is treated onsite or in cluster systems. The town voted in October 1998 to adopt a community wastewater management plan for these decentralized systems. In July 1999, the town finalized the community wastewater management plan and made it compatible with the town's previously-planned Vineyard Haven Wastewater Project. In August 2000, the town received a grant from the National Decentralized Water Resources Capacity Development Project (NDWRCDP) to

assist with implementation of the wastewater management program. Six steps were taken to implement this program:

1. “Perform a risk assessment through delineation of environmentally sensitive areas in the community, conduct nitrogen-loading studies, and develop growth projections.”
2. “Develop a risk-based water quality protection matrix through public workshops and information sessions.”
3. “Define risk-based wastewater management districts in Tisbury.”
4. “Install and use a computer database to track on-site system installations, upgrades, and maintenance.”
5. “Institute a long-term maintenance program for on-site systems. For each system, the program will include a schedule for initial inspection, regularly scheduled follow-up inspections, function checks, and pumpouts.”
6. “Expand availability of loans to system owners for wastewater treatment system upgrades.”

A.9 Evaluation of Chemical and Biological Indicators for Source Apportionment of Phosphorus in Table Rock Lake, on the Missouri-Arkansas Border

Authors: Angenent, L.T.; Ramaswami, B.; Dryden, S.; Falke, S.F.; Yuan, Z.; Giammar, D.E.
Year: 2006

Abstract: “Phosphorus contamination of surface waters from point and nonpoint sources remains an environmental problem of great concern. This project evaluated chemical and biological species as potential indicators of specific phosphorus source types. Evaluation of a suite of chemical and biological species was performed through field sampling and laboratory analysis. Samples were collected from potential sources and in the near-field of sources to determine whether the source profiles were apparent in the receiving water. This project was conducted at the Table Rock Lake watershed on the Missouri-Arkansas border. A geospatial information systems (GIS)-based multicriteria decision analysis was used to choose sampling locations in Table Rock Lake to capture the influence of discharges from wastewater treatment plants and septic systems and runoff from animal feeding operations. A suite of chemical species was evaluated for potential indicators. The following are requirements of useful indicators.”

- ◆ “Presence in the receiving waters at detectable concentrations”
- ◆ “Uniqueness of source signatures”
- ◆ “Consistent concentration ratios of potential indicators to phosphorus”

“Almost all of the chemical species, except for synthetic organic compounds (SOCs), met the requirement of having detectable concentrations. Bromide was a unique indicator of large wastewater treatment plants (WWTPs). No other chemical species observed could be used as unique indicators of other sources. However, nickel and copper can potentially be used as indicators of septic system effluents. Sulfate can potentially be used as an indicator of WWTPs for receiving waters with larger proportions of water from these source types. No chemical species observed had consistent concentration ratios to phosphorus for all sources and seasons due to the high variation of phosphorus concentrations for the three septic systems and a small WWTP.”

“Coliphages were evaluated as potential biological indicators for wastewater input from human and nonhuman origins. A reverse transcriptase polymerase chain reaction (PCR) technique was used to identify bacteriophages, and traditional methods were used to quantify bacteriophages. This study shows that F+ RNA phages can be used as biological indicators of fecal pollution; however, these phages cannot be used to distinguish between human and nonhuman sources because nonhuman bacteriophages were present in sources of human fecal pollution. Phages also cannot be used for phosphorus source apportionment because there was no statistically significant correlation between phage numbers and total phosphorus concentrations. Seasonal effects on bacteriophage presence were found, as winter samples contained the highest concentration of coliphages, while fall and spring samples contained the lowest.”

A.10 Integrated Risk Assessment for Individual Onsite Wastewater Systems

Author: Jones, D.S.; Efroymson, R.A.; Armstrong, A.Q.; Muhlheim, M.D.; Carnes, S.A.
Year: 2004

Condensed Abstract: “The primary objective of a project completed by Oak Ridge National Laboratory in 2004 was to develop an approach to risk-based decision making for individual onsite wastewater treatment systems (Jones, Efroymson, et al., 2004). The framework of this approach integrated engineering, public health, ecological, and socioeconomic risk analyses. The three stages of risk assessment were used to structure the framework: problem formulation (a planning process), analysis of site-specific exposure and effects, and risk characterization.”

“The engineering risk assessment component framework makes use of Failure Modes and Effects Analysis to address the issues specific to the design and performance of the OWT system of interest. The public health risk assessment component framework is used to evaluate potential health risks from exposure to wastewater effluent or environmental media that have come in contact with wastewater effluent. The human health property evaluated as the result of exposure to chemicals is systemic toxicity (non-carcinogenic effects). The microbial assessment endpoint evaluated in this public health framework is risk of infection.”

“The ecological component framework is used to evaluate the potential adverse impacts on non-human biota and ecosystems. Two types of surface water ecosystems are distinguished based on differences in prevailing nutrient dynamics: freshwater systems (for example, ponds) and estuarine systems (for example, coastal lagoons). The socioeconomic component framework is used to evaluate potential socioeconomic impacts and risks from exposure to wastewater effluent or environmental media that have come in contact with wastewater effluent, and efforts to manage those effluents with an OWT system. The socioeconomic component addresses many issues that are typically part of the risk-management process.”

Significant data gaps and opportunities for future research were identified during this project that may be relevant to definition of research needs within ES&E:

For improving assessment of engineering risks:

- ◆ “Failure rates for OWT system components under a wide range of real-world conditions (as opposed to certification test results) over extended periods of operation”
- ◆ “System performance information that has been collected in a way that supports development of continuous failure rates”

- ◆ “Additional relationships between performance of wastewater soil absorption systems and changes in environmental conditions (such as seasonal changes in precipitation and in the separation from the water table)”

For improvement of public health risk assessments:

- ◆ “Dose/response information to support quantitative microbial risk calculations”
- ◆ “Viral dose/response models and rates of human infectivity”
- ◆ “Information on survival of viral particles in the environment”
- ◆ “Environmental fate and transport of microbial pathogens”

For conducting assessments of risks to ecological receptors:

- ◆ “Field studies of amphibians in wet soils, ponds, streams, and other areas around septic tanks versus control areas”
- ◆ “Studies to develop relationships between multiple stressors and effects on various aquatic trophic levels”
- ◆ “Improved technologies for remote sensing of nutrients, phytoplankton, and sea grass area and condition”

A.11 Variability and Reliability of Test Center and Field Data: Definition of Proven Technology from a Regulatory Viewpoint

Authors: Groves, T.W.; Bowers, F.; Corriveau, E.J.; Higgins, J.J.; Heltshe, J.F.; Hoover, M.T.
Year: 2005

Abstract: “A consortium of environmental agencies concerned with the quality and relationship of test center data to real world data for alternative onsite technologies recently completed a project comparing test center data to real-world field performance data. The goals of this research were:

- ◆ “To develop a statistical and sound scientific relationship between test center data and actual field data of installed alternative technology onsite wastewater treatment systems”
- ◆ “To develop a decision support system to help regulators evaluate the quality and quantity of data submitted for regulatory decisions”

“The study included the evaluation of three different alternative onsite technologies that had ample test center and field data sources. Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) data from National Sanitation Foundation (NSF) International Standard 40 evaluations, Environmental Technology Verification (ETV) projects, National Onsite Demonstration Projects (NODP), and data collected by regulatory agencies and vendors was assembled and reviewed to eliminate duplicate samples, samples from non-residential facilities, and others.”

“Datasets for each system were analyzed statistically using appropriate models. The statistical analysis concluded that the variability associated with test center data was significantly less than the variability of data collected from real world situations. Therefore, the two data distributions are dissimilar and one data distribution set (such as test or field) cannot be used to accurately predict the other. Since the test data distribution cannot predict the field data distribution, if time or funding is limited it is probably best to sample as many sites as

possible on a random basis for a few samples rather than to thoroughly evaluate a small number of locations for an extended period of time. The validity of these conclusions was not evaluated for parameters other than BOD and TSS.”

“Additionally, a Decision Support System (DSS) tool was developed to help regulators evaluate all sources of data (including test center and field data) to determine the field performance of a technology and guide the regulatory and manufacturing communities on the amount and quality of data needed to accept a technology as “proven.” The DSS consists of a series of spreadsheets, examples, and documents that guide the user through the ranking of study types, weighting factors, and performance for a stated end-goal. The ideal use of the DSS is as a support tool for regulators making decisions on the evaluation of technology. This is best done by using a multi-reviewer expert panel approach that includes both scientists and regulators. At the end of the project period, the DSS had not been applied to any real world cases.”

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Alabama

Montgomery Water Works & Sanitary Sewer Board

Alaska

Anchorage Water & Wastewater Utility

Arizona

Glendale, City of, Utilities Department
Mesa, City of
Peoria, City of
Phoenix Water Services Dept.
Pima County Wastewater Management
Safford, City of

Arkansas

Little Rock Wastewater Utility

California

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Corona, City of
Crestline Sanitation District
Delta Diablo Sanitation District
Dublin San Ramon Services District
East Bay Dischargers Authority
East Bay Municipal Utility District
Eastern Municipal Water District
El Dorado Irrigation District
Fairfield-Suisun Sewer District
Fresno Department of Public Utilities
Inland Empire Utilities Agency
Irvine Ranch Water District
Las Virgenes Municipal Water District
Livermore, City of
Los Angeles, City of
Los Angeles County, Sanitation Districts of
Napa Sanitation District
Orange County Sanitation District
Palo Alto, City of
Riverside, City of
Sacramento Regional County Sanitation District
San Diego Metropolitan Wastewater Department, City of
San Francisco, City & County of
San Jose, City of
Santa Barbara, City of
Santa Cruz, City of
Santa Rosa, City of
South Bayside System Authority
South Coast Water District
South Orange County Wastewater Authority

Stege Sanitary District
Sunnyvale, City of
Union Sanitary District
West Valley Sanitation District

Colorado

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Boulder, City of
Greeley, City of
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Metro Wastewater Reclamation District, Denver

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Greater New Haven WPCA
Stamford, City of

District of Columbia

District of Columbia Water & Sewer Authority

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Fort Lauderdale, City of
Miami-Dade Water & Sewer Authority
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Reedy Creek Improvement District
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St. Petersburg, City of
Tallahassee, City of
Tampa, City of
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West Palm Beach, City of

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Clayton County Water Authority
Cobb County Water System
Columbus Water Works
Fulton County
Gwinnett County Department of Public Utilities
Savannah, City of

Hawaii

Honolulu, City & County of

Idaho

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Wheaton Sanitary District

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Iowa City

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Kansas City, City of

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Sanitation District No. 1

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Howard County Department of Public Works
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Butler County Department of Environmental Services
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Metropolitan Sewer District of Greater Cincinnati
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Tulsa, City of

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Albany, City of
Clean Water Services
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Authority

Washington

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King County Department of
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Yakima, City of

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Sewerage District

Kenosha Water Utility

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Wastewater Treatment

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Corporation

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San Francisco, City & County of
Santa Rosa, City of
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Colorado

Aurora, City of
Boulder, City of

Georgia

Griffin, City of

Iowa

Cedar Rapids Wastewater
Facility

Des Moines, City of

Kansas

Overland Park, City of

Kentucky

Louisville & Jefferson County
Metropolitan Sewer District

Maine

Portland Water District

North Carolina

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Stormwater Services

Pennsylvania

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Management

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District, Texas

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& Environment

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