Creating a Sustainable Water Infrastructure for the 21st Century

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September 28, 2009

WorrellWater TECHNOLOGIES

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Executive Summary

Water and energy are fundamental resources in the human economy as well as in natural ecosystems. Since the time of the Romans, economic growth has been accompanied by increasing centralization of large scale water and energy infrastructure networks. Centralization of these water systems is passing the point of diminishing returns; continuing to attempt to meet water needs only with these systems is unsustainable in today's economy.

Today, the advocacy for a new 'green' economy has been predominantly focused on energy, but water needs to be elevated to the same level. For continued economic strength in the 21st Century and a solution to our dwindling water supply, we need an ecological, decentralized approach to water infrastructure that applies the best of technology to work with nature's principles to create a renewable, sustainable water cycle.[1]

This paper illustrates an approach to this more sustainable, natural and decentralized water infrastructure by using the example of wastewater treatment technology. Wastewater rarely receives the attention given energy and drinking water as crisis issues; however, cost-effective solutions to the wastewater problem are essential for the health of the economy, the environment and the public, and can also contribute significantly to solving our energy and drinking water challenges.

Using natural systems as our guide, we can build on and transform the existing, outdated wastewater treatment system. New, advanced technology and ecological engineering concepts and methods can regenerate nature's approach of decentralized water treatment cycles and begin to integrate natural and human ecosystems into mutually supporting cycles. This integration offers a strategy to simultaneously serve environmental strength and human economic and health needs.

[1] Leading professionals and community leaders are taking these approaches into practice. See for example the report by The Aspen Institute on Sustainable Water Systems (www.aspen.org), and Philadelphia's announced stormwater plan (www.philly.com).

Water Infrastructure

Water issues are surfacing with such frequency that the concerns of water professionals are becoming widely shared by businesses, government policy makers, and the general public. At the same time, this attention is usually focused on specific local issues, leading to individually targeted fixes. Stepping back for a more comprehensive view allows the development of a framework to help identify appropriate local solutions that also fit into the larger context of national and regional energy, environmental, and economic strategies.

This larger context allows us to see that the current conceptual approach is becoming less successful in addressing the problems we face. The current approach, with some exceptions, is focused on large-scale, centralized systems, using water once before sending downstream, and treating all water to drinking standards regardless of intended use. In many areas, this approach requires moving water long distances, with obvious high consumption of energy, and using treatment technologies that also are large energy consumers and large generators of greenhouse gas emissions (GHG). Many scientists, engineers, and community leaders are now aware that continuing this approach to water infrastructure can't deliver the quality, quantity and consistency of water we currently consume, much less meet the demands of the future.

An alternative approach could apply an ecological model to wastewater infrastructure. This model can inform both the design of the infrastructure and of the treatment processes. The ecological model is based on more decentralization, integration with local economic and ecosystem needs, local water reuse, and adaptation of ecological water treatment processes. The technologies and concepts necessary for the ecological model are being tested, demonstrated, and put into practice in a wide variety of applications. This paper advocates a broader recognition and application of this new approach and outlines key steps to develop the conceptual and design tools, technical standards, and professional rigor necessary for widespread adoption as standard practice.

Background

The massive problems facing water and wastewater infrastructure and the limitations of current approaches to the problem are the subject of a growing body of reporting and documentation. Some recent highlights summarized below indicate that the problems are systemic.

Inadequate Infrastructure

Illustrated by a number of failures including water main breaks, combined sewer overflows, and sewage spills, infrastructure is unavoidably deteriorating and in dire need of upgrading. In addition, areas of rapid growth are encountering limits to the capacity of sewer collector and interceptor piping. Treatment plants themselves are often overloaded and unable to adequately treat the concentrations of pollutants that are coming in to them.

According to EPA's Sustainable Water Infrastructure Initiative:

- Our water and wastewater infrastructure is aging, with some components older than 100 years.
- 240,000 water main breaks per year in the U.S.
- Customer inconvenience and service disruptions are increasing.
- Our growing and shifting population requires investment for maintenance of existing systems and development of new systems.
- Collateral damage, such as the danger of water main breaks and the spread of waterborne diseases, costs private business and local government.
- Up to 75,000 Sanitary Sewer Overflows per year resulting in up to 5,500 annual illnesses due to exposures to contaminated recreational waters.
- 5-20% of energy expenditures on a state level are to transport water from sources to users, and back to treatment and dis charge facilities.
- Investment in research and development has declined as needs have increased. Plus, the prospects for continued large federal investment are limited.

According to the American Society for Civil Engineers (ASCE), not only does the U.S. water infrastructure receive a D- rating, but they estimate to upgrade the drinking and wastewater system would require a total investment of $255 billion; with estimated spending at $146.4 billion, there is a shortfall of $108.6 billion. (http://www.infrastructurereportcard.org/fact-sheet/wastewater)

Accelerating Demand

Replacing existing water infrastructure is just one part of the problem. Consumption of water is rapidly increasing, which is creating demands for additional treatment capacity and networks of pipes to move water to, and wastewater from, new areas. As reported in a recent Wall Street Journal "Parched State Searches for Ways to Expand Water Supply" (July 9, 2009), California is considering far-reaching approaches such as new canals, larger water storage and very stringent water conservation measures.

According to U.S. Department of Energy projections, the demand for energy and water resources worldwide is projected to grow at an alarming pace in 20 years, with demand for energy doubling and water tripling. To meet this water demand through conventional, centralized wastewater treatment will exact a huge cost when it comes to upgrading and building new water pipes, consumption of energy, and disruption of the environment.

Resource Limitations

Beyond deteriorating infrastructure and increasing demand, supplies are strained in many areas due to depletion of aquifers, pollution, and drought. Climate change forecasts indicate the potential of dangerous multiplier effects as droughts become more severe, rainfall becomes concentrated in fewer, more intense events, and higher temperatures increase water demand over a broad spectrum of industry, agriculture, and municipal uses. In recognition of this situation, the Intergovernmental Panel on Climate Change (IPCC) states that "water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change."

Western civilization grew based on the Roman model that provided public services by centralizing infrastructure. That model worked well when cities were smaller and energy was cheap, but now increasing centralization is becoming more costly and less efficient. Now it's time to rethink water infrastructure from the ground up.

The centralized model is a 'once through' model. Turn on the tap and good water is always there, but once used, it's thrown away down the sewer and moved downstream for treatment and release back into the environment. This wastewater travels long distances to a centralized wastewater treatment plant – hidden from public view for its unsightly appearance and offensive smell. Reuse of the water is usually too expensive because of the energy and infrastructure cost of moving large quantities of water back upstream.

Besides the inability to reuse the water, the treatment process itself is a source of environmental pollution. Conventional wastewater treatment uses large amounts of energy and chemicals and produces substantial quantities of greenhouse gas (GHG) emissions, odors, and hazardous waste (sludge) to be dried and disposed offsite.

The current model outlined in Figure 1 is complex, energy intensive, and water inefficient. While historically, it represented a great advance in public health and reduction of local pollution, the explosive growth in population and economic activity over the past century is overwhelming the ability of centralized systems to serve the need.

Limits are appearing that were unimaginable 100 years ago. For example:

- Water resources are declining in quality and quantity – the watershed hydrologic cycle is being outpaced by the once-through model of centralized treatment
- The capacity of receiving waters is being exceeded – the quantity of waste is so large in most places that dilution is no longer adequate.
- Maintenance and new construction costs are becoming intolerable – water systems are showing evidence of a basic principle of general systems theory: as size increases linearly, cost to grow and maintain the system tends to increase exponentially.

Simply put, our centralized water system is reaching the point of diminishing returns; resources have become constrained, and we can't safely dispose of the harmful by-products. We need to think about creating a smarter, more natural wastewater treatment system.

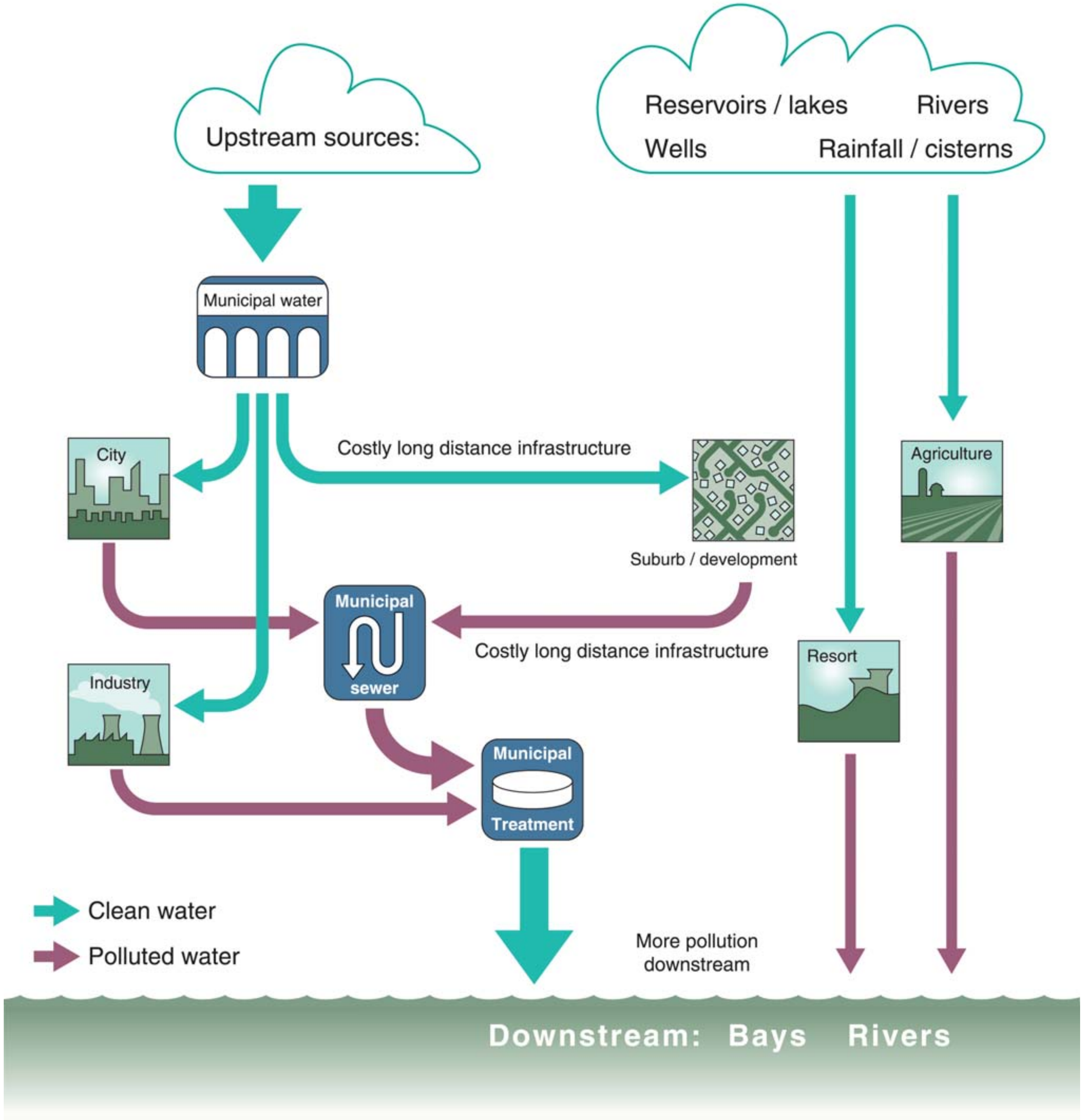


Figure 1: Where We Are Now: Centralized, Once Through Model

A new wastewater strategy must be put in place that is cost-effective, technically sound, and sustainable economically and ecologically. Such a strategy will include and maintain the best of the current systems and the tactics, such as water conservation, that have already been effective in stretching critical supplies by reducing demand growth. In addition, continued, reliable access to water requires the new approach to be resilient in the face of changing conditions and help deal with ongoing drought and water scarcity challenges.

Beyond being a well-conceived approach to providing water, the new water strategy must also contribute to addressing other interrelated issues such as energy, climate change, and economic strength. An ecologically based model of wastewater treatment infrastructure has the potential to meet all of these goals.

Ecological, Natural Wastewater Treatment Systems

Everything is fractal and decentralized in Nature. Resources are used and reused multiple times in close proximity, using low energy processes that minimize the need to transport materials over long distances. If one processing unit is damaged or destroyed, there are numerous back up units to continue the function and rebuild the lost capacity. Integrated strategies for wastewater treatment are available that can mimic that approach. They include decentralized, ecological treatment technology, local water reuse, and low impact development. With technologies such as these and others that can be developed, it will be possible to create a sustainable water system and re-couple the economy to natural cycles.

> **Ecological, decentralized treatment technologies** include a wide variety of measures that can be used individually and combined into a suite of strategies to create an integrated, decentralized water cycle. The best of these approaches use ecological systems design to help bring natural water processing and human water processing together, so that there is mutual benefit and support.
>
> These treatment technologies include such measures as Living Machine® systems (for black water and gray water), stormwater wetlands, gray water treatment systems, rainwater harvesting, AC condensate harvesting, onsite reuse, low impact development, water efficiency devices and practices, and other ecological water treatment and reuse technologies. These technologies are designed to treat and reuse the water close to the need, thereby saving infrastructure cost and disruption, reducing construction time, reducing energy cost of moving water, regenerating local water cycles, and reducing GHG and hazardous waste produced by centralized systems.

In the 1980s, a movement began to develop wastewater treatment systems that could mimic nature more closely and reduce the chemicals and by-products of traditional, centralized treatment plants. First generation approaches created a self-sustaining system much like we see in Nature’s wetland ecosystems. These systems can be more readily decentralized than conventional wastewater treatment technology because the natural approaches are aesthetically pleasing and not hazardous when closely integrated with human activity.

The continued development of these approaches paved the way for much improved systems as technology advances. The new systems have much smaller footprints, are more energy efficient, and have been designed to eliminate exposed wastewater surfaces, odors and hazardous by-products. The most advanced of those systems apply 21st Century technology to replicate and improve the performance of Nature's most productive ecosystem – the tidal estuary.

These "Tidal Flow Wetlands" speed up the natural processes by combining natural ecological processes with 21st Century engineering and controls so that the system is energy efficient, cost-effective, and reliable for wide-scale use. Applying advances in wetland science and engineering along with innovative technology, engineered tidal wetlands are now at the forefront of creating more natural, decentralized water treatment systems that can cleanse gray or black water in a wide variety of residential, commercial, industrial, and agricultural applications. These systems are described in Appendix 1.

A new approach to water systems for the 21st century begins with adapting the best of the current infrastructure and easing loads on it with upstream conservation and decentralized, ecological systems. Figure 2 shows an overview of this concept.

A new decentralized, more natural architecture can be designed to evolve from the current model. The evolution to this new model is already underway, but can be accelerated and improved if we recognize the value of this direction and adapt policies, design standards, engineering models and monitoring technologies, funding programs, and management structures to facilitate the transition.

Economic Value

The EPA Office of Water estimated that if capital investment and operations and maintenance costs remain at current levels, the gap in funding for 2000–2019 would be about $263 billion for our drinking water infrastructure and $270 billion for our wastewater infrastructure.

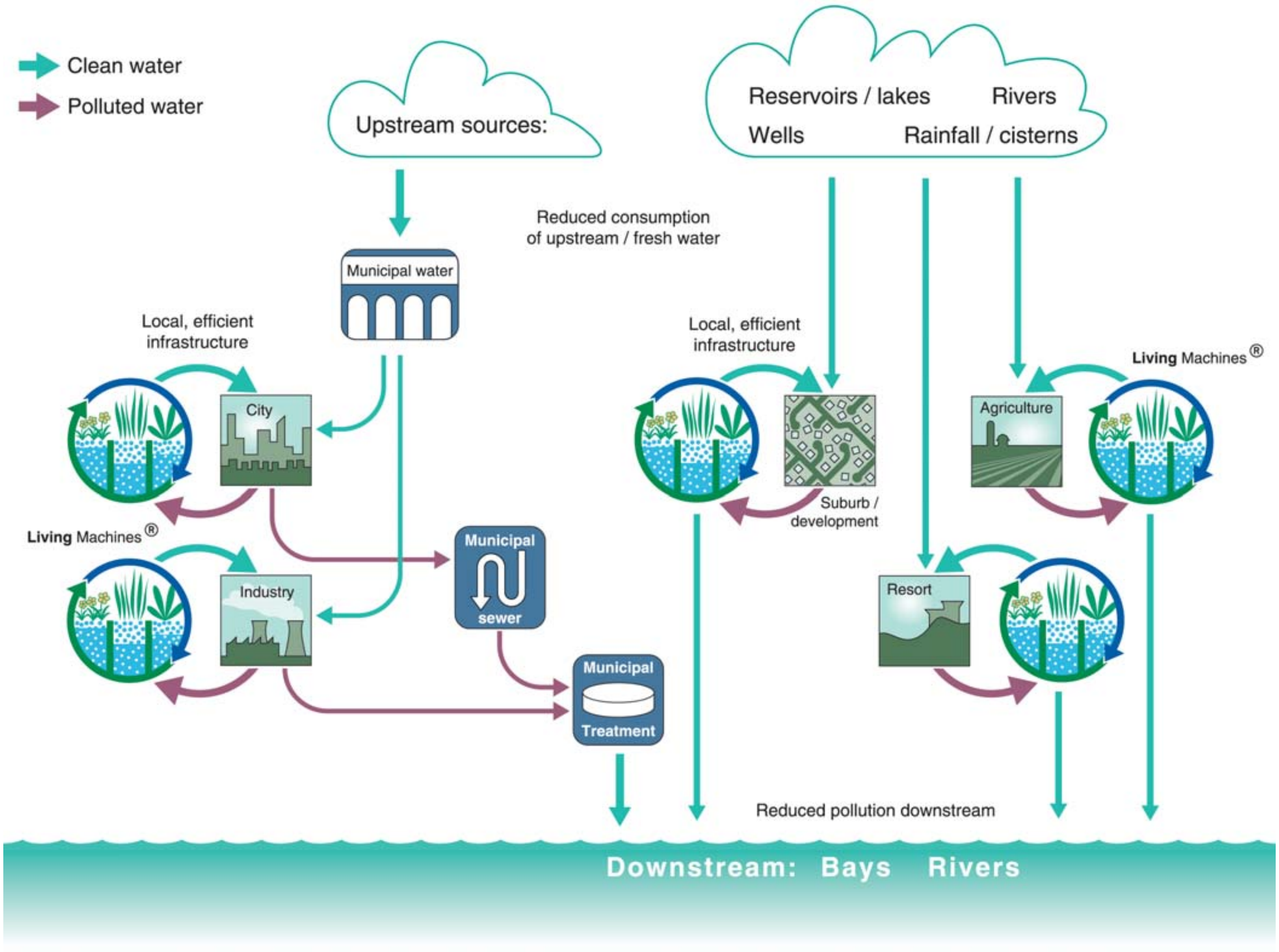


Figure 2: Where We Need to Be: Decentralized, Ecological, On-site Water Recycling Approach

However, there are a number of reasons to believe that the cost of the new decentralized, ecological model could be significantly lower, especially if based on life cycle costing, including:

- Reduced need for long distance piping, pump stations and associated infrastructure
- Better ability to meet demands as they arise, rather than having to build large systems with long lead times to handle forecasted future demand
- Reduced need for sludge drying and disposal in landfill areas
- Ability for dual use of land, thereby reducing the need for large tracts of land unusable for any other purpose
- Lower operating cost due to low energy and labor requirements compared to conventional systems
- Lower construction cost using local skills and materials for many of the technologies

Health and Environmental Value

Originally designed to improve health and the environment, the early successes of the centralized model are becoming eclipsed by larger scale negative effects on public health and the environment. These effects range from the dead zones at the mouth of major rivers, to large sewage spills, to downstream impacts on fish and human water supplies.

An ecological wastewater treatment model can positively impact our health environment by:

- Reducing the creation of sludge and other harmful by-products
- Reducing GHG emissions from construction and operation of the systems
- Reducing energy demands (many ecological treatment systems use only 10 to 25% of the energy required to operate a conventional system, and additional huge savings come from reducing the amount of water that has to be moved long distances)
- Producing high quality water (equal or better quality than conventional) available for local reuse, thereby conserving drinking water.
- Integrating human activity with the natural ecosystem.

Making the Transition

Municipalities and cities charged with providing water and public health services to their citizens are appropriately conservative; however, they are also on the front lines dealing with intractable water problems. Especially in water scarce areas of the country, most municipalities enforce strict, aggressive water conservation measures and increased water charges to ensure everyone has enough water. A transition to a decentralized, ecological wastewater system can be a natural evolution in response to crisis combining existing, functional systems with proven innovations in ecological treatment.

Strategies for the Transition

- <u>Rehabilitating and extending the life of critical infrastructure</u> – there is no question of the need to keep the existing systems working as well as possible for as long as economically feasible. The investment in these systems is a huge store of value that provides a framework upon which to build 21st Century infrastructure.

- Decentralizing new construction – focus the application of new ecological treatment systems in areas of rapid growth or failing existing treatment (e.g. septic systems), in regional networks as a means of avoiding expansion of a centralized plant and the interconnecting infrastructure, and as stand alone applications to serve specific needs.

- Enhancing local water cycles -- view the decentralized systems that are constructed as part of a regional natural and human ecosystem, so that the design of the wastewater treatment can help integrate natural water cycles with human and environmental needs. In some cases, it may be appropriate to undo or modify some of the existing infrastructure such as sewer mining to reuse water, removing water control structures, or restoring natural water channels.

- Enhance the basis of the local economy – water is the basis of economic activity as well as the basis of ecosystems and human existence. The design of wastewater treatment can be coupled with the creation of business opportunities and new jobs by involving community interests in planning of water reuse opportunities to optimize the creation and maintenance of livelihoods and locally productive economic activity.

Implementing the Concept

It's possible and appropriate to begin the transition to a decentralized, ecological wastewater treatment infrastructure within the context of existing policy, funding, and knowledge; however, we can multiply the effectiveness and accelerate the implementation of the ecological approach by pursuing parallel development of a new context. In particular, we need to reexamine and update policies, design standards, engineering models and analysis tools, monitoring and control technologies, funding programs, and management structures to support decision making and maintain quality and public health standards. These efforts are much too extensive to detail here, but the following areas need to be addressed:

- Policies – review of the laws and regulations governing water and public health to identify and remove unwarranted barriers to adapting innovative technologies to ensure that all technologies are competing on a level playing field. In addition, target government research efforts to developing new information and technology for ecological wastewater treatment systems.

- Design standards – technical examination and expansion of existing design standards by engineering societies and research organizations, or creation of new standards as necessary to ensure that there are clearly defined performance standards that protect public health and the environment, but also support innovation in ecological systems design.

- Engineering models and technologies – develop new analytical tools, information systems, construction techniques, remote monitoring and control methods, and performance tracking approaches that improve the ability to evaluate, design, build, and operate individual treatment systems as well as integrated regional wastewater ecosystems.

- Funding programs – examine government funding and grant programs to remove barriers, equalize subsidies, and provide a level playing field for funding decentralized, ecological treatment systems.

- Management structures – experiment with new ways of management, ownership, and operations of regional systems. For example, centralized management and ownership of decentralized systems by a municipality or regional authority may offer advantages in cost effectiveness, quality control, and coordination of treatment. In other cases, ownership by a cooperative or by a DBOO (design, build, own, operate) company could be appropriate.

Rather than pointing out difficulties of a transition to a decentralized, ecological wastewater treatment system, the complexity of the areas described above show the great potential for even more innovation than already exists. We know how to get started; then the innovative intellectual resources of the nation’s technical, business, and government organizations can build on that start at an exponential pace.

Summary:

More natural, ecologically-based water infrastructure can help solve major, paralyzing water supply issues in the most drought-stricken states and provide the basis for a 21st Century economy in tune with natural cycles. We need a comprehensive strategy, supporting the rehabilitation and life extension of current critical centralized infrastructure, reducing downstream water treatment loads, offsetting potential water load growth, and creating a sustainable, renewable water resource cycle.

Economic success in the 21st Century requires a highly functional and effective water infrastructure that doesn't do unnecessary work, restores and utilizes natural processes, and has the resilience to handle a wide variety of conditions. It's time to accelerate the evolution of our water infrastructure to an ecological model that will coevolve with, and be able to support, the changes coming in energy, agriculture, business, transportation and other economic sectors.

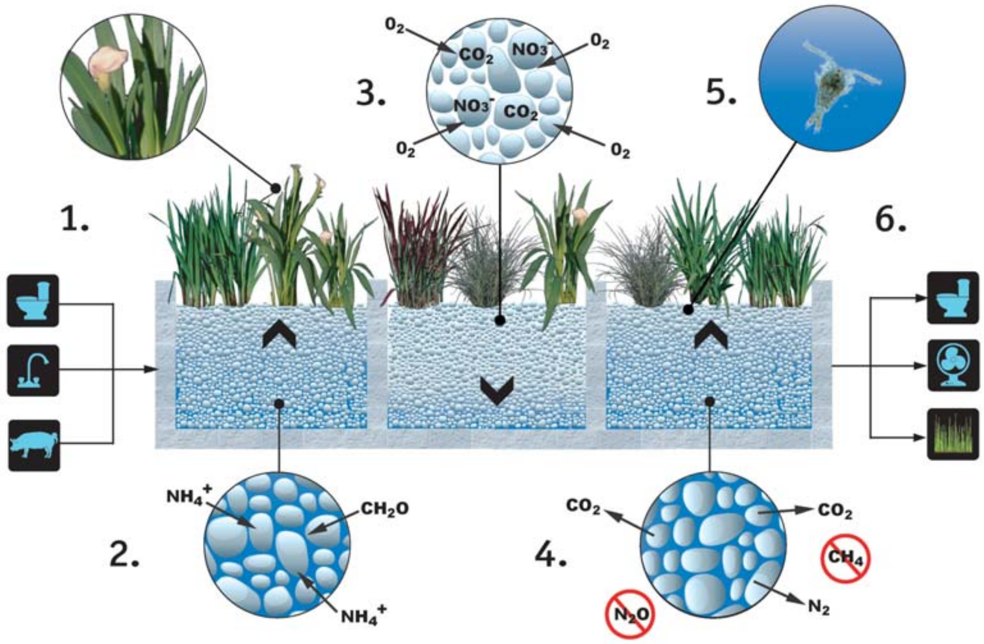
Over the next 20 years, hundreds of billions of dollars must be invested to keep our water systems from falling further into disrepair and further behind the demand. If we target the available portion of those funds to building 21st Century decentralized ecological wastewater treatment infrastructure, we can create a sustainable infrastructure to support a sustainable economy. That would provide a real economic stimulus.

APPENDIX 1

“Tidal Flow Wetlands” for wastewater treatment are the most advanced ecological treatment systems applying 21st Century technology to replicate and enhance the performance of Nature’s most productive ecosystem – the tidal estuary. These systems speed up the natural processes by combining natural ecological processes with engineering and controls so that the system is energy efficient, cost-effective, and reliable for wide-scale use. Advances in wetland science and engineering have produced systems that can cleanse gray or black water in a wide variety of residential, commercial, industrial, and agricultural applications.

The most efficient of these tidal wetland systems incorporate a series of wetland cells, or basins, that are filled with a special packed gravel medium. This medium allows extensive surface area to support the formation of diverse ecosystems of microorganisms – biofilms – that are the key to cleaning the water. As water moves through the system, the cells are alternately flooded and drained to create multiple tidal cycles each day, much like we find in nature. Again like nature, the cycles promote the growth of diverse wetland vegetation and microorganisms, especially in the wetland plant root zone. Thus, a complex and stable ecosystem generates clean water under a variety of conditions. The diagram illustrates how this process works in the Living Machine® Tidal Wetland System.

The Living Machine® Tidal Wetland System



1. Living Machines are engineered systems which utilize plants in porous gravel substrate to create a large surface area for biofilms, thin films of active treatment microorganisms. Biofilms efficiently treat wastewater from municipal, agricultural and other sources.

2. Each system is composed of a series of discrete cells which alternately fill and drain. A microcomputer optimizes the pumped flow from cell to cell. When the cell fills, carbohydrates and ammonia in the wastewater attach to the gravel and biofilms.

3. On the next drain cycle atmospheric oxygen passively diffuses into the cell as the water rushes out. This oxygen is used by biofilm bacteria to convert ammonia to nitrate and a portion of the carbohydrates to carbon dioxide.

4. When the cell fills again, different bacteria convert the nitrate to nitrogen gas and remove the remaining carbohydrates. Because no methane or nitrous oxide is created this process has a very small climate footprint.

5. A complex food chain of microorganisms such as protozoans and microcrustaceans develop on the gravel and plant roots and consume excess biofilm in the system.

6. Living Machines systems consist of complex ecologies to treat wastewater to stringent standards allowing the treated water to be reused for a variety of applications including toilet flushing, cooling towers, and landscape or agricultural irrigation. They use less than 1/3 the energy of conventional wastewater treatment plants saving energy and water.

This patented tidal process naturally brings atmospheric levels of oxygen to the wastewater. These concentrations are significantly higher than conventional technology and allow improving treatment performance using significantly less land area than other constructed wetland technologies and significantly less energy than conventional technologies such as activated sludge.

The wastewater flow is always subsurface, or belowground, in the pore spaces between the rock particles. This is another significant difference from earlier approaches. The wetland produces no smell, mosquito habitat, or potential human or wildlife contamination. As a result, on-site wastewater treatment systems such as these can be placed indoors, as well as outdoors and as dual use areas in close proximity to buildings and people.

A computer system integrates operation of the wetland cells, controlling water levels and cycling to optimize performance and record system information for operators to view and control via the Web. And, unlike traditional wastewater treatment systems, ecologically based wastewater treatment is visually appealing and creates quality freshwater without chemicals, odor or offensive by-products. Integrating ecological wastewater treatment into the human landscape on a large scale could be an important part of returning beauty to human settlements.

APPENDIX 2

Case Studies

Revitalizing local water cycles can be quickly implemented by communities and regional economies as described in this paper. Example success stories show the economic, environmental, and community benefits of shifting the focus toward efficient, resource conserving, decentralized water systems. These success stories demonstrate potential water strategies that provide for the rapid creation of jobs, the addition of self sufficient local community water assets, and an overall improvement in energy efficiency, cost effectiveness, and flexibility.

Urban Setting/Commercial Development: Decentralizing wastewater treatment simply means moving away from a one-size-fits-all strategy for water capture in both urban and rural settings.

With a decentralized system, buildings and neighborhoods could set up their own wastewater treatment system right inside or next to their building or area. Now, all gray or black water (from toilets and sinks to commercial storm water run-off) would be captured and recycled at the point of use and re-used for another round of use as irrigation, lavatory needs, car washing, and other water heavy uses. Water would not move long distances, and each community would be in control of recapturing, re-using and saving on water costs and environmental impacts.

> **Case in Point**: An on-site wastewater treatment system at the EcoCentre, an office building in water-starved Lake Worth, Florida, treats gray water from the building's sinks and showers, producing high quality, recycled water clean enough for exterior irrigation. In addition, rain water is collected in an

8000 gallon cistern on the roof and recycled for lavatory flushing, saves the building about 200,000 gallons of water a year.

Case in Point: A new headquarters office facility for the Port of Portland (Oregon) being built at the Portland Airport will feature an on-site wastewater treatment system designed to treat all of the facility sanitary wastewater to a quality suitable for reuse, including toilet flushing and water for landscape irrigation. This approach will cut water consumption close to 80 percent compared to a conventional office — from 1.1 million gallons a year to a mere 250,000 gallons.

Rural Setting/Educational Institutions: Rural areas in any town, municipality or state are hard-pressed to build more neighborhoods or buildings since they are often difficult areas with limitations due to poor soils or water/sewer accessibility. On-site, decentralized water systems would allow for building in rural areas without necessitating new sewer/water lines.

Case in Point: Guilford County School District, a leading school system in North Carolina, installed an on-site water treatment system instead of opting to spend $4 million to extend city sewer lines to the new site. Their on-site water system treats and recycles more than 30,000 gallons of wastewater per day from the middle and high school buildings and produces enough clean water to irrigate three athletic fields – all without chemicals, odor or hazardous by-products.

Agriculture: Whether it's domestic or abroad, decentralized systems can help tackle one of our most urgent issues – tainted run-off from animal feed lots and food processing operations. Decentralized systems can be located at the point of water contamination (near a pig farm, for example) and be used to treat water for re-use on the farm and ensure water flowing into public watersheds is clean. Also, in developing countries, on-site water treatment systems can provide much cheaper, safer water for local communities' agricultural needs.

Case in Point: In the developing West African country of Ghana, a community set up a decentralized wetland-based wastewater treatment system in an effort to address challenges where source water used to irrigate crops is extremely polluted. Where building water pipes is not an option, decentralized water treatment is a critical strategy to produce clean water for survival.

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