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06.
THE RESOURCE INFINITY LOOP:
Ecoshed Planning for Resilient Cities

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ABSTRACT
Nature has been recycling water within the Earth's closed ecosystem since the very beginning of time. Humans, although a part of the ecosystem, have misappropriated this precious reserve, severely imperiling the availability of freshwater for future use for all life on Earth. Civilizations have thrived or collapsed because of water. The restructuring of our established water and food systems is urgently needed in order to eliminate the constant waste inherent to present systems, and to reverse the detrimental impact they have had on our climatic system. Global warming, water scarcity, food insecurity, and social inequity are just some of the myriad problems facing cities globally. The decrepit state of much existing infrastructure provides a unique opportunity to implement major change. This research focuses the discussion on ecoshed planning - a new paradigm that conveys a multitude of benefits to humankind's physical and social health, cities' environmental and economic health; and above all, the health of the planet's ecosystem. Ecoshed planning closes the loop of water and nutrients – the Resource Infinity Loop – by reclaiming wastewater through natural processes and reusing it for urban farming. San Francisco is well suited for implementing ecoshed-based planning, as shown by the system envisioned for one of the city's watersheds. Arcata, a real-life, built example of these processes in use, which is now almost 40 years old, demonstrates how such a system can succeed. With rigorous multidisciplinary research and collaboration, and progressive policies that push boundaries, it is possible to build the ecologically-regenerative, resilient cities that the future requires.

KEYWORDS: water scarcity, food security, wastewater treatment, urban agriculture, ecological processes, regenerative landscape

1.0 INTRODUCTION
In nature's hydrologic cycle, water is not lost nor created. The volume of water in our ecosystem has always remained constant. Humans' lifestyles, however, have resulted in the decrease of readily available surface freshwater, the less than one percent out of the total volume of water in the ecosystem that is available for all life on earth[1]. Used water, commonly but shortsightedly referred to as wastewater, is pumped daily into saltwater sinks of the world at a pace far greater than nature can replenish freshwater bodies. If we were to mimic nature and recycle used ("waste") water to form closed loops that are a source of freshwater, we could help keep the freshwater-to-all-water ratio from decreasing any further. Recycling urban used water not only reduces the volume of freshwater being discharged into saltwater bodies, but also minimizes the need to draw freshwater from nature's dwindling reserves. Over time this will effectively allow nature a chance to regain ecological balance as well as capture otherwise-squandered nutrients, rehabilitate decrepit or disused post-industrial landscapes, and revitalize communities. Taking this strategy a step further, the article gives a practical examination of the reuse of urban used water to illustrate the concept of an ecologically resilient food and water infrastructure for cities.

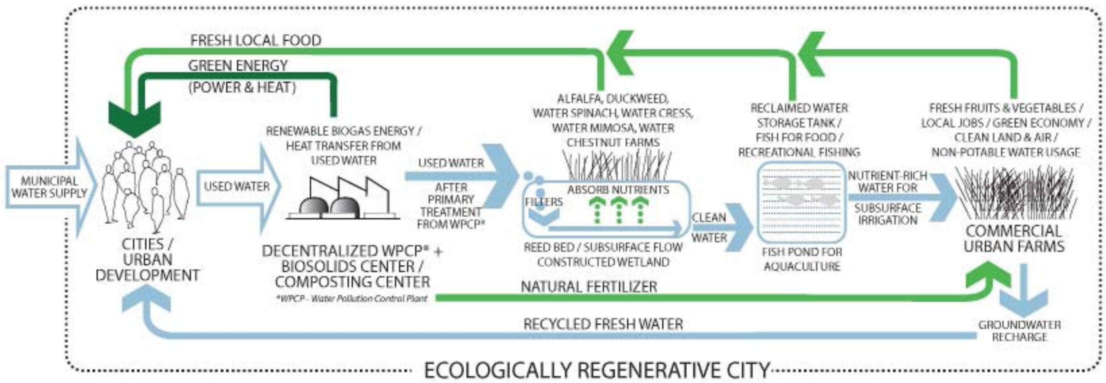


Figure 1: The Resource Infinity Loop concept.

2.0 RESILIENT CITIES CAN SAVE PLANET EARTH

The fast-paced lifestyle of city-dwellers is powered primarily by tapping into an inordinate proportion of fossil fuels, burning through the carbon reserves of our ecosystem. Most transportation, heat, and electricity needs are met by burning fossil fuels, which releases sequestered carbon into the atmosphere as carbon dioxide—a primary component of greenhouse gases (GHGs). Once covered with mature trees, vast land areas that acted as sinks for GHGs have been cleared to make way for cities. With limited opportunity for carbon capture and sequestration that would have contributed to future fossil-fuel reserves, these emissions have instead increased the concentration of carbon dioxide (CO_2) in the atmosphere. Increased levels of greenhouse gases trap heat within the earth's atmosphere, resulting in a gradual rise in our planet's temperature. This steady warming of the globe has had a major impact on the climate already. Recent crippling storm surges, coastal inundation due to sea-level rise, and severe disruption of weather patterns affecting everything from Alaskan glacier melt and Atlanta's schools running out of snow days to zebra migrations and Zimbabwean food security are all effects of global warming. California declared drought this winter while the rest of the country was lashed with severe rain and snow-storms, often where such weather is very far from the norm. Patterns of extremes, as a result of global warming, are a living reality.

In nations across the world, the agriculture economy is giving way to technological- and service-based economies as once-reliable rainfall patterns disappear and agricultural land is consumed by cities. Rapid migration from farms to cities and reduced farm areas will burden remaining agricultural lands with the colossal task of sustaining an ever-growing global population. How we feed our billions, with more than 70 percent of the world's population living in cities by the year 2050, poses enormous challenges to our food system – its production, transportation, storage, distribution and disposal[2]. It threatens our food security and demands a plan of action.

The world will not go hungry for lack of food, but rather waste of food. Nelson (1996) makes the argument that the world's farms produce enough food to provide the world with an adequate diet, attributing food scarcity to a disconnect between places of production and place of consumption[3]. United Nations Food and Agriculture Organization (FAO) studies illuminate the alarming worldwide state of affairs[4]:

- Every year, about one third of the food produced in the world for human consumption, approximately 1.3 billion tons, is either wasted or lost to natural forces,
- Every year, rich nations waste almost as much food (222 million tons) as the entire net food production of sub-Saharan Africa (230 million tons),
- Every year, 40 percent of all food in the United States is thrown away. It is estimated that about half of the water used to produce this food also goes to waste.

Food waste is economically and environmentally disastrous. It encompasses unjustifiable squandering of the tremendous amount of water necessary for the food's production; increased use and misuse of the high-embodied-energy chemicals in fertilizers and pesticides;

and unnecessary contribution to global warming due to factors ranging from the extra fuel consumed in transportation to the methane emissions from food rotting in landfills. All of this food waste is wasted, yet again, when it is not reclaimed and recycled back into the land to be used as nutrients to grow more food. In the United States, organic waste is the second-biggest component of landfills, which are the largest source of methane emissions[5]. Methane is the most harmful component of greenhouse gases. It is 23 times more potent than CO_2 as a greenhouse gas[6].

Food production accounts for 70 percent of global fresh water needs (in United States agricultural demands constitute 80 percent of water needs), an onerous demand on a rapidly dwindling resource[7]. Extreme weather patterns due to global warming will result in dry regions getting drier and wet regions getting wetter. Half the world's population will live in water-stressed regions by 2025[8]. How we conceive (or re-conceive) the urban water infrastructure and how we spatially organize our cities is the key to tackling water scarcity; to succeed we must maximize the capture, use, and reuse of every precious drop.

To mitigate some of the irreversible changes our present city systems have inflicted on our ecosystem, and to begin to have a net-positive impact on the planet, we need to fundamentally rethink the way we plan and build our cities.

3.0 The Resource Infinity Loop

Cities are under growing pressure to determine and deploy optimum water and food infrastructure systems in order to reduce waste; this raises the all-too-immediate question of how we intend to tackle our present overly centralized, overly mechanized, and now crumbling infrastructure. According to the U.S. Environmental Protection Agency's report "The Importance of Water to the U.S. Economy," released November 2013, an investment of an additional $84 billion between now and 2020 is needed, mainly in three areas[9]:

- *Water Treatment Plants* – Upgrading and replacing old plants.
- *Pipes* – The EPA reports that 60 percent of drinking water needs and 28 percent of wastewater needs are pipe-related (51 percent of wastewater pipe-related needs are repairs).
- *Wet Weather Management* – The EPA reports that 772 cities are working to prevent untreated sewage from entering waterways when sewer systems are overloaded.

These anticipated infrastructure improvements are a big investment. At a time of large-scale replacement, it is irresponsible to maintain or reinstate what has contributed to the crisis in the first place. We have the opportunity to introduce a transformative solution to water infrastructure that simultaneously addresses issues of global warming, food security, and water scarcity. The moment begs us to explore the immense potential of reusing our urban wastewater in an infinite loop, using processes that mimic nature, only on an accelerated timeline.

The Resource Infinity Loop upends the way we think about and build our cities. At present we seem to have been accustomed to the idea of the city as a consumption powerhouse with a challenged food system, water-polluting waste streams, and outdated infrastructure transporting large-carbon-footprint food and water resources. The concept of the Resource Infinity Loop, on the other hand, rests on our acceptance of the integral role human beings can play in re-establishing the regenerative ecological flow of our ecosystem; it offers a way to reassert the progress of humankind, to take ownership of our fates, and to be responsible to ourselves and the future.

City dwellers tend to think of the urban ecosystem as birds and critters, trees and gardens, and parks and ponds. We believe that by nurturing these non-human, natural elements within our cities, we can address the ailments of the urban ecosystem to create a healthier city. Though an honest start, this solution is incomplete. Humans are the predominant species in the urban world and the critical link in repairing the ailing urban ecosystem, and can be an active force for renewal. To find regenerative solutions for our cities, we need to step into the ecosystem and take our place in nature's cycle.

The Resource Infinity Loop is a new ecological and social paradigm that uses urban wastewater as a renewable and reliable resource for urban farming, thus closing the water and nutrient loop within the urban environment. Largely unexploited in the more developed economies—but used to great advantage in water-scarce parts of the world—it directs nutrients in human waste for urban farming, thus constantly renewing the food and energy resources being consumed. The used water (it is wastewater only if we let it go to waste) contains vital nutrients - phosphates and nitrates - that are essential for farming, and are the chemicals applied in conventional agricultural practices. Used water is the inexpensive, renewable resource for nutrients and water. The Resource Infinity Loop envisions urban open

Figure 2: Celebrating the abandoned grain silo as a cultural landmark and a place making opportunity.

spaces as productive landscapes that engage natural processes; put fresh food closer to consumers; enhance biodiversity; act as a catalyst for an agriculture-based green economy; and provide a nexus of education and community-building, a framework for social interaction across the food system within the confines of a city.

The Resource Infinity Loop is a cost-effective, low-energy, low-maintenance, resilient approach for replacing the traditional expensive, energy-intensive, centralized infrastructure for water, food, and energy needs. It treats wastewater locally through ecologically advanced treatment processes and reuses it in food-producing constructed wetlands, aquaculture ponds, and urban farms. It successfully creates and embeds decentralized water and food resource-recovery ecosystems within the fabric of the city. Unlike the current systems, it has the capacity to self-renew in the wake of disruptions, and as a modular, decentralized approach, has an infinite capacity for expansion. Cities will keep growing, and humans will continue to cluster there; the fundamental ways in which we plan, design, and build our cities should be redefined to include the infinite resource loop of used water to feed every city.

4.0 DESALINATION, A RESOURCE-INTENSIVE DEPENDENCY

In contrast to the Resource Infinity Loop, desalination of ocean water is a hasty and short-sighted solution that has been adopted by countries with limited access to fresh water, despite its tremendous negative environmental impacts. The chief ecological detriment is the brine disposed back into the ocean after the desalination process, which increases the salinity of the ocean bed, resulting in loss of habitat for marine life—essentially, stretches of dead ocean.

Desalination systems are already in use, and despite the very significant environmental costs associated with this process, the body of local and international environmental law regarding disposal of brine back into the sea does not yet include a single stringent policy. Another drawback is that: the pre-treatment level of salinity of sea-water makes desalination an extremely energy-intensive and an expensive solution from the beginning. In comparison, as indicated in Table 1, although the Resource Infinity Loop concept does entail a kind of desalination process, the removal of salts that are ben-

Table 1: Salinity level comparison of fresh water sources.

FRESH WATER SOURCE	AVERAGE SALINITY (mg/L)
Rainfall/Snowfall	5-10
Potable Water	<100
Waste (Used) Water	500-2,000
Ocean Water (source for desalination)	35,000

eficial nutrients for plants from urban wastewater is far easier and less energy-intensive than from ocean water, and the salts can be retrieved for application in farms.

Although desalination is an early water-supply solution for some water-stressed regions, it cannot be a solution for places with challenging geographical conditions — at high elevation, or deep in the interior away from the coast; nor is it a solution for economically challenged nations. More often than not, places facing the most acute water shortages have these challenges. Desalination also fails the tests of scalability, resilience to adverse weather events and operability in emergency conditions, environmental responsibility, long-term sustainability, economic sense and social progress. In the long run, any true solution must address every stage of the water-use cycle including stemming the flow of waste and reconnecting infrastructure to community and landscape, none of which desalination can accomplish.

5.0 ECOSHED PLANNING TO ENABLE CLOSED WATER AND NUTRIENT LOOPS

5.1 Defining an Ecoshed

Ecoshed signifies the extent of the physical area of a city within which all systems—the natural watershed, the water-treatment and waste-reclamation catchments, the food supply-chain—could work in concert as a closed cycle of use and reuse. Ecodistricts, a recent coinage in contemporary thought on cities, are neighborhoods committed to accelerating sustainability that integrate building and infrastructure projects with community and individual action. Ecosheds take that concept a step further; each ecoshed's distinct boundary is established by the natural topography, like the watershed of a creek, in order to take advantage of the inherent ecological systems within its extent, and to integrate the infrastructure framework with the natural systems already present. The Resource Infinity Loop is such a decentralized framework for water and food infrastructure that we can build ecoshed by ecoshed. The goal is to install productive landscape systems that allow natural processes to operate as infrastructure at an urban scale. Reducing the quantity of mechanized infrastructure and embracing ecological processes will create resilient systems that possess the capacity to renew themselves in the wake of a stormwater surge or other disruption. This is a major advantage over the conventional, centralized, mechanized water infrastructure that alienates itself from the natural landscape and then has to build barriers to protect itself from natural forces. The Resource Infinity Loop paradigm rests on the optimization of capture, distribution, and recapture of the water, food, and energy within the extent of an ecoshed—in essence, ecosheds are the units or building blocks of this new paradigm, each one a place of self-sufficiency and renewal.

5.2 Theoretical Planning of an Ecoshed

San Francisco's topography lends itself easily to this theoretical exploration. Due to its fortunate topography, San Francisco can boast of an extremely low-energy waste-disposal system, wherein all the combined stormwater and sewer lines transport wastewater to the seven receiving pumping systems along the water's edge using only gravity; energy is then used to pump it to San Francisco's two wastewater treatment plants: Oceanside Water Treatment Plant and the Southeast Water Pollution Control Plant. The city, thus has nine natural watersheds that drain either into the bay (eastern San Francisco) or the Pacific Ocean (western), but only two mechanized wastesheds. This following exploration brings back to the fore the underlying topography of the city, to propose each watershed as the basis for an individual ecoshed that would close the loop of water and nutrients within its boundaries.

The Islais watershed, along with the existing Southeast Water Pollution Control Plant (WPCP), is the focus of this study of ecoshed potentials. The Islais-Agro-Park plan, described here, repositions the Southeast WPCP as a catalyst for economically and physically revitalizing this under-utilized and neglected industrial neighborhood of San Francisco. While maintaining the current

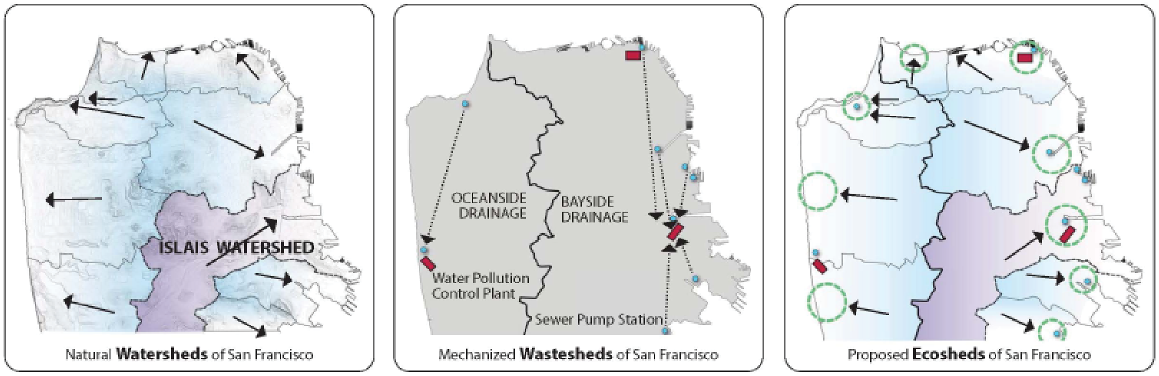
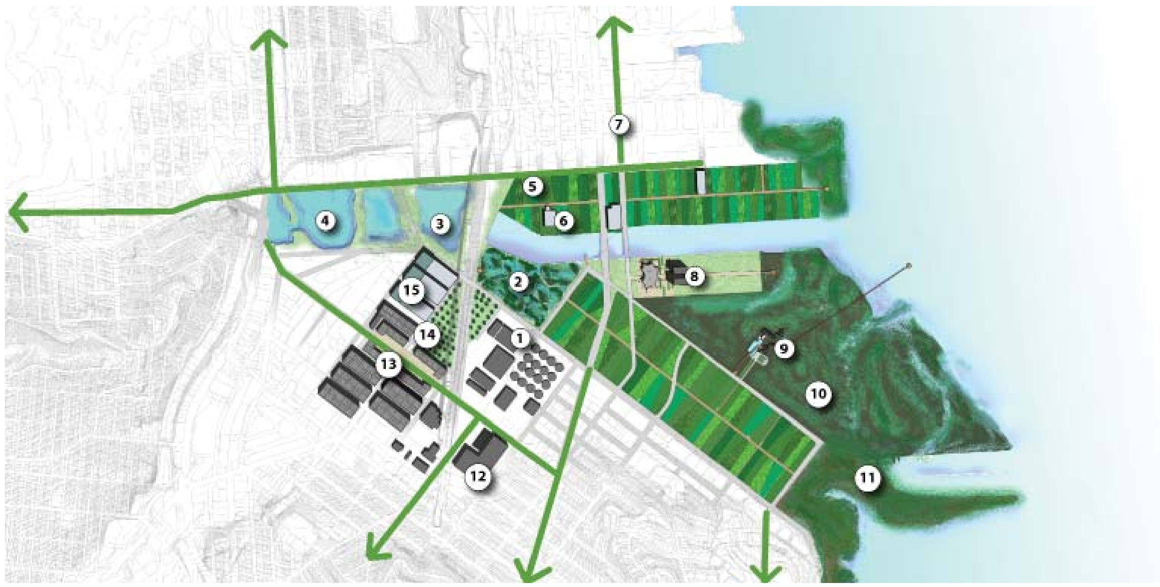


Figure 3: Adapting to San Francisco's drainage pattern for decentralized ecosheds.

job-centric use of the neighborhood, the plan proposes a clean, green, agro-based economy. The San Francisco Wholesale Produce Center is located immediately adjacent to the WPCP (Figure 5), making this ecoshed well-positioned to build on some of the existing uses for the greater economic, environmental, and social good of the neighborhood.

The effluent discharged from the WPCP system following conventional secondary treatment is our starting point. Under the new system, this waste-turned-resource will be tapped and redirected to flow through areas of reed beds for tertiary treatment. Nutrients are absorbed by plants growing in the reed bed (a source of food and biofuels), making this water fit for collection in large tanks for the next step: a controlled-environment aquaculture. Wastewater-fed aquaculture, if the right techniques are used, reduces the E. coli count of the water entering the wetlands from about 10 million organisms per milliliter to only 10 to 100 per milliliter[10]. The idea is akin to the East Kolkata Wetlands in Kolkata, India, where the sewage of the entire metropolis is fed into engineered wetlands that are one of the largest and most productive aquaculture systems of the world[11].

As long as there is a constant slow flow of water through the system of constructed wetlands and aquaculture ponds, this already nutrient-rich water, further nourished by droppings from the fish, can be reused once more in raised-bed urban farms. These urban farms would replace some of the land-intensive light-industrial uses that are, for the most part, growing obsolete. Run-off from these raised-bed urban farms can be recaptured and channeled back to the reed-beds / constructed wetlands. The Resource Infinity Loop, thus recovers water, nutrients, and energy from wastewater; replaces land-intensive, obsolete industrial use with ecologically regenerative food-production use; and creates job—reconnecting urban dwellers with their ecosystem and manifesting and inculcating values of social and environmental responsibility. Other cultural educational and recreational activities can be layered on top of this ecological framework to make it a true model of an ideal ecoshed. This functional unit of the Resource Infinity Loop would lend balance to San Francisco, giving the eastern half of the city its own amazing open space amenity—Golden Gate Park—a distinct, functional, and productive landscape called the Islais-Agro-Park.



1 Southeast Water Pollution Control Plant (WPCP)

2 Used Water, after primary treatment from the WPCP, is filtered in the constructed wetland for secondary treatment. Constructed wetlands produce edible plants like alfalfa, duckweed, water spinach

3 Nutrients get added back into the water during its flow through the acquaculture pond and is recycled on to the urban farm

4 Stormwater biofiltration ponds, a working landscape of ecological stormwater measures are integrated within the city's open space framework

5 Urban farms irrigated by recycled water from aquaculture ponds

6 Existing warehouses adapted to be greenhouses + urban farm tool shed or food-processing centers

7 A new, high-functioning streetscape, the result of overhauling the existing street surface to install functional and visible landscape infrastructure that collects, filters, and transports stormwater run-off

8 Silo Food Museum + Urban Agriculture Center, with its existing iconic silo structures, preserved, reimagined, and adapted to acknowledge the history of the site, showcase the present, and help imagine the future

9 Wetland Center, a visitors' center educating visitors about the wetlands

10 Saltwater wetlands provide flood protection while helping treat the high volume of runoffs during unpredictable wet weather; besides promoting biodiversity within the city

11 Ecocenter at Heron's Head Park is an educational community center

12 Cogeneration Plant + Composting center. Cogeneration Plant recovers heat from WPCP. Composting Center recycles organic waste from the WPCP, nurseries, produce market, urban farms, and the surrounding community

13 Wholesale Produce Market, after its early morning activities, transforms into a Bargain Produce Market that sells produce unfit for supermarkets and restaurants to the local community

14 Horticultural nursery + agricultural experimentation laboratory captures and utilizes excess heat from WPCP

15 Food innovation center + agro-business incubator spaces that train community members and promote entrepreneurs to target a food-based economy in "Islais-Agro-Park"

Figure 4: Ecoshed planning in the Islais watershed of San Francisco.

Heron's Head Park in the Bayview-Hunters Point Shipyard neighborhood adjacent to the Southeast WPCP, is a 24-acre thriving wetland restoration/nature preserve recently created in the Southern Waterfront. It was the result of an abandoned shipping terminal construction that was taken over by nature, and then in the 1990s, was improved with funding from the City and County of San Francisco Public Utilities Commission, the Port, the California Coastal Conservancy and the San Francisco Bay Trail Project to enhance the emergent wetlands. This peninsular park is home to salt marshes and upland restoration activity, walking trails, bird-watching, environmental education activities and the EcoCenter. The EcoCenter at Heron's Head Park (for location see label 11 of Figure 4), is an educational community center that uses sustainable on-site power, water and wastewater systems. Nearly every feature of this facility is designed to educate the public about renewable energy, pollution and greenhouse gas reduction, wastewater treatment, sustainable building materials, rainwater harvesting and the green economy. In July 2013, the EcoCenter was certified by the United States Green Building Council as a Leadership in Energy and Environmental Design (LEED) Platinum building. It was the first LEED Platinum - Zero Net Energy Building in San Francisco. This recent effort in this ecoshed has already set a precedent for natural, restorative interventions that will heal the community and the land.

5.3 Ecoshed Thinking Required to Revolutionize Planning Policies and Programs

City agencies need to restructure their policy creation environment to foster multi-departmental collaboration that synergistically looks at goals and targets of different departments to promote "ecoshed thinking." We urgently need progressive policies and innovative programs that reveal the concealed and invisible underlying natural systems of our cities and emphasize the need to harness the messy, though highly beneficial, regenerative capacity of natural processes as urban infrastructure. These policies will require:

- Developing a stronger nexus between urban health policies, urban agriculture policies, and policies on the reuse of urban used water, in order to remove unnecessarily stringent regulatory barriers and encourage innovation in all fields;
- Establishing an integrated framework addressing water reuse, urban agriculture, and public health goals and targets;
- Identifying and protecting areas of wasted interstitial public land – along freeways, rail lines, airports, and utility easements, for example – and capturing them as opportunities for city-scale strategies for this framework;
- Decentralizing the implementation of this framework by establishing a network of individual ecosheds, in order to allow close monitoring, periodic follow-up of performance, and active local community engagement in the process; and
- Partnering with institutions and organizations that provide sound technical know-how and educational support for implementing waste-to-fork programs.

Urban environmental policy should mandate that all new urban developments, whether private or public, must neither damage nor deplete the natural environment, but rather start a positive cycle of regeneration and resiliency, with projects required to:

- Develop an environmental stewardship action plan to increase awareness of and participation in proactive management of natural resources;
- Identify land for regenerative uses and develop a biodiversity plan contributing to a targeted increase in landscape biodiversity;
- Identify areas and opportunities to enable urban farming - small or large scale, on individual private property or as a community activity;
- Allocate land for landscape-based solutions, or develop building-design strategies, for on-site capture, treatment, and reuse of wastewater; and
- Develop action plan to promote local, small-scale agro-businesses, to support local entrepreneurs, boost local economies, and develop a resilient food infrastructure.

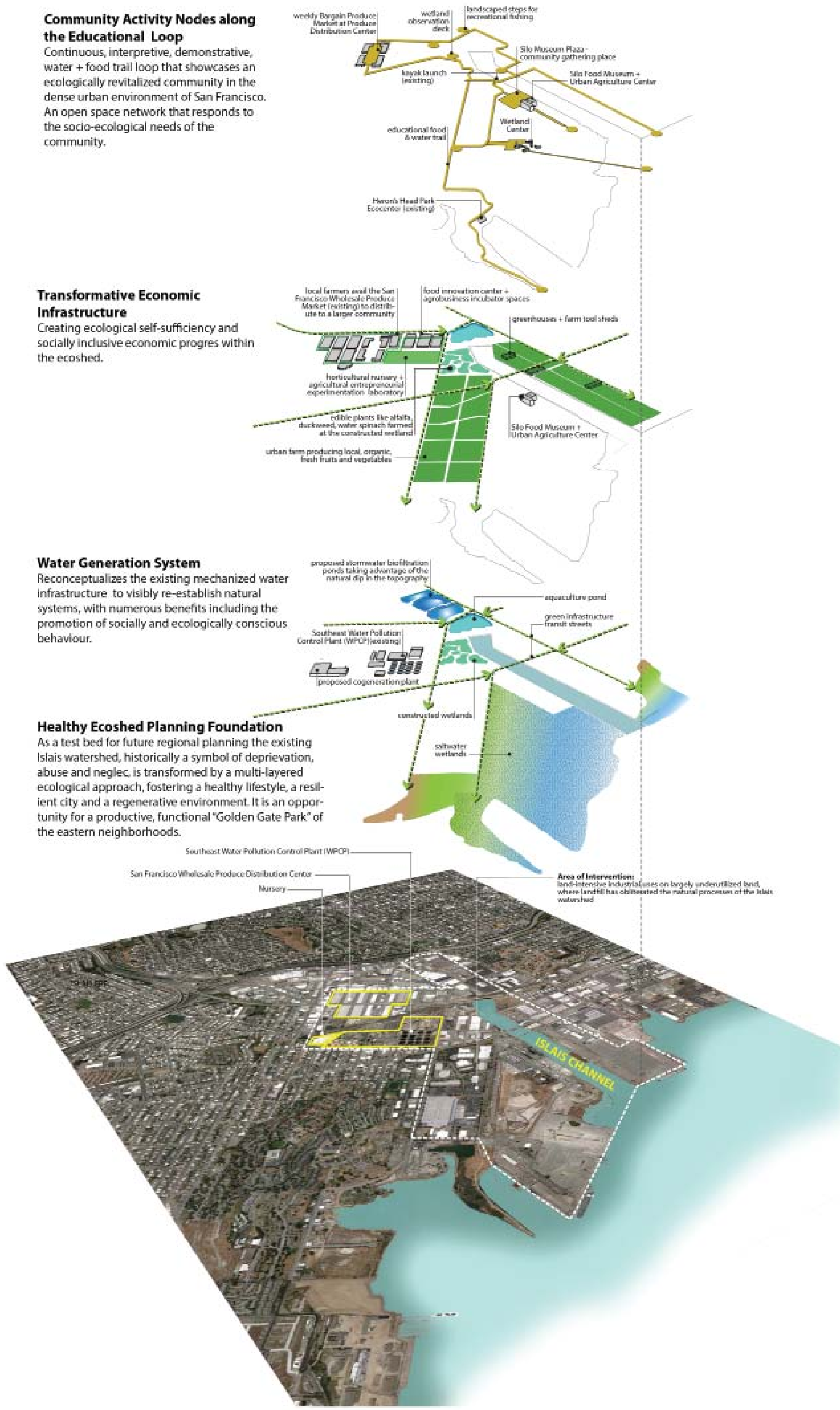


Figure 5: Significant components and benefits of the ecoshed plan.

6.0 CASE STUDY: ESTABLISHING THE TREND IN THE RIGHT DIRECTION

Arcata Marsh and Wildlife Sanctuary + Wastewater Treatment Plant in California is world-famous as an innovative, integrated wetland wastewater treatment system that has repurposed a degraded landfill area and transformed it into a 154-acre valuable resource. The town treats the wastewater of its 17,000-person community in this facility, which provides a popular tourist destination. It is a small-scale, decentralized system that combines the process of a conventional treatment plant with an ecological process, not just to restore, but also to use the restored marshes for the purpose of tertiary treatment and enhancement of the treated water. The plants in the marshes absorb nutrients, cleaning the water before it is discharged into Humboldt Bay. The facility has proved to be an economic boon to the local community; has replaced a landfill with a bird and wildlife sanctuary, now well established; and, with its five miles of trails, has become a recreational destination for locals and tourists. In addition, the Arcata Marsh Interpretive Center is an educational resource for the community.

The City of Arcata established this innovative treatment system as a reaction to an expensive regional wastewater treatment plant being proposed to comply with California's Bays and Estuaries Policy in 1974; the policy states its purpose as, "to provide water quality principles and guidelines to prevent water quality degradation and to protect the beneficial use of waters of enclosed bays and estuaries"[13]. The active wastewater treatment plant had experienced an event of discharge of unchlorinated effluent into Humboldt Bay in 1970, and needed an effective and efficient solution to prevent any future reoccurrence.

Figure 6: Arcata Marsh and Wildlife Sanctuary + Wastewater Treatment Plant, Arcata, California[12].
Area: 154 acres of freshwater and seawater marshes, tidal mudflats, and grasslands.
Design Population: The facility was designed to handle wastewater for up to 19,000 people.
Year Completed: The Arcata Marshes were added to the active Wastewater Treatment System in 1986.

The Arcata marshes comprise three two-acre constructed wetlands that treat all the wastewater generated from the existing wastewater treatment plant through the natural processes of wetland ecosystems. The marshes are planted with thick bulrush and cattail vegetation that slow the flow of water, allowing suspended material to settle and preventing growth of algae due to absence of sunlight reaching the surface of water. The water is then pumped into a chlorination facility to kill any viruses. It is further processed naturally through 31 acres of additional constructed wetlands called the enhancement marshes. At this stage it is clean enough to be released into the bay; however, it is required by regulation to go through a second chlorination process because fecal matter from the birds in the marshes technically violate the regulations.

Innovations and benefits that are associated with the Arcata Wastewater Treatment plan include:

- A low-energy, low-maintenance, decentralized wastewater treatment facility, as compared to conventional treatment facilities.
- Ecological transformation of a landfill and an industrial site into a restored marshland.
- Early wastewater aquaculture experimentation project (since discontinued) that raised Pacific salmon and trout in ponds mixed with partially treated wastewater and seawater, demonstrating wastewater as a resource to be reused.
- Public access to the shoreline of Humboldt Bay (previously inaccessible to the public due to the lumber mills, the landfill, and the wastewater treatment plant) and emergence of a regional destination for bird-watching and natural recreational trails.
- A successful attempt to limit expensive infrastructure investment by adding a cost-effective natural process to wastewater treatment. The cost of the Marsh and Wildlife Sanctuary was half that of its proposed alternative regional sewage processing plant. Moreover, the annual maintenance cost is about $500,000 instead of the $1.5 million the conventional plant would cost.
- Effectively prevented the sprawl that might have

occurred as a result of the pipe network expansion needed for the centralized regional sewage processing plant that had been proposed.

By constructing a cost-effective and environmentally sound wastewater reuse and treatment solution, the facility has received international recognition and numerous awards for municipal planning design, cost-effective public utility operation, an urban redevelopment plan, and natural resource project design.

Arcata is not a holistic example of a Resource Infinity Loop, but it went a long way in demonstrating the scientific and ecological integrity (and multiple benefits) of using cost-effective natural processes.

7.0 MULTIPLE AND MULTI-SCALED BENEFITS OF THE RESOURCE INFINITY LOOP

7.1 Access to Fresh, Local, Organic Food

Providing easy and regular access to fresh produce and other food addresses one of the most prevalent problems in the city: food deserts. A food desert is a large area of a city with no access to grocery stores that stock fresh fruits and vegetables. Growing food within cities and distributing locally through mobile vendors/food trucks or to stores and food hubs eliminates this situation. It gives all city dwellers the choice to adopt healthy food habits and live a healthy lifestyle, thus reducing the likelihood of health issues like malnutrition, obesity and related ailments, and even heart disease. This is a boon

Table 2: Beneficial impacts of the Resource Infinity Loop.

BENEFITS	Local / Community	City-wide	Regional	Global
Access to fresh, local, organic food	✓	✓		
Strong local economies / economic drivers	✓	✓	✓	
Educational amenity established at water treatment plant	✓	✓	✓	
Reconfigured streets with visible water infrastructure and reduced stormwater runoff	✓	✓		
Renewable energy from urban waste	✓	✓	✓	✓
Reducing the ‘heat island’ effect	✓	✓	✓	✓
Changes made to ‘urbanscape’ / institution of productive landscapes	✓	✓	✓	✓
Improved water quality in our rivers, bays, and oceans	✓	✓	✓	✓
Biodiversity promoted and flooding reduced through wetland restoration	✓	✓	✓	✓
Phosphorous recycling	✓			✓
Social equity	✓	✓	✓	✓

Figure 7: Reimagining city infrastructure: an urban landscape that closes the cycle of water and nutrient use.

Figure 8: Access to bargain produce at the wholesale produce market/food distribution hub.

for the public as well as for cities' often over-subscribed neighborhood clinics and hospitals. Establishing a balance of commercially viable farms and ensuring access to affordable fresh produce will require further investigation into successful urban agriculture typologies and models.

7.2 Strengthening Local Economies with New Drivers

The Resource Infinity Loop introduces opportunities for commercial organic urban farming and aquatic ecologies within the city that generate and support an aquaculture economy. This creates new local economies that are fundamentally structured around the environmental and economic health of a city and the physical and social health of its residents. In addition, ancillary support businesses focused around urban agriculture – such as a food distribution hub, experimental nurseries and laboratories, urban agriculture-focused training center, and agrobusiness incubator spaces – further boost the economy with clean, green jobs.

7.3 Renewable Energy Created from Urban Waste

Bio-methane is an extremely potent GHG emission. Bio-methane, unlike fossil fuels, is produced from fresh organic matter like manure, sewage, and organic waste, which means that it is a renewable source of energy that can be produced rather inexpensively worldwide[14]. Studies have shown that bio-methane, if captured and used as biofuel for powering light vehicles, can actually produce a negative GHG emission, which will result in the long run in reduction of GHG emissions and a positive impact on the environment[15]. Bio-methane is also used in larger-scale energy production: heat, a by-product of the gas, is converted into electricity—another way in which bio-methane can be a responsible source of energy.

7.4 Educational Community Amenity Established at Water Treatment Plant

Given the innumerable benefits from urban used water, water treatment facilities deserve better status within our urban fabric. These should be places of education and community pride, with careful thought given to their aesthetics and the opportunity for placemaking. A wonderful precedent can be found in the recently built Omega Center for Sustainable Living (OCSL) facility, also known as the Eco Machine. OCSL is not just a wastewater treatment plant that treats water through biological process to recharge the acquifer, it is also a demonstration project and an education center orienting visitors to a regenerative future.

7.5 Reconfigured Streets with Visible Water Infrastructure and Reduced Stormwater Runoff

We now have the advantage of a growing repertoire of tested best practices that offer ways to reconfigure street cross-sections to reduce unwieldy, hidden infrastructure with visible functional landscape features. For example, bioswales that provide attractiveness to land-

Figure 9: Public access with interpretive signage provides an immersive educational experience.

scapes can dramatically reduce sewer overflows during severe wet-weather events; they treat storm-water run-off either by infiltration or by conveyance to other water collection/treatment locations.

7.6 Reducing the “Heat Island” Effect

The open space and greenery that are part and parcel of the various natural processes introduced by the Resource Infinity Loop have a positive impact on the problem of heat islands (excessive buildup of heat in cities). Heat islands affect communities by increasing energy demand, air conditioning costs, heat-related illness, and mortality, particulate air pollution and greenhouse gas emissions as well as decreasing water quality. Having nature-scape open spaces is one of the most effective ways to reduce the urban heat island effect within cities.

7.7 Changing Urbanscape to Institute Productive Landscapes

Given the development pressures on any available land within a city, it is immensely beneficial to initiate a strategic framework of streets, easements, open spaces, and under-utilized areas, which together establish a valuable integrated green infrastructure as well as provide productive landscape opportunities allowing natural processes to aid in the functioning of the city. Parcels adjacent to such landscape greatly benefit from an increase in property values.

7.8 Improved Water Quality in Rivers, Bays and Oceans

Agricultural run-off is one of the largest sources of non-point-pollution affecting freshwater bodies. Chemicals added in fertilizers and pesticides are only partially absorbed by crops, and much of it drains away as run-off, seeping into our rivers, lakes, aquifers, and oceans. This practice is financially unsound and a huge loss of finite resources, in addition to the fact that when these resources drain away, they become pollutants. This pollution endangers aquatic life, due to eutrophication causing algal bloom. It is difficult to control non-point-source pollutants like this. Removal of chemicals is currently achieved largely by chemical precipitation, which is expensive. A less-expensive, environmentally friendlier alternative is biological control and removal through buffer zones like wetlands, riparian zones, and aquatic ecotones (transition zones) that filter and retain the nutrient elements from agricultural runoff.

7.9 Establishing Wetlands to Promote Biodiversity and Reduce Flooding Events

Wetlands serve as detention ponds during a storm surge, drastically reducing run-off into water bodies, and infiltrating it over time to recharge the ground water. These functions buffer adjacent communities from inundation during a heavy storm event and serve as natural flood control. Wetlands also promote biodiversity. The wetlands environment has a distinctive vegetation pattern of hydrophilic plants, which in turn provides important habitat that attracts local water-fowl and migratory birds, making constructed wetlands a successful way to welcome larger diversity of nature into our cities. In addition to these benefits, some hydrophilic plants are edible including alfalfa, duckweed, water spinach, watercress, water mimosa and water chestnut. These wetlands, thus constitute an added source of fresh food.

7.10 Phosphorus Recycling

Phosphorous in chemical fertilizer is mined from finite, shrinking phosphate reserves, the majority of which are in Morocco and South Africa. Fabricating and transporting phosphorous is an energy-intensive and expensive process. There are large environmental and cost-saving benefits achieved by replacing chemical fertilizers with phosphorous recycled from human waste.

7.11 Addressing Social Equity

Historically, large parcels in low-lying areas of the city have been zoned for industrial uses. With the changing economy these industrial parcels have remained vacant or under-utilized, failing to repurpose to more relevant, job generating economies. Oftentimes these sites are environmentally degraded, requiring expensive clean–up before reuse. Residential neighborhoods adjacent to these industrial areas have been generally under-served communities, impaired by poverty, and lacking the most basic social infrastructure and community amenities. The Resource Infinity Loop provides the framework to provide for the social needs of these communities and enable a livable environment.

Repurposing these sites for controlled-environment agriculture could heal blighted sites and convert them into an economic and environmental asset for the owner and the community. The Resource Infinity Loop, by its very nature, favors sites where communities are most in need, and therefore, inherently promotes social equity through the elevation in quality of life for the immediately surrounding community; an urban farming setting (as compared to an industrial environment) has long-term economic, social, and health benefits to the communities that need them most.

8.0 CHALLENGES IN IMPLEMENTING THE RESOURCE INFINITY LOOP

8.1 Public Health Regulations

Applying wastewater in agricultural fields is an age-old farming tradition practiced by civilizations across the globe. Since the 1800s, farmers in California have used wastewater for irrigating crops. Of all the various uses, agriculture irrigation accounts for almost half of the use of treated water available annually in California. California is the national leader in use of treated water for both agriculture and landscaping. Despite its benefits, however, wastewater contains pathogens and poses a risk to public health, especially in urban areas.

California's Department of Public Health Services determines the permitted use of recycled water. Listed in Title 22 of the California Code of Regulations for recycled water use, these regulations are among the most stringent in the entire country. Table 3 shows the permitted irrigation use of the three main reclaimed water types - secondary treated recycled water, tertiary treated recycled water, and advanced water purification recycled water.

Current inconsistent policies and regulations, in addition to a cumbersome permitting process, have hindered the large-scale use of recycled water. By adopting uniform health standards, the Department of Public Health will be able to provide project designers with the direction needed to cost-effectively design for water recycling facilities that are fully protective of public health and provide ecological benefits to the city.

Water-abundant nations, like Sweden, have experimented since the 1990s with eco-sanitation in an effort to protect the water quality of the Baltic Sea. Recycling and reuse of nutrients in wastewater is promoted in their various legislation pieces and environmental policies.

Table 3: Permitted use of recycled water by type under Title 22, California Code of Regulations.

TYPES OF RECYCLED WATER	PERMITTED REUSE
Secondary Treated Recycled Water	Surface irrigation of orchards, vineyards, landscaping areas not subject to constant human use
Tertiary Treated Recycled Water	Spray irrigation on recreational venues –parks, golf courses school yards; industrial uses; irrigation of edible food crops
Advanced Water Purification Recycled Water	Replenishment of potable water sources – groundwater and surface reservoirs

8.2 Cost of Water

Subsidized farm irrigation and the cost of transporting water to farms from distant sources have undermined the push to look for sustainable new freshwater sources. The perception that water is relatively low-cost has been exacerbated by water utility rates that are set substantially below their true values. We have been slow to respond to our many drought cycles. We need to reassess the cost of water and adjust our water rates. The increase in price of water in Australia has, over the years, contributed to an overall decrease in water use[16]. Australia is one of the global leaders in water responsiveness because of its undeniable reality of being a water-scarce region.

8.3 Land Availability

The idea of a functional landscape serving as an infrastructure on an urban scale conjures an image of vast expanses of expensive land unavailable for real estate development. The need for large land area that engage natural processes is a potential deterrent to the implementation of the Resource Infinity Loop. Further research is required to determine the size and scale of such a landscape infrastructure, however, advancements in technology (with Worrell Water Technologies' Living Machine® system that uses living plants and beneficial microorganisms to turn wastewater into clean water) make one hopeful of future possibilities of a compact land-engineered solution that minimizes land requirement, keeping urban land available for high-intensity urban development.

8.4 Societal Perception

There is a preconceived, emotion-driven, public perception of risk that weighs against the reuse of urban wastewater for food production in many developed countries. Mainly, this seems to be a psychological barrier, which is to say, a matter of public education and political will. However, with growing awareness of the fact that water is a limited resource, and with increasing demand, societal perception of wastewater is changing. Treating and reusing water locally has the potential to win over a community when proposed as an alternative to using a conventional, mechanized, large-scale facility built for a region of which the community is a small part, especially as it also gives the community a chance to come closer to meeting its local environmental and economic goals.

9.0 CONCLUSION

In order to make ecologically-sound design and engineering decisions when planning our cities, it is imperative to understand wastewater ecology. Efficient, aesthetically appealing, decentralized, natural treatment features within urban developments are the energy-passive, community-engaging, resilient, and scalable solutions that will help maintain the water balance of an urban watershed and serve as one of the many regenerative solutions essential to the survival of cities. Complementing a basic treatment facility with additional natural treatment, as in the case of Arcata, avoids expensive, high-maintenance, conventional infrastructure solutions. Cities stand to gain manifold benefits from such an ecological process within an urban development. These solutions still have challenges to overcome, and will need to be adapted to specific local context as well as local policies and regulations—but the stage is set and there has never been a better time to act.

Issues pertaining to water access are issues of basic human rights and of social justice. Around the globe, water concerns are contentious across political boundaries, determine national security policies, and have enormous consequences to world economies. There is no overstating the fact that water issues are fundamental issues of survival to any and all species. We need to protect our water reserves and design for resilient cities.

REFERENCES

[1] Shiklomanov, I., (1993). "World Fresh Water Resources" in *Water in Crisis: A Guide to the World's Fresh Water Resources*, ed. Gleick, P., New York, NY: Oxford University Press.

[2] World Health Organization Global Health Observatory, (2014). "Urban Population Growth", Retrieved on 2/2014 from http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/.

[3] Nelson, T., (1996). "Closing the Nutrient Loop", *World Watch Magazine*, Vol. 9, No. 6, pp. 10-17.

[4] United Nations Food and Agriculture Organization, (2011). "Global Food Losses and Food Waste", Report, Retrieved on 1/2014 from http://www.fao.org/docrep/014/mb060e/mb060e00.pdf.

[5] United Nations Environment Programme, (2013). "Food Waste Facts", Retrieved on 2/2014 from http://www.unep.org/wed/quickfacts/.

[6] United Nations Environment Programme, (2009). "The Environmental Crisis: The Environment's Role in Averting Future Food Crisis", Retrieved on 2/2014 from http://www.unep-wcmc.org/environmental-food-crisis_62.html.

[7] National Resource Defense Council, (2012). "Wasted: How America is Losing Up to 40 percent of Its Food from Farm to Fork to Landfill", Retrieved on 2/2014 from http://www.nrdc.org/food/files/wasted-food-ip.pdf.

[8] United Nations Environment Programme, (2008). "Vital Water Graphics: An Overview of the State of the World's Fresh and Marine Waters", Retrieved on 2/2014 from http://www.unep.org/dewa/vitalwater/article186.html.

[9] U.S. Environmental Protection Agency, (2013). "The Importance of Water to the U.S. Economy", Retrieved on 2/2014 from http://water.epa.gov/action/importanceofwater/index.cfm.

[10] Nelson, T., (1996). "Closing the Nutrient Loop", *World Watch Magazine*, Vol. 9, No. 6, pp. 10-17.

[11] Ghosh, D., (1999). "Wastewater Utilization in East Calcutta Wetlands", UWEP Occasional Papers, pp 36-56, Retrieved on 2/2014 from http://dhrubajyoti.brinkster.net/publ/OP_calc.pdf.

[12] U.S. Environmental Protection Agency, (1993). "A Natural System for Wastewater Reclamation and Resource Enhancement: Arcata, California", Report, Retrieved on 3/2014 from http://yosemite.epa.gov/water/owrccatalog.nsf/9da204a4b4406ef885256ae0007a79c7/aca69b66acdb47b885256b0600722f8a!OpenDocument.

[13] California State Water Resources Control Board, (1995). "Resolution 95-84: Water Quality Control for the Enclosed Bays and Estuaries of California", Retrieved on 2/2014 from http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/1995/rs1995_0084.pdf.

[14] U.S. Environmental Protection Agency, (2013) "The Importance of Water to the U.S. Economy," Retrieved on 2/2014 from http://water.epa.gov/action/importanceofwater/.

[15] Yarris, L., (2011). "Berkeley Scientists at AAAS Highlight Challenges of Meeting State Energy Goals by 2050", Retrieved on 2/2014 from http://newscenter.lbl.gov/feature-stories/2011/03/01/berkeley-scientists-at-aaas-state-energy-2050/.

[16] Cahill, R. and Lund, J., (2013). "Residential Water Conservation in Australia and California", *Journal of Water Resources Planning and Management*, Vol. 139, No. 1, pp.117-121.