BIRKHÄUSER

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OUT OF WATER

DESIGN SOLUTIONS FOR ARID REGIONS

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Foreword

Water has always been one of the strongest driving influences for structures in both the natural and urban environments. Societies in arid and desert regions maintain powerful and deep-rooted cultural narratives about water. It is such a significant resource that people in some desert regions actually use numerous words for each of the various manifestations of water—perhaps unsurprisingly, since every drop counts.

Water events can effect dramatic changes to such fragile landscapes. Although a prolonged period of aridity ultimately creates a desert landscape, the character of desert morphology is nonetheless influenced by the flow of water. Water reshapes topography through erosion and sedimentation, digs new *wadis*, carves out rock formations, and alters the structure of plains. What is considered an ordinary rain shower in a temperate climate may temporarily transform a barren desertscape into a flowering paradise. Seemingly overnight, the dryland turns into a bustling hub of animals, insects, and plants, brightly colored and emitting exotic scents and fantastical chirping sounds. This transformation is among the most magical that one can experience in the desert.

There are critical questions at hand about climate change and other man-made alterations to natural water systems. Increasing urbanization of arid regions and the gradual desertification of formerly non-arid regions urge us to ask the questions: How should water be understood in relation to human habitation? What relationship should exist between natural water systems and urban water infrastructure in arid regions?

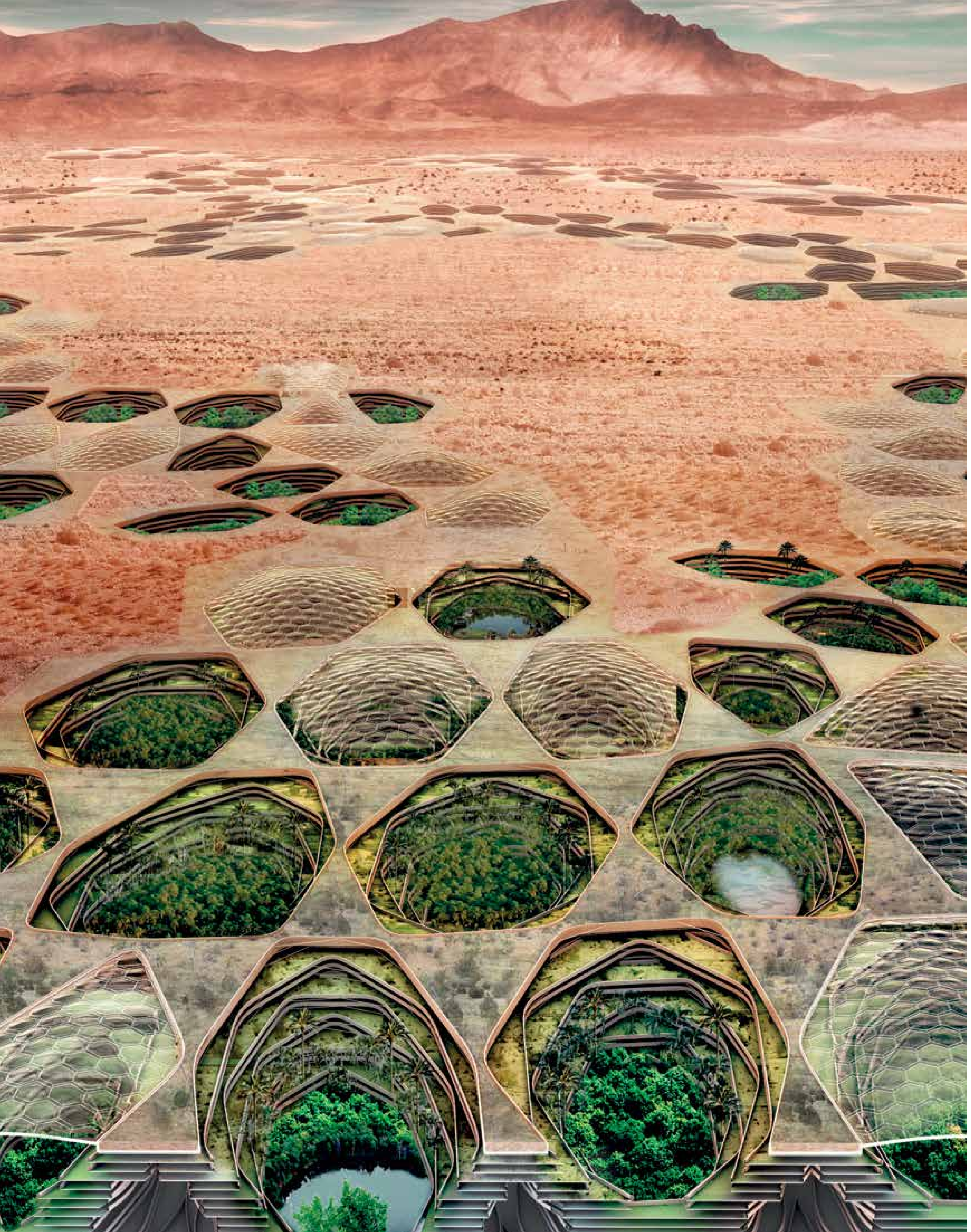
To explore these questions effectively, we must consider the social and technological aspects of human habitation as intertwined systems. All cultural values, practices, rituals, and beliefs, including those that influence food production, trade, and craft, have an impact on how water is perceived and managed. In order to evaluate the relationship between human habitation and water, we need to understand the priorities behind the regulation of water quantity via storage and supply systems, as well as how water quality is improved by way of filtration. A lack of appropriate water management systems and practices reflects a failure of sustainable human development and of any related design agenda.

Water research and development today focuses primarily on water engineering, such as development of mathematical models for hydraulics, flood risk analysis, and energy efficiency. Although we have acquired a sophisticated array of engineering tools and planning instruments to modify and modulate water, we have done very little research into how urban communities in arid zones can co-evolve with their fragile environments, and with ongoing water shortages. The main challenge, in my view, is *not* a lack of technological know-how, but a lack of integration between technology and urban design, and a shortage of multi-functional design strategies that can address a variety of often conflicting requirements.

Based on my 30 years of experience studying and working with water in a diversity of regions and climate zones across the globe, I have come to realize that traditional engineering solutions often fail to address the issue of extreme water variability in arid regions. Therefore, we need to develop a new approach, in the form of a multi-disciplinary conversation which includes the perspectives of city planning, urban design, landscape architecture, architecture, material technologies, engineering, policy, and community capacity building. Perhaps most importantly, we would benefit from the creation of a stronger emotional and spiritual connection to water. This could be done with artworks that celebrate the value of water and designs that emphasize its boundless properties.

Out of Water: Design Solutions for Arid Regions showcases essays from a diverse group of experts, and features projects by innovative designers. These studies are strong contributions to key topics, such as the sustainable city, water conservation design, and best water management practices. By analyzing different case studies through drawings, diagrams, and text, the book brings theory into the realm of practice, and reaches a wide audience within the design world and beyond. This book presents new insights about water scarcity, and new strategies for keeping water-sensitive regions livable.

Professor Herbert Dreiseitl



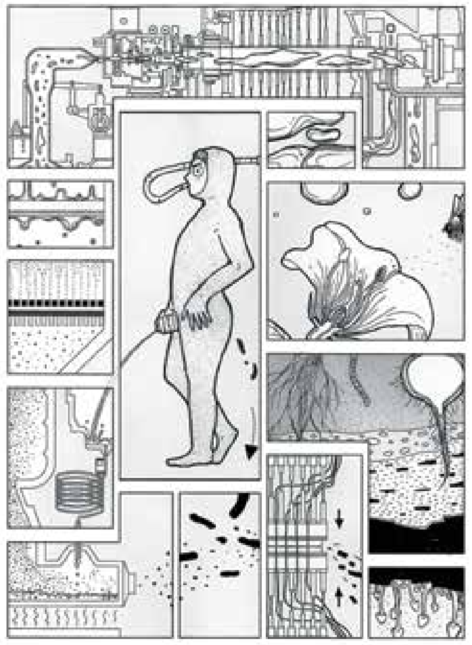


Figure 1: The "Out of Water" exhibition featured five mobile "toilet thrones;" viewers were required to occupy the toilet seat when reading the case studies. Self-conscious and slightly embarrassed by the invasion of privacy, the viewer was invited to reflect upon his or her individual relationship to water and accountability to wastewater cycling (top)

Figure 5: Inspired by David Lynch's 1984 movie *Dune*, architect Jimenez Lai's illustrated narrative "Super Earth" investigates the future of a water-less world (bottom)

Figure 3: Architect Andrew Kudless' "Sietch Nevada" proposes a new typology of underground communities to form around subterranean water storage canals in Nevada (opposite)

Preface

Based on five years of research, the preparation of and feedback from a traveling exhibition, and the output of a major conference, the results of the *Out of Water* project are represented here in a series of case studies and essays by international experts, including analytical drawings of both projected and implemented solutions. It may be helpful, in the case of this rather complex topic, to describe some of the project's background.

In 2008, architecture professor Aziza Chaouni invited me to collaborate on a design project in the Moroccan Sahara. Born and raised in Fez, Morocco, Aziza had cultivated an interest and expertise in desert tourism and rural developments. She had been working with the Moroccan Ministry of Tourism to develop design models for "eco-tourism" as a way to protect the delicate desert ecology and ethnic culture, prone as they are to the damage and stress associated with a booming tourism industry. We focused on the Drâa Valley, located at the edge of one of the largest oases in Morocco, which has been the home of nomadic and sedentary tribes throughout many centuries.

The Drâa Valley is 1,000km long, reaches from the Atlas Mountains to the edge of the Sahara, and is known as Morocco's "date basket." In the last 40 years, the Drâa Valley's oasian ecology and economy have been threatened by the rapid advancement of the desert dunes in the south, and ongoing desiccation of vast agricultural areas. This transformation is the result of two processes: climate change and man-made alterations to the natural flow of the Drâa River. The agriculture-based economy in the southern reaches of the Drâa began to shrink, defenseless in the face of ongoing desertification, and tourism began to take its place. Our charge was to develop new architectural and landscape models for tourism that would promote water conservation and reforestation as a means to reinforce the oasis edge.

As part of our continuing research, I attended the 2008 International Conference on Drylands, Deserts, and Desertification at Ben Gurion University of the Negev, Israel. The conference was a global gathering of scientists, industry and government representatives, international development aid agencies, and other stakeholders from over 60 countries, concerned about land degradation, sustainable use, and development in the drylands. Lecture topics ranged from agriculture and biotechnology to hydrology, desalination and water treatment, climate change, policy, and desert ecology. Over the four days of the conference, I took the opportunity to introduce myself to a number of presenters, all of whom were absolutely perplexed by my attendance: "What does landscape architecture have to do with water scarcity, land degradation, and climate change?" they would ask.

It immediately dawned on me that the gap between science, politics, and design with respect to water conservation and sustainable development still poses a great challenge to deeper understanding of these issues. I also noted that research efforts in architecture with respect to arid climates are largely concerned with thermal insulation and energy efficiency, while water is considered a given resource to be configured by science and engineering and governed by municipal and regional entities. Architecture, landscape, and urban design were not part of the conversation to discuss mitigating water scarcity and land degradation in drylands. This lack of communication and exchange meant that innovations in water engineering and agricultural science were not being carried over to architecture, landscape, and urban design. That struck both Aziza and myself as untenable, so we decided to address this lack.

Back in Toronto, we created the exhibition "Out of Water: Innovative Technologies in Arid Climates," intended to highlight the vital mechanisms of water flow and sanitation in arid climates. It featured a range of design proposals and built projects, and questioned their roles in contemporary design. In particular, we asked ourselves whether today's environmental preoccupation with water scarcity is actually discernible in the design of urban form. In the exhibition, 24 built and unbuilt case studies were visually analyzed for their approaches to the integration of three water processes: collection, treatment, and/or distribution. The drawings focused on how water management is embedded into design form, environmental function, and experience, while the case studies were selected to represent a diversity of scales and geographical contexts (Figure 1).

Figure 2: Landscape architect David Fletcher's "Age of Waste" envisions Los Angeles to transition from a watershed to a waste-watershed (opposite)

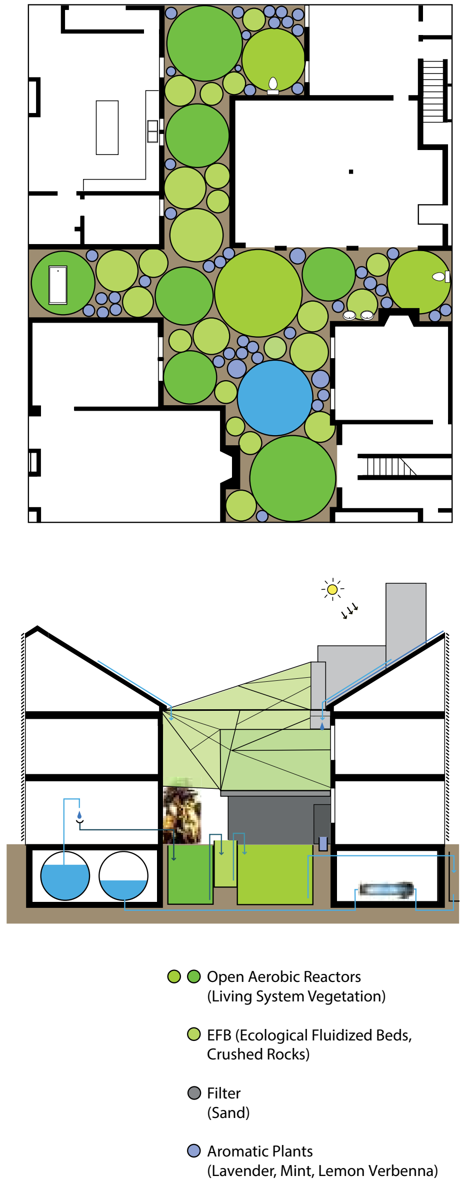


Figure 4: N-1 Architects and their team propose to invert the McMansion such that it ingests its own front- and backyard. Titled the Out-House, its ingested interior yard becomes an activated organic machine for the harvesting and recycling of water. The newly ingested yard is sustained by the bathroom—the site of human waste disposal becomes the site of production, providing the necessary nutrients for plant and organisms, which in turn clean the water. What was once the exterior of the house is now the most private zone

The exhibition also invited ten designers to imagine the future of arid cities, 100 years from now. David Fletcher, for example, imagined the incremental urban densification of Los Angeles, which in turn opens up vast areas for wastewater reclamation via reservoirs and wetlands. As sea levels rise, tidal energy is harnessed to operate desalination, as well as the distribution of reclaimed water (Figure 2). Andrew Kudless inverted the typical urban pattern found in Nevada, imagining an underground community structured around a network of subterranean water storage canals (Figure 3). N-1 turned the house and garden relationship inside out; they employed a biological system for the recycling of grey water in situ that would, in turn, provide interior cooling (Figure 4). And Jimenez Lai told a story of spaceship travelers who fled a parched Earth in search of fresh water, but who, in the meantime, depended on a mechanism that processed their bodily waste into potable water (Figure 5).

The exhibition attempted to speculate upon the relation between water technology and design and to reassert the designer's role in synthesizing the environmental and technical aspects of water systems in arid regions. The "Out of Water" exhibition generated enough interest to travel to six architecture programs across the U.S., so we felt the time was right to go a step further. We wanted to extend our conversations to specific fields of study beyond our own, and so open up a broader dialogue with other disciplines about the sustainable development of arid regions, in particular the natural and social sciences.

The result was the two-day conference "Out of Water: Sustaining Development in Arid Climates," a forum to discuss water scarcity and management in arid regions. The conference encouraged knowledge transfer among a diversity of disciplines with regard to methods and priorities.

The attendees consisted of 22 established and emergent designers, scholars, and scientists, brought together to evaluate currently implemented solutions with regard to their efficiency and geographic relevance. The disciplines represented included environmental law and water policy, public health, agronomy, hydrology, geography, building science, business strategies, civil engineering, landscape architecture, architecture, and urban design. Our primary objectives were, first, to identify applied and theoretical intersections among distinct areas of expertise; and second, to discuss the diverse definitions of water scarcity, technology, and transdisciplinarity. The speakers were selected to represent an array of arid and semi-arid regions, including Australia, Nepal, India, United Arab Emirates, Saudi Arabia, Jordan, Israel, Egypt, the Sudano Sahel, Morocco, Arizona, and Southern California. Despite regional similarities in climate, each project was unique both in the scale of the intervention and in the cultural, economic, and political contexts. The opportunity to transfer lessons learned across regions and disciplines was augmented by the opportunity to compare geographic specificities of arid regions.

- **You may ask: Why focus on arid regions?**
  The answer is clear; arid regions have had no choice but to mandate, innovate, and fully integrate water conservation modalities. From city planning to investment in engineering and infrastructure, to the redesign of building facades, societies in arid climates are faster to embrace a retrofit of their entire operations.
- **You may also ask: Why study water scarcity in non-arid regions?**
  Water scarcity is a symptom of a variety of factors, not only climatological but also anthropogenic, such as water diversion, over-consumption, deforestation, unsustainable agriculture, contamination, and failing or non-existent infrastructure. In fact, some of the world's wettest, most water-rich countries continuously rank highest in water scarcity due to the lack of infrastructure. Other water-rich areas that have reliable access to water and sanitation may be characterized by a general perception of abundance, often resulting in high water usage, and a lack of urgency to rethink water systems in order to make them more efficient and multi-functional.

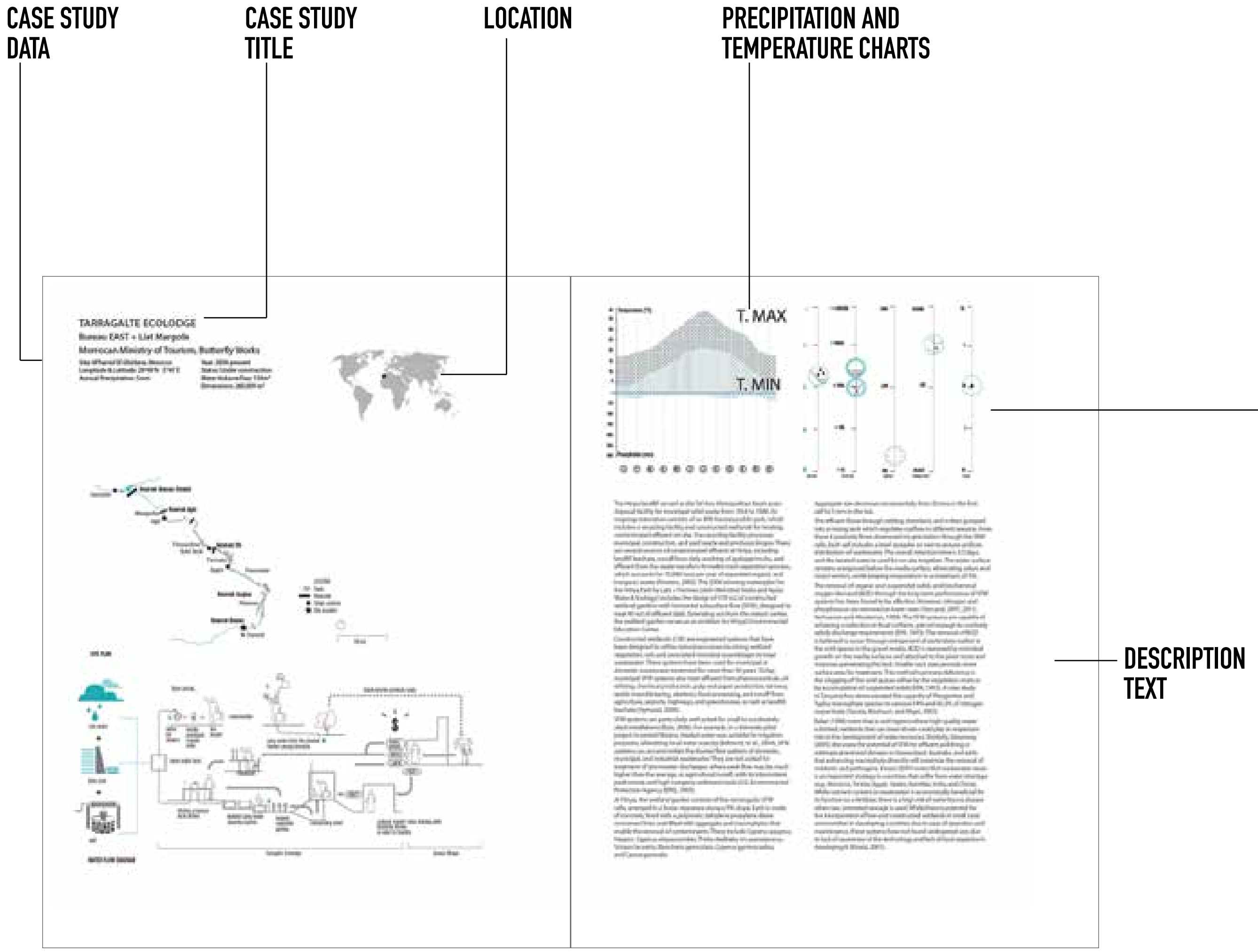
Arid climates are where necessity begets inventions that may serve as examples for action across a multitude of climate zones and geographies, examples that may soon be even more directly relevant in light of population growth, peak resources, and climate change projections.

We hope that this publication will create new insight about the development of sustainable cities, and inspire designers to exchange ideas and expertise with a broader set of academic and professional fields. The goal, as we see it, is to learn about new concepts, technologies, and materials, as well as to gain exposure to different methods and tools as derived from such exchanges. We are optimistic that this publication will engender new discussions within architectural schools and professional practices, and that these discussions will feature a greater range of approaches that landscape, urban, and architectural designers can apply in conjunction with their own specific professional skills and expertise.

How to Read the Case Studies

The case studies in this book are meant to support the essay contributions with built and speculative design project examples. The projects range in scale and geographical context. These are explored through an original set of architectural drawings and diagrams, generated by Margolis and Chaouni. The drawings are based on materials sourced from the respective design firms or institutions.

To support the main premise of the book, a legend of water quality and flows are represented in each project's drawings using a color legend. Each project can be read in terms of five gradients of blue; for example, the lightest blue represents potable water and the darkest blue represents contaminated/saline water. The case studies are also explored through an evaluation matrix, which ranks from high to low energy use and quantity of water flowing through the project, and identifies the level of connectivity (e.g., regional, site, object) and scale (e.g., small, medium, large). Using icons, this ranking system is overlaid with additional information about the water input (i.e. the original source of the water) and water output usage (e.g., drinking, irrigation). The water output icons are marked by an additional blue ring according to the water quality legend (i.e. gradient).



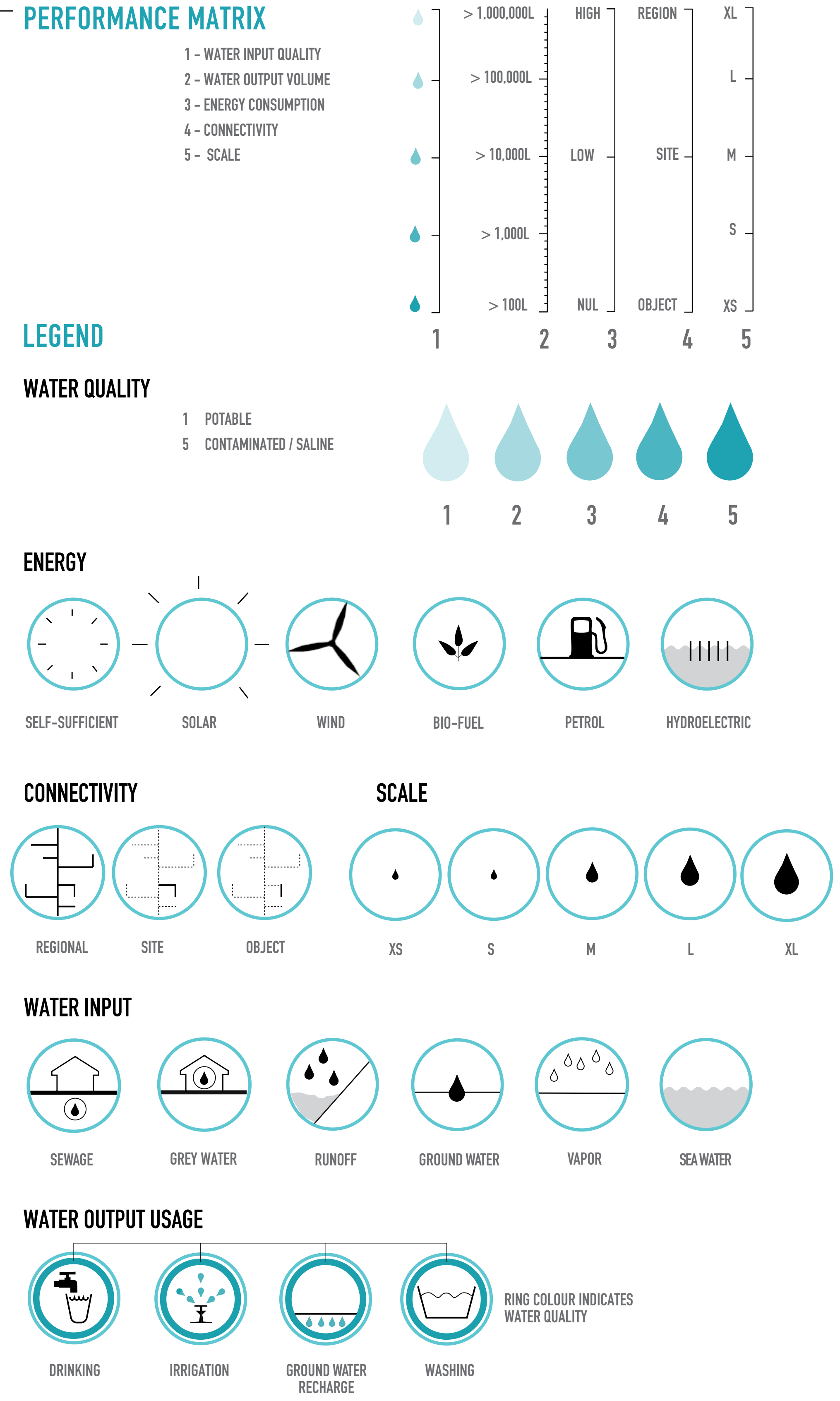


Figure 3: An aerial view of the Wadi Hanifah bioremediation facility

Introduction: Are We Out of Water?

On one level, this book is focused on contemporary technologies and design solutions to problems associated with water scarcity and fragile aquatic ecosystems in urbanized arid regions. The issues and projects discussed in the essays and case studies address the limited and unpredictable water availability—alternating from drought to flood, scarcity to surplus—and offering a window into the technological ingenuity that emerges from arid regions.

Yet the book's title, *Out of Water*, is meant as a provocation. Although the book highlights a growing crisis, its collection of essays and case studies actually demonstrates that water scarcity is a relative term—a condition that is contingent upon the interrelation between humans and water, and upon water management and technology. Therefore, the book is intended to provoke a new perception of water. Instead of framing water as a given and inert resource, and as a backdrop to habitation and development, it asks us to imagine new relations between availability (quantity and quality) and allocation, use and reuse; it asks us to imagine new relations between human habitation and aquatic ecosystems over variable time (daily, seasonally, annually) and spatial scales (site, neighborhood, watershed).

Water scarcity is becoming increasingly familiar to us, and it is no longer limited to arid regions. The 2014 U.S. Drought Monitor reported that more than 80% of California is now in a state of extreme or exceptional drought. In 2012, nearly two-thirds of the continental United States was in a state of drought, the most severe and extensive drought in at least 25 years, prompting the U.S. Department of Agriculture (USDA) to declare a disaster (USDA, 2012). Central and eastern Canada experienced equally catastrophic economic and environmental ramifications, also threatening food security (CBC News, 2012). Although arid and semi-arid regions have always struggled with prolonged periods of drought, now regions that were historically "wet" are experiencing record droughts. The arid belt is expanding. Some predict that drier and drier seasons are on the horizon. But it is the increase in demand due to population growth and mismanagement of water that is making the situation more controversial. Waterlessness is not only defined according to its climatic context, but also by its socio-technological milieu. In fact, water should be reframed as a factor of natural-social-technological dynamics (Bakker, 2012).

Along the same lines, water technology requires a broader definition that goes beyond its association with engineered or mechanical solutions. Water technology must be considered as a set of strategies that value the benefits of natural system functions, such as the capacity of aquatic and vegetal ecosystems to regulate water flow, cool ambient air, and provide green open spaces for public recreation within cities (Larson, et al., 2013). At the same time, technology should be understood in the context of a social dimension, for example, the ways in which technology can be mobilized under varying centralized or distributed social structures. In that regard, technology encompasses a range of expert (high-tech) and non-expert (low-tech) solutions.

The essays and case studies represent perspectives from several science, engineering, and social science fields. We believe that it is the designer's role to mediate, translate, and synthesize the range of approaches and priorities of the natural, social, and engineering sciences. Moreover, it is the designer's role to communicate to a broader public and to decision-makers the possibilities of implementing, or integrating new solutions. Finally, it is also the designer's role to engage the public in imagining new societies, new communities, and new ways of defining water, both culturally and physically (Nassauer, 2013).

Water Scarcity and Desertification

Two terms, water scarcity and desertification, merit a brief description, as the approach taken in this book differs from the standard approach to water management and urban planning. In the standard approach, municipal potable water supply is distinct from the environmental management of streams, rivers, and lakes, and also distinct from agricultural irrigation, which typically takes place outside of cities. By contrast, the essays and case studies in this book take as a starting point an interest in "integrated urban water cycle planning and management,"

Figure 1: The Wadi Hanifah's naturalized channels employ check dams to attenuate water flow (bottom)

Figure 2: Wadi Hanifah has become a poplular public park and a civic destination (top)

which is defined as an integrated management of waterways, groundwater, stormwater, wastewater, and potable water supply, a comprehensive urban and regional strategy (Wong and Brown, 2009).

Water scarcity is the outcome of a complex set of factors, and is therefore defined through different models and priorities. One of the most common models, which is known as the "Falkenmark indicator" or "water stress index," measures the amount of renewable fresh water availability per person, per year (Falkenmark, 1989). Although straightforward, this method fails to recognize differences in water availability and water use habits from region to region within one country, or accessibility to water resources (e.g., deep aquifers), or man-made sources (e.g., desalination; Rijsberman, 2006). Another model defines water scarcity according to a criticality ratio, which is based on demand and supply, or annual water withdrawal relative to available water resources (Raskin, 1997). Yet, again, this model does not consider a range of water technologies such as desalination, or water treatment and recycling (Rijsberman, 2006).

Others maintain a wider assessment of water management, taking into consideration both physical and economic factors. For example, the International Water Management Institute (IWMI) defines water scarcity according to each country's water infrastructure and technologies (e.g., desalination, water recycling) as well as its adaptive capacity, the potential for infrastructure development and improvement (Seckler, 1998). This enables an assessment of economic investment relative to water demand (Molden, 2007). Water scarcity is also measured according to the "water poverty index," which is better suited for analysis at a local level, since it takes into account income and wealth in relation to water access, quantity, quality, and variability, as well as water uses for domestic, food, and productive purposes, the capacity for water management, and environmental conditions (Sullivan, 2003).

There is no single definition for water scarcity. Water scarcity in hot arid regions is largely affected by low rainfall and prolonged droughts (see essays by Lee and Wescoat). Water-intensive agricultural and over-extraction of ground water are also common factors (see essays by Chaouni and Masoud), as well as environmental degradation (see Wadi Hanifah case study), contamination (see essay by Baker and Ngai), damming, and diversion of surface water (see essays by Chaouni and Masoud). Economic water scarcity typically manifests in an absence of water and sanitation infrastructure (see essay by Baker and Ngai), failure to upgrade aging infrastructure (see Isla Urbana case study), or inappropriate water management practices (see essay by Pasternak and Woltering), all of which are directly correlated to poverty and hunger.

The term "desertification" is defined as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities (United Nations Convention to Combat Desertification [UNCCD], 2014). It is interrelated with water scarcity, as the same factors that contribute to water scarcity (e.g., water diversion, deforestation, soil erosion, climate change, unsustainable agricultural practices, etc.) result in land degradation. Regardless of the semantics, what is pertinent here is that water systems must be understood in the context of their broader ecological systems, both natural and constructed, specifically in relation to plant ecology and soil.

Water for What?

Globally, we are not out of water. In fact, there is enough water for present and future needs for drinking and food. But as Antoine Picon notes in his opening essay, water is not where, or when, we want it to be. Nor is it in the quality state that we always want it to be, but instead salty or contaminated. The first paradigm shift suggested by this book is that attention should shift from availability to quality of water. As Eilon Adar states in his essay: "There is no water deficit, but a deficit in high water quality." By reframing the questions—what is water used for, what is the required quality state, and when is it needed?—water can be perceived in a much more nuanced way, a valuable resource in all of its quality states.

The main thematic thread running through the essays and case studies in this book articulates a new, or expanded water vocabulary: there is not just one water, but a gradient of water qualities. In other words, in addition to conventional fresh water resources (lakes, rivers, aquifers), non-potable water sources (seawater, contaminated surface runoff, grey water, vapor) have become viable by means of a variety of treatment processes, including the relatively new reverse osmosis (see essay by Tal), but also the traditional sand filter (see Kanchan Arsenic Filter case study) and the well-known principle of vapor condensation (see Vena Water Condenser case study). Consequently, total available water has increased.

The vocabulary of water ought to exceed the binary mode of water and sanitation at either end of the pipe, which is still the primary model that dictates the relationship between water and city in the developed world. In most cities today, stormwater runoff is not collected for reuse. Furthermore, in cities with water and sanitation infrastructure, greywater reuse is commonly disallowed rather than mandated or incentivized. Non-potable quality water should be allocated to various uses such as toilet flushing and irrigation in urban and rural areas, utilizing a dual water supply system with parallel potable and non-potable pipe networks. As a result, the pressure on diminishing potable water resources would be minimized, while wastewater discharge would be diverted away from natural water systems, reducing their environmental degradation.

Framing water in terms of chemical and biological quality requires not only a new organizational scheme to link a range of water qualities and use requirements, but also a comprehensive water calendar that takes into account natural water cycles in conjunction with non-potable water streams. In other words, what is the quality and quantity needed, and when? As James Wescoat describes in his essay, the design of arid land habitation has been traditionally structured around the variability between scarcity and surplus. The legacy of this design approach is rooted in water budget analysis and water conserving design, and in methods of regulating the presence of water according to temporality—frequency, intensity, and duration of weather events—as well as the spatial scale and physical attributes of a site—volume of water relative to topography, surface porosity, vegetation, and built structures. While having no water or too much water is often seen as a vulnerability, it can also be thought of as an opportunity to develop joint strategies for water management that mediate the two extremes.

Modifying the presence of water offers vast possibilities for design and for shaping both social and ecological systems. At the regional scale, for instance, municipal sewage offers a continuous source of water that can bridge the seasonal and annual gaps caused by drought with respect to both irrigation and hydro-ecological needs, including stream restoration and aquifer recharge (see Wastewater Treatment and Reclamation in Israel, Hiriya Landfill Recycling Park, and Taragalte Ecolodge case studies). The detention and attenuation of water flow on-site or within a riverbed via reservoirs, check dams, micro-catchments (see essay by Masoud as well as Wadi Hanifah and Wastewater Treatment and Reclamation in Israel case studies; Figure 1), and inflatable dams, as well as the mechanical distribution of water via pumps and channels, can be utilized to dissipate or attenuate water (see essays by Chaouni and Wescoat), and conversely, to intensify or concentrate water in specific areas.

Lastly, all the examples featured in this book point to spatial configurations and aesthetic potentials based in an understanding of the temporal and spatial scales of various water sources. At the urban scale, the regulation of an ephemeral river transforms a barren landscape into a civic destination (see Wadi Hanifah case study; Figure 2). At the site scale, a network of sunken courtyards or constructed open and covered reservoirs, in combination with planting geometries and materials selection, come to reveal the fluctuating levels of water, and the seasonal transformation of space becomes its aesthetic expression (see essay by Wescoat).

Design with Water: Integrated Water Cycles

The second paradigm shift that emerges from this collection of essays and case studies is a transition from an extremely utilitarian, single-purpose system to integrated or hybrid systems that are multi-functional—a kind of opportunism by a large number of interactions at multiple and nested scales (material, building, site, area, region, inter-region; Nassauer, 2013), which prioritizes a range of values (natural, social, technological) as follows:

- Effectiveness vs. efficiency
- Interconnectedness is more important than self-sufficiency
- Multi-objective optimization
- Diverse and redundant solutions generate resilience
- Adaptive and flexible water management

Effectiveness vs. Efficiency

Open-loop water and sanitation systems are indeed efficient. Potable water is delivered to a variety of end users, and sanitation infrastructure removes wastewater as quickly as possible, ensuring that there is no overlap with drinking water supplies. By contrast, a water management model that best exemplifies "effectiveness" is Integrated Water Cycle Management (IWCM). The central idea of IWCM is that the value of all natural waterways, groundwater, stormwater, wastewater, and potable water supply is assessed and managed as part of a comprehensive urban design strategy. A key component of this strategy is incorporation of closed-loop systems in which excess water or effluent becomes an input for new processes (Khouri, 2006).

One such closed-loop system, called Water Sensitive Urban Design (WSUD), is intended to manage the impacts of stormwater from development by integrating water cycle management into urban planning and design. WSUD considers, among other things, urban design, infrastructure design, streetscapes, roads, and drainage systems, and aims to protect and improve waterway health by working with the natural water cycle as closely as possible (Wong and Eadie, 2000).

In Australia, where IWCM is well established, the national water recycling guidelines include regulations for stormwater and wastewater reuse and have consequently reduced domestic potable water consumption significantly. The cycling of non-potable water resources is implemented through a dual water supply system: two parallel systems of which one supplies potable water for household uses such as drinking, cooking, and washing, and the other supplies recycled wastewater and/or stormwater runoff for toilet flushing and outdoor uses such as garden watering (Lazarova, et al., 2013).

Interconnectedness is More Important than Self-Sufficiency

Eilon Adar, in his essay contribution, offers an exemplary closed-loop model in the agricultural sector in Israel. At a business-to-business scale, networks of end-users synergistically exchange surplus low-quality water and residue. In effect, multiple end users utilize the same unit of water for their crops and operations. In parallel, 75% of all municipal wastewater across the country is treated and reused for irrigation in agriculture and parks, as well as stream restoration and aquifer recharge (see Wastewater Treatment and Reclamation case study). The unconventional idea here is that while urbanization can alter and degrade aquatic ecosystems and exacerbate water scarcity, urban effluent maintains a constant flow into otherwise dry river systems. The result is not only significant with respect to water conservation, but also to combined economic and ecological productivity, which arguably could not be realized at this scale without the interconnectedness of public and private entities.

These closed-loop agricultural models could equally serve as a reference for design thinking. Through the interconnection of end users in the city and beyond, new and unconventional pairings of urban land uses could emerge, which in turn could generate new architectural typologies, cultural or commercial programs, and amenities. This idea invokes a proposal by the architecture firm BIG (Bjarke Ingels Group) for a new way of thinking about a sustainable energy future for Denmark. Of course, the deployment of renewable energy technology, such as solar arrays or windmills, might be the first idea to come up and may be the most efficient. However, this proposal takes the position that rather than maintaining the idea of cities as consumers of energy, cities can be designed to be zero net energy. The BIG proposal offers a new approach to urban design that is based on interconnected energy users. For instance, they imagine new pairings of end users who produce excess heat with end users who require energy for heating. They couple supermarkets, which generate excess heat from refrigeration, with indoor swimming pools, which require heating. The new urban architectural typology could produce a scenario in which a parent is grocery shopping while their child enjoys a swim lesson at the pool. This level of synergy and opportunism can be extrapolated for water cycling in the city and the ways in which new programs and experiences could develop.

In addition to interconnectedness among end users, closed-loop systems at the urban and regional scales can also pertain to the interaction between urban water systems and hydrological flows or natural aquatic ecosystems. This type of interaction is defined by the term "ecosystem services"—physical, economic, and cultural benefits gained from the functions of ecosystems. Urban aquatic ecosystems can provide a range of such ecosystem services: as flood

Figure 4a: The bioremediation wetland garden and adjacent environmental education center with the Hiriya Landfill "mountain" in the distance (top)

Figure 4b: The wetland garden and environmental education center seen from the top of the Hiriya Landfill "mountain" during construction, Israel, 2007. The bioremediation garden is part of a complex of waste recycling and demonstration projects (bottom)

Figure 5a: The Solar Enclosures for Water Reuse (SEWR) are exterior building façade modules that decontaminate grey water via ultraviolet exposure for reuse within the building (opposite)

mitigation, erosion control, or the protection of property and human life, as well as water quality improvement and conservation, wastewater treatment, the creation of habitat, and provision of education, recreation, and aesthetic value (Larson, et al., 2013). Furthermore, the management of urban aquatic ecosystems also has a direct relation to urban energy management, as the presence of water within the urban landscape is imperative for such functions as evaporative cooling and subsequent reduction in energy consumption.

Multi-Objective Optimization

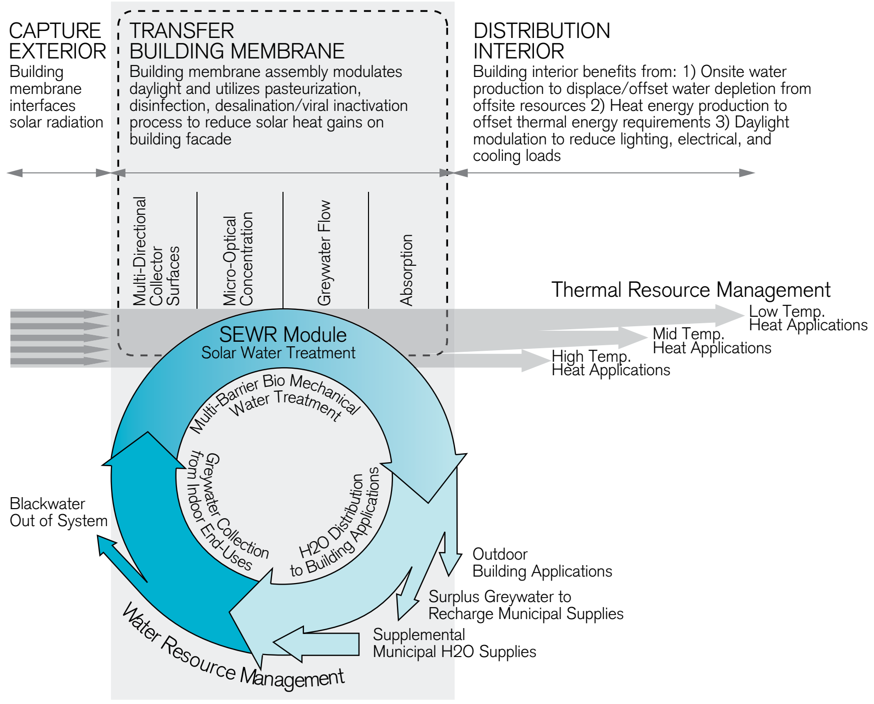
Integrated water cycle management is also characterized by solutions that are multi-functional. The Wadi Hanifah restoration project, for instance, diverts urban wastewater to a bioremediation facility, which also functions as a public park and a landmark for the city. This project demonstrates that although regional water cycling programs are typically legislated and operated by water authorities and affiliated engineering services, the shift toward multi-objective optimization at the regional and metropolitan scales offers designers and planner the opportunity to rethink emergent infrastructural landscapes as a socio-cultural, economic, and ecological extension of the city (Figure 3).

For instance, the network of wastewater treatment reservoirs in Israel that span vast agricultural valleys can integrate wildlife sanctuaries, recreational parks, and agro-tourism destinations, learning from case study examples such as Emscher Landschaftspark and Peter Latz's Duisburg-Nord Landscape Park (Weilacher, 2008). In fact, it is Latz's design at the Hiriya Landfill Recycling Park which gives context to the subsurface wetland garden featured in this book (see Hiriya Landfill Recycling Park case study). At a much smaller scale, this bioremediation facility serves as an extension of the park's environmental education center by meeting not only ecological objectives—water conservation, pollution reduction, and habitat forming—but also educational and aesthetic objectives (Figures 4a and 4b).

Masoud's proposal for the Jordan Valley, as described in his essay, blurs the line between urban and rural by conceiving of a new urban code for systematic integration of agricultural production and recycling of non-potable sources. His proposal visualizes water systems as a framework around which urban development, public space, water-sanitation infrastructure, ecological systems, and agriculture are organized. Here, natural, social, and technological systems converge as multi-use spaces that operate in a mutually beneficial manner.

Two projects under development that were presented as part of the "Out of Water" conference at the University of Toronto are evidence of similar trends in the field of architecture, with experimental building façades that utilize atmospheric elements to collect or recycle water. The Solar Enclosures for Water Reuse (SEWR) by the Center for Architecture Science and Ecology (CASE) are exterior building façade modules that decontaminate grey water via ultraviolet exposure for reuse within the building (Figures 5a, 5b, and 5c). Water out of Air Device (WOA) by Transsolar and Foster + Partners is a vapor condensation façade that incorporates a desiccant material to absorb humidity for reuse in irrigation (Figure 6).

Here, we may recall that the integrative model is not new, but in fact has been a part of recurring 20th century architectural debates about whether to camouflage or celebrate the innards of a building. One recalls LeCorbusier's famous hatred of tubes and his regretful conceit to hide them within his buildings; Reyner Banham's extreme embrace of the building's mechanical systems to the detriment of the rest (Banham, 1969); as well as the high-tech, postmodern, water-carrying green pipes exposed on the façade of the Centre Pompidou. These approaches never questioned the very necessity or functioning of these systems, but they did question their aesthetic expression and their position within theoretical discourses. In both SEWR and WOA, as well as in many of the essays and case studies featured in this book, focus on the interaction between environmental dynamics and architectural or landscape structure represents an interest in integrated and hybrid systems, requiring multidisciplinary collaboration across the fields of design, engineering, and the natural and social sciences.



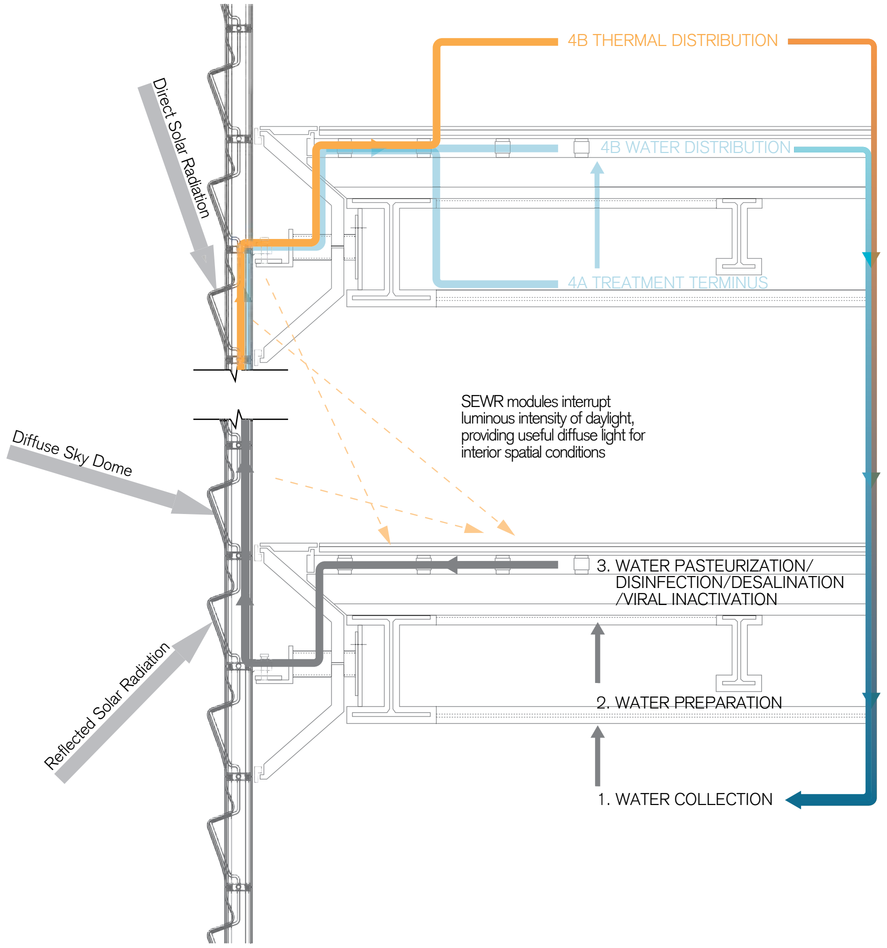
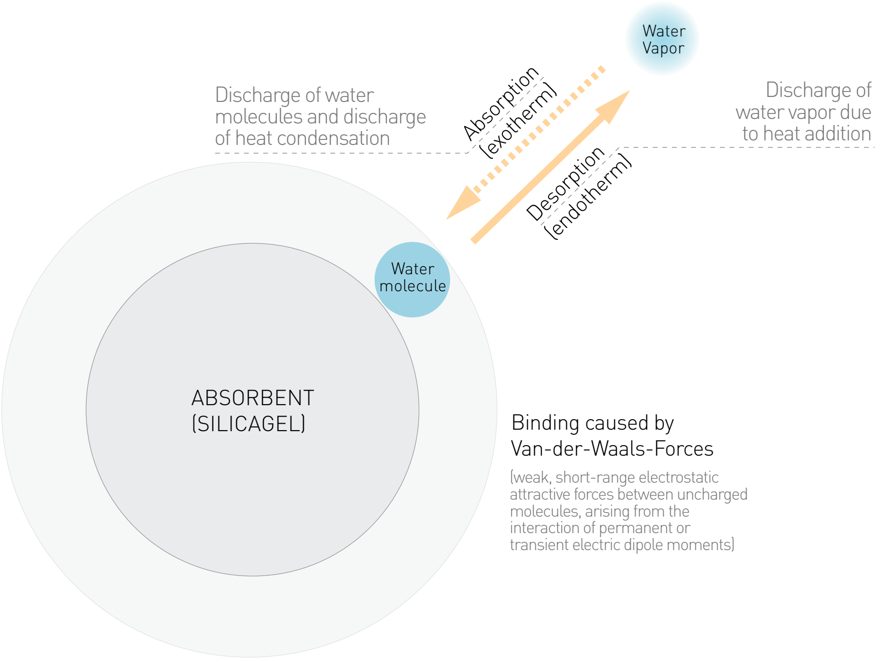


Figure 5b: Diagram of the Solar Enclosure for Water Reuse (SEWR) system's water and thermal resource management (top)

Figure 5c: Section-daigram of SEWR (bottom)

Figure 6: A diagram of the principle of absorption and desorption of the Water out of Air Device (WOA)



Diverse and Redundant Solutions Generate Resilience

A collaborative approach is key to achieving effectiveness, interconnectedness, and multi-objective optimization, as well as resilience to environmental or socio-economic changes. A collaborative approach, which includes a range of expertise, methods, and perspectives, implies the facility to develop a diverse set of solutions. Diversity could be manifest in terms of implementing multiple solutions at the various scales of region, city, street, and building. It could also manifest itself in different typologies, including mechanical-hydraulic solutions, ecosystem services, and social engineering strategies. Deploying a range of solutions also produces redundancy, in the sense of a duplication of various components or functions of xa system with the intention of increasing reliability.

The role of the designer is not only to glean information from the natural and social sciences, but also to communicate how design methods may offer new approaches to scientific research and practice. It is possible and important to embed design into the scientific lexicon in order to make use of every aspect and component of the urban realm—from streetscapes to buildings, gardens, and parks—in order to reconcile ecological and urban systems. For instance, the essays by Chaouni and Masoud highlight the important roles that landscape, urban, and architectural design can play in hydrologic analysis and projective modeling of water management (whose algorithms often include data from the fields of political science, economics, sociology, and geography, as well as hydrology, geology, ecology, climatology, and agronomy) in relation to sustainable urban development. These analyses are concerned with how water cycling could be made more effective with respect to ecosystem services, in terms of urban form (e.g., density, built vs. open and vegetated space) and construction (e.g., pervious vs. impervious surfaces).

Chaouni and Masoud also remind us that the designers have the capacity to envision new and unconventional scenarios and produce multi-functional solutions that meet both technical and cultural needs, and they are also able to identify forgotten or abandoned vernacular building practices that not only have high performance attributes, but also cultural significance.

Adaptive and Flexible Water Management

Inherent to diversity and resilience is the ability to adapt to changing conditions, or to easily compensate for gaps between supply and demand. For instance, mass migration into city regions often exceeds the speed at which water-sanitation services are implemented. According to the essay by Baker and Ngai, 780 million people in both urban and rural areas around the world still lack access to improved water, and 2.5 billion lack sanitation (World Health Organization and United Nations Children's Fund [WHO/UNICEF], 2012). Therefore, we must adapt water-sanitation technology and infrastructure to suit a variety of geopolitical conditions. This may result in independent or networked systems that are able to balance the gap in public infrastructure. These may be non-governmental strategies for in situ implementation of simple, non-expert, and low-cost technologies, whereby the individual is responsible to construct, operate, and maintain their water-sanitation needs (see essay by Pasternak and Woltering, as well as Kanchan Arsenic Filter, Liquid Wrap, Vena Water Condenser, Isla Urbana, Down to Earth, Hiriya Landfill Recycling Park, and Taragalte Ecolodge case studies).

The term "technology" is understood as "Technology" (upper-case)—expert, advanced, mechanical, intensive, and large-scale; but also as "technology" (lower-case)—non-expert, individual, community-based, grassroots, and small-scale. It is important to note that the two approaches to technology are not mutually exclusive and certainly not strictly associated with specific political scenarios. In other words, lower-case technology can be integrated in parallel to upper-case Technology as a means to increase resilience and redundancy. Likewise, Technology can be implemented at a small scale and modified from expert to non-expert practices. For example, Pasternak and Woltering describe how the informal (private) small-scale irrigation sector, which operates in a more market-driven fashion, has proven to be more profitable than more expensive formal-sector irrigation initiatives.

Also pertaining to the idea of flexible water management is the ability to customize the chemical-biological composition of water for each farmer according to specific crop requirements, discussed in Eilon Adar's essay. Although the economic and political contexts do not necessitate complete self-reliance, the example here demonstrates the possibility of evolving beyond the standard approach to the provision and cycling of water.

A theme that emerges here highlights the social dimension of lower-case technology. For instance, Baker and Ngai discuss methods of community capacity building through education and training. Both Lee and Chaouni emphasize the significance of local know-how of the landscapes and ecosystems within which they have lived for centuries. Wescoat also discusses the adaptation of reference materials with input from local expertise and site-specific data and proposes that vernacular water budgeting and crop cultivation could offer both technical and spatial models for contemporary design schemes. Lee and Chaouni lament the loss of memory with respect to water in the landscape, which affects the way urban development encroaches upon flood plains. Both argue that solutions must be comprehensive and engage the social and cultural dimension. Otherwise they are limited in their effectiveness; without being embedded within cultural and economic practices, lifestyles, and people's perception and understanding of the landscape they inhabit, they would be merely technical solutions (see also Nassauer, 2013). The Wadi Hanifah Restoration is a case in point as to how the transformation of a landscape can alter public perception, and vice versa. In fact, all the design projects featured in this book seek to either reintroduce a historical relationship with the landscape that was lost, or generate a new narrative.

Structure of the Book—An Overview

This book is organized into three parts that are specific to the relationship between water and human habitation, namely access to clean drinking water in the domestic environment (Part 1), agricultural production (Part 2), and ecosystem services (Part 3). These subjects are recognized as the most basic and fundamental requirements to human and environmental health and to the sustainable development of urbanized regions. Each part is meant as an assembly of diverse perspectives, socio-geographical contexts, and prevalent trends in progressive water management solutions.

Building upon recent publications such as *Resilience in Ecology and Urban Design: Linking Theory and Practice for Sustainable Cities* (Pickett, et al., 2013), *Water Centric Sustainable Communities: Planning Retrofitting, and Building the Next Urban Environment* (Novotny, Ahern, and Brown, 2010), *Water Sensitive Cities* (Howe and Mitchell, 2012), and *Resilient Sustainable Cities* (Pearson, Newton, and Roberts, 2014), this book is ultimately interested in the design and planning of sustainable cities—whereby the extreme problems that arid regions and regions lacking water-sanitation infrastructure face serve as a model for out-of-the-box solutions—and in the roles that architectural, landscape, and urban design can assume with respect to water management.

- **Part 1—Water For Domestic Use**
  The first part is primarily focused on two questions: 1) How can design integrate water collection, treatment, and cycling into the home or building? and 2) What components of the building structure or materiality can facilitate these functions? This part first challenges designers to move beyond the complacent position of accepting conventional water infrastructure and merely specifying water-conserving devices. The part encourages designers to take into consideration the quality of water needed for different uses (with reference to dual water systems in Israel and Australia), as well as the different governance and social structures under which water is managed. Environmental policy expert Alon Tal makes the case for the manufacturing of "new water" via desalination technologies. He uses the cases of Israel, Australia, and Spain to deliberate on the political and economic settings and changes in public opinion that made this technological shift possible. Camille Dow Baker and Tommy Ngai, of the non-governmental organization Centre for Affordable Water and Sanitation Technology, represent political and economic circumstances that necessitate self-reliance. In this context, water technology is defined as expert and non-expert, public or private, and multi-scale. The case studies in this part showcase built and proposed designs for water collection and treatment that could be implemented by non-expert individuals in conjunction with new or existing structures.

- **Part 2—Water for Agricultural Production**
  The second part focuses on the relationship between water and food in the context of contemporary design interest in urban food production and the integration of crop cultivation within the urban environment. In particular, it asks, what can the designer learn from the ways in which the agricultural sector has overcome water shortages? And can city regions develop a water management strategy that meets the synergistically unified agriculture, urban design, and aquatic ecosystems? Here, designers are challenged to focus their efforts on the transition to closed-loop urban water-sanitation systems, as well as to the systemization of new productive landscape typologies within the built environment.

  Hydrologist Eilon Adar opens the part with a call to reframe water as commodity, not a resource as a means to incentivize a zero-waste approach to water use in agriculture. He delivers a fascinating account of how one unit of water can be used by multiple end users, with high economic returns. Agronomists Dov Pasternak and Lennart Woltering describe the introduction of efficient irrigation technologies along with the optimization of crop selection for smallholder farms in the Sahel as a means to increase productivity and reduce labor. They demonstrate the advantages of the informal (private) small-scale irrigation sector over more expensive formal sector irrigation initiatives. Architect Aziza Chaouni contemplates possible future scenarios of a designated cultural heritage oasis in southern Morocco, with emphasis on the influence of urban development and tourism on water management. And finally, landscape architect Fadi Masoud offers a landscape urbanism approach for the integration of housing, open spaces, water-sanitation infrastructure, and agriculture along the Jordan River basin.

- **Part 3—Water For Ecosystem Services**
  The third part focuses on design strategies for water management that regulate and benefit from the limited and unpredictable availability of water—from drought to flood. In particular, the essays and case studies are interested in the mutually beneficial outcomes of integrating urban and ecological systems. The themes that emerge include the fragility of ecosystems and their interdependent culture and economy, the importance of local and vernacular knowledge of the landscape for present and future design and development, and the transformation of public perception of water in the city. Landscape architect Gini Lee discusses the significance of ephemeral water holes in the barren lands of Central Australia for a diversity of species habitats and the ways in which human communities have evolved. She argues that contemporary design and planning should be informed by an interdisciplinary understanding of the history of water and human habitation in the region. Landscape architect and geographer James L. Wescoat outlines the history of methods and tools for regulating the presence of water, from earthworks to sensor technologies. Drawing conclusions from case studies in India and the United Arab Emirates, Wescoat demonstrates how historical concepts can be adapted to modern water supply systems, and how these can generate the aesthetic and experiential characteristics of a site. The case studies provide examples of landscape design strategies that incorporate bioremediation and bioengineering techniques at various scales.

Water, Technology, and Society

The three parts inform an emerging design dialogue around water, technology, and society. As Antoine Picon notes, water technologies and management have a systemic character as well as a sociopolitical dimension as they force people to redefine theirrelationship to nature and technology. Hence, this dialogue is of a transdisciplinary character, which necessitates the inclusion of diverse perspectives, the development of a shared reference, and a broadening of definitions and concepts (Nassauer, 2013).

The roles of the architect, landscape architect, and urban designer are as mediators, by virtue of design, between political and social agendas at one end and the technological and organizational means at the other end. Landscapes, buildings and urban spaces offer visual and material evidence of the natural and cultural processes that produce and change dynamic environments. Their inherently integrative character enables the synthesis among different disciplines, decision makers, and stakeholders that is needed to affect change. As well, landscapes and urban spaces not only link everyday experience with other environmental phenomena that are invisible or not widely understood, but also mediate diverse environmental and technological functions and human perspectives (Nassauer, 2013). As such, design has the capacity to shape individual behavior and perception, and bring about a cultural adaptation that has the potential to propel political action.

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Figure 1: Pierre-Paul Riquet presenting to the King's envoys his project for the Canal du Midi at the watershed between the Mediterranean and the Atlantic, after a 19th-century engraving

Water, Technology, and Society: A Historical Overview

Antoine Picon

The following is an edited transcript
of Antoine Picon's keynote lecture
delivered at the "Out of Water" conference,
Thursday, April 1, 2011.

The management of water is among the oldest technological challenges to confront humankind. Its terms have been strikingly variable from one region of the globe to another. Whereas the abundance of water was often a problem for Northern Europeans in past centuries, it was its scarcity that represented the major obstacle to development in countries belonging to the dry belt, such as those in the Middle East. In any given region in the world, water could be at once abundant in certain conditions and for certain uses, and scarce in others.

What can we learn by looking at the relationship between water and technology from a broad historical perspective? Given the diversity of conditions, the topic is inexhaustible. Certain themes and perspectives must be privileged, and so two major historical threads are outlined in this essay.

The first concerns the systemic character of water management. From very ancient times onwards, water has been associated with technologies that possessed a decidedly systemic dimension. Until the 18th century, the European technological system as a whole could even be described as water-centered. History shows that, at times, profound crises disrupted these systems and technologies and forced them to evolve. From this perspective, our present-day incertitude is perhaps an early sign of a transition from current types of systems to new ones, the characteristics of which have barely begun to appear. One of the ambitions of this book may be to contribute to a better comprehension of these emerging features.

Yet, technology is only part of the problem. The second historical thread concerns the intricate links between technology's societal and political influences. Dating back to the most ancient periods, hydraulic systems have been the products and mechanisms of society and politics as much as of technology in a narrow sense. These social and political aspects are among the greatest challenges that we are facing today. Obstacles to technology and technological innovation are, of course, part of the problem, but the most pressing issues have to do with technology's socio-political implications. Following science and technology scholars such as Bruno Latour, the term "politics" here is used in a broader-than-usual sense. Water possesses a political dimension because it is a public resource and a public affair, and above all because its management and use force people to redefine their relations. We are definitely in need of a new politics of water.

Among the Oldest Technological Challenges

Management of water plays a seminal role in the development of technological expertise. In Europe, for instance, water management was among the key domains of early engineering. Besides the design and realization of waterways—the true high-tech enterprises of the Renaissance and 17th century—engineers also mobilized the power of water for fortification purposes. We tend to forget today how defense was, in many cases, based as much on water as on earthworks and masonry walls. Such was the case with the voluntary floods of the

Figure 2: Pierre-Denis Martin, *Vue de la Machine Marly*, view of the Marly hydraulic engine, 1783

Figure 3: Turbulences created by bridge piers (opposite)

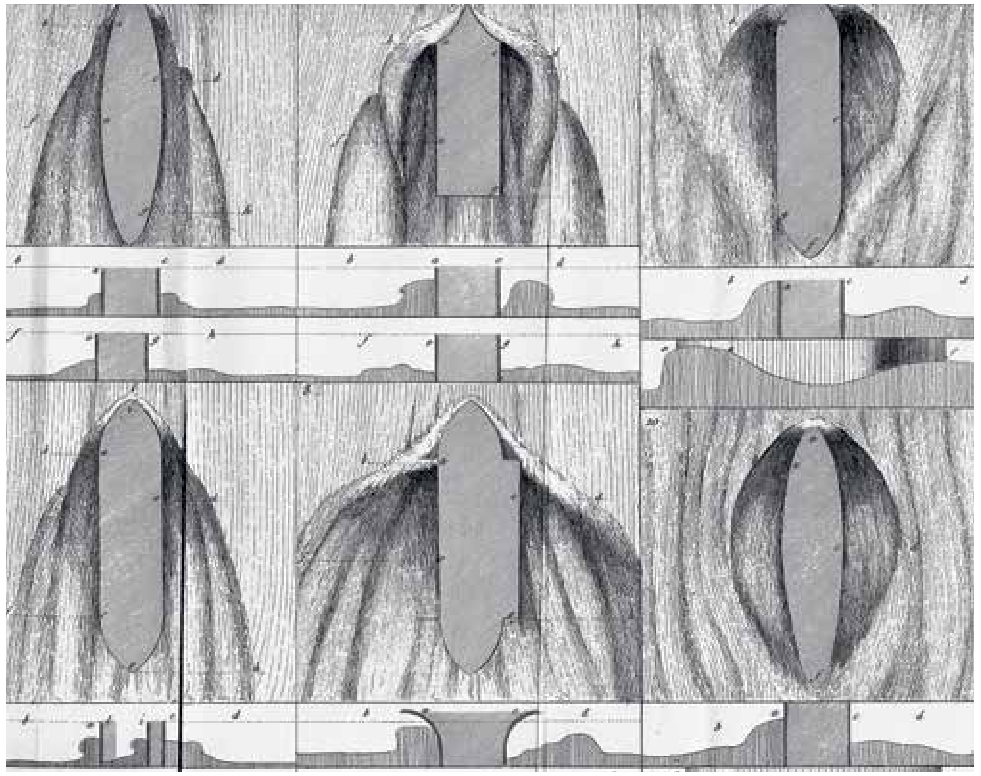
Netherlands, employed to resist the invasion of the French troops of Louis XIV in 1672—a tactic that epitomizes the defensive importance of water.

Until the mid-18th century, engineering was often presented as a discipline which was primarily focused on hydraulic problems; in fact, it was commonly known as "architecture hydraulique"(hydraulic architecture). In Charles D'Aviler's influential late-17th century dictionary of architectural terms, engineering appears under this denomination, as a sub-branch of architecture. Architecture Hydraulique is also the title of the 18th century's most important engineering treatise, by Bélidor, which was concerned with the art of conveying, distributing, and managing water for all of life's needs.

In the context of Northern Europe, one would readily suppose that the main problem was the abundance of water, rather than its scarcity. Traditional engineering design, such as that of Dutch polders and masonry bridges, seemed to evince a pressing need to resist the abundant flow of water. However, even in Europe, water was neither abundant nor scarce; rather, the issue was if it was where, and when, it was needed.

Take, for example, water canalization in Europe; for many years, the sole, rather ineffective, method to maintain water availability year-round was to waterproof the canals with clay. In northern France, for instance, canals were often dry throughout the summer and fall months. Moreover, the most strategic canals linked different river basins and watersheds, which meant that canals had to circumvent the ridges that separated them. Consequently, canals had to be designed to reach high elevations. Yet the higher the canal section, the more difficult it was to locate a water source. This was the main difficulty for the Canal du Midi of 17th-century France, which was considered at the time to be one of the masterpieces of French engineering (Figure 1). At one of its highest elevations, the canal passes through a plateau, where water supply is very limited.

The most spectacular expression of this relative scarcity of water is perhaps Versailles, where Louis XIV had envisioned a spectacular display of waterworks. One of the major works built to supply water to Versailles was the Marly machine. Considered one of the most impressive hydraulic engines built in early modern Europe, the machine had 14 paddlewheels, each about 38ft in diameter, turned by the Seine to power more than 250 pumps, all in order to send water uphill (Figure 2). Another massive waterworks, a giant aqueduct, was never completed, although construction involved the death of a few thousand workers. Despite the colossal works, which also included pumps, reservoirs, channels, and an aqueduct, the Sun King was never able to achieve his ultimate goal.



These two cases reveal that waterworks are seldom simple and linear. Even a canal requires multiple reservoirs and channels in order to supply it with water, reinforcing the systemic character of water management. The problems raised by water can seldom be apprehended in simple terms, such as overabundance or scarcity. The most common condition is actually that the right kind of water is not where it should be, which seems to be more the case today than ever before.

On the other hand, Middle Eastern engineers, whether Arab or Persian, were always confronted with scarcity. It is worth noting that in the Muslim world, water management was also at the core of emerging engineering competence, and for centuries was more advanced than its western counterpart. The realizations of the Cairo Nilometer and the Corduan Noria bear testimony to the level of sophistication, far before the technological rise of Western Europe.

Past these early moments, it is important to note the long-term influence of hydraulic considerations and models on the engineering field, far beyond hydraulics and water management proper. This includes the conception of flow within modern and contemporary engineering thought. This influence emerged during the 18th century and onward, when the laws of hydrodynamics were beginning to be better understood at both the theoretical and practical levels. For example, a relatively new idea at the time concerned the study of turbulence generated by bridge piers (Figure 3).

Modern engineering generalized the notion of flow, applying it to many elements both natural and human—from water in canals, to goods in the circulation systems of nations (Figure 4). Simultaneously, stagnation and stagnating water became synonymous with decay and unhealthy conditions. This was a spectacular inversion from the classical notion of optimum, which was static in essence; this is seen in medieval theology, where God is immobile and mobility is associated with imperfection. Dynamics became the norm, and with modern hydraulic models, strange ideas arose, such as the claim by Parmentier that the water that flows out of Paris is cleaner than when it entered the city—in direct proportion, paradoxically, to all the garbage thrown into it. As he explains in his 1787 dissertation “Sur la Nature des Eaux de la Seine”, water is purified by the movement given to it by what is thrown into it.

From the 18th century on, fluidic models have been found in all types of domains, from material engineering to network management. They are at the core of modern material physics, which is based on the assumption that forces literally flow in structures, and that strains are analogous to pressures. This is among the reasons for the rediscovery in the 18th century of the Gothic, where constructive techniques are based on fluidic conceptions of effort. This, too, remains characteristic of engineering thought. In the French case, this fluidic model permeates the general layout of the Haussmannian city, as well as the design of its gardens. Such is the case with Parc des Buttes-Chaumont, which was designed by engineers in a way that clearly bears the mark of a fluidic conception of the garden.

Today, however, one of the main challenges has to do with a very different notion: flows are not infinite. Thus, new conservation imperatives have arisen. To progress from a monomania with flow to a more complex understanding of hydraulic models, we may need to recapture a sense of the meditative character that was associated with water in so many traditional cultures. We must think about how we can reconceive water circulation while also rediscovering the lure of unproductive stagnation, which was not of interest to the rational, industrial mind.

Hydraulic Systems

The most important aspect of water management is its strong systemic turn; in other words, water technologies are strongly interdependent on each other. They constitute a coherent whole, linked by numerous feedback loops. This is especially evident in the case of irrigation, one of the first large-scale technologies ever invented, with origins that can be traced back to the sixth millennium B.C. in Mesopotamia and Egypt. Irrigation, and hydraulic works more generally, are principally about preserving water, which largely accounts for the systemic character of the technologies involved. In the case of irrigation, its relevance throughout history is also striking. A classic example is that of the shaduf, a mechanism for raising water, consisting of a pivoted pole with a bucket at one end and a counterweight at the other. Though it first appeared around 1700 B.C. in Egypt, it was still in use when the French invaded the country in 1798.

For centuries, water management techniques represented the core of the technologies in use by most societies; one could say that most traditional technological systems were, in fact, water-based. This is quite clear in the Middle East, but it also became the case in Western Europe, in a number of decisive steps. The Middle Ages in Western Europe were marked by a decisive water moment: the invention of the watermill to power the engine. Until at least the end of the 18th century, watermills remained the fundamental source of energy for all types of artisanal and proto-industrial fabrications. The importance of water as a source of power led to a very different manufacturing geography than the one that would prevail after the first industrial revolution; mountainous regions, such as the Alps, were often highly industrial because of the presence of numerous fast-flowing streams. Yet, this geography would again be radically altered by the development of the steam engine and railway (Figure 5).

Since the start of their discipline, historians of technology have been very aware of the systemic dimension of hydraulic technologies. It played an essential role in their early attempts to define precisely what a technological system was. In his 1934 *Technics and Civilization,* Lewis Mumford famously divided the evolution of technology into three distinct phases: “eotechnical,” “paleotechnical,” and “neotechnical.” The eotechnical phase is marked largely by early attempts at rational uses of water, particularly of its energetic power.

Figure 4: Abraham-Louis-Rodolphe Ducros, *Cascata delle Marmore*, Marmore’s Fall, Terni, Italy, circa 1785 (opposite)

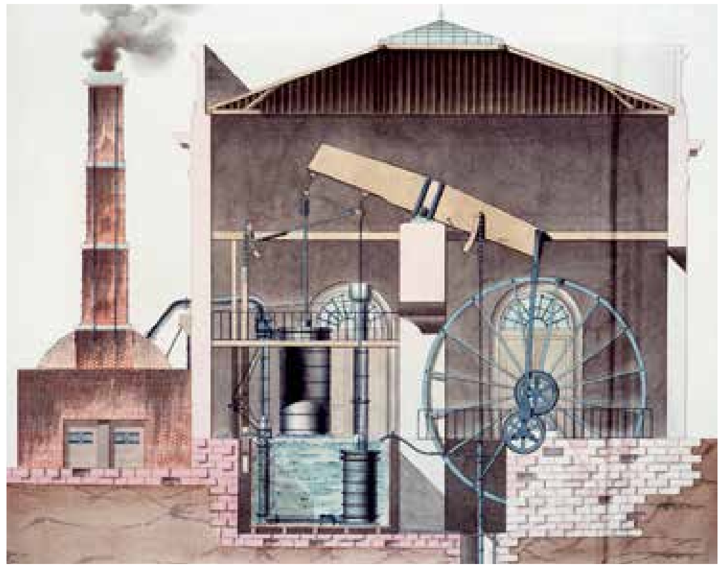


Figure 5: Watt steam engine, after the drawings made in England by Augustin de Betancourt y Molina, circa 1788

Figure 6: Nicolas and Jean-Baptiste Raguenet, *Joust of Sailors Between the Bridge of Notre-Dame and the Bridge au Change in Paris*, 1752 (opposite)

A few decades later, the founding father of modern French history of technology, Bertrand Gille, framed this evolution in terms of two different periods. He characterized the first as the period of classical and traditional technological systems, marked by the predominance of water, and the second as the period of the industrial system, beginning with the first industrial revolution of the 19th century. For Gille, the two essential components of the classical technological systems were water and wood. Water was the main source of energy, and its presence or absence determined the possibility of large-scale production and its geography. Water also acted as the main means of transportation, as there were very few roads until the 18th century, and navigation through Europe was mainly on water. The other element, wood, was by far the most important construction material, before brick or stone, and was also the main combustible. This meant that the productive geography of Europe was drawn at the intersection of water and wood resources. For Gille, water and wood technologies were constitutive of a system, because they were also highly interdependent and interconnected.

Ultimately, this water-wood system reached a limit towards the beginning of the 18th century, for a series of reasons. The main one was that its inputs and outputs were limited. There was only so much hydraulic power one could harness using waterwheels, and wood was also becoming depleted. For Gille, the first industrial revolution saw this fundamental water-wood coupling replaced by a triadic coal-iron-steam structure. This triad functioned in a series of feedback loops: coal fed the steam engines, which enabled the production of iron, from which steam engines were made, and they, in turn, made extensive coal mining possible by enabling deep underground water pumping. These three elements brought with them a whole new series of feedback loops and ultimately led to a totally different system, for which the geography was also very different. Coal, iron, and the steam engine were also responsible for the two major technological transformations of the time: the great textile mills of the Midlands, and the railway, leading to what has often been characterized as the transportation revolution.

This shift appeared to be the starting point of a massive change that would deprive water of its central technological role. However, in recent decades, historians of technology have become more nuanced in their assessment of how rapid the change was. First, water still continued to play an essential role in production and transportation for a very long time. It is worth noting that the industrial revolution itself was a revolution first linked to canal building rather than railways. This was, for instance, the case in England where, prior to the development of railways, a dense network of waterways and canals was developed from the mid-18th century onwards. This English waterway network included some remarkable engineering works, like the Pontcysyllte navigable aqueduct, completed in 1805. Waterways were just as important in North America, where canals were key to the development of the cotton economy in the South and played a crucial role in the growth and development of the northeast, as in the case of the Erie Canal.

More generally, the transition between systems was far more gradual than what either Mumford or Gille had in mind. In France for instance, steam engine power exceeded hydraulic power relatively late, in the 1860s. While the transition between systems took a long time, it is what happened during this transition that is important. Water began to lose its centrality in the 19th century, but it did not yet lose its importance. Furthermore, spectacular progresses and innovations were still made, making hydraulic energy far more efficient than in the past. For instance, with the 19th century came the invention of the turbine, which came to play a major role in the development of electricity. The turbine also led to one of the major uses of water in the 20th century: the production of electricity with hydro-powered dams.

The turbine, then, provides a good transition towards the return of major hydraulic work, led by the development of electricity. Examples of such large-scale hydraulic works were to be found everywhere throughout the 20th century, from France's Barrage du Sautet on the River Drac, built in the 1930s, to incomparable achievements like the Tennessee Valley Authority and the Hoover Dam. In some ways, water itself became less important, but dealing with it was still an absolutely essential problem.

If we consider waterworks in the context of landscape architecture, we can address the overall systemic character of what Bertrand Gille called the classical period and how it connected intimately with landscape. For centuries, hydraulic works had shaped landscape in a slow and methodical way. Irrigation techniques were emblematic of this patient remodeling, applied in a constant negotiation with the natural elements. In cases such as that of the famous Balinese terracing culture, the overall remodeling could involve extensive, massive reshaping, but nevertheless its methods are respectful of a certain equilibrium between man's constructs and nature, outlining a strong landscape dimension. This equilibrium had been maintained despite the development of engineering during the Renaissance and the desire to overcome the limitation of nature. Eighteenth-century engineers often saw themselves as gardeners of the territory. At the time, engineering students studying at the Ecole des Ponts et Chaussées continued to employ a pervasive presence of water and waterworks, from garden canals and fountains to harbors. Interestingly, 18th-century Ponts et Chaussées engineers were taught landscape drawing. Later, with industrialization, this equilibrium was broken, and it has disappeared completely in the brutality of the current relationship between infrastructure and landscape. This approach to infrastructural building can, of course, evoke sublime effects, yet ultimately it results in unresolved problems. Today's hydraulic works still shape the landscape, but, as is evident in projects such as the Three Gorges Dam in China, they do so with sublimity rather than with the traditional negotiation between nature and man-made work. Negotiation is certainly among the skills that we may have to learn again. Water management in arid climates could serve as a laboratory for this rediscovery.

Water and Cities

In cities also, water was, from early on, managed in systemic ways. A striking example of this was studied by French historian of technology André Guillerme, who showed how overwhelmingly present water was in the medieval and classical-age cities of northern France. Guillerme describes a multiplicity of "little Venices." In a series of plans, he compares the center of Venice to those of various northern French cities to illustrate how hydraulic systems were not only important for transportation, but also for industry and production, like that of tanning. Water was truly a complex urban system, situated at the locus where public and private realms met. The 18th-century Seine in Paris is a good example; houses sat on public bridges, so that the Seine was in a certain respect their backyard (Figure 6). This is a relationship that is likely to seem contradictory today.

At the dawn of industrialization, a series of changes occurred in Europe. First, water was made less immediately accessible, less familiar, more monumental and public. In Paris, this was a process that began with the destruction of houses on bridges, followed by the construction of embankments along the river. Water was also increasingly assimilated into technical resources and harnessed through technologies. Simultaneously, new challenges arose, such as the need to deliver more and better-quality water. This led to constructions such as the Ourcq canal, completed during the Napoleonic period. In essence, the old system was completely destroyed and gradually replaced by a very different one. This process of change in Paris lasted for 20 – 30 years, and quickly became emblematic of European cities in general. It also marked the emergence of a key notion in contemporary engineering and infrastructure thought: the network.

To return to the influence of hydraulic systems in modern and contemporary engineering thought, the notion of network is among the ways in which this influence has exerted itself. The notion has a definite hydraulic origin, relating to the idea of circulation in the body. At the onset, urban networks were literally supposed to irrigate the body of the city. This new regime went hand in hand with a series of new problems, such as water quality control and epidemic prevention. The cholera epidemics of the 19th century played an essential role in triggering this trend. In his famous map of London, Doctor John Snow illustrated a cholera attack in the Broad Street and Golden Square area in 1854. Snow mapped the houses struck by the disease and suggested that the contamination of a specific public pump was responsible for its spread. Accordingly, the pump was removed, and the plague stopped. Snow's discoveries about cholera led to a radical redesign of wastewater management in London. The new networked urban system for water functioned well for a large part of the 19th and 20th centuries. Today, however, we are likely on the eve of its demise, or at least of a major transformation for water in the city.

We can identify a few crucial factors related to the transformation of the networked water model discussed here. First, we have a growing desire to live in close contact with water, which challenges the place to which it was typically assigned at the dawn of the industrial era. The contemporary obsession with waterways is evident all over the world; for example, in people's tendency to migrate to the world's coasts, which raises difficult questions concerning flooding and sea level rise.

Second, traditional networks tend toward dysfunction. For example, a large amount of water is lost due to poor state of pipes and the difficulty of maintenance and repair. In France, which is far from the worst case, the loss of water averages around 25% in most urban water networks, reaching levels as high as 41% in cities like Nîmes. All kinds of catastrophes are generated and amplified by factors linked to waterproofing and network management. These issues have called into question the viability of large, integrated urban networks as the sole model and have spurred the emergence of smaller feedback loops, which work at a lesser distance and with a higher degree of interaction between urban and technological processes. For example, in the Hammarby Sjöstad district of Stockholm, tests are being done on a new model, which includes small-scale, interactive feedback loops among various types of networks. We may, once again, be on the eve of a major mutation in the way water is managed in cities.

A Political and Cultural Problem

The use of water has a clear political character. The politics of water exists beyond the narrow confines of ordinary political life. Its politics is what tends to generate social relations. Its politics is what may be a subject of concern and even disagreement between people. Its politics is also what tends to define and redefine individuals and their relation to the collective. Here, "political" is taken in the sense given to it by contemporary thinkers like Ulrich Beck or Bruno Latour. The impact of risk and catastrophe is an integral part of this.

Why does water have a political dimension? Throughout its history, the management of water has generated social relations. First of all, water is often rare, difficult to access, or erratic, and this entails coordination among different groups regarding its use. For instance, in 19th-century France, the function of water use coordination was given to the "police des cours d'eau" (water flow police), as well as to the bridge and highway administrations. Water is political, not only in moments of scarcity but also in moments of abundance and inundation, when land must be protected. The Dutch were seen as a political model because of their strong collective hydraulic management. This became one of the sources of inspiration for the 19th-century French reformer Frédéric Le Play. Having studied the polder flood-protection system, Le Play was convinced that this was the model to follow in order to reconcile modern technology with the collective spirit of ancient times. Hydraulics would remain an important subject for Le Play throughout his days as a social reformer. Later in his career, his philosophy became instrumental in promoting social geography, in which factors like the abundance and scarcity of water played a definite role.

Figure 7: Bathroom of the well-to-do in the United States, early 20th century

Le Play's approach is in striking contrast with one of the most famous attempts to connect hydraulics with politics: the notion of hydraulic empire, also known as hydraulic despotism. The terms were introduced by German-American historian Karl August Wittfogel in his 1957 book *Oriental Despotism* to characterize regimes whose strict control over access to water was their key to power. One of Wittfogel's most popular assertions is that several societies, including Ancient Egypt and Mesopotamia, established monopolies over water control in order to overcome water scarcity. This notion is still found in writings today, but like any oversimplifying thesis, it has been challenged. For example, Joseph Needham has argued that such political practices were not in fact adopted in China, as Wittfogel claimed. Nevertheless, the notion suggests an intersection between hydraulic technology and hydraulic management. One could even argue that technology and management are one and the same in the case of hydraulics. The diversity of perspectives outlined above suggests that technology is not deterministic, but that it raises issues that are political and need to be addressed as such. Regardless, one thing is certain: water management is typically aligned with a certain degree of centralization, whether despotic in nature or not. Hydraulic works are often linked to the existence of a powerful bureaucracy.

Emerging Challenges

Three pressing issues arise in relation to this centralized control of water. The first pertains to the ongoing tendency to privatize the management of water, including the provision of water services and sanitation. Bureaucracy used to be an instrument of the state, whether despotic or democratic; it is unclear what the state of water management would be following the increasing privatization of resources and services across the world. Would we see a new kind of hydraulic despotism in the name of global capitalism?

The second issue relates to the internationalization of water issues, a process that has been underway since the realization of giant infrastructural-scale works such as the Suez and Panama canals. Dealing with projects at the scale of the watershed increasingly requires the resolution of cross-border conflicts by policy makers, diplomats, and planners.

The last, and perhaps most insidious, issue has to do with the increasing individualism of today's lifestyles and the ensuing challenges. One aspect of globalization is that it has created a short circuit between individual behaviors and collective problems; the issue of water is a representative facet of this situation. Traditionally, water was seen as a large-scale and collective challenge; however, today, we are starting to see it as the object of a new dialectic between the individual and the collective. Toilets, for example, constantly remind us of how individualized and personal the question of water is today. The bathroom is fascinating, since it is the first technological room, far surpassing the computer room or kitchen in seniority (Figure 7). It is the first room where one's naked body encounters a large network of the city as a whole. The bathroom is in a strange place, at the direct interface between the individual and collective faces of water. This is also where our individuality and subjectivity in society has been shaped and reshaped. We are probably again on the eve of a new reshaping. As Ulrich Beck and others have pointed out, many contemporary issues can be effectively dealt with only if one takes into account individual behaviors. This is perhaps a true challenge for hydraulic technologies that used to rely heavily on bureaucratic coordination.

Beyond the realm of collective action, water technologies have always possessed a cultural character. Various historians of technology have drawn connections between the pervasive presence of slow and continuous hydraulic movement and a cyclical vision of time and human history. For these historians, the rapid, nervous, linear movement of modern steam engines marked the advent of a totally different system of cultural representations. Another set of cultural determinations has to do with the everyday use of water and how it has shaped our modern identity, from the possibility of running water in the kitchen to the use of domestic swimming pools, and from the Victorian bathroom to today's Jacuzzi. This is part of what is at stake today; we face not only a political but also a cultural adaptation.

1
WATER
FOR
DOMESTIC USE

Introduction: Beyond Low-Flush Toilets

Despite the staggering figures of water shortage worldwide, the provision of water within the domestic environment is a problem that is not nearly addressed enough in architecture, landscape architecture, and urban design. Whereas the topics of food security and environmental management, addressed in the following chapters, have become integral to design practice, the technical aspects of collecting, treating, and delivering water still remain within the purview of science and engineering, while issues of water governance fall under policy and economics.

At the building scale, projects attempting to address water scarcity in arid climates typically focus on water use and conservation standards (e.g., LEED, BREEAM). These performance benchmarks center primarily on the specification of water-saving devices, such as low-flush toilets, toilet dams, low-flow showers and appliances, combined toilet and sink systems, smart meters, and real-time water consumption feedback devices. The implementation of water conservation devices within the home has proven to decrease domestic water use by 30% (U.S. Environmental Protection Agency, 2014). That said, in many cities the reuse of wastewater, rain, or surface runoff within buildings is disallowed due to health concerns. Reuse in irrigation is somewhat more acceptable, particularly in agriculture, but still not a routine practice within the urban environment. The main question that this chapter raises is what the role of design could be in shaping water technology and management as it relates to the domestic environment and the individual user, beyond merely specifying water-conserving products.

It is important to first recognize the political context within which water flows through the urban environment. As such, the two essays and five case studies in this chapter depict two opposite, rather extreme, ends of water management. One is set within a context where the supply of water is deemed a human right and a public service and, thus, water and sanitation infrastructure is centrally governed and its quality controlled. The other is where water and sanitation infrastructure is non-existent. The latter context is typically found in the developing world, where tenuous economic and socio-political conditions frequently form the backdrop to a broad absence of public infrastructure, necessitating alternative approaches such as self-reliance and building capacity of local institutions and communities. Despite the contrast, both positions are first and foremost motivated by human health and survival at the most fundamental level. Water is life.

Two Water Scarcity Scenarios

Hot, arid regions that have water-sanitation infrastructure no longer rely on water conservation as the single answer to increasing demand caused by population growth and persistent droughts. As Tal describes in his essay “Technical Optimism as an Antidote to Water Scarcity,” over the last 20 years arid nations such as Israel, Australia, and Spain have been taking bolder steps to actually “produce” or “manufacture” drinking-quality water with technologies for desalination of seawater and brackish groundwater. Critiques of these countries’ approaches focus on sole reliance on a single mechanical technology, failure to diversify solutions and build in redundancy, emphasis on supply-side solutions that encourage wasteful consumption habits, and the valid concern around the adverse environmental impacts on marine biology, carbon emissions, and high energy dependency. However, the economics behind desalination outshine what are deemed as “surmountable obstacles.”

Tal’s essay, as its title suggests, represents a growing confidence in “upper-case” Technology’s capacity to overcome water scarcity (see Introduction for a discussion of “lower-case” technology vs. “upper-case” Technology). In all cases, the political, economic, and technological setting has allowed for the robust growth of the desalination industry. Despite public debates around associated environmental issues, Tal states that “recent experience in several countries offers an empirical basis for assessing the potential of desalination, which, along with wastewater reuse, might obviate the projected water shortages of the future.” Therefore, with today’s advanced technology, water is in fact “a renewable resource more than ever before.”

The opposite scenario is a complete lack of water-sanitation infrastructure, a scenario that, as Baker and Ngai discuss in their essay, currently affects over 780 million people. This condition is not exclusively associated with arid climates, but describes more broadly a prolonged state of water scarcity due to contamination. In such conditions, most evident is the unclear distinction between drinking water and wastewater. Typically, if water infrastructure is missing, so is sanitation, and vice versa. Two and a half million people have no access to sanitation services. Two point two million deaths every year, mostly children under 5, are attributed to diarrheal diseases due to ingestion of contaminated water. The collection and treatment of wastewater is therefore paramount to the improvement of drinking water quality and cannot be considered an independent problem. Importantly, the lack of both water and sanitation services has a direct corollary to underdevelopment and poverty (Side Note 1).

Baker and Ngai's essay discusses non-governmental strategies for in situ implementation of simple, non-expert, and low-cost "lower-case" technologies. The key principle is empowerment of local population and organizations through education and training, and encouragement of self-reliance, ownership, and leadership. While this may seem an insurmountable task, the essay cites the example of CAWST (which Baker co-founded), a non-governmental organization (NGO) which projects to help 20 million people with better water and sanitation by 2020.

Baker and Ngai describe a process of disseminating ideas and inventions that would otherwise remain strictly within academic institutions. They do so by acting as a two-way bridge between universities and research labs on one hand and with local NGOs and community leaders on the other. The local groups ensure widespread adoption of new solutions and practices, which in turn provides product testing and feedback to the universities.

Several case studies characterize the type of decentralized/distributed solutions that could address the lack or failure of water infrastructure. The Kanchan Arsenic Filter and Liquid Wrap technologies offer affordable and simple solutions to remove contaminants from unregulated water supplies. The former is typically built within a home; the latter is a portable and wearable vessel. Another small-scale device, the Vena Water Condenser, produces water from vapor through condensation. Isla Urbana and Down to Earth both collect rainwater and surface runoff, in barrels and underground cisterns respectively. These small-scale interventions, ranging in size from human- to household-scale devices, can be multiplied across a community, ultimately creating health or social impacts well beyond the individual appliance, as conveyed in the Isla Urbana and Down to Earth case studies.

The common drawbacks associated with such distributed, off-the-grid, do-it-yourself solutions concern lack of quality control, inability to regulate the level of contaminants in the sourced water, and unreliable commitment of individuals over the long-term. Nonetheless, despite their unquestionable benefits, centralized water infrastructure systems are also criticized today for 1) their lack of capacity to withstand and adapt to extreme weather events and environmental crises, 2) the prerequisite of functioning governance, 3) negative impacts on existing ecological systems, 4) lack of integration with public, or civic space, and 5) the fact that where water infrastructure is a public service, built projects habitually rely on the assumption that faucets, showerheads, hoses, and sprinklers are connected to a limitless piped supply of water.

A Gradient of Water Qualities

The two scenarios are generally representative of the predominant conditions and approaches to water management and technology around the world today. But rather than perceive them in opposition, perhaps a more productive approach would concurrently employ multi-scale solutions that comprise both expert "Technology" and non-expert "technology" as a multifaceted and redundant (fail-safe) urban design strategy.

The common thread between the essays and case studies points to two key design principles: diversifying water sources, and allocating diverse water qualities to a variety of use requirements. In other words, in addition to conventional fresh water resources (e.g., lakes, rivers, and aquifers), non-potable water sources (e.g., seawater, contaminated surface runoff, greywater, and vapor) have become viable by means of a variety of treatment processes, including the relatively new reverse osmosis, but also the traditional sand filter and technologies employing the well-known principle of vapor condensation. Consequently, the total available water is increased. The second principle involves the allocation of non-potable quality water to various household uses, such as toilet flushing or irrigation (Side Note 2) through a dual water supply system, thus reserving potable water for only such uses as necessitate drinking-quality water. Consequently, the pressure on diminishing potable water resources is minimized, and at the same time, the adverse effects of wastewater discharge are mitigated.

The idea that there is not just one water but a gradient of water qualities opens up new opportunities and trajectories for design. We would like to point to several case study examples that offer integrated design strategies to link regional water management and large-scale water technology with opportunities for design development at the building, site, or material systems scale.

Dual Water-Supply Systems

Israel and Australia represent the most progressive examples of an implemented dual water system at both regional and neighborhood scales. Israel recycles more than 75% of all municipal wastewater across the country for reuse in agriculture (see pp.142–145). In addition to a long-standing culture of water savings (e.g., use of low-flush toilets) and restrictions (e.g., prohibiting lawn irrigation during droughts), as well as desalination of 500 million m^3 of seawater per year, this has resulted in massive savings of potable water. The purple-colored treated wastewater pipes, distinct from the blue potable water pipes, are often seen in use also in municipal parks and gardens.

Such advances in water engineering and agriculture have yet to influence the ways in which architecture, landscape, and urban design are conceived, regulated, and practiced in Israel. New projects, let alone existing ones, do not frequently incorporate surface runoff collection for irrigation in park systems and urban gardens, nor do most buildings incorporate the reuse of treated wastewater for toilet flushing and other such uses where potable water is not required.

In Australia, Water Sensitive Urban Design (WSUD), part of an overarching concept called whole-of-water-cycle management, is intended to integrate the management of waterways, groundwater, stormwater, wastewater, and potable water supply as a comprehensive urban design strategy. The national water recycling guidelines include regulations for stormwater and wastewater reuse and have consequently reduced domestic potable water consumption by 40%. For example, Australia's Rouse Hill Recycled Water Network System Plan (Lazarova, et al., 2013) serves as a pioneering example for new developments. A suburb of Sydney, the Rouse Hill Project Area has implemented a dual water supply system. Two parallel systems are provided, a potable supply for household uses such as drinking, cooking, and washing, and a recycled supply for toilet flushing and outdoor uses like garden watering.

These groundbreaking projects, however, still only operate within the realm of hydraulic infrastructure such as the pipe network, and miss the opportunity to rethink the potential that the building and landscape could contribute at a site scale to increasing the overall water portfolio. The subsequent parts offer a range of design strategies for capturing and reusing water.

Increasing the Overall Water Portfolio

With nearly 15,000 facilities worldwide, often located along coastlines, desalination plants have an enormous footprint in the landscape. Public pressure around environmental mitigation and coastal integration has changed the approach to the design of desalination plants in recent years. Landscape and architecture play a key role. The Victoria Desalination Project (Australian National Construction Review, 2013), the largest project in Australia, produces 150 billion liters of water per year, and provides an exemplary precedent for a multidisciplinary collaboration between engineering, design, and ecology.

Driven by goals to minimize the ecological footprint and maintain the integrity of Victoria's prime nature tourism, the project's ambition was to seamlessly integrate the desalination plant into the landscape. Thus, the project team included green roof designers, architects, ecologists, and structural, hydrologic, and civil engineers. The roof of the biggest building on site (28,900m^2) is the key aspect of the design. Made up of 438 individual panels installed at 23 different angles,

1. According to a 2006 United Nations survey carried out in 177 countries, women and girls spend as much as five or six hours per day fetching water (a total of 40 billion hours collecting water each year), keeping girls out of school. The lack of working toilets in schools also deters girls from attending school, thus greatly limiting opportunities to improve their circumstances (Barlow, 2010).

2. The use of water for outdoor irrigation accounts for most of the potable water used in North America, while the largest amount of water indoors is used for toilet flushing (Mayer, et al., 1999). According to the U.S. Environmental Protection Agency, irrigation of residential landscapes accounts for more than a third of residential water use—more than nine billion gallons per day (U.S. Environmental Protection Agency, 2013)—while households located in arid regions such as Arizona use up to 70% of potable water for irrigation (Arizona Department of Water Resources, 2014).

the roof is designed to mimic the undulating sand dunes in the surrounding environment. The green roof vegetation comprises around 100,000 plants of 25 different species of indigenous ground covers, tussocks, and low-lying shrubs (Growing Green Guide). The project is also one of the largest ecological restoration projects undertaken in Victoria. The 263-ha site includes a 38-ha area dedicated to the buildings of the desalination plant, and a 225-ha area dedicated to ecological restoration. This ecological restoration area includes constructed dunes intended to provide visual and acoustic insulation, as well as wetlands, coastal and swampy woodlands, and new habitat for local fauna. Millions of trees, shrubs, grasses, and other endemic coastal scrubland species are being replanted across the site's open spaces.

An emerging area in the fields of architecture and building science involves the engineering of building façade systems to utilize their modular framework and interface with air and sunlight in order to collect or recycle water. The Center for Architecture Science and Ecology (CASE) at Rensselaer Polytechnic Institute (RPI) is currently developing a new façade system called Solar Enclosures for Water Reuse (SEWR). SEWR aims to conserve water through the development of a solar-collecting building envelope that transforms both solar irradiation and greywater into functional resources for reuse. The SEWR building envelope includes arrays of interconnected solar-driven greywater treatment modules. These modules provide both interior shading and passive daylighting through their optical surfacing. On-site water and thermal resource management intersect at the point of tertiary water treatment; ultraviolet light initiates photocatalytic activity to decontaminate and heat greywater for reuse within the building. End uses range from drinking and bathing to toilet flushing, irrigation, cooling, and heating. The SEWR system exemplifies the architectural integration of conventional and isolated plumbing with mechanical and electrical building components (Dyson, et al., 2012). Greywater treatment is made visible through a highly articulated and aestheticized design. The foregrounding of contaminated water reuse is also meant to provoke a new public perception of wastewater as resource, not waste.

Transsolar Klima Engineering is currently developing a vapor condensation façade called the Water out of Air Device (WOA). The façade is part of the Zayed National Museum in Abu Dhabi, designed by Foster + Partners, and demonstrates a collaboration between architecture and engineering. The coastal location of Abu Dhabi presents viable opportunities to augment water availability by drawing water from the air, which has high humidity levels (20–25g/kg).
At nighttime, a desiccant material (small silica gel pellets) absorbs humidity. The absorbent material dries during the day using solar radiation, resulting in condensation of the absorbed water on a cooler surface. The condensed water is then collected in a tank. The water is not potable, but suitable for irrigating the site's garden. With a total surface area of 16,000m^2, and with a relative humidity above 80% (22g/kg absolute humidity at 30°C air temperature), the façade is estimated to produce 32,000 liters per day. The water collected from the WOA device is completely decoupled from the interior water system of the building, but fully integrated into the façade's design.

Like net zero energy for buildings or sites where the total amount of energy used is equal to the amount of renewable energy created on site, net zero water is a standard intended to close the loop of water consumption. Net zero water means that the water consumed by a building or landscape does not exceed the water captured and produced on site. The above examples offer a middle ground between large infrastructural projects (e.g., desalination plants, dual water networks) and plug-in devices (e.g., low-flush toilets) that can allow designers expand their participation in urban water management, thereby giving agency to building structures and site design in the collection, treatment, and distribution of water.

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WATER FOR AGRICULTURAL PRODUCTION

Introduction: Water Equals Food

Water equals food. Conversely, water scarcity equals famine, which is inextricably linked to poverty and underdevelopment. Although agriculture accounts for 70% of all water withdrawn by the agricultural, municipal, and industrial (including energy) sectors worldwide (World Water Assessment Programme, 2012), there are 842 million hungry people in the world and 98% of them are in developing countries (World Food Programme, 2014). Three-quarters of all hungry people live in rural areas, mainly in the villages of Asia and Africa. Around half of the world's hungry people are from smallholder farming communities, surviving off marginal lands prone to natural disasters like drought or flood. Another 20% belong to landless families dependent on farming and about 10% live in communities whose livelihoods depend on herding, fishing, or forest resources. The remaining 20% live in shantytowns on the periphery of the biggest cities in developing countries. The numbers of poor and hungry city dwellers are rising rapidly along with the world's total urban population (World Food Programme, 2014).

Food demand is predicted to increase 60% by 2050, and at the same time, economic growth and individual wealth are shifting diets from predominantly starches to meat and dairy, which require more water. Furthermore, the distance food travels from field to fork along an extensive supply chain results in wasted food at each step along the way, which also equals wasted water (World Food Programme, 2014).

Another aspect to the relation between water and food is that agricultural practices are often associated with environmental degradation including, among many other negative impacts, the rapid depletion of aquifers and the degradation of aquatic ecologies as a result of over-extraction, damming, diversion, and contamination. Today, 250 million hectares of land are cultivated, which amounts to about five times more area than at the beginning of the 20th century. This exponential expansion is a key factor in the vast deforestation and decline of biodiversity worldwide, which results in recurrent flooding, erosion, and loss of viable agricultural land, not to mention loss of human communities.

Globally, we are not "out of water." In fact, there is enough water for present and future needs for food cultivation. Clearly, water availability and high agricultural productivity is not only a question of geographical distribution and climate patterns, but also a question of management and technology. The Sudano Sahel region, for instance, has ample surface and underground water resources, yet 80% of the population derives its income from rain-fed agriculture. A combination of drought, poor soils, and inappropriate crop selection results in low agriculture productivity and endemic poverty. As authors Dov Pasterank and Lennart Woltering demonstrate, a transition to irrigated agricultural practices, which utilize the existing water resources, is the necessary solution to alleviate famine and poverty. In contrast, irrigated arid and non-arid regions alike still depend on non-renewable fresh water resources as the primary water source. Here, a technological shift to desalinated water and/or treated wastewater would ensure a consistent water supply.

The Design Perspective

Given the recent interest in urban agriculture among the architectural design fields, the questions we wish to raise here pertain to how design can contribute to rethinking food production in relation to land use and water management, particularly in context of the above-mentioned issues, such as the redevelopment of rural areas and shantytowns, the environmental mitigation of aquatic ecosystems, and the integration of urban food production as a means to increase urban food security and water conservation.

This chapter invites a diversity of perspectives from the fields of agronomy, hydrology, and water engineering, as well as architecture, landscape architecture, and urban design, to open up a discourse around the following questions:

- How is water configured in urban agriculture today?
- What are some of the most progressive water management strategies for agriculture in arid regions?
- How can these approaches serve as design principles for urban design?
- Finally, what are the potentials for arriving at a unified water management strategy that would synergistically serve agriculture, urban design, and aquatic ecosystems?

Urban Agriculture

The topic of urban food production is at the forefront of contemporary architectural discourse. Several publications and conferences (Side Note 1) that investigate the relationship between food and cities have surfaced in recent years partly as a response to sustainability, namely issues of environmental mitigation and adaptation, human health, and social equity. Although urban agriculture is not a new concept or practice, the subject has evolved as an extension of design objectives such as smart growth that supports mixed land use developments as a means to achieve livable cities, the repurposing of urban dross and vacant lots, and the design of productive and performative landscapes such as constructed ecologies and green infrastructure. Urban food production ultimately addresses a life style question concerning the individual's stake in making decisions about where food comes from and how it affects one's health.

The subject of food production in urban contexts touches upon a vast array of technical and logistical details ranging from horticulture and greenhouses, to policy and business strategies, to community engagement. Within the discipline of urban design, the subject links to a lineage of 20th century Modernist visions for urban planning and ambitions for social engineering (Waldheim, 2010), as well as more contemporary Everyday Urbanism (Chase, Crawford, and Kaliski, 2008) which includes backyard kitchen gardens, community gardens, and farmer's markets. The focus is primarily on the transformation of built form and program. The efforts, thus far, have been in generating visions for a new life style and getting various stakeholders to buy into the general idea. Few publications have focused on analyzing the pro forma of urban agriculture and associated implications on infrastructure (e.g., increased water demand, potential for a dual water system), environmental impact (e.g., effect of fertilizer runoff on water bodies), and economic feasibility (e.g., labor, distribution) (see, for example, Viljoen, Bohn, and Howe, 2005).

Fadi Masoud critiques the superficial imagery that the New Urbanist model paints of "(an) agrarian landscape as a backdrop to settlement" for neglecting to consider and reconfigure water infrastructure. Masoud calls for an integrated water cycle management where water supply, stormwater, wastewater, and aquatic ecosystems are managed as interconnected systems that span multiple organizational, neighborhood, and regional boundaries, and where the flows and cycles of resources are embedded in architectural and urban code. Such a charge is important insofar as it shifts the focus from haphazard urban agriculture as it primarily manifests in the form of community-run gardens, and opens up a bigger question to decision makers about transitioning to closed loop urban water-sanitation systems and systemizing a new productive landscape typology within the built environment.

That said, the essays by Masoud and Chaouni highlight the important role that an integrated approach to landscape, urban, and architectural design can play in hydrologic analysis and projective modeling of water management in relation to food production. Designers have the capacity to envision new and unconventional scenarios and produce multi-functional solutions by synthesizing and materializing diverse sets of scientific data. The authors, however, encourage designers to collaborate with the natural and social science disciplines in order to quantify the performance metrics of their proposals. They also highlight the relevance of often forgotten, or abandoned vernacular building practices that not only have high performance attributes, but also have an ongoing cultural significance.

Closed Loop Systems

As Eilon Adar describes, a major shift in approaching water in context of agricultural production is to consider water a commodity, not a resource. Although contradictory to the notion that water is a human right with regards to drinking water supply, in context of the economics of food production, water as commodity means that its utilization is extremely efficient. Since every drop counts, farmers use a range of water qualities including brackish water and treated municipal or agricultural effluent, as well as efficient and smart (e.g. sensor activated) irrigation control methods. In effect, water's monetary value incentivizes invention and inventiveness, and a zero-waste policy.

A few nations have systematically replaced potable water with alternative water sources, including treated wastewater and desalinated water. Water conservation is further optimized through an industrial ecology approach, whereby water cascades through a network of end users to produce a closed loop system in which waste becomes input for new processes (by-product synergy, "waste-to-feed" exchanges), as well as smart irrigation techniques and appropriate crop selection.

Effluent reclamation and reuse on a national scale in Israel, for example, is highly effective in bridging the gap between demand and availability. Moreover, it is infinitely more reliable than annual rainfall thanks to the year-round supply of municipal sewage. The extensive treatment method, which includes stabilization reservoirs or constructed wetlands, is massive in size at the city-region scale but offers seasonal and multi-year storage which bridges seasonal and annual gaps of drought with the potential for constant irrigation and peak irrigation in the summer.

At a business-to-business scale, networks of end users synergistically exchange surplus low-quality water and residue. In effect, multiple end users utilize the same unit of water for their crops and operations. For instance, surplus water collected from peppers and tomatoes is redirected to a grape variety that can tolerate a higher level of salinity and benefit from the residual fertilizers. Brackish water is used in aquaculture and then reused for irrigation of a salt-tolerant olive tree. Surplus nitrate from ornamental fish cultivation is used for aquatic flowers, while the effluent from fish farms is used in date palm plantations. The final residue, sludge, is digested into methane and redistributed to the fish farms. In addition to achieving zero waste, each end user has the ability to custom-formulate the appropriate water quality flowing through their operation.

Technological Adaptation

According to Dov Pasternak and Lennart Woltering, the Sudano Sahelian region is not "out of water" but lacking in the appropriate irrigation technology. The region has significant quantity of underground and surface water, but less than 1% of its cultivated land is irrigated even though 80% of the population is dependent on subsistence agriculture. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) specifically targets millions of smallholder producers who currently use labor-intensive and wasteful manual irrigation methods that result in low agricultural productivity. Its African Market Garden (AMG) system is a kit comprised of a low-pressure drip irrigation that is complemented with suitable varieties of high-value vegetable and fruit crops. It allows small producers to have access to drip irrigation, usually limited to large commercial farms, thereby improving their productivity. This case demonstrates that the informal (private) small-scale irrigation sector, which operates in a more market-driven fashion, is more profitable than more expensive formal sector irrigation initiatives.

According to the World Food Programme, women are the world's primary food producers, yet cultural traditions and social structures often mean women are much more affected by hunger and poverty than men (World Food Programme, 2014). The AMG provides a return on labor that is 3 to 3.5 times greater than that of a traditional system, and 15 to 18 times greater than the average daily income in Niger. Aside from numerous benefits such as increased production, yield, and income, the kit reduces water chores usually assigned to women. It also reduces the labor required for irrigation by about 80%; this reduces the operation cost to the producer by about 40%, and allows women to fully participate in irrigated horticulture. AMG can triple yields in long-duration vegetable crops. Women could cultivate 10 times more land while spending half as much time in the garden as they had spent with the traditional system. As a result of this extra time, they had almost four times the earnings from non-agricultural activities as before. Water technologies often have impacts on the socio-economic structure of societies where they are used.

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1. Design publications: *On Farming (2010), Carrot City: Creating Places for Urban Agriculture (2011), Urban Agriculture: Growing Healthy, Sustainable Places (2011), Designing Urban Agriculture: A Complete Guide to the Planning, Design, Construction, Maintenance and Management of Edible Landscapes (2013)*.

Design conferences: 6th International AESOP Sustainable Food Planning Conference, Leeuwarden, The Netherlands, 2014; Global Urban Agriculture Summit, Bonn, Germany, 2014; Urban Agriculture Summit, Toronto, Canada, 2012; Food and the City, Dumbarton Oaks Research Library and Collection, Washington, DC, 2012.

Tool Kit: Food Production Issues for Project Design Briefs

In order to achieve the ambition to synergistically integrate food production with cities and aquatic ecosystems, designers must be provided with a tool kit, a set of criteria that can figure in design briefs. Some of these criteria are outlined below:

Conceptual Framework

- Water is a commodity and has a market value; water utilization is therefore highly efficient.
- There is no water shortage but a shortage of water quality and/or technology to efficiently collect and distribute water.
- Innovative technology and cycling of water can bridge the gap between availability and demand.
- Water cascades through a chain or network of end users to produce a closed loop system; the same unit of water is used multiple times.
- Automating operations (e.g., water collection, irrigation) can create significant savings in labor and increase overall earnings from non-agricultural activities for smallholder producers.
- Vernacular water budgeting and crop cultivation (e.g., quanats, seguias) can offer both technical and spatial models for contemporary design schemes.
- Analytical and projective modeling of water availability for both ecological systems and agricultural production could benefit from investigating the existing and potential implications of urban, landscape, and architectural form, technology, materiality, and environmental performance on water (e.g., water harvesting and reuse, pervious vs. impervious surfaces, preservation of canopy, urban density).
- Diversify the scale, type, and distribution of water solutions. Develop multi-functional solutions.

Water Collection, Treatment, and Delivery

- Distribute a variety of water qualities (potable, effluent, treated effluent, brackish) via different colored pipe networks.
- Each end user customizes water quality according to crop requirements.
- Conserve water, fertilizer, and soil through drip irrigation to deliver both water and fertilizer, confine root zone and reduction of percolation, and implement smart irrigation control (e.g., calculation of transpiration rates through the use of sensors).
- Adapt technology through testing from large-scale to small-scale operations (e.g., low-pressure drip irrigation is suitable for small plots).
- Use of alternative energy sources like solar radiation, gravitation, or artesian pressure to further cut down the costs of water supply.
- Construct attenuation reservoirs to collect runoff water, settle sediment, recharge aquifer, and store for irrigation during peak demand.
- Construct stabilization ponds and reservoirs for extensive treatment and storage of municipal effluent to provide constant supply and bridge seasonal and annual gaps in precipitation.

Planting and other agricultural activities

- Match crops with irrigation method.
- Select water-thrifty crops and crops that can tolerate low-quality water.
- Graft commercial crop species with salt-tolerant plant shoots.
- Identify unconventional agricultural activities (e.g., algae production) and potential use of by-products (e.g., sludge converted into methane for energy).
- Refer to traditional oasian agriculture for planting schemes whereby a tall canopy provides shade and evapotranspiration; mid-height fruit trees are planted below; and the groundcover consists of legumes, grains, and a range of vegetables.

Spatial Organization

- The spatial extent of wastewater reclamation can be local, regional, or inter-regional.
- Consider the potential overlap and synergy between hydrological structures and water-sanitation infrastructure (e.g., hydrological corridors can integrate wastewater treatment via bioremediation and public recreation space, while providing ecological habitat).
- Topography, geology, and microclimate variation form the basis for the organization of cities and land uses.
- Housing and streetscape design play a role in on site water recycling.
- Cluster and communal systems allow producers to benefit from the collective use of water, energy resources, land, purchasing, and marketing.

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WATER
FOR
ECOSYSTEM
SERVICES

Introduction: Urban Aquatic Ecosystems

The term “ecosystem services” refers to the benefits that humans gain from the functions of ecosystems, which are often assigned economic values. The Millennium Ecosystem Assessment has designated several categories of ecosystem services, which include provisioning (e.g., food, water), regulation (e.g., climate and water flow), support (e.g., nutrient cycling, pollination), and culture (e.g., aesthetic value, recreation, sense of place). With respect to water and cities, ecosystem services such as flood mitigation, erosion control, and the protection of property and human life, as well as water quality improvement and conservation, wastewater treatment, the creation of habitat, and provision of education, recreation, and aesthetic value, can all be derived from urban aquatic ecosystems.

At the same time, the extreme manipulation of urban aquatic ecosystems (e.g., damming, discharge of contaminated water to waterways), coupled with the increase of impervious surfaces and aging or inadequate water-sanitation infrastructure, results in degraded ecological functioning of waterways and increased risk to human life through flooding, water contamination, and so on (Larson, et al., 2013). Aridland aquatic ecosystems are all the more vulnerable to both natural and anthropogenic disturbances due to their limited and unpredictable water availability. The following three sections provide a framework for understanding the temporal and spatial scales of water availability in relation to existing and possible aridland habitation.

Hydrological Flux

One of the key attributes of desert streams and rivers is the high inter-annual variability in water flow availability (Larson, et al., 2013). Aridland aquatic systems are largely characterized by intermittent ephemeral water systems due to low precipitation and long periods of drought, as well as elevated temperatures and high evaporation rates. Equally severe is the infrequent yet voracious flooding that rapidly transforms the landscape from a dune scape or barren land to a surging river or a waterhole as large as a lake. Such conditions may also be further intensified with urban and regional development and infrastructure, as well as with changes to climate patterns.

The extreme hydrological flux between desiccation and flood, and consequent unpredictability in water availability, have influenced the way water in drylands is perceived. For example, Gini Lee’s essay in this part recounts the long-standing view of Central Australia’s arid landscape as a “hideous blank—a barren, alien, and useless place,” which “comes alive” once record-breaking rains fill inland waters and lakes with more water than has been seen for years. The primary theme that emerges here is the recurring loss of cultural and institutional memory of such profound hydrological transformation. This loss often results in the gradual encroachment of habitation into waterways during prolonged periods of drought. The Wadi Hanifah case study illustrates this phenomenon. With an unprecedented growth and rapid urbanization of Riyadh, Saudi Arabia, parts of the ephemeral waterways (*wadis*) were quarried and mined for construction materials, while other parts have been filled in to accommodate new subdivisions, roads, and infrastructure. Many areas had become dumping grounds for as much as 1,000,000m^3 of solid waste.

The southern reaches of the Drâa River (described in Chapter 2) convey a similar lapse of memory. The river had been significantly desiccated over the last 40 years due to both anthropogenic factors, such as construction of a dam upstream, increase of population and water demand, and rise in tourism, as well as natural factors, such as climate change. During the rain event in 2009, which was of a magnitude that had not been seen in more than 15 years, the tourist lodges built within the flood plain during this prolonged period of drought were washed away, and one fatality was reported. Children under the age of 15 had never seen a full river flowing through their town. Old men strolled along the river hand in hand, reminiscing of the last time the river was full.

Lee argues that in order to fully comprehend aridland habitation and associated technical or technological approaches to hydrology, we must first examine the etymological origins of technology as a synthesis of *techne* (skill, craft) and *logia* (knowledge). In other words, local knowledge of natural and constructed systems, both past and present, must be viewed as a crucial part of technology. In her work, Lee traces the character and coexistence of human and hydrological systems and the remnant structures that frame the landscape—bridges, overpasses, dams, towns, and cultivated gardens. She argues that in order to understand the arid terrain, one must look for these cues to fully comprehend and anticipate the location, quantity, and quality of water. Whether they are ancient or modern, man-made or geomorphological structures, the observation of landscape cues, Lee argues, has been an integral part of indigenous knowledge as a way of reading, inhabiting, and working with the landscape. It is a cultural knowledge and set of skills embedded within a community that should inform land use and spatial planning.

Another key attribute of arid landscapes is their fragility, both ecological and cultural. As Lee points out, the limited presence of critical refugia waterholes in the Central Australian landscape jeopardizes the existence of relict species that depend on the ecological habitats the waterholes provide. And while the rise in tourism has shifted government attention and funding to better protect these barren lands, the accompanying increase in water demand in turn puts additional pressure on their fragile ecologies. Aziza Chaouni's account of the Drâa Valley (see Part 2) describes the gradual decline of the oasian ecology, which has a direct and significant impact on human habitation, economy, and culture. Chaouni's essay and the Taragalte Ecolodge case study describe a process of desertification, or land degradation (Side Note 1).

Most importantly, the loss of ecological quality contributes to the loss of an integrated cultural knowledge; conversely, the ongoing cultural transformation furthers the ecological degradation. As a result, the ministerial solutions to the ecological problems are divorced from the ways in which people now inhabit and engage with the landscape. They are merely technical and isolated solutions to ecological problems (e.g., dune stabilization) but lack a comprehensive approach to aridland habitation, both past and present, and vernacular practices to manage flooding. It is no surprise then to identify the didactic aspiration of the Taragalte Ecolodge, Hiriya Landfill Recycling Park, and Wadi Hanifah projects. The aim to restore the ecological health of these landscapes is embedded in their commercial and civic redefinition.

In the same capacity that urbanization can alter natural hydrology and exacerbate water scarcity, urban effluent maintains a constant flow into otherwise dry natural water systems. In other words, urban water systems greatly alter the natural hydrological flux, and herein lies the potential to hybridize and integrate urban water management and natural hydrology as a synergistic system.

The case of Wadi Hanifah provides a good example. Despite the increase in water supply, due to stormwater runoff and sewage dumping from the city of Riyadh, until very recently the quality of the water was so poor that it was considered an open-air sewer. The massive restoration project, led by Moriyama and Teshima and Buro Happold, radically recovered this condition as both runoff and sewage are treated via a variety of bioremediation techniques. Fadi Masoud's essay on the Jordan River (see Chapter 2) describes a similar condition where decades of water diversion, low precipitation, and urban effluent have left the river a polluted trickle, although the 2013 restoration project has begun to remediate and replenish the river with desalinated and treated wastewater (Abdelrahman and Jägerskog, 2013). In the same vein, the River Restoration Project, described in the Wastewater Treatment and Reclamation in Israel case study (see Part 2), greatly depends on reclaimed wastewater supply to maintain surface flows in streams and, conversely, it diverts wastewater away from surface and subsurface water resources.

Tools for Water Conserving Design

The design of aridland habitation has been traditionally structured around the variability between scarcity and surplus. The legacy of this design approach, as Wescoat tells us in his essay, is rooted in water budget analysis and water conserving design, and in methods of regulating the presence of water. The idea is that while having no water or too much water is often seen as a vulnerability, it can also be thought of as an opportunity to develop joint strategies for water management that mediate the two ends of the spectrum.

Water budget analysis is the evaluation of water demand for natural and constructed landscapes with respect to temporality—frequency, intensity, and duration of weather events—as well as the spatial scale and physical attributes of a site, and volume of water relative to topography, surface porosity, vegetation, and built structures. The basic idea of water budget analysis, as Wescoat describes, is comprised of simple mass balance analysis of inputs (precipitation in various forms) minus outputs (evapotranspiration and runoff) plus change in storage (soil moisture recharge and discharge). This idea becomes more complex when applied over different time steps (e.g., daily, monthly, and decadal scales) and spatial scales (e.g., from weather station data at a point in space, to sites, regions, and global assessments). In that respect, water budget analysis today involves real-time monitoring of evapotranspiration and dynamic weather data via sensor instrumentation and online tools (Side Note 2), as well as irrigation design and scheduling that incorporates weather data and soil moisture irrigation control technologies. Approaching water budget analysis in this manner, Wescoat argues, defines it as a technology for water conserving design that links measurement, computation, and integrative analysis.

Yet, water budget analysis and water conserving design are also defined by age old practices that have been recently revived, ranging from rainwater and surface runoff capture in small to large reservoirs, the reuse of treated wastewater (often through bioremediation, for example using constructed wetlands), and the planting of native and drought-adapted species, also known as "xeriscaping" or "waterwise" planting.

This part's contributions provide examples for bridging the seasonal and annual gaps in water availability over a range of spatial and time scales. In the Wadi Hanifah case, hundreds of micro-catchment structures and planting swales were constructed throughout the floodplain to capture the scarce annual rainfall and enhance soil moisture, and thus increase the survival rates of plantings. In conjunction, check dams were constructed to attenuate flow, reduce erosion, retain sediment, and increase water infiltration to help establish vegetation. The Taragalte Ecolodge operates in a similar fashion on a much smaller scale; a series of cut-and-fill operations enable water capture for irrigation purposes during drought periods. Other examples for water collection methods are found in Part 1, while Part 2 provides examples for wastewater reuse, smart irrigation techniques, and appropriate plant selection.

Three themes emerge from this chapter's contributions in the context of water budget analysis and water conserving design.

The first concerns the adaptation of reference materials with input from local expertise and site-specific data. For instance, for the Mahtab Bagh conservation project, the California-based guidebook (known as Water Use Classifications of Landscape Species, WUCOLS) was used with input from Rajasthani horticulturalists for plant selection. The guidebook classifies plants as having high, medium, or low water requirements in different climatic regions of California, and it adjusts reference evapotranspiration by microclimate and planting density as well as species coefficients.

The second theme concerns the adaptation of historical concepts to modern water supply systems and the extension of water budget methods beyond the garden or site scale and into the city and surrounding region. For example, the proposed Residential Development at Al Ain in Abu Dhabi links traditional and modern water systems: *aflaj* irrigation systems tap hillslope aquifers and convey water by tunnels to the surface water distribution canals of an oasis and are linked to desalination and wastewater collection and reuse systems, as a joint strategy for a new urban development. The Taragalte Ecolodge was developed as a prototype for ecotourism that could be replicated in other locations as a broad anti-desertification strategy. In the Wadi Hanifah case study, the serial aggregation of micro-catchments and planting cells acts as a significant infrastructural component of the watershed management plan, specifically through mitigating the erosive forces of flash floods and conserving water used in irrigation.

Lastly, the third theme concerns the spatial implications and aesthetic potentials of water regulation. For example, site grading and a network of sunken courtyards or constructed open and covered reservoirs, in combination with planting geometries and materials selection, can reveal the fluctuating levels of water, whereby the seasonal transformation of space becomes its aesthetic expression. The Nagaur Mughal-Rajput Palace-Garden Project in Rajasthan, India, is a good example.

1. Land degradation points to the interdependent relations between water, soil, and vegetation. For example, hydrological changes affect plant and soil ecology; the loss of vegetation leads to topsoil erosion and decrease in soil infiltration capacity; over-pumping of groundwater increases salinity in the soil, impacting the viability of plant growth, and so on.

2. Online tools, such as the California Irrigation Management Information System (CIMIS), provide hourly, daily, monthly, and annual water budgets for user-specified time periods, weather stations, and regions. An online tool called WebWIMP (Web-Based Water-Budget Interactive Modeling Program) calculates water budgets globally at a half-degree grid cell resolution, and can incorporate variations in soil depth, infiltration rates, and climate change scenarios. The U.S. Environmental Protection Agency has recently created a "Water Budget Tool," including a spreadsheet and associated analytic methods, to bring this analysis in landscape design into the mainstream.

Mutually Supportive Systems

Modifying the presence of water offers vast possibilities for design and for shaping both social and ecological systems. Water can be detained on site or within a riverbed via reservoirs, check dams, micro-catchments, and inflatable dams (Side Note 3). Mechanical distribution via pumps and channels can be utilized to dissipate or attenuate water, and conversely, to intensify or concentrate water in specific areas.

What is most evident in this collection of essays and case studies is the aspiration to surpass the typical urban grid layout and planometric design approach, which often overlooks hydrological dynamics. In all of these projects, water systems serve as the framework around which urban development, public space, water-sanitation infrastructure, ecological systems, and agriculture are organized. With this approach, natural, social, and technological systems converge as multi-use spaces that operate in a mutually beneficial manner.

The proposed residential development in Al Ain, the Wadi Hanifah Restoration project, and the Jordan River Valley masterplan by Masoud (Chapter 2) provide excellent models for a closed-loop water management system, integrating hydrology and hydraulics as a means to rethink urban form and public landscape. The Wadi Hanifah bioremediation facility, which is in itself a hybrid of mechanical and biological processes, is nestled within a bioengineered riverbed and located in proximity of a massive highway interchange; it acts as an extension of the city in terms of wastewater management and public space. Masoud envisions the *wadi* as the spine for each neighborhood, where water collection, sanitation infrastructure, and public space converge; the relation between individual lots, street right-of-ways and open space are organized around surface water collection and effluent reuse. The Hiriya Landfill Park and Taragalte Ecolodge exemplify the same principle at a smaller scale and as strategies to unify architecture and landscape.

Bioremediation and bioengineering are key approaches to achieve multi-use and mutually supportive water-human systems. In some of the case studies in this chapter, such interventions are conceived as modern-day icons of progressive water management and open space design. Constructed wetlands, for example, are often designed as a food chain which supports habitat ranging from small organisms to fish to fowl, and as an interface between the terrestrial system (birds) and the aquatic system (fish, plants, invertebrates). Terrestrial and aquatic species not only provide nutrient removal function but also add value for public interest. Undoubtedly, bioremediation projects are successful in radically changing public perception of wastewater reuse and inhabiting water infrastructure.

3. See the Rio Besos project featured in Margolis and Robinson (2007).

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