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# Rethinking Water: A CAAS (City As A Spaceship) design approach

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**Abstract:** Water is ubiquitous and essential, yet we struggle to understand it from a systems perspective. Water is a terrestrial closed-loop system involving individuals, communities, cities and geographies, and as such, might it serve as a metaphor for sustainable design?

We identify four locations and frame their connections through water and society. This interaction is highly relevant to future dense urban environments and of interest to CAAS (City As A Spaceship) who explore reciprocities between terrestrial and extra-terrestrial architecture and design. CAAS explores these approaches to water management:

- 1) California State (United States)
- 2) New Delhi (India)
- 3) The International Space Station (Lower Earth Orbit)
- 4) Micro-Ecological Life-Support System Alternative (European Space Agency Research settings)

In this paper, CAAS applies design research approaches to curate and frame reciprocities between situations and societies. Using locational case studies and city-by-city scale infographics it generates a discursive space from which to imagine conceptual shifts in sustainable design.

Keywords: **Water, Resource Management, Reciprocity, City, Spaceship**

## 1. Introduction

Water is one of the most pressing challenges of the 21st century: whether it's too much, too little or too dirty. Violent tensions over water are certainly nothing new, but they are on the rise. Basic demand-supply rules go a long way to explaining the reasons behind this growing friction and threat. Water resources are finite and the combination of a surging world population and steady industrialisation means the scramble for water is heading rising and this drives the need to develop a multitude of sustainable approaches to water management and recovery.

Understanding societal needs and their implication for a finite resource is difficult at the global level, and challenging even at the urban level. The Brundtland Report (*Our Common Future, 1987*) published by the World Commission on Economic Development, is where the term sustainable development was first used. It described the need for development that would enable us to meet our present needs in ways that wouldn't jeopardize the needs of others, particularly future generations (WCED, 1987).

Water management and water recovery systems are therefore becoming increasingly important in everyday urban, sub-urban and rural settings as systems become stressed, as we start to anticipate the implications of failures. Clean drinking water and sanitation are essential to the realisation of all human rights, yet 884 million people do not have access to potable water (UNICEF, 2015). This paper explores through a series of case studies that highlight challenges and solutions; three terrestrial (4.1, 4.2 and 4.4) and one extra-terrestrial (4.3). These, when analyzed with a design-led CAAS (City As A Spaceship) lens, can set the groundwork for looking at water from a systems-perspective, and help to conceptualise future approaches to considering sustainability from a position of resource abundance to a fully closed-loop bio-regenerative system.

## 2. Background

CAAS is a metaphor for learning from reciprocities between a spaceship and a dense city – environments challenged by issues of density, self-sufficiency, multi-cultural 'society', confined spaces, hygiene, recycling of resources and energy efficiency – a launch and landing at the same time. Using a spaceship as a precedent, with its imminent contextual requirements, the value of each drop of water, single breath of air, fresh lettuce or self-grown potatoes is immense because they are essential for survival in the extreme environments beyond our earth's atmosphere. Facing environmental changes, fast growth of population, and natural disasters on earth, there is a need to prioritise the terrestrial environment and its' resources to sustaining human life. CAAS offers viable approaches to meeting the needs of terrestrial societies, today and in the future, and emphasizing sustainable design solutions away from waste-driven production that serve economies.

In this paper, the CAAS design-led approach provides a broadly framed analysis of water. At the core of a systems perspective on water would sit the African proverb: "*Filthy water cannot be washed.*" The frames through which CAAS explores water systems flow from the perspectives of; **Society**, **Environment**, and **Ecology**, which are further expanded on with an overview of **Design** and **Technology**. The frames help to shape the space for considering future water management systems.

**Society:** With global population beyond seven billion, and rapidly expanding, there are already challenges in meeting the human rights set out by the United Nations (UN). UN General Assembly Resolution 64/292 states that clean drinking water and sanitation are essential to the realisation of all human rights. WHO/UNICEF reports that over 90% of the world's population now has access to improved sources of drinking water, however that still leaves hundreds of millions of people without access (UNICEF, 2015).

In understanding global freshwater demands, the first realization is that it is virtually impossible to model Environmental Water Requirements (EWR) on a global scale. Smakhtin and colleagues (2004) presented one of the first attempts to do so, based on simulations using a global hydrology model, with an aim to inform environmental water management approaches and policies. Their global assessment approach attempted to estimate the volume of water required to maintain freshwater dependent ecosystems, In doing so, they conceived of four categories of environmental water management approaches: Natural (unmodified), Good (slightly or moderately modified), Fair

(moderately or considerably modified), and Poor (critically modified and degraded). Their work highlighted the need to contextualise the categories from a societal perspective, and to identify water management approaches that meet the 'Good' criteria, though it may be that 'Fair to Good' is a more realistic target for cities and governments.

**Environment:** This paper focuses mainly on urban environments; locations with high human density where there is extensive exploitation of water resources. Smakhtin and colleagues' (ibid) model identified significant urban/rural concerns and the need for management interventions to restore flow patterns and river habitats, thus acknowledging a reliance on areas outlying. They defined a water stress indicator and showed the proportion of utilizable water in river basins withdrawn for direct human use. Their findings highlighted the challenges facing water management, the imperative to consider the system at scale, and the need for regular global water assessment. Hence, current systems and approaches need re-thinking, and re-designing, to achieve alternative water management practices within urban societies, rapid integration of ecosystem perspectives, and uptake of promising emergent technologies. This macro/micro perspective is of interest to CAAS.

**Ecology** is the relationship between organisms, people and their environment. When looking at the "spaceship" paradigm of CAAS, the ISS serves as living example (Fairburn, et al., 2014), with a spaceship resembling a whole system, a complex system that provides shelter, energy, and nutrition, and houses inhabitants using technologies to manage water, air and other resources. Thus the ecologies of the ISS reference the interrelationships between shelter, energy, life support and the inhabitants (Figure 1).

**Design and Technology:** Increasing problems of water shortage have stimulated the design of technological approaches and new partnerships. One of two examples found in India, is the 'Sujala Dhara project (Toilet to Tap Water)', an example of a solar-powered plant that utilises technology in the form of a series of seven-layers of organic and inorganic filters, and a nano-filter membrane. This approach can produce around 4,000 litres of clean water per hour and can operate around the clock. An alternative technological example is the 'Janicki Omniprocessor', which integrates simple technology and utilises sewer sludge to generate clean drinking water, electricity and pathogen-free ash; an approach that has attracted the attention and support of philanthropists (Gatesnotes, 2015).

Technologies that emerged from extra-terrestrial pursuits are finding their way to inform terrestrial contexts, though there are more opportunities to apply these approaches in water management. The treatment of water in spaceships belongs to the area of Life Support Systems (LSS), which also includes the revitalization of breathable air, food production and treating organic waste materials, hence the system perspective is inherent in extra-terrestrial operational design methods. Figure 1 conveys spaceship ecologies through a closed-loop visualisation – thus reinforcing the life support system, and specifically water, in the extreme scenario of life in space.

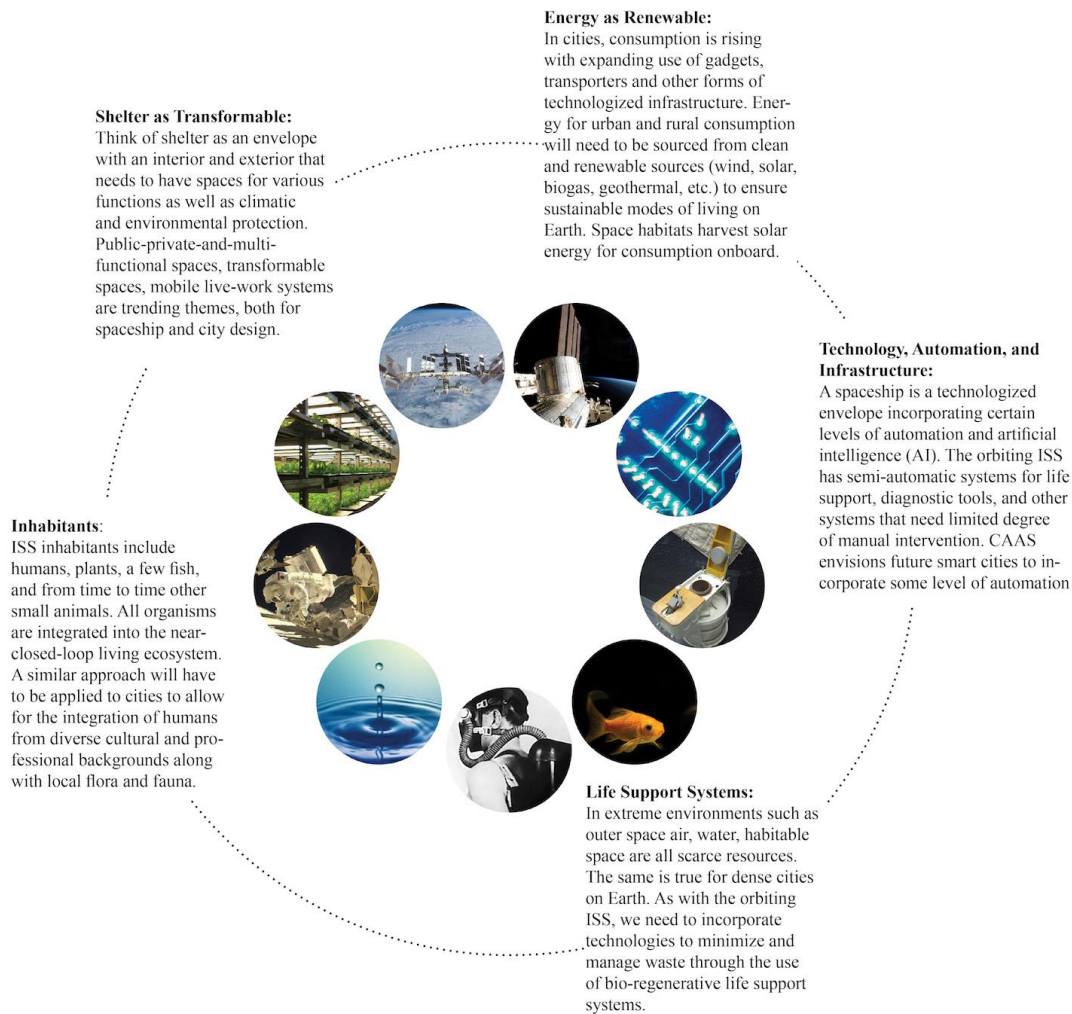


Figure 1. CAAS-ISS ecologies schematic. (Image Credit, Barbara Imhof).

### 3. Design research and methodology

The authors created CAAS as a working research methodology to consolidate very different scenarios and environments (space and terrestrial), to be assembled under one umbrella, to study commonalities and reciprocities. In 2010, when the CAAS initiative started, overlaying space and terrestrial habitation, particularly habitation within dense mega-cities distributed across the planet, was unheard of. To use case studies from these contrasting and extreme environments, which seem at first glance to be far apart, and search for their overlap, is a methodology for innovation (Figure 2).

More specifically, the CAAS methodology is about goal-oriented problem solving and the ability to channel information, which furthers the project or research question towards the theme and focus of the project. It is about the evaluation of data through creative means, in this case, constantly making inferences from overlaying scenarios – through imagination, creation and visualisation – a sort of thought experiment (Nersessian, 1992). It is immersed in the broad field of Design Research. According to Malika Bose, Associate Professor at the Penn State University, design processes are similar to a critical analysis as undergone in scientific work (Bose, 2007, p.126). Design studios offer a productive environment to enrich a scientific way of working with a creative culture, and to merge both cultures. CAAS was conceived in such an environment and the authors have been developing this research approach in collaborative work sessions and two work residencies; one was self-

organised at Lake Como in Italy and more recently in 2015, when the authors were invited by the Khoj International Artist Association in Delhi to conduct a two-week intensive Art/Science residency “The Undivided Mind” (Khoj, 2015). The authors developed the design research approach on two different levels:

**Research by design:** taking design or case studies for research analysis

**Design by research:** taking research results as basis for design-oriented outputs

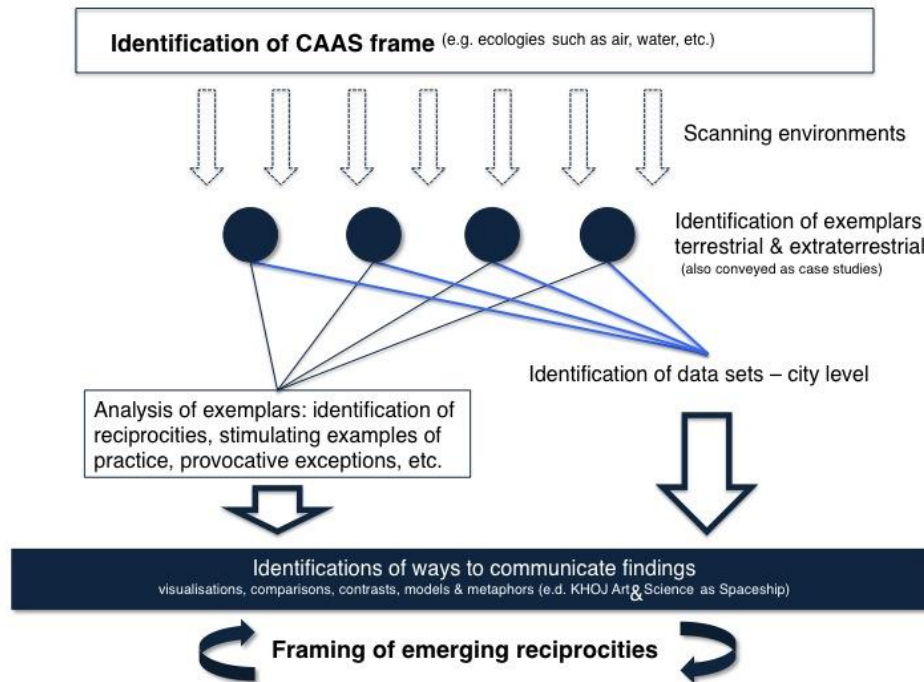


Figure 2. CAAS' Design research methodology. (Image Credit, Barbara Imhof, Sue Fairburn).

As shown in Figure 2, this design research approach involves locational scenarios and infographics, which are composed to deliver the analysis of the work, from which insights are drawn to add to the discourse within a given area, such as the design of environments. The CAAS mental model is the first step towards a conceptual shift, beginning with a carefully curated set of case studies selected for analysis, as outlined in the next section, and followed by comparative analysis at a city-by-city scale.

## 4. Locational Scenarios

This section presents case studies covering a range of global locations, approaches and issues pertinent to analysing and informing future approaches to water management. Central to all scenarios presented is the connection framed through water and society. Three of them are terrestrial-based and one is extra-terrestrial.

### 4.1 CASE STUDY “A”: CALIFORNIA, USA

**Location:** Northern Hemisphere. Latitude 120 W, Longitude 37 N

**Remoteness:** Well connected to the rest of the United States and major cities worldwide

**Society:** 38.8 Million in 2015

**Water sources:** Ground water, Colorado River, San Joaquin River, San Francisco Bay, Lakes

Starting in 2011/2012 (and still ongoing), California, one of the world's most prosperous economies has been facing one of the most severe droughts on record. Water in California is very closely managed, with an extensive pipeline network to serve the most populated and dry areas of the state. Precipitation is limited, with the vast majority of rain and snowfall occurring in the winter months, in the northern part of the state. This delicate balance means that a dry rainy season can have lasting consequences. As the world's largest, most productive, and most controversial water system, it manages over 49 km<sup>3</sup> of water per year (Jenkins et al, 2004).

Water and water rights are among the state's divisive political issues. An ongoing debate is whether the state should increase the redistribution of water to its large agricultural and urban sectors or increase conservation and preserve the natural ecosystems of the water sources. As the most populous state in the U.S. and a major agricultural producer, drought in California can have severe economic as well as environmental impact. The state administration has responded with a sense of urgency worthy of emulation by other parts of the world that are seeking solutions, regulations and the resolve to conserve water aggressively. California has brought in regulation, behavioural campaigns, and dissemination of practices, as the main 'technology' to save every drop of water they can. Californians are urged not to relax their water-saving habits and to continue conserving by reducing or eliminating outdoor irrigation when it's wet and keeping household water use to the essentials. Their approaches could be criticized as too lax given the long-term implications on wider society.

## 4.2 CASE STUDY "B": 'SUJALA DHARA-TOILET TO TAP' WATER PROJECT, NEW DELHI, INDIA

**Location:** South Hemisphere, Latitude: 28.6139 E Longitude: 77.2090 E

**Remoteness:** India's capital city with excellent connectivity by rail, road and air

**Society :** 18,686,902 as of February 2016

**Water sources:** Rivers Yamuna and Ganga, Bhakra storage in Punjab

In July 2015, Arvind Kejriwal, the Chief Minister of New Delhi inaugurated the pilot project "Sujala Dhara --Toilet to tap water" at the Keshopur Sewage Treatment Plant. The Delhi Jal Board has partnered with SANA (Social Awareness, Newer Alternatives) to implement a project that recycles sewage waste into drinking water. The plant is generally affordable and powered by solar energy. It can produce around 4,000 litres of clean water every hour, and running continuously that's 25 million litres of drinking water per year. The technology was designed by Absolute Water, an integrated water management company (Absolute Water, 2016). The water from the sewage pit goes through a bio filter that has seven layers of organic and inorganic material including plants, earthworms, sand and pebbles, and then through a nano-filter membrane for further treatment. However, interest in this technology has come up against a societal mental block around the use of treated sewage, even though we know from experience on the ISS that the technology is doable in both settings and that the treated water is fit for drinking.

These kinds of water projects, emergent from environmental design and technology, are not limited to Delhi. Driven by necessity and water scarcity, densely populated urban Indian cities have begun pursuing other water management strategies that are akin to the systems that are being designed and used in extra-terrestrial environments. Many cities have made it mandatory for all new residential and commercial developments to recycle and reuse water locally and local municipalities are encouraging and enforcing rainwater harvesting in some states. For example, in Tamil Nadu, *rainwater harvesting* was made compulsory for every building to avoid ground water depletion and

has been rather successful (Waterharvesters, 2016). The harvested rain water can be used as drinking water, longer-term storage and for other purposes such as groundwater recharge.

The culture of water conservation is not entirely new to an old civilization such as India. An architecturally picturesque way to access ground water access was through beautifully designed “stepwells”. Most common in western India and arid regions of south Asia, stepwells are wells in which the water may be reached by descending a set of steps. The practical idea spread north to the state of Rajasthan, along the western border of India, where several thousands of these wells were built, with this construction approach hitting its peak from the 11th to 16th century (Livingston and Beach, 2002). Most existing stepwells date from the last 800 years.

Stepwells are excellent examples of built water management to cope with seasonal fluctuations in water availability, to access ground water, and to maintain and manage the systems. As well as providing access to potable water, stepwells also served a leisure purpose for society, with the base of the well providing relief from daytime heat and a place for social gatherings and religious ceremonies. Water management and societal customs need not be divisive.

### 4.3 CASE STUDY “C”: INTERNATIONAL SPACE STATION, LOW EARTH ORBIT

**Location:** ISS cruising altitude 400 km from Earth

**Remoteness:** Orbits the Earth every 90 minutes; serviced by human and cargo ferries

**Society:** maximum of 6

**Water source:** The ISS receives water supplies via cargo ships such as the Russian Progress spacecraft, European ATV (Automated Transfer Vehicle), Japanese HTV (H-2 Transfer Vehicle), American Dragon capsule.

The ISS orbits the earth every 90 minutes 400 km above the earth’s surface with a speed of 27,000 km/hr. The ISS is big enough to be viewed with a naked eye from earth with a total volume of 916 m<sup>3</sup> and the spread of a soccer field. Since 2000 it has been permanently occupied, first with a crew of 3 and from 2009 onwards, with a 6-person-crew. It is the largest international cooperation project for the peaceful use of outer space. It serves as scientific test-bed in preparation of future missions to the Moon and to Mars.

For a six-month stay, an astronaut needs approximately 0.5 tons of water, and for six astronauts that translates to nearly 3 tons of water (Figure 3). With international launch rates ranging from €30000-36000 per kg, water becomes a rather expensive resource that is shipped to orbit, thus recycling this precious resource becomes imperative with the push to explore off planet.

Item	On Earth		In Space	
	kg per person per day <sup>1</sup>	gallons per person per day	kg per person per day <sup>2</sup>	gallons per person per day
Oxygen	0.84		0.84	
Drinking Water	10	2.64	1.62	0.43
Dried Food	1.77		1.77	
Water for Food	4	1.06	0.80	0.21

Fig. 3: Life requirements on Earth and in Space according to NASA, courtesy of NASA.



On the ISS there are two different water treatment systems. On the US side, the astronauts drink a filtered mixture that includes recycled hygiene water, condensate, astronaut breath and sweat, and urine from crewmembers. Sometimes the astronauts go over to the Russian segment and collect the urine to use it for the US system. The ISS also stores about 2000 litres of water in reserve for emergency purposes. The ISS water system was designed and developed together with the air revitalization system. Both systems are part of the overall ISS Environmental Control and Life Support System (ECLSS). While the ISS ECLSS has undergone constant upgrades and improvements, it is not a fully closed-loop yet but it would need to be for long duration human missions to Moon and Mars.

Parts of the ISS ECLSS have been used in terrestrial water treatment systems e.g. the Microbial Check Valve (MCV) that is an integral component of the water purification and filtration process. The MCV is an iodinated-resin that provides a simple way to control microbial growth in water without the use of power. By dispensing iodine into the water, it performs an important secondary nutritional function for humans. This chemical, when added to the diet, promotes proper brain functions and maintains bodily hormone levels -- which regulate cell development and growth. Collaborations between NASA and aid organizations have led to water recovery systems using the MCV, thus these extra-terrestrial approaches to water management have been applied to address terrestrial issues.

#### 4.4 CASE STUDY “D”: MELISSA, UNIVERSITAT AUTONOMA de BARCELONA, SPAIN.

**Location:** Northern Hemisphere. Latitude: 41.390205 Longitude: 2.154007

**Remoteness:** In the province of Catalunya, Spain. Excellent connectivity.

**Society:** Irrelevant; Currently it is an experimental test bed housed in a university

**Water source:** Irrelevant

This final case study draws our focus to future long-term space missions and permanent stays on extra-terrestrial surfaces for which will require a closed Life Support System. It is intended to be a closed-loop system, and is conceived as a network of five connected biological compartments. Each of these compartments has a different biochemical function that allows for exchange of gases and fluids. The astronauts produce biowaste that is fed into the liquefying compartment where anoxygenic fermentation takes place using bacteria, a process which sets free volatile fatty acids, ammonia, and minerals. These reach the second compartment, which allows for a photoheterotrophic process i.e. the decomposition of the materials through another type of bacteria. Both compartments and the astronauts release carbon dioxide which is fed into the loop to the algae compartment. In this compartment, the algae transform the carbon dioxide into oxygen through a photosynthetic process, and the astronauts can recover water as a by-product. After the second bacterial decomposition, ammonia and minerals go into the nitrifying compartment where oxygen is added. The resulting nitrates are used for the plant compartment. The crew tends the plants and harvests vegetables. A fully closed loop bio-regenerative system that serves to inspire and innovate future terrestrial and extra-terrestrial water and resource management systems, alike.

One of the ESA-incubated Dutch companies IP-Star offers grey, yellow, black water recycling, nutrient recovery, food production, toxin/pathogens and micro-pollutant removal, all derived from the MELISSA system (figure 4). Also, in the very isolated Antarctic Concordia Research Station, black and grey water treatment translated from the MELISSA space application produces water, which follows the hygiene and safety standards for potable water. (Battrick 2004)

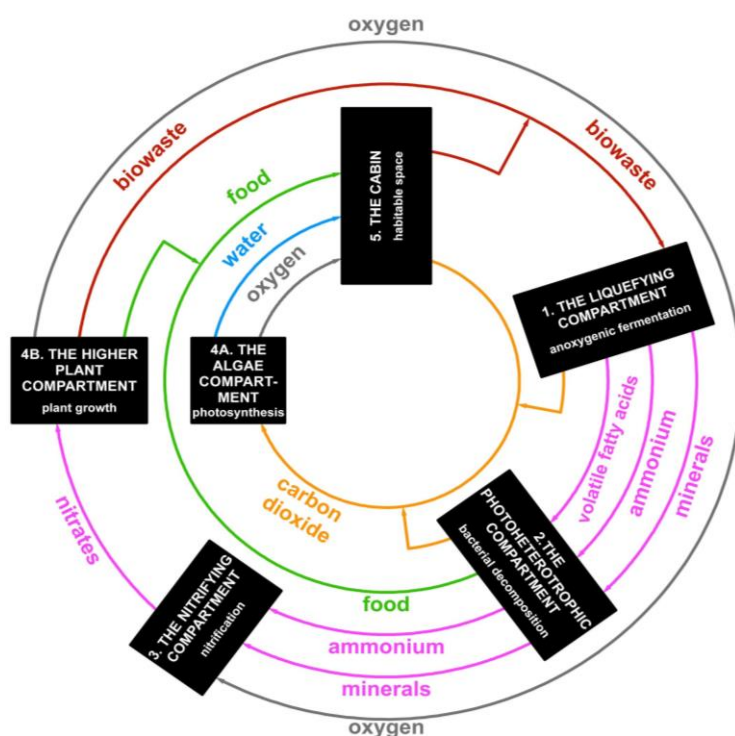


Figure 4: MELISSA support systems diagram (water is shown as blue line).  
(Credit: LIQUIFER Systems Group, Schematic: Anne Marlene Rüede, 2014)

## 5. CAAS Comparative Analysis

We further explored the “city” as a “spaceship” metaphor and using graphical representations of information on water management and recovery (data on specific urban settings) as a complementary way to communicate and make inferences. We attempted to map terrestrial water tendencies, specifically looking at water consumption, waste water treated, water quality at source, investment into water systems per capita, and efficiencies. This section provides a CAAS-based analysis through two sets of visual data. Figure 5 presents a set comparing and contrasting the world’s densest cities such as Mumbai, Tokyo, New York, Sao Paulo, Cairo, Mexico City, Amsterdam, Paris, Lagos, Johannesburg, and compares them to smaller counterparts, such as San Francisco, Toronto, and Vienna.

This set comparing 15 cities of the world allows us to see how cities manage their water resources and the degree to which they invest in quality and efficiencies. As an infographic, it evidences the variable relationship in water efficiency and waste water treated between cities from industrially advanced nations (e.g. Amsterdam, New York, Tokyo, Toronto and Vienna) and those less industrialized ones (e.g. Sao Paulo, Mexico City, Cairo), with the former achieving a good balance of overall system efficiency, likely confirmatory of their investment per capita, despite the indicative water quality at source. But there is more to it - even among the industrial nations, water consumption patterns vary widely. Although this comparative analysis offers insights into societal factors of water use, management and recovery, and given ‘profile’ might suggest the combination of approaches for sustainable thinking and practices, further analyses and thinking is necessary to get an in-depth understanding of what these maps convey.

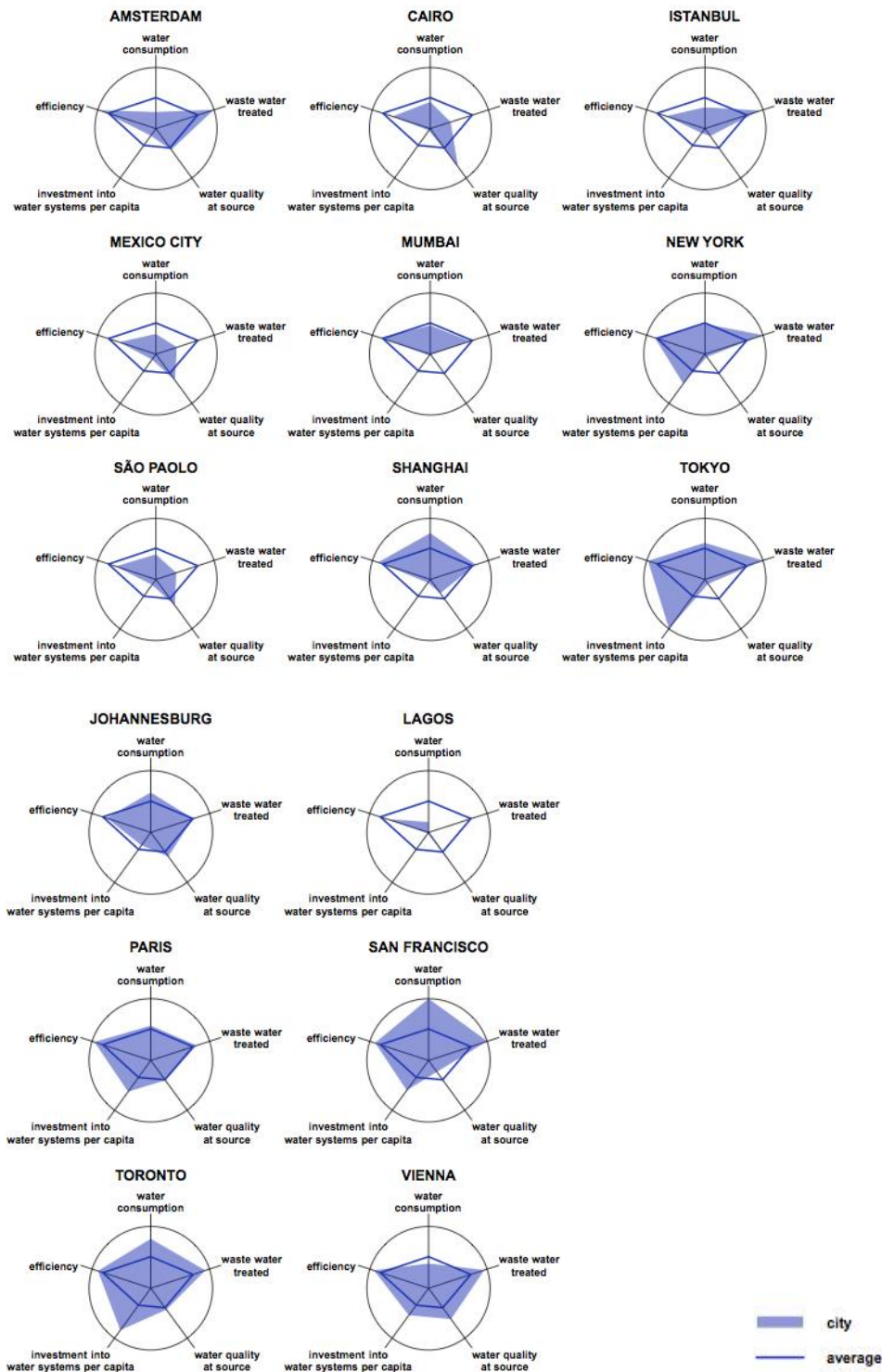


Figure 5: Cities of the world: WATER – a visual vector portrayal of comparative data points for Water Management and Recovery, Image credit: Anne Marlene Rüede, 2016.

## 6. Conclusions

This paper proposes in part, that water serves as a metaphor for a shared, common good, that links us through our shared responsibilities. It positions this alongside the ‘spaceship’ paradigm, whereby the spaceship resembles a whole, complex system that provides shelter, energy, and nutrition, and houses inhabitants using technologies to manage water, air and other resources. It is proposed that

this paradigm relates strongly to sustainability – which at the core considers resource utilisation and depletion (Walker, 2006, p.81), giving priority to the environment (ibid, p.5), and requiring a shared sense of responsibility across the system. We have not yet achieved that shared responsibility, but this paper frames the emerging reciprocities between living on and off planet and the systems that have had to be developed to support life in the latter extreme.

Waste management strategies on Earth are now starting to mirror those of Space. The closed-loop MELiSSA life-support systems implemented in Spain, as well as the semi-closed loop ISS-based life-support systems, are now finding their way into urban and suburban parts of the world – from California to New Delhi. The technologies employed from place to place might vary somewhat, but the ultimate objective is the same: treatment of sewage effluents to generate potable water. The New Delhi case study is playing out in other parts of the world with their own regional narratives. With the depletion of ground water, river water and lakes, both industrialized and emerging economies have started to employ policies and regulations that treat waste as a resource. Seeking to stretch the global allotment of river water, lakes and ground water, water agencies worldwide are starting to recycle sewage effluent, legislating rainwater harvesting, promoting renewability and efficiency, and responsible lifestyles. Additionally, the California case study, highlights issues grounded in historical approaches to large-scale land-based infrastructure for urban prosperity, plus issues arising from water scarcity, supporting the lack of correlation between resource value, societal use, and lifestyle.

CAAS' research methodologies, involving consolidating very different scenarios and environments to study their commonalities and to frame reciprocities, offers a means to enrich a scientific way of working with a creative culture, and to merge both cultures. Closing the loop on water is a priority and this paper presents content and applies design research to inform our understanding of sustainability through water, which is itself a closed-loop system. As a challenge of global proportions, providing a consistent supply of potable water has become a key talking point of politicians, philanthropists, citizen activists and policy makers alike. Architects, designers and engineers have an important role to play in applying design strategies to minimize the use of water and maximize water management and recovery – both on and off the planet. In the words of David Schindler, one of Canada's most influential environmental scientists: "*We are going to forget all about the economy when we run out of water*".

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