A Line in the Sand:
A Sustainable Hydrological System for the Sahara Desert

by

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For my parents, Paul and Carol Healy.

Without you, these would still be blank pages.

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ABSTRACT

Water scarcity is a concern in the Sahara Desert, which has been amplified by climate change and, combined with ever-expanding agriculture, has caused an unprecedented rate of desertification. The region cannot strain water supplies any further and must move towards sustainable methods of water usage, procurement, and preventing desert expansion.

A systematic approach using maps layered with specific spatial parameters (topography, infrastructure, climate) is used to define relational and locational sets for water harvesting, and therefore constraints for a sustainable water system for the Sahara Desert. Concentrated regions of activity such as the fog capped Anti-Atlas Mountains and humid valleys of the Niger River all offer the opportunity to further explore several alternative water harvesting methods at a mezzo and micro scale. Architectural interventions at these scales can reveal empirical knowledge of a macro sustainable water system, and in doing this, reconcile an ancient forgotten respect of our water supply.

ACKNOWLEDGEMENTS

I would like to extend my sincerest gratitude towards both my supervisor and advisor. To my advisor, Catherine Venart, for dealing with my indecisiveness and believing in my thesis, even when I was filled with self-doubt. You have given me such a solid foundation, without which this thesis would not have been possible. To my supervisor, Cristina Verissimo, for the hours of guidance and late night international calls, your support has been immeasurable. I will remember you and the lessons you have taught me for the rest of my professional career.

A very special thank you to my family for your unwavering emotional and physical support. Your encouragement and compassion has given me strength to face any challenge.

CHAPTER 1: INTRODUCTION

Till the Last Drop: A Worldwide Dilemma

Water scarcity is a rapidly growing issue across the globe. Despite 70% of the earth's surface being covered in water, only 2.5% of that is fresh water, and only 1% is reachable and drinkable.[1] Currently there are 1.8 Billion people worldwide affected by water scarcity, both economic scarcity and physical scarcity. Physical water scarcity is when a community's demand for water outweighs the supply. This currently affects a select few countries, namely arid countries such as the U.A.E, Saudi Arabia, Morocco, Algeria, Chile, and a few more. South Africa is predicted to be the first country to deplete their own water resource.[2] Economic water scarcity occurs when an immediate population does not have the infrastructure to clean water, unlike physical scarcity, countries facing economic scarcity might have a source of water, it is just not potable and/or clean. This is currently the largest problem facing many countries in Africa, and South America. There are 7.5 billion people living on the earth, and our constant growth, agriculture, and industry are accelerating the rate at which we are using water. This issue is predicted to become a devastating problem in the next century. Climate change also contributes to the blame. Erratic weather changes have already caused drought in many areas of the world and the increase of temperatures has caused higher evaporation speeds. Because of this the aquifers and surface water that we rely on today are quickly being depleted. It is estimated by 2020 40-50% of the population will be affected by water scarcity. Scientists even predict that by 2100 the American Midwest will experience a devastating multi-year

1 United Nations, "UN World Water Development Report 2017: Water for a Sustainable World." 2018.

2 Zachary Donnenfeld, *A Delicate Balance: Water Scarcity in South Africa* (Johannesburg: ISS, 2018), 2.

drought similar to the dustbowl of the 1930s.[3]

A Promethean Divide

> In the imagination of the twentieth century, water lost both its power to communicate by touch its deep-seated purity and its mystical power to wash off spiritual blemish.[4]

In *H2O and The Waters of Forgetfulness* Ivan Illich discusses just how water has been transmogrified in the 20th century, elaborating on the divide and disconnect that has occurred between us and the waters of our imaginations. Throughout history water was imbued with imagination and shape, but now it has been transformed into "H2O" the cleaning fluid. Water has become a memory of a wild and romantic past, that had slowly been tamed by the faucet. This promethean urge to domestic water is a central theme in Maria Kaika's *City of Flows*, she defines it as the "historical geographical process that started with industrialization and urbanization and aimed at taming and controlling nature through technology, human labour, and capital investment."[5] The need to control nature eventually drove nature out of our cities all together. Water systems were removed from our cities and buried below surface in pipes, only to pump conveniently into our domesticated lives. The convenience provided by modern technology created a rift between society and its water supply. Water "slowly disappeared from the urban domain of the Western world", there was no longer a sustainable dialect between a populations demand and its water supply.6 As Illich suggests, the twentieth century had turned water into "H2O" a man-made inexpensive and abundant substance that was readily available from any tap. Without the empirical knowledge of the supply, we became a population that over-indulged and

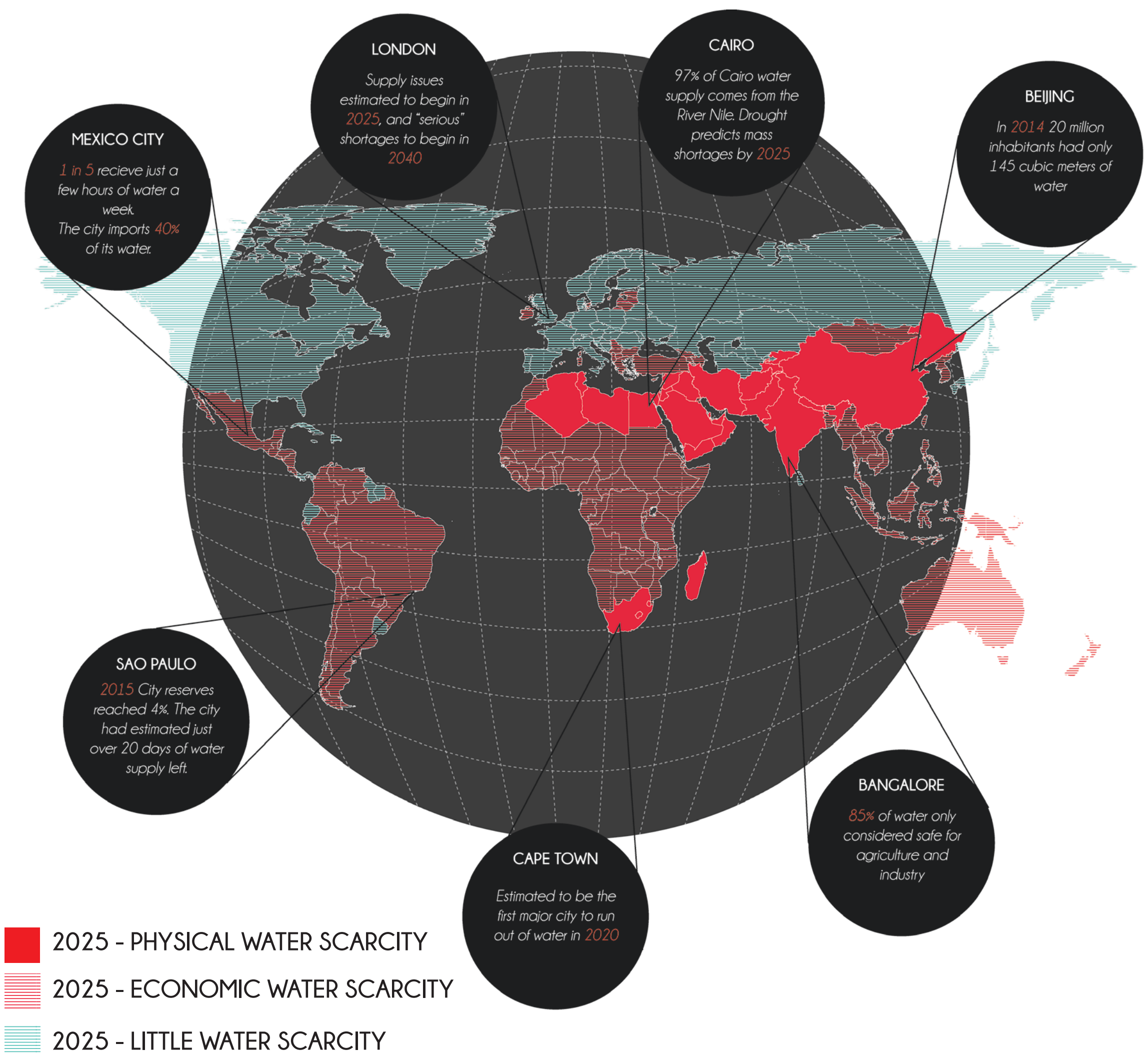
3 Benjamin Cook, "Unprecedented 21st Century Drought Risk in the American Southwest and Central Plains," *Science Advances Online* 2015, https://advances.sciencemag.org/content/1/1/e1400082.full.

4 Ivan Illich, *H2O and the Waters of Forgetfulness* (London: Marion Boyars, 1986), 36.

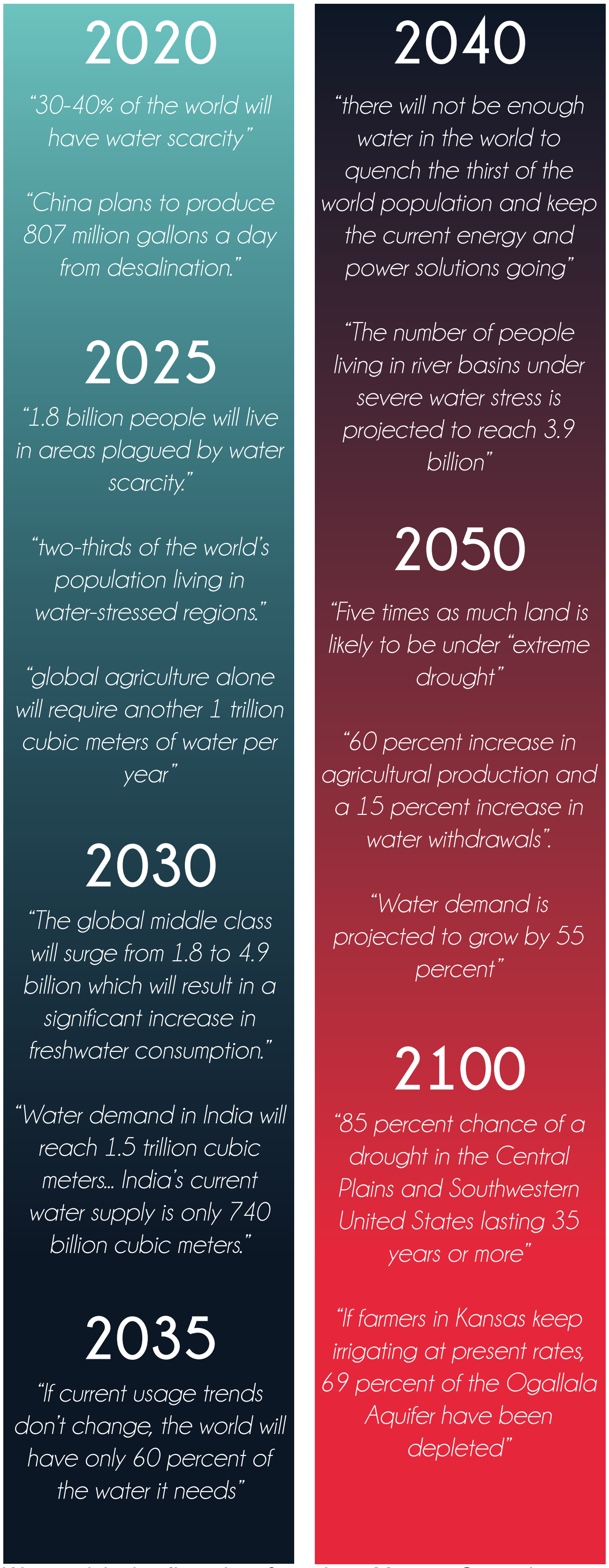
5 Maria Kaika, *City of Flows: Modernity, Nature, and the City* (New York: Routledge, 2005), 5.

6 Ibid, 57.

wasted our most precious resource. Water scarcity can be seen as a direct impact of this abusive relationship, one could not hope to tackle this issue without also addressing the other, otherwise the problem is never truly fixed, it is just delayed. Architecture provides the opportunity to repair and reconcile this divide, by creating a space that promotes awareness, elicits an emotional response and educates the community on the abuse of the finite supply of water they possess. Architecture at the human scale can also serve as a mediator between the macro and micro scales, directly engaging us with the much larger water infrastructure.



Water scarcity issues across the globe; data from Jean Margat, *Groundwater around the World* (2013).

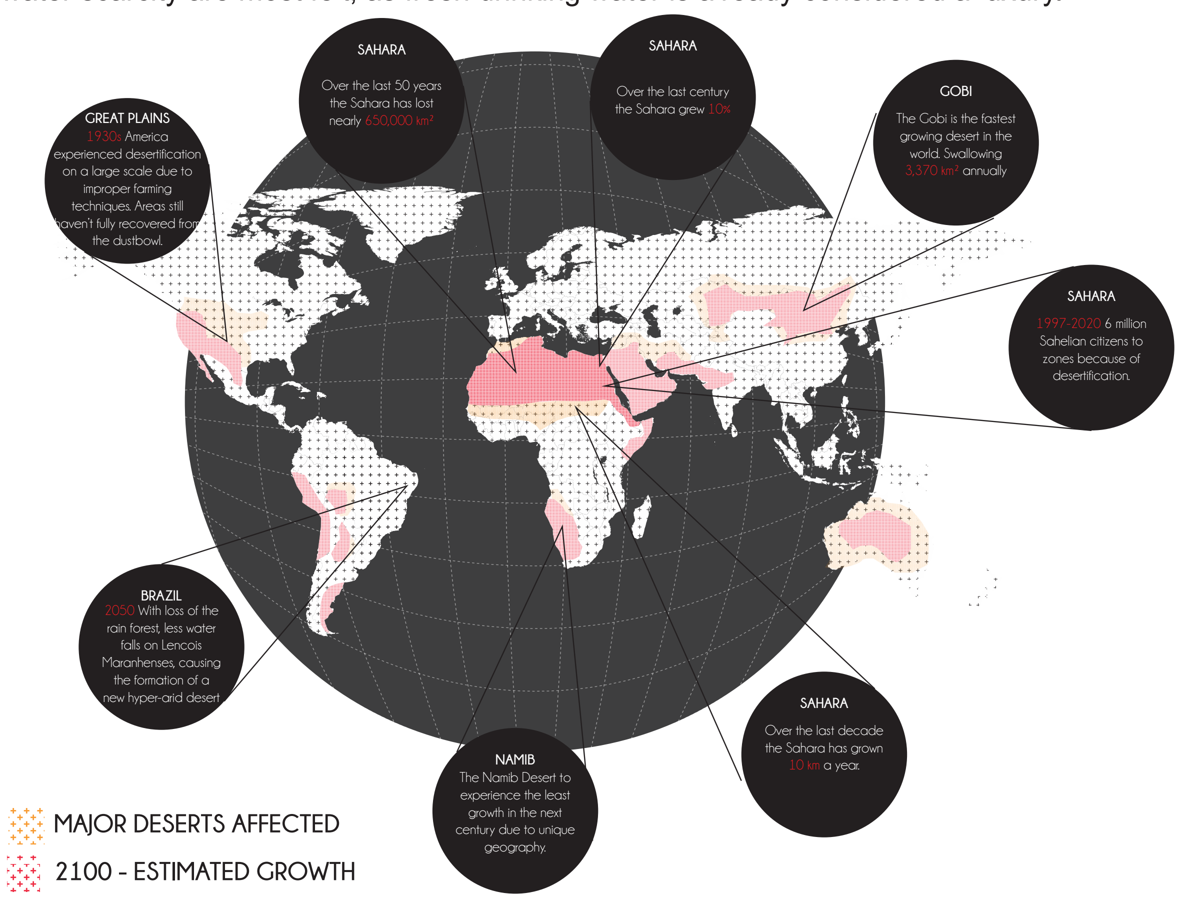


Water crisis timeline; data from Jean Margat, *Groundwater around the World* (2013).

CHAPTER 2: THE ENCROACHING DESERT

Desertification

Water scarcity is not a new issue for specific regions of the world; some are defined by their very lack of water. In total one third of the earth's surface is classified as a desert region. These deserts are by nature, barren and arid landscapes; they are characteristically desolate, with minimal vegetation and sparse settlements. Their large open expanses generate high unforgiving winds, and often suffer extreme temperatures. In most deserts temperatures regularly reach over 40$^{\circ C}$ in the summer, they commonly experience daily temperature variances of 20$^{\circ C}$, and sometimes as much as 30$^{\circ C}$ change between night and day temperature. Rainfall is between 0 to 25 cm per annum. In these areas the impacts of water scarcity are most felt, as fresh drinking water is already considered a luxury.

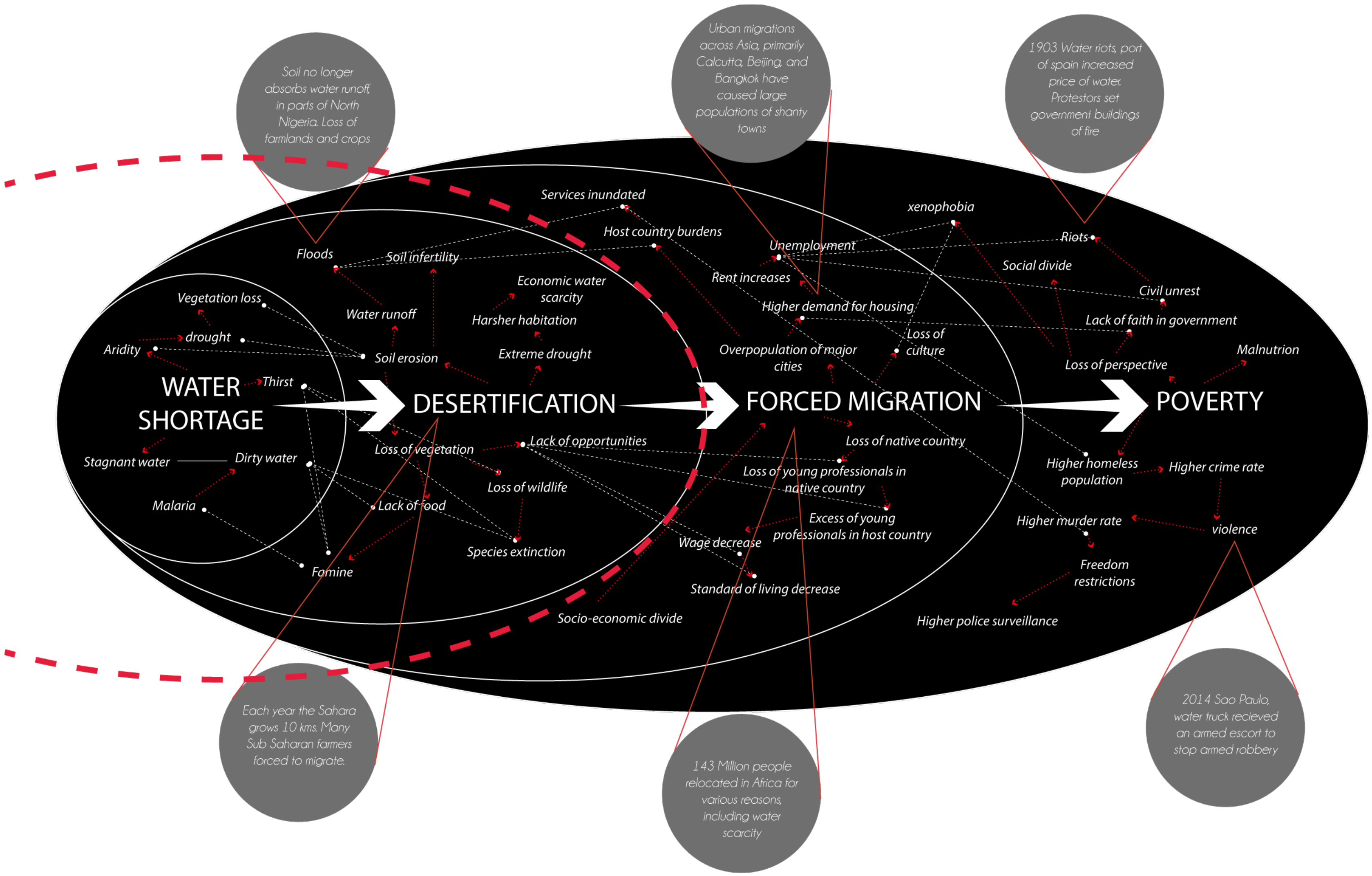


Desertification issues across the globe; data from ESRI USGS, *Aridland Area* (2012).

Water shortages in these regions have led to drought, and an increased rate of desertification. In North Nigeria arable soil no longer absorbs water runoff and has led to losses of 350,000 hectares of farmlands and crops.[7] The encroaching desert has caused a massive migration of people towards urban centres in hopes of more opportunities. This is turn is leading to a greater strain on services, due to an influx of a larger population. There follows an assumed inundation of services means a greater drain on water supplies, which in 2014 during long periods of water shortages, caused water riots to break out in Sao Paulo.[8] There have been countless events through-out history that allow us to map the consequences of water shortages. By doing this we can see how, in order to prevent serious problems in our major urban centres, we must tackle the issue of water shortages along the desert border. Because of this it is these borders that need to be strengthened that will allow for us to fully understand water conservatism in its harshest condition.

7 L.U. Abubakar and M.A. Yamuda, "Recurrence of Drought in Nigeria. Cause, Effects and Mitigation." *International Journal of Agriculture and Food Science Technology 4, no.3*. (2013):3-15

8 Jon Gerberg, "São Paulo: A Megacity Without Water." *Time*. October 13, 2015. http://time.com/4054262/drought-brazil-video/.



Micro to macro, consequences of water shortages

Out of all the deserts of the world, the Sahara Desert of North Africa is experiencing some of the greatest impacts of desertification. The Sahara is the largest of all the 'hot' deserts, it is the defining characteristic of Northern Africa.[9] Its borders are the most varied and diverse of any desert. Its northern most limit is defined by the Atlas Mountain range and the Mediterranean Sea, the Nile and the Red Sea define its most easterly perimeter. The Niger River Valley and semi-tropical Savanna are the beginning of the Sub-Saharan region, and the Atlantic Ocean is located to its west. With 910 million hectares of near uninhabitable land it is not surprise that it has one of the smallest population densities of anywhere in the world. However due to land degradation the desert is encroaching and consequently affecting larger populations.

Over the last 50 years the Sahara has lost nearly 650,000 square kilometres of arable land, and forced nearly 6 million people to migrate in 10 years.[10] The Sahara is home to an estimated 3 million nomadic peoples, whose free movements and way of life has long been challenged by governments. However, they are most threatened now by the encroaching desert. Traditional grazing fields of pastoral nomads are undergoing land degradation, and oasis relief points along caravan routes have begun to falter. These nomads were originally believed to be the source of desertification, as they continuously graze what little vegetation protected the border. However, more recently it has been identified that the settled farmers have been far more detrimental on the land. The growth of less robust cropland has decreased the area of much more resilient savanna coverage, then during drought croplands are more susceptible to the hungry desert. In spite of this

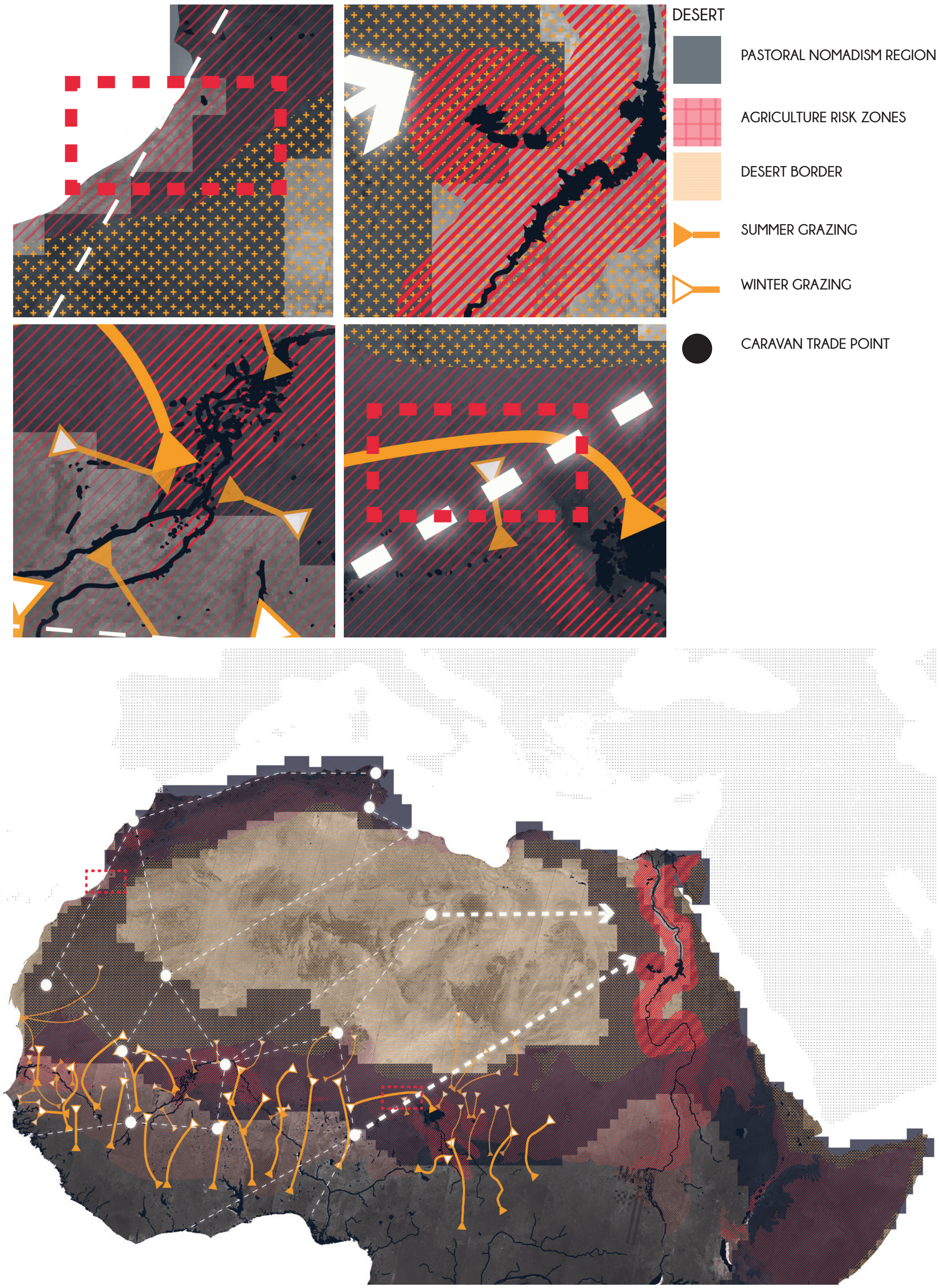
9 The Sahara is the third largest desert in the world. Both the Arctic and Antarctica are larger, but these are considered 'cold' deserts. The next largest 'hot' desert is the Arabian Desert.

10 "La progression du désert du Sahara augmente chaque année ? https://www.savezvousque.fr/monde/progression-desert-sahara-augmente-annee.html.

recent knowledge, most countries are attempting to settle their nomadic communities, out of fear of spreading desertification. However, as will be discussed later in this paper, nomads practice a much more holistic method of grazing, that allows for regrowth and avoids excess concentration on desert vegetation. This is unlike the settled farmers whose land practices are responsible for the most water wastage on the continent. Currently the region of North Africa uses 175% of its total renewable water, with a large majority of this going to agriculture.

Relying heavily on surface water, and ground pumping.[11] However, with climate change, growing population, and loss of arable land, the region cannot afford to strain these resources any further to combat the desert border. This thesis will not attempt to replace existing water infrastructure, nor attempt to curb farming practices in the area, as a sustainable water system would simply not be able to replace the existing infrastructure. Neither could it replace contemporary farming practices in the Sahel, instead it will focus on the promotion of nomadic life in these decertifying regions, strengthening their holistic regrowth and way of life. Therefore, reviving the nomadic institutes and management practices that could renew and restore the desert border.

11 United Nations, "Food and Agriculture Organization of the United Nations," *AQUASTAT Database* (2016), http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en.

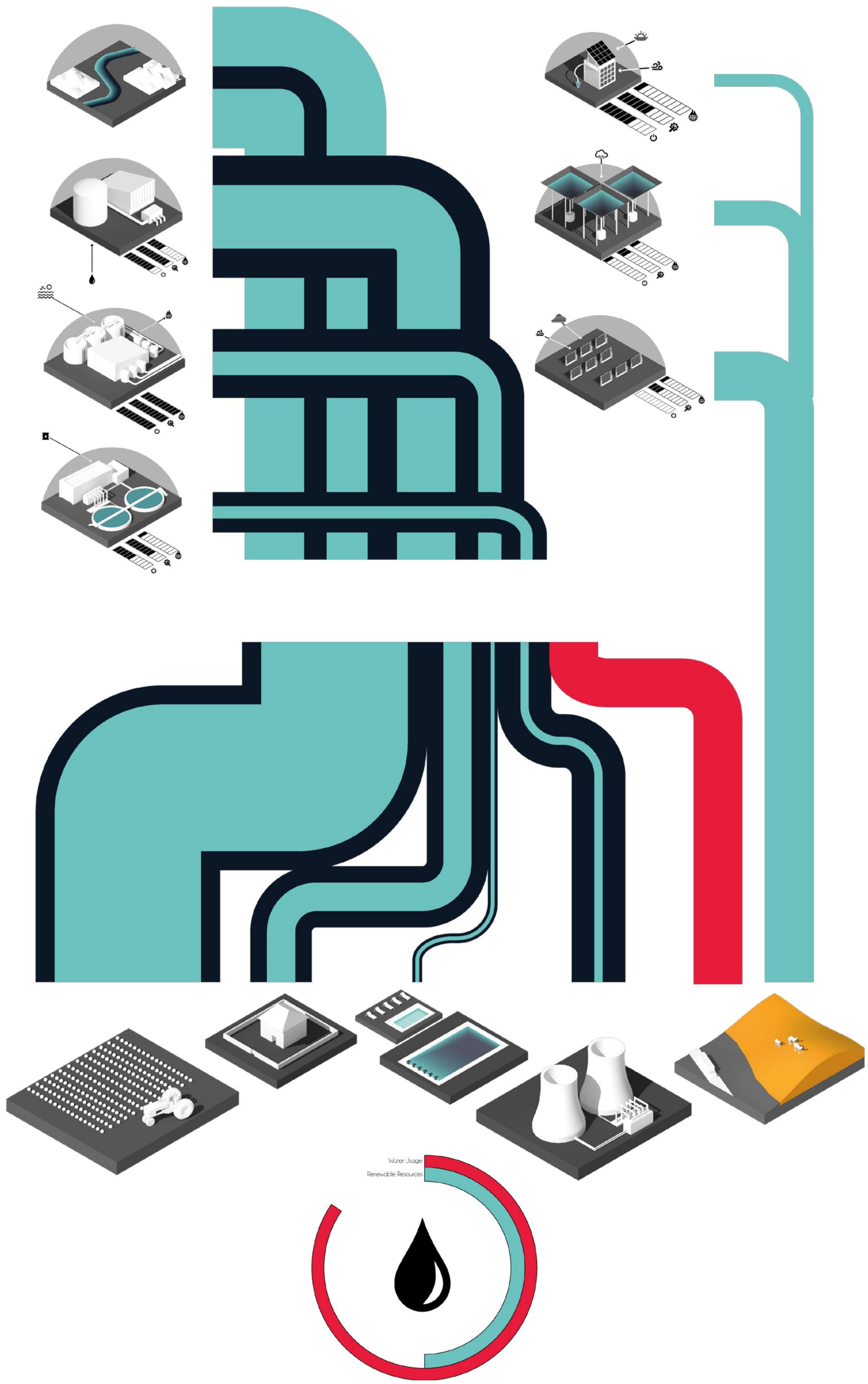


The Sahara Desert; data from J. Brachet, *Trans-Saharan Migrations* (2009).

Thesis Question

This thesis explores the idea of a sustainable promethean hydrologic system for the Sahara at the macro, mezzo, and micro scale. Investigating the architecture that might intersect with the urban fabric and infrastructural systems, so as to create a dialogue between water and community. Here, architecture will augment the hydrological system through sensorial engagement, providing much needed empirical knowledge of an external water system so that we might understand and preserve this precious resource. Architecture can reconcile a desert community and its water supply, in doing this not only combat the desert, but also repair our abusive relationship with water.

The Sahara becomes an ideal testing ground for such a thesis. The unique geography that surrounds the desert, allows for a deeper investigation into various sustainable water harvesting methods. There exist complex intersections between landscape, actors and infrastructure, which forms the spine on which such a system might be built. Ultimately, the Sahara and the populations surrounding are the most abusive in relation to their renewable water resources, it therefore stands to reason that they could benefit the most from architectural intervention that seeks to incubate an understanding and respect for the water system. The main challenge here is not of situating the technology into the desert landscape and climate, but in its representation architecturally. Integrating the hydrological system into the urban fabric and community, in such a way that it creates both a physical and visual connection with the public, in hopes to reconcile a dialect that is slowly being forgotten.



The existing water situation for the Sahara region, Data from United Nations, "Food and Agriculture Organisation of the United Nations."

CHAPTER 3: WATER HARVESTING TECH

Our Current Path

For the most part we have always relied on our renewable water resources, farmers have pulled water for irrigation from rivers, and communities have drawn from groundwater using wells. We have long existed as a simple part in the hydrological cycle, using the water that was readily available, and not exceeding the recharge rate of our wells, but that changed in the 20th century. Our relationship with water has become delicate, and modern water infrastructure has allowed us to become devastating consumers, to the point where countries are demanding water far above the recharge rate, and slowly depleting what once was seemingly infinite. In some cases, we are drilling 15 times more than groundwater is being recharged.[12] Our over consumption is driving water to become even more precious, and leading to businesses attempting to privatise water supplies for their own benefit.[13] Water is a basic human right, that needs to be available to all, and not just the elite. There is no doubt that we will continue to draw from aquifers for the next century, but it is evident that we must begin to supplement our supply with alternative sources.

There are countries in the world that already exist without much natural water reserves; Saudi Arabia, U.A.E, Oman, Spain, and a few others. These countries rely on alternative methods of getting their drinking water. The primary way of doing this is through desalination plants. This process uses large amounts of energy to remove salt from sea water and make it drinkable, and is believed to be one of our only solutions for addressing water shortages. However, there are numerous downsides to desalination, most notably the cost associated with the process and the impacts on the environment. In Twenty Thirst Century,

12 *Blue Gold World Water Wars*. Directed by Samuel Varteck (Purple Turtle Films, 2008).

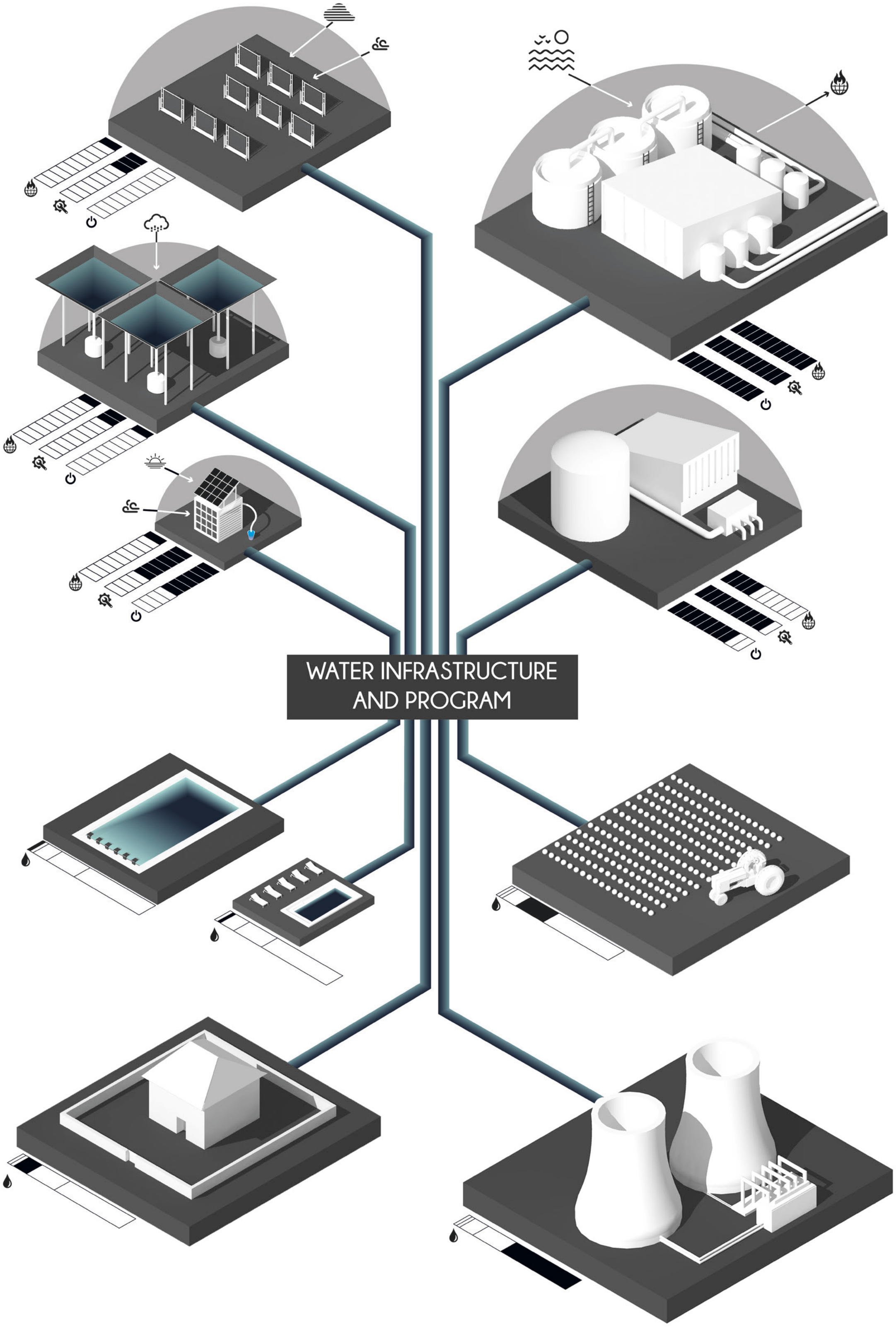
13 Ibid.

John Archer's critique of Australian water conservation efforts, Archer discusses a new plant being constructed in Sydney. The plant, initially would only be capable of producing one hundred mega litres of water a day, which is only equivalent to one and a half hours of Sydney's current needs. Although, to recover this much water the plant produces 232 million kilograms of greenhouse gases every year.[14] Osmosis can only reclaim 35-60% of ocean water, the leftover is a toxic concentration of brine which is pumped back out into the ocean, damaging the immediate marine system. Peter Gleick of the Pacific Institute wrote that because of the costs and environmental concerns desalination is an "elusive dream" and that it is more of a "soft path" rather than an answer.[15] Environmentalist Archer perhaps put it best; "desalination of the sea is not the answer to our water problems. It is survival technology, a life support system, an admission of the extents of our failure."[16] It is evident that, in order to avoid polluting and draining our ecological and hydrological systems, we must seriously explore the possibility of a sustainable approach towards water harvesting.

14 John Archer, *Twenty Thirst Century: the Future of Water in Australia* (Sydney: Pure Water Press, 2005), 18.

15 Peter Gleick, *The World's Water; the Biennial Report on Freshwater Resources* (Chicago: Island Press, 2014), 32.

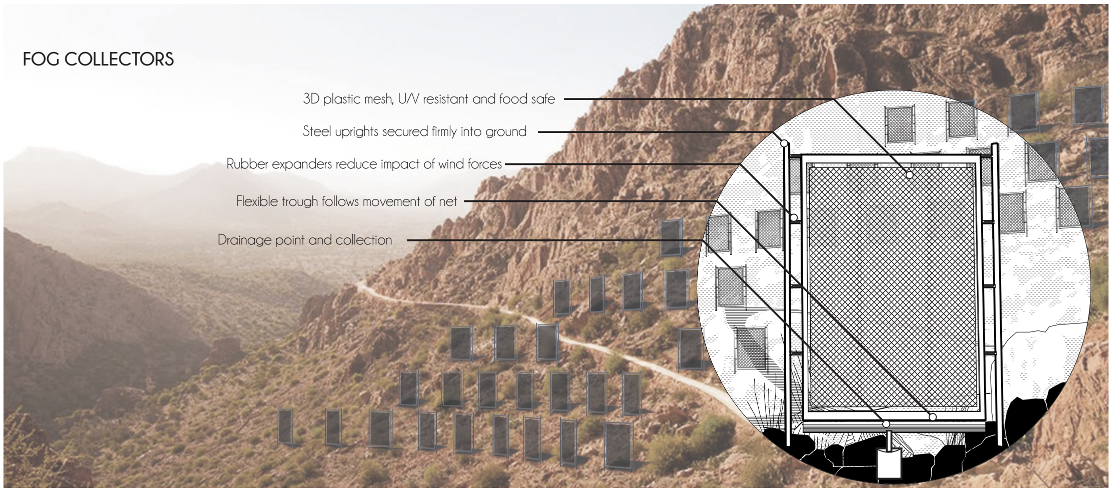
16 Archer, *Twenty Thirst Century*: *The Future of Water in Australia*, 20.

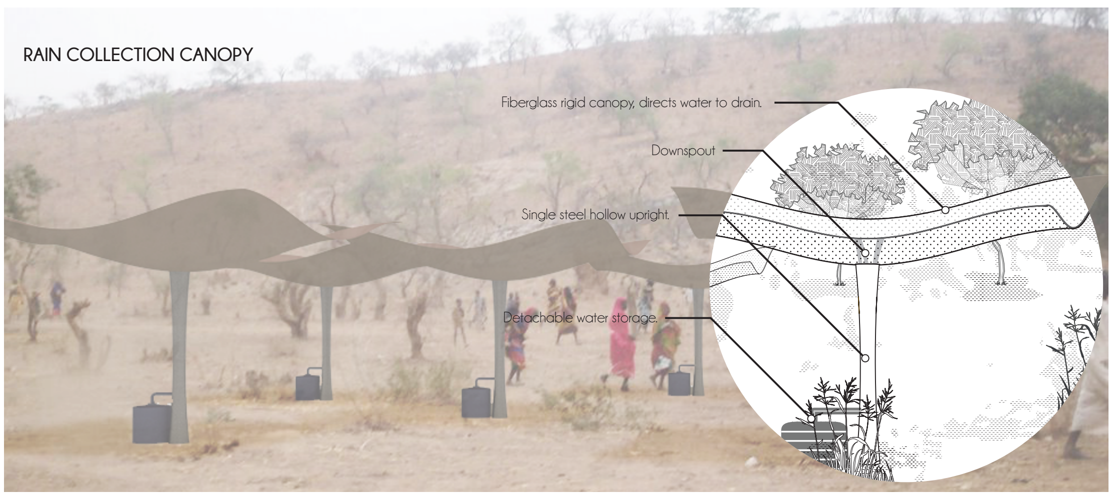


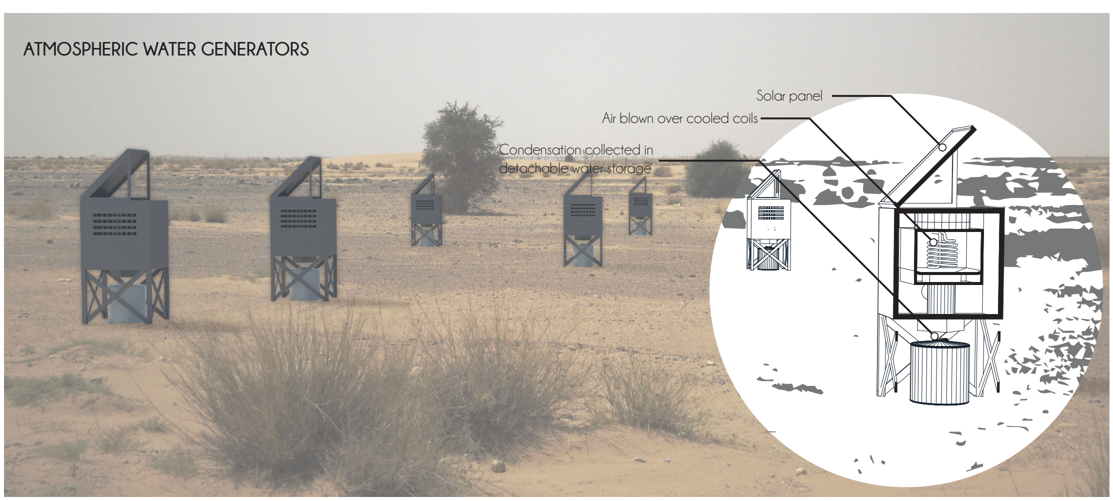
Global water infrastructures, evaluating impacts, efficiencies, maintenance, and usage of different water systems.

A Sustainable Tributary

Harvesting water from fog is an example of such a sustainable method of water harvesting. Fog collectors collect fresh drinking water from the air, it does this by creating a fog catchment area. A thin mesh like material allows the air to blow through it, but as fog passes through the mesh small droplets form on the material. These droplets run down the web of mesh collecting in a trough below. The collected water accumulates and is fed into pipes, which can then be pumped for various needs. Fog occurs for various reasons, most commonly though in areas of high altitude, steady wind direction, and a mixture of air temperature. Upslope fog occurs when orographic winds push air up a mountain, forcing it to cool as it rises, eventually moisture condenses and fog forms. This is amplified when in proximity to a large body of water, where cooler air is pushed up the mountain, where it converges with warmer air which has come from the land. This creates a more severe temperature change, and more fog is condensed from the air. This is currently being used seriously in various parts of the world such as; Chile (Andes Mountains), Eritrea (Emba Soira Mountains), and Morocco (Anti-Atlas Mountains). Another form of water harvesting that should become prominent for a sustainable future to exist, are atmospheric water generators. These work in a very similar way to dehumidifiers. Intaking warm humid air, and passing it over cooled copper pipes, in doing so the water in the humid air condenses on the pipe and can be collected. Everywhere in the world the air holds some moisture, and it is possible to draw this out of the air even in extremely arid climates. The main disadvantage to this method is that is doesn’t produce an awful lot of water in dry climates, and requires a lot of energy to do so. However, it is possible to work these from solar energy, which is becoming more and more affordable, and in arid sunny regions it is a worthwhile venture.







Examples of sustainable water harvesting technologies some of which will be further explored in this thesis. Fog catchers, rain collection, and atmospheric water generators.

CHAPTER 4: APPROACHING DESIGN

Systems Thinking

> We can't impose our will on a system. We can listen to what the system tells us, and discover how its properties and our values can work together to bring forth something much better than could ever be produced by our will alone. [17]

Donella Meadows introduces readers to the concept of a system, which is a set of complex entities that can be conceived as a whole. Thinking in Systems, is a vital aid in studying systems, it can also be seen as a distinct set of considerations that a man-made system should adhere to. The knowledge provided by Meadows is therefore critical in the realisation of a sustainable hydrological system for the Sahara Desert. Some of the more relevant considerations will factor heavily into this thesis.

One particular theory introduced by Meadows is "Systems Zoo," which compares the study of a system to that of a caged animal. In the same essence that you cannot truly study a tiger in a cage, you cannot understand an entire system by exploring a singular part of said system in isolation. To completely understand the tiger, it must be studied in its wild habitat, so that you might truly see the impact the animal has on its surrounding, and vice versa. The issue of water in the Sahara cannot just be tackled as a shortage, but it is vital to understand the reasoning for the shortage and the impact, otherwise the solution would simply be to provide more water, however this wouldn't address our abusive relationship with water. With understanding the system as a whole, you can begin to assign a hierarchy to the system. This "hierarchy" is another useful theory discussed in *Thinking in Systems*, understanding that a system is essentially a Russian nesting doll of other systems, and is in itself part of a larger system. This is the rationale for exploring and designing various

17 Donella H. Meadows and Diana Wright, *Thinking in Systems: A Primer* (White River Junction: Chelsea Green Publishing, 2015), 169.

scales of a sustainable hydrological system. If a macro system consists of several micro architectural systems, and if these work to preserve water and stop wastage, it becomes plausible that the larger system will succeed in a similar manner.

Donella Meadows also identifies common pitfalls of man-made systems, and reasons as to why they can fail. Considering these pitfalls and designing for them is a prominent factor in successful system making. “Policy resistance,” according to Meadows is when a system is rejected because it is too unfamiliar, and that even when the alternative is “better”, people would prefer to live in a known but flawed system, then an unfamiliar one. In designing any system interventions, considerations must be made for the existing systems in place, and be based on the regions culture and beliefs. In doing this the system will better assimilate into the community, and therefore face less resistance. “What is common to the greatest number gets the least amount of care”, Aristotle was among the first to realise the “Tragedy of the Commons”, in that a resource available to all is often the most abused for private gain.[18] Meadows identifies this as a prominent problem with systems, in that people can be greedy, and abuse a resource until there is nothing left. We can already see this with our ground water reserves, where we are pumping faster than the source can recharge. The concept that there exists a delicate relationship between us and our water supply, is a difficult issue to address in system design. Nonetheless, a sustainable water system has to create accountability and a common identity over a water supply, in hopes that the community will limit its water usage.

18 Aristotle, *Aristotle’s Politics* (Oxford: Clarendon Press, 1905), 28.

Mapping Theory

> In this active sense, the function of mapping is less to mirror reality than to engender the re-shaping of the worlds in which people live. [19]

As established in the previous section, a system must be realised as part of many smaller systems, and integrate itself in a familiar manner. In order to do this, the existing intersections of actors, landscape and infrastructure must be identified for the Sahara region, so that the sustainable water system can attach onto a familiar spine, and merge with existing systems. James Corner offers the belief that through the act of mapping we can uncover "realities previously unseen or unimagined, even across seemingly exhausted grounds."[20] We can use mapping as a tool to understand the Sahara, allowing us to identify not only a footprint for the system to land, but also find nodes of water harvesting potential. By overlaying and superimposing both weather data, infrastructure, landscape and various others, we can begin to imagine how a sustainable water system might come into fruition. These parameters created through mapping begin to define where the system can exist, shape the paths taken, and realise the necessary interacting relationships.

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19 James Corner, "The Agency of Mapping: Speculation, Critique and Invention," *Mappings* (London: Reaktion Books, 2011), 222.

20 Ibid, 214.

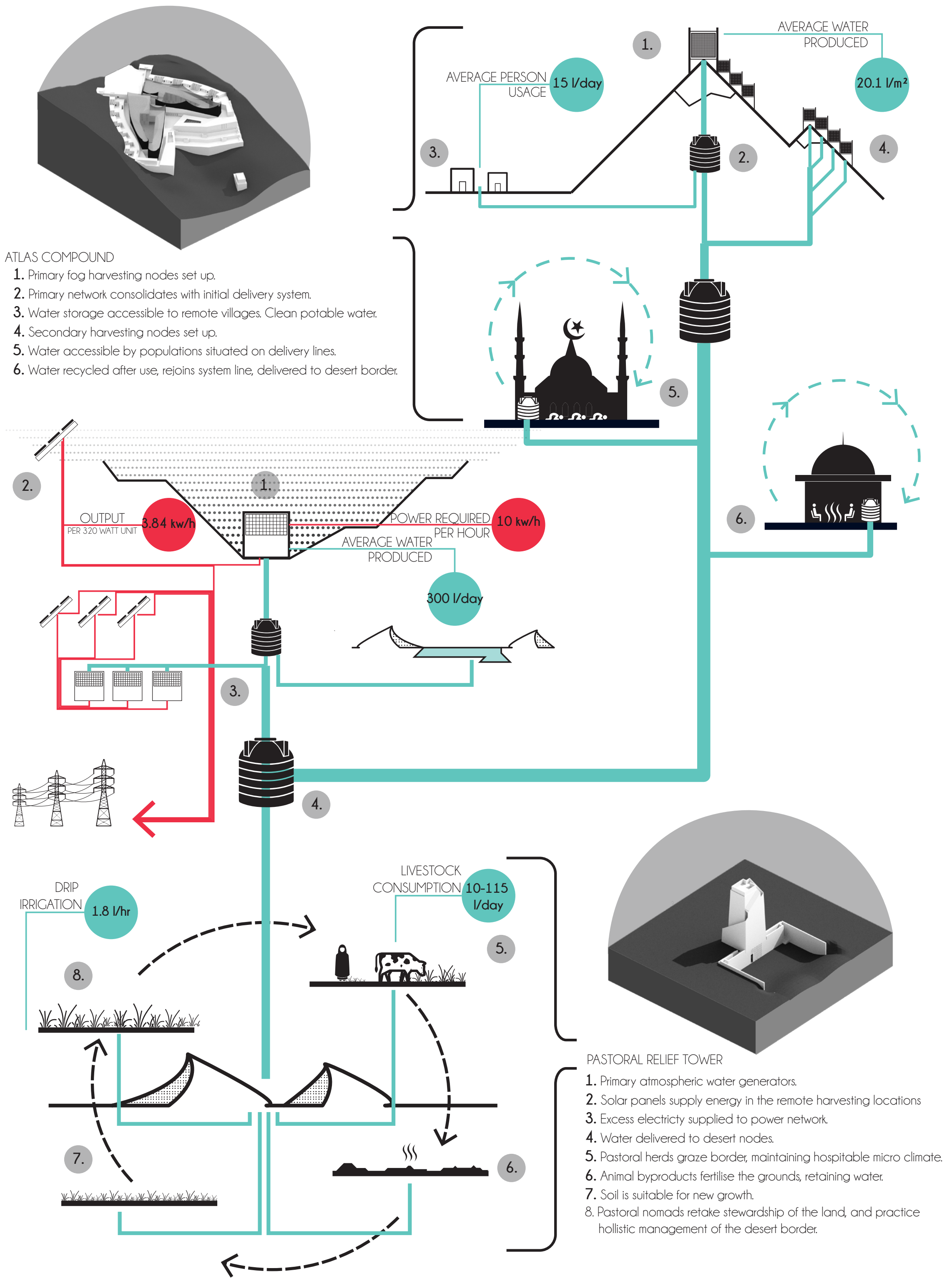


Diagram of major moments in the proposed water system, illustrating how individual water conservation systems work together to form a larger system aimed at desert regrowth.

Method Implementation at a Macro Scale

> So, the task was given to those who, by instinct and training, were especially suited to gouge and scar landscape and city without remorse - the engineers. The landscape architects were then retained to apply balm to heal the scars and wounds inflicted on the landscape.[21]

The previous section has proved that mapping as a method is one of the most ecologically sensitive approaches to design. Through the visual superimposition of spatial data over a landscape it can reveal subtle design routes. In order to avoid scarring the landscape and creating a larger divide between us and the natural world, we must start by mapping the Sahara Desert, in hopes that it will reveal fertile ground for a sustainable water system to grow. Once, regions of growth are identified, we can use systems theory to design and network the system in a resilient manner. The following sections provides revealed observations of the mapped Sahara.

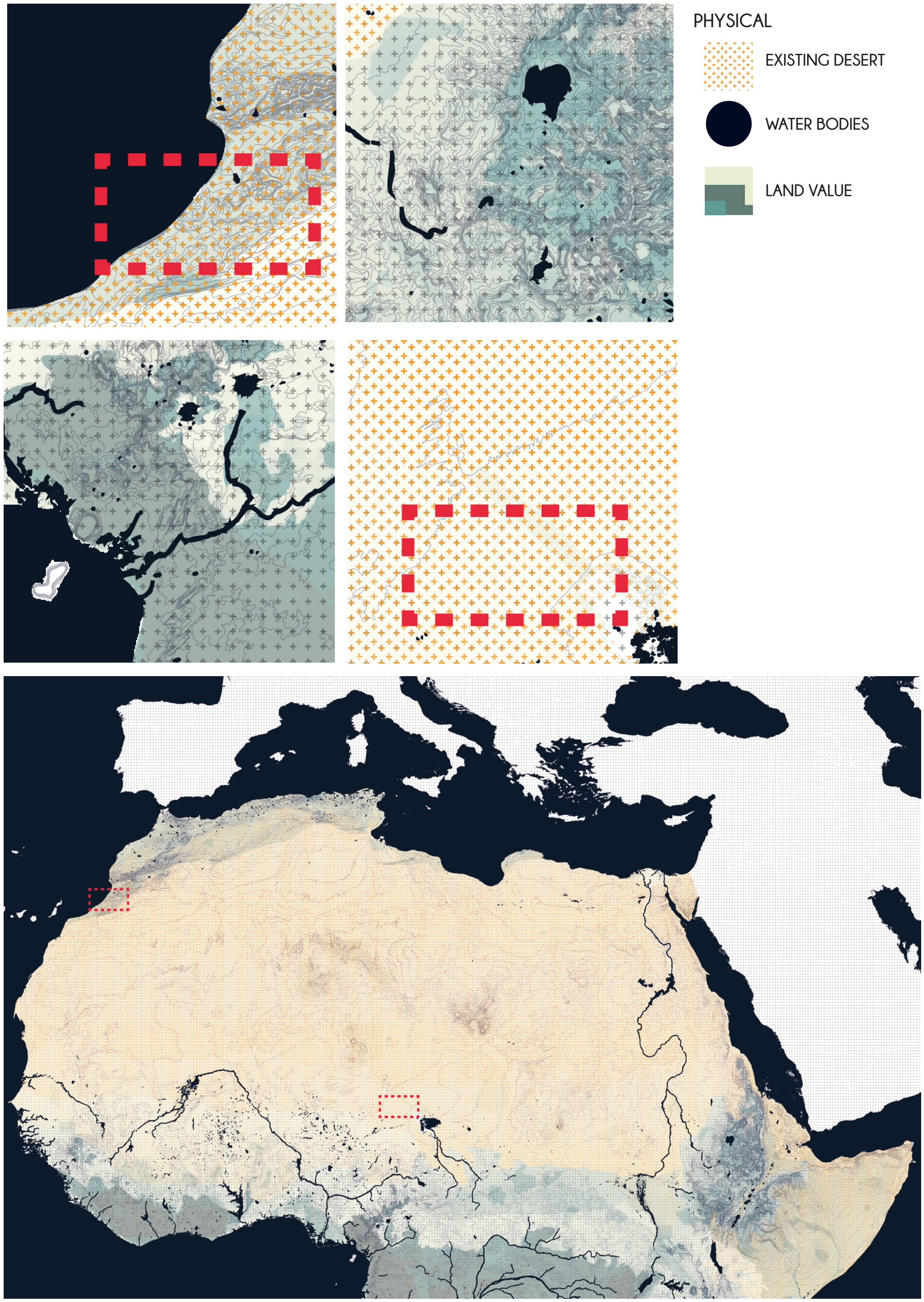
The Sahara has some of the largest reserves of aquifers underground, however these large bodies of water are over 500m deep in most cases. Without post-colonial country lines, it can be imagined how North Africa could be divided by the footprints of underground aquifers, already many aquifers are trans-boundary and shared. The greatest density of water is located south of the Sahara, where the region receives a lot more rainfall. Bodies of water also identify the areas of arable land, the Nile generates a green barrier around itself, despite running through the heart of the desert. The Anti-Atlas Mountains also creates a barrier to the encroaching desert, protecting the arable land behind them. Whilst all countries in the region suffer desertification, Sub-Sahara faces the greatest threat. The vast desert generates harsh winds, and the lack of a physical barrier means that the rate

21 Ian L. McHarg, *Design with Nature* (New York: John Wiley & Sons, 2005), 35.

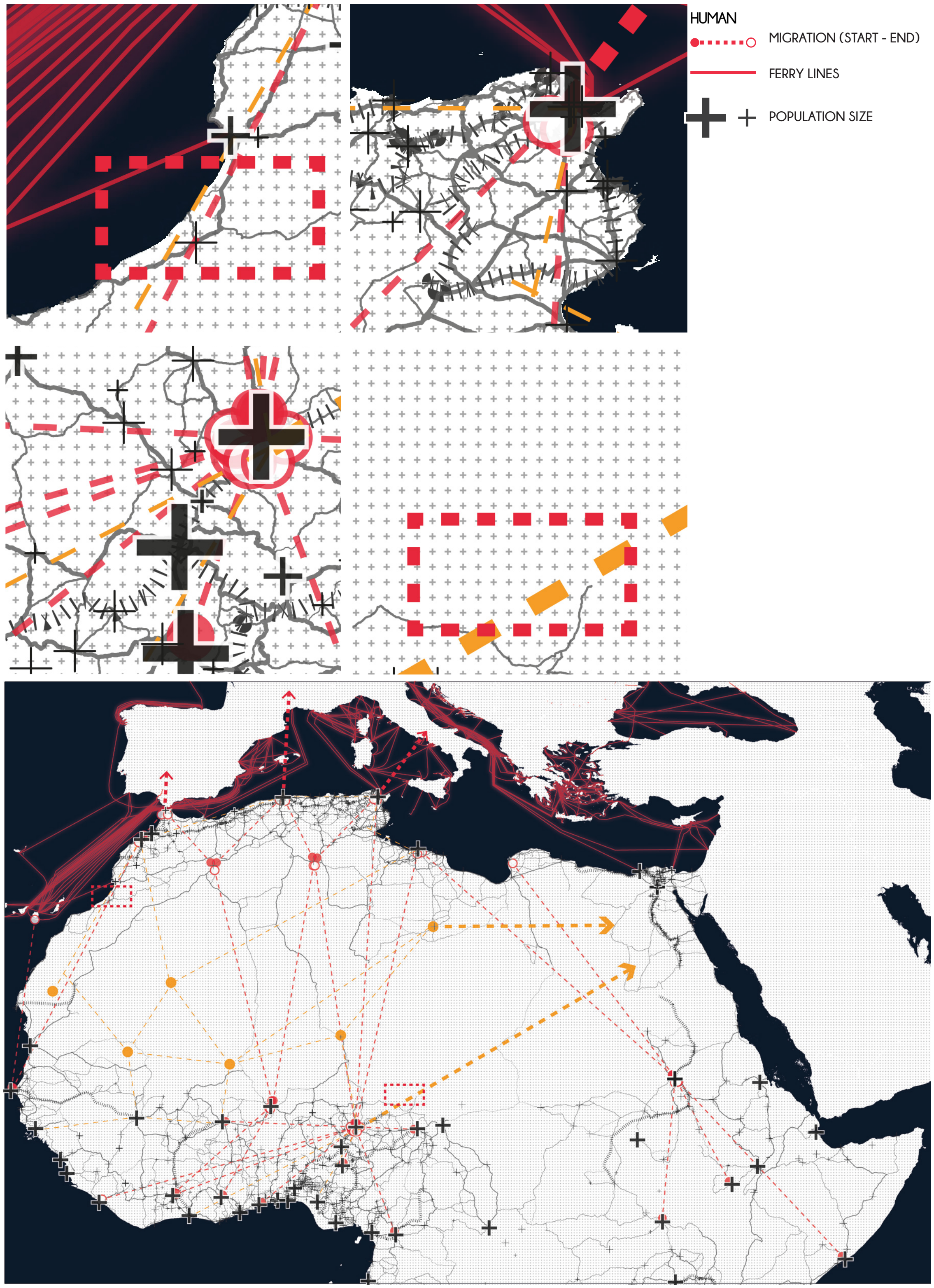
of wind erosion and desertification is extremely high.

The physical geography of Africa directly influences the human geography. We can see large populations surround bodies of water. Egypt despite its boundary stretching far into the desert, all of its population live on the Nile. There are very few settlements in the desert, any settlements here are mostly industry or oasis towns. Even the settlements on the edge of the desert are experiencing masses of people migrating, either through the desert to a coastline closer to Europe, or retreating further south to more secure, less threatened land. There still exists many traditional routes through the desert, and these are the paths of Tuareg and nomadic peoples. Recent surveys provide evidence that even the nomad way of life is threatened by climate change. The routes of pastoral nomads move with the desert border as it fluctuates between wet seasons and dry seasons.

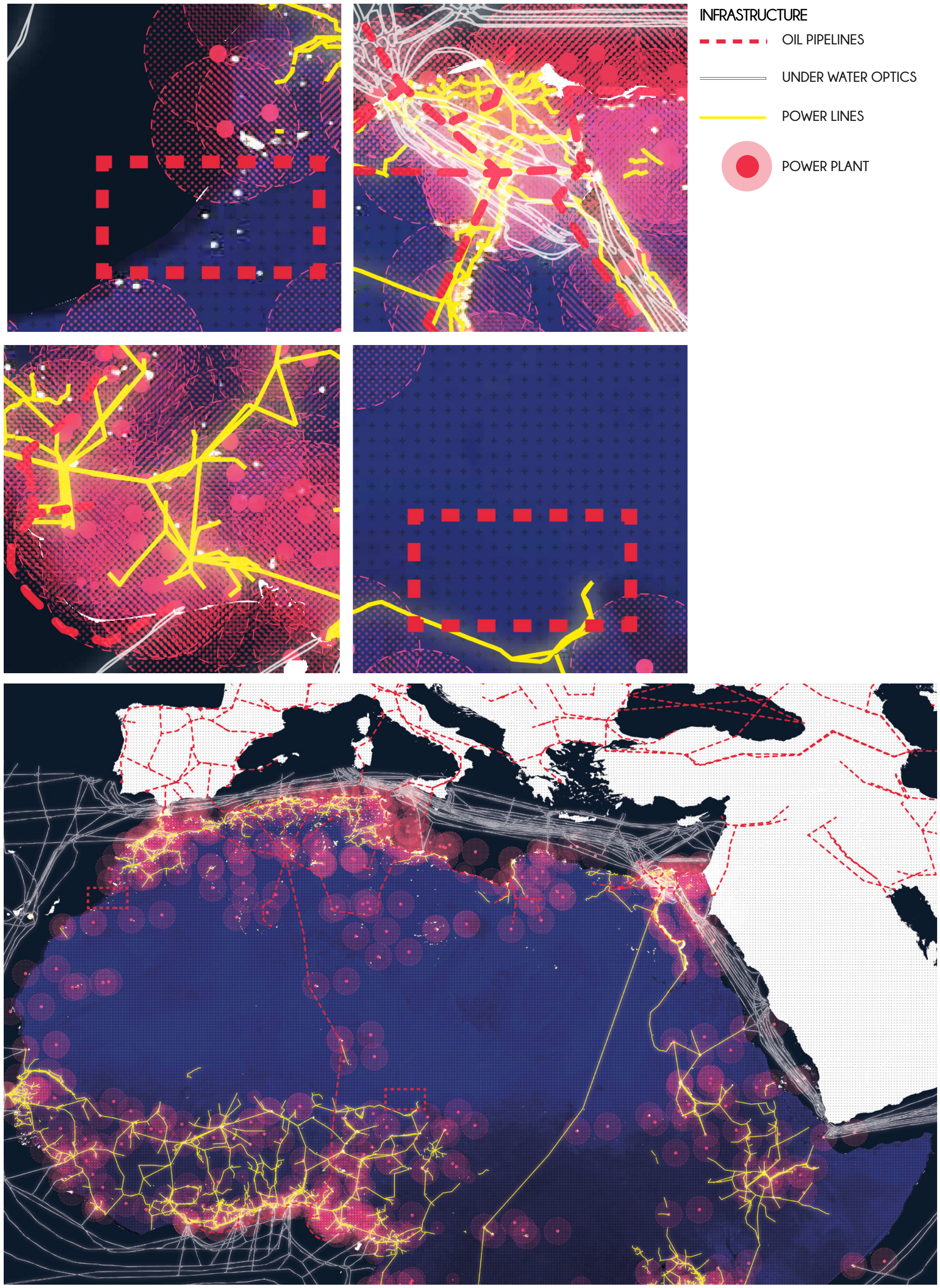
In mapping the existing infrastructure of the Sahara, certain observations can be made. Similar to population there is a large density of power plants around bodies of water, primarily running bodies of water so as to gain power hydro-electrically. A higher percentage of power plants are being planned for construction in the desert, with the ever-decreasing cost of solar panels, the potential for solar power plants in the Sahara is great. For the most part, power lines connect power plants with populations by following existing roads. Unlike oil lines which forge their own path through the desert, and are controlled more by political and economic positions than geographical ones. This is a perfect example of a man-made scar through the landscape.



Physical geography of North Africa; data from ESRI USGS, “Africa terrestrial ecosystems” (2014).

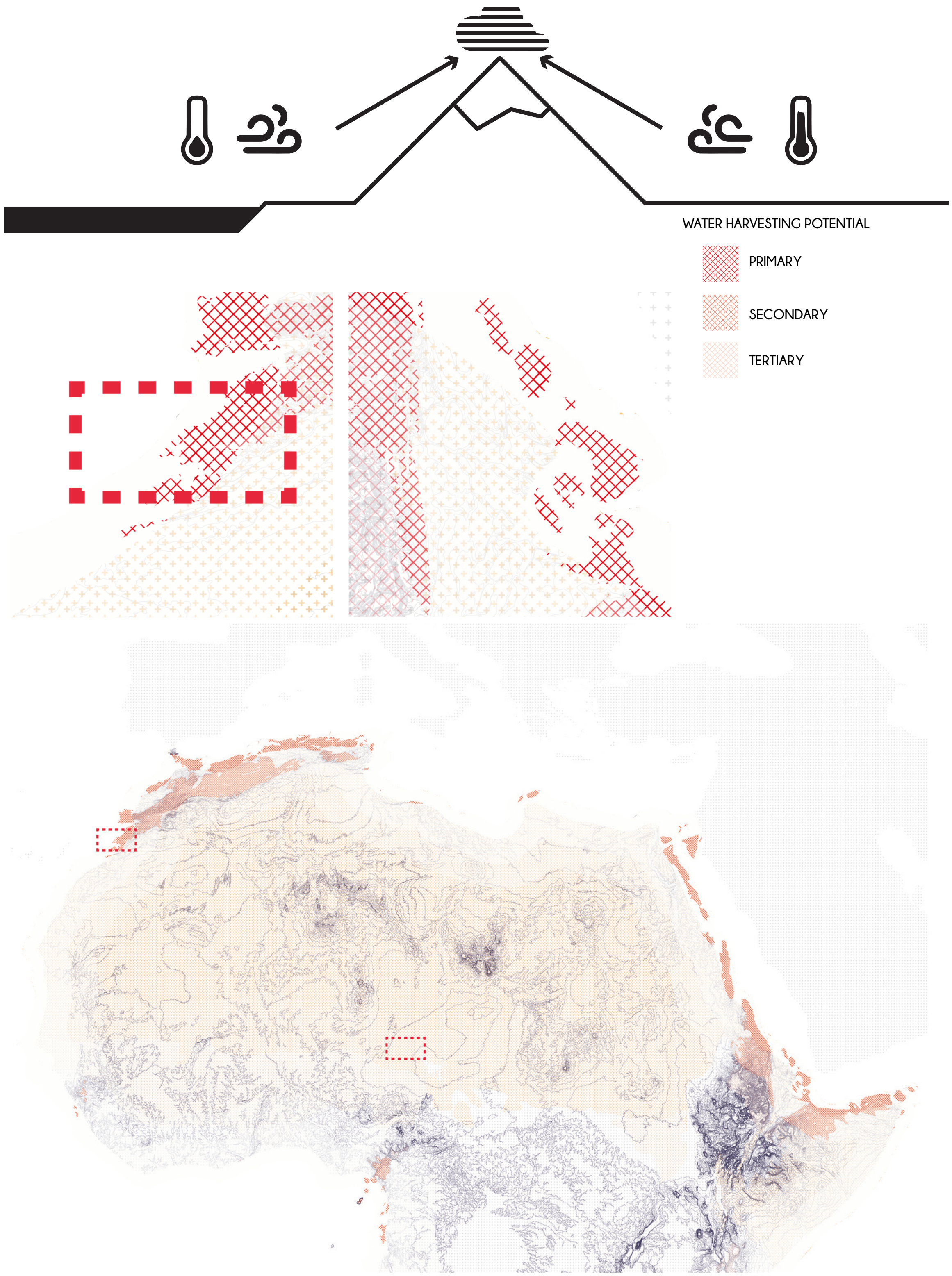


Human geography of North Africa; data from ESRI USGS, "Africa's patterns of movement" (2016).

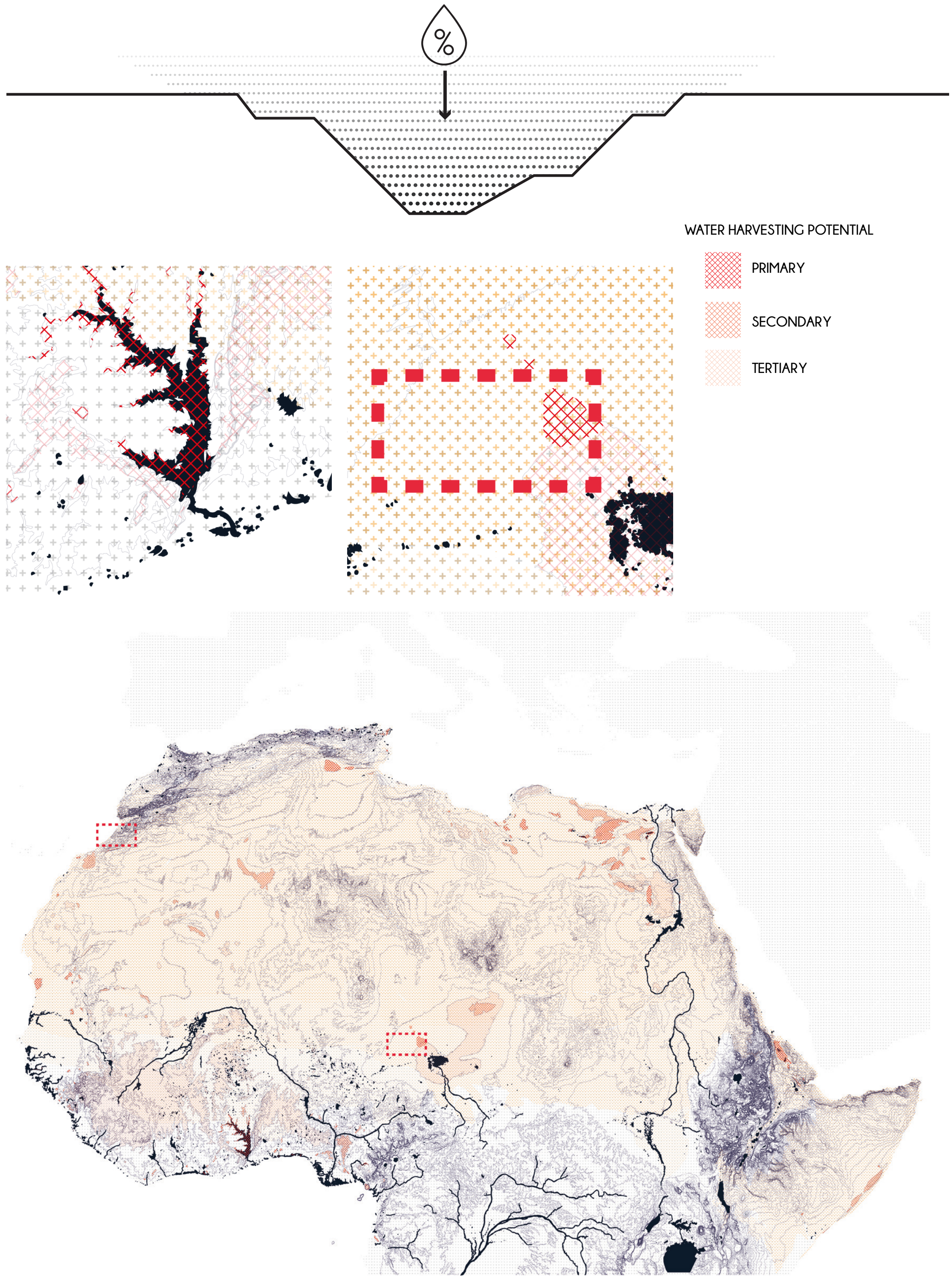


Infrastructural geography of North Africa; data from ESRI USGS, “Africa’s infrastructure of connectivity” (2014).

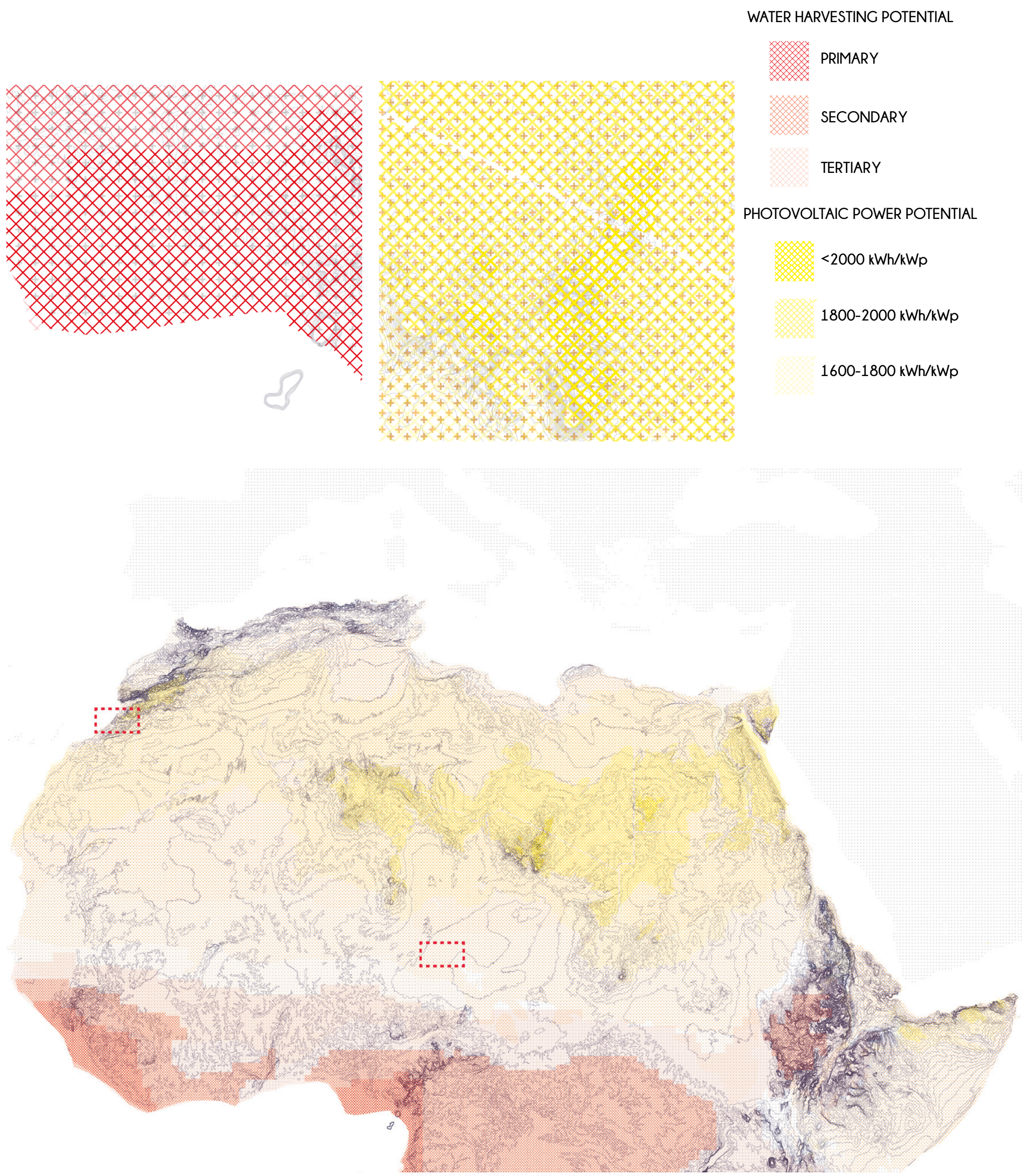
In order to map the water harvesting potential of the Sahara, we must overlay the necessary weather data with the physical geography. In order to uncover regions of fog, primarily upslope fog, areas of high altitude are the first priority. Then areas where two vastly differing temperature winds might collide, in this region of North Africa that would occur near large bodies of water and the desert border, so areas within a certain distance of the ocean are mapped. These regions are then supported by weather station data. In mapping humid regions, weather data is the primary tool to find regions, the next is locating valleys. Valley regions are more humid than flat lands and highlands, this is due to the fact that humid air is heavier. By combining the two we are presented with water harvesting regions from humidity. Water collection by Rainfall is the easiest region to map, as there is significant available data on rainfall throughout the Sahara. These regions can be separated by water harvesting potential into primary, secondary and tertiary regions, which gives us the roots in which to plant nodes of the sustainable hydrological system.



Fog harvesting potential of the Sahara.



Atmospheric water harvesting potential of the Sahara.



Rain harvesting and solar potential of the Sahara.

A Sustainable Hydrological System

The system begins by forming independent nodes in areas of high-water harvesting potential, providing drinking water for small immediate communities. Then the network grows, branching along existing infrastructure and the paths given by the landscape, connecting to nodes in secondary and tertiary regions of water production. This forms a country wide sustainable water network, supplementing communities on the edge of the desert. Finally, once the flow of water has reached the desert border, the network unites with each countries border, until there exists a sustainable water supply to the desert that can be used to create and regrow the border.

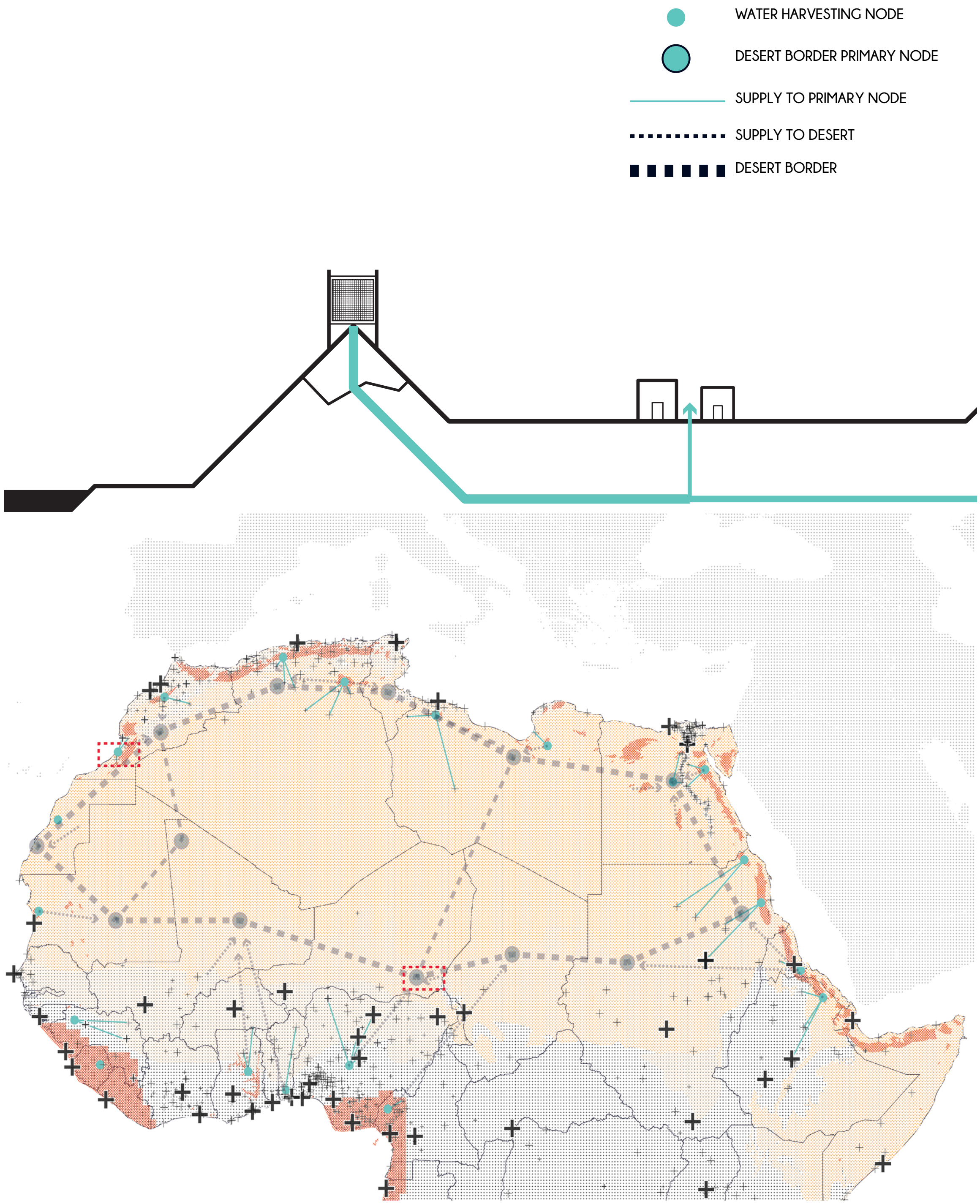


Diagram of first step. Initial node formation in the sustainable water system.

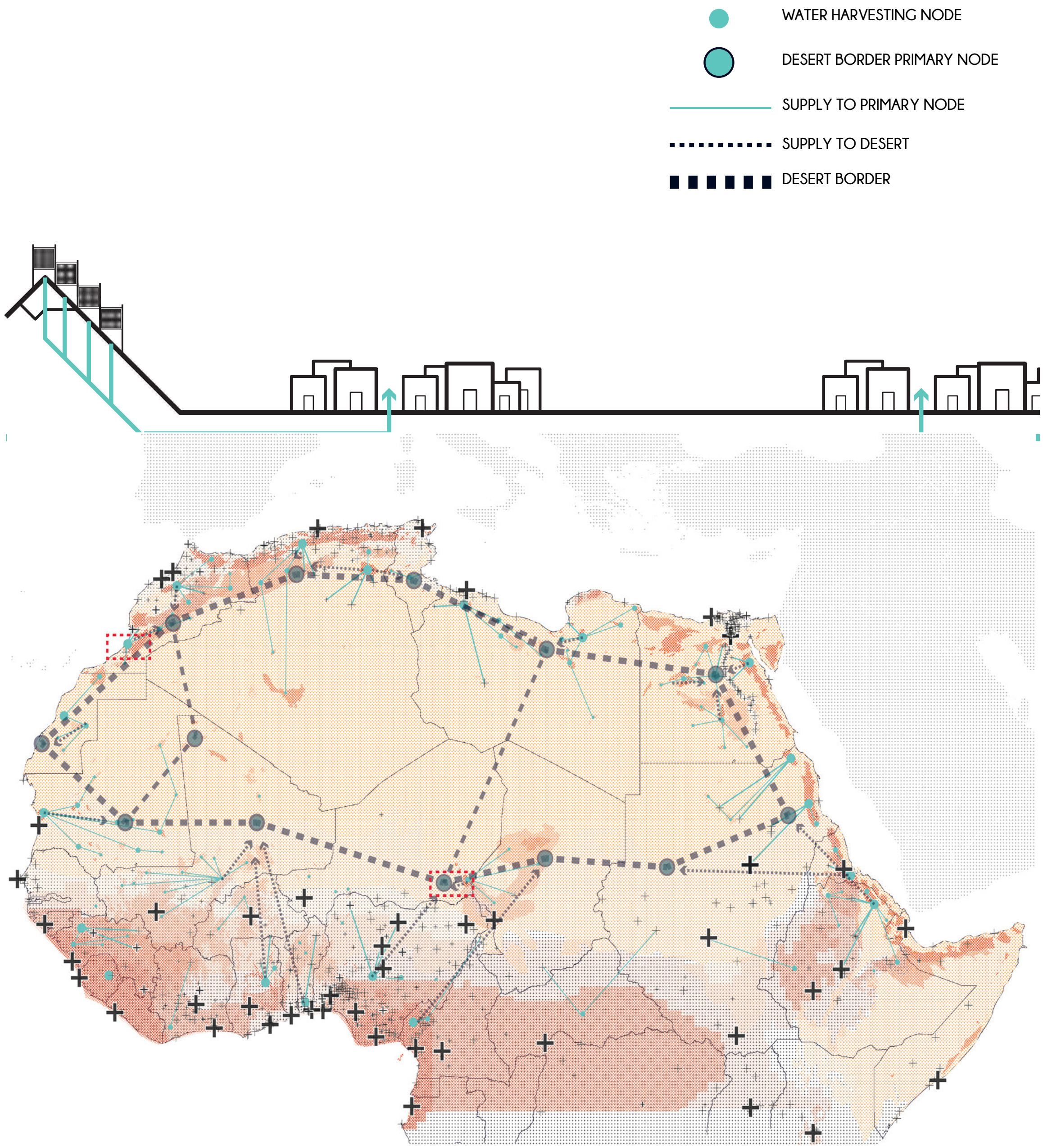


Diagram of second step. Secondary and tertiary node forms country network.

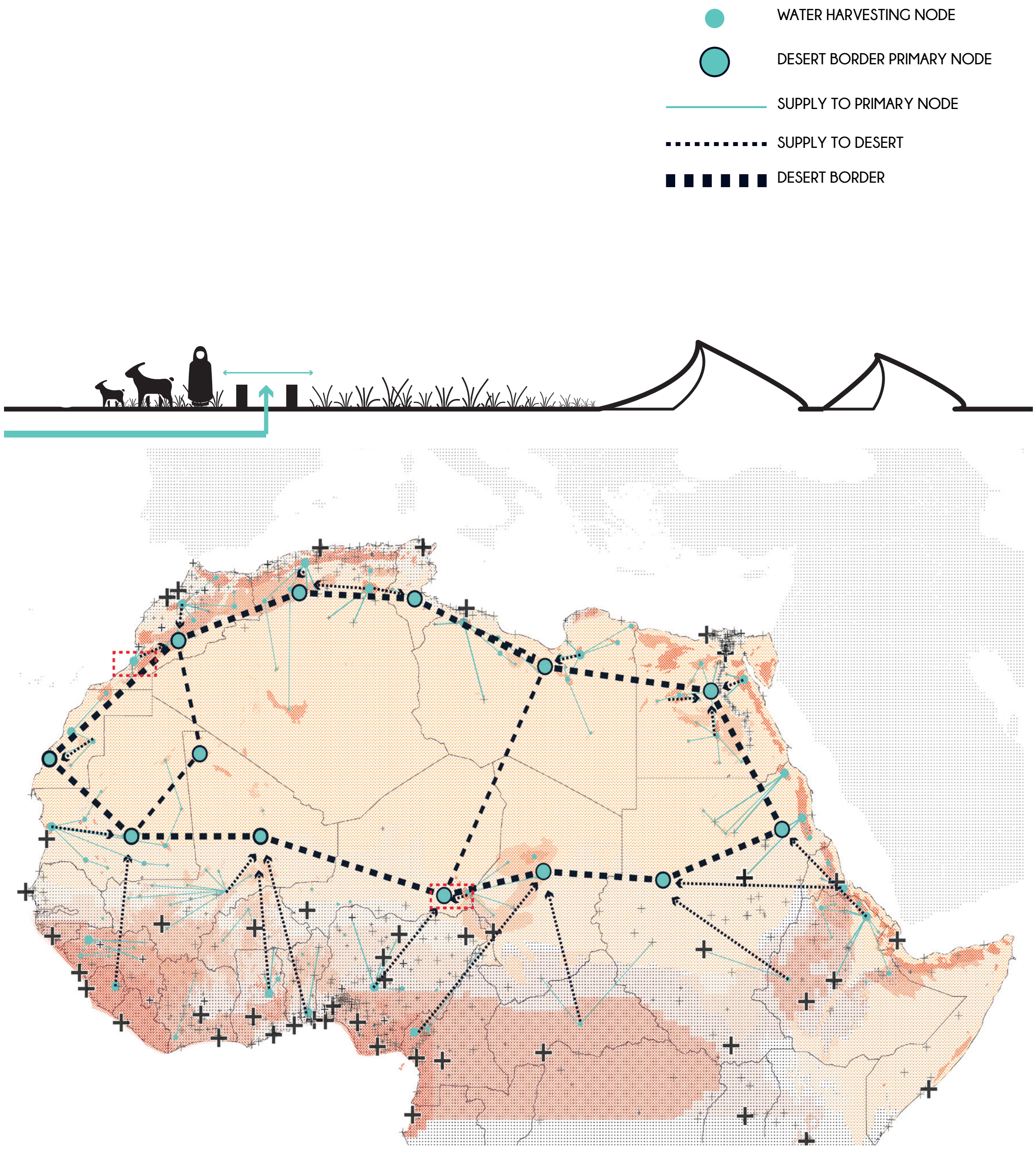
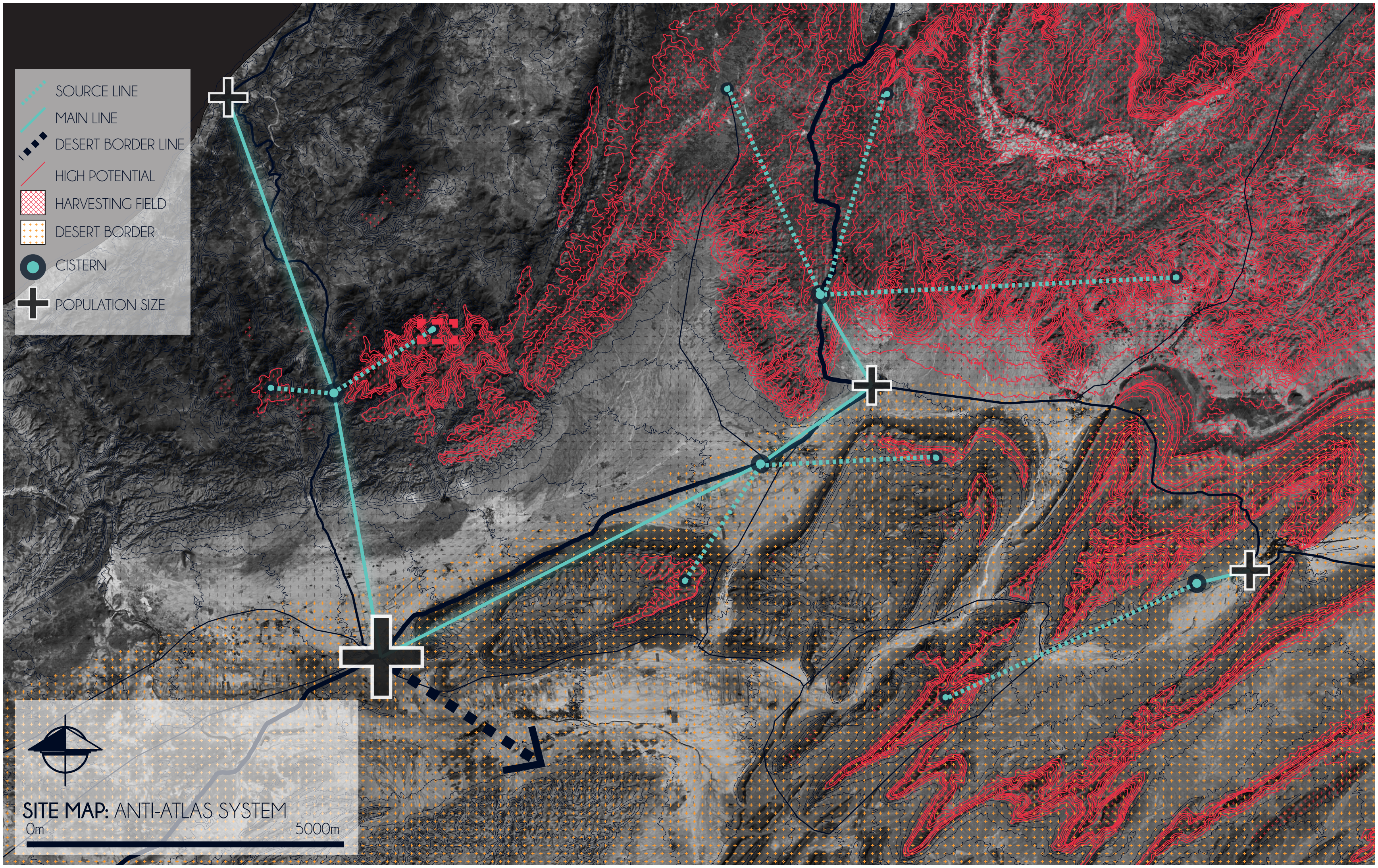


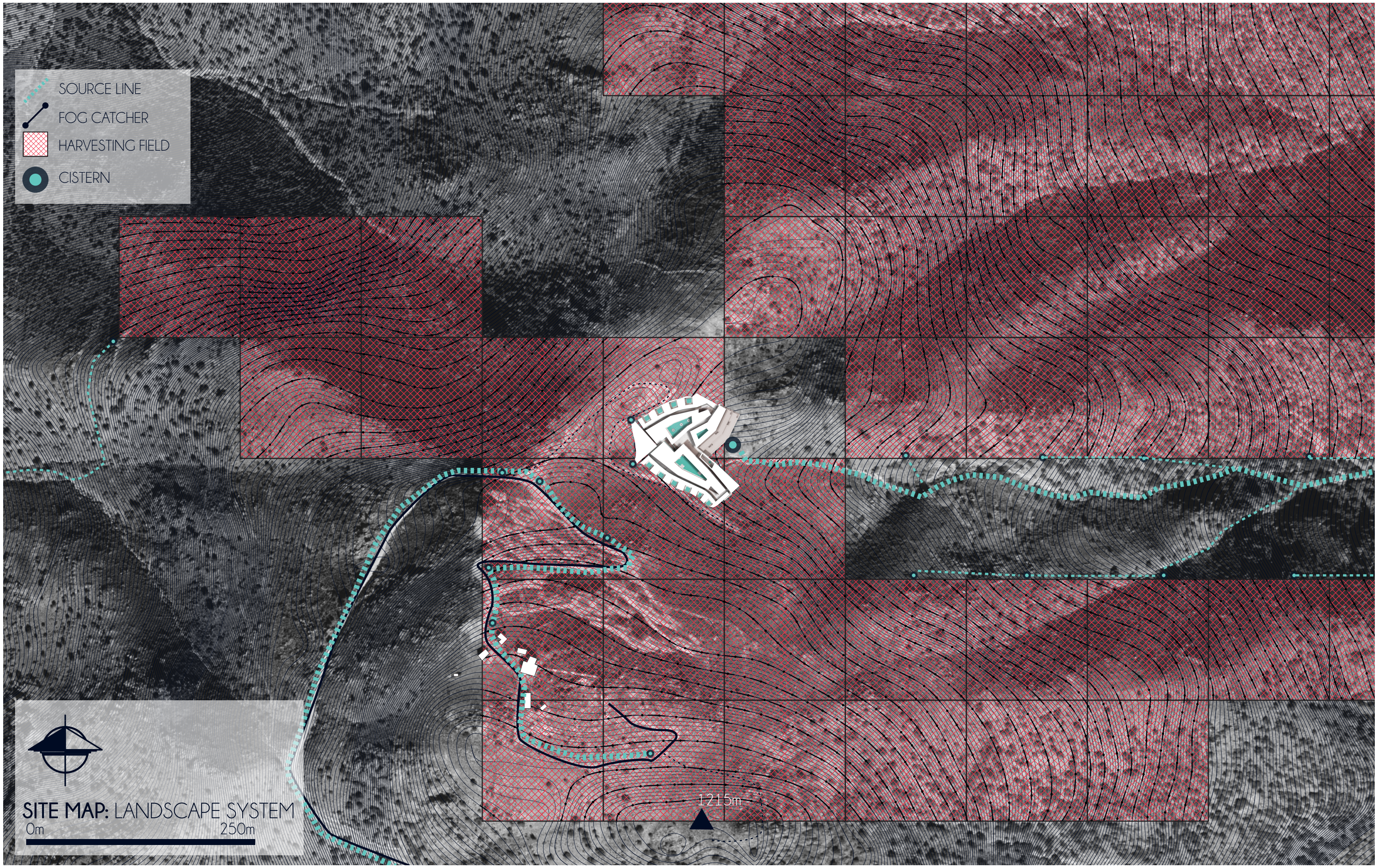
Diagram of final step. Network surrounds desert border.

Mapping the system conceptually at the macro scale provides the opportunity to survey all the interesting intersections of activity that might occur throughout the new hydrologic system. We can then identify regions that encompass several different nodes in the sustainable water system, so that we can explore various facets of the system and conceive how they connect in a few select locations. For these reasons two regions were chosen, the Anti-Atlas Mountains of Morocco, and the Sahel region in the Niger Valley.

The Anti-Atlas Mountains of Morocco have a very high potential for fog harvesting. There already exists case studies, and ample data into how much water can be produced in this region through fog harvesting. On top of Mount Boutmezgouda, we can begin to understand how landscape would influence placement of fog harvesting technology. Predominate winds dictate where fog catchers are most effective, and contours provide a guideline for gravity fed water systems. Near this region of high-water harvesting potential resides the city of Guelmim, with a population of 100,000. Existing infrastructure through the landscape provides routes through the city for water delivery to the desert border, and its open spaces provide opportunity for small scale architectural interventions to mix water and community.



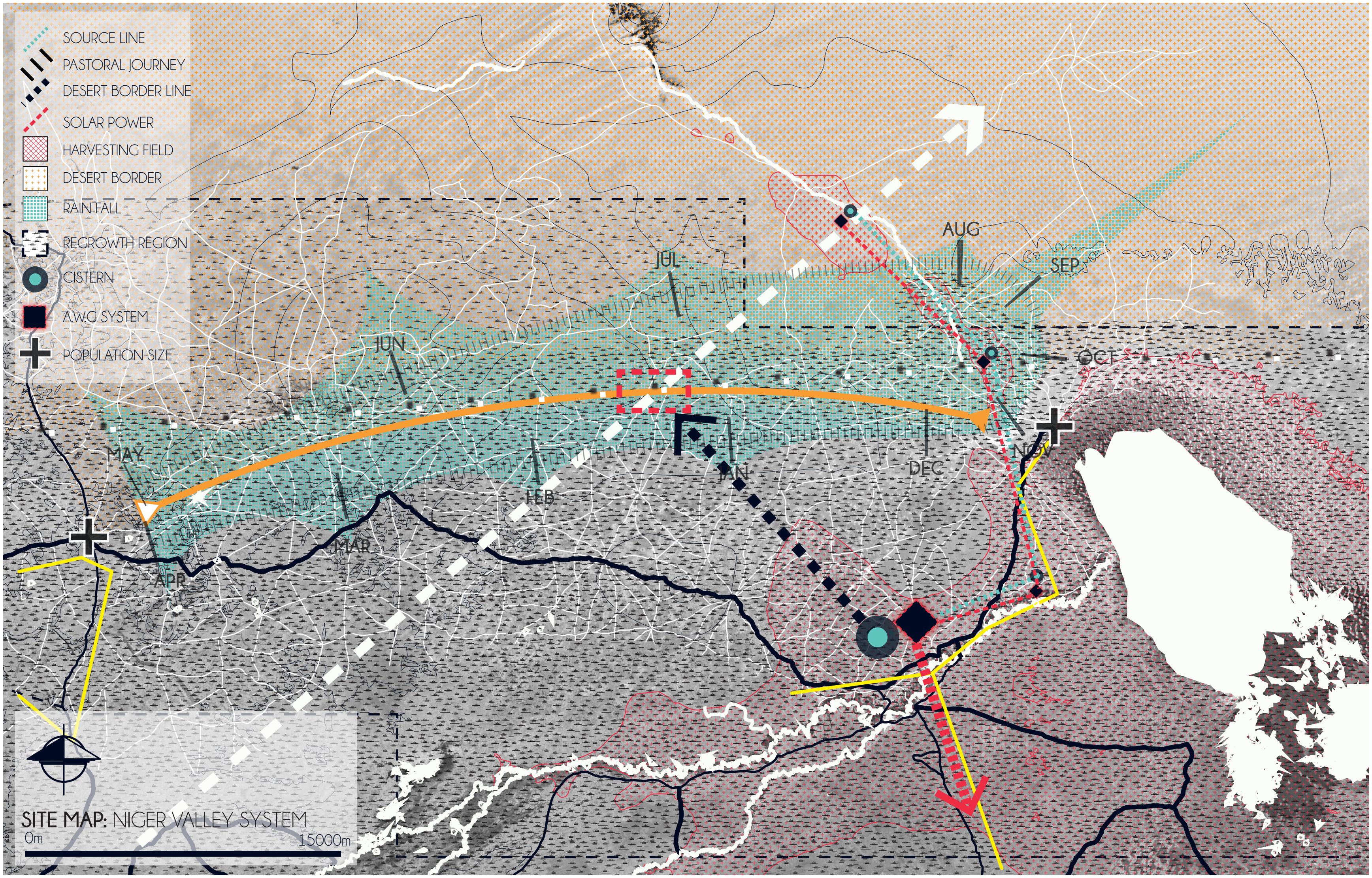
Anti-Atlas Mountains, diagrammatic water system supplying the city in the valley.



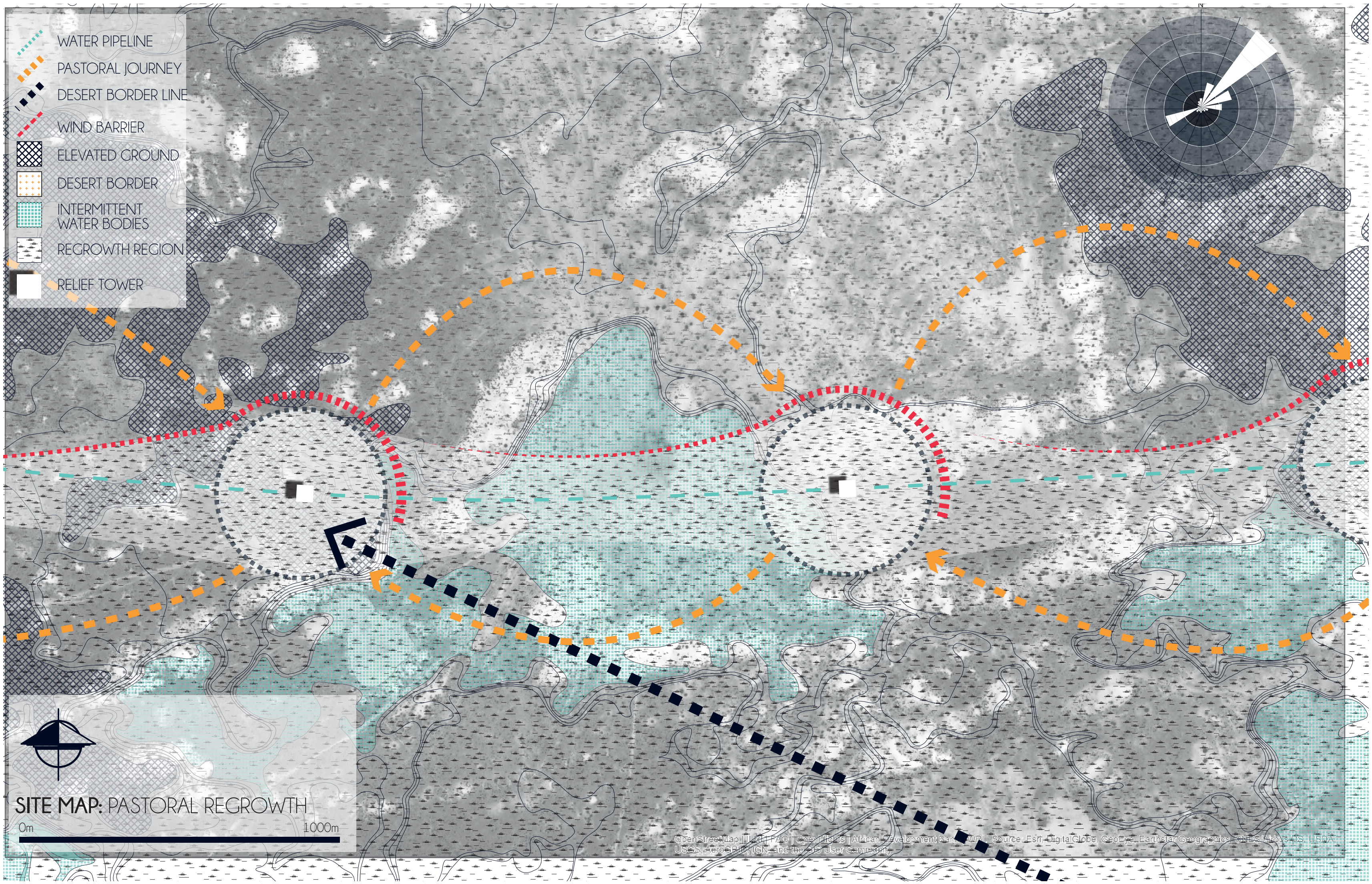
Anti-Atlas Mountains, diagrammatic source of the water system, and location of primary architectural intervention.

The second region of study is the Sahel region in the Niger Valley. This region has the ability to harvest large quantities of water from humidity for majority of the year, also receives occasional heavy rainfall. The region is also quite heavily populated by nomads, and traditional caravan routes, which is vital for saving the nomadic way of life and the regrowth of the desert. Further into the desert there is a valley region which allows for higher humidity harvesting, and it also has ample solar potential to power atmospheric water generators. There is also a traditional Tuareg caravan route through this region into Algeria and North Africa. Again, we can see how the landscape influences technology placement. Such as south facing slopes for solar aspect, slightly elevated areas for the atmospheric water generators to allow for gravity fed water pipe systems. Roughly 250 km out of the desert, along its fluctuating border, there is a traditional pastoral nomad route and marketing town. Pastoral nomads practice animal husbandry, so the grazing routes of their herd is vital to maintain nutrients in the land, and trampling groundcover maintains a hospitable growing micro climate. Therefore, the desert border should promote the holistic movement of pastoral nomads, instead of, as most governments have sought to do, which is settle the nomadic people, under the belief that they cause desertification.

Designing a system for the macro and mezzo scale is beneficial in identifying how the landscape and technology might coexist together, and where the system intersects human activity. As previously mentioned, in order for the larger system to have any chance at succeeding, we must delve deeper and oppose water scarcity at a micro and more human scale. This can be achieved through architectural design.



The Sahel: A region of the Niger Sahara border and how a sustainable water harvesting system might exist in the landscape.



The Sahel: A collection of connected regrowth relief towers situated along a nomadic grazing route.

CHAPTER 5: APPROACHING ARCHITECTURE

Understanding Begets Respect

> The consequences of the disregard of natural systems are now being felt and there is a shift in thinking among built environment disciplines towards repairing the natural environment as a meaningful and enduring framework for urban form. [22]

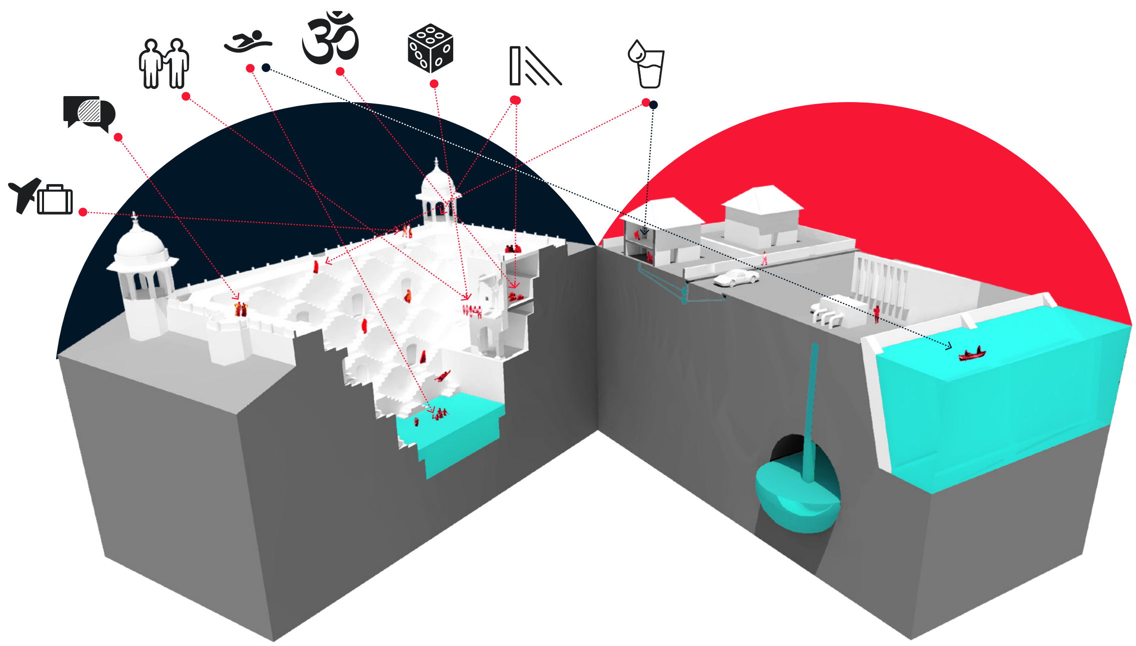
Our promethean urge to tame water has created a very convenient lifestyle for us, however it has also created a large divide which has rendered us without any empirical knowledge of this precious resource, and ultimately led to a mostly unaware and immoral wastage of water. It is therefore critical that architectural nodes that exist along the macro system reconcile this disconnect between community and water at the micro scale. It is important to understand that over-consumption was never an issue historically, and that by studying water infrastructure of the past we might learn how to design for the future. Prior to doing that, we must first attempt to distil a reason as to how humans develop respect, in an attempt to stop the abusive water relationship. Since it is generally excepted that understanding produces respect, we must slightly delve into the philosophical theory behind understanding. The following section consists of an analysis of a small portion of Kant's *Critique of Judgement*, in which he offers insight into human understanding.

Following the premise that understanding begets respect, it is necessary to explain how humans make sense of the surrounding world and understand it. In Immanuel Kant's *Critique of Judgement*, he explores the theory behind understanding. Kant classifies all knowledge of the world into noumena and phenomena. Noumena means the thing-in-itself, which is a reality that exists outside of our perceived world. Phenomena therefore, is the reality that we are able to understand by experiencing it sensorially.[23] Kant believes

22 Mauro Baracco, Louise Wright and Linda Tegg, *Repair* (New York: Actar Publishers, 2018), 3.

23 Immanuel Kant and James Creed, *The Critique of Judgement* (Oxford: Clarendon Press, 1982), 112.

that because we do not experience noumena, then we cannot truly understand it, we can only truly understand that which is filtered through our mental/sensorial facilities. In a sense, our modern water system can be classified as noumena, as it exists independently of our own reality. There is an argument then, that we don't understand the system, and therefore we don't respect our water supply. Transforming a water system from noumena to phenomena becomes a significant architectural challenge.



Comparison drawing between traditional water infrastructure (left) and our modern water system (right).

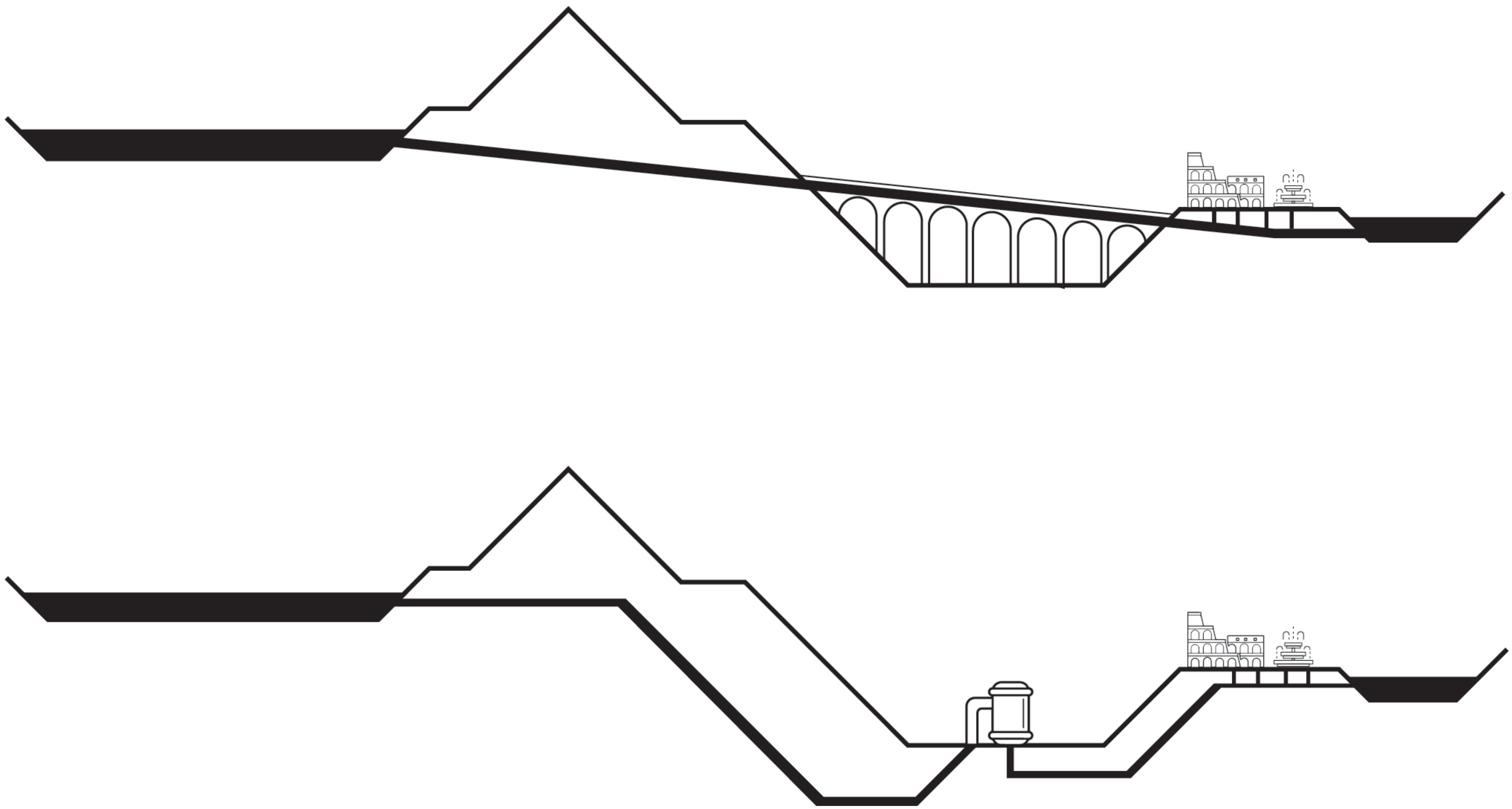
Case Studies

In the interest of further developing design intentions, the following section investigates two case studies. It is important that they are studied in the same manner, so as to compare and draw conclusions. For this reason, they shall be studied in a technical manner, which will describe how the infrastructure functions. Secondly the case study will be explored as an urban landmark, investigating how the infrastructure situates itself in the built environment. Finally, the infrastructures will be looked at in a social aspect, understanding the cultural significance the water supply offers the community. The investigation starts with the water system of Rome, then the stepwells of India, and finally will end with observations and important lessons for designing water infrastructure.

The Waters of Rome

Technical

Early Romans got their water supply from aqueducts that allowed water to travel large distances over the landscape. The ancient Aqua Virgo is the name given to the large aqueduct that supplied early Rome, today the modernised predecessor Acqua Virgine still draws from the same source outside the city. The Aqua Virgo was a traditional ancient Roman aqueduct, which mostly used gravity and a slight slope to carry water long distances over the landscape. These aqueducts were giant marvels, and could clearly be seen from great distances. Nowadays, the Acqua Virgine is a pressurised aqueduct, where the majority of infrastructure is hidden underground. The water goes on to supply the Trevi Fountain, a very famous fountain in the city.



Comparison between ancient Roman water delivery system (above) and the modernised system (below).

Urbanisation

Water is taken from a spring in Salone, previously it was the carried over the landscape by massive structures, today the water travels underground in pressurised pipes. When the water enters the city, it travels through underground aqueducts, which are still in use today. From this point the water is expelled from the Trevi Fountain, where is as been enjoyed as a fountain since the 17th century, previously the fountain was simple a spout for the surrounding houses to retrieve water from. The Trevi Fountain is located in a moderately open plaza in Rome. The fountain is not peripheral, it is located in the heart of the city, here it is well connected to the surrounding neighbourhood.

Social

> We stand at the Trevi Fountain with little sense of its connection to the larger world of water that supports it – the hydrological cycle, the springs that supply its water just as they have for more than two thousand years. [24]

Even though the water still travels below the city, the fountain as an object draws a connection to the waters below, and therefore of the source. The Trevi Fountain has arguably become the most popular fountain in Rome, not just with the masses of tourists that flock to it every summer. Local Italians frequent the fountain constantly, and it has become an iconic symbol of the city. Following the football world cup victory of 2006 locals celebrated in the waters of the fountain, and in 1996 the fountain was turned off and draped in black crepe in memory of the actor Marcello Mastroianni. "In many ways it is the Trevi Fountain that beats as Rome's heart." In Katherine Rinne's *The Waters of Rome*, she aptly summarises the importance of the fountain to the Roman capital.[25]

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24 Katherine Wentworth Rinne, *The Waters of Rome: Aqueducts, Fountains and the Birth of Baroque City* (New Haven: Yale University Press, 2011), 232.

25 Ibid.

Path of the Aqua Virgine to the Trevi. Imagery from Google Earth, 2018

Celebrations in the Trevi following football World Cup victory, 2006; photograph by Panino Zozzone.

Trevi Fountain dyed red in protest of the lies told by the Italian government, 2007; photograph by Evan Theroux.

The Stepwells of India

Technical

The step wells of India have been harvesting water for settlements since 100 AD. Perhaps the most well know is Chand Baori of Rajasthan. Stepwells work by collecting runoff surface water and catching rainfall. They are often situated in natural valleys, with the city surrounding them, this allows for water captured in the hardscape of the city to drain into the stepwell. The levels fluctuate drastically, which is why there are so many steps, allowing villagers to always be able to reach their water supply. The stepwells shaded gully is cooler than the surface, deep walls present only a parapet to the sun, which helps keep the water climate and prevent loss of water through evaporation.

Urbanisation

As previously stated, the stepwell is located in the natural basin of the landscape. This city in the case of Chand Baori is located east to the well, this is where there is more slope. By building the city here, it creates a less porous hardscape, so that more water is collected. The stepwell has been given its own space in the city fabric. A public green zone is around the well. A possible reason for this is to create public space but also it prevents domestic contaminations from seeping into the water supply. This suggests that there is a shared responsibility to not pollute.

Social

> Even a stepwell in a city with millions, like Ahmedabad, rarely carries noise from above; its separation from the earth is marked. [26]

The Stepwells are relaxing and offer the chance to reflect and meditate, a retreat from

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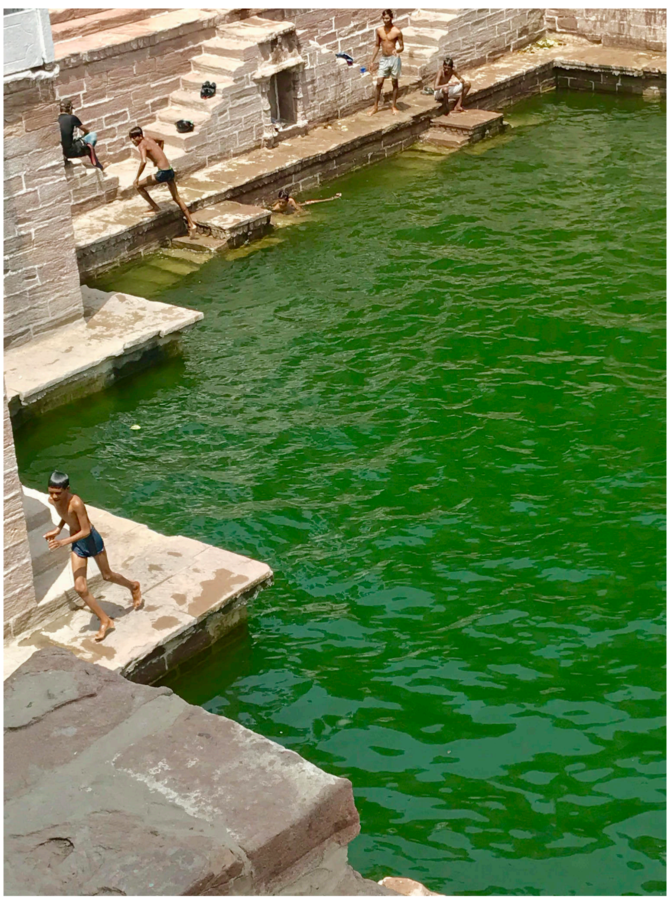
26 Morna Livingston, *Steps to Water: The Ancient Stepwells of India* (New York: Princeton Architectural Press, 2002), 3.

the bustling city. Deep wells offer not only shade, but the water creates a cooler climate. Stepwells in India, because of the frequency of visitors, are often points of convergence, people come to bath, swim, play cards, rest, discuss, and meet. Stepwells are also very spiritual places in most of India, often being located next to a temple so that the devout can clean before visiting. Most stepwells have shrines built into them. The journey down deep into the ground, under the many decorative arches, toward the cool body of water is seen as many as a metaphorical pilgrimage for the religious.

Simple diagram of how stepwells collect water (above). Corresponding site map illustrating water collection hardscape, and location of stepwell (below). Imagery from Google Earth, 2018.

People swimming in the Jhodpur stepwell, 2015; photograph by Avikal Somvanshi.



Children playing around the Jhodpur stepwells, 2017; photograph by Christopher Nine.

Observations and Design Aims

The case studies were chosen primarily because they successfully offer a community empirical knowledge of its water supply. The infrastructure dedicated to the supply clearly displays the significance the culture places on the water system, which indicates respect. From these studies we can draw conclusions as to how they achieve such importance. This becomes a critical step, and provides design goals that the nodes in the sustainable hydrological system should strive for.

Both case studies generate an atmosphere of respect from its surrounding city, which is an important step in developing an understanding of the water system. The assumption can be made that a population is less likely to abuse that which it respects. The Trevi Fountain in Rome achieves this by becoming a cultural icon. Because of the beauty and significance placed on the fountain by the locals and tourists alike, the fountain has become synonymous with the city. It is an element that the city is proud of, it celebrates wins of sporting events, and mourns with the city. Through the fountain the water supply is given meaning and statue in the city, which in turn engenders respect from the population.

The tragedy of the commons entire problem is due to people's greed, and one possible solution is to create accountability over the commons. For most resources it is possible to witness the slow decline in productivity, therefore the public can realise the threat and act accordingly. However, our water systems are hidden from our cities, and abuse of the resource is rampantly unchecked. The stepwells of India hold the population accountable for their water usage. The water levels of the stepwells fluctuate a lot between wet season and dry season, the many intricate steps that lead to the water act as indicators for how much water is remaining. In forcing this visual connection between a water supply and user, the public is reminded that water is a finite resource. Just as the water level fluctuates so does the demand of the public.

Finally, both water infrastructures offer alternative use, in the sense that they are not simply a source of water. As mentioned before, the stepwells offer many alternative activities simple because it is a “hotspot” of frequency. Water gatherers are constantly arriving throughout the day, not just to collect water but to socialise, pray, and relax. Similarly, the Trevi Fountain of Rome is situated in a plaza surrounded by shops and activity, but many simply sit and enjoy the spectacle of water. This is perhaps the most important lesson to be learned in regards to designing water infrastructure, in order to prevent over usage, it is paramount that water infrastructure situate itself in a community through hosting a variety of activities. This encourages the community to place importance on the infrastructure, and therefore on the water it provides.

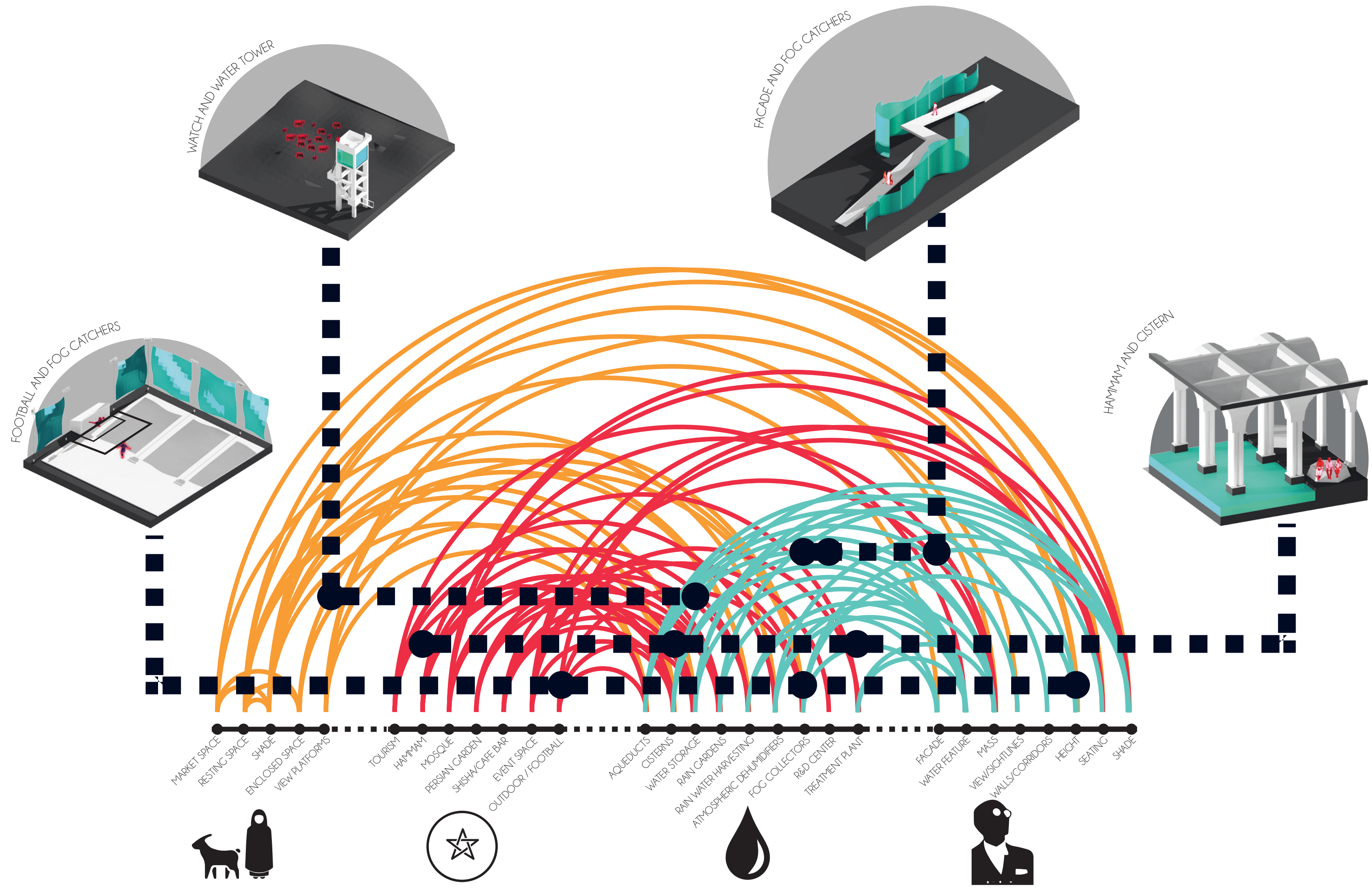


Diagram showing possible connection between peoples of the desert and architecture.

Site and Proposal

Through mapping and systems thinking, a blueprint can be designed for the hydrological water system at the macro scale. As identified earlier, for the system to work at a macro scale we must address mezzo and micro scales. To further understand how these scales might too be successful, case studies were conducted and an underlying methodology for design was identified. It must be recognised that the case studies success is a result of its strong positioning in a culture. Whether it be a cultural icon, encourage a variety of activities, or embed itself in the community's belief system. The water infrastructure must be integrally linked to a culture, and by doing so receive understanding and respect. As this is the ultimate goal of architectural intervention within the macro system, understanding the culture will enable the design to situate itself in the community. The following section briefly investigates the peoples of the Sahel, specifically in Niger, this is followed by an exploration into the culture of the Anti-Atlas region of Morocco.

The Sahel and Niger

The word Sahel comes from the Arabic word for coastline/shore. The beginnings of a vegetation band after a vast expanse of desert void of fresh water, evidently the comparison is fitting. Unknown to most, the Sahel is actually a forested region. The forest is most apparent during the erratic wet season, when the area undergoes an immense green transformation. Several countries depend on this transformation for many diverse reasons, such as; grazing, farming, fuel for burning, medicine, climate control and others. However, this transformation is getting less and less noticeable, climate change has affected the amount of rainfall and caused long periods of drought. Most devasting was a drought that lasted from 1968 to 1974, where over 100,000 people and one third of all cattle died due to food and water shortages. Whilst climate change is a universal issue that can only be tackled by a massive unified effort, desertification and drought is greatly hastened by the improper land use of local communities. This key fact was understood by the nomadic peoples of the Sahel, undertaking efforts of stewardship over the community ground, so as to avoid land degradation. This section will primarily focus on the nomadic and settled community's relationship with desertification, and will focus on Niger an area that is predominantly Sahelian and savanna with very little grassland. This will provide more fertile soil for the designed architectural intervention/water system to situate itself.

The nomadic peoples of Niger took ownership over the forest, and as a result acted as stewards for the land, knowing that their way of life depended on the lands regenerative ability. Their movements are greatly influenced by the seasons, moving cattle with the fluctuation of available vegetation. The movement of the herd is decided by carefully selecting paths that offer the best grazing opportunity and least impact on new growth. They achieve this through sharing information, with the advent of telephones and radio the nomadic peoples have been able to communicate with each other about what routes can be fed on, and areas that are recovering and should be avoided. This holistic movement of cattle is also dictated by vaccination stations, market towns, salt flats and wells. The cattle of pastoral nomads are among the largest contributors to Niger's economy, because they are the farmers of the forest, they brought communities that which the forest offered. Despite their integral part of Niger's society, the nomadic peoples are often referred to as vulnerable rural people, and seen as primitive by the settled Hausa farmers. The two largest groups of nomads are the Wodaabe and the Tuareg.

The Wodaabe have the largest nomadic presence in Niger, and there are approximately

65,000 living in the Sahel. Their main traditions revolve around the concept of beauty, and there are strict codes for appearance to adhere to. For example, women part their hair into segments, and at a young age are scarred with razors in which charcoal is sprinkled to create tattoos. The men wear eyeliner, and apply facemasks of minerals to improve their complexion. Beauty is celebrated once a year following the wet season at a large festival called the Geerewol. During this seven-day festival men adorn festive garments and elaborate make-up, and women choose a suiter based on physical attraction. The event brings together large numbers of the Wodaabe, and is held throughout Niger. Like other pastoral nomads, the tribe moves with the herd, they are never sedentary for longer than a couple of days, and as a result carry all their possessions with them, setting up camp wherever fertile land is. The Tuareg are the other major nomadic population in Niger, unlike the Wodaabe, the Tuareg move frequently across country boundaries in search of pastures. Tuareg caravans come down from the Sahara into the Sahel to graze their animals, usually moving between wadis and oases in the desert for sustenance. As a result of this, the Tuareg are found in every country that borders the Sahara, and principally their livestock consists of camels which are best suited for the desert conditions and distances travelled by the nomads. Both nomadic peoples practice Islam contemporarily, having once believed in their own unique mythologies, but were converted at a similar time in the 7th century. The two groups are both threatened by desertification that jeopardise their respective ways of life, but this threat is amplified by the improper land use adopted by the settled farmers in Niger. As resources dwindle tensions between nomads and farmers escalate. Farmers claim land that had previously been seen as common ground, conflict arises when nomads return to their former grazing fields and find fences around them. Unfortunately, the farmers over farm the land, and the soil is ruined after a couple of seasons, at which point they abandon it for new fertile land. The diminishing resources have led to people taking more than they need out of fear of running out, and as a result have hastened the land degradation process.

The situation facing those that depend on the Sahel is a perfect example of the Tragedy of the Commons. It is easy to identify what has escalated the problems in the region, and therefore explore opportunities to repair the land. The Sahel is not suited for traditional farming methods, as the land simply cannot sustain the demand placed on it, it is much better suited for a more holistic method of farming that allows the land to recover its nutrients. Architectural intervention should promote the nomadic way of life, whilst at the same time reconciling the commons. This means, as mentioned in a previous section, that water infrastructure must generate accountability, respect and cultural significance, which should be aimed at the nomadic peoples of the desert.

Wodabee men wearing make-up during the Geerewol Festival, 2017; photograph by Hannes Rada.

Tuareg riding one of his camels, 2000; photograph by Dominique Weis.

Wodabee camp in the Niger Sahel, 2012; photograph by Saverio Kratli.

The Anti-Atlas Mountains

The Anti-Atlas Mountains, sometimes referred to as the “Lesser Atlas”, is a range in Morocco. The range is located predominantly in the south of Morocco, starting at the Atlantic Coast, and runs roughly 500km to the east, ending in the city Tafilalt. Although not as tall as the Atlas range, the Anti-Atlas offers peaks over 3,000m, and with an average elevation of roughly 2,500m. For this reason, the range is a popular destination for hikers and tourists alike. The range doesn’t offer a difficult objective for any hiker, as all peaks are easily accessible/driveable and is fairly climate all year round, only receiving 200mm of precipitation annually. The mountain range is one of the regions in Morocco where there is an intersection between traditional and modern Morocco. The area is traditionally Berber, populated mostly by small conventional mudbrick villages and a couple of modern cities. The following section will attempt to briefly summarise the two Berber cultures that exist in the region, in other words studying the conventional Berber villages and contemporary Moroccan people. As previously done with the region with the Sahel, this will allow for the designed water system to better assimilate into the culture, and as previously shown, understood and respected by the cultures.

The Anti-Atlas Mountains are particularly dry, and like many other regions in the area, are experiencing long periods of drought. Whilst the valley rivers are drying up, the mountains retain sparse vegetation thanks to fog that coats the mountains 143 days a year. Because of this, many farmers and small villages are located in the mountains, allowing cattle to be close to fertile land. Usually men of the village move the cattle around the mountains depending on the season. The women are left with the household duties, including fetching water for cooking purposes. On average this takes them 3.5 hours daily, and they spend most of their day travelling to wells and rain catchments. Other chores include textile weaving, which is a significant part of their culture. These villages are scattered and scantly present across the landscape. Down in the valleys larger populations reside, communities that are less dependent on the changing of the seasons. The largest city in the region is Guelmim, known as the “gateway to the desert”, with a population of just under 150,000 people. The population here is far more contemporary then their mountain counterpart. The city is supplied by pumped ground water, like many other parts of Morocco. Without constantly having to fetch water, the population is able to engage in more “luxurious” activities. They primarily practice Islam, and observe all the holidays and prayer times. Much like other countries in the region, football is the number one sport and past-time in Morocco, and is quite fanatically followed. Once upon a time buildings were built with Mudbricks protected from the rain with intricate tiling, however water intensive concrete has now become the favoured building material of Morocco.

The Anti-Atlas region of Morocco offers a rich culture to work within, it also already has an existing relationship with water, which should facilitate the implementation of a water infrastructure. The primary connection the culture has with water is through Islamic worship, which requires frequent and daily cleaning before prayer, as a result water stations can be found around places of worship. The secondary connection is through their architecture, traditional courtyard houses (Riad) enclose intricate fountains made of marble. The courtyard combined with the fountains creates a cooler microclimate for the space, and is much appreciated in the Moroccan summers. Finally, like most Arabic influenced cultures, they are connected to water through their unique bath house. The Hammam is a hot steam, bath, and massage, traditionally done before prayer, but currently done for relaxation and socialising. In order to avoid the system being rejected by the culture, it must be resilient, and as identified by the teachings of Donella Meadows this occurs with a system is too different to the surrounding context. Therefore, architectural reconciliation should be built upon this existing relationship the culture has with water, so that design can incorporate awareness of the water supply into the existing programmatic elements. So that understanding and respect can form.

Berber farmer grazing his cattle on the mountain side, 2011; photograph by Joseph Wilkes.

Traditional stationary Berber dwelling, 2000; photograph by Mosa'ab Elshamy.

Traditional Morocco courtyard and fountain, 2012; photograph by Christopher Rose.

CHAPTER 6: DESIGN

Anti-Atlas Research and Development Compound

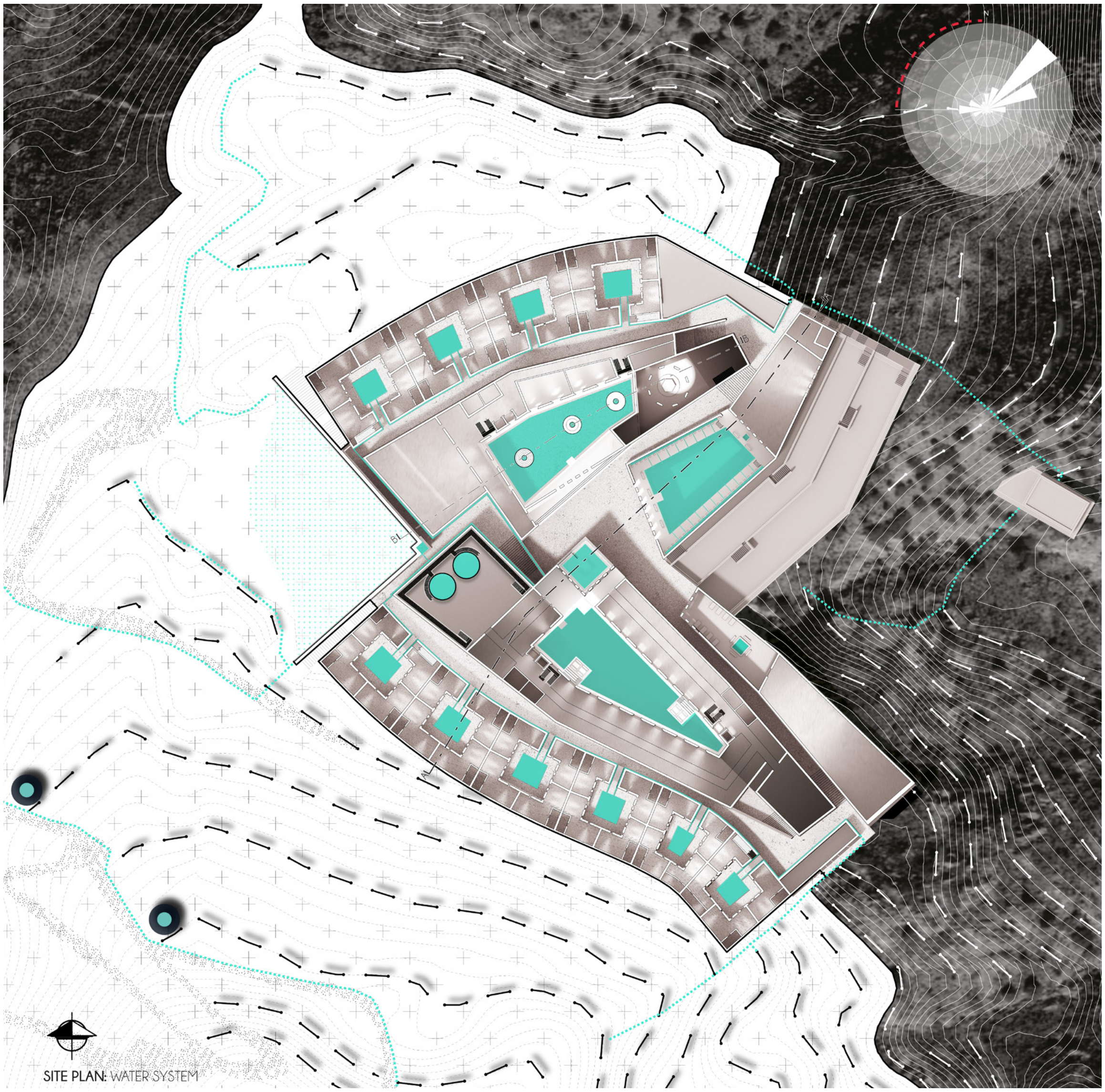
As established in the previous section, the Anti-Atlas Mountains of Morocco have a high potential for harvesting water through fog catching. In fact, not far from the city of Guelmim there already exists a small farm of fog catchers that are providing water for small mountainous villages nearby, they were originally installed to study the possibility of such a technology and record data. A research and development compound in this region strengthens this innovative pursuit, and presents the opportunity to further explore a source in the macro system. The compounds design primarily strives to reconcile a community with its water supply, as such the compound becomes a testing ground of how architecture can achieve such a goal, allowing the architectural interactions designed here to be replicated in existing cities.

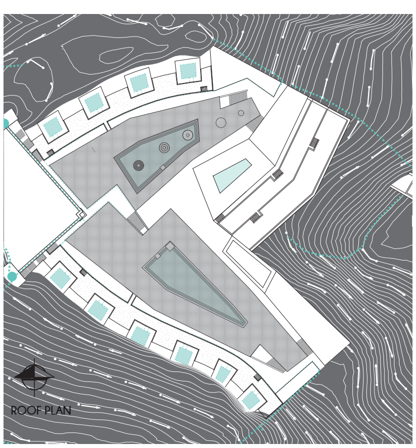
The architecture takes notice of smaller berber communities in the region, following key elements of town planning. Most notably the compounds form follows the contours of the mountain, leaving a clear demarcation for the existing watershed of the mountain, at the same time burrowing into the face of the mountain providing a cooling thermal mass. The crowns on top of the larger buildings provide additional water through fog catching and shade for courtyards below. The form is a result of the aesthetic of Berber tents and a practicality wind study.

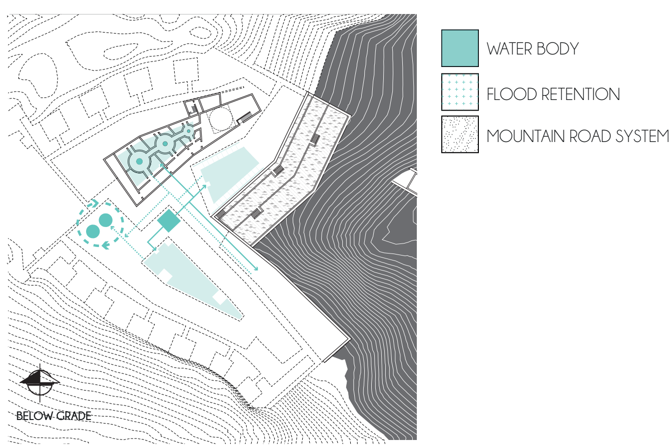
A usual fog catcher of 54 square meters on top of this mountain can collect up to 197,000 litres of water a year, a region of these fog collectors provide a source of water to the compound. Once the water is collected it enters the compound through several channels, the Canyon is the main tributary of water into the compound. The Canyon aims to make a spectacle of the water entering the compound, allowing it to fall 10 meters into a basin below. The spectacle of falling water fluctuates throughout the year, depending on the success of the source outside the compound, reinforcing water as an impermanent and natural resource. The slope of the rendered concrete walls forms a small opening for which sunlight can enter the space below, this combined with the falling water creates a deep cooled circulation corridor sheltered from the Moroccan sun. As the compound is nestled into an existing water shed of the mountain, the canyon also acts as a barrier and guide to surface water. Water collected below the elevation of the Canyon arrives along smaller channels in the north and the south of the complex. This water meanders through several residential and office riads, creating small comfortable microclimates within the compound. Eventually all tributaries meet and flow together towards the beating heart of the compound; the bell siphon. A bell siphon is a self-starting siphon, it works without any mechanical components. Once the bell siphon reaches capacity it empties the entire volume of water, in this design the water falls into a basin below which is connected to three main storage courtyards. The bell siphon acts as the heart of the system, pumping water to other parts of the complex, again this action depends on the amount of water that is being harvested. Courtyards are nodes of activity, and therefore the productivity of the system is always present in the background everyday life.

Courtyards primarily act as storage space for the harvested water, but similar to the riad courtyards they attempt to reunite a community with the water supply they use. The research courtyard achieves this in the simplest fashion, little dry sunken platforms extend slightly into the water providing break spaces for the researchers and developers. The mosque courtyard creates direct interaction between a principal aspect of Moroccan culture and the water system. Surges of water created by the bell siphon force the water in the courtyard to travel to its outer limits via small channels. These channels define individual seating spaces facing the wall that allow people to perform ablutions before entering the mosque. Finally, the leisure centre courtyard distributes water to the Moroccan hammam below. Like many types of bathhouses, the hammam incorporates rooms of different temperatures for a varied experience in the bathing cycle. In order to enhance this experience, the rooms revolve around spillways located in the courtyard above. Each spillway has a different angle of entry, which decides the rate at which water enters the hammam, for example the coldest room in the bathing cycle plunges water below, and the hottest lets it trickle down. The speeds of falling water in the space not only effects the atmosphere but also the experiential temperature of the individual bathhouse rooms. Usually hammams blend in with their local fabric, and the only distinguishing feature is its proximity to the mosque. In keeping with that, the compounds bathhouse plays with the dichotomy between exterior and interior, the large dome inside not only contrasts the angular exterior but it is also reminiscent of the design of a traditional hammam. The large oculus allows sunlight to move periodically through the grand hall, serving as an entry point for water collected by the roof structures.

Finally, when the water has served its main purpose, a small portion is directed to the garden where it waters plants, but the majority of it is pumped back to the research centre here it is recycled and re-enters the system at the bell siphon.







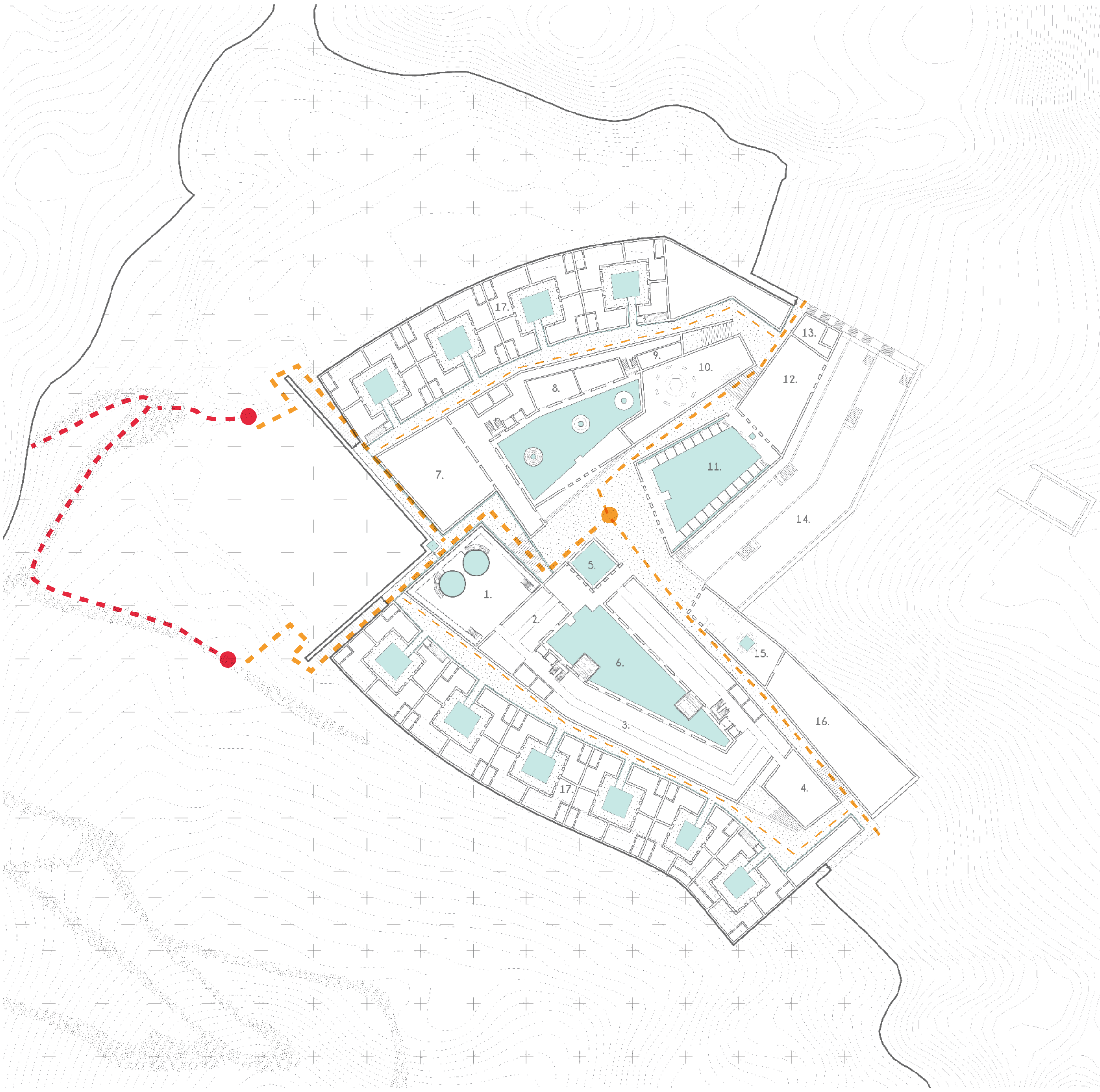
Site Plans: Anti-Atlas compound, highlighting the water system

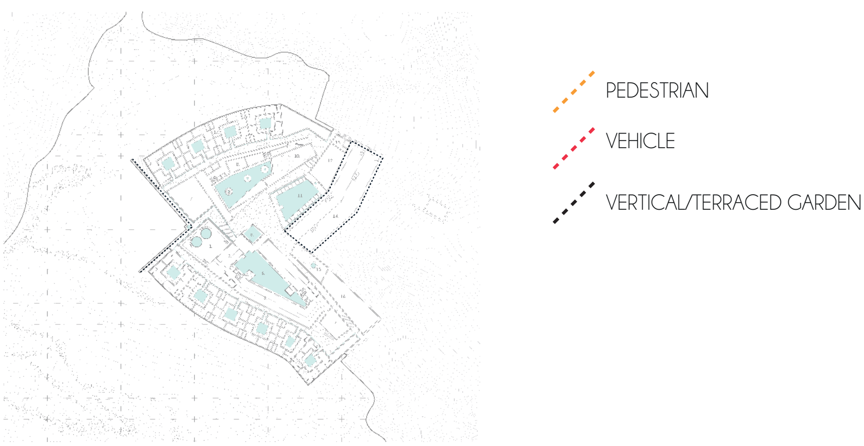
Program and Organisation

Primarily the building will operate as a water research and development facility, accommodating staff for long term stays. The largest of the buildings in the complex provides the necessary spaces for such a program. A large recycling plant resides in the north of the building, here water is cleaned and redistributed to the compound. Apart from space dedicated to central cores, the rest of the floor plan consists of flexible lab space, leaving the floor plate mostly un-intruded by mechanical systems that are moved to an interim space between floors. Administration space is separated from the rest of the building to prevent unnecessary interruption for lab staff. Communal break platforms extended into the water storage courtyard, providing unique cooled areas for socialising.

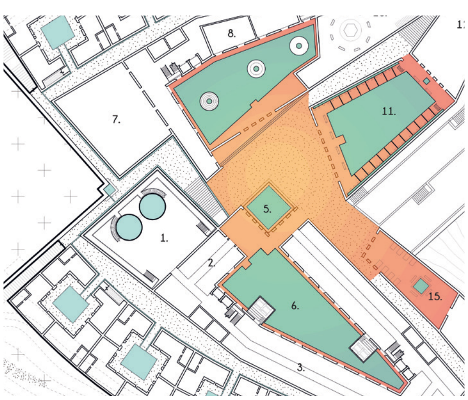
In order to serve the staff during their stay, the compound also includes leisure centre, mosque and restaurant. The leisure centre provides space for gymnasiums, fitness studios and even a traditional hammam, which is one of the biggest interactions the community have with their water supply. In close proximity to the hammam is the mosque. The mosque defines private space for the imam, and public prayer hall. The restaurant sustains the community during their stay, exterior seating over looks the mountain side, and small fountains contribute to the shaded microclimate.

The research and development compound was chosen as the best way to showcase many different elements of how architecture can reconcile a community with their water supply. It provided the opportunity to explore many interventions that could potentially be translated to existing cities and infrastructures. As a result the compound portrays an interactive water system integrated into varied facets of Moroccan life, from housing and social life to religion and work.





Circulation (above) and green space diagram (below).



RESEARCH
1. Recycle Plant
2. Lobby
3. Flexible Lab Space
4. Admin Space
5. Bell Siphon
6. Break Spaces

LEISURE
7. Gym
8. Fitness Studio
9. Storage
10. Hammam

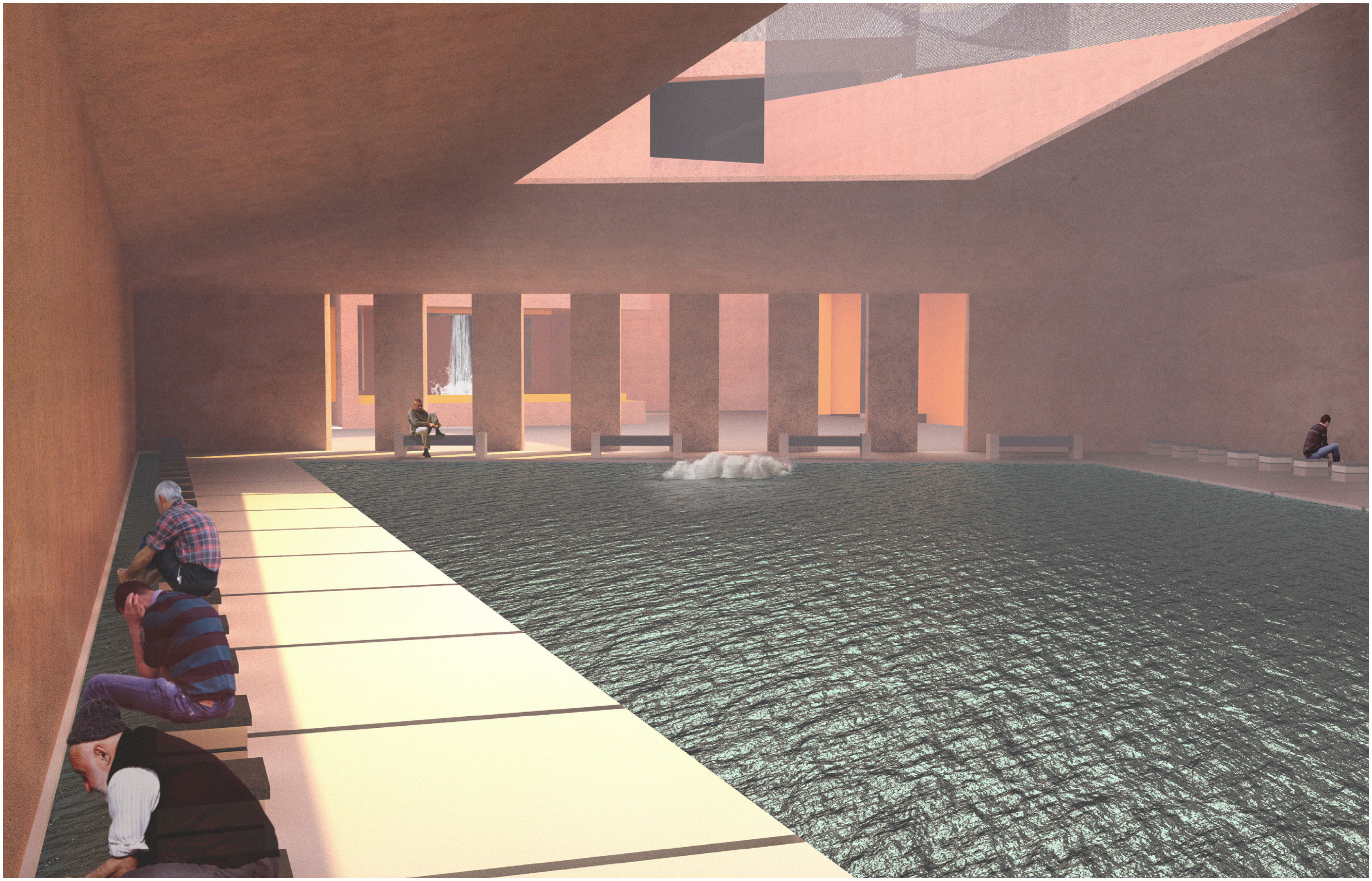
MISC
11. Mosque Ablution Space
12. Main Prayer Hall
13. Imam Quarters
14. Gardens
15. Dining Exterior
16. Dining Interior
17. Residential/ Private offices.

PUBLIC

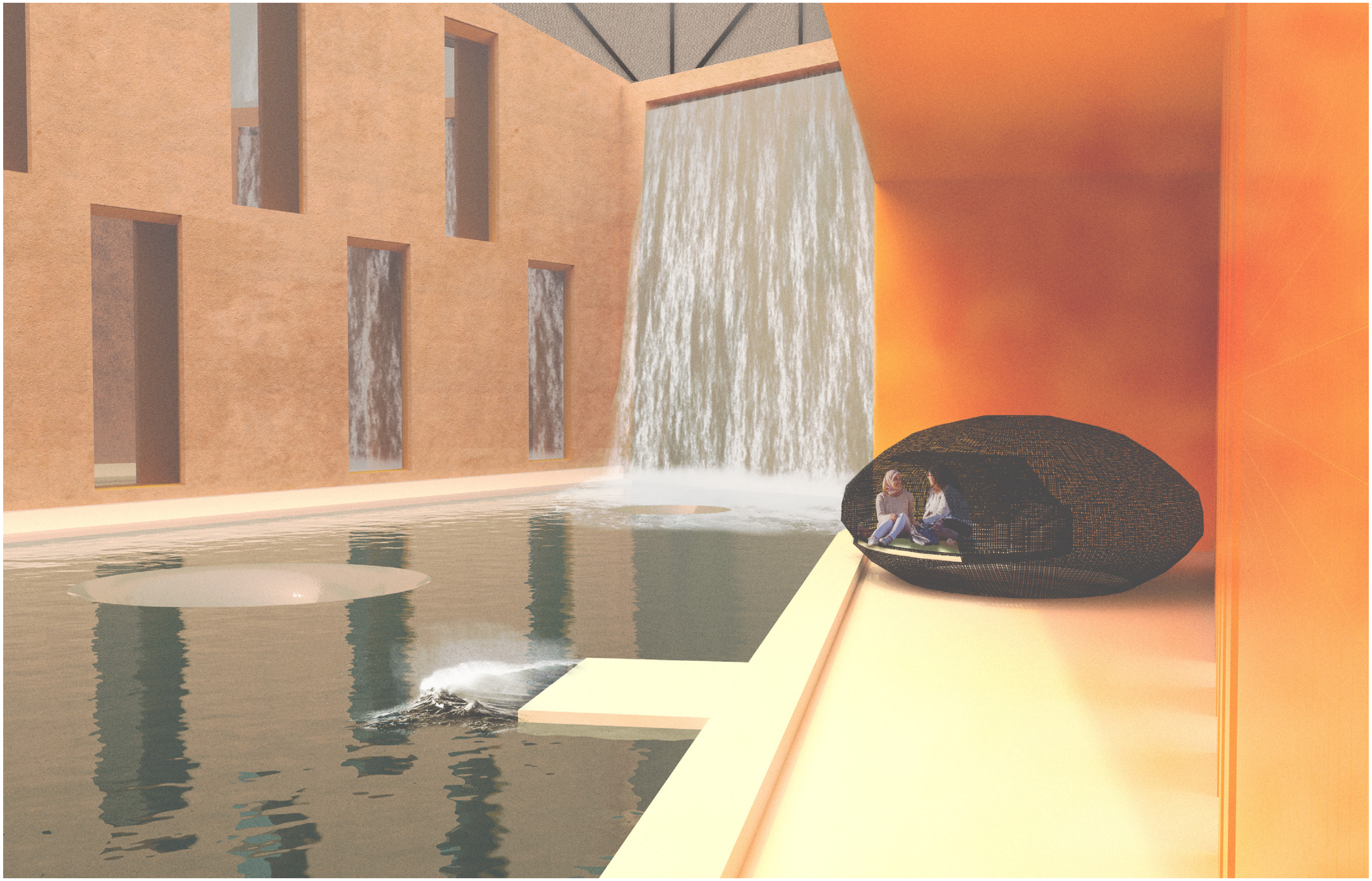
PRIVATE

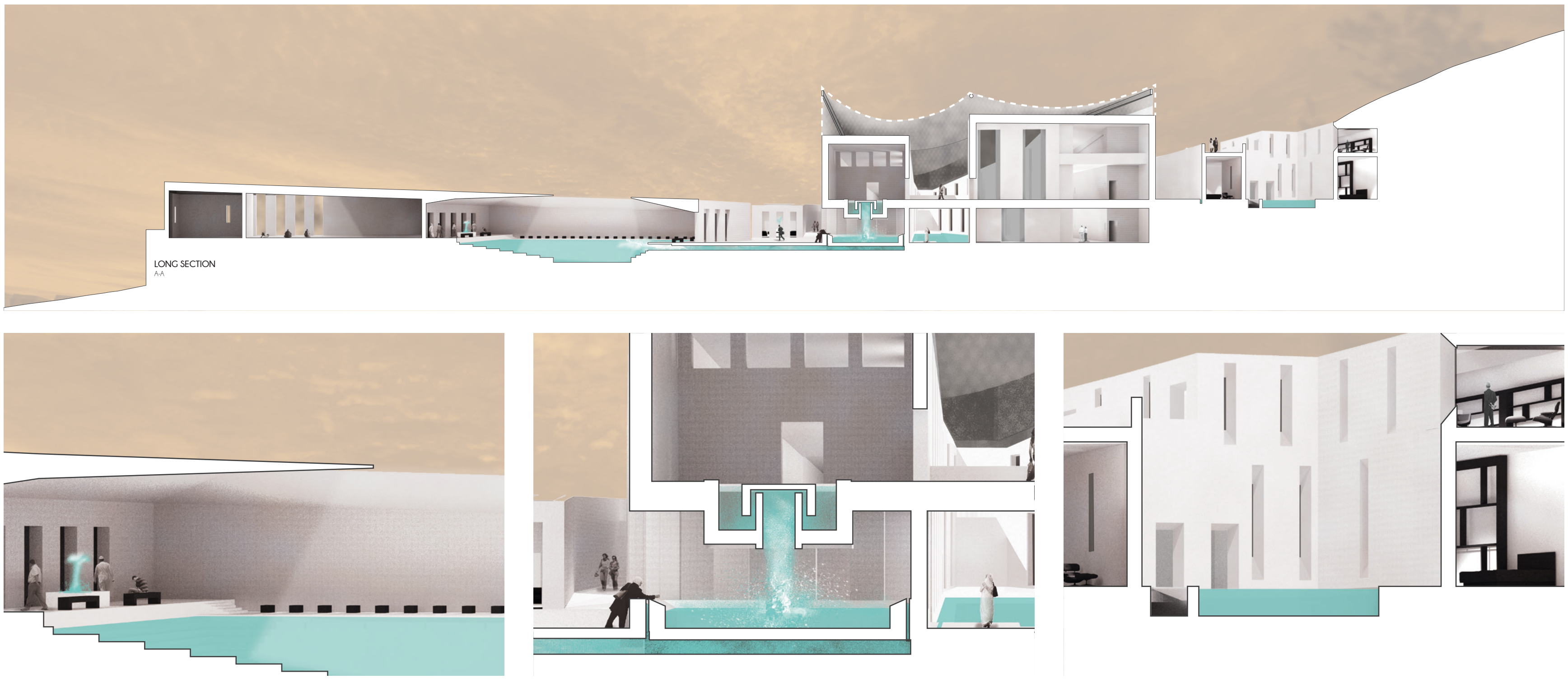
Program diagram (above) and outdoor plaza diagram (below).

Render: The Canyon

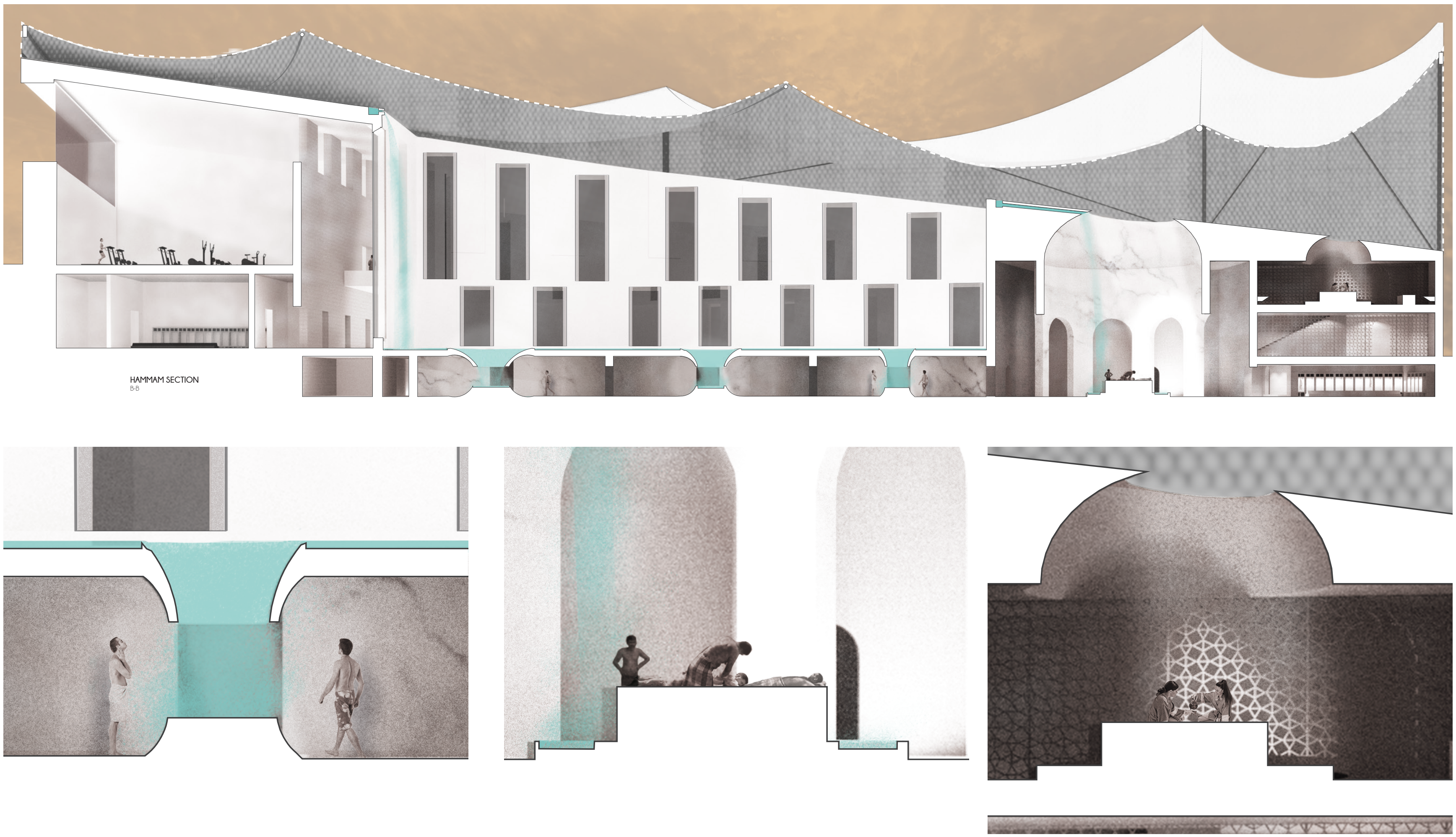


Render: Mosque courtyard.

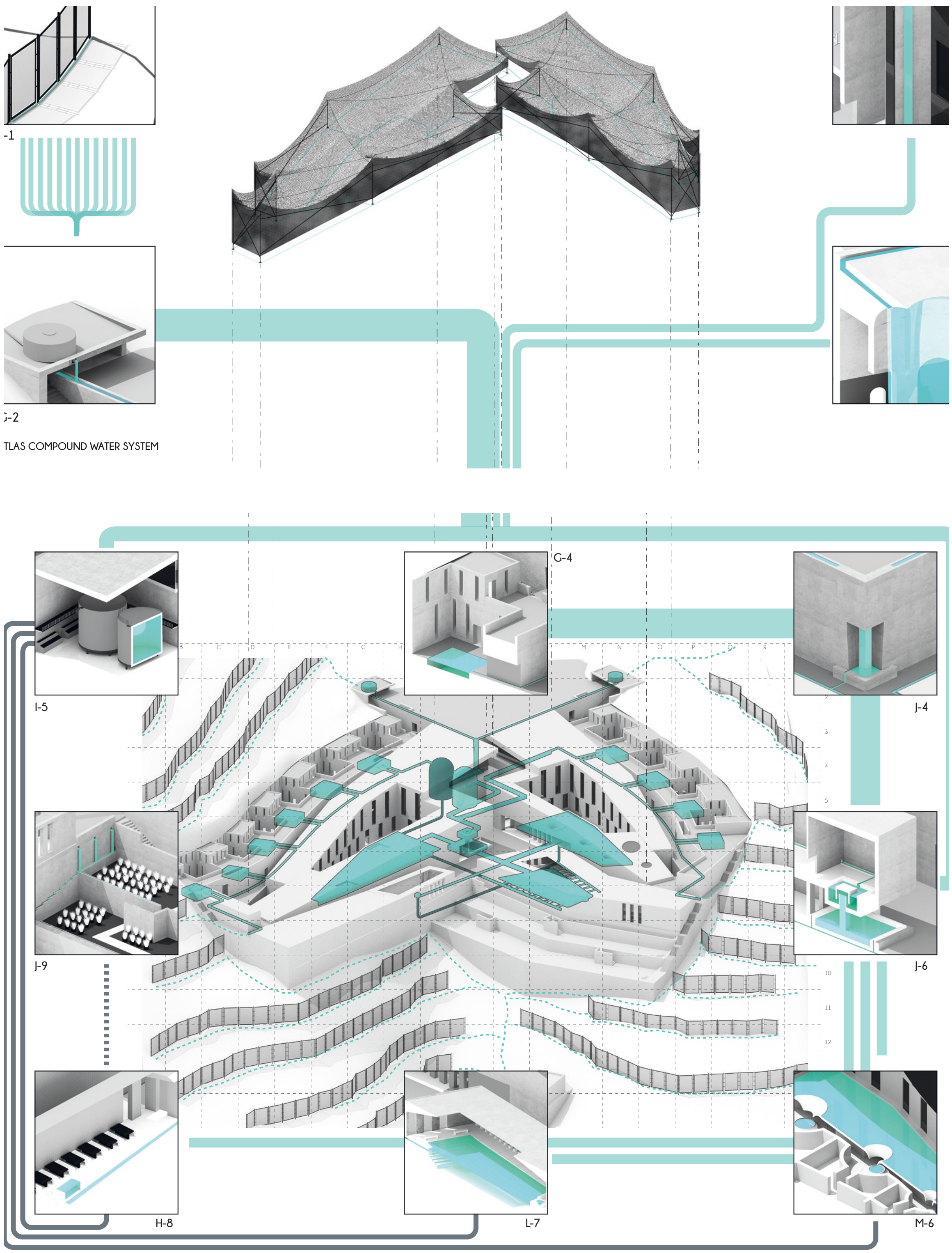

Render: Spillways to hammam.



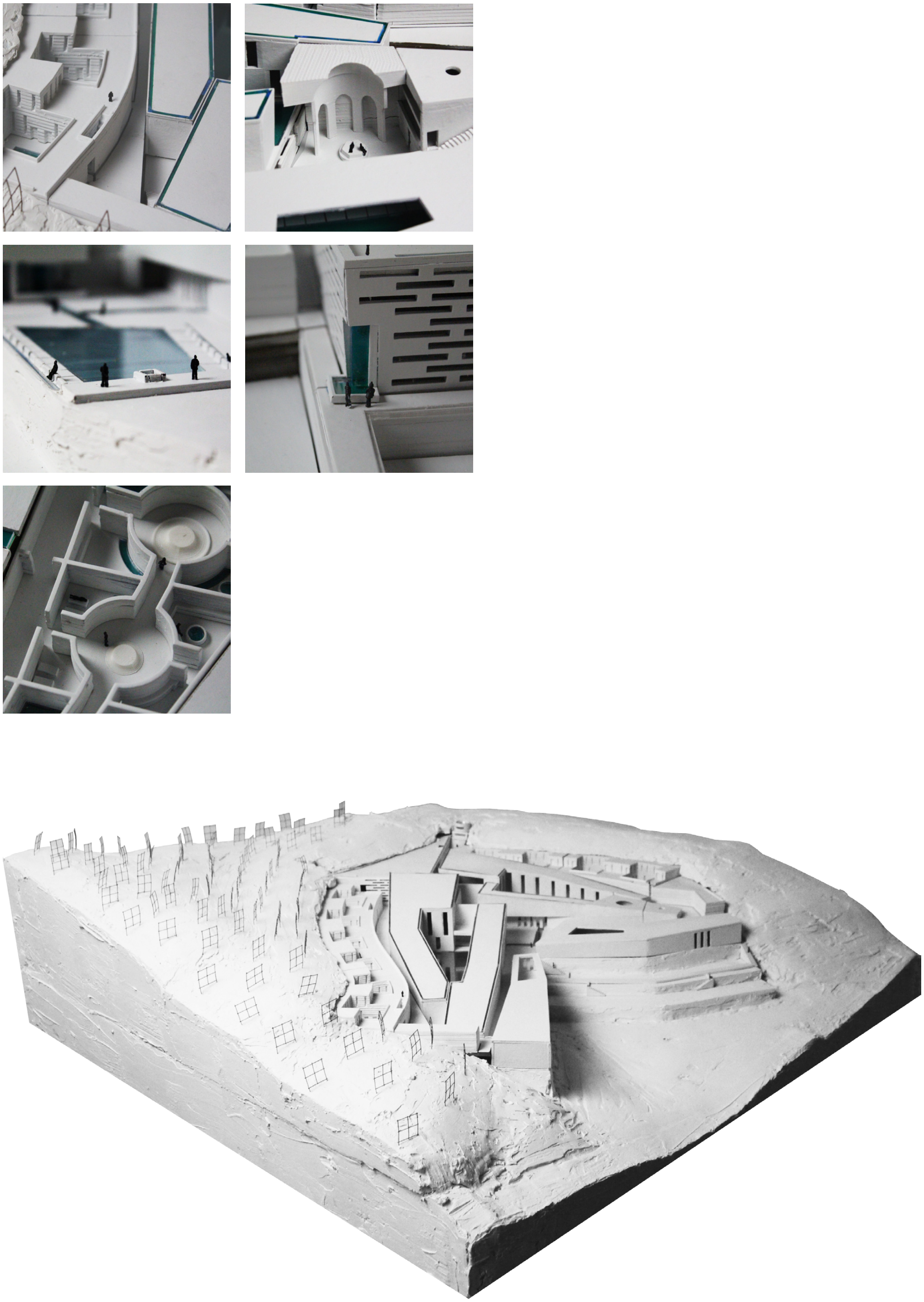
Section: Long section illustrating the connection between water bodies and the bell siphon.



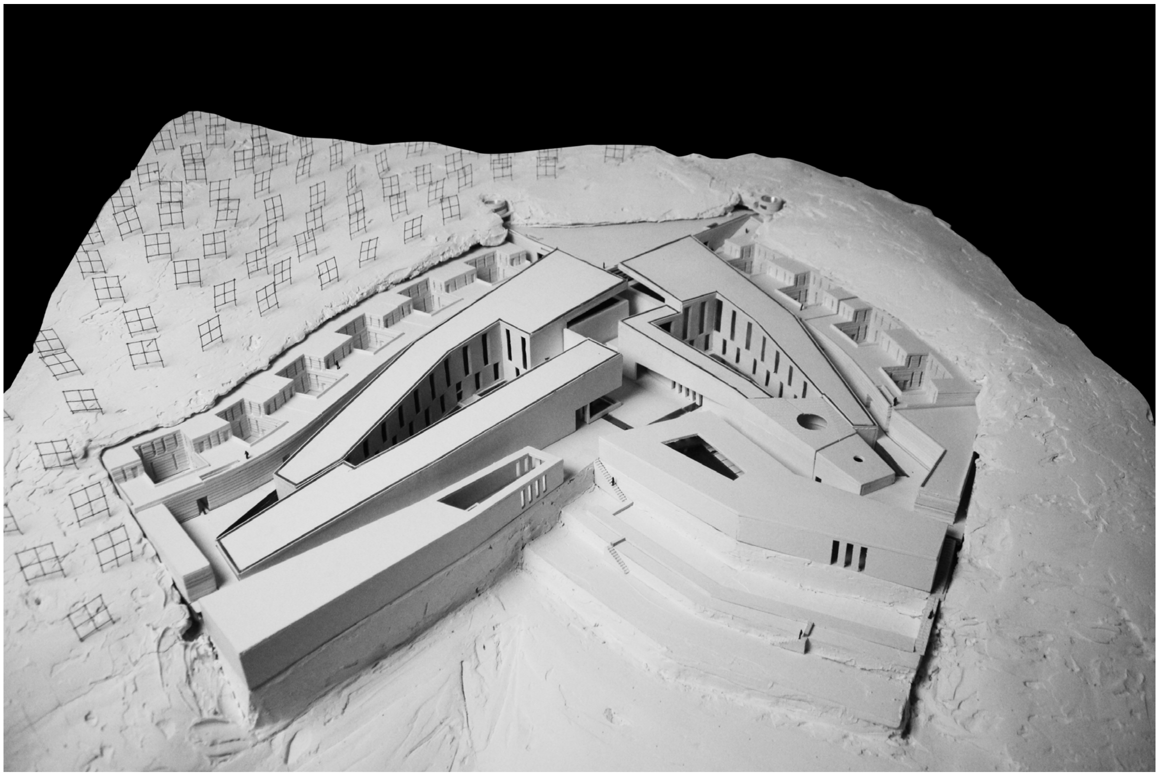
Section: Hammam section shows the spillway’s flow control, hammam dome and private rooms.

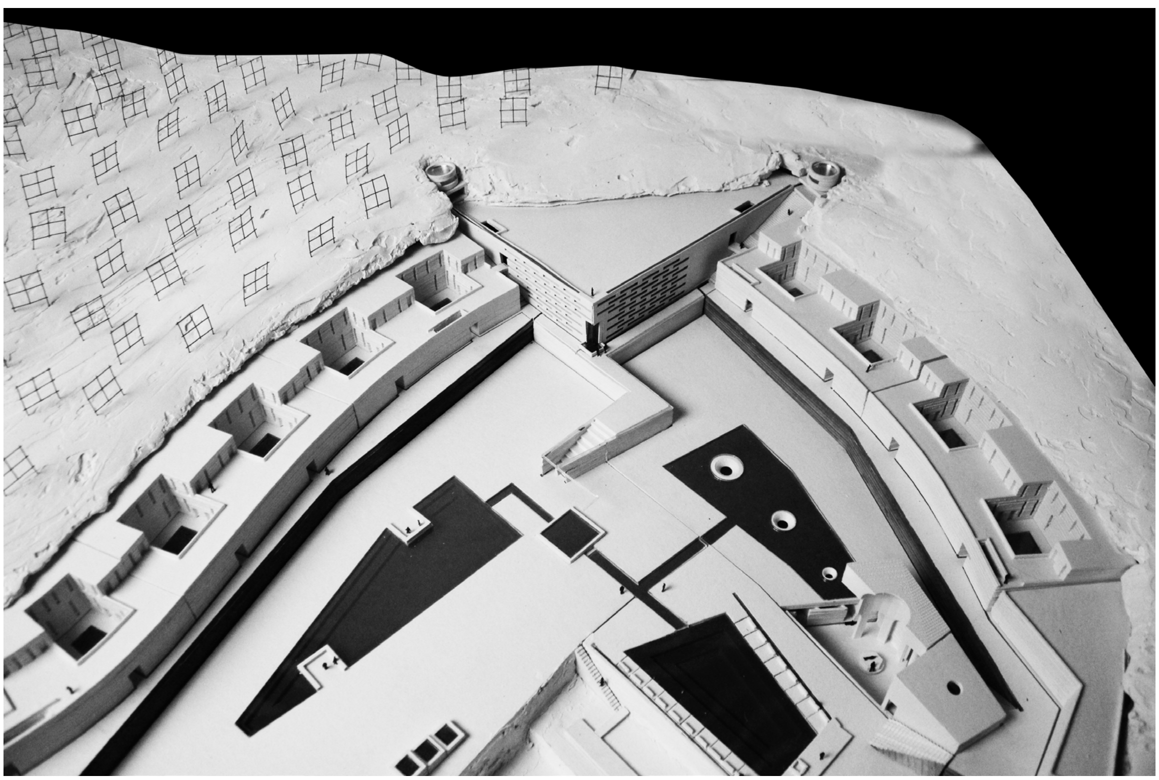


Axonometric: Illustrating the interconnectedness of the water system, and exploring architectural interactions.



1:250 model images with select close-ups of details.





1:250 model images showing water system, both exposed and hidden.

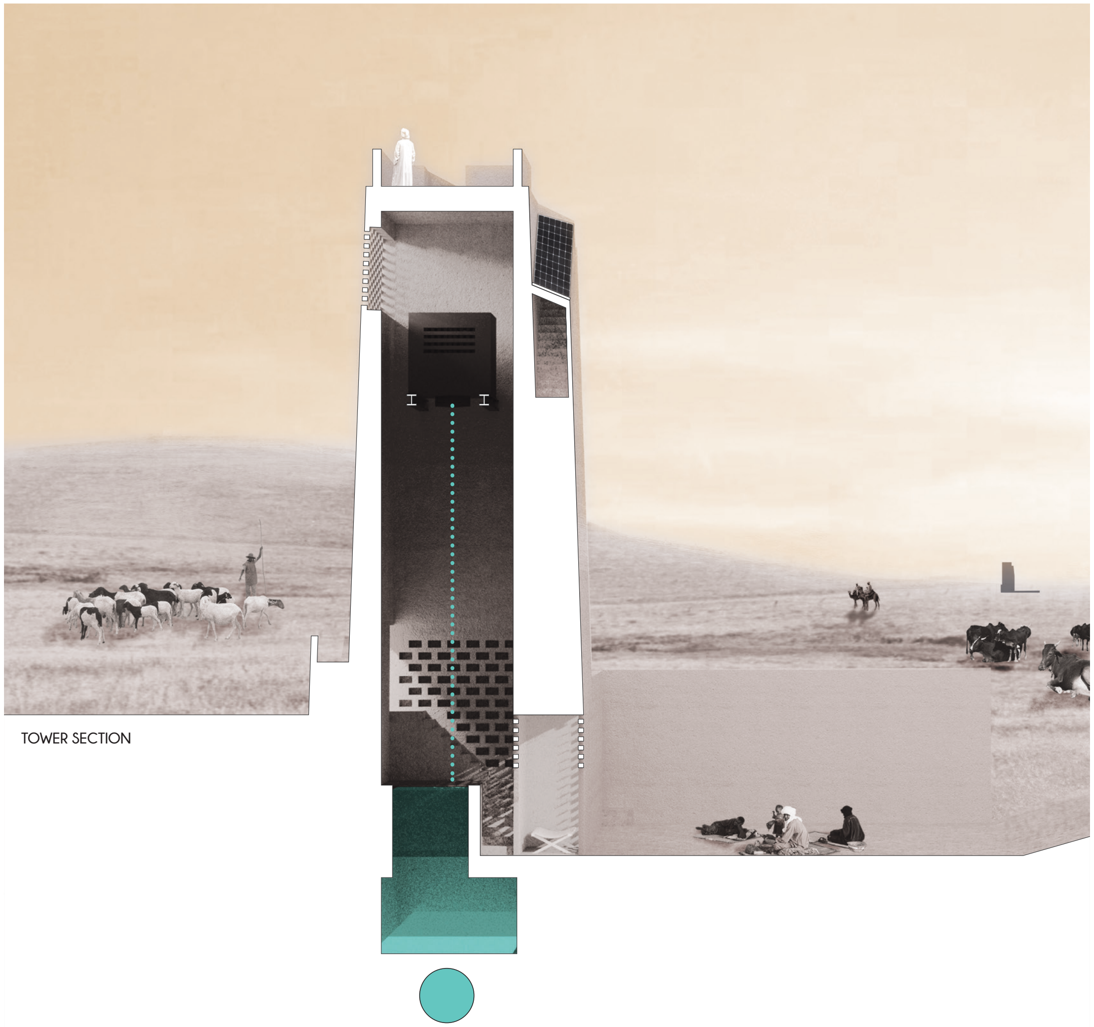

1:250 model image of roof structures on top of compound.

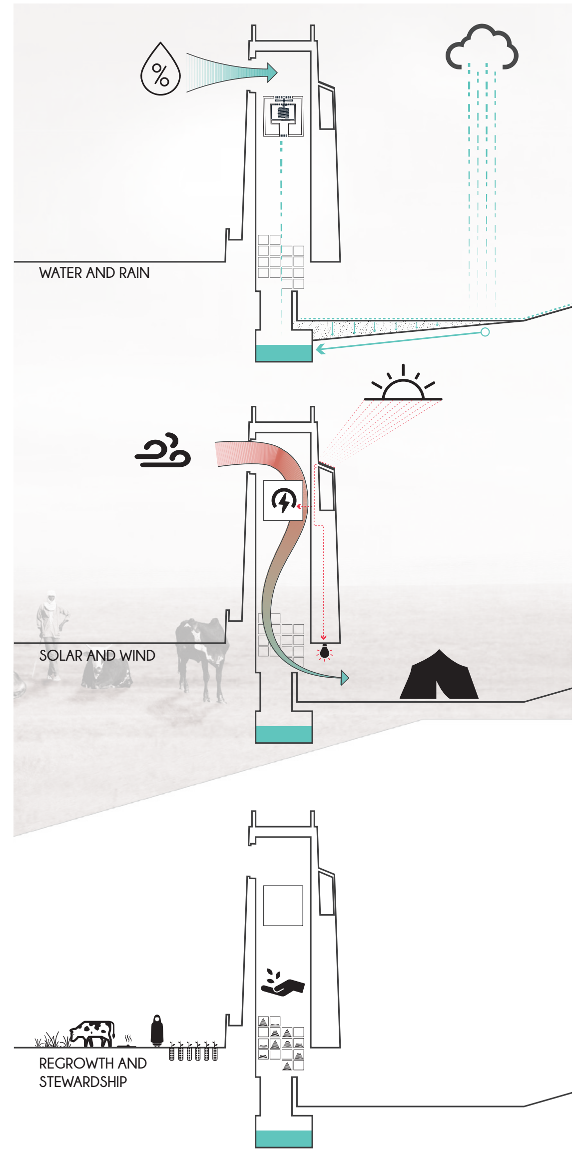
The Niger-Sahel Border: Pastoral Relief Tower

Along the other border of the Sahara and the final stage of the macro system are the pastoral relief towers, which help define the Niger-Sahel border. While the Anti-Atlas Compound is centred around a source and focuses on rebuilding respect within a community for its supply, the relief towers seek to utilise that previously wasted water for an intended purpose of revitalising the desert border and combatting the spread of desertification. In order to achieve these goals, the towers target the existing nomadic communities in the region, strengthening their way of life and returning them as stewards of the desert.

The reinforced adobe towers become landmarks along pastoral grazing routes, helping orient travellers, whilst also indicating to the presence of a man made “oasis” along the dry desert border. The water presence of the tower is the biggest weapon given to the nomadic communities to retake arable land. A single solar panel powers an atmospheric water generator housed within the tower, producing water throughout the morning and evening. The storage tank contained in the base of the tower catches the generated water, and during the rainy season it works as a well, storing runoff water from the surrounding area. Between the two sources the tower will provide water throughout the year. By positioning the towers into the predominant wind and sinking a space below grade behind the tower it creates a sheltered campsite. Further making use of the predominant wind the building acts as a traditional wind tower cooling air by forcing it to rapidly decrease altitude, the atmospheric water generator contributes to pulling the air into the building and the presence of the water generated by the technology helps cool the air. The height of the wind tower allows for a small vantage point for nomads to survey their cattle and also the surrounding landscape.

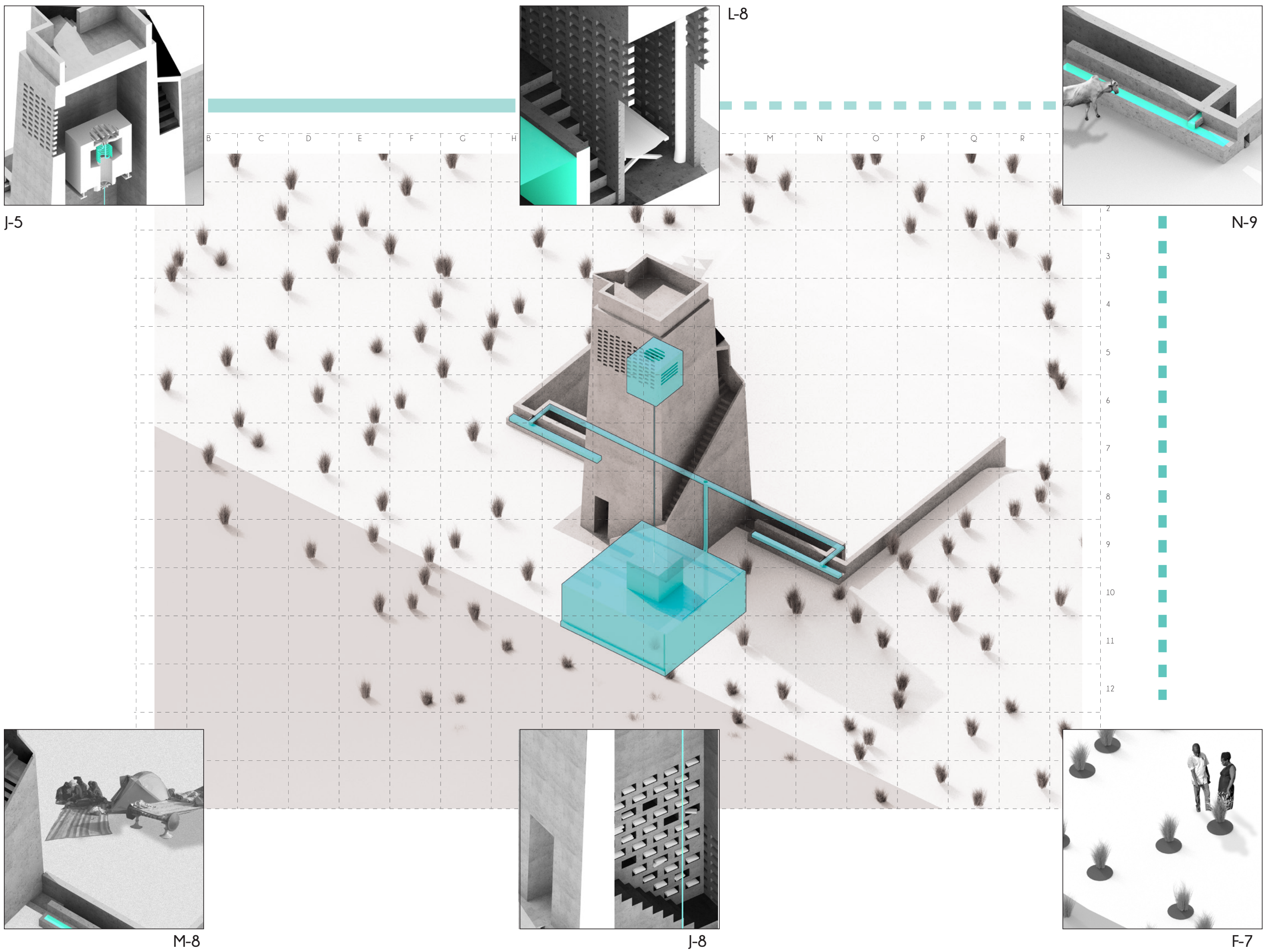
To further contribute to the success of re-growing the desert border, the towers contain small seed stores, so that groups of people might plant the seeds as they go, nourishing saplings that they find along the route. The regrowth depends on the pastoral grazing routes as they help to mimic the natural sustainable movement of migratory animals across the border. This holistic approach to grazing prevents overgrazing, promotes the movement of fertilizer and trampled undergrowth creates unique growing microclimate vital for new growth. Once sand begins to turn to soil, nutrients and water will be longer retained in the ground and new resilient growth will create a stronger desert border and prevent the wind spread desert.





Section: Tower section and diagrams portraying the goals and mechanics of the relief tower.

Render: Nomadic pastoral relief tower.



Axonometric: Illustrating the various moments provided by the tower.

CHAPTER 7: CONCLUSION

Climate change and a growing population is quickly devasting arable land through drought and over-farming, we are slowly being overwhelmed by desertification. Sustainable water systems offer us the opportunity to draw a line in the sand, and protect the millions affected by the encroaching desert. The Sahara, as a testing ground, proves that such a large-scale water system could exist. Through an exploration of mapping and overlaying data, water harvesting nodes and the macro system revealed itself. Although, as discussed previously such a macro system on its own would only delay the encroaching desert, and that it is the small systems that encourage the success of the scheme. Primarily at the human scale, architectural interventions reveal empirical knowledge, and in doing so reconcile a forgotten respect of our water supply.

The vast disconnect that has occurred between a community and its water supply can only be remedied through an architectural exploration. The Anti-Atlas Compound stresses the importance and fragility of water. Here, Moroccan life is intrinsically linked with the productivity of their water supply, confronting the community with its presence, such a system breeds accountability and respect of a precious resource. The water saved is used along the Niger-Sahel border, where architectural systems facilitate an endangered way of life, returns stewardship of the land to the nomadic peoples of Niger, and supports a sustainable barrier to the encroaching Sahara Desert.

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