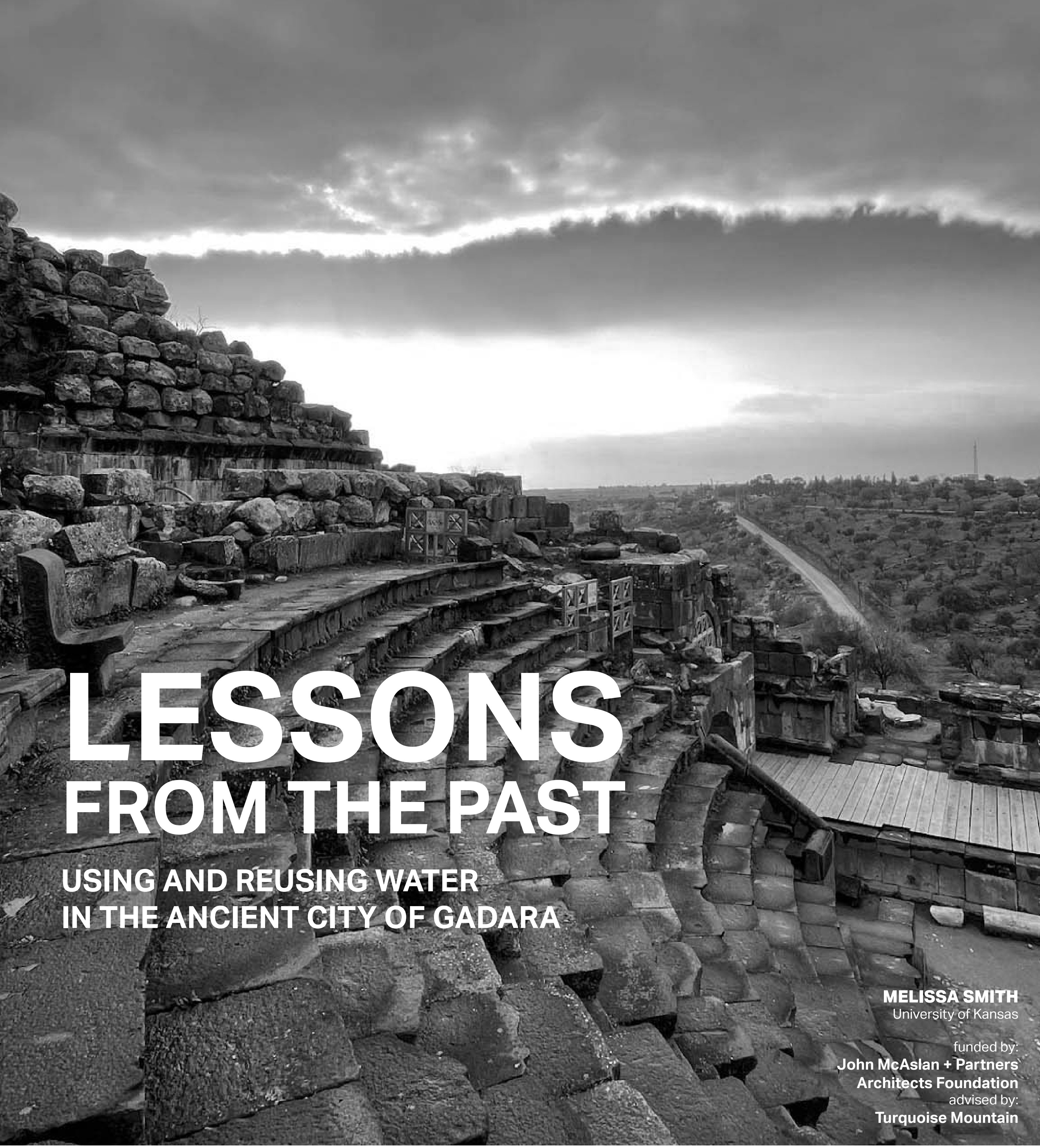

LESSONS FROM THE PAST

USING AND REUSING WATER IN THE ANCIENT CITY OF GADARA

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01 THE GLOBAL WATER CRISIS

Jordan, the second water-poorest country in the world[1], is facing a serious water scarcity issue. But it's not only in Jordan, water scarcity is a major global crisis. Although geography impacts access to fresh water - the majority of water-poor countries are scattered around the hot, arid Middle East (fig. 2) - even water-rich countries like the U.S. are feeling the effects of long-term water mismanagement in states like California. Human habits value water less and less[2]. We take longer showers, we leave the tap running, we don't reuse greywater, but worst of all we undervalue water in agriculture, industry, and infrastructure. We use excessive amounts of water to grow wet crops in dry lands, we don't price goods based on the water used to produce them, and we neglect water infrastructure, losing large amounts of water to leaky pipes or evaporation[2]. Additionally, what little water we do have we pollute. Each day, roughly 2 million tonnes of sewage drain into the world's water supply and industry is responsible for another 300-400 megatonnes of waste dumped into water bodies each year.[3] Pollution and water mismanagement aside, Jordan faces a unique problem associated with an influx of Syrian refugees, significantly increasing demand on the country's already strained water supply.[1]

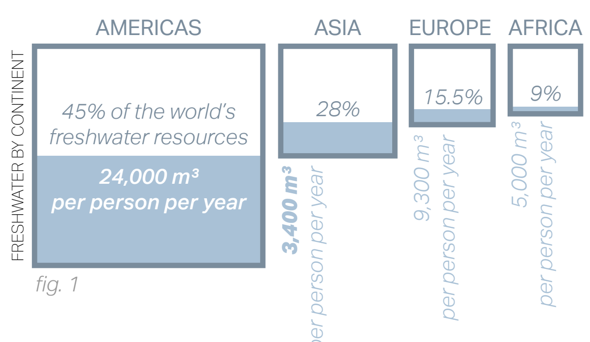
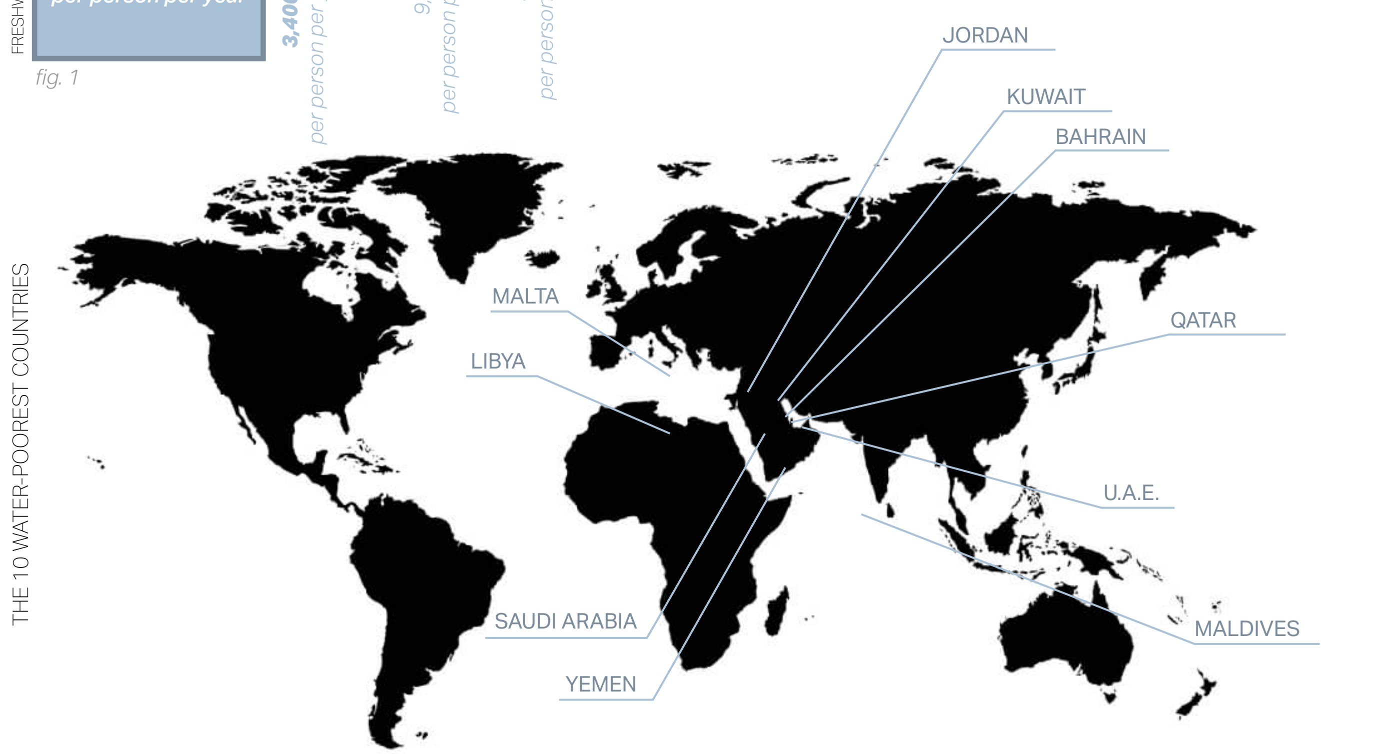


fig. 1



* ***33 countries**, including Egypt, Israel, Iraq, and Syria - which all border Jordan - depend on other countries for **over 50%** of their renewable water resources*

fig. 2

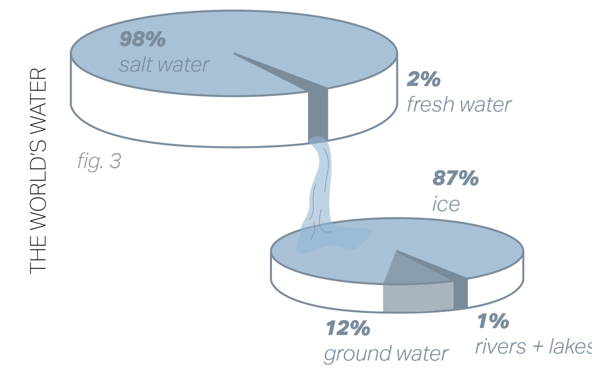


fig. 3

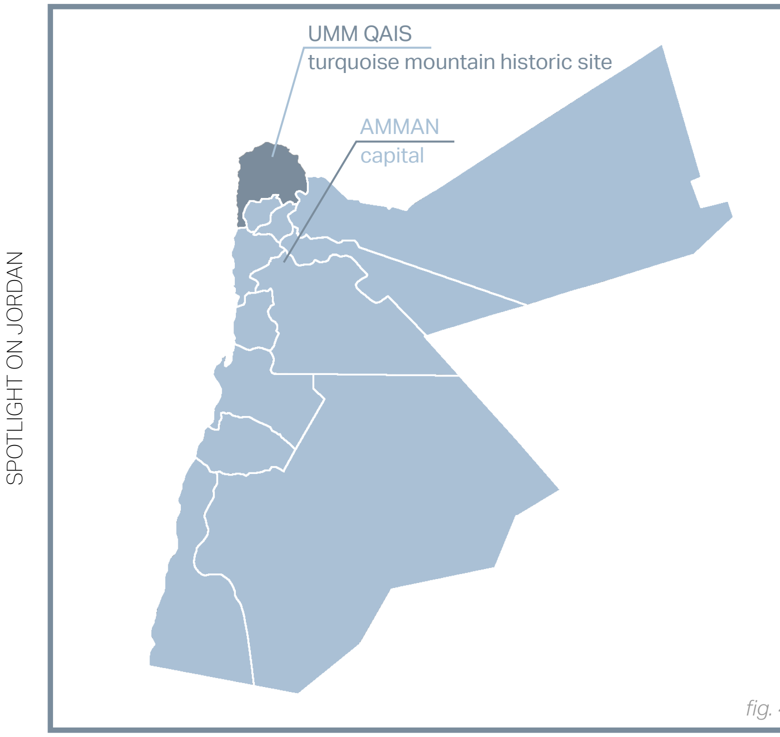


fig. 4

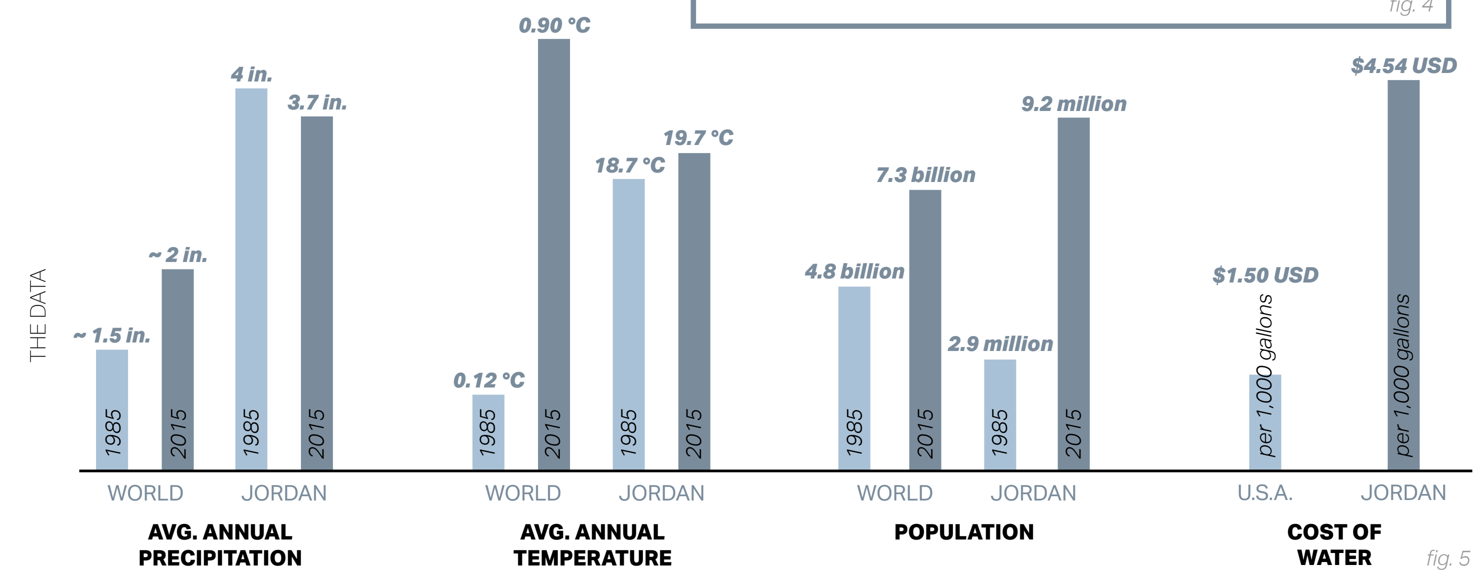


fig. 5

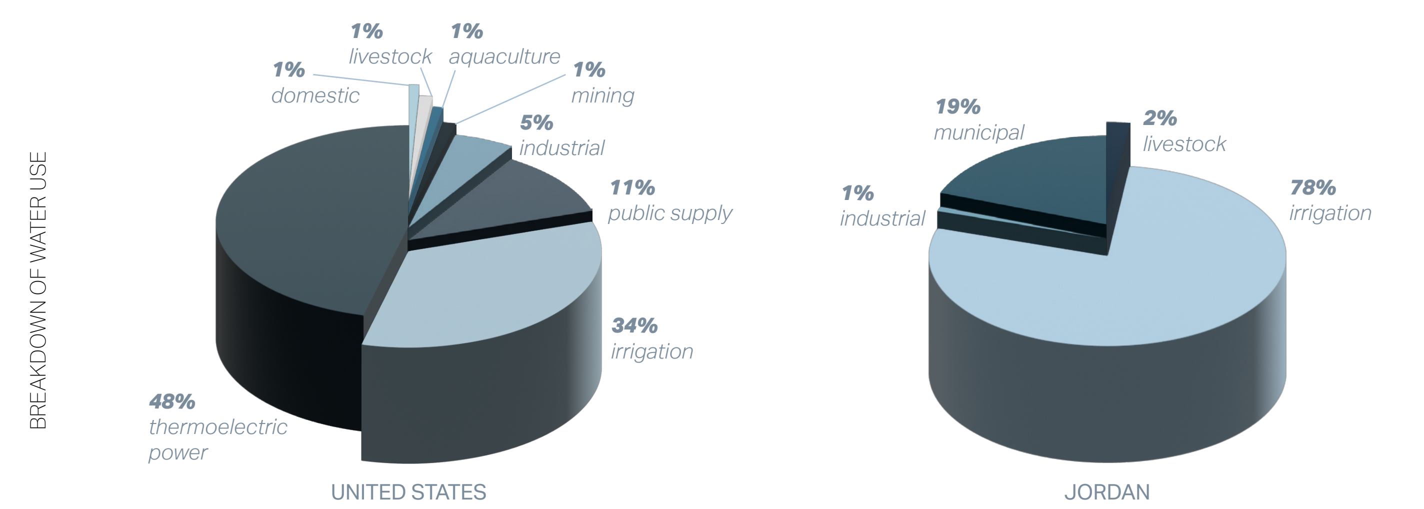


fig. 6

02 THE DECAPOLIS CITIES

The Decapolis cities, shown in black on fig. 8, formed a Hellenistic confederation located in the east of the Roman Empire.[4] Although the cities shared similar language, culture, religion, and policies they acted as autonomous city-states within the Roman Empire. These cities shared trade routes and water resources to form a network. Several of these cities still survive today, although the Decapolis has long been disbanded. Philadelphia is modern-day Amman, the capital of Jordan, Gerasa has become Jerash, Jordan, Scythopolis is now modern-day Bet She'an, Israel, and of course ancient Gadara has become modern-day Umm Qais. Many of the Decapolis cities are now extensive excavation sites, helping us learn from the past in the hopes of creating a brighter future.

Gadara (modern-day Umm Qais, shown as a red dot on fig. 8) was a critical city within the Decapolis. Its position on a hill over 350 meters above sea level[5] gives it a distinct geographic advantage for defense. From Gadara, it is possible to view several neighboring countries, the Sea of Galilee, the Yarmuk River, and the Golan Heights (fig. 7). Gadara also had access to excellent water sources via its two impressive aqueducts, Qanat Ayn Turab and the Gadara Aqueduct (one of the longest recorded aqueducts) (fig. 8). These geographic features and its central location made it an important node within the Decapolis.

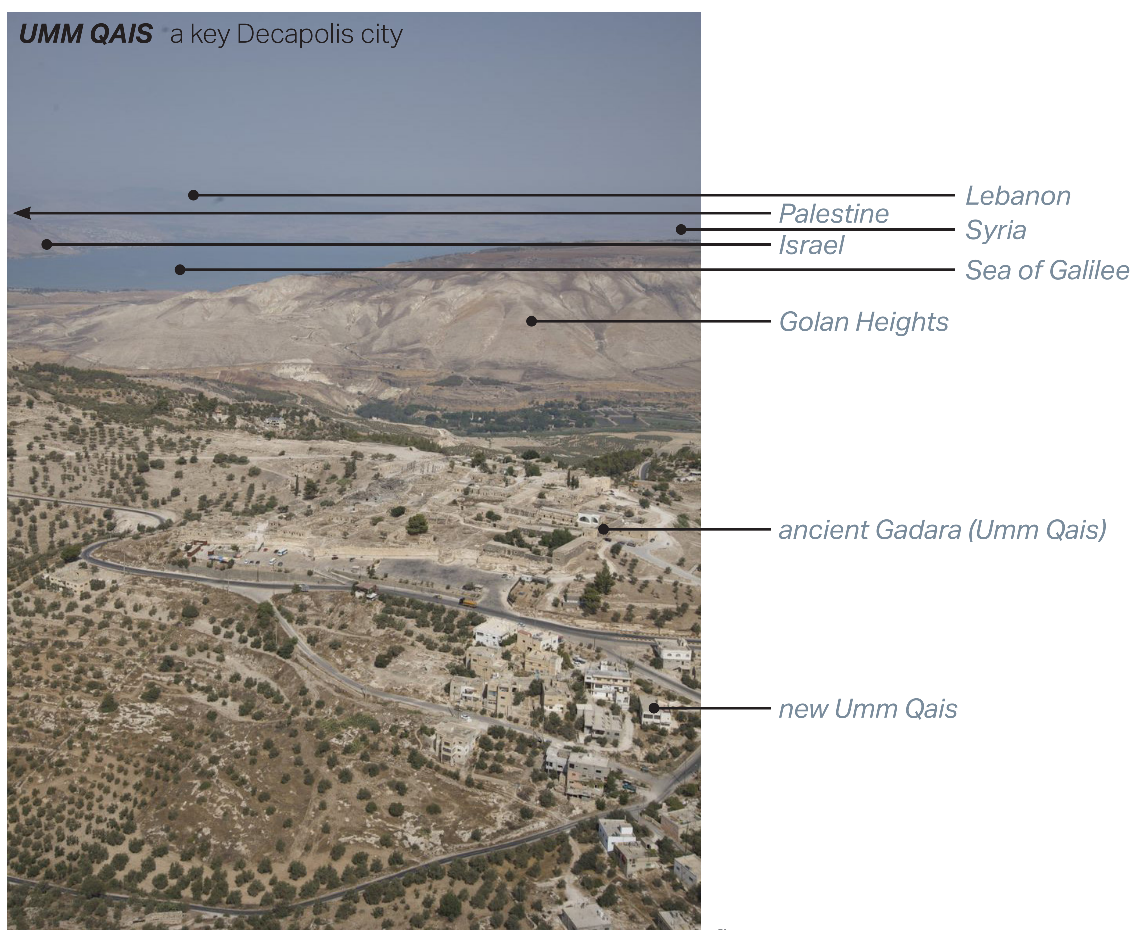


fig. 7

fig. 8

03 AN OVERVIEW OF UMM QAIS

Modern-day Umm Qais was once the ancient city of Gadara, a Hellenistic settlement founded roughly 2,300 years ago.[6] It's an extraordinary site with remains spanning thousands of years, including remains from the Seleucids, Ptolemies, Romans, Byzantines, Umayyads, and even up to the 19th century Ottomans and 20th century military defenses from regional wars.[6] Gadara was originally founded by the Ptolomies, became quite prosperous during the Roman and Byzantine periods, then fell from power around 634 AD after the Muslims took over.[5] Although Gadara hit its peak of prosperity during the Roman and Byzantine periods, it was occupied long before then. There is pottery evidence showing occupation as early as 7th century BC, during the late Iron Age.[5] Further pottery analysis shows the city has been continuously occupied from prehistoric to modern times.[5]

Gadara was heavily influenced by Greek culture after Alexander the Great conquered Syria and Palestine in 333 BC.[5] After a series of conflicts, Gadara became part of the Roman Empire and was under the control of Herod the Great from 31 BC until his death in 4 BC, at which point Gadara recovered its independence but remained a Decapolis city.[5] Towards the end of Herod's reign, Gadara solidified itself as central point along several trade networks (fig. 8) resulting in a significant expansion of construction in the city.[5] As Christianity spread, Gedara transitioned into the Byzantine period and became a major Christian center between 4 and 636 AD.[5] In 636 AD the Umayyad won a battle against the Byzantines, following which the site was occupied by several groups throughout the Islamic period.[5] Following the fall of Syria under Ottoman rule, several earthquakes devastated ancient Gadara and left the site unoccupied for roughly 1100 years until it was successfully resettled around 1860, slightly before the turn of the century.[5]

The city planning was based very much in the Greek and Roman traditions, with much of the construction being organized around two main streets the east-west *decumanus* and the intersecting *cardo* running along the western slope of the hill (fig 11). The paved decumanus served as a connection between Gadara and other Decapolis cities and southern Syria and features five gates, marking the growth phases of the city.[5] The limestone block city walls, most of which no longer exist, were equipped with towers and helped to protect the city from attacks.

One of the most iconic remains within the old village of Umm Qais is the 2nd century Roman theater (fig. 10) made almost entirely of black basalt stone.[6] Another important feature is the 3rd century Byzantine Bath (fig. 9), also referred to as the Central Bathhouse because of its prominent location at the intersection of the cardo and decumanus streets.[7] Within the old city of Umm Qais three baths have been uncovered, the Byzantine Bath, Herakleides Bath (home to an impressive mosaic), and Al-Qasr Bath (fig. 9). Bathhouses were not only architecturally impressive thanks to their massive scale and clever spatial sequencing, they also served as the "heart of Roman community life".[5] They were used for bathing but also served as cultural hubs, hosting musical performances, lectures, and poetry readings, as well as housing other facilities such as libraries, gyms, art halls, and gardens.[5]

fig. 9

fig. 10

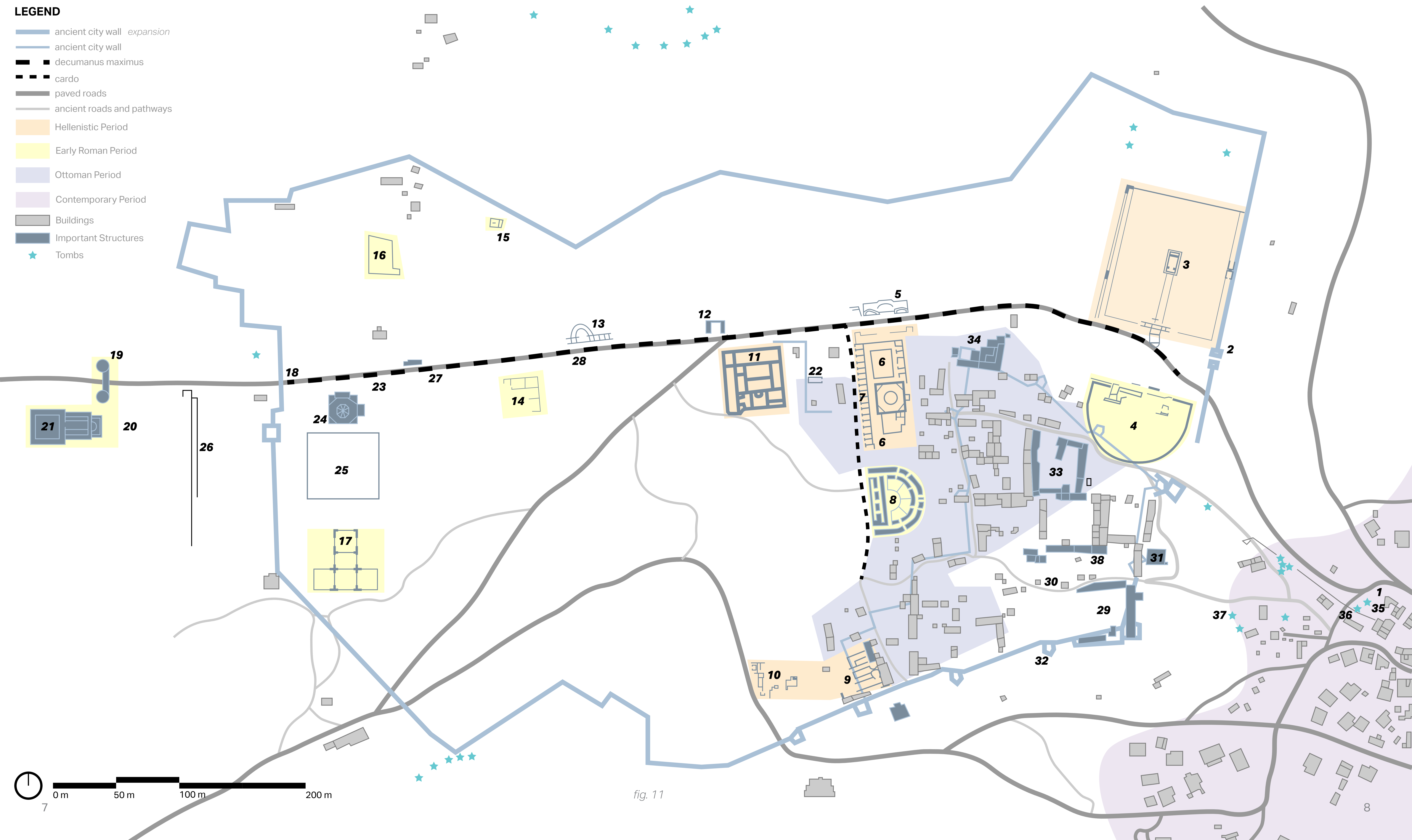

LEGEND
ancient city wall expansion
ancient city wall
decumanus maximus
cardo
paved roads
ancient roads and pathways
Hellenistic Period
Early Roman Period
Ottoman Period
Contemporary Period
Buildings
Important Structures
Tombs
0 m
50 m
100 m
200 m
1
2
3
4
5
6
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fig. 11

UMM QAIS HISTORICAL FEATURES

1 Eastern Cemetery
2 Roman Eastern City (Hauran) Gate *(Abila Gate)*
3 Hellenistic / Roman Podium Temple
4 Roman North Theater
5 Nymphaeum
6 Byzantine Church Complex (Basilica) with Colonnaded Courtyard
7 Roman / Byzantine Street-Front Shops
8 Roman West Theater
9 Trikonchos Building (Basilica) and Later Byzantine Structure
10 Domestic Quarters
11 The Byzantine Bath *(Thermae)*
12 Podium Monument *(Nymphaeum)*
13 Exedra Building and Church
14 Sanctuary and Propylon
15 Northern Mausoleum
16 Herakleides Bath
17 Al-Qasr Bath
18 Early Roman City Gate
19 Tiberias Gate
20 Crypt and Hypogeum *(Underground Mausoleum and Circular Building)*
21 Five-Aisled Basilica
22 Temple
23 Propylon
24 Marcellum and Colonnaded Courtyard
25 Peristyl
26 Street
27 Western Gate
28 Eastern Gate
29 Beit Melkawi *(with trench revealing city wall)*
30 Cave Tomb
31 Ottoman Mosque
32 Towers
33 Beit Rusan *(now Umm Qais Museum)*
34 Elementary School *(now Rest House)*
35 Tomb of the Germani
36 Tomb of Modestus
37 Tomb of Chaireas
38 Beit Husban

6

7

8

11

24

33

Photos by Melissa Smith

04 THE WATER SYSTEMS OF UMM QAIS

Umm Qais is situated on a defensible acropolis, near the cross of the rivers Yarmuk and Jordan. Although this site was a strong military defense, it was not ideal for access to water. Umm Qais received 400 - 500 mm of rainfall annually, making agriculture possible without the need for irrigation.[8] However, rainfall alone was not enough to sustain all the needs of the population and its city, including bathhouses, fountains, and possibly an artificial lake.[8] Gadara instead relied on two large tunnels, called aqueducts, extending from the main water sources to the city (fig. 12).

Within the city itself, Gadara used an extensive set of cisterns (fig. 13) to collect and store rainwater and surface water for use in homes, public buildings, and agriculture. Because it only rained during the winter and spring, the cisterns helped balance the seasonal fluctuations in terms of access to water.[9] It is estimated that roughly 2000 people survived within the city walls through a 10-month besiegement until the Hasmonaen king Alexander Jannaeus took over by using water stored in cisterns.[9] Gadara also used two large underground aqueducts (fig. 13) to transport water throughout the city. A complex system of ceramic, basalt, and lead pipes delivered water from the aqueducts through the city.[8] This system is how water was delivered from a faraway spring, through aqueducts, into pipes, then to buildings, water features, bathhouses, and more.

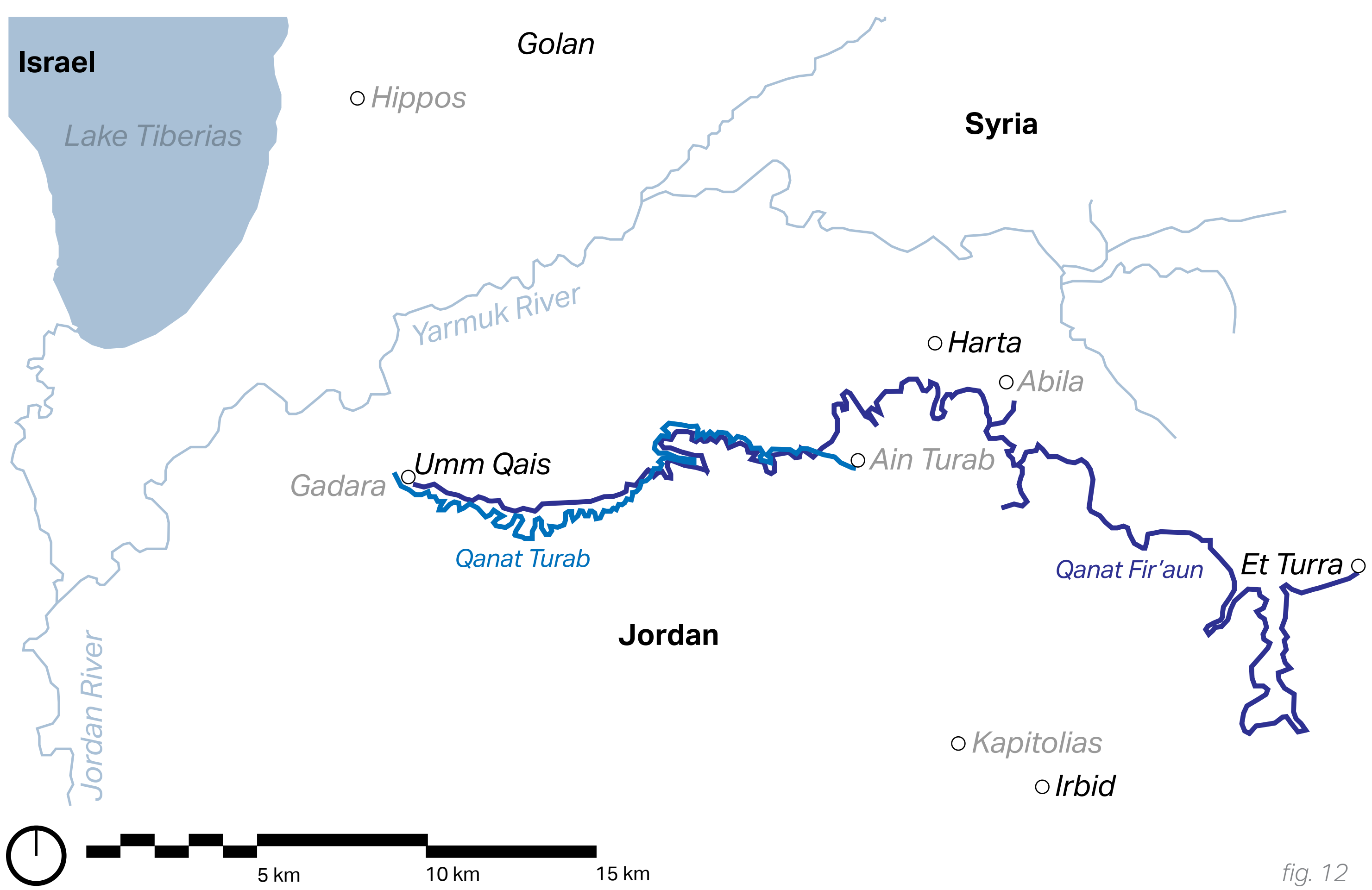


fig. 12

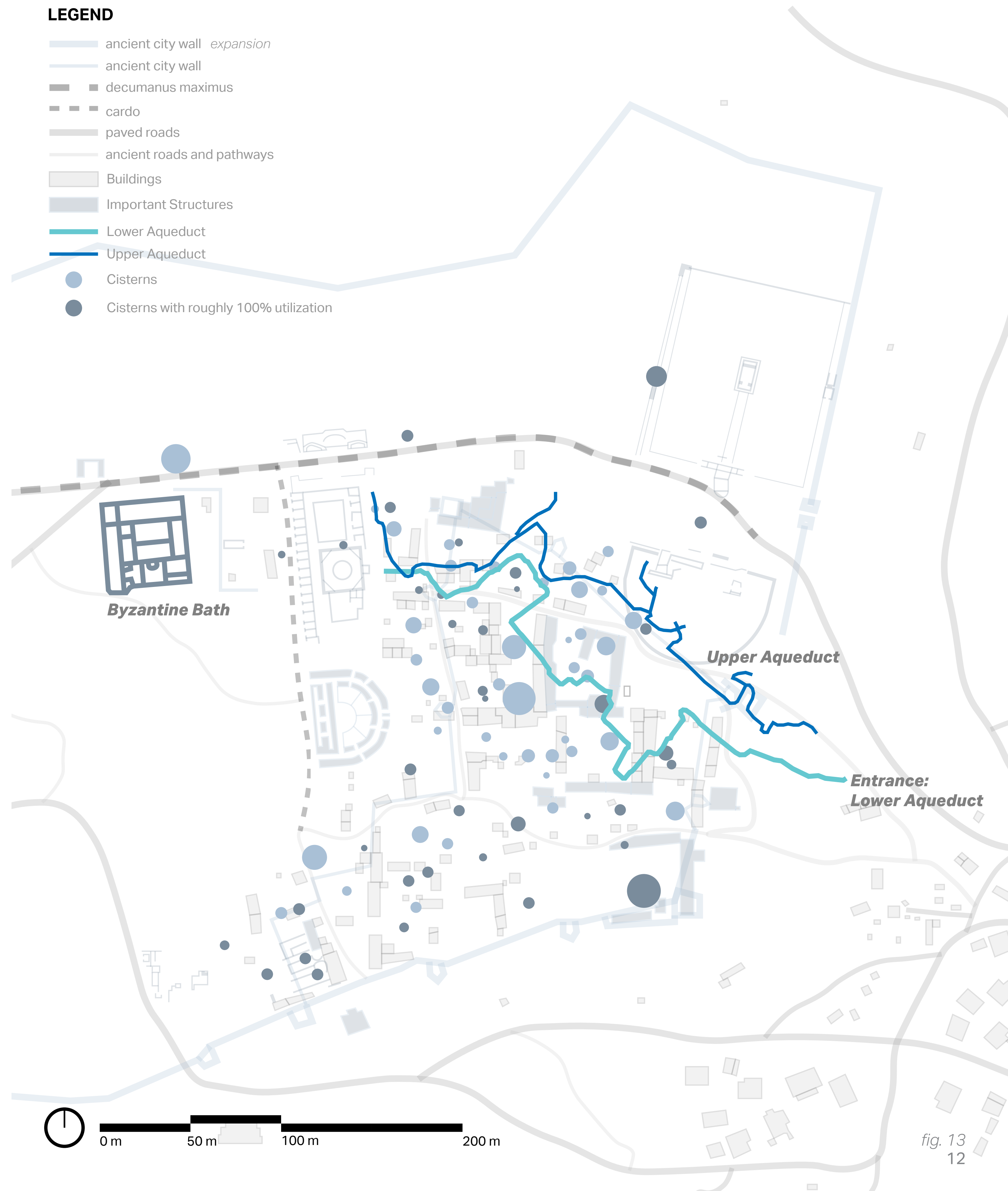


fig. 13

05 PRECEDENTS: *PETRA, JORDAN*

Although Petra only received an average of 4" of rainfall annually,[10] this extraordinary city sustained its people, livestock, and culture through a system of channels, cisterns, and dams (fig. 14) that brought water into the city via desert springs. Petra, at its peak of civilization, is estimated to have had a population of roughly 30,000 people, although its on-site water resources could have only sustained a maximum of 3,000 people.[10] This feat is extremely telling of the ingenuity and engineering skill of the Nabataean people who inhabited the land.

The water collection, storage, and transportation system began at the highest points of the city, where large cisterns were located which collected as much winter rain as possible.[10] From these cisterns, water was brought down into the city through a massive network of channels cut into rock (fig. 15).[10] The channels were made of small segments of terra cotta pipes (fig. 17), each 40 cm long, connected together to strength incredibly long distances. There are more than 100 miles of terra cotta channels within Petra.[10] The angle of the channels, measured at 3 degrees, was critical; the angle is just steep enough to keep water moving but shallow enough to prevent backup. Additionally, every 40 meters there is a small, rectangular pocket cut into the base of the channel (fig. 16) which was used to filter the water as it traveled into the city. This system was able to provide Petra with an impressive 12 million gallons of water per day, enough to satisfy the needs of agriculture, the people, and even enough to fill a 140 foot public swimming pool.[10]

There are many principles we can extract from the genius of the Nabataean people when considering how to solve our present-day water crisis, such as maximizing rainwater collection, controlling the flow of water through pipes, and using water more conservatively in argicultural settings.

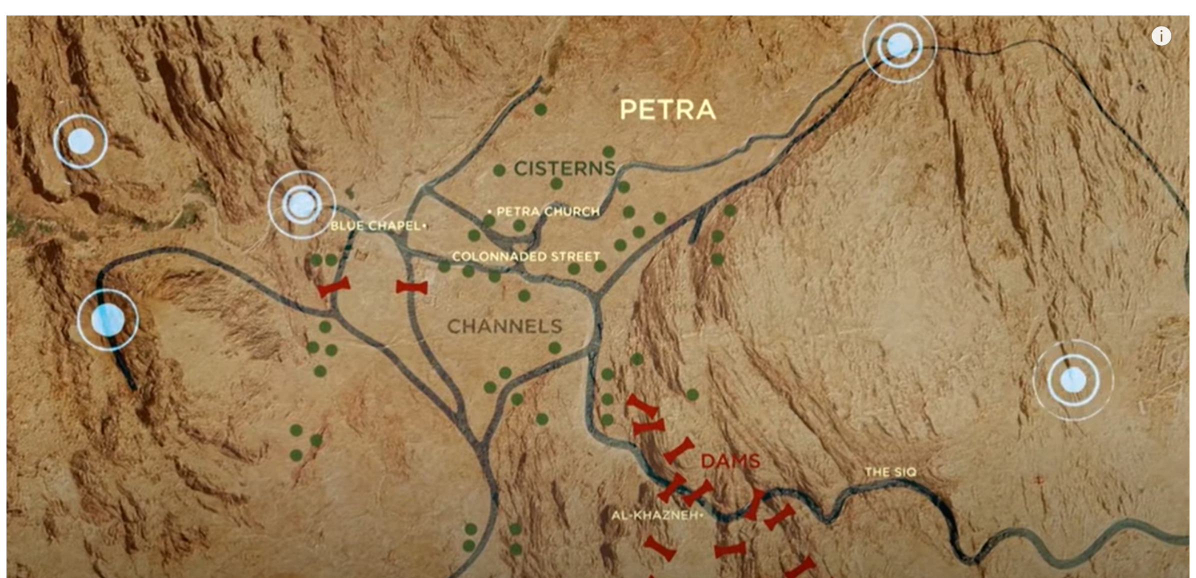


fig. 14

fig. 15

fig. 16

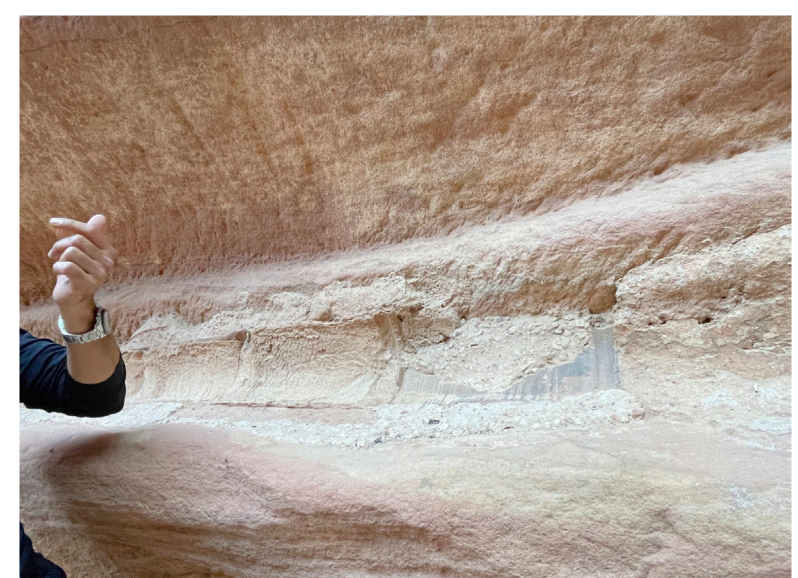


fig. 17

14 a map showing the locations of channels, cisterns, and dams that functioned as a system to bring water into Petra

15 The Siq - main entry road into Petra, a channel cut into the rock can be seen in the left wall

16 a filter to collect sediment from the water as it passes through a channel

17 remnants of the ancient terra cotta pipes

05 PRECEDENTS: *THE QATAR CRISIS*

Qatar, much like Jordan, struggles with access to water. Food insecurity is also a major issue in Qatar, which, as of the early 2000s, imported almost all of its food from neighboring countries. A select few individuals noticed in 2008 that Qatar's dependence on foreign food was a potentially serious weakness and set out to study the issue in depth.[11] What began as essentially a one-man research report developed into an over five year study of the causes of and potential solutions to food insecurity and lacking water that involved extensive international travel and hundreds of collaborators, including engineers, economists, and agricultural scientists.[11] They discovered that the main hurdle to achieving food security was the desert country's distinct lack of water.[11] Qatar once had vast aquifers, but their water reserves have been almost entirely depleted by farms growing fava beans to feed racing camels, which made up the majority of farming in Qatar.[11] Qatar, it must be noted, is one of the wealthiest nations in the world, thanks to their involvement in the oil and gas industry, which is both what allowed the water reserves to be depleted so rapidly and what allowed Qatar to investigate so deeply into solutions to resolve the problem.

Qatar begin solving its water and food shortage problem by investing significant time and resources into understanding the problem in its entirety. They created the Food Security Program, which studied in depth the region's historical geography, access to water, and current farming practices.[11] After the research phase was fully underway, the task force began creating an agricultural industry outside Doha.[11]

The key to solving the food insecurity issue was differentiating between and resolving the challenges associated with food insecurity both in normal times and in times of crisis. The task force knew something needed to be done swiftly and effectively when it performed a risk analysis early in the research phase and predicted a 46% chance of a blockade at the border[11], meaning Qatar would not be able to receive its food and water imports. Flash forward nearly 10 years, and in 2017 the blockade occurs as a result of an arms deal - the largest arms deal in history, in fact - with the Trump Administration.[11] Neighboring countries then placed a blockade on Qatar, but the task force has been preparing for this moment.

Growing food and managing livestock in the desert without the use of underground water reserves is of course a significant challenge, which the task force addressed by pouring resources into their ceoncept of "farming for resilience".[11] First, the agricultural industry was placed under strict water regulations, unlike other farming industries around the world that consume immense amounts of water with minimal regulations, such as the U.S. Then the new industry became the perfect place to test new technology in agriculture and sustainability. They designed and adopted highly efficient greenhouses, methods for water retention by capturing moisture from hot air, and huge desalination plants. Additionally, the task force closely monitored food consumption by the people of Qatar to understand and prepare for the needs of the people during a potential blockade. Lastly, Qatar communicated and made use of its international allies, such as Jordan, Oman, Turkey, Lebanon, and even Australia, that provided Qatar with agricultural resources like cattle and hay.[11] When the blockade eventually came, Qatar was ready and able to supply its people with all the food they would need, in addition to solving its problem with dependence on foreign nations.

18 satellite view of Baladna Farms, Qatar
19 the world's largest rotary milking machine, Baladna Farms, Qatar
20 Tourism to Baladna Farms

fig. 18

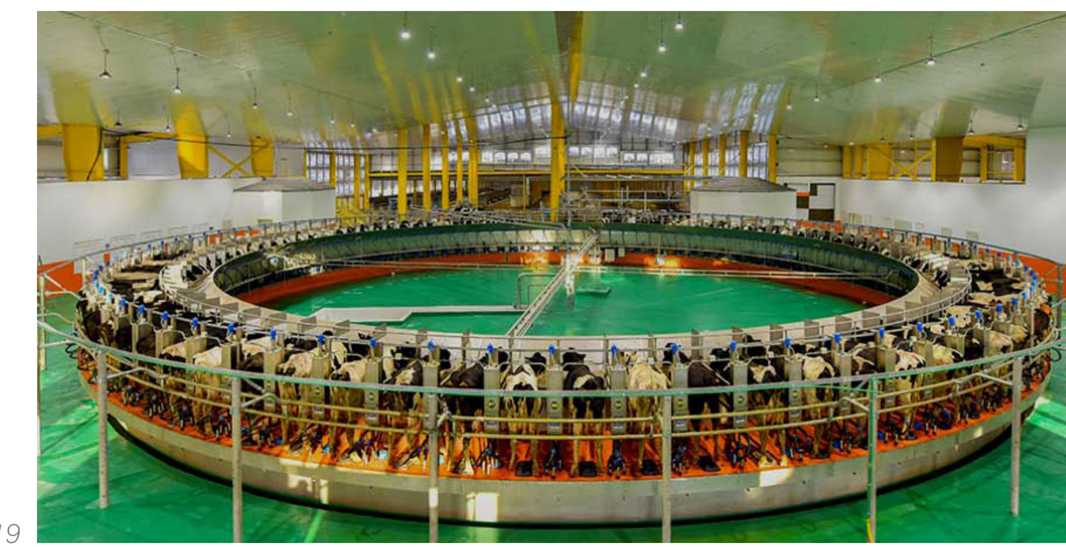


fig. 19

fig. 20

05 PRECEDENTS: *CAPE TOWN, SOUTH AFRICA*

After years of drought, Cape Town, South Africa was a mere 90 days from Day Zero - the day the municipal water supply would be shut off.[12] But this day never came. In fact, a year later the city's dams were over 80% full and water restrictions were relaxed.[12] They did this by encouraging water conservation, placing restrictions on businesses, and putting hard quotas on agricultural water use.

Cape Town was quickly urbanizing and water demand was at an all-time high. To reduce demand, residents were presented with water-conserving initiatives and competed to save water.[12] Households using large amounts of water were fined, showers were restricted to two minutes, toilet-flushing was discouraged, social media was used to share tips, and washing cars was banned.[12] Water pressure was reduced which cut consumption and decreased water loss from leaky pipes.[12] Placing strict quotas on commercial and agricultural use was instrumental. Usage of water by farms was reduced from 30% of the Western Cape water usage to just 15% in a few months.[13]

Water reuse, which incorporates greywater (recycled water that has been treated and purified) into the municipal supply, was instrumental in helping Cape Town push back Day Zero.[14] Water reuse only costs 60% of the cost of desalination (the process of purifying sea water to drinkable standards), has minimal environmental impact compared to dams, doesn't draw water from natural supplies, and has been tested and seen much technological improvement in recent years.[14]

Collecting water use data on households, businesses, and companies helped the city understand the challenges and solutions to the water crisis. They placed restrictions on the right sectors and ensured water consumption was reduced. Contiuning to collect data allows the city to track its success and avoid a potential future Day Zero.

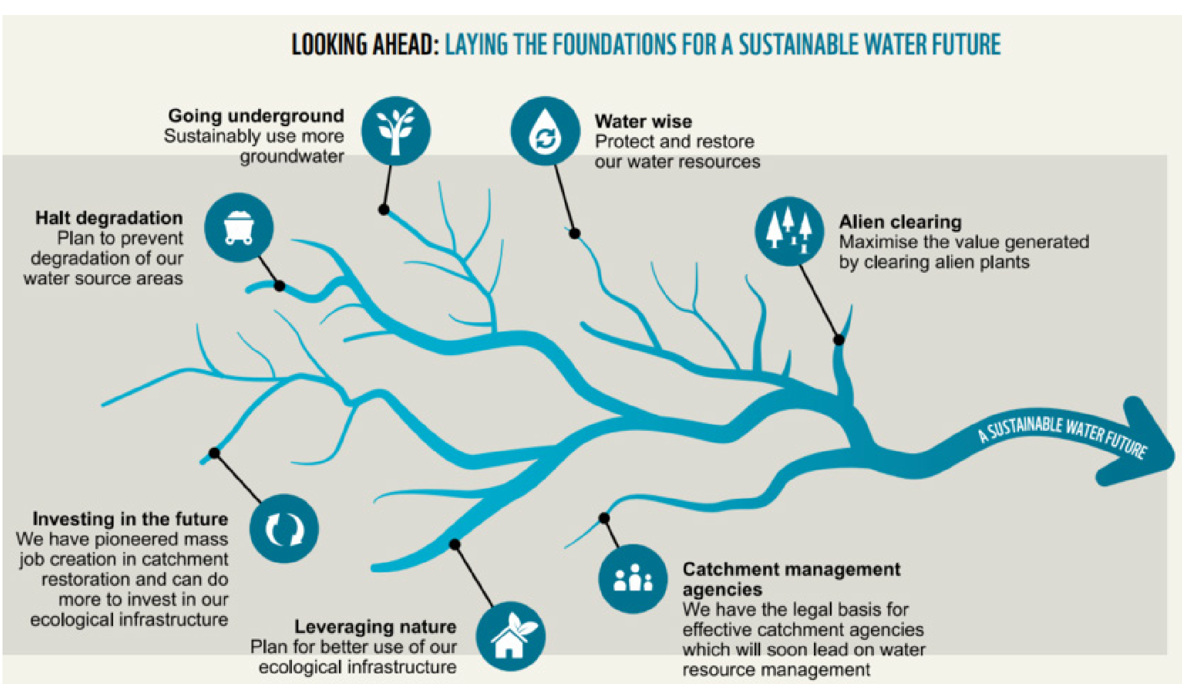
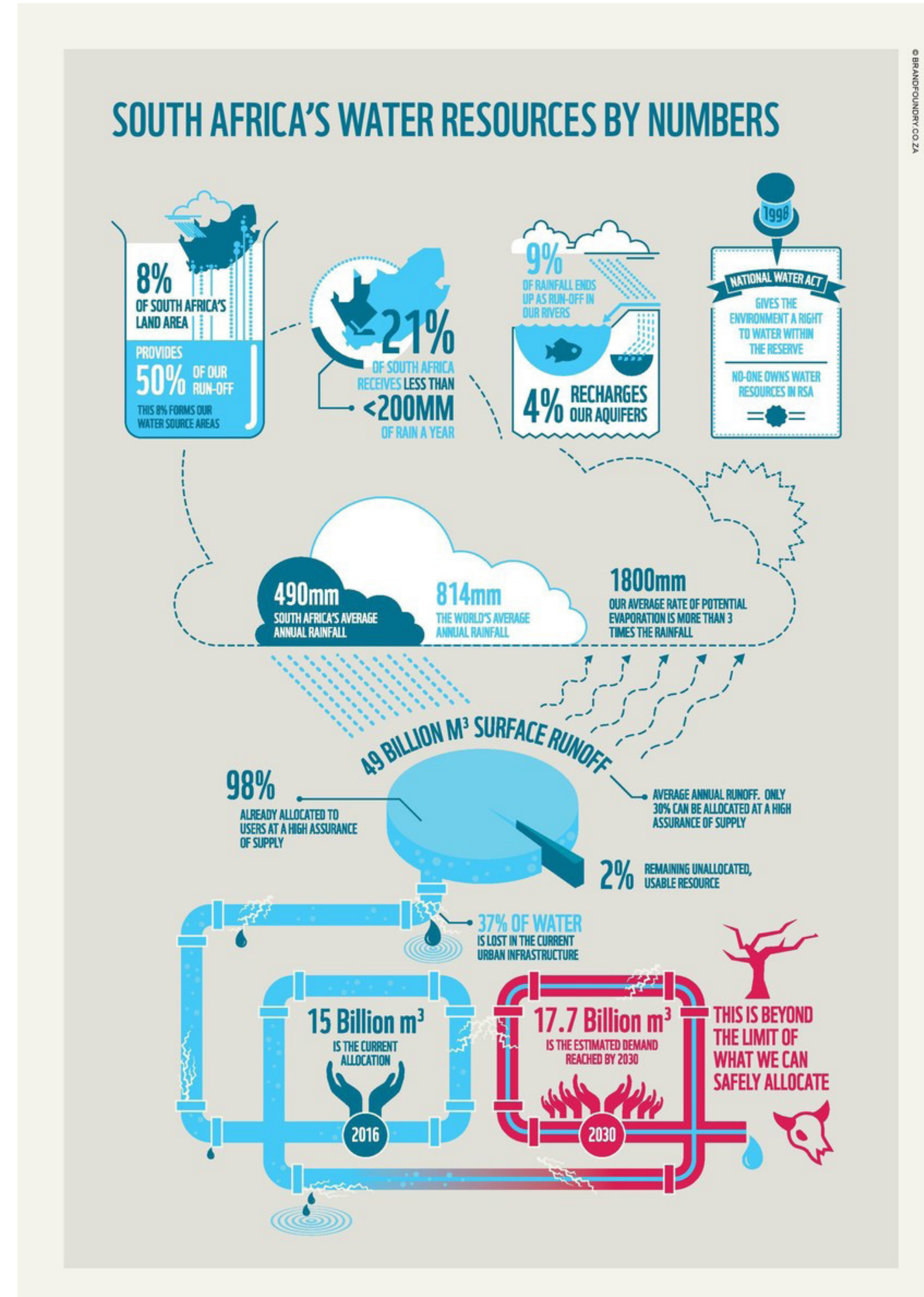


fig. 21

fig. 22



05 PRECEDENTS: *CLIMATE-AWARE DESIGN*

Xerophytes are plants that have adapted to grow in hot, dry cliamtes.[15] In desert climates, plants experience high rates of transpiration (the loss of water through the pores, also called stomata, on the surface of their leaves and stems) due to high temperatures and low levels of humidity.[15] Xerophytes have developed clever adaptations to avoid excess transpiration and survive in desert climates.[15] They have fewer and smaller leaves compared to other plants, reducing the surface area for water loss. They have long tap roots to reach water that is deep in the ground. Some desert plants, such as succulents, can store water in their thick leaves, stems, and roots. Desert plants are often shorter, making them less exposed to winds and easier to shade. There is a thick, waxy cuticle on the leaves of xerophytes which helps prevent water loss from the surface. Additionally, the stomata of desert plants are often sunken into pits and surrounded by hairs or needles to help trap water near the leaf and reduce transpiration. Lastly, some desert plants even have rolled leaves which helps reduce the exposure of the stomata to the air, thus reducing evaporative water loss. Many desert plants also have CAM (crassulacean acid metabolism) physiology, meaning they have adapted to separate the processes of photosynthesis between day and night.[16] These plants only open their stomata to take in CO_2 at night when it is cooler and more humid, which reduces water loss via transpiration.[16] The plants store the CO_2 as organic acid in vacuoles then release it into the Calvin cycle the following day to complete photosynthesis and produce the sugar the plant uses as fuel.[16]

Plants, architecture, and infrastructure may seem unrelated at first glance, the former being so natural and the latter being man-made, but a group of young architects in Tucson, led by Binary Design, are studying desert plants and primitive dwellings to create new techniques in environmentally conscious architecture for desert climates.[17] For example, this team has designed "cooling blocks" that mimic the capillary system and porous membrane of desert plants' water-harvesting mechanisms.[17] Water trickles down the blocks helps to draw cool air passively into the building, using a similar principle to evaporative cooling. They have also designed a concrete "thermal block" that admits solar radiation during the winter and shades itself in the summer, somewhat similar in design to the human eyebrow.[17] Their designs emphasize the human ability to adapt to one's climate, encouraging the dweller to more passively live within their surroundings rather than change their surroundings to suit their desires. The team uses local materials and supports fine-tuning designs to their particular location,[17] rather than using standardized sustainability approaches promoted by groups like LEED and Passive House. While LEED emphasizes tight construction and high insulation, Binary Design tends towards a more open, climate-aware design. They work with nature to create designs that are sensitive to the changing environment of a particular location by using more passive principles, such as natural ventilation, careful building orientation, and overhangs. Then they weave in new materials and technology to make the building more efficient. Their principles can be found in their recent designs, such as their first speculative house, called Mariposa de Acero (fig. 25), and their alternative affordable dwelling units called SEED (pods) (fig. 24).

Although "sustainability" is listed as a core value of half of the world's 500 largest companies,[17] we still struggle to build with nature in mind. Brooking's Institute estimates that half of the buildings that we will live in by 2030 do not exist today,[17] meaning an enormous architectural boom is upon us. This is the perfect time to shift our architectural perspectives and build with climate in mind.

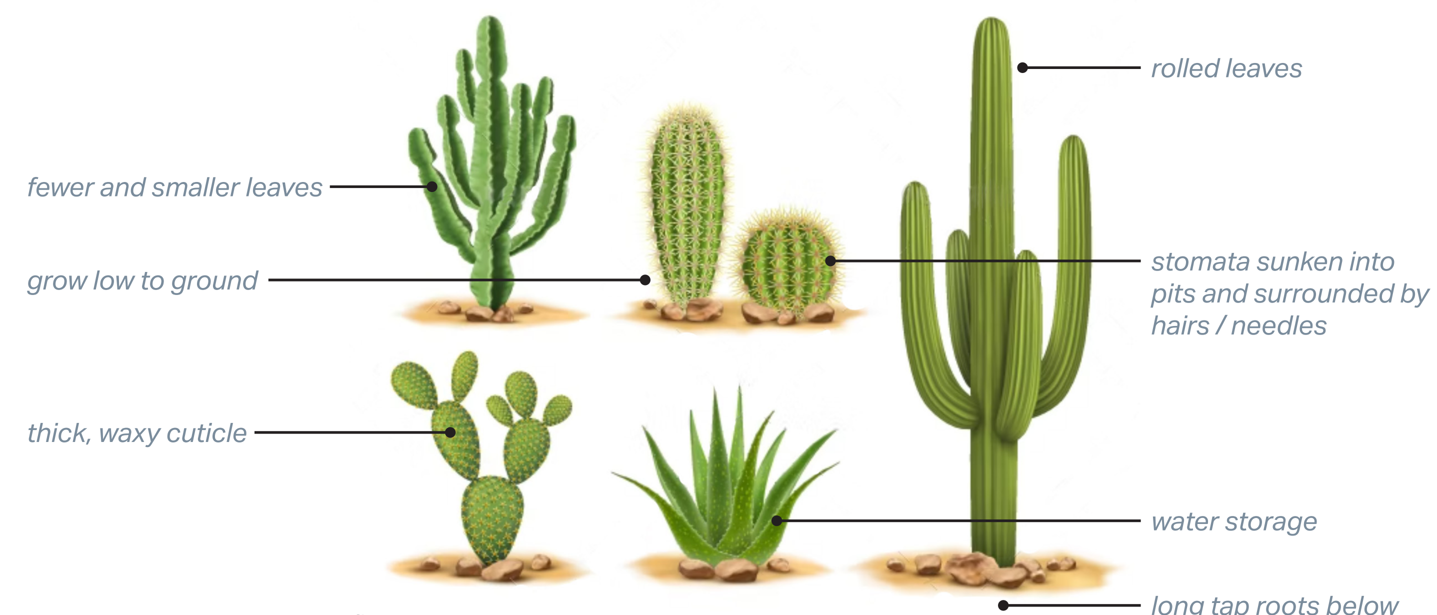


fig. 23

SEED (pod) *fig. 24*

The SEED *(small energy efficient dwelling)* (pod) is the smallest form of a livable module that can be added to as needed by the user. The design is sensitive towards sustainability and aesthetics, while also supporting equitable building. This unit affords all with the opportunity to purchase the smallest unit of a home, thereby entering into the housing market, and allows them to add to it in affordable increments over time.

MARIPOSA DE ACERO *fig. 25*

The first speculative home designed by Binary Design, Mariposa is mounted on bridgework of steel struts to avoid disrupting the soil below. Cool mountain air is pulled through the building by a courtyard separating the two major elements of the house, inspired by breezeways seen in primitive dwellings. The exterior surface of the courtyard is lined with passive cooling blocks to aid in this process.

05 PRECEDENTS: *AQUA VIRGO, ROME*

Many Roman aqueducts are still around today, although not many are used. At one time there were at least 11 aqueduct systems in the capital of Rome alone, supplying water from up to 92 km away.[18] The Aqua Virgo, constructed in 19 B.C. by Agrippa during the reign of Augustus,[19] still functions, watering Rome's famous Trevi Fountain. During the Augustean era, in the year Zero, Rome's 1 million inhabitants had access to two times the water per capita than the city's current inhabitants.[20]

Aqua Virgo supplied water to the Campus Martius, and some other regions.[19] It's source was located east of Rome, but entered Rome from the north (fig. 26) - the only aqueduct to do so. This route avoided populated areas, possibly as a result of Agrippa's inability to secure enough private property and instead to routing the aqueduct through public lands.[19] Two-thirds of the water carried by Aqua Virgo supplied Campus Martius.[19] It supplied *Thermae Agrippae*, the first of the great Roman baths, the *Stagnum*, a large artificial lake, and *Euripus*, an artifical canal extending to the Tiber.[19] At the height of its use, the Virgo was the third largest aqueduct in terms of capacity, however it only had 18 distribution tanks (castella) in Rome, a small number in comparison to what it could have serviced.[19] The water of the Virgo was known to be particularly pure, as it ran through underground channels, making it less susceptible to pollution and changes in temperature.[19] A zigzag pathway rather than small settling tanks (like those seen in Petra) served to remove sediment from the water supply.[19]

Aqua Virgo was exceptionally long, given that its construction led around the city instead of through it. Every 240 Roman feet was placed a boundary stone, tracing the course of the aqueduct.[19] Many of these stones are still visible today. The Virgo was one of the lowest aqueducts in terms of elevation.[19] Because of its low elevation and long length, the gradient of the channels was quite flat. The gradient of an aqueduct is one of its most critical design elements, needing to be just steep enough to keep water moving but not so steep that it pools or clogs (fig 27). Some of the greatest minds of the time, including Vitruvius in his writing *On Architecture*, did various calculations, trying to determine the ideal slope of an aqueduct.[19] Gradients also must vary over the course of the length of the aqueduct, making small adjustments depending on the slope of the land around them. Most Roman aqueducts fall between a 0.15% and 0.30% slope (1.5 to 3.0 meters per kilometer).[19]

The channels of the Virgo supplied water to the imperial palace and other official buildings, private individuals, and the public for general use.[19] Public uses included military camps, baths, circuses, markets, fountains, and open basins. The first major disruption to the functionality to the aqueduct came in A.D. 537/538 when the Goths besieged Rome, attempting to infiltrate the city through one of the dry channels of the Aqua Virgo.[19] The Goths attempted to cut off all aqueducts to the city to prevent the Romans from accessing water.[19] After the siege, repairs were difficult due to lacking resources, so the Romans turned instead to water from the Tiber and from wells.[19] However, because the water flowing the the Virgo was so pure and free of sediment, it allowed the aqueduct to remain functional with less maintenance than others may require. Since then, many channels have been intubated with concrete works to improve functioning. Aqua Virgo is the only ancient aqueduct still functioning in Rome today, although it now only supplies water via its original course to the fountains in the Campus Martius, including the Trevi. Its water is no longer potable and thus only supplies the fountains and helps to water serveral gardens and landscapes.

fig. 27

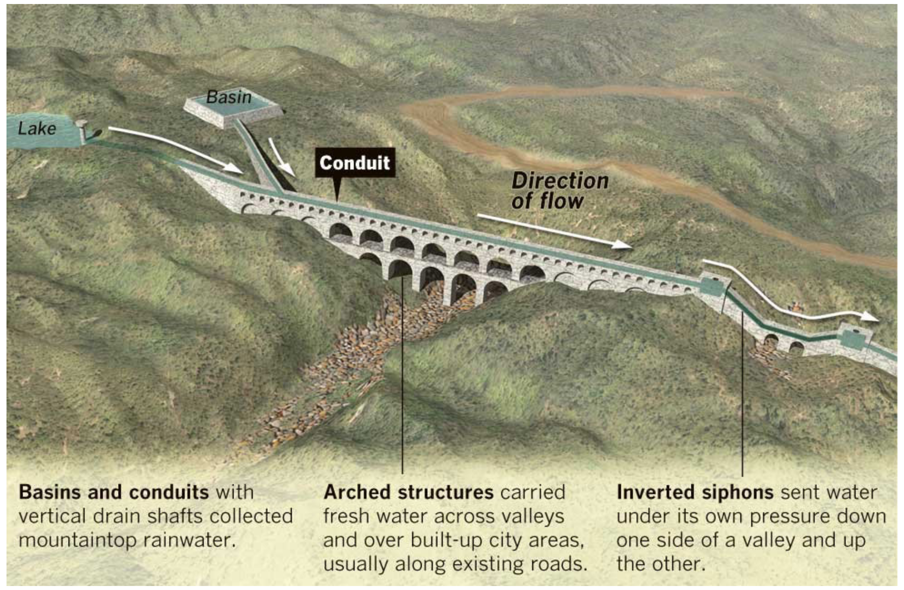
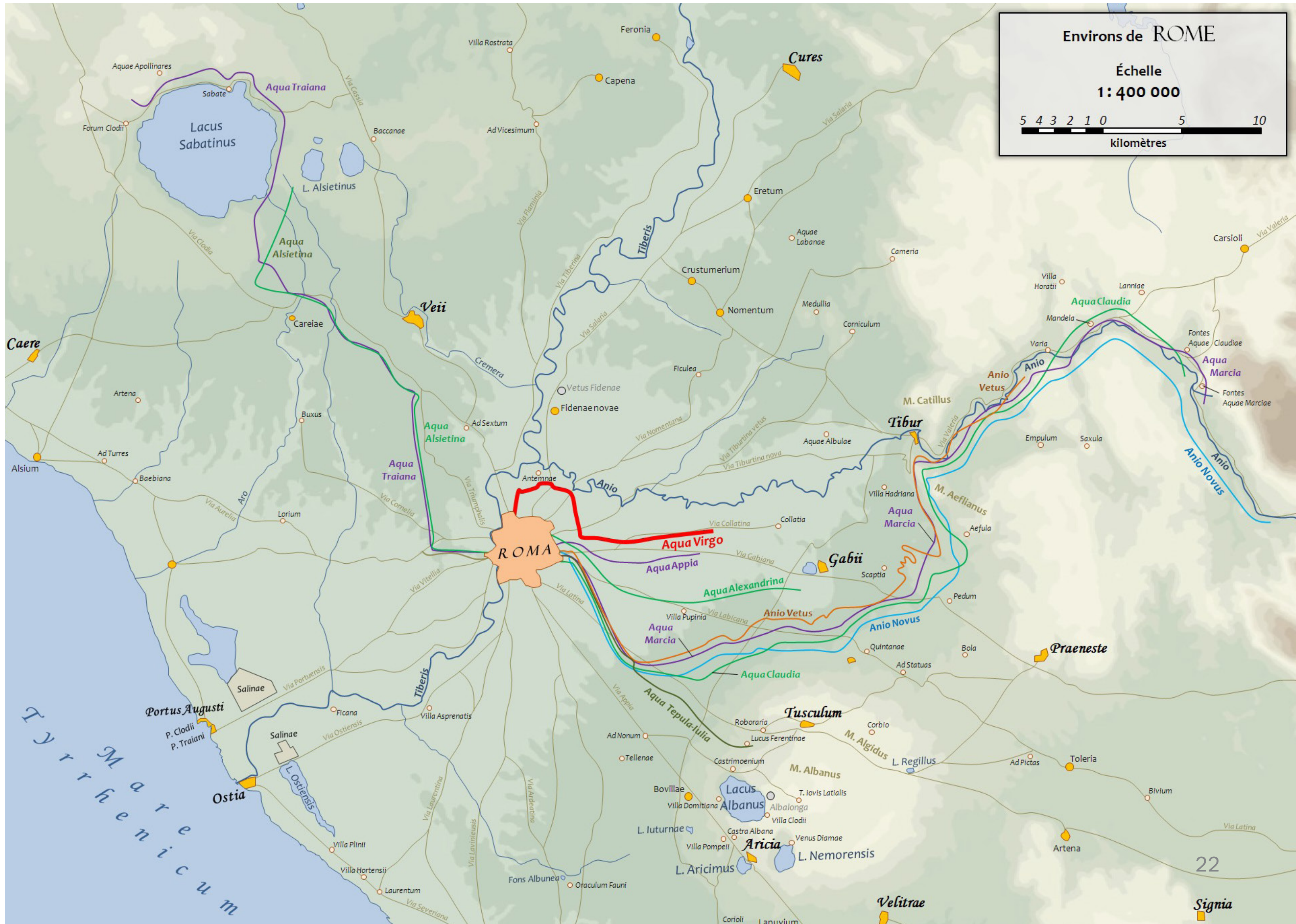


fig. 26



06 SUGGESTED WATER MANAGEMENT IMPROVEMENTS

For Umm Qais - and Jordan as a whole - to resolve its water crisis, it's necessary that the four critical issues causing the crisis are fully understood and addressed.

The unmet water demand in Jordan is rapidly increasing; it is projected to reach 300 million cubic meters annually by 2040 if no intervention is attempted.[21] This is due to several factors including population growth, the influx of Syrian refugees, and climate change. Lacking long term planning has prevented Jordan from adequately preparing for the needs of its growing population and influx of refugees. Increasing temperatures and lessening rainfail (Jordan saw 20% less rainfall in recent years than 50 years ago[21]) have contributed to desertification (the process by which fertile land becomes dry, arid desert)[22].

Because Jordan has seen very little rain and lacks its own reliable water supply, they have turned to depleting their groundwater and water stored in aquifers.

Water loss due to failing infrastructure and poor water management and distribution is another critical issue. Jordan's people have access to 61 liters of water per person per day, but an additional 65 liters of water per person per day is lost due to "physical and administrative gaps."[23] Conversely, the average American uses over 350 liters of water per day.[23] Water supply from the government is delivered on an infrequent and unreliable basis; many Jordanians have reported going weeks or even months without their allotted water delivery from the government.[23]

Finally, the cost of public water is high. When Jordanians do not receive their water delivery, they are forced to resort to stored well water, water from local sources (if they have access), or purchasing costly water from private companies.[23] This leaves many poorer Jordanians without alternatives to the government supply of water, creating a wealth gap in terms of water access.

COOPERATION WITH OTHER NATIONS *LARGE-SCALE SOLUTION*

Much like how Qatar succeeded in increasing local food production by enlisting the help of other nations, Jordan could benefit from cooperating with other nations to trade resources. In fact, Jordan recently entered into an agreement with the United States, the UAE, and Israel in which Jordan will receive 200 million cubic meters of desalinated water a year from Israel (equivalent to 20% of what the Jordanian government currently supplies its citizens with).[21] In return, Jordan will allow UAE companies to build 600 megawatts of solar power within their borders for export to Israel.[21] This is an acceptable deal for now because each country relies on the other. In the long term this solution could create a dangerous dependence on Israeli water for Jordan, especially because Jordan already imports gas from Israel.[21] Additionally, the hostility between Israel and Palestine creates extra challenges because Jordan has taken in many Palestinian refugees through the years. Some believe this deal would be better with Saudi Arabia. Others were in favor of a similar deal with Syria that was halted due to the war. The important thing, though, is that Jordan now has the opportunity to learn about desalination from Israel, which is currently leading the world in desalination technology. If Jordan learns to desalinate its own water, it puts the country in a better position for future resiliency.

DESALINATE WATER WITHIN JORDAN *LARGE-SCALE SOLUTION*

If Jordan began desalinating water within their borders, their dependence on foriegn water would lessen significantly. Desalination is the process by which ocean water is purified to drinking water standards. This process is highly technical and quite expensive, making it challenging to establish in Jordan. Still, the Jordanian government has expressed a goal to desalinate water within Jordan by 2027, according to Water and Irrigation Minister Mohammad Al Najjar.[21] To accomplish this Jordan has invited five consortiums to bid to build a desalination plant at Aqaba capable of desalinating 300 million cubic meters of water a year from the Red Sea, 1.5 times more than what Jordan would receive from Israel.[21] A pipeline from the plant will then direct water to Amman and other areas.[21] It is important to note that Jordan has been taking advantage of its prime solar location and turning to solar power for more and more of its energy needs. Solar power and the desalination of water can go hand in hand, as is being shown in Pakistan.[22] In 2015 Pakistan opened the Solar Hybrid Reverse Osmosis Water Desalination Complex in Mithi, which can provide 8 million liters of drinking water per day to Mithi and neighboring cities.[24] This plant, and several other in Pakistan, are partially solar-powered,[24] solving the issue of accessing electricity in poorer desert areas.

SOCIAL CHANGE *LARGE-SCALE SOLUTION*

Addressing wealth disparity through social reform could help more Jordanians afford water, additionally it would help raise the standard of living in Jordan as a whole and close the gap between quality of life in urban versus rural settings. This would directly benefit Umm Qais and other smaller cities in Jordan. As an example, Kenya narrowed the gap betweenrapidly urbanizing cities and struggling countrysides by implementing strategies like a universal basic income, improving access to technology, wifi, and cell service in rural towns, improving education via partnerships with large universities, improving transportation between cities and rural towns, and encouraging countryside tourism.[11] There is a bus that goes from Amman to Petra that many tourists take each day; something like this could be initiated from Amman to Umm Qais to increase tourism. Additionally, investing in public works projects like improving Jordan's water infrastructure, building public transportation, or investing in solar energy would create jobs in more remote areas and help decrease the wealth gap.

DEDICATED RESEARCH *LARGE-SCALE SOLUTION*

The key discovery from this research report has been the scale and severity of the water crisis in Jordan and the subsequent need for further research into the topic. When Qatar saw how their reliance on food imports could pose a threat to the properity of the country, the government used its resources to study the problem in depth and execute solutions accordingly.[11] Jordan should devote government reurces to study regional and global economics to find sources of money to solve Jordan's water crisis, to closely monitor water comsumption in Jordan to determine need, to understand the depth of the reasons behind the present water crisis in Jordan, and to measure the environmental health of the area in terms of biodiversity, soil quality, water quality, air quality, and other related factors. It is my hope that this research report encourages further research in this area.

EXPAND USE OF UMM QAIS CISTERNS

LOCAL SOLUTION

According to fig. 13 there are at least 79 cisterns within the ancient city of Umm Qais however only 37 are being used at roughly 100% capacity. The recommended steps to maximize usage are as follows:

- Further research into how much water could be stored on-site and how much is being stored.
- Conduct a search to locate any cisterns on site that are currently unknown.
- Examine all underused and unused cisterns on-site and make repairs where necessary.
- Alter landscaping, paving, gutter, and roofing designs to improve direction of water toward cisterns. Avoid planting trees or plants that absorb large amounts of water near drainage paths to maximize the water heading towards the cisterns.
- Use cisterns to store water for Umm Qais heritage site and town residents.
- Create a water management plan to avoid overuse and plan for emergencies.

ADAPT AQUEDUCTS FOR USE TODAY

LOCAL SOLUTION

The Aqua Virgo is still capable of delivering water to Rome today thanks to regular repair and maintenance, its protective underground design (much like those in Umm Qais), and regulations in place to protect the purity of the water and the structure of the tunnel.[25] There is much Umm Qais could learn from the Aqua Virgo in order to bring the aqueducts back to a functional state. The first step in the improvement of the condition of the aqueducts is to thoroughly examine the existing aqueducts. A team must determine if there is documentation of construction or previous repairs, note all necessary repairs, accurately trace the paths of each aqueduct, determine if the water sources for each are still viable, create a plan for the repair, maintenance, and the reuse of the aqueducts, and create a water purification and distribution plan. Regular aqueduct maintenance often involves the repair of leaks and breeches, the clearing of debris, and the removal of calcareous deposits that naturally occur in the water.

DEVELOP PLAN TO REUSE GREYWATER

LOCAL SOLUTION

By committing to reduce water loss and reuse greywater, Umm Qais can close the water cycle gap and become an example for other towns and heritage sites across the globe. It is important to differentiate between primary water uses, such as drinking, cooking, and cleaning, that require pure water, and secondary water uses, such as toilets and agriculture, that do not. Although the reuse of greywater is not common in Jordan due to cost and lacking infrastructure, it may be possible on a smaller testing ground in Umm Qais. Excess water from faucet drains can be directed towards cisterns (those that are currently unused but could be repaired) and stored for use in agriculture, landscaping, and toilets. The reward of an albeit complex infrastructure shift would be two-fold: first, Umm Qais becomes a more independent town, capable of using, reusing, and cleaning its own water (much like it was historically) which decreases dependence on government or foreign water; second, Umm Qais would be elevated on a national and potentially global level as an innovative and forward-thinking town capable of finding solutions to the pressing water crisis. Water shortage is a daunting global issue so if Umm Qais and, on a larger scale, Jordan can find solutions, they will be in a strong position globally when more countries face the same challenge in the coming years.

PRACTICE SUSTAINABLE AGRICULTURE

LOCAL SOLUTION

It is important to address sustainable agriculture because roughly 78% of Jordan's available surface water goes to irrigation each year, as can be seen in fig. 6. There are several techniques that have been studied and tried around the world in rural settings[11] that could be tested on a small scale in Umm Qais then adapted to a larger scale in other areas of Jordan.

- Drip line irrigation reduces water use by using a low volume of water at a low pressure to water crops or landscaping, avoiding any unnecessary waste.
- Planting climate-concious, drougt-resistant crops avoids using excess water to support non-native plants.
- Regenerative agriculture involves farming and grazing practices that reverse climate change by rebuilding organic matter in soil and supporting biodiversity.
- No-till farming avoids disrupting the soil through tillage, which reduces soil erosion and improve absorption of water.
- Along with no-till farming, covercropping can be used to slow erosion, improve soil health, improve water absorption, help control pests, and increase biodiversity. Cover crops are grown primarily to fertilize and rebuilding soil instead of for consumption.
- Precision farming can be used to manage different parts of a field separately, responding to variability in soil, micro-climate conditions, and crop variability to maximize yield and minimize negative environmental impact.
- Along with precision farming, electronic data collection from global positioning systems and location-specific measurements has improved farming techniques. Apps have been developed that collect real-time data from fields including temperature, rate of planting, and wind speed.
- Lastly, newer in the world of agriculture, is pixel-farming which behaves like nature, growing a variety of crops within a small area, but actually requires a lot of data collection and planning to get successful yields.

CREATE A LONG-TERM PLAN

LOCAL SOLUTION

In order to implement any of the solutions discussed in this report, significant efforts in long-term planning will need to be made. While Umm Qais has a long-term plan for heritage conservation, it is important that the town extend that to include water usage and sustainability. Umm Qais should adopt a long-term plan for the use of their cisterns, for potential testing and refinement of farming practices, and for expansion of renewable energy on-site. Although Umm Qais being sited further north does not have access to as much solar energy as other parts of the desert, it does sitll have high temperatures and a lot of sun throughout the year which could be utilized to potentially power the whole of the heritage site. This could elevate Umm Qais as both a tourist site and as a global symbol for renewable energy. Additionally, much like Turquoise Mountain has created a plan to increase jobs via tourism and artistry, Umm Qais could make a plan to improve its economy and increase job creation in the water and energy sectors.

07 IMPLEMENTATION ON A LOCAL SCALE

WATER HARVESTING

REDIRECT DOWNSPOUTS + GUTTERS

RAIN BARREL

You can redirect your downspouts to drain into a rain barrel. A rain barrel is a container used to capture rainwater flowing from the roof through downspouts.[26] The rainwater can be stored for use later when conditions are dry. Rain barrels are ideal for improving water conservation efforts and reducing stormwater runoff, which is wasteful and does not serve the community or landscape.

Water from rain barrels can be used for irrigation in plants or gardens. If you are using the rainwater to water edible plants, keep in mind that the water should be poured into the soil rather than directly onto the plants. The soil will filter the water before it reaches the plants. Water from rain barrels can also be used to flush toilets, clean outdoor spaces or vehicles, or water indoor house plants.

Regularly inspect the rain barrel, especially after storms, to determine whether it needs to be emptied. Seasonally check that the rain barrel is functioning and its part are working properly. Keep the rain barrel, gutters, and downspouts clear of debris. Clean the inside of the barrel when needed.

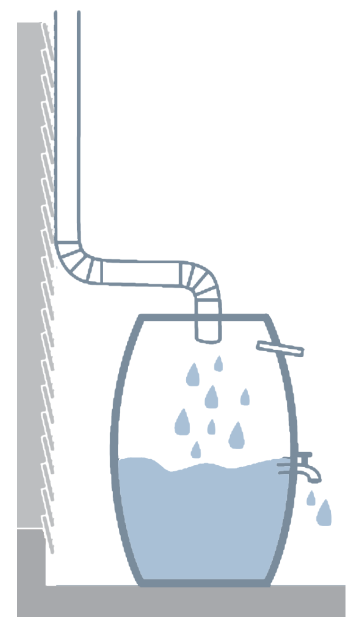


fig. 28

WATER HARVESTING

REDIRECT DOWNSPOUTS + GUTTERS

RAIN CISTERN

Similar to a rain barrel, a rain cistern is a container used to capture and store rainwater for non-potable reuse.[26] You can redirect your downspouts, channels, and landscaping to the rain cistern to collect water that can be reused for irrigation, toilet-flushing, some outdoor cleaning, or other industrial uses.

Cisterns, unlike rain barrels, may be much larger and may receive rainwater from multiple sources. Cisterns can also be located above or below ground, unlike rain barrels which are exclusively above ground. Umm Qais already has a large amount of cisterns from ancient times, some of which are still in use and could easily expand their use of these cisterns.

The collected rainwater can also be purified on-site and reused for potable uses, such as drinking, hand-washing, and cooking, although this is an added challenge.

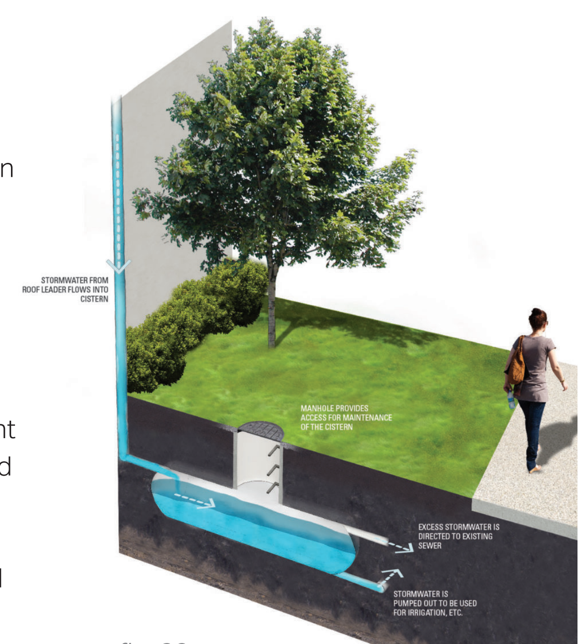


fig. 29

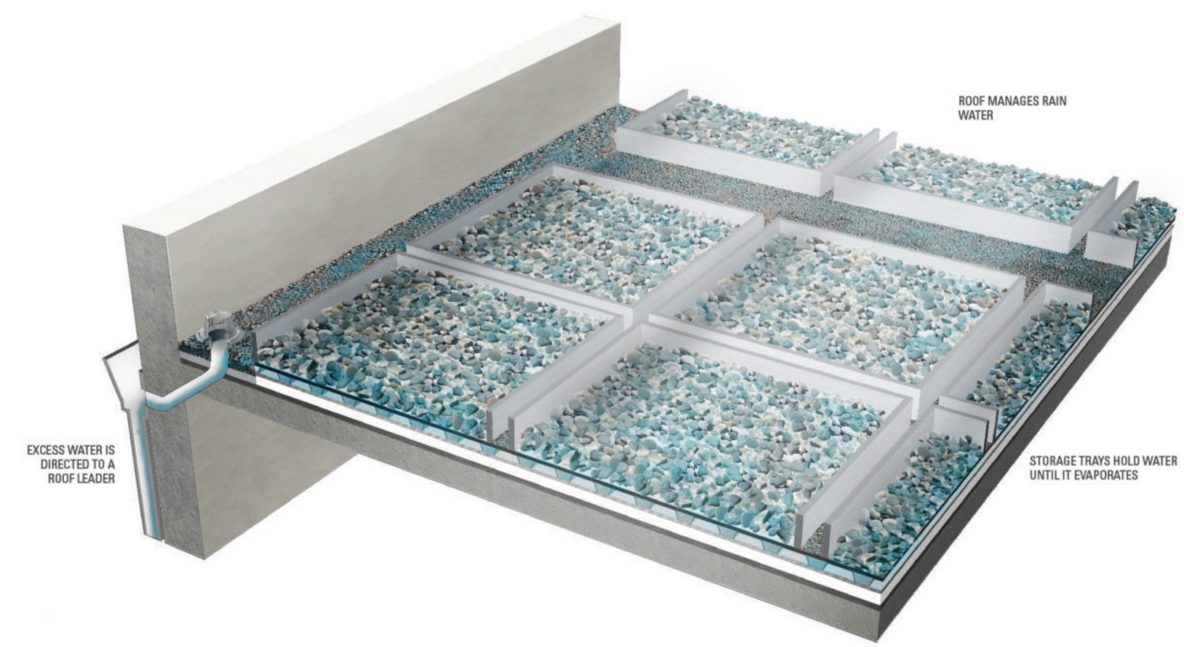
WATER HARVESTING

ROOF ADAPTATIONS

BLUE ROOF

A blue roof is a rooftop rainwater storage system made from stone and a sealed waterproof membrane that allows the roof to act as a stormwater retention system.[27] Water stored on the roof is slowly released via the roof drains, which could be directed to drain into a rain barrel or cistern. Roof water that is not drained will slowly evaporate over time, returning to the atmosphere. This water can be reused for the same functions for which rainwater from rain barrels or cisterns can be used. Blue roofs are best suited for sturdy buildings with flat or almost flat roofs. Many Umm Qais homes and buildings already utilize roof cisterns, so it is possible that these structures are capable of supporting the added load of a blue roof, although this will need to be confirmed by a structural engineer.

The benefit of this system is that it slows rainwater runoff from the roof during a storm, which gives the rainwater a chance to flow down the correct channels into a rain barrel or cistern, rather than overflowing the roof and being wasted.



BLUE ROOF SYSTEM
fig. 30

WATER-CONSERVING STRATEGIES

LOW-FLOW FIXTURES

LOW-FLOW FIXTURES AND ENERGY-EFFICIENT APPLIANCES

Low-flox fixtures use less water than traditional fixtures. Switching to low-flow fixtures will help residents and businesses in Umm Qais conserve water, plus will conserve energy and save money. Low-flow fixtures are designed to use less water than traditional fixtures, for example low-flow toilets only use about 1.5 gallons of water per flush whereas traditional fixtures use roughly 6 gallons per flush.[28] Low-flow fixtures reduce energy use because when using less water for showering or hand-washing, less water needs to be heated.[28] Switching can save you money on both your water and electricity bills, while also decreasing wear and tear on your water heater thereby extending its life.[28] The most common low-flow fixtures are low-flow faucets, toilets, and showerheads.

WATER-CONSERVING STRATEGIES

REUSE GREYWATER

THE BUCKET METHOD
Greywater is domestic water produced from daily activities like showering, handwashing, and laundry. It is not toilet water or water with high concentrations of organic matter. One way to use greywater is to collect it in a bucket from showering or handwashing, then use it to refill the toilet tank.

LAUNDRY-TO-LANDSCAPING
Water from washing clothes in a machine or by hand can be reused for outdoor or indoor plants. A bucket can be used to collect and redistribute greywater from clothes-washing by hand. Washing machine piping can be adjusted to divert water to a garden rather than the sewage system. This can also be done with tubs, showers, or sinks with accessible pipes. This water can be used on edible plants, however it should not come into contact with the edible parts of the plant.

SINK-TO-TOILET
There are more advanced systems that reuse handwashing water from bathroom sinks for flushing toilets. One of which is called a "toilet top sink." Instead of a traditional cover over the toilet tank, it has been fitted with a small sink. The water collected from the sink fills the toilet tank for the next flush. A slightly more advanced and expensive option integrates into the plumbing system of the home or business, using a box below the sink to collect then pump greywater from the sink to the toilet tank.

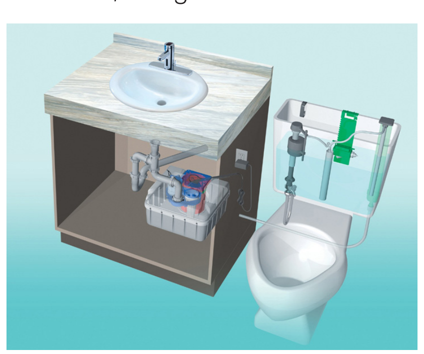


fig. 31

fig. 32

CITY-WIDE EFFORTS

MASS WATER CONSERVATION

REGULARLY INSPECT AND REPAIR LEAKY OR MALFUNCTIONING PIPING
Jordan loses a significant amount of water each year from failing infrastructure. Fixing leaky pipes and maintaning water infrastructure in Umm Qais and in the whole of Jordan could go a long way in conserving water admidst the country's growing water crisis. Turquoise Mountain could parter with the government to teach infrastructure maintenance courses in Umm Qais, then hire those students to repair and maintain pipes in Umm Qais.

MAINTAIN PLUMBING FIXTURES IN PUBLIC, COMMERCIAL, AND PRIVATE BUILDINGS
Additionally, it is important to make a campaign to encourage residents and business-owners regularly maintain and repair their personal fixtures. Ensuring plumbing fixtures are operating at their most functional levels helps reduce water waste.

CAREFUL LANDSCAPING WITH NATIVE PLANTS
Avoid planting any landscaping near pipes, ducts, or other water-related infrastructure. Plant roots can bore into and damage pipes, making them less effective. Plants also soak up groundwater, meaning there is less water available for human use. It is best to landscape in designated areas away from water infrastructure with plants that are native to the region. This will help reduce water loss for the town. The use of native plants can also help improve biodiversity and air quality.

COMMUNITY OUTREACH AND ENGAGEMENT
Much like the city of Cape Town, South Africa did during their drought, it would be a good idea to start a campaign to better communicate the importance of water conservation to the public. Turquoise Mountain could serve as a point of contact between the government and the people on this matter. Useful techniques could include: public announcements about ways to reduce water use and waste, such as only flushing the toilet when necessary or taking shorter showers; creating a phone app to help people track their daily water use so they are more aware of their impact; hosting guest lectures on the global water crisis; offering monetary assistance to residents who want to switch to low-flow fixtures or install toilet top sinks, etc.; or offering incentives for using the least water. The most important technique, though, is regular communication with the residents to hear their concerns and provide assistance as they need it. The only way to address the water crisis in Umm Qais, and the rest of Jordan, is to act collectively for a common goal.

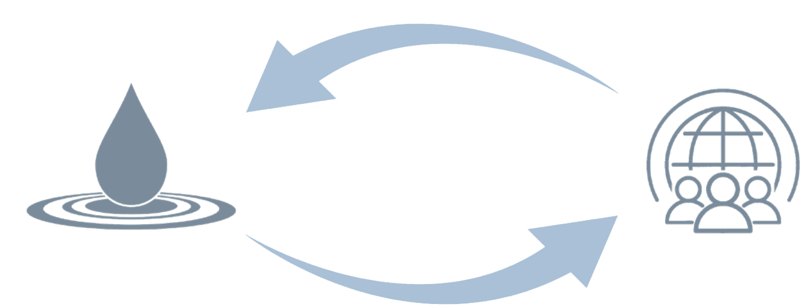


fig. 33

08 CAN MORE EFFICIENT WATER USE SOLVE OTHER GLOBAL ISSUES?

It is well documented that the effects of cliamte change most affect those living in poverty and water scarcity is no exception. Although much of Jordan has felt the effects of water scarcity, those with the most intimate understanding of the challenges caused by water scarcity are those that live in poverty or those of lower incomes. According to the AIA Code of Ethics, members are obligated to "promote sustainable design and development in the natural and built environment and to implement energy and resource conscious design". The Code also extends to respecting and conserving natural and cultural heritage while "striving to the environment and quality of life within it". The connections between climate change and human health and wellbeing are innumerable, so research into design solutions that respect both cliamte and people is essential.

There are many ways that the more efficient use of water, even on a small scale, could be expanded to address the energy crisis and further reduce the negative effects of climate change. For example, ancient builders used a combination of a qanat (tunnel similar to an aqueduct) and a wind tower to cool interior spaces passively (fig. 28). If Umm Qais works to restore one or both of their aqueducts, they may be able to use this method to cool buildings during the hot summers. Historically, these qanats were also used by the Persians in the process of ice storage before the invention of refrigeration.[29] Qanats, dug underground to prevent evaporation, delivered water from uphill wells to the downhill population (fig. 29). They collected the water in shallow ponds shaded by large walls.[29] The shallow water would freeze overnight, then be collected in the morning to be stored in large, dome-like ice houses.[29] The ice house, or yakhchal, stores ice underground and protects it with an insulated dome.[29] Understanding these ancient practices may allow us to adapt them to the modern day, thereby helping to solve the water scarcity issue and energy consumption issue simultaneously.

Expanding the use of solar energy in Umm Qais would also be highly beneficial. Although installation costs can be high, the increased use of solar power on-site or in the nearby town would help Umm Qais become more financially independent if they are capable of producing more of their own power. Expanding the use of renewable energy in both Umm Qais and Jordan as a whole would lessen dependence on non-renewable sources, thereby improving the overall environmental quality of the country as a whole. There may even be a way to use water movement through the aqueducts or pipes to create electricity, although the feasibility of hydropower used in conjunction with aqueducts would need to be studied further.

In conclusion, there are many solutions, large and small, to the water scarcity crisis in Jordan. Creating a plan to devise short-term solutions, like expanding the use of cisterns on-site, and long-term solutions, like restoring the aqueducts, would be highly beneficial. The water scarcity issue affects Jordan accutely, being the second water-poorest country in the world, but is also a global issue that has changed the lives of many and will continue to pose serious challenges if we do not act. It is my hope that this research report raises awareness for this issue and encourages Umm Qais residents, the Jordanian government, and the general public to learn more, get involved, and advocate for change.

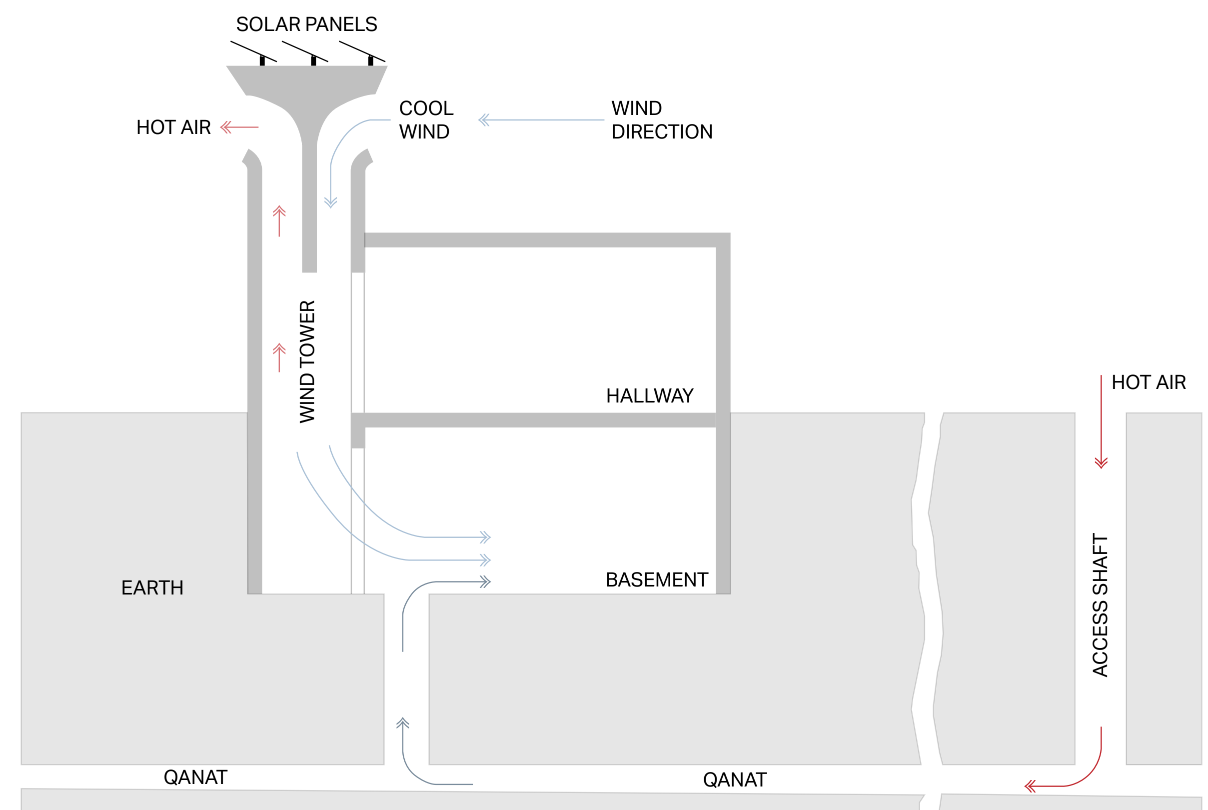
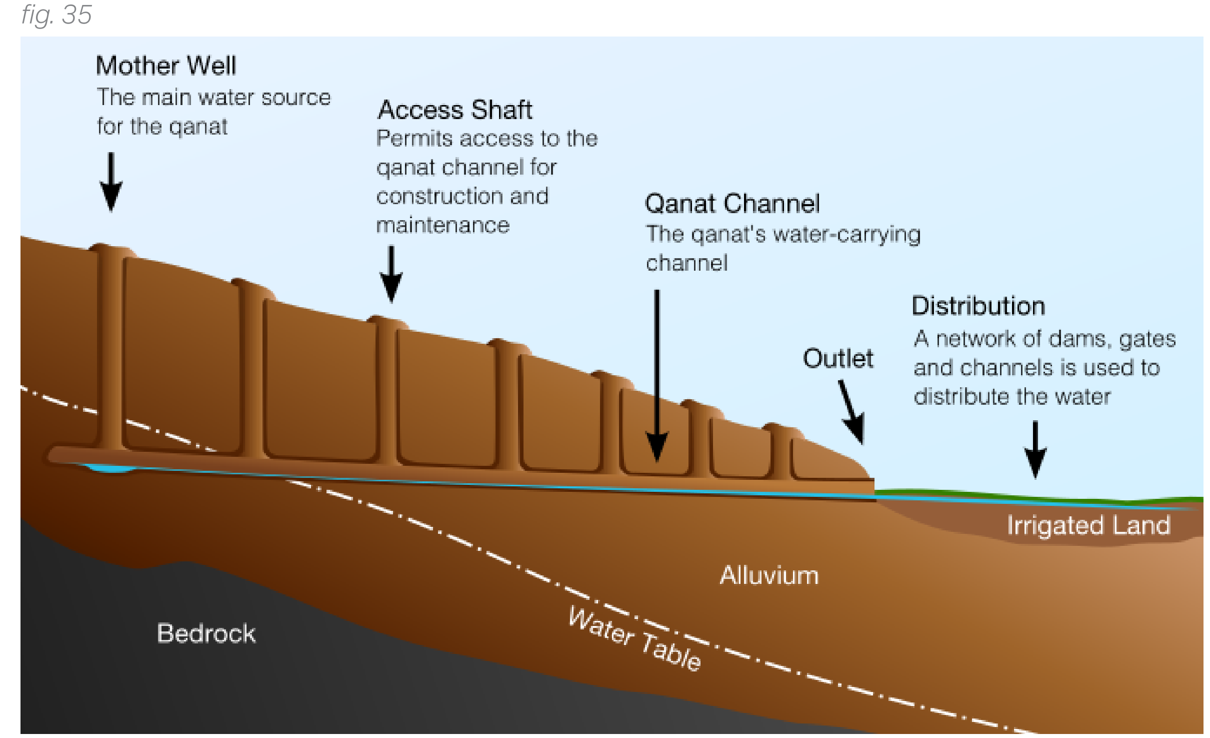


fig. 34

fig. 35



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