A New Water Infrastructure Paradigm for the Arid City of Kerman, Iran

by

Hamid Reza Mohammadi

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Dedicated to

architecture and design that crosses boundaries, borders and cultures

to international co-operation and initiatives for a more prosperous future

and to the hard work and beautiful discoveries of our ancestors.

CONTENTS

ABSTRACT

This thesis investigates ancient methods of water storage, delivery, access and treatment that have formed the basis of traditional Persian settlements and culture. These methods are contrasted with modern techniques and technologies, imported and adopted to the Iranian landscape throughout the twentieth century. The logic and cultural impact of modern water infrastructure is questioned as it relates to natural landscape processes and architecture in the city of Kerman, located in the central Iranian Plateau. Through the lens of traditional means and methods developed over several millennia, modern water infrastructure is questioned for its continuity, engagement and future viability. Water problems found in Kerman can be generalized to other arid cities as the patterns of use and development are similar. The research and design address the issues of aquifer depletion and pollution, social engagement with water, de-abstraction of water, de-centralized treatment, and appropriate climatic use of forms and materials.

ACKNOWLEDGEMENTS

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Finally, I am thankful for the efforts of the numerous scholars who have built the body of knowledge that has made my work possible, as well as Google Maps for being a pivotal research aid.

CHAPTER 1: INTRODUCTION

Thesis Question

How can architecture mobilize traditional and modern water technologies to create a new water infrastructure that is better for the water supply, treatment and social engagement processes of the arid city of Kerman, Iran?

Why?

The increasing population of Iran has brought the issue of water scarcity to the forefront of discussions about its development and future prospects. Many large scale nationwide projects such as dams, desalination plants and pipelines have been undertaken to supply water to various cities. These solutions have many consequences and shortcomings including increased pressure on distant water sources and reliance upon a great deal of energy input for their continued operation. They also do not address the issue of what a responsible and sustainable use cycle for water would be once it reaches the city or agricultural lands.

Why Here?

The city of Kerman is like a microcosm of Iran. Surrounded by mountains of the Zagros range, it displays the natural characteristics of the Iranian landscape as well as historic and social patterns seen throughout the country. Issues found in this city can be found in other Iranian cities and solutions to the issues concerning water will be applicable to other cities. Water usage in Iran has increased steadily along with its population for the past 50 years, this has caused rapid city growth and an ever increasing need for water infrastructure. Rural areas are equally as important as cities since over 90% of water use in Iran goes to this sector. The Kerman Plain and the outskirts of the city have many agricultural lands that supply the province and the country, and show all water use types within a confined region.

Clean and safe water is a fundamental requirement for any city, however the last century has seen growing populations put continuously increasing pressure on water resources worldwide. This issue is especially sensitive in arid cities that are supplied with water from underground aquifers. The limited water resources and ecologies of these areas make them highly vulnerable to human actions. Water infrastructure is a form of interface between humans and the landscape, however current practice dictates that it is predominantly out of sight and out of mind, both in terms of supply and treatment.

This thesis proposes to develop a more pleasant water infrastructure, in which the built environment is strategically designed to facilitate the cycling and recycling of water at every point of contact. In this regard, the customs and practices of traditional Iranian water infrastructure as well as the most modern ecological practices can offer solutions for the human-water interface.

The historic city of Kerman is located in southeast Iran in the Zagros Mountain chain at an altitude of 1755m, in the province of Kerman. It began as a fortified settlement around the 3rd century. Like nearly all Iranian settlements, it was initially supplied with water from qanats, a technology which was developed in Iran 2800 years ago. These were man-made subterranean tunnels that extended the mountain watershed far into the desert plain, following the natural topography to surface in cultivated areas and cities. The qanats stitched together historic cities spatially and socially, weaving their way into houses, public baths, gardens, ice houses and water reservoirs, through watercourses above and below grade. Since the 1950s, qanats along with their associated urban infrastructure and architecture have been gradually replaced by pumps and mechanized systems which are regulated by human demand rather than natural cycles.

Today, only remnants of the previous water infrastructure remain and their significance to the origin of the city is all but forgotten, even though water supply is the most important issue facing Kerman. As water sources continue to deplete, this issue will become more and more pressing. It has been projected that in 20 years water sources in Kerman will deplete to the point that inhabitation will not be possible. There are projects in the works to bring water from distant sources as well as expansion of desalination plants (Interviews with Kerman engineers). Both of these solutions are hugely expensive and require a sustained input of energy and resources for their continued operation. They also do not address the question of what a responsible and sustainable use of water would be when it is delivered to its destination.

My thesis aims to provide real world solutions to help Kerman with water provision and treatment, greening the city, and cultural awareness of the population about the city's water history and the current water situation. For this, I have chosen three sites with distinctly different relationships to water supply and treatment, and with very different social characteristics. The sites follow a path of water as it originates in the mountains and makes its way through various parts of the city and into the aquifer. They relate to the agricultural valley, the old city, and the new city of Kerman. The agricultural solution aids in the daily storage of qanat water in the winter, to be used as needed in the summer. The old city site looks to make new the cultural tradition of celebration and respect for water through a community and cultural center in the form of a "Water Future Pavilion" to showcase proposals, predictions and ideas about the potentials for future water infrastructure, while still appreciating and studying the past. The new city solution addresses the fastest growing part of Kerman, which is apartment housing. Reconfiguring the apartment with a courtyard, water filtration, gardens, and a windcatcher, with a focus on the most responsible utilization and celebration of water from the private to the public realm.

Agriculture Site

Agriculture is by far the biggest user of water in Iran at around 95% of total use. Agricultural lands are supplied with water by motorized pumps, qanats and surface streams. Qanats still remain a significant source of water for agriculture but their biggest weakness as a water supply system is that they flow all year round, and water flow is best in the winter when it is not needed. This thesis proposes a design to store qanat water on a daily basis in the winter in a completely gravity fed system. The proposed reservoir draws on historic principles of Iranian water reservoirs as well as modern methods to produce a strong, durable structure made from local materials that is an authentic part of the landscape. There are currently 19 active qanats in the Kerman plain and this method could be sited appropriately for each.

Figure 1: Water flows from the mountains toward: 1) the agricultural qanat water storage site 2) the old city site 3) the agricultural fields at the periphery of the city. (photo from 2015)

Old City Site

This site has a cultural significance as it is the last flowing qanat attached to the city of

Kerman. It is a natural node and junction where the water from the mountains is split into different channels for its final destination. A Water Future Pavilion is proposed for this location within a newly built community plaza. The plaza would be paved in stone, offer tree shaded seating beside the watercourse and leave a 2m buffer between the existing housing entrances. The central pavilion draws on the courtyard typology of historic buildings in the region, provides a focal point on the ground floor with a central pool and trees. The upper level could house and disseminate historic and modern understandings of the landscape, water usage, dwelling and climate.

Figure 2: Water from the nearby mountains makes its way into the site, it is diverted to various lands based on their time share of water, the vegetation of adjacent agricultural lands is visible. (photo from 2015)

The buildings around this site use absorbent wells, a traditional method of sewage disposal. Population increase makes this method no longer appropriate for the city due to its pollution of the aquifer. With a blackwater filtration system made as a constructed wetland the water from these houses could be filtered before being fed into the ground.

New City Site

The new city is the fastest growing part of Kerman, as it is in nearly every other Iranian city. Growth is accommodated mainly into steel and concrete residential apartment buildings. This part of the city has been connected to a sewage treatment plant that is located about 10km outside the city. The scope of work required to build a distant centralized treatment plant means that only 15% of the city is currently connected to the system and further expansion will require substantial investment and time.

The proposal for the new city is an apartment typology that draws on courtyard principles, wind tower ventilation, thick walls, forms for heat optimized dissipation, and local materials. It separates grey and blackwater for different on site treatment. The apartment units feature spacious bathrooms and kitchen that feed into one wet wall that then feeds a vertical filtration system and pool located in a brightly lit central atrium space. This water is then used to green the gardens, fill pools and wash cars. It can also supply water to the watercourses that are typical of any major Iranian street. Blackwater exits the building and gets fed to a sewage treatment line that uses living organisms to break down and treat the waste on site naturally. This water can also be used for greening and replenishing the aquifer. The modular plan of the courtyard and surrounding gardens can be shaped to local site conditions.

Figure 3: The newest parts of Kerman are built as apartment blocks on lands that were previously agricultural. (photo from 2015)

Figure 4: The main streets of Kerman are quite lively in the evenings, as the weather is cooler at night. (photo from 2015)

Figure 5: The *jube* (indicated by white lines) runs along the main street adjacent to the site. Trees which are watered by it provide shading and help beautify the city. (photo from 2015)

The City of Kerman is at a point where it needs to make important decisions about the future of its water supply and treatment, and the numerous vacant lots in the city provide an opportunity for Kerman to integrate treatment and residential growth equal to the current rate of growth at many localized points in the fabric of the city. Kerman is not alone in the water crisis and the principles of this project extend beyond just this city and could be applied to others as well. Growing populations and depleting water sources mean that a city must not just think about water access and disposal but rather be in tune with the full water cycle, and new architecture should be sensitive to appropriate and responsible use of water at every point of contact with the built environment

CHAPTER 2: ANCIENT WATER INFRASTRUCTURE

Context

In the hot and harsh climate of the desert, Iran's indigenous water infrastructure has had a formative influence on city morphology and urban configurations. The structure of urban forms as they relate to water has in turn organized social orders which are both a result of and a requirement for operation of daily life. The main factor for sustaining life in this arid climate has been the 3000 year old qanats which tap into the aquifer and carry clean freshwater from the mountains to the settlements below by gravity. The water supplied by *qanats* was traditionally used in mills, bath houses, food storage facilities, as well as supporting air conditioning and agriculture activities, all in a sustainable and consistent way. The effects of history, and the passage of time have added to and altered the personality and characteristics of Iranian water infrastructure, buildings, neighborhoods and cities. These factors have had various positive and negative influences on Iranian culture.

The origins of arid settlements and city forms have influenced Iranian culture on many levels, however there is an apparent disconnect between the past and present in Iran's building practices. Lessons of the methods used over thousands of years have been overlooked and disregarded as Iran has adopted a building culture and typology that is very similar to western countries which are located in a humid continental climate and not ideally suited to its arid context. At the same time Iranian building practice has ignored the principles of its own time tested siting and construction methods and crafts. The impact of qanats on ancient town planning and social organization can be contrasted with today's ubiquitous water distribution through motorized wells and pipes which have altered the rules and restrictions of the past, thereby irreversibly altering Iranian culture. The use of electrically powered wells to supply the country's water needs is not a sustainable practice and has been causing the water table to drop by half a meter each year in all major Iranian cities due to over-extraction, while rendering nearby qanats useless. The new water infrastructure has completely altered the mechanical and social rules of the water distribution system and has undermined the previous network.

A comparative study between the maps of old the qanat system and modern pump wells disbursed throughout the city of Kerman helps shed light on the irreversible alterations made to the country's water infrastructure. It is a pattern that can be seen in virtually any Iranian city today. This leads one to imagine a modern water infrastructure that takes sustainable lessons from the past and applies them in the modern context, so rather than

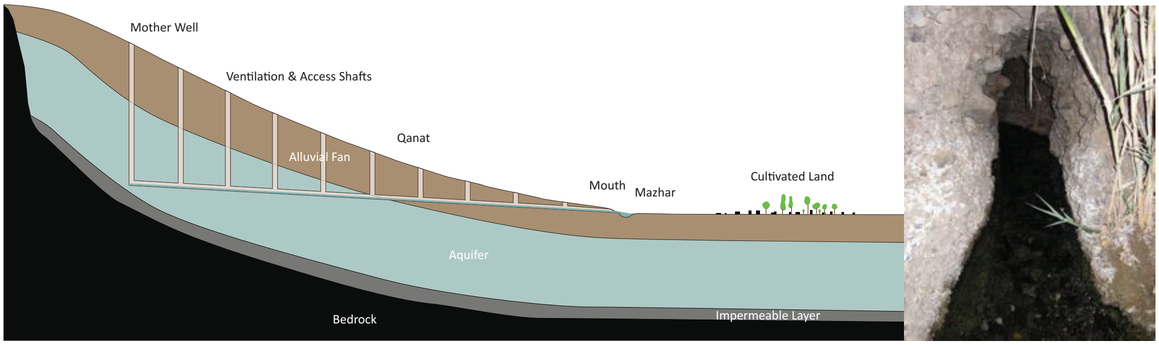


Figure 6: Typical section of qanat and its exit point, supplying water to the villages and farmlands near Shahdad. Mouth of Shahdad qanat (right) dug out of alluvium. (photo from 2014)

a continuously falling water table, the infrastructure is self-controlled and regulated by natural processes while taking into consideration the cultural, climatic and ecological influences on city forms. The origins, mechanisms and functions of the city need to be better understood as an organism where every individual building is influenced by water, ecology, transport as well as technological and cultural understanding of the era.

Qanat

Ancient Water Infrastructure in Iran, the Qanat

The first qanats were constructed in the Iranian plateau around 3000 years ago and subsequently spread to distant areas. Qanats are gently sloping subterranean tunnels that were dug deep into alluvium or water-bearing sedimentary rock, using simple tools and manual labor. They penetrate aquifers below the mountains and transport their water to settlements as far as 70 km away. Water from the aquifer seeps into these channels, flows down their slope, and emerges as a surface stream of water at or near settlements. For several millennia, this groundwater collection system brought water to the surface, supporting settlements in areas that otherwise would be too arid to inhabit.

Figure 7: Mazhar of qanat near Shahdad. (photo from 2014)

Figure 8: Watercourse and vegetation of qanat near Shahdad. (photo from 2014)

Water Systems: Anatomy of Kerman Plain Aquifer

Most of the world's fresh water other than the water frozen in glaciers is located underground, this is especially true of Iran. Rainwater and snow in the mountains flow through loose porous material such as gravel, sand or silt or through cracks in the bedrock. The water collects in permeable geological formations called aquifers. The composition of aquifers varies from fractured rock to silt, clay, fine and thick porous sand.

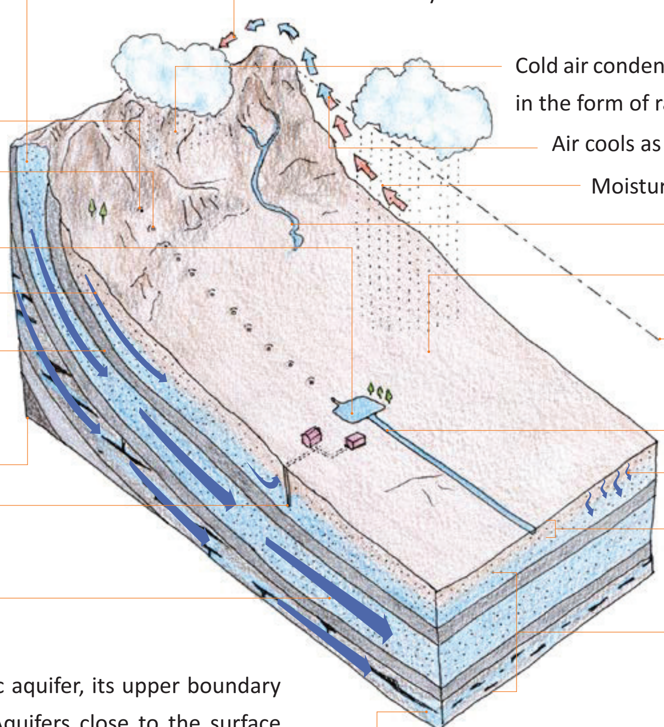


Figure 9: Anatomy of Kerman Aquifer. (drawn by author based on information from Natural Resources Canada, National Geographic, Kerman Water Authority)

Qanats were constructed by skilled laborers called *muqannis* who passed down their trade from generation to generation. A location for a *mother well* was chosen by the head muqanni and using simple tools and manual labor. Qanats were constructed with a slope of 1 to 3 degrees based on siting conditions so that water flowed at a regulated rate without being stagnant or flowing too fast. Tunnels were dug out of the ground and lined with baked clay rings, stones or sometimes they were left unlined. Qanats were used for irrigation purposes in agricultural areas and they also weaved into the city providing water to the urban fabric for individuals both in the private and public realm depending on their wealth. Qanats are no longer operational in cities, they are currently only functional in rural areas.

The qanat technology is not only an engineering feat, but a significant social phenomenon as well. Qanats required collective and cooperative work. Individuals possessed neither the capital nor the manpower to construct and maintain the qanat system, so they relied on larger systems of production such as multi-family collectives called the *Buneh*. The major function of the Buneh was the efficient exploitation of productive land and the careful use of scarce water resources. This social structure has been dispersed due to the modernization of water infrastructure where today every household has its own water supply through pumps, pipes and faucets without needing to know where it comes from.

Construction

The construction of qanats was carried out by hand, so progress even in unconsolidated material was slow. As a consequence, it normally took many years to construct a single qanat. Almost all qanats were constructed in alluvial material where the water table is relatively close to the surface. This means that tunnel collapse was often a serious problem which necessitated the lining of the tunnel with baked clay rings. Average tunnel dimensions are 1.2 m in height by 0.8 m in width, large enough to give access to a single worker digging underground.

Support for Ecology and Biodiversity of the Desert

A significant proportion of fish habitats in Iran are in small streams, springs and qanats. The climate of arid regions means that there are very few perennial rivers while qanats are home to around 25 species of fish and these constitute around 40% of the fish on the Iranian Plateau (Abdoli 2002). Qanats support some of the most important inland aquatic ecosystems in arid and semi arid regions. They are home to frogs, crabs, aquatic plants,

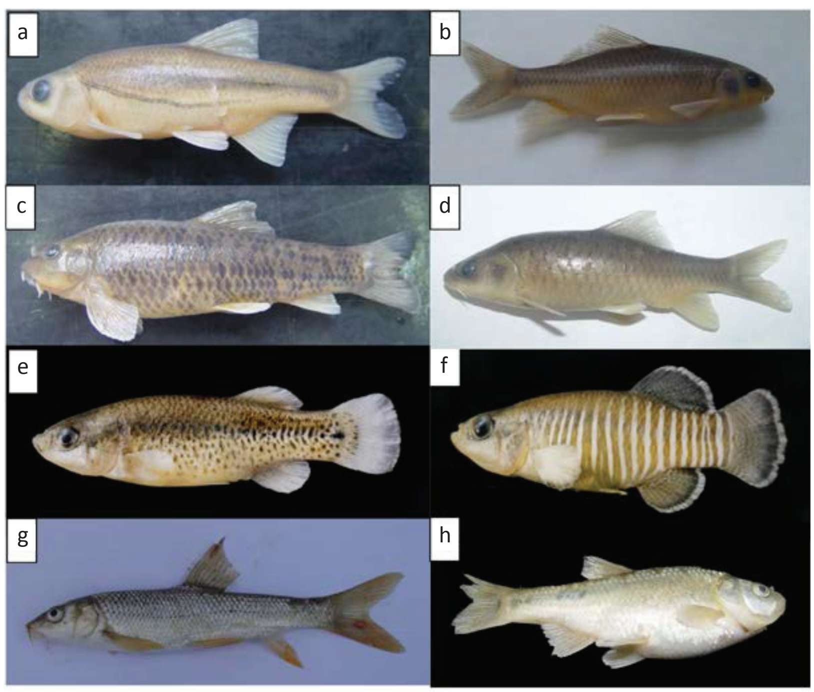


Figure 10: Qanat fish diversity in Iran. a) Alburnus Bipunctatus, b) Cyprinion Tenuiradius, c) Garra Rufa, d) Barbus Luteus e) Aphanius Sophiae - female, f) Aphanius Sophiae - male, g) Barbus Barbulus, h) Petroleuciscus Persidis.

Top image: a qanat stream near Fasa, habitat of Capoeta Damascina, Garra Rufa, Chalcalburnus Mossulensis and Barbatula Persa. (Esmaeili 2006) aquatic insects, snails and other invertebrates. Qanats provide water both for drinking and agriculture. Based on universal standard classification, the concentration of all physico-chemical properties are in the range of fresh water. Groundwater has a number of key advantages over surface water. It is usually of higher quality, better protected from direct pollution, less subject to seasonal and perennial fluctuation, and more uniformly spread over large regions (Siadat 2002). A high rate of water discharge is required to provide adequate water quality for settlement of fish species and more biodiversity is observed in qanats with higher water volumes. Qanats are quickly being replaced and undermined by pump wells which are faster and easier to excavate, but excavated wells and pipes do not provide a habitat for fish or other aquatic animals. Dwindling qanat water and flow rates are affecting the ecosystems that they have supported for centuries, so preservation and better management of these important aquatic ecosystems is needed.

Figure 11: Tall grasses and other plants growing beside Shahdad qanat. (photo from 2014)

Figure 12: Frog seen near Shahdad qanat. (photo from 2014)

Figure 13: Cows and other livestock can only live in Shahdad because of its qanats. (photo from 2014)

Ancient Water Infrastructure and Urban Forms 800 BC - 1950

In the context of the arid Iranian landscape, water supply has been a constant preoccupation of its inhabitants since the beginning of the country's establishment thousands of years ago. They learned to design and implement efficient techniques for harnessing their limited water resources for domestic use and irrigation. The methods used became a part of an indigenous network of solutions that addressed the issue of water access. This network of vernacular infrastructure and architecture allowed for the establishment, development and growth of both urban and rural areas.

The Iranian city is the product of a number of factors which include the physical environment of the Iranian Plateau, trade routes and historical events along with the religious and social structures of Iran and neighboring countries which have influenced it. The impact of trade and historical events on the city and its form give insight into its development while the rationale behind the physical morphology and spatial patterns of Iranian cities can be understood by examining historic town forms. The main principles include compactness, uniform buildings, tight streets and alleys, orientation for optimal water access, thermal control and courtyard based dwelling. The structural elements of the traditional city form include the bazaar, access roads for trade, city walls, water supply buildings and residential quarters. The introduction of Islam to Iranian cities around 600 AD added an additional layer to the city fabric with its own rules of space and organization and influences on the culture of the city.

The *yakhchal* (ice house) was capable of storing nearly 3000 tons of ice in the winter to be sold during the summer months for food storage and preparation of desserts. Qanat water was used to fill a shallow pool in front of the ice reservoir during winter months. A very tall wall on the west side of the pool would keep it completely shaded and help the water freeze. After it was frozen the ice would be broken and stored in the underground reservoir with alternating layers of straw and ice, waiting to be used in the summer. The classic Persian house is centered around the courtyard with a small pool or fountain. These houses were traditionally supplied with water by qanats running underneath. Below grade was an area where inhabitants would have spent much of their time in the summer months due to cooler temperatures caused by water and air circulation. The *hammam* (public bath) was typically located in the *bazaar* (market) where people from different social classes would come to bathe and socialize. Public gardens were also supplied with water from qanats, both for watering the ground and operation of fountains, water features and watercourses. The construction of these buildings within the water infrastructure network was so site-specific that materials and mixtures were custom chosen and formulated based on various local climatic conditions. This shows a high level of understanding and sophistication with regards to water conservation and efficiency.

Figure 14: A view of the Kerman Plain from the “Ya Ali” inscription. (How steep the ascent to the inscription is can be seen by the mountain side on left of observer.) (Landor 1902)

City

The City of Kerman

The city of Kerman was founded in the 3rd century AD and began as an enclosed fort with a citadel and city gates. Its water supply was provided by qanats gently flowing into the city and meeting the urban fabric both in the public and private realm. The city experienced very little growth until the last thirty years. This rapid growth coincided with the general population increase in Iran. Land reform policies as well as the need to accommodate more people at a quicker rate caused the city to adopt a practice of deep well drilling that grew and eventually replaced the qanats and has rendered them useless. Unused qanats remain in some parts of the city, while in other parts they have been damaged by negligence or earthquakes.

The influence of water sources and infrastructure on the growth of the arid city of Kerman at various stages in time is reflected and revealed within the urban fabric while the manifestation of water in the built environment influences the social patterns within it. In the past, public spaces such as plazas, gardens, bath houses, fountains, ice houses and water reservoirs provided a close relationship with water and promoted social gatherings, cohesiveness and appreciation for this vital necessity. Water infrastructure had a different relationship with streets, sidewalks and houses, one that was sustainable and engaging. The relationship of the underground water network and the urban fabric that was supported above had a direct link to the mountains that surround the city and the hydro-geological relationships of the region informed the beginning of the water distribution process. These relationships were the historic basis of sustainable irrigation of the city.

Qanat Infrastructure Influence on Urban Form and Traditional Architecture

Within urban and rural areas the qanat traditionally had a very influential role in the organization of built structures. The *ab anbar* (water reservoir) would have been among the most prominent built structures in the traditional Iranian city and would have guided city organization and development by supplying water to a neighborhood within walkable distance to surrounding houses. These reservoirs were subterranean spaces that were connected to the qanat network. Ab anbars took different forms and shapes, depending on whether they were private residential, urban, rural or on a trade route. A typical public urban water reservoir would have the capacity to hold 2500 m^3 of water. It would be filled once every several weeks, and have its inside surfaces cleaned from sediments once a year.

Figure 15: Kerman rulership house, Qajar era. (Images collected from families in Kerman, books, various documents, private collections and government collections, Nikpour 2011)

Figure 16: H. E. Ala-el-Mulk, Governor of Kerman, in his Palace. (Landor 1902)

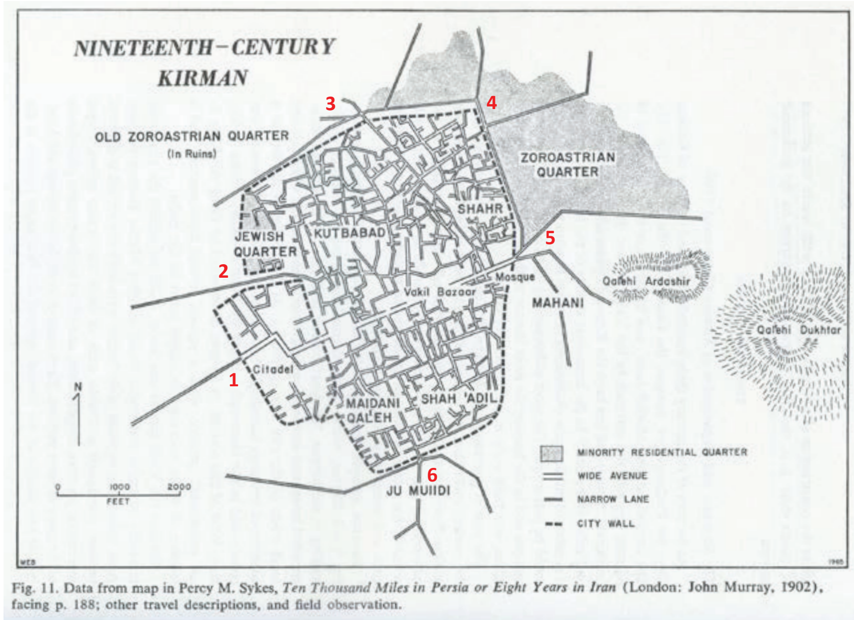


Figure 17: Kerman in the 1800s. 1) Arg (Citadel) Gate, 2) Soltani Gate. 3) Gebery Gate 4) Naseri Gate 5) Mosque Gate 6) Reeg-Abad Gate. (Ward-English 1966, overlay of six city gates based on Zangiabady 1991)

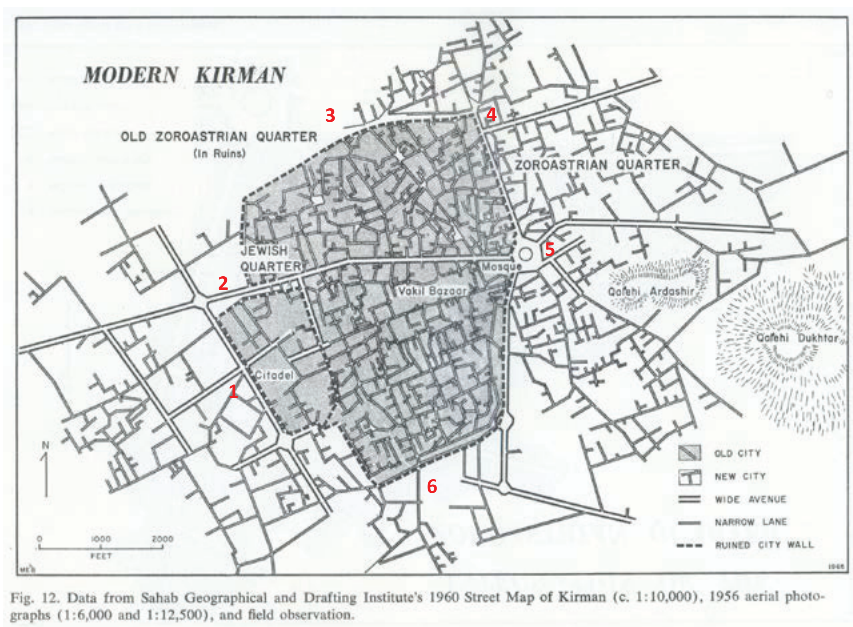


Figure 18: Kerman in the 1950s. 1) Arg (Citadel) Gate, 2) Soltani Gate. 3) Gebery Gate 4) Naseri Gate 5) Mosque Gate 6) Reeg-Abad Gate. (Ward-English 1966)

Figure 19: Arg (Citadel) gate, Qajar era.
(Number 1 in map on previous page)
(Nikpour 2011)

Figure 20: The wall around Kerman (Qajar era) Haj Akbar Sanatti and students at Sanatti nursery. Picture taken at the present day Arg Square. (Nikpour 2011)

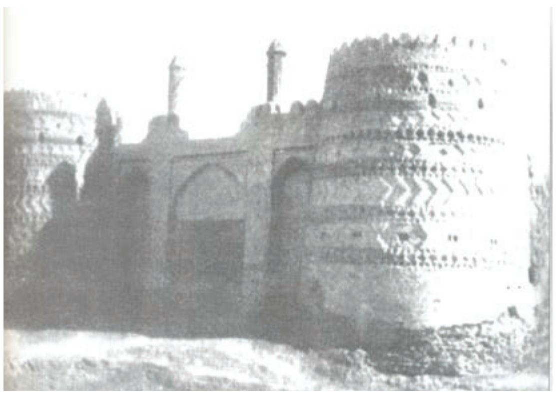


Figure 21: Gebery Gate. (number 3 in map on previous page) (Nikpour 2011)

Figure 22: Naseri Gate, Qajar era. This gate was the last to be built Kerman in 1896 by Vakilalmolk in Naseraldin Shah Qajar's era and known as Naserieh. (Number 4 in map on previous page) (Nikpour 2011)

Figure 23: The Mosque Gate.
(Number 5 in map from previous page)
(Hume-Griffith 1909)

Figure 24: Making a Qanat.
(Hume-Griffith 1909)

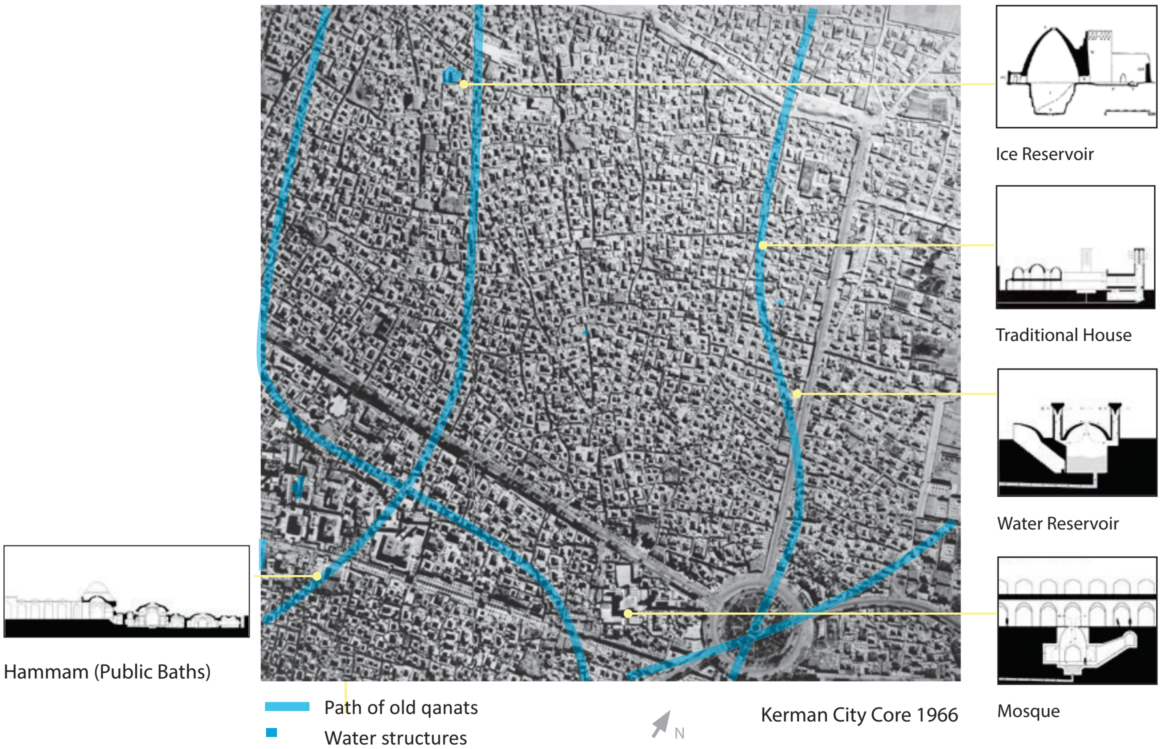


Figure 25: The historic core of Kerman overlaid with the path of qanats (blue) that would have run underneath the city fabric, originating from various sources at higher elevations. (National Cartographic Institute of Iran 1966)

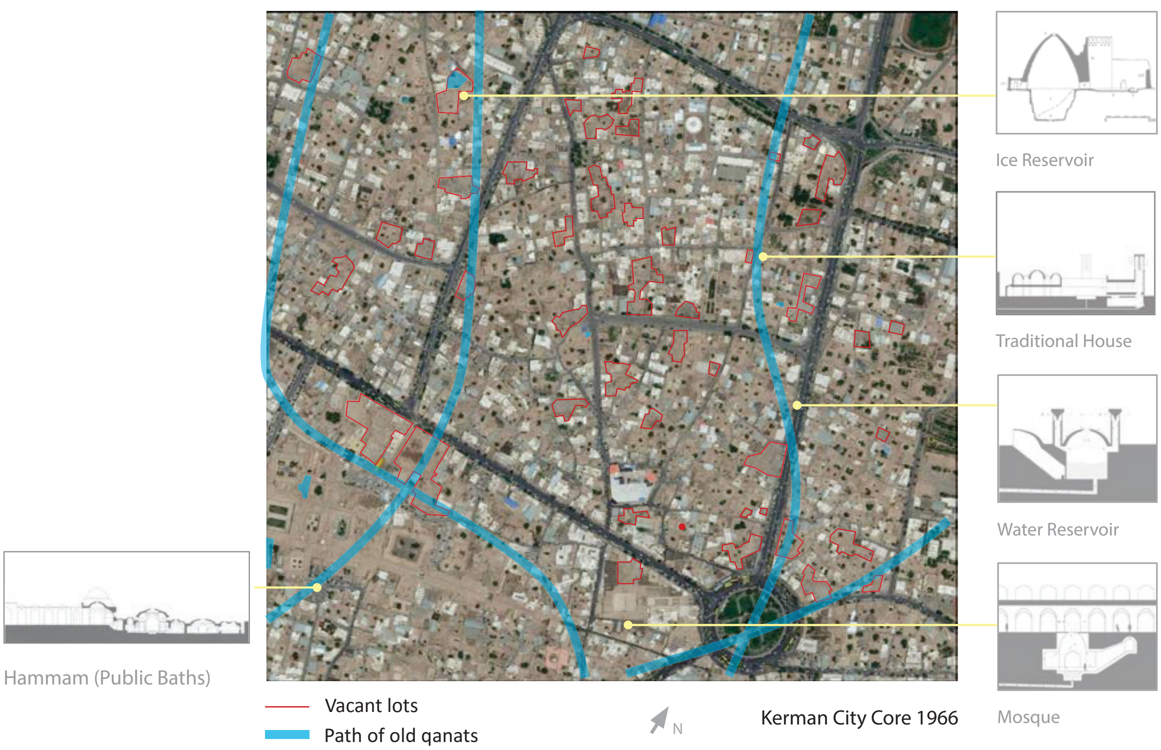


Figure 26: The historic core of Kerman showing qanats (blue), dissolving urban fabric as historic houses crumble and leave empty lots (red) to be replaced by new buildings. (Bing Maps 2014)

Old City, Vacant Lots, Decommissioned Infrastructure

Looking at the fabric of the old city and overlaying it with the qanats that once ran underneath it, the connection between water from the mountains, the urban fabric and ancient infrastructure becomes evident. The aerial photograph of the present day condition of the city shows the dissolving of the fabric with widening of streets, numerous vacant lots and disconnection from its original water infrastructure.

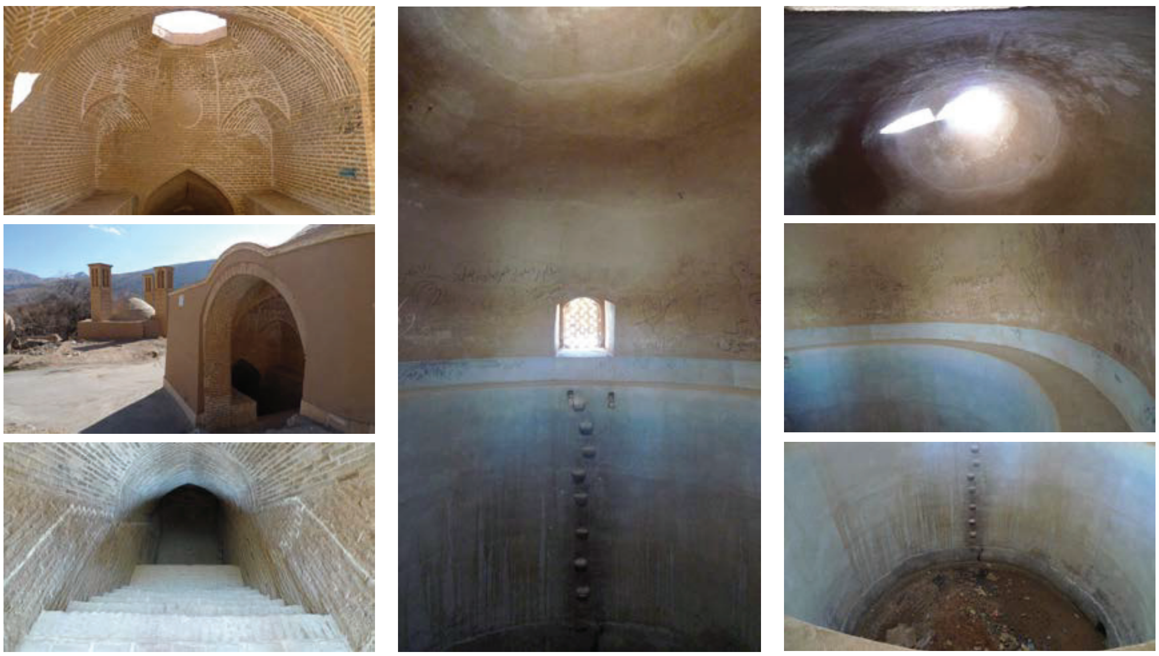


Figure 27: Interior and exterior of Ab Anbars, made with bricks. The interior of reservoir is lined with *sarooj*, a specially formulated water resistant plaster. The exterior brick is sometimes left exposed and sometimes covered with a clay and straw compound called *kah-ghel*.
(photos from 2014)

Tectonics and Principles of the Ab Anbar (Water Reservoir)

The principles of each part of the ancient system can be analyzed and provide lessons for new water infrastructure. Ab anbars varied in shape and size depending upon the community they were serving. The various types included public, private, urban, rural, castle and midway ab anbars. Urban ab anbars had a higher capacity than others and provided the water supply of an area for several months. Purity of the water was maintained by isolating the main tank completely from human contact and freshness of the water was achieved by air circulation and reduction of humidity. Materials were locally sourced and formulated based on climatic conditions.

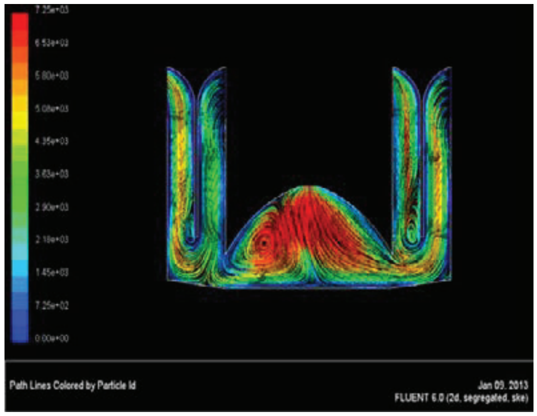


Figure 28: Airflow through the dome and wind towers of a water reservoir. (Hooshmand 2014)

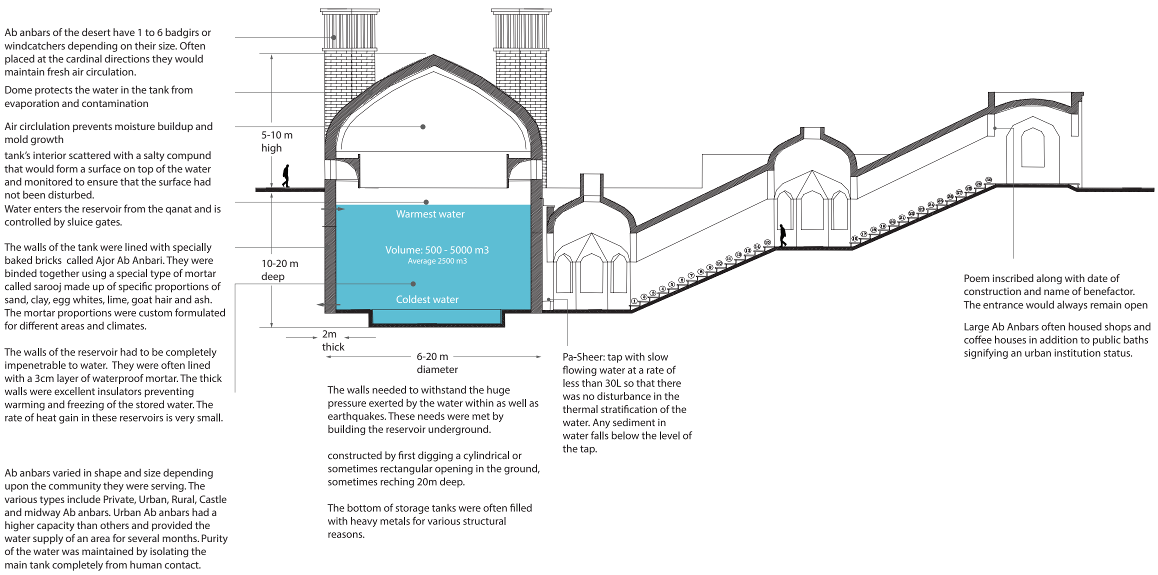


Figure 29: Section through a typical public water reservoir with various features.

Geometries of Ab Anbars

The masonry construction of the ab anbar roof is based on two intersecting circles that meet each other at an angle between 40 and 55 degrees.

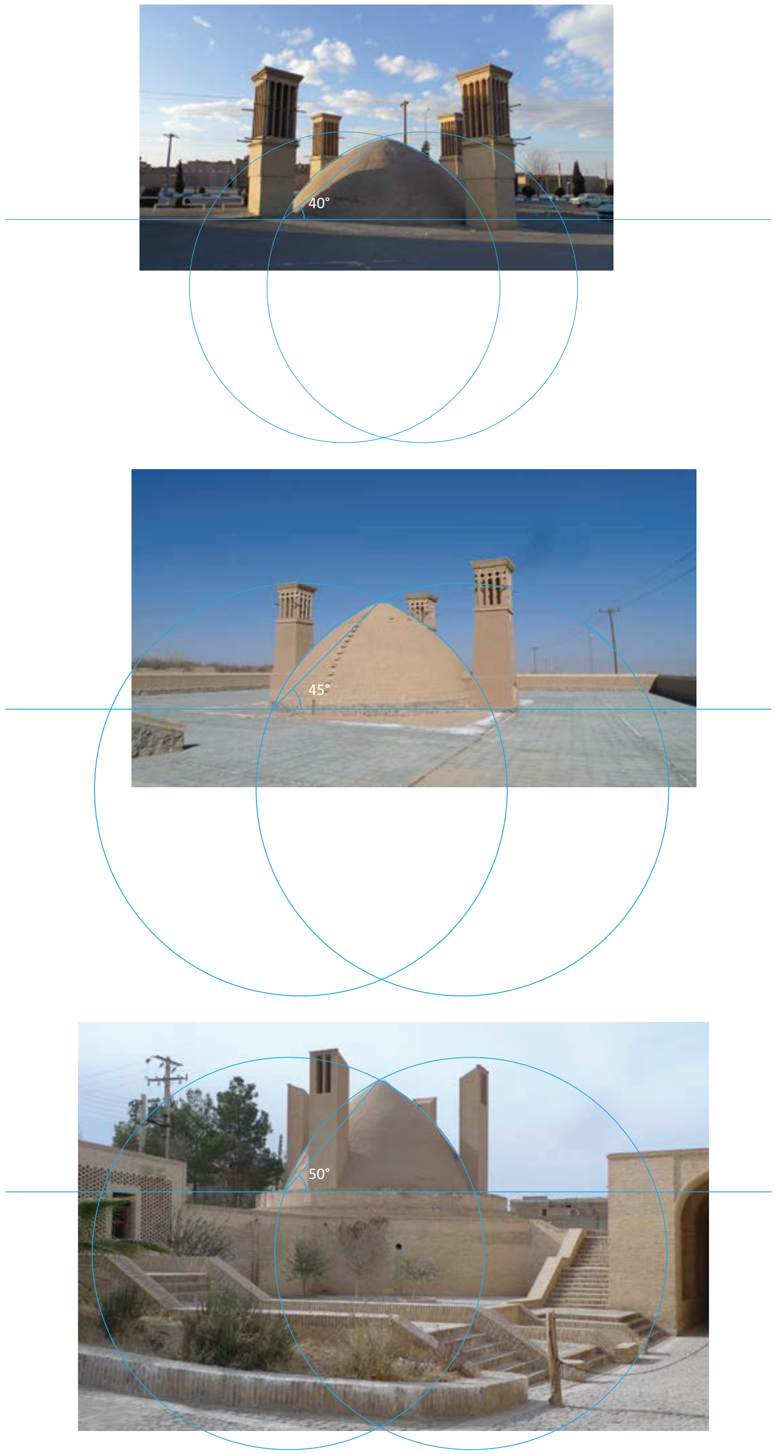


Figure 30: Currently empty water reservoirs with a variety of siting, geometry and climatic conditions. (photos from 2014)

Elements of Traditional Iranian Housing

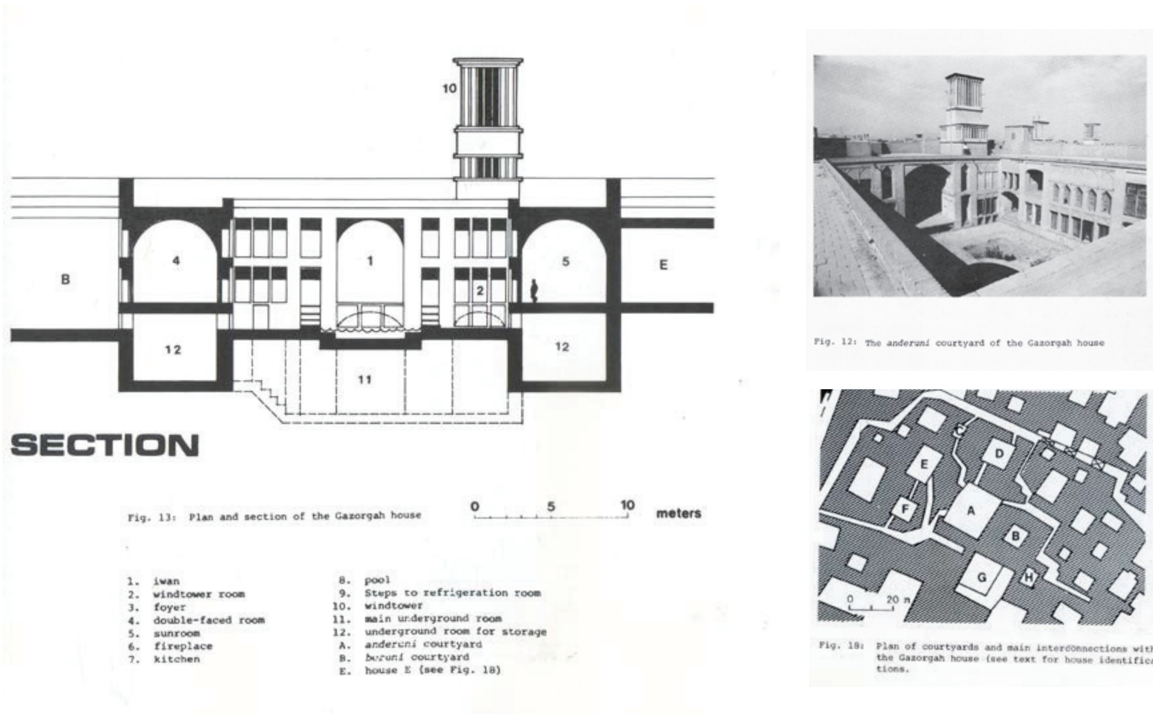


Figure 31: Section, courtyard photo and keyplan of traditional Iranian house. (Bonine 1980)

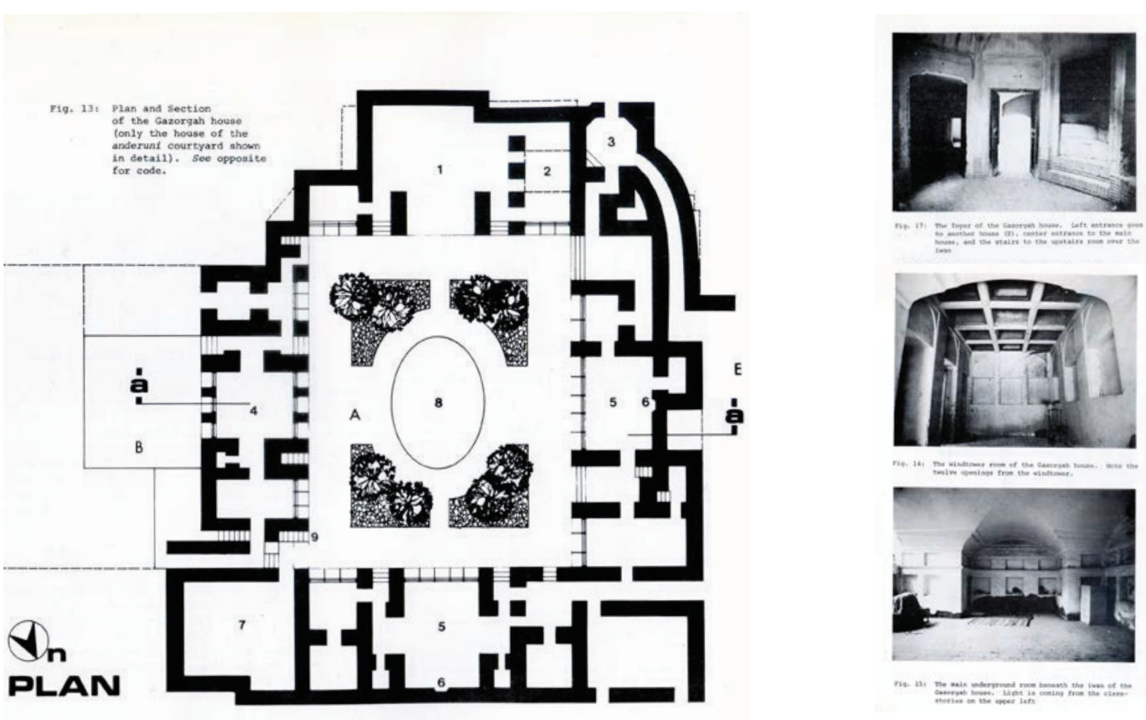


Figure 32: Plan and interior photos of traditional Iranian house. Photos: entrance (top) Windtower room (middle) Main underground room beneath the iwan (bottom). (Bonine 1980)

Principles of Traditional Iranian Housing

The traditional Iranian house was based around a courtyard with features for ventilation and water access. The climatic conditions mean that thick walls were used to preserve comfortable interior temperatures.

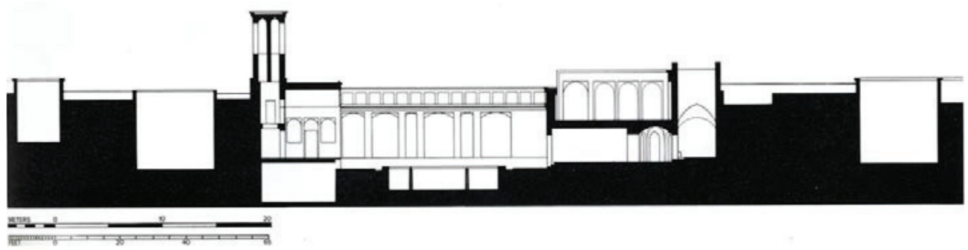


Figure 33: Section of traditional Iranian house. (Herdeg 1990)

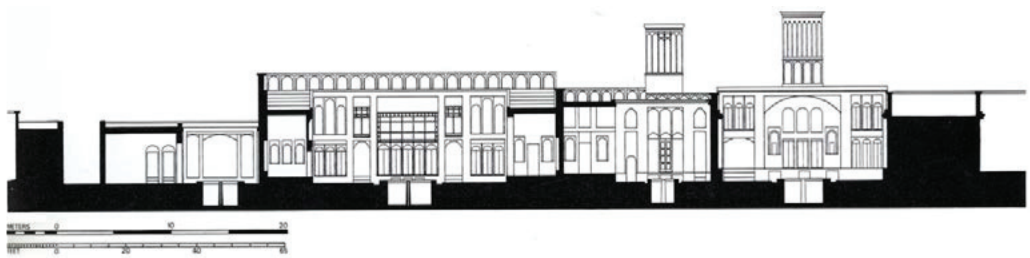


Figure 34: Section of traditional Iranian house. (Herdeg 1990)

Figure 35: Plans of traditional Iranian house. (Herdeg 1990)

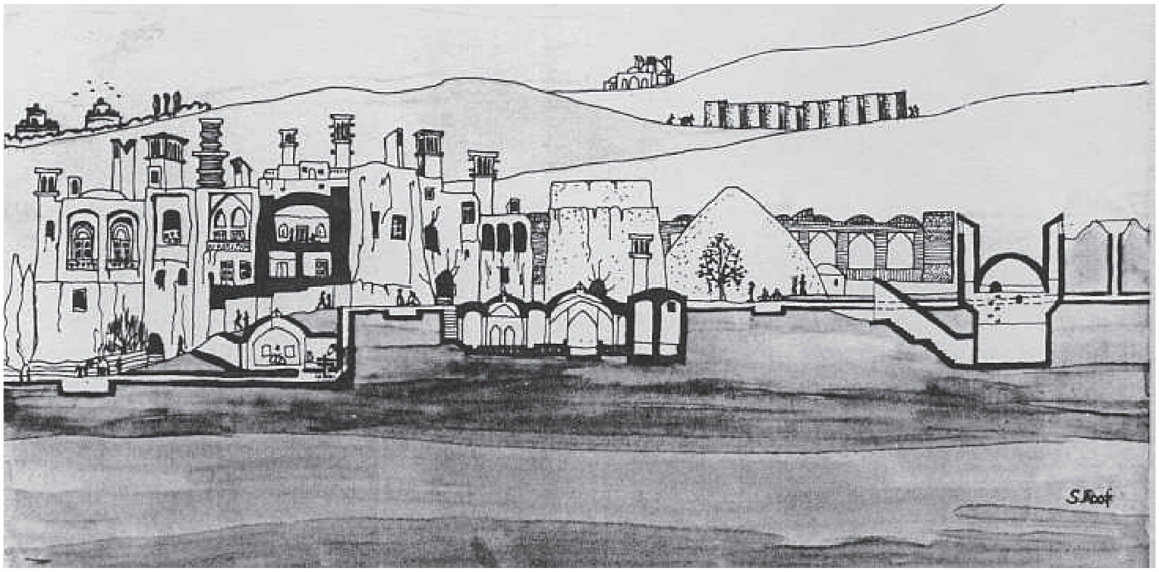


Figure 36: Sectional elevation of an idealized village from the central desert of Iran showing the architectural features of the central Iranian Plateau. Water can be seen as it goes to a reservoir on the far right, a bath-house in the middle and a stone mill on the far left. (Beazley 1982, based on Khuranaq)

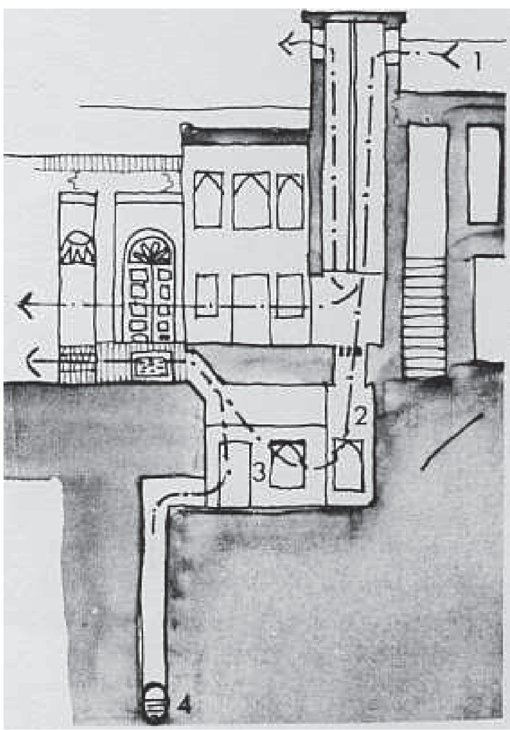


Figure 37: Section showing how a qanat can cool a basement:
1) 36.5°C 20%RH
2) 29.9°C 30%RH
3) 24°C 45%RH
4) qanat. (Beazley 1982)

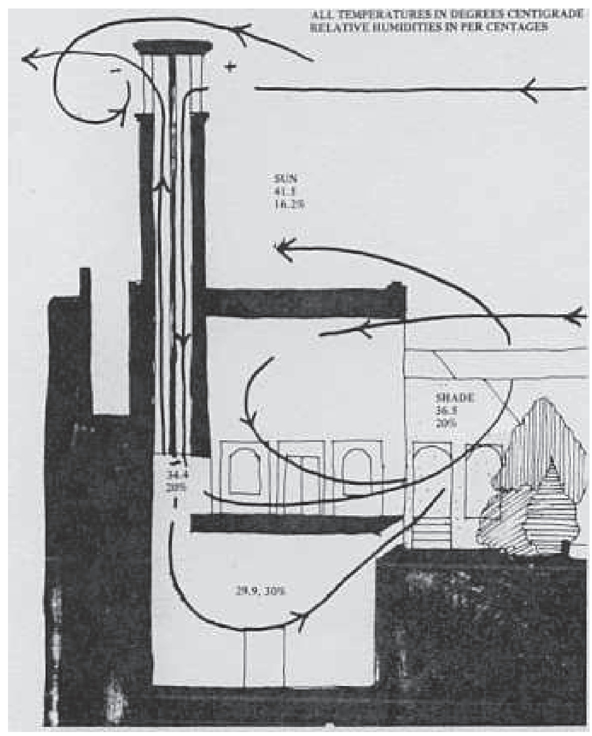
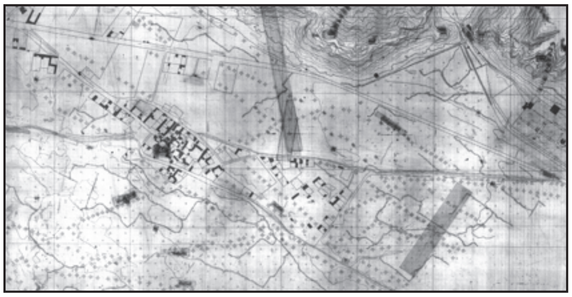
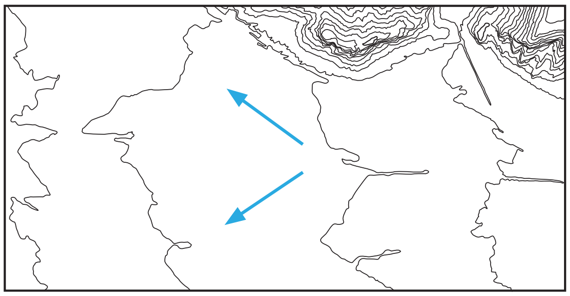


Figure 38: Section showing the performance of a wind-catcher. (Beazley 1982)

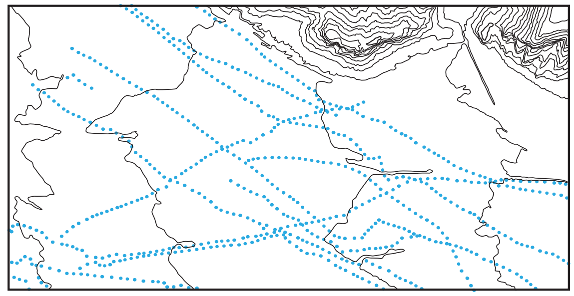


Southeast area of Kerman **1966**

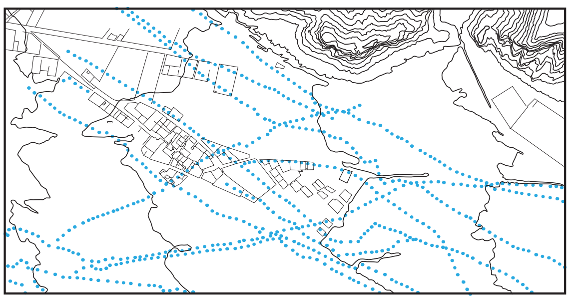
Southeast area of Kerman **2015**



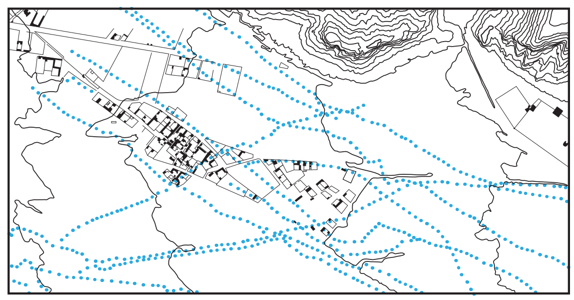
1. The slope of the ground is determined. A range of orientations for qanats are possible with this slope.



2. Qanats are made to allow gentle gravity fed movement of water based on the slope of land.



3. Land divisions are based on the direction of qanats and the movement of water. The long side of the land plots (korts) are normally in the direction of the qanat.



4. Dwelling orientation and property ownership are based on plot (kort) divisions. Roads, alleys, and future development are built upon these original conditions.

Figure 39: The formation process of the historic fabric of Kerman based on land slope, qanat water infrastructure, and agricultural land divisions. (sequence drawn by author, full map in appendix)

Inventory of Ancient Water Infrastructure

The inventory of ancient infrastructure allows for an understanding of the relationships of the indigenous Iranian water infrastructure and can serve as an inspiration for new systems. The cultural and technical aspects of these built structures have been developed and refined over thousands of years. Technical principles such as efficiency, airflow, use of local materials and use of gravity are reminders that these buildings are instruments which can help us understand the systems embedded in the landscape and climate patterns. Cultural principles such as collaboration, community and walkability are also present in these structures. Aside from being forms of inspiration, these buildings should be preserved and reinvigorated rather than neglected. This inventory will surely grow as more insight into ancient methods is gained.

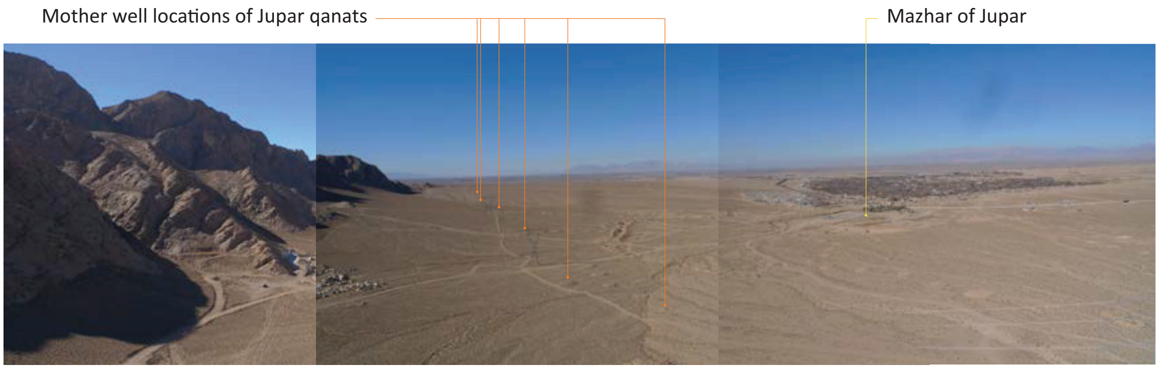


Figure 40: Mother wells and qanats from Jupar Mountain to the town of Jupar 25km south of Kerman. View looking northwest. (photo from 2015)

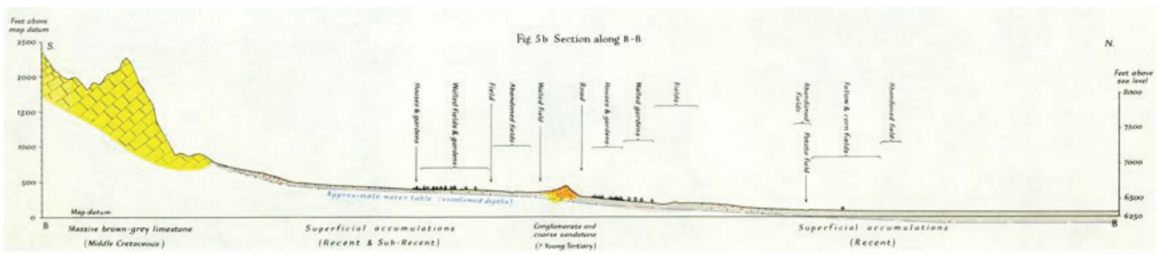


Figure 41: Section of Jupar mountain, and the town of Jupar showing the water table, land use types and desert plain. (Beckett 1966)

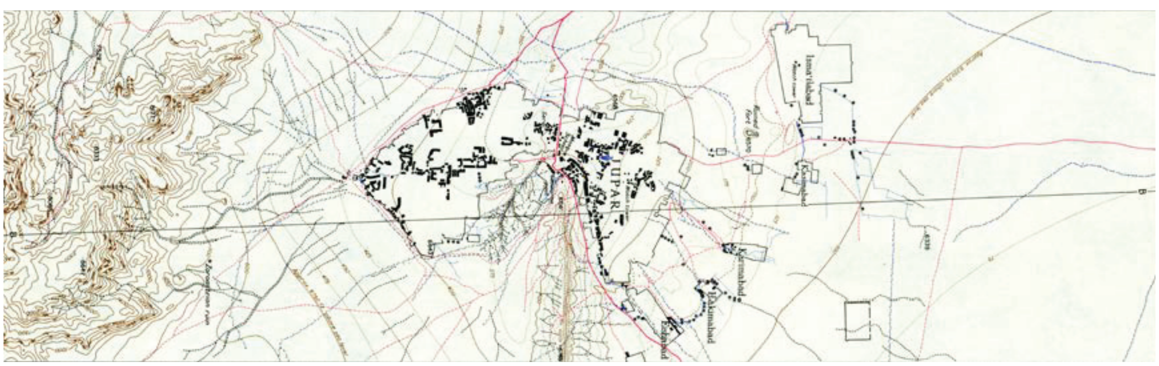


Figure 42: Plan of Jupar mountain, and the town of Jupar showing the settlements (black) and qanats (blue). (Beckett 1966)

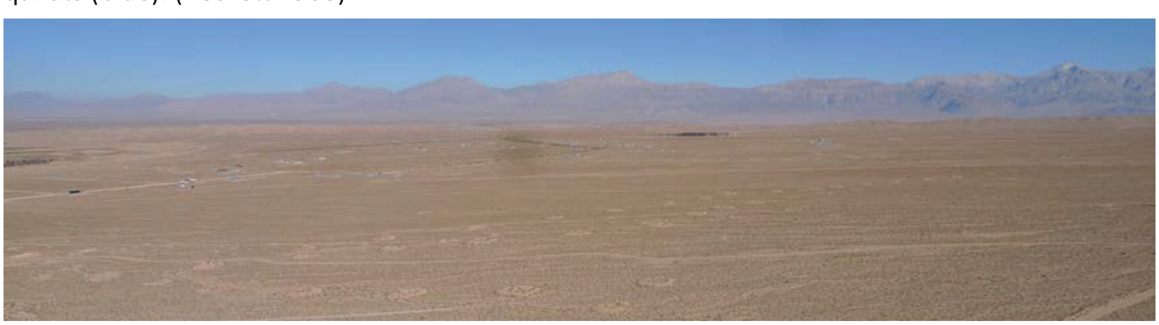


Figure 43: Qanats from Jupar mountain to the town of Jupar 25km south of Kerman. View looking east. (photo from 2015)

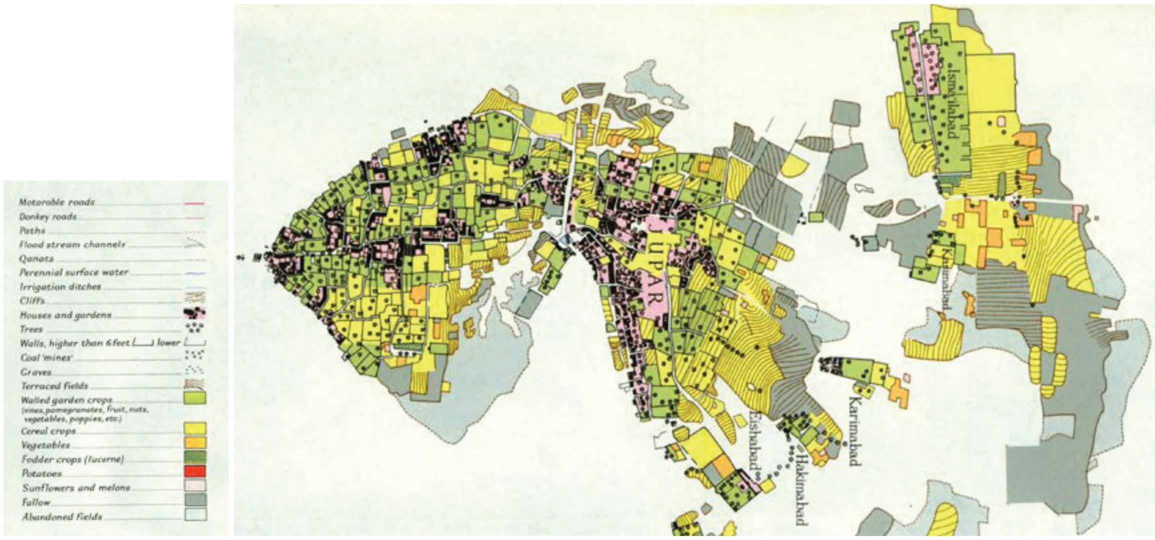


Figure 44: The town of Jupar, its various land use types and the relationship between dwelling and agricultural lands. (Beckett 1966)

Figure 45: A satellite image of town of Jupar in 2015 shows that it has remained virtually unchanged since it was surveyed 49 years ago by Beckett in 1966. This is the case in many rural areas in Iran and a key factor in why qanats are still operational in these settlements. (Google Maps 2015)

Figure 46: Mazhar

The first point of exit for qanat water is called the mazhar. It is a public place where everyone can access water, the architecture can be formal or informal depending on the location. Clothes and dishes would not be washed here, rather they would be washed at a payab which is further downstream. The cleanliness of the water in the rural qanat shown above is due to the fact that it is in a remote location and the density of nearby settlements is low. It is operational because there are very few pump wells in the vicinity.

Figure 47: Desert Watercourse

After the water has surfaced at a mazhar, it makes its way to its destinations downslope. Most watercourses are now made of concrete to prevent the water from infiltrating into the ground.

Figure 48: Orchard Watercourse

The traditional flood irrigation that was common practice in Iran brings water from the watercourse into *korts*, or divisions of land with a small raised dirt edge to hold water. The pistachio orchard shown above is located in Kahn-Shahr and was owned by my grandfather, it was a place where I have many fond memories of playing, eating, relaxing, exploring and spending time with my family and relatives beside the calming and refreshing qanat water.

Figure 49: Sluice Gate
Water that was brought into an orchard could be directed to various parts of land with metal sluice gates. Units of water time are bought and sold just like real estate. In a rural setting workers or land owners were in charge of timekeeping and directing water to their lands while in an urban setting this role was fulfilled by a person known as the *Mirab*.

Figure 50: Water Divider
Watercourses get split and redirected in the city fabric as they reach their final destination.

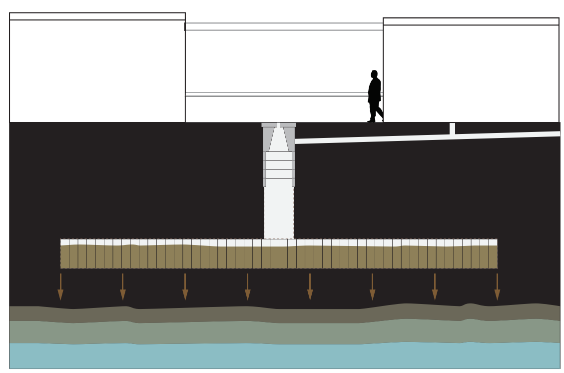


Figure 51: Absorbent Well
The traditional method of waste disposal which is still serving nearly 80% of Kerman was to dig wells in the yard or alleyway near a residence. Sewage from the house goes into the wells and slowly leaches into the ground and replenishes the aquifer. This system is only viable when population densities are low. The current situation is that sewage from the majority of buildings in Kerman is leaching into the ground, polluting the aquifer and causing the water table to rise in the old part of the city, ruining the foundations of historic buildings. Sewage trucks provide the service of septic removal but this is still not enough to deal with the rate of pollution.

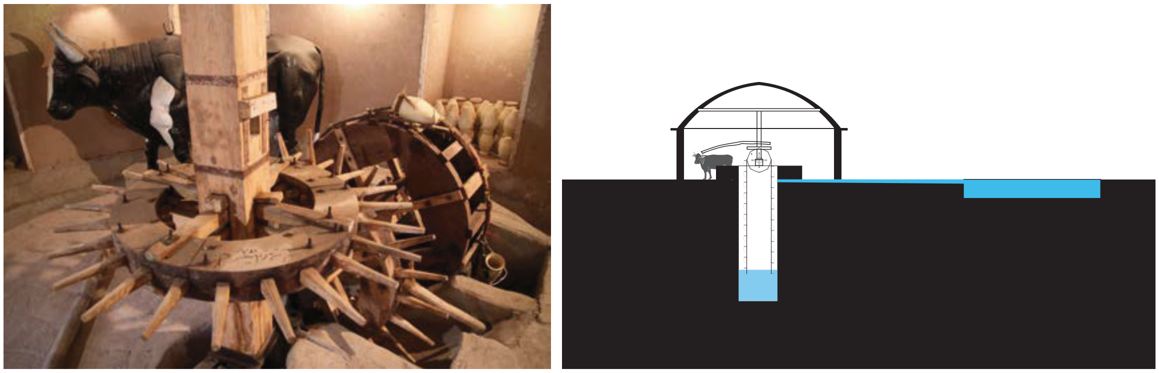


Figure 52: Gav-gard (Bull well)
In the past when the water of the aquifer below the city was clean and could be used for drinking as well as gardening, various types of wells were used to extract water from the ground. The bull well was a circular room located in the corner of a wealthy courtyard house. A bull would walk in circles and two interlocking wooden gears would transfer the movement of the bull to a series of clay containers that would get submerged into the water table and fill a reservoir on the surface in series. (photo by Mohammad Barshan)

Figure 53: Public Payab
The payab is the access point of qanat water within the city or village and takes various shapes and forms depending on its location and wealth of its residents. I took a tour of some qanats and payabs near Sirjan with a muqanni who was deeply affected by the modernization of his town and shift of water infrastructure toward a system which has alienated him along with the people of the previous generation.

Figure 54: Private residential payab accessed below grade due to cool temperatures in the summer.

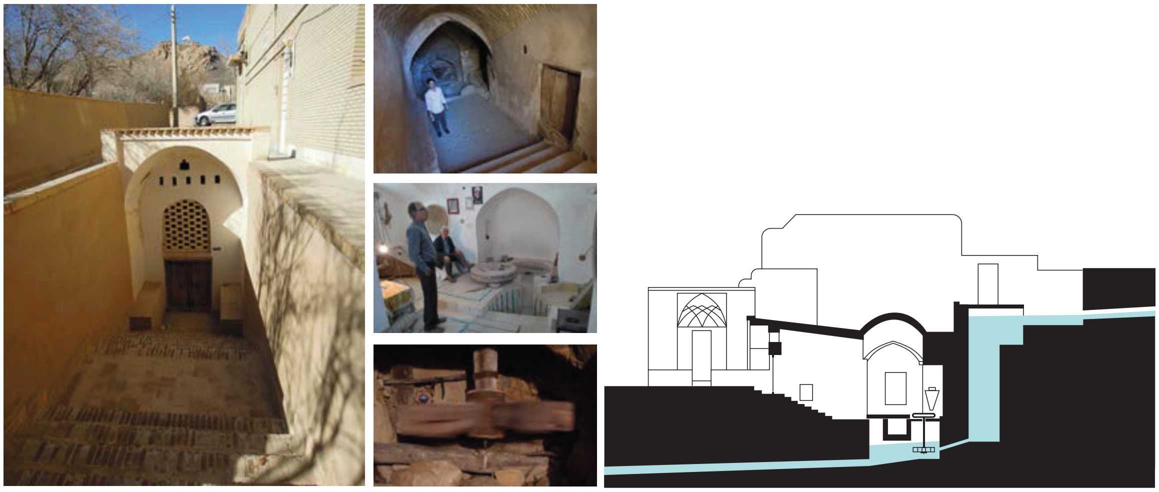


Figure 55: Stone Mill in Mountains
Traditional uses of qanat in rural areas included power generation of stone mills.

Figure 56: Rainwater Collection Cistern
On islands in the Persian Gulf where the salinity of the local water makes it unusable for drinking or irrigation, rainwater traditionally was collected in cisterns for use by the residents. This infrastructure still remains in place, although it is obsolete and the water in the cisterns is no longer drinkable.

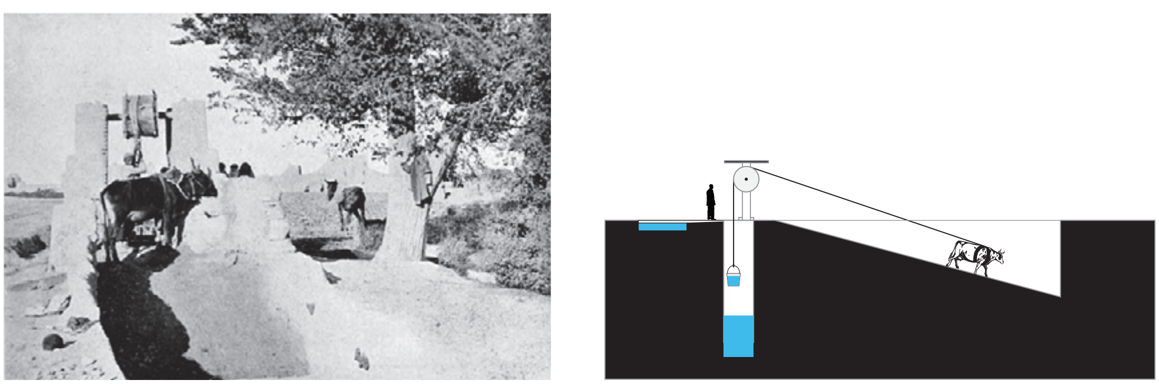


Figure 57: The ox, who patiently walks up and down the inclined passage, draws up from the well a large skin of water, or sometimes an iron bucket, which empties itself into trenches prepared beforehand. (Hume-Griffith 1909)

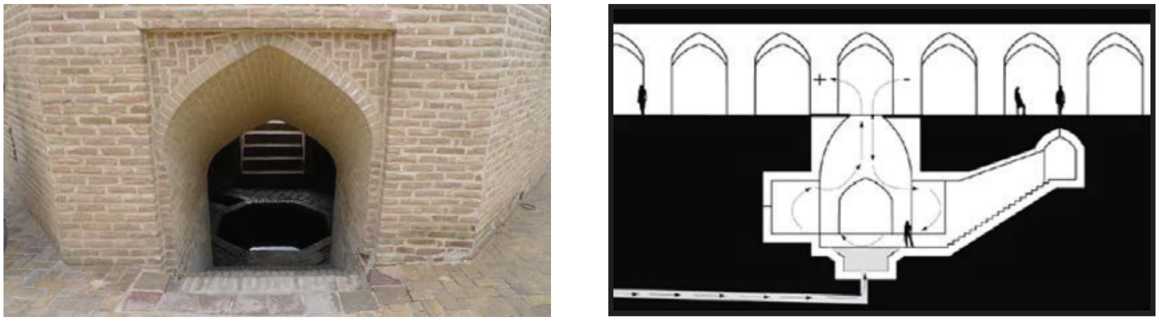


Figure 58: Caravanserai
The caravanserai is where desert travelers traditionally would have stopped for rest, food, and water, for both themselves and the animals that traveled with them. A payab (access point for water) was centrally located in the caravanserai and had water flowing through it to be accessed underground by thirsty travellers.

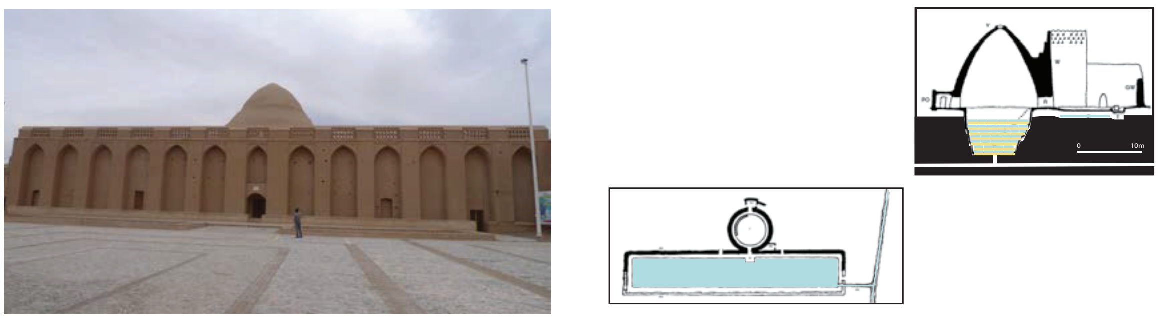


Figure 59: Ice Reservoir
Qanat water was used to fill a shallow pool in front of the ice reservoir shaded by a large wall during winter months. After it was frozen the ice would be broken and stored in the with alternating layers of straw and ice. The reservoir was capable of storing 3000 tons of ice to be sold during the summer months.

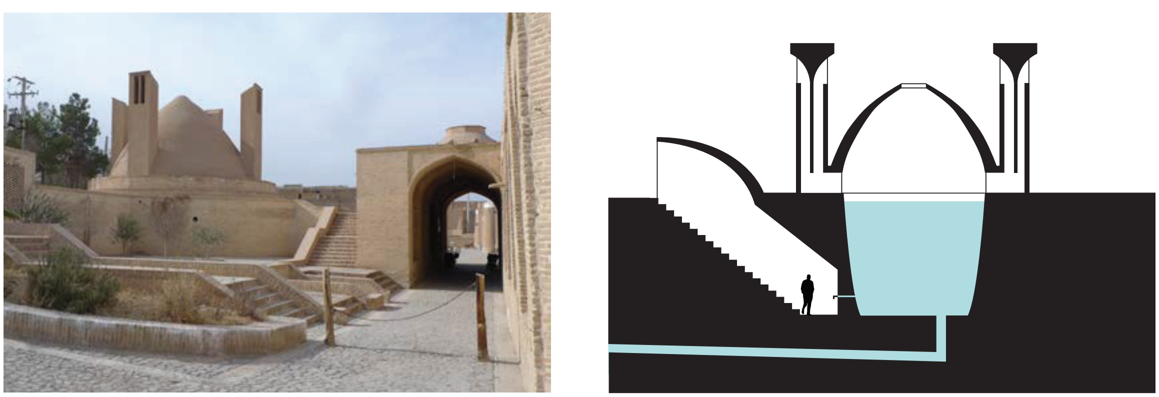


Figure 60: Water Reservoir
These reservoirs are subterranean spaces that were connected to the qanat network in the city. A typical residential reservoir would have the capacity to hold 50 m^3 of water, whereas a public water reservoir would have a capacity of 500 - 5000 m^3 it would be filled once every two weeks, and have its inside surfaces cleaned from sediments once a year.

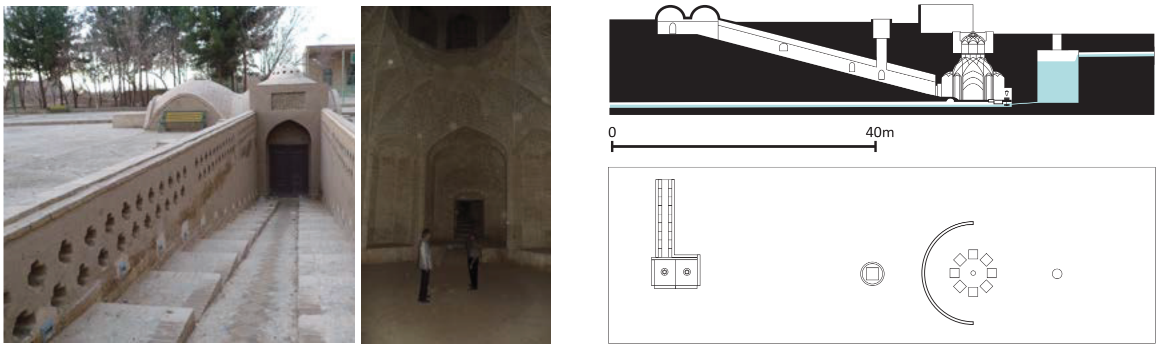


Figure 61: Stone Mill in Desert Plain
The stone mill in the desert had a gentle slope so that animals could walk up and down for carrying goods. At a depth of 20m below grade the water reservoir behind the mill would have enough pressure to turn the stone mill.

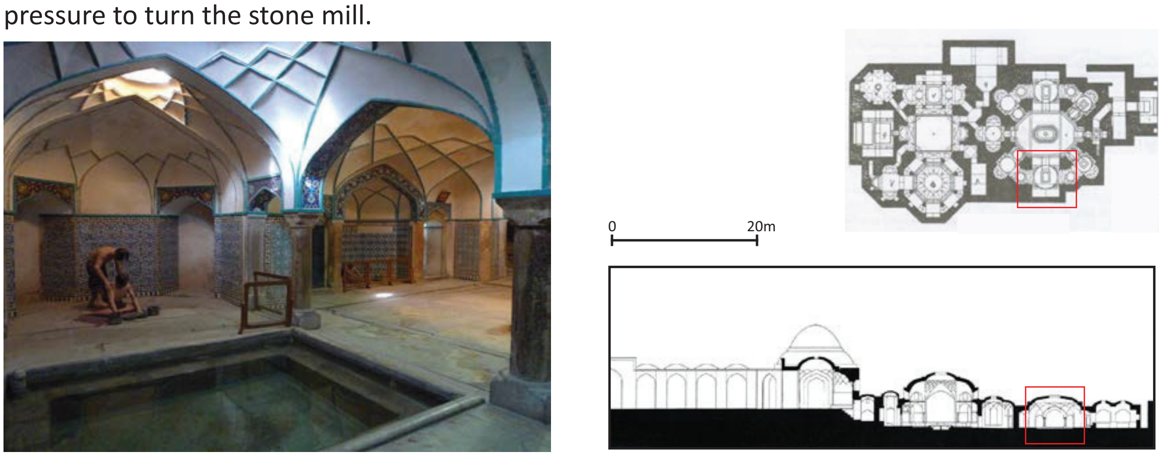


Figure 62: Hammam (Public Baths)
North-south section of the Hammam, cutting through the bazaar entry, through the disrobing room, the cold room, the warm room, and the water reservoir with heating chambers for the hot room beyond. Men and women were scheduled at different times for bathing. Location of image shown in red. (Section by Herdeg 1991, plan by Resouli 2013)

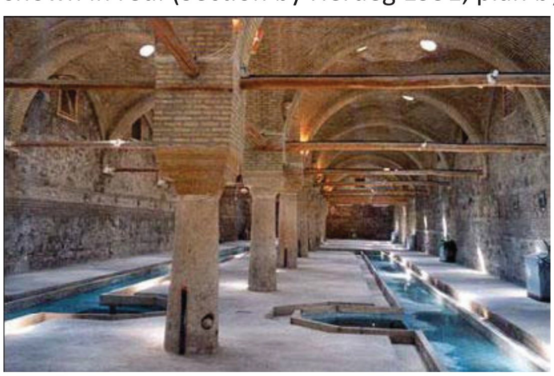


Figure 63: Rakhtshooy Khaneh (Laundry Washing House)
While the payab is an area that offered open access to qanat water for the public to wash dishes and clothes the rakhtshooy khaneh allowed people to perform the same tasks indoors. The one shown above is in Zanjan and was constructed by two brothers, one an architect and the other a mason. The building is divided into a care-taker area, as well as a public laundry washing area.

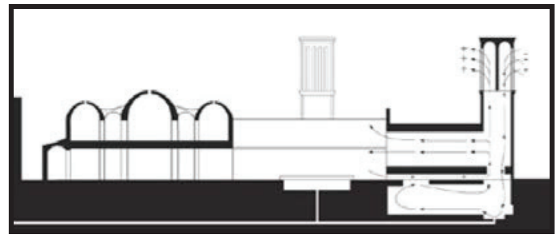


Figure 64: Traditional Persian House
The classic Persian house is centered around the courtyard with a small pool or fountain. These houses were traditionally supplied with water by qanats running underneath. Below grade is the area where inhabitants would have spent much of their time in the summer months due to cooler temperatures caused by the water evaporation, air movement and insulation from the sun's heat.

Figure 65: Formal Water Course
Typically when the watercourse reaches an area that is a celebrated domestic or public space, it is lined with tiles and surrounded with stonework. Sometimes a fountain is located in the formal watercourse.

Figure 66: Courtyard Pool and Fountain
The majority of traditional Iranian houses feature a pool in the courtyard which becomes a focal point and provides some refreshment and relief from the dry heat of the desert. The pools often had fish in them and they were also used for watering gardens.

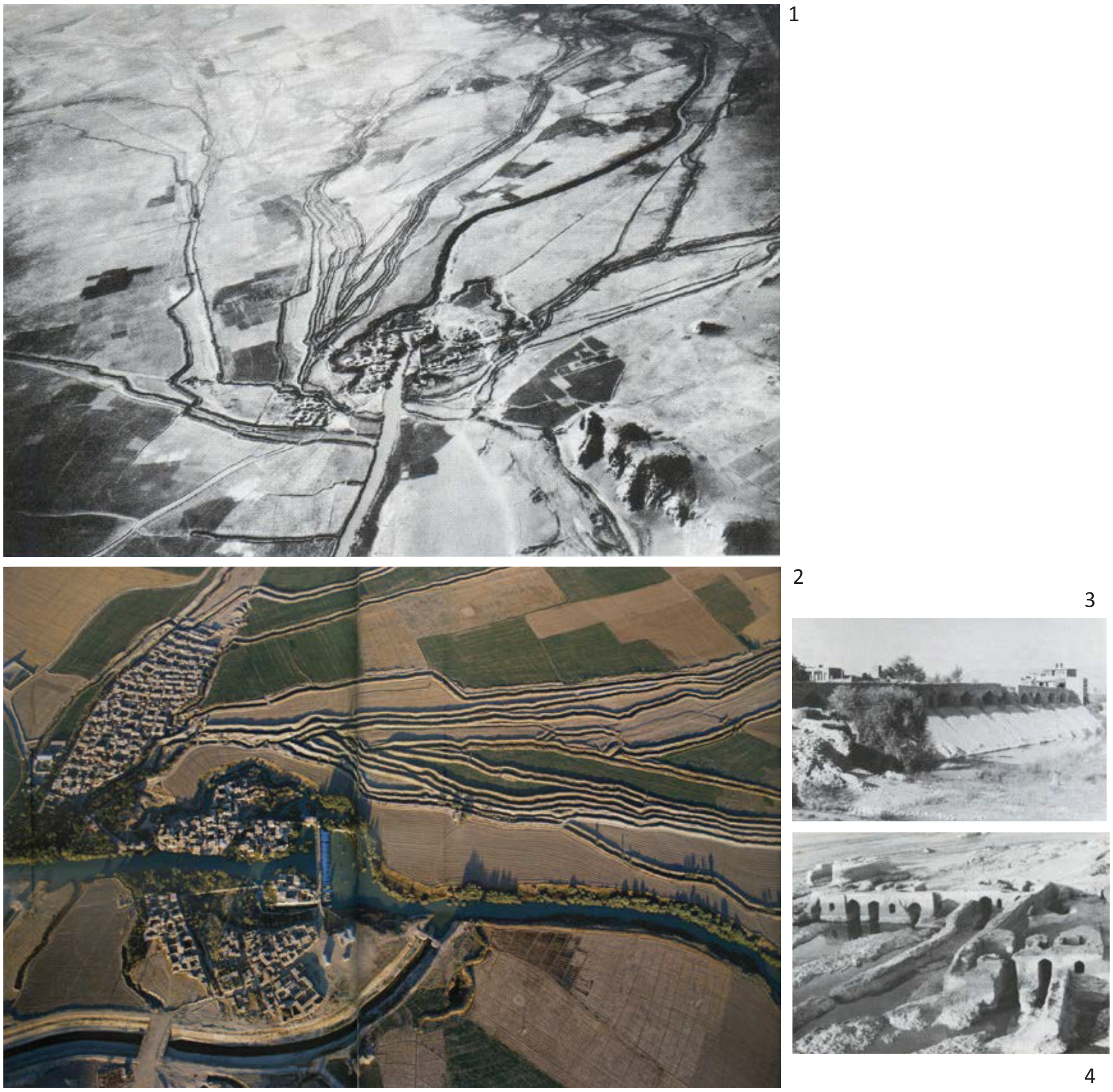


Figure 67: Dams
Dams played a historic role in controlling the flow of water and irrigating lands in Persia as most of its rivers do not carry water all year round.

1) Band-e Amir, the head of an irrigation system in the Marv-e Dasht. (courtesy of the Oriental Institute, University of Chicago) (Wulff 1966)
2) Marv-e Dasht. (Gerster 1977)
3) The Dam at Band-Amir. (Wulff 1966)
4) Remnants of a Sasanian Dam at Dizful. (Wulff 1966)

CHAPTER 3: MODERN WATER INFRASTRUCTURE IN KERMAN

The conflicting position of modern and traditional water infrastructure in Iran today is a result of land reform policies of the 1960s. They have shaped the development of modern Iranian cities and altered social structures of the past. The White Revolution was a reform program launched by Mohammad Reza Shah in 1963 as an effort to import modern economic ideas and government financed heavy industry projects. The reform also had political motives, as the Shah was attempting to remove the influence of landlords and gain support among peasants and the working class. In the package there was a redistribution of agricultural lands which took away much of the influence of landlords and this changed the socio-economic situation in Iran (Labbaf 2013). Before the land reform, most of the Iranian population lived in villages which were based on agricultural units of buneh where each farmer had a specialized duty and lived under the management of a landlord who owned the whole village. The land reform law meant that the villages were purchased from landlords and sold to a few farmers of the same villages at a decreased rate. Mechanized farms were the exception to this rule, therefore many landlords hurried to drill wells for pump extraction to save their land from being redistributed, even if it was not required. The majority of villagers had no share in the buneh and did not profit from land reform. The intricacy of the relationship between landscape, environment, production systems and culture was disregarded in this process toward modernization. The socio-economic structures broke up and lost their traditional functions. In this situation qanats were severed from their socio-economic role and became unfeasible. The impact of these reforms can be observed in the fact that the last new qanat in Iran was built in the early 1960s. Before the White Revolution, 30% of Iranians lived in cities while the rest of the population lived in rural areas. Today this figure has been reversed and now less than 30% remain in rural areas.

A decade before the reform policies of the 1950s, Iran began to make a shift from ancient to modern infrastructure because of the notion that ancient was inferior to modern. Authorities believed that Iran could not become fully developed unless it abandoned its traditional practices and so the technical shortcomings of qanats were exaggerated while pump well performance was promoted. It has become quite obvious that the opposite is true. Although there are limitations and drawbacks to ancient methods, their principles should not be ignored. The highly resilient level of performance of ancient infrastructure becomes very clear when we realize that it has operated continuously for 3000 years before being abandoned for another system. This new system is a radical shift from the

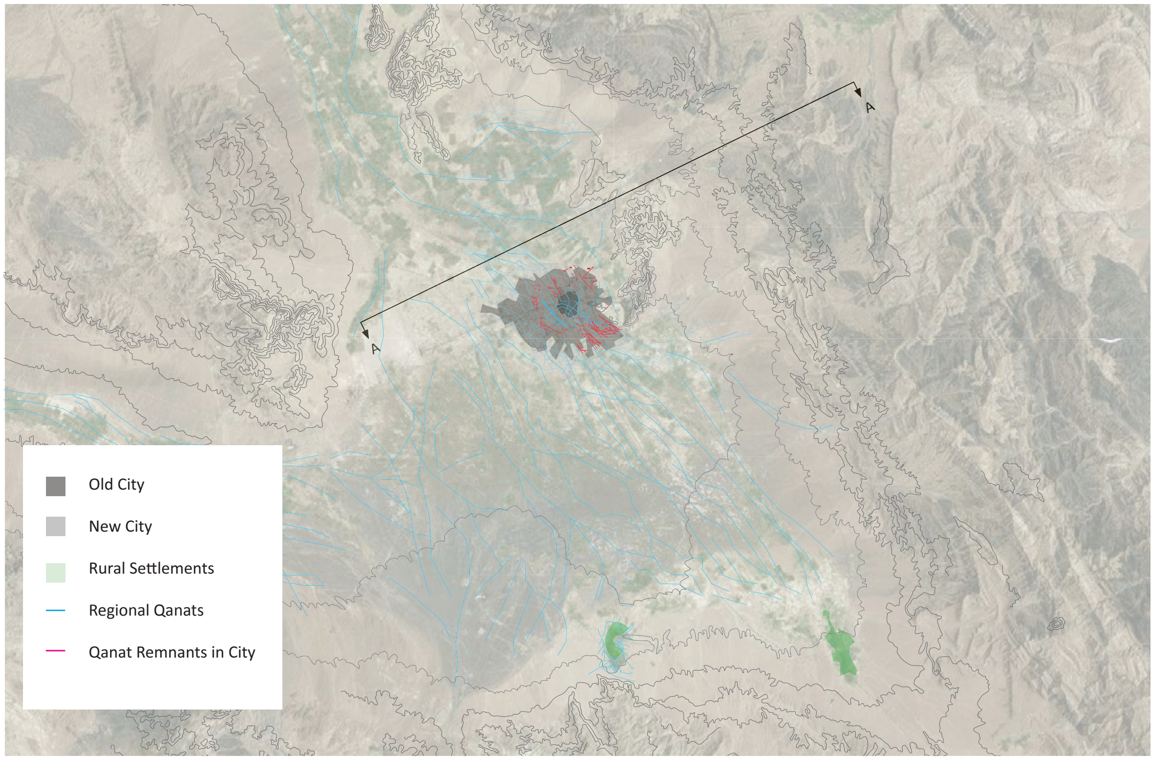


Figure 68: Past water infrastructure, 300AD - 1960: Qanats form the basis of water supply for agriculture and drinking. (base map from Google Maps)

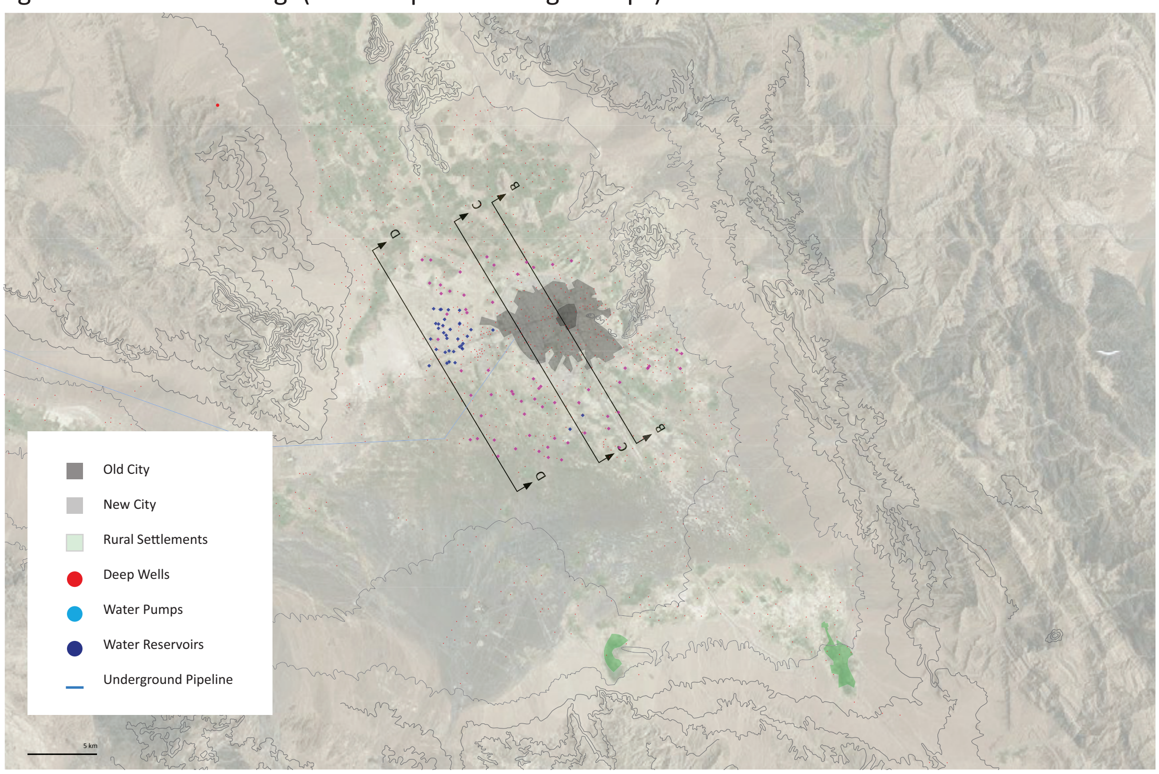


Figure 69: Present, 1960 - Today: Pump and electric well infrastructure distributed across the landscape. (base map from Google Maps)

previous one and although it has its own strengths and weaknesses the knowledge and lessons from previous designs have been disregarded. This gap is the place where our knowledge is lacking, and will provide a vital link between past and present.

Pros and Cons of Ancient and Modern Systems

The following comparison shows that both ancient and modern water systems have their own particular strengths and weaknesses. This can start to form the basis of requirements for a newly proposed system that could embody the technical and cultural strengths of each system while minimizing their associated shortcomings and drawbacks.

Qanat Pros

Made of local materials. Requires no source power other than gravity. Draws water from the top of the aquifer. Will continue to supply water for long periods with little energy input apart from annual cleaning and maintenance. Self-purification due to water flowing over long distances resulting in gradual sedimentation of suspended matter. Supports biodiversity of arid regions. Minimal loss of water through evaporation and little risk of pollution. The very nature of its construction and operation requires the collaboration of a community, thereby becoming a unifying factor between neighbors and communities. It is a celebrated piece of infrastructure which is named and endeared by its community.

Qanat Cons

Expensive to construct, $10,000 per km (in 1960s). Water discharge is uncontrollable, ranging from 0-300 m^3 per hour (average 60-100 m^3). Fluctuations in the height of the water table lead to variations in discharge. Water runs during the winter season when irrigation is not required. Can fall into disrepair quickly if not maintained regularly.

Pump Well Pros

Cheap to install $3,000 - 15,000. More productive, 30-900 m^3 per hour depending on the diameter of pipe used and aquifer condition. Not limited by slope or soil conditions and can be drilled in convenient locations in close proximity to final destination, or located in relation to market needs or other considerations.

Pump Well Cons

Requires energy input for operation. Drains aquifers regardless of their recharge rate. Disconnected from the recharge process. Draws water from the bottom of an aquifer which may be saline or polluted. Land subsidence and settlement is a result of over-extraction.

It alters the distribution of town and village arrangements to a position of reliance upon wells. Has caused major alterations in social patterns, customs and laws that have been developed around traditional water supply systems. Pipes are ubiquitous and anonymous and do not hold the same social or cultural significance for a community as qanats.

New Water System Requirements

Made mostly of local materials. Uses gravity and grade changes to move water and uses pumping only when absolutely necessary. Water flow rates are steady and controlled. Integration of life forms in water system for water purification, biodiversity and production with the landscape systems doing the bulk of the work. Social spaces are an integral part of the new water infrastructure system, not separate from it. Decentralization of water treatment, creating smaller but more localized and manageable treatment facilities integrated directly in the city fabric. The aim for this system is to reach an equilibrium with the landscape where the rate of clean water extraction from the aquifer is equal to the rate of clean water replenishment back into the aquifer after its responsible cyclical usage.

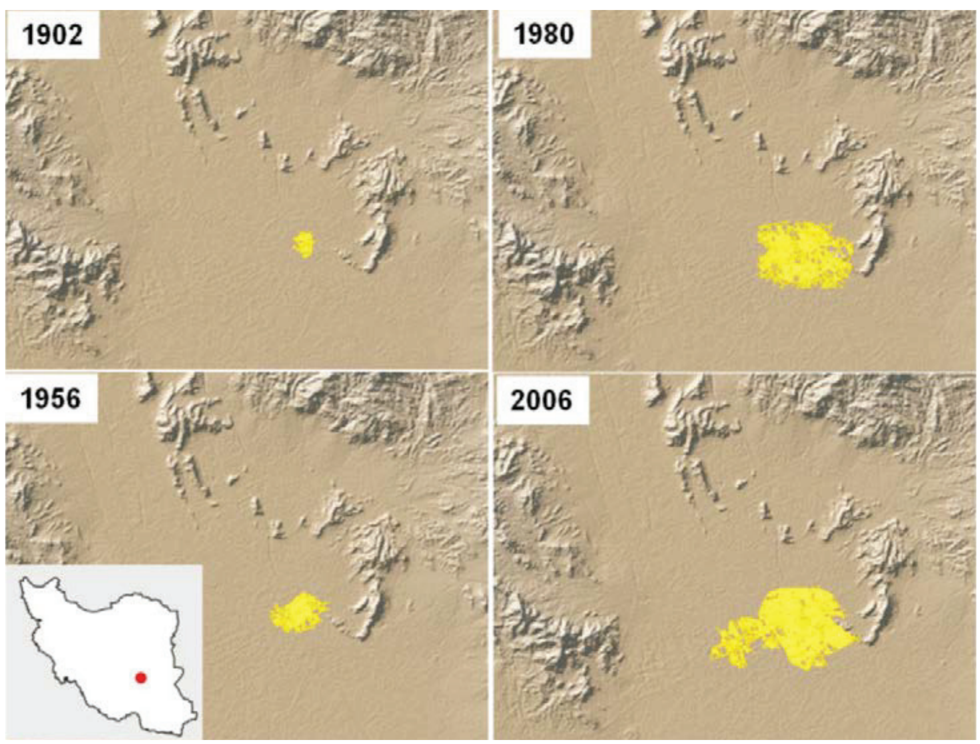
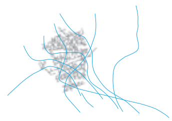
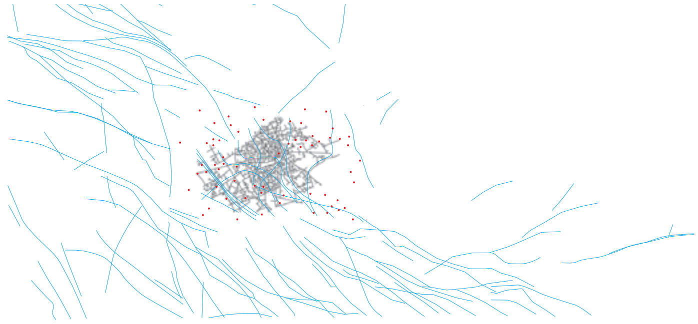


Figure 70: The location of Kerman, Iran, and its street network evolution from 1902 - 2006. (Mohajeri 2014)

Morphology of Kerman City and its Water Infrastructure





1902

Population: 50,000

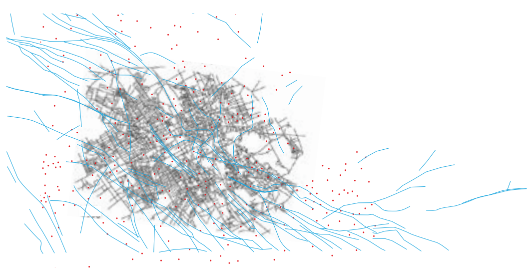
Qanats supply water to the city of Kerman from the Jupar and Mahan area which are at higher elevations.

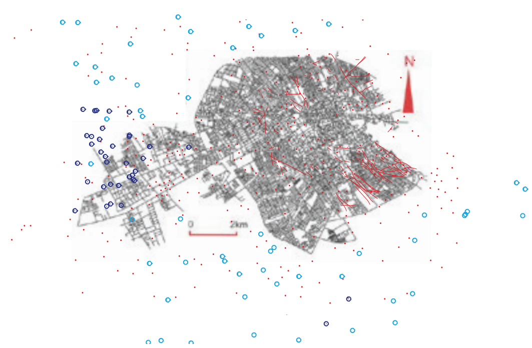
1956

Population: 101,716

~200 wells in the Kerman Plain.

Qanats still supply water to Kerman city.





1980

Population: 310,000

~850 motorized deep wells in Kerman Plain.

The “Salsibil Qanat” which flowed from the Mahan area into Kerman was the last functioning qanat in the city of Kerman, and dried out in 1988.

2006

Population: 515,000

~1020 motorized deep wells in Kerman Plain.

Qanats no longer functional in Kerman city, only in surrounding rural areas.

Figure 71: The growth and transition of the water infrastructure of Kerman 1902 - 2006. (underlay street maps, Mohajeri 2014)

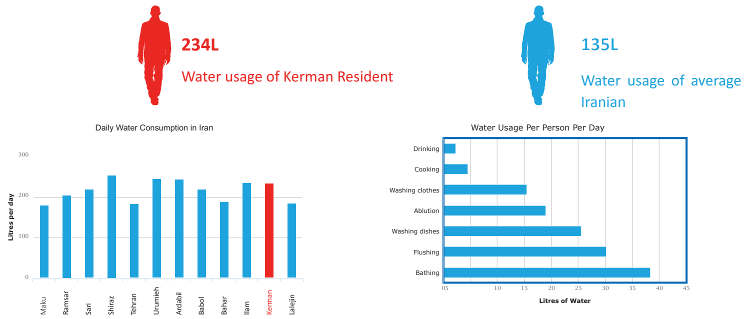


Figure 72: Daily Water Consumption in various Iranian cities and water usage of average Iranian. (Standard No. 117-3, State Organization for Management and Planning).

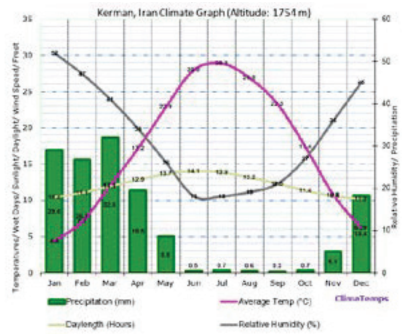


Figure 73: Kerman, Iran Climate Graph. (ClimaTemps)

Water Usage in Kerman

Water usage of individual residents of Kerman is relatively high compared to other Iranian cities. This can possibly be attributed to the abstraction of water which is a result of a shift in infrastructure, or it could be the result of an attitude held by residents toward water consumption. Residents should aim to use less than 200L of water daily, as is the case in several other cities shown in the graph above. The breakdown of average Iranian water use shows that bathing requires the most amount of water while drinking water requires the least. Attempts by authorities to promote decreased water use have so far been unsuccessful. Although the domestic sector uses a very small portion of water compared to agriculture, it is an important area to address for cultural awareness. The climate of Kerman is such that it receives little water during the summer and receives most of its precipitation in the winter, while there are large daily fluctuations in temperature. These fluctuations can perhaps be exploited and provide water capturing possibilities.

Figure 74: The city of Kerman looking southwest toward Jupar mountain from Ghal-e-Dokhtar. In the historic city core. (photo from 2015)

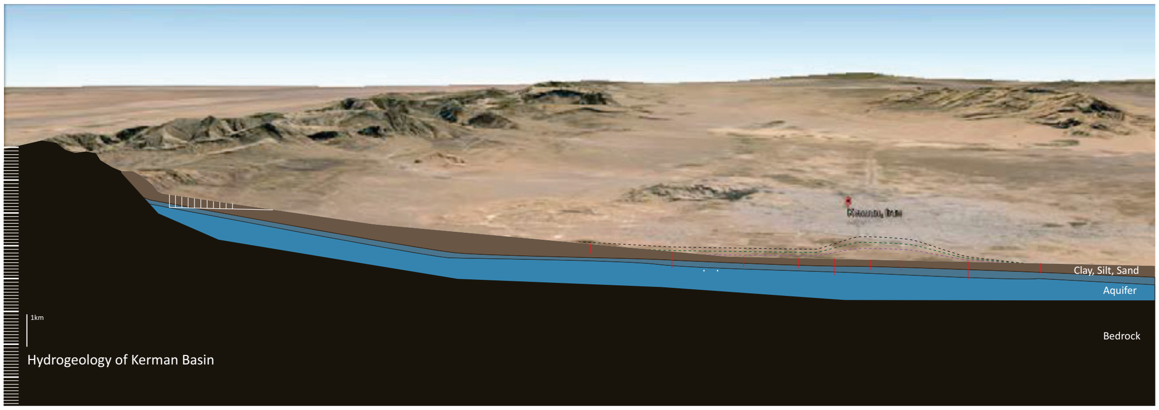


Figure 75: Bedrock, aquifer overlay and land subsidence approximation drawn by author. Dotted lines indicate land subsidence. Vertical scale (km) and a typical qanat is shown on the left hand side (white) while wells are shown at the center of the valley (red). (underlay Google Earth 2014)

Kerman Plain Aquifer and the City

The water table below Kerman has dropped 50cm each year since 1970 as a result of the rate of use being greater than the rate of replenishment. Although there are few pump wells in the old city, the area has been affected by the use of wells all around it. The entire city itself has also been affected as the shifting aquifer has caused the ground below the city to shift in two directions, sinking in one direction and being raised in the other. This land subsidence has caused deterioration of the ancient qanat infrastructure below ground and has caused damage to building foundations. This also affects current water systems as it changes the grade of the ground. Just as the modern system of water infrastructure has disregarded the principles of traditional water infrastructure, the forms and materials of the new city have disregarded the principles of historic Iranian cities.

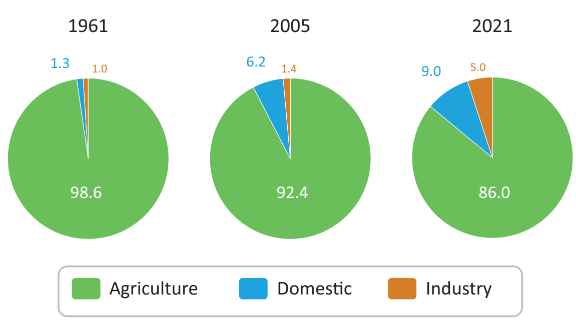


Figure 76: Water usage in Iran by sector, 1961, 2005, 2021 (data from Statistical Centre of Iran)

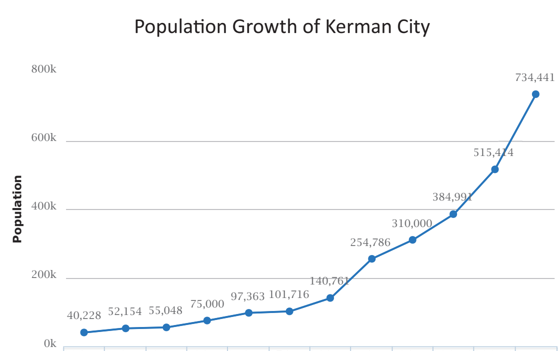


Figure 77: Population Growth of Kerman City, 1896-2011. (data from National Census)

Shift of Water Systems and Elements of Human Interface

The water supply of Kerman and many other Iranian cities was traditionally provided by qanats weaving into the city and meeting the urban fabric both in the public and private realm. The city of Kerman experienced very little growth until the last thirty years. This growth coincided with the general population increase in Iran and a large scale migration from rural areas into cities. Land reform policies as well as the need to accommodate more people at a quicker rate caused Kerman and other cities to adopt a practice of deep well drilling that grew and eventually replaced the qanats and rendered them useless. A small fraction of the original qanats remain in some parts of the Kerman province, and in other parts they have been damaged by negligence or earthquakes. The traditional system of infrastructure brought water into peoples homes and engaged them by the ways it was delivered and accessed. It was related to other sustainable systems such as wind-catchers for air conditioning, appropriate local materials for insulation and water retaining properties, as well as careful siting to make optimum use of lighting and climate. The shift in infrastructure has caused an abstraction of water resulting in a less intimate relationship with it and has brought about an ignorance or disregard for its source or supply.

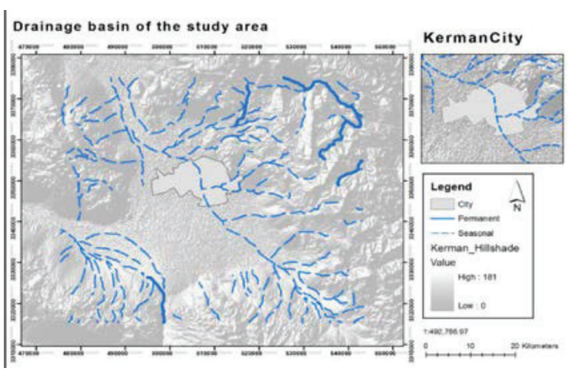


Figure 78: Drainage basin of the Kerman plain. (Ghazanfarpour 2013)

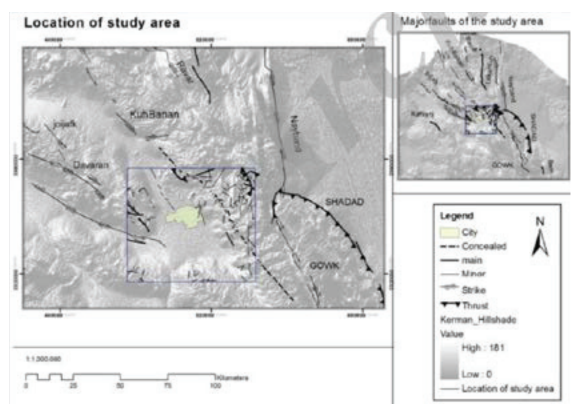


Figure 79: Major faults affecting the Kerman Plain. (Ghazanfarpour 2013)

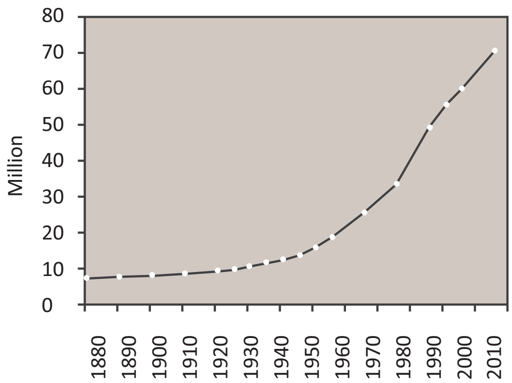


Figure 80: Population of Iran, 1880 - 2005. (data from Statistical Centre of Iran)

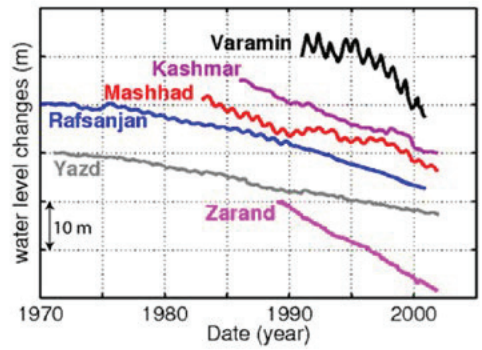


Figure 81: Depletion of aquifers seen in all Iranian cities. Between 1970 and 2006 the water table below most Iranian cities has dropped between 10-20m. (Motagh 2008)

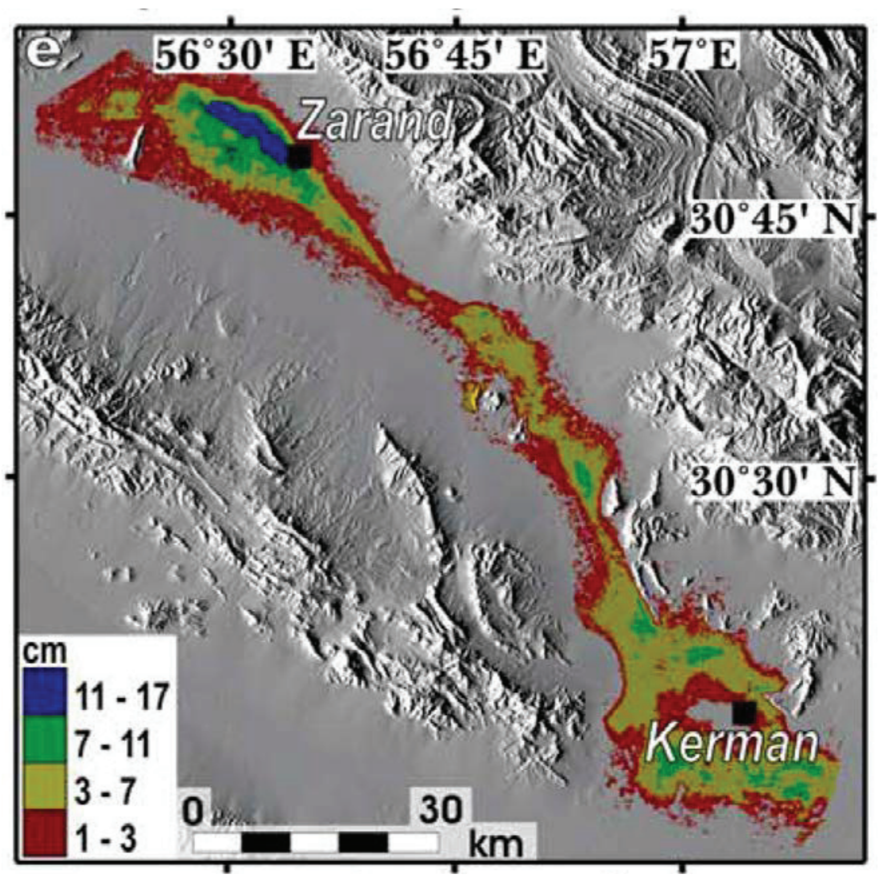


Figure 82: Land subsidence in the Kerman Plain due to over extraction of water. The city of Kerman has subsided between 1-11 centimeters. The reason that the center of city has not subsided is due to the shape of the bedrock, as well as the fact that it is routinely replenished with untreated water from absorbent wells in the city. The Zarand region (a city 80km northwest of Kerman) has shown much more land subsidence than Kerman. This could be attributed to the fact that it is an agricultural area and water extraction is very high. It could also be due to its geographic location. (image by Motagh 2008)

Shift of Infrastructure in the Kerman Plain

The city of Kerman was founded in the 3rd century AD and began as a enclosed fort with a citadel and city gates. The city remained nearly the same size for hundreds of years for various political, geographic and economic reasons. The growth of Kerman and corresponding water systems is apparent when looking at maps of the city and the development of its water infrastructure over the past century. In the beginning of the 1900s, before the discovery of oil in Iran in 1908, the water supply of Kerman was based on qanats and the population at the time was 50,000. Nearly 50 years later when the population had doubled, there were around 200 deep wells in the Kerman Plain. Another 30 years would see the population of the city triple and at that point there were 850 deep wells in the Plain. The shift of infrastructure that had been put in motion by policies of the 1960s along with the need to accommodate an increasing population meant that the ancient system would be overtaken by a modern system which neither had a relation to it nor drew any lessons from it. In 2006, with a population of 510,000 people, Kerman had over 1000 wells in the plain. For the past 30 years the water table under Kerman has been steadily lowering at a rate of 50cm every year due to over-extraction. Recently Kerman and other arid cities such as Yazd, have had water supplements from surface sources in other parts of Iran. For example Yazd receives 30% of its water supply from the Zayandehrood River of Isfahan, which has itself been greatly diminished. The concept of far reaching supply lines and big scale infrastructure projects for the cities of Iran is an unsustainable and overall detrimental practice that can only be sufficient in the short term. More localized solutions that raise cultural awareness and bring about more efficient use of water are among the most viable long term solutions for the water supply of Iranian cities.

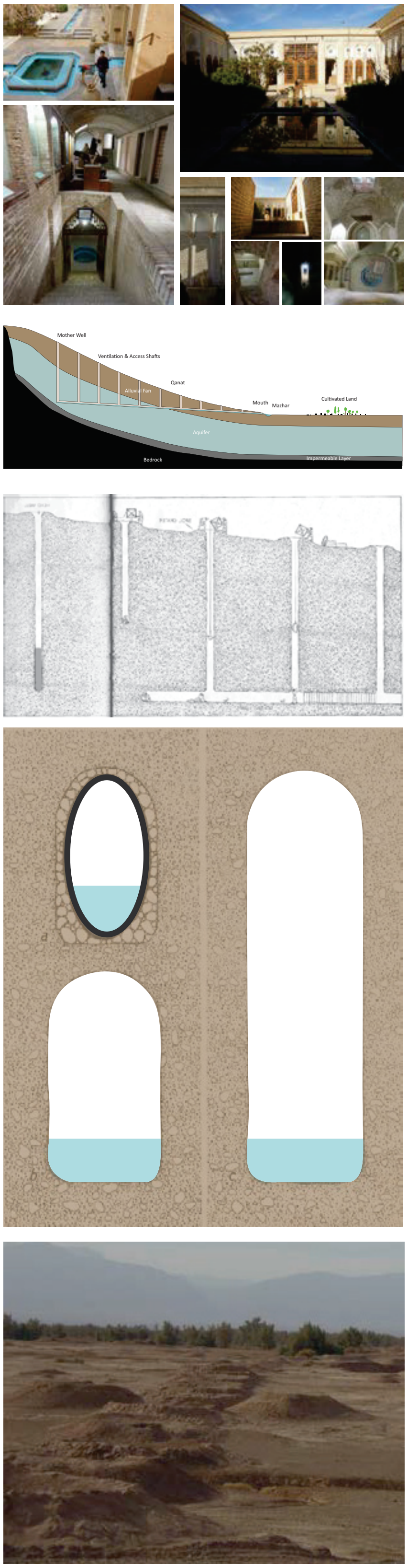


Figure 83: Elements of traditional Iranian water system 800BC-1950.

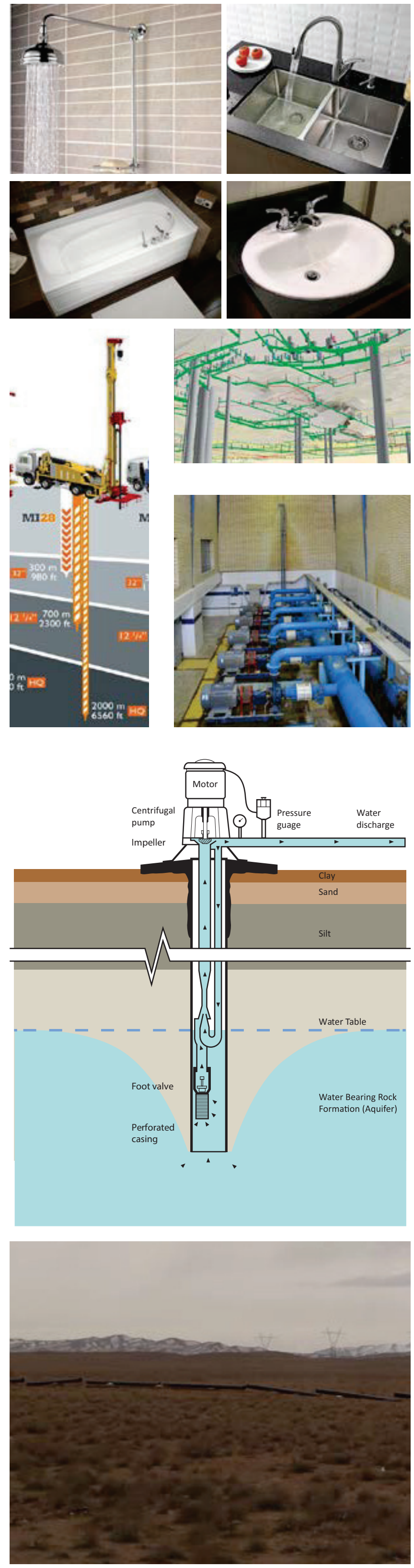


Figure 84: Elements of modern Iranian water system 1950-Present.

Inventory of Modern Water Infrastructure

The inventory of modern infrastructure shows the array of technical possibilities that are available to us as an interaction with the landscape. Modern infrastructure can overcome limitations of the landscape in terms of speed and scale but the issues of sustainability, efficiency and biodiversity have yet to be realized with these systems.

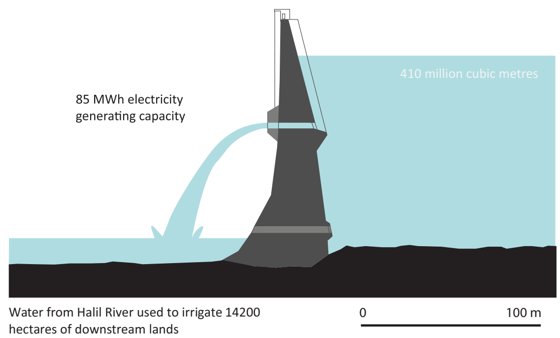
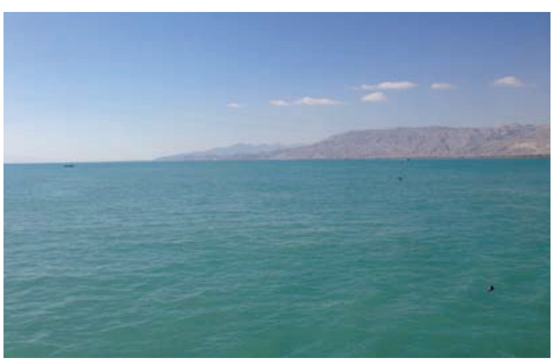


Figure 85: Hydroelectric Dam
Jiroft Dam is a hydroelectric and irrigation dam with an electrical generating capacity of 85 MWh. Its reservoir capacity is around 410 million cubic meters up to its normal level. The spillways and other hydrodynamic outlets of the dam can discharge up to 6,500 cubic meters per second. The reservoir irrigates 14,200 hectares of downstream lands that produce food for the province and the country.



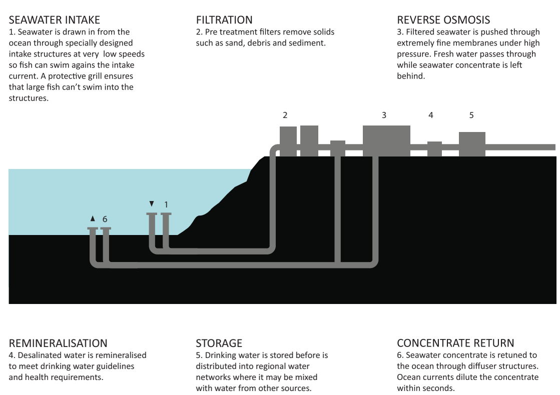


Figure 86: Seawater Desalination
Due to the deterioration of water resources in many areas of Iran, desalination plants such as a reverse osmosis desalination plant are being constructed near Bandar Abbas to supply desalinated water from the coast to distant cities.

Figure 87: Small agricultural pump
Agricultural pumps usually feature a pool in which the water is poured and the sediments allowed to settle before the water reaches its destination.

Figure 88: Large agricultural pump
A significant amount of land subsidence is visible in the image above. Due to the continuous extraction of water, the pumphouse building has dropped nearly 100cm below its original foundation over the course of several years.

Figure 89: Vertical Lineshaft Turbine Pump. (Peerless Pumps 2015)

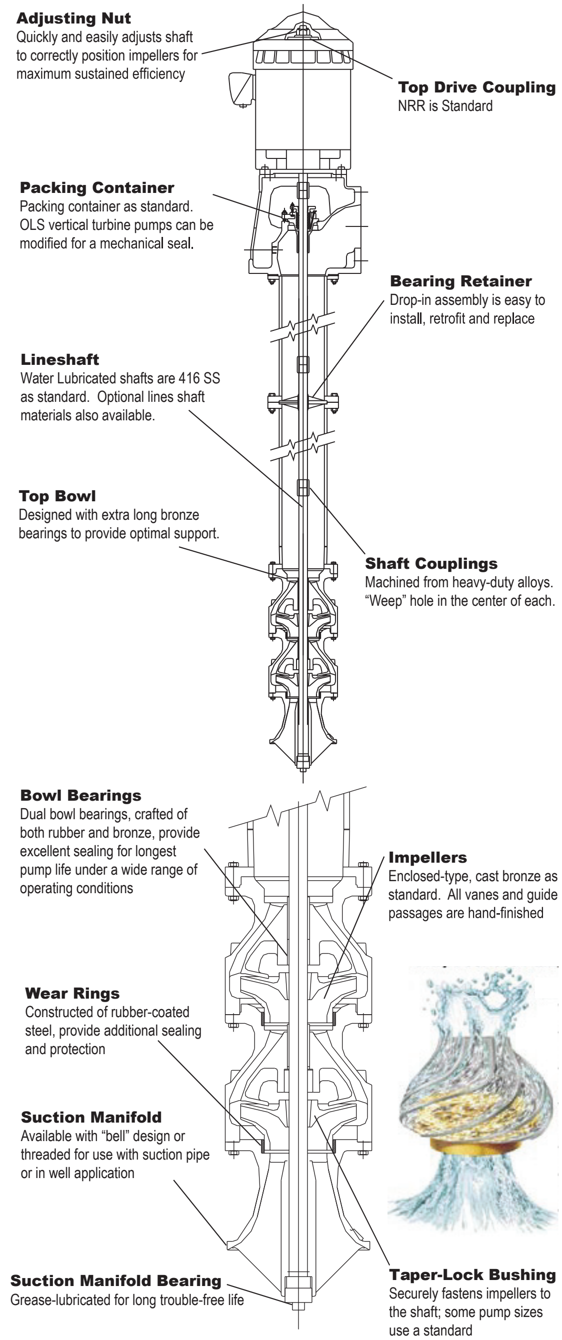


Figure 90: Vertical Lineshaft Turbine Pump. The pumps used in the Kerman Plain are operated by a motor that rotates a shaft which then rotates turbines that extract water from the ground in an upward spiralling motion. (Peerless Pumps 2015)

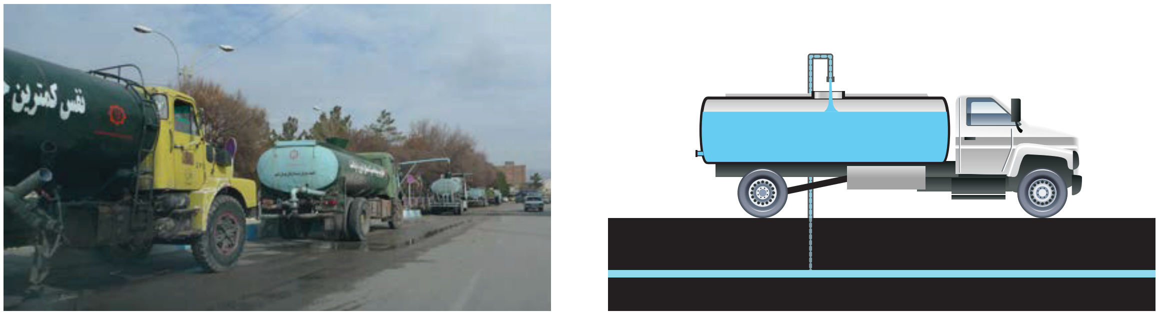


Figure 91: Tanker trucks
The mobility of large quantities of water is a modern phenomenon created by the use of motorized vehicles. The image above shows water being pumped from the aquifer under Kerman near Motahari Park into tanker trucks. The water under the city is not clean enough for drinking but is used for watering plants and crops, it is also used in the construction industry.

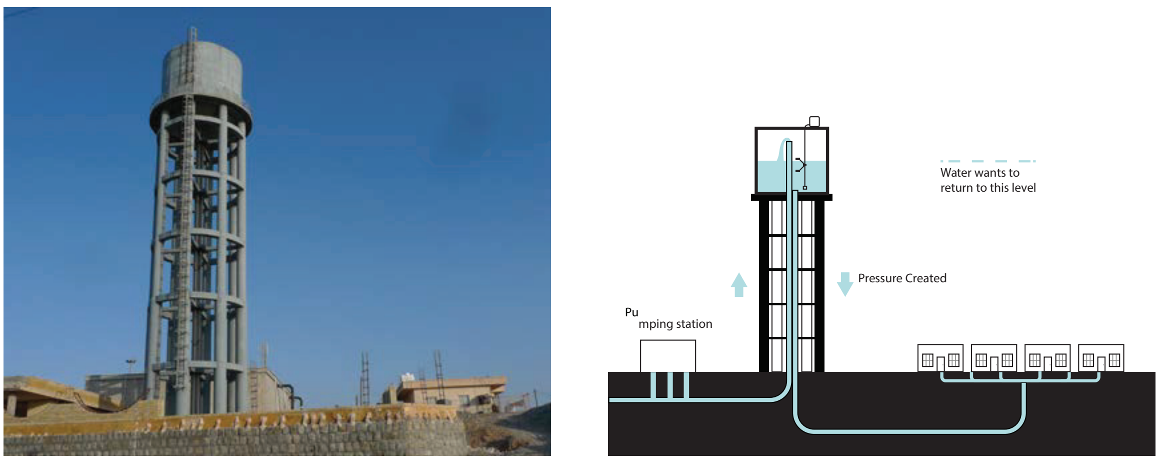


Figure 92: Water tower
Water towers in Iran take numerous shapes and forms in concrete, metal and plastic. They are continuously replenished with water to a certain level in order to maintain adequate pressure levels in the system.

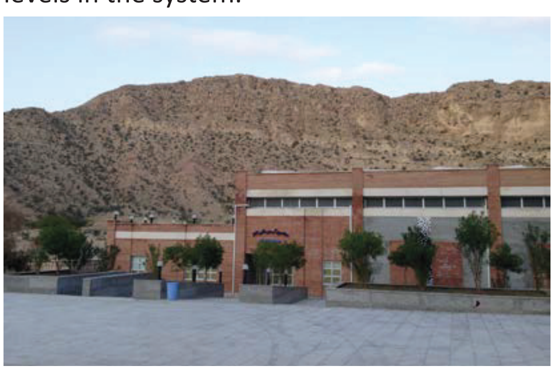


Figure 93: Thermal baths
On the outskirts of Bandar Abbas is an area called the Geno Biosphere Reserve, with a total area of 27,500 hectares. It was designated as a protected area by the Iranian Department of Environment in 1976. The water from the hot springs in the area contains sulfur and attracts many tourists for its healing qualities.

Figure 94: Sewage Treatment Plant
The newest parts of the city of Kerman are serviced by a water treatment facility that is capable of cleaning 15,000 m^3 of water daily. The cleaned water is then sold to farmers with adjacent lands for watering crops. (Google Maps 2015)

Figure 95: Headworks.
(photo from 2015)

Figure 97: Screening.
(photo from 2015)

Figure 96: Screening.
(photo from 2015)

Figure 98: Aeration tanks and clarifiers.
(photo from 2015)

Figure 99: Agricultural piping
Due to the shortage of water, precautions are taken on modernized farms to preserve as much water as possible. This farm has been retrofitted with underground pipes that are fed by a qanat and sent to drip irrigation lines to prevent evaporation of water and its infiltration into the ground.

Figure 100: Drip Irrigation line
Drip irrigation is now common practice for most farms as it preserves water, many pistachio farms have been retrofitted with this system as it is more efficient than flood irrigation.

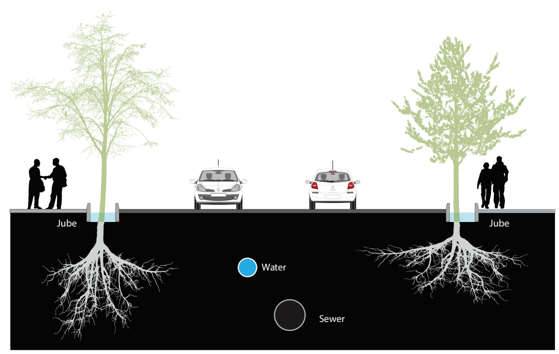


Figure 101: Jube
Streetside watercourses are common to all major Iranian roads. This watercourse in the town of Shahdad has clean qanat water running through it to reach agricultural lands. The streets of Kerman also have these jubes. Although they currently do not have qanat water running through them, they are watered by pumps and tankers routinely.

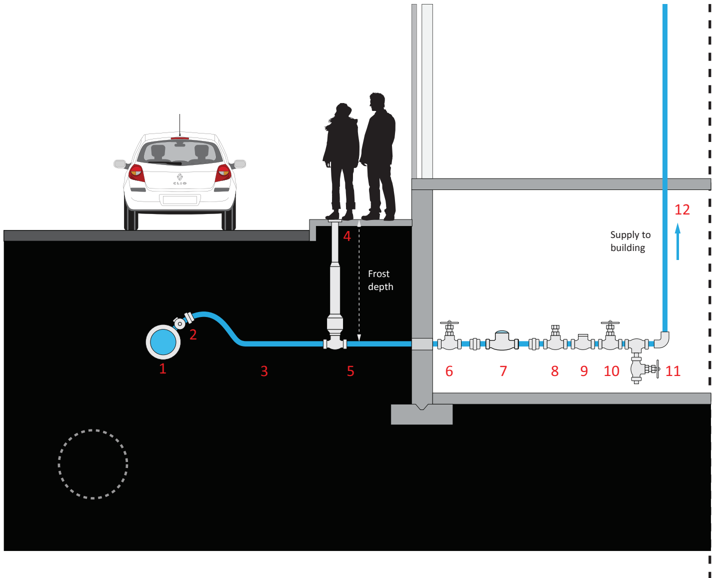


Figure 102: Water main and supply to building
Section of typical street main and building water supply. Modern water infrastructure delivers clean water to buildings through water mains under streets in an enclosed and pressurized system, isolated from external contact until it comes out of a faucet, spout or nozzle. 1) Street main 2) Corporation stop 3)Service pipe 4) Service box 5) Curb stop 6) Stop valve 7) Meter 8) Testing tee 9) Check valve 10) Valve 11) Drip valve 12) Supply to building.

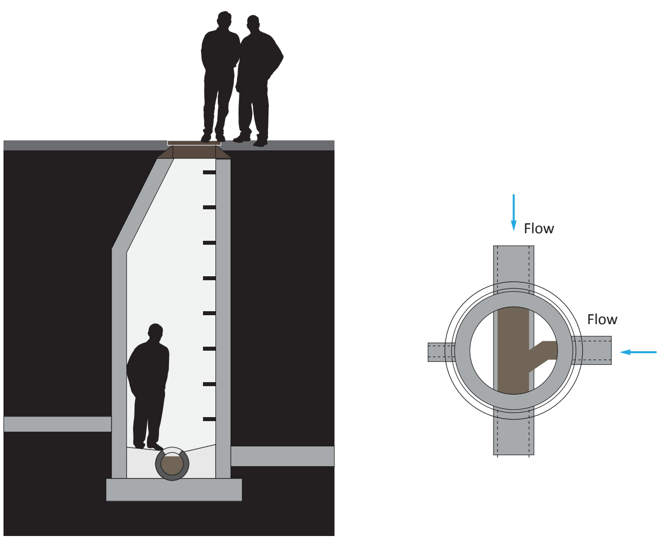


Figure 103: Manhole
Manholes are required at junctions of gravity sewers and at each change in pipe direction, size, or slope, and they can be spaced no more than 123m in sewers of less than 45cm in diameter, and 183m for sewers over 45cm in diameter. (Shammas 2011). In many regards the interaction between humans and water through infrastructure below ground is an old concept but the new underground infrastructure is not designed as something to be experienced or enjoyed by the public, it only serves a utilitarian purpose accessed by city workers and engineers. There are many possibilities to rethink the spaces and types of interactions that are created by manholes.

CHAPTER 4: DESIGN

Focus on Three Zones of Kerman Fabric

The new water infrastructure of Kerman can serve numerous uses with the proper integration of historical knowledge and modern technologies. The new water system can embody the intimate and brilliantly simple connections with water that was visible in historic buildings, however there is no reason to simply remain nostalgic. The water system of the future can also provide the highest levels of safety, production, monitoring and usability. When the two modes of thinking are merged, the possibilities start to become endless as they offer very different solutions and options for the same issues. To show some of the ways that the two systems can be referenced to create new water sustainable architecture, the agriculture, old and new city sites shown below are presented in this chapter with their water recycling, efficiency and social qualities highlighted.

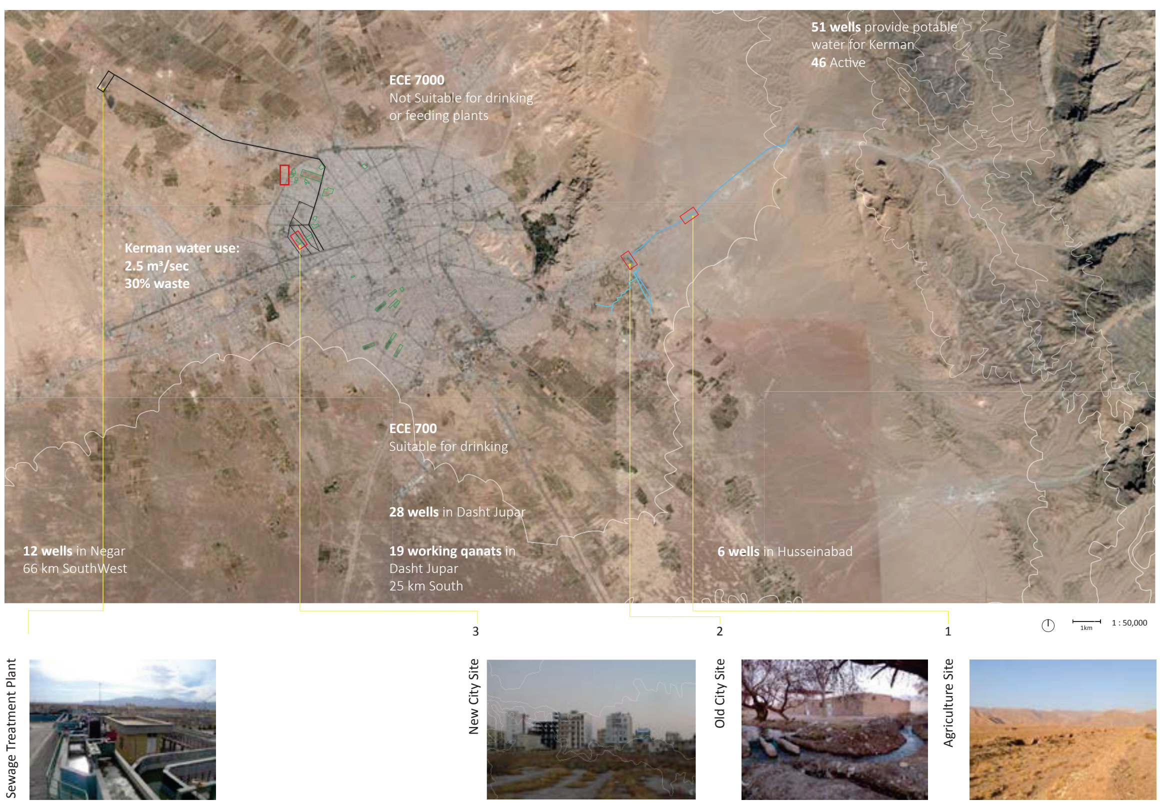


Figure 104: Kerman City, and three design sites. The sewage treatment plant and distance of water travelled (black). The last qanat attached to the city of Kerman (blue).
(map from Google Maps, data from interviews, 2015)

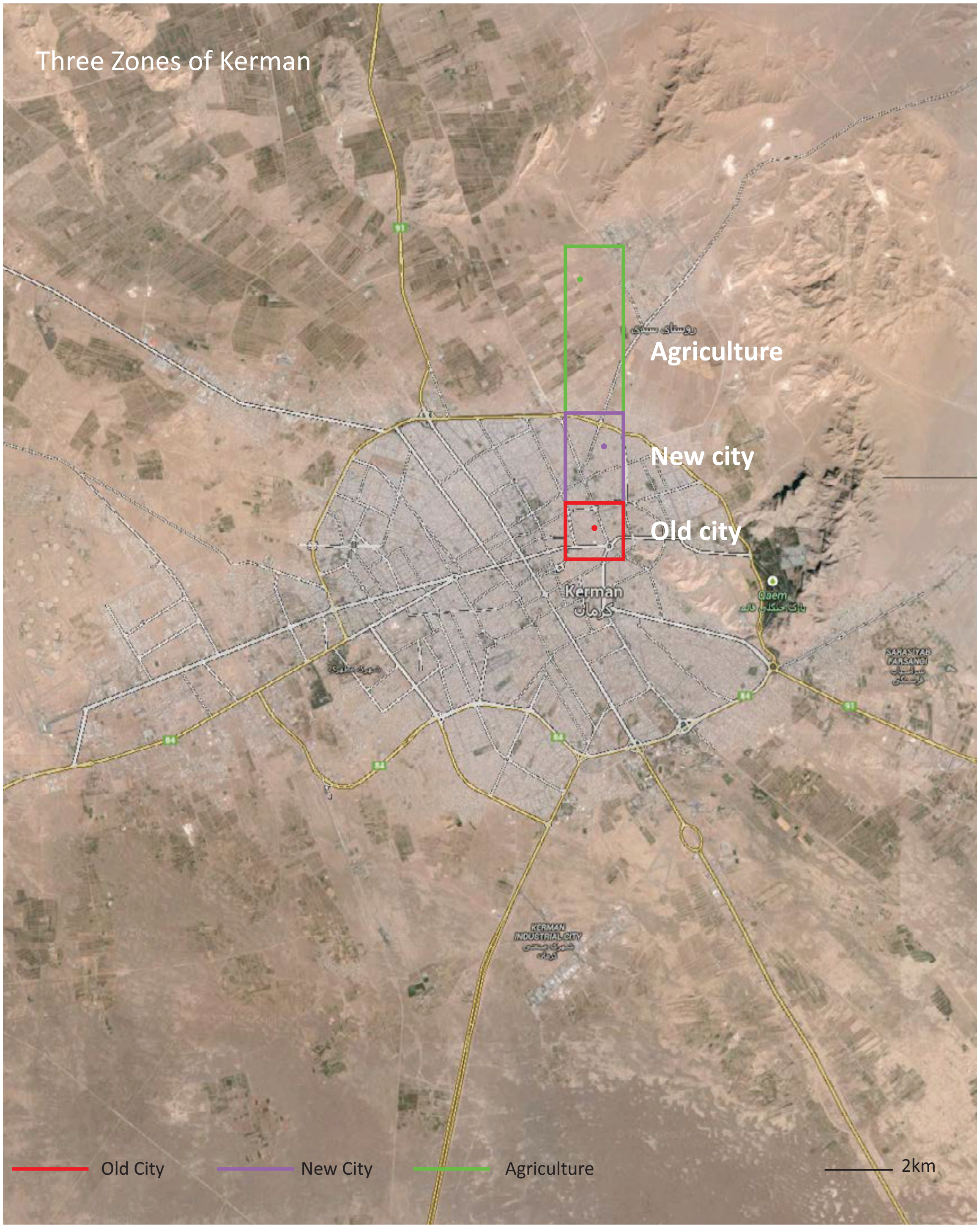
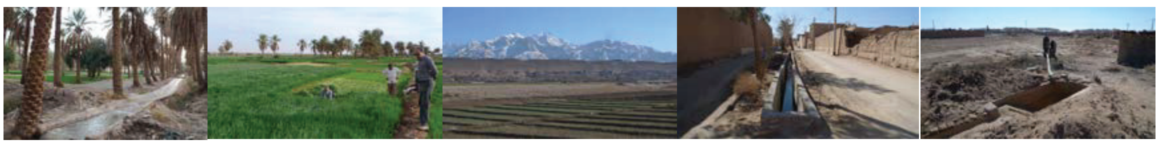


Figure 105: Three zones of importance to the water infrastructure of Kerman, Old City, New City, Agriculture. (Google Maps 2014)

Figure 106: Plan of agricultural outskirts of Kerman. (Google Maps 2014)



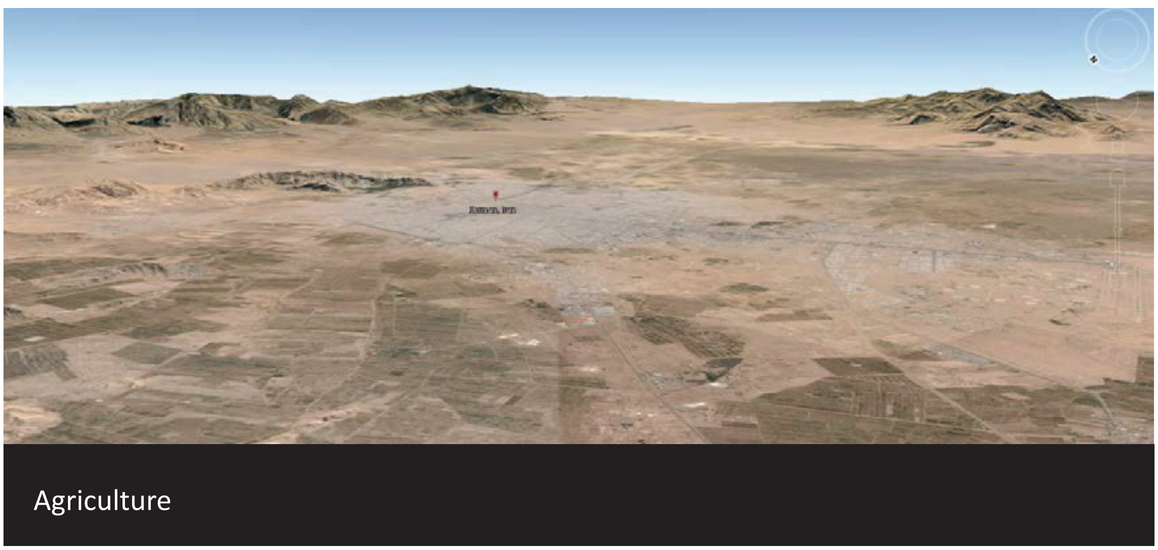


Figure 107: View of the agricultural outskirts of Kerman. (Google Earth 2014)

Agriculture

The city is surrounded by agricultural land and as the biggest sector of water in Iran this is an area that requires much scrutiny. By understanding the agricultural practice and its shortcomings I would like make proposals for better and more efficient use of water. An overall strategy should also involve crop selection to use water resources and investments in the most efficient way. The last 30 years has seen wheat and a variety of other produce grown on farmlands of the Kerman plain get replaced mostly with pistachio orchards. The consequences of this shift as well as the relationship between choice of export crops and overall water balances needs to be better understood.

Figure 108: Agriculture Design Panel.

Farm Perspectives

The agricultural sector is by far the largest user of water in Iran, with around 95% of total water usage, the methods and practices in this area deserve a great deal of scrutiny. Agricultural lands are watered by dams, pump wells, surface streams and qanats. The proposal for the agricultural lands of Kerman is to address the biggest technical weakness of qanats which is that they flow all year round, including in the winter when water is not needed for many types of crops. This proposal takes mechanical, material and construction lessons from traditional water reservoirs and applies them in a newly designed configuration. The reservoirs that get embedded in the landscape store qanat water on a daily basis throughout the winter, to be used for watering farmlands in the summer. Downslope from each series of 10 reservoirs at the first point of water exit is a modern mazhar, which sees the water surface in an area constructed to allow for social gathering, personal reflection, community events and beautiful views of the landscape.

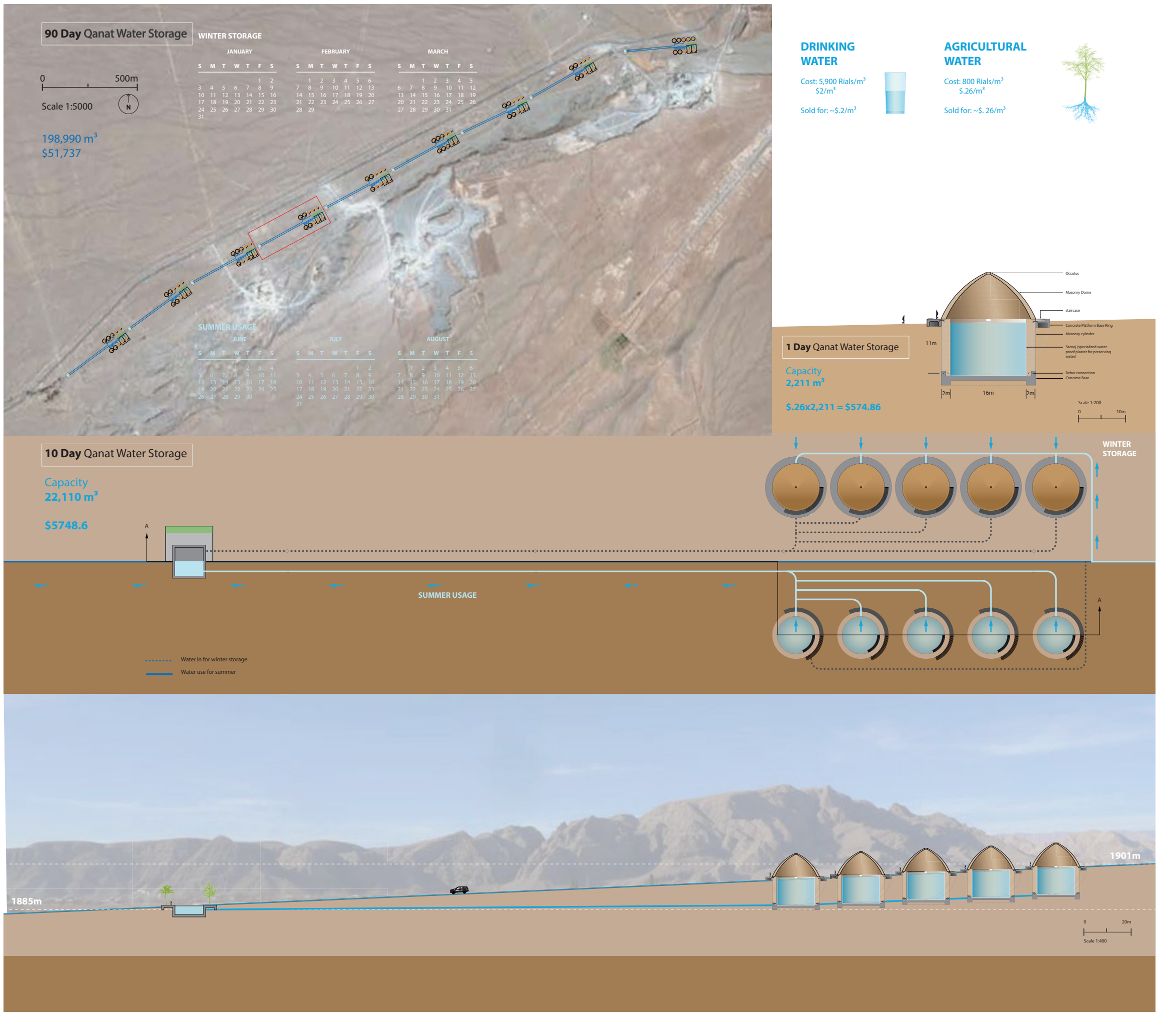


Figure 109: Proposal for new gravity fed water storage reservoirs based on historic systems.

Agriculture Design

This design proposal promotes qanat usage for agriculture and addresses one of their biggest weaknesses which is that the water runs all year, even during winter when it's not needed. The summer months have the weakest flow even though that is when water is needed. The usage of both modern and traditional techniques for this proposed gravity fed system would let this new ab anbar be made with local, traditional and appropriate materials while having the structural integrity through modern materials and design. Each ab anbar can store a days worth of qanat water which is roughly the same as an Olympic sized swimming pool. Rather than flowing straight into the ground the water is stored daily during the winter and used daily during the summer with a controllable flow rate. A total of 90 ab anbars could be built as required and store water for a whole winter, to be used later in the summer with a completely gravity fed method.

Figure 110: Plan of the historic fabric of Kerman. (Google Maps 2014)

Figure 111: View of the historic fabric of Kerman. (Google Earth 2014)

Old City

The old city has many potential sites for intervention, these include the numerous vacant lots that have downgraded the spacial and social quality of this part of the town. I have started the analysis of the range of spaces through sections. I believe a public space or series of public spaces that engage residents with water in traditional ways can inform them about the history and roots of the city while reintroducing them to lost methods of water use.

Figure 112: Old City design panel.

Old City Perspectives

The old city has a cultural significance for Kerman because the last active qanat attached to it runs through this site into nearby farmlands. It also displays characteristics of the formation and organization of traditional Iranian settlements, shaped and configured by the flow of water across the landscape. To highlight the significance of the integration of architecture and water within the urban fabric, a “Water Future Pavilion” is placed in this site. As a place to disseminate information about Kerman’s water history, current situation and future prospects, this pavilion would serve to contextualize the visions of the future with the lessons of the past.

Figure 113: Site plan and section of old city and proposed water future pavilion.

Old City Design

The qanat water that runs through this site brings life and joy, while showing a direct connection between the water infrastructure and the mountains that feed it. The historic qanats that ran in the northwest to southeast orientation throughout the city have all been destroyed due to new construction, neglect, and land settlement. However this site shows the characteristics of a premodern city organization and still has qanat water running through it. As such, this site is an ideal location for a Qanat and Hydraulic Systems Future Museum as well as a community gathering pavilion. The formalization of the site with hardscaping, formalizing the entrance and qanat alignment will bring a small new paradise to the city and offer an alternative to modern mechanized fountains seen throughout Kerman.

Figure 114: Plan of the new urban grid of Kerman. (Google Maps 2014)

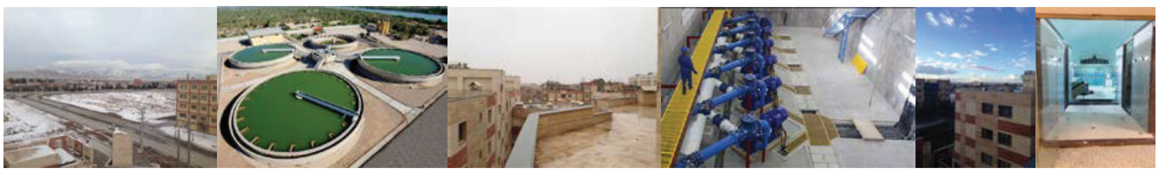


Figure 115: View of the new fabric of Kerman. (Google Earth 2014)

New City

The new city is the fastest growing region of Kerman, residents have a desire to live modern and comfortable lives, however there are many shortcomings of the current construction and water infrastructure paradigm. I would like to propose that water infrastructure can grow as a decentralized and integrated part of the city, making maximum use of grey and black water while contributing to green spaces that can grow with the city.

Comparative Water Usage

The rationale for the proposed designs as well as their scale and scope can be found in the comparative water usage diagram below. On a city scale It shows the daily water withdrawal of Kerman, how much is lost due to inefficiencies in the system and how much is treated in the sewage plant 10km northwest of the city. On a neighborhood and user scale the diagram shows the daily water usage as well as greywater and blackwater output of individuals, households, apartment buildings and blocks. These figures are key in determining sizes and placements of elements of the newly proposed water infrastructure. A city block is approximated as 12 residential apartment buildings with a population of 500 people. The blackwater output is 15m³, and that is equal to the amount that one localized sewage treatment line can filter and clean. The diagram also shows that 30% of total water extracted from the aquifer is lost due to inefficiencies in the system. This number is currently too high and should be between 5-10%.

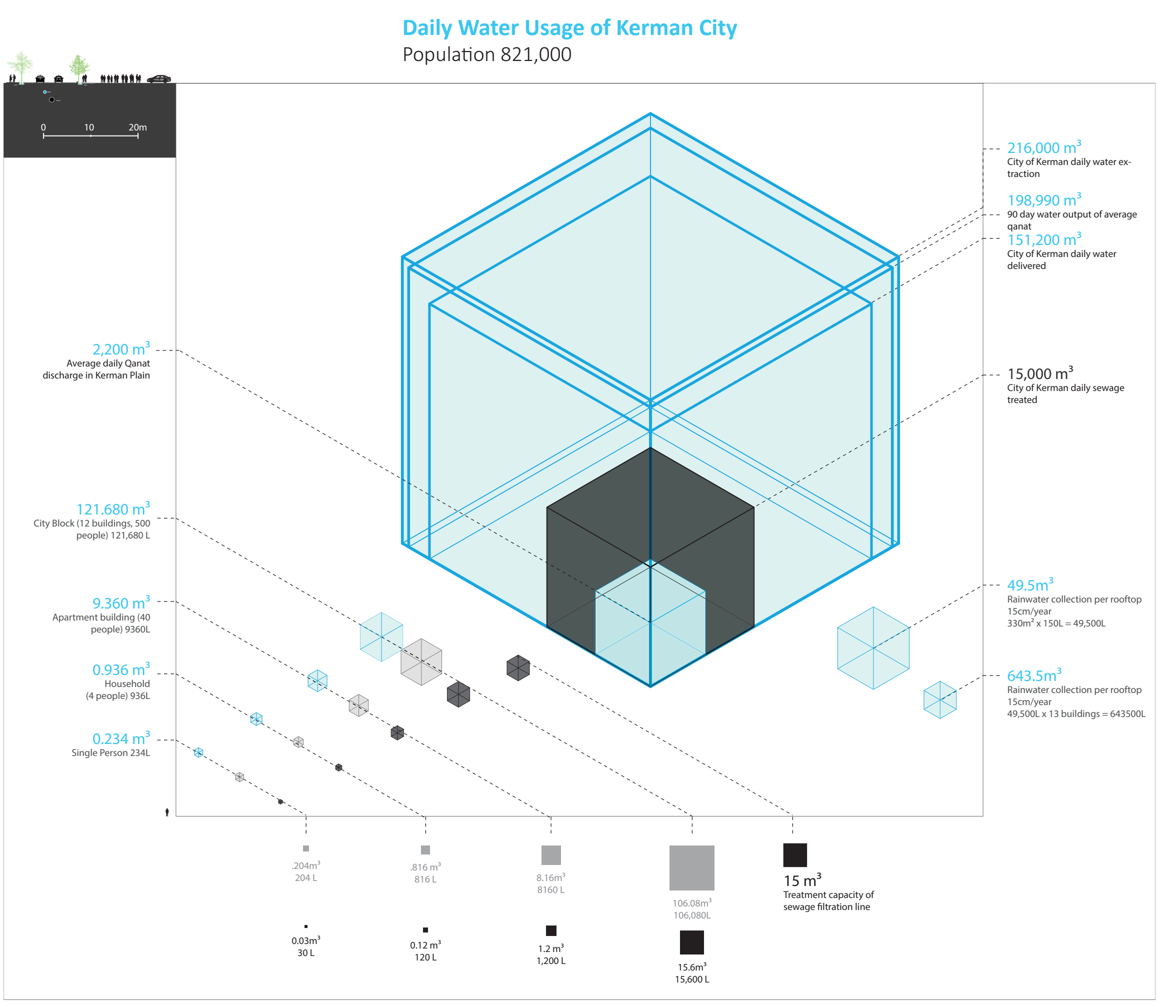


Figure 116: Daily water usage in Kerman (data from Kerman Water Authority and interviews, 2014)

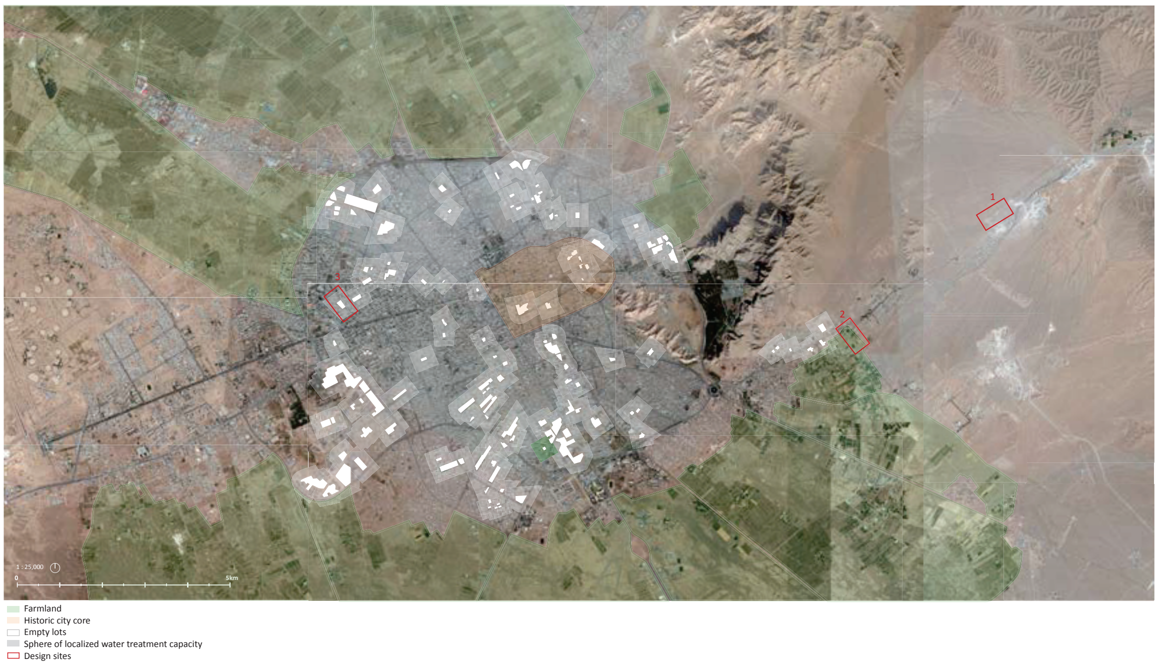


Figure 117: Empty lots of Kerman City (white), and agricultural lands (green). (underlay image Google Maps 2015)

Empty Lots in Kerman City

The above map shows the various empty lots in the city of Kerman that have the potential to be developed with new water-conscious apartment housing. The sites shown in white can have localized greywater and blackwater treatment. The lighter grey areas surrounding them show the potential for neighboring sites to be treated by these sites due to their ability to take on additional capacities. This new proposal brings the responsibility of water treatment right to each site, prepares water for reuse and eliminates the need for costly and distant centralized treatment expansion projects. It also allows for the city expand its residential accommodations at the same density that is required to meet the current rate of population growth.

Figure 118: New City design panel.

New City Perspectives

The newest and fastest growing parts of the city of Kerman have been built over the last 30 years and this area continues to grow as the population and demand for housing increases. In order to accommodate the growing population, the majority of buildings are multi-storey residential walk-up apartments with a concrete or steel frame that is earthquake resistant. The current water supply model delivers clean water to this part of the city and takes both grey and blackwater to a sewage treatment plant 10km away to be treated and used for nearby farmlands. The newly proposed housing scheme offers:

New City Building Features

1. Separate treatment of grey and blackwater.
2. Localized treatment and recycling of water by ecological means.
3. Greening and watering of the housing as well as neighboring streets, with a variety of interior and exterior gathering spaces.
4. Capability to take on sewage from surrounding blocks that are not currently hooked up to the city’s treatment plant.
5. Rooftop rainwater collection system. Solar panels to supply at least half of the buildings water heating and electrical needs.
6. Appropriate siting, building forms and material thicknesses for airflow, daylighting and insulation.
7. Amenities, stores and garages and a greywater carwash on the ground floor
8. Car Free zones

Figure 119: New city building features.

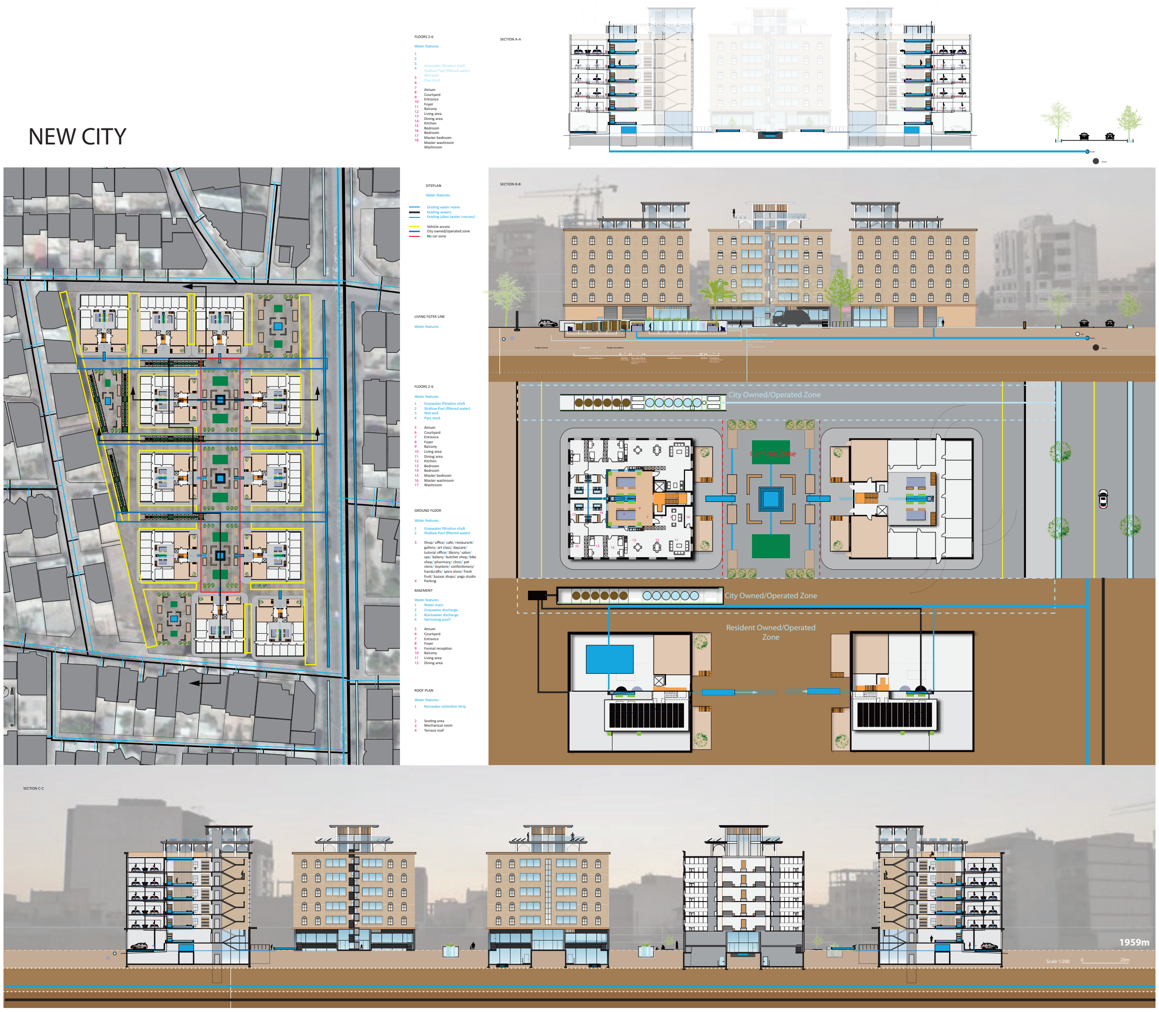


Figure 120: Plan and section of newly proposed buildings and treatment lines in city fabric with attention to water recycling as well as the greenery and pools that create social spaces.

New City Design

The new city is the fastest growing part of every major Iranian city and provides an opportunity for a completely new and vitally operative fabric to become part of the city of Kerman. The newly proposed urban grid is one that provides a walkable community, plenty of green space and shows responsible use of water with respect to ecology, tradition and modern standards at every point of contact. The design proposal is a 6 storey building based on the traditional Iranian courtyard housing typology. The apartments have a central kitchen and spacious bathrooms. Greywater is fed to one wall that delivers the water to a vertical filtration container that purifies the water before it flows into a pool in the atrium, and makes its way down the building and out to the gardens and green walls on site, and finally to the jubes beside the main street. Blackwater is sent to a living system filtration line beside the apartment which cleans the water through a constructed wetland.

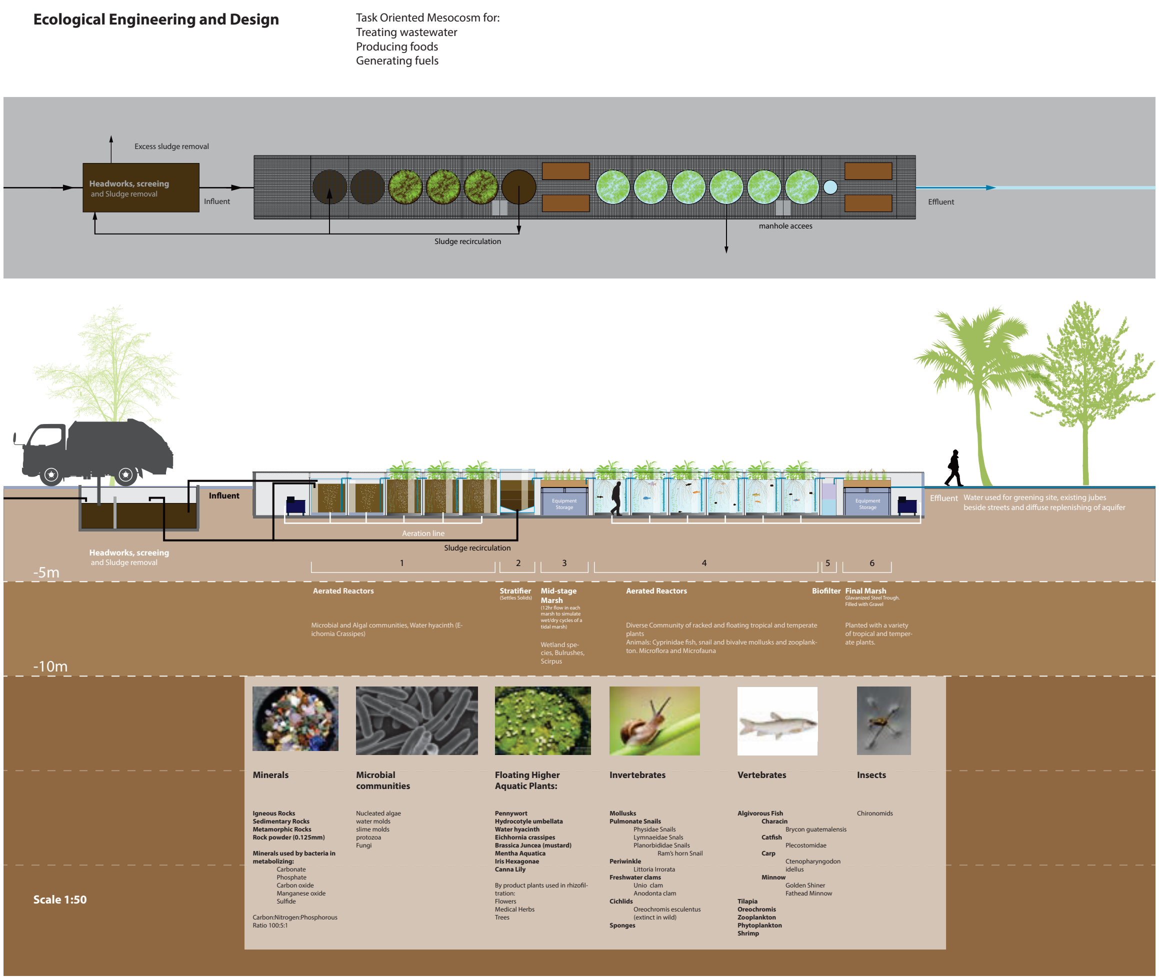


Figure 121: Ecological filtration process of proposed sewage treatment line. (drawn by author based on information from Todd 2003)

Task Oriented Mesocosms and Ecological Engineering

The proposal for a localized blackwater filtration system is a module that can fit in tight urban spaces while performing both the task of cleaning water, greening and beautifying the city, increasing biodiversity and even producing usable goods such as herbs and flowers. The proposed design is based on John Todd's eco-machines and reconfigures the elements to fit in an urbanistic and open air design, that can be assembled on site rather than in a closed, confined, or localized greenhouse treatment space. The ecological and living components of these machines can be selected from local sources. Fish, snails, frogs and plants that would have been previously found only in a qanat setting can become part of the urban fabric once again.

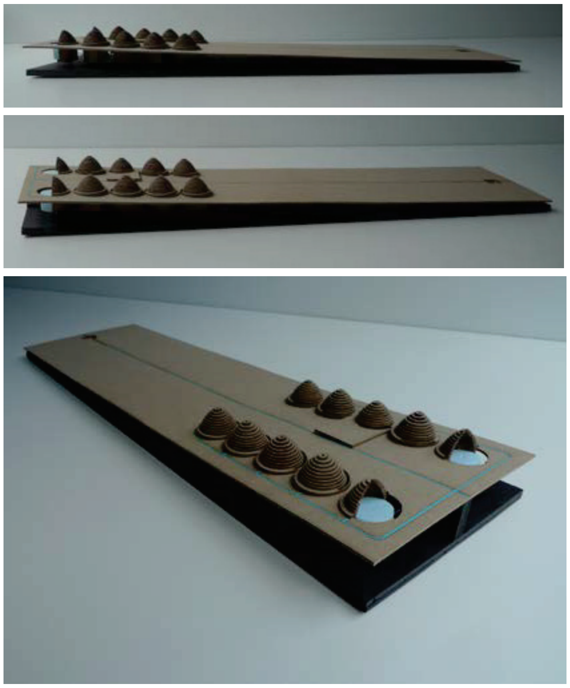


Figure 122: 1:500 physical model of agriculture site, showing a series of 10 water reservoirs and the mazhar located downslope. Each reservoir is filled with qanat water daily and can store the same amount of water as an Olympic sized swimming pool.

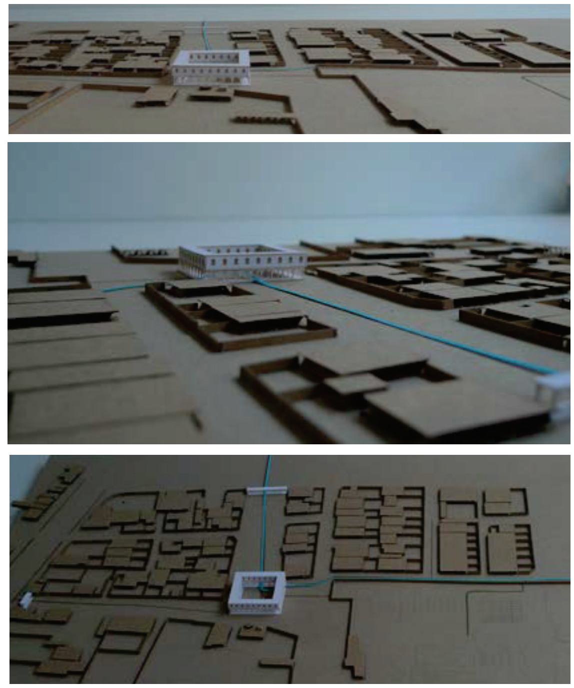


Figure 123: 1:500 physical model of old city site, with the water future pavilion at the center. The organic and intricate structure of buildings as well as their flattness are the key features of this neighborhood and common characteristics of traditional Iranian urban fabric.

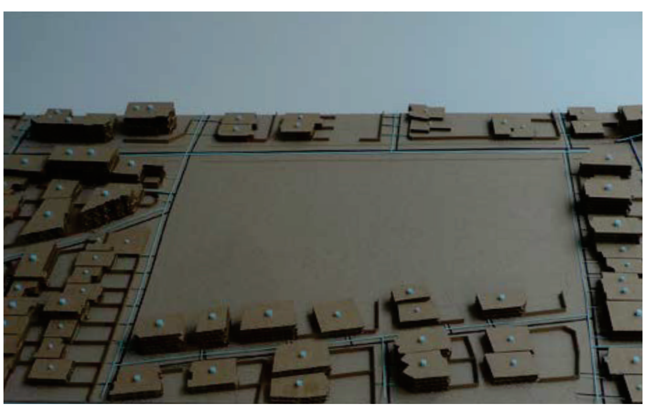


Figure 124: 1:500 physical model of new city site. Small blue cubes represent daily water usage of various buildings and households in Kerman. Blue lines indicate underground piping and black lines show sewage piping. The walled off division of private space used as a garden and/or parking area is the current norm in Iranian housing.

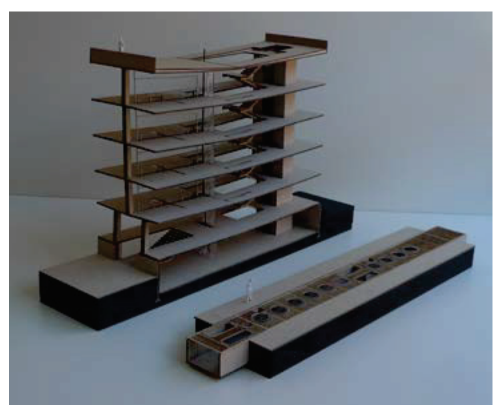


Figure 125: 1:50 physical model of new city water infrastructure integrated in buildings. The grey and blackwater from apartments are separated and the blackwater is sent to a sewage treatment line which is an integral part of the new city.

CHAPTER 5: CONCLUSION

Potentials for Architecture and Water Infrastructure

Our abilities to overcome the limitations and balances of the natural systems embedded in the landscape have fooled us into thinking that they can exist or be sustained without having negative long term consequences. Our attention is drawn to this issue particularly when we reach or are past the point where natural resources can replenish themselves. The current state of infrastructure as a mediator between us and the landscape is detrimental in many ways because it alienates us from natural cycles and abstracts resources into commodities such as tap or bottled water that fit neatly within our built arrangements regardless of their source or supply. The arrangement is useful in some ways because the necessities of life are readily available to us on a consistent basis but what we really need is an infrastructure that brings us closer to natural systems and helps cities co-ordinate themselves with the processes of the landscape. Rather than constantly inputting energy to extract water, we can input appropriately sited infrastructure in the landscape to extract both water and energy from natural processes. For this we can draw lessons from traditional stone mills that use gravity and water pressure for localized power generation. Recycling of water is an important method for efficient water use, therefore grey and blackwater should themselves be a supplier in the system and wherever possible rainwater should be captured and used. While the water and infrastructure of the past has influenced social norms and the daily life of people in a top down way, this does not need to remain the situation as we are in a position that we can optimize the relationship of society to the land and its water resources. Buildings are often designed as a plug-in to be added to the city and hooked up to its amenities after construction, but it is less often considered how they can play a useful role in the vast underground network. Since much of our infrastructure is hidden, it is normally out of sight, out of mind and is only made visible when something goes wrong. It is important to understand the catalysts that influence a change in infrastructure and how lessons can be learned from them in order for new ideas to be promoted to influence and grow in the system.

Water is a vital, versatile and descriptive element that makes life possible and is one of the basic lifelines of a city. The manner in which its power is harnessed, it is enjoyed and interacted with it are all very telling actions about the cultural and technical understanding of a society and an era. As a gauge for the quality of interaction between humans, the built environment and the natural environment, water is a very telling source. Infrastructure is where our technical and cultural understanding comes into contact with the landscape to provide the necessities for the built forms which we call cities.

The Role of the Architect, Engineer and Policymaker

Infrastructure is defined as the fundamental facilities and systems serving a city, country or area. The evolution of these facilities goes hand in hand with technological understanding, social constructs and site specific resources. The factors that have influence over infrastructure include policy, finance, population and construction norms of a region. The role of the architect becomes increasingly important in this discussion as the direction we have been led by policy makers and engineers has so far only provided temporarily acceptable solutions, none of which are forecasted to be sustained for the long term. This is in contrast to ancient systems which were sustainable and lasted for nearly 3000 years, with some still in operation today. Very few people actually understand the systems of infrastructure well enough to have a positive impact on it. Each profession has their own skills and interests. While the engineer will have mastery of the technical aspects of the system and bankers and politicians will have the skills to finance operations and construction companies will be able to mobilize human and material resources, the nature of their professions limits their scope. While the architect is not an expert in technical details or finance, the nature of the profession allows for a view that encompasses technology, culture, history, landscape and design. The architect can bring in information from numerous sources and compile them into a comprehensible package so one can visualize and understand the full scale and scope of the problems and possibilities. Once this has been achieved, the architect, the engineer and the policymaker can have a hand in an educated and appropriate intervention.

Preparing for the Future

There are currently several large scale nationwide projects underway to deal with the issue of water scarcity in Iran. Resources are being put toward desalination plants, pipelines from one city to another, water shipments, dams and expansion of sewage treatment facilities. Although these are impressive large scale feats of engineering that have their own strengths, the big questions remain. How long can they be sustained? At what environmental, ecological and energy cost? Do they address the root causes of Iran’s water issues? Do they add social and cultural value to our built environment? Do they bring us closer to the landscape or isolate us from it? Is the large amount of investment and time required to build this infrastructure providing maximum monetary and cultural return?

As fresh water resources deplete, tensions around water provision will increase, and a state of panic and distress will only allow for short term fixes. A long term vision and planning process for water sustainability in the built environment must be undertaken. The proposals that have been made in this thesis are in contrast to large scale feats of engineering, and as such they can take on a localized role and be implemented on a smaller scale, much more quickly than any provincial or national project. In order to prepare for future water scarcity conditions of the country, a water-architecture research facility should be established to test a full scale prototype of each of the proposals made in this thesis for the agricultural and domestic sectors of the old and new city. The first prototypes could be sited in the proposed sites or the many empty lots available in Kerman. This facility could serve as a national and international resource for the development of sustainable water infrastructure through appropriate architecture and design, with a focus on arid climates. The purpose of this new facility or facilities would be to perform rigorous testing for water safety, durability, cost effectiveness, efficiency and usability of the new proposals. This would be an ongoing research facility that would require the collaboration of architects, engineers, biologists, designers, planners and policymakers. The ultimate goal would be the integration of the water preservation designs as a new urban grid with architectural elements that can become the new construction norm for Kerman and address its water related problems. The success of this water-architecture integration could then be used to inform water conservation projects in other cities.

APPENDIX

Rossetti Scholarship Research and Site Visits

In January 2014 I visited Iran for a month and a half as part of a travelling research scholarship called the Bruce and Dorothy Rossetti Scholarship. During this time I visited over 10 cities and villages in the dry central Iranian Plateau as well as the southern coast and islands of the Persian Gulf in the pursuit of an understanding of the current water situation in Iran, as well as a discovery of ancient methods and systems of water delivery. I spoke to Yazd and Kerman water history experts. I visited numerous qanats, historic and modern water infrastructure sites as well as historic housing and public spaces that had a strong tradition of water usage. The work was presented as part of an exhibition at Dalhousie in October 2014.

After conducting a term of thesis preparation work, I visited Iran again for another month in December 2014 with a specific focus on Kerman city. I spoke to many people currently working in the field including Kerman Water Authority engineers, a Kerman city councillor, and a Kerman historian. The design work was done in two terms at Dalhousie following my return to Halifax. Unless otherwise stated, the pictures shown have been taken by myself during first hand site visits. Charts, graphs and diagrams have also been drawn by me based on previous maps, site visits, interviews or data from noted sources.

Figure 126: Exhibition of Rossetti Research at Dalhousie School of Architecture, October 2014.

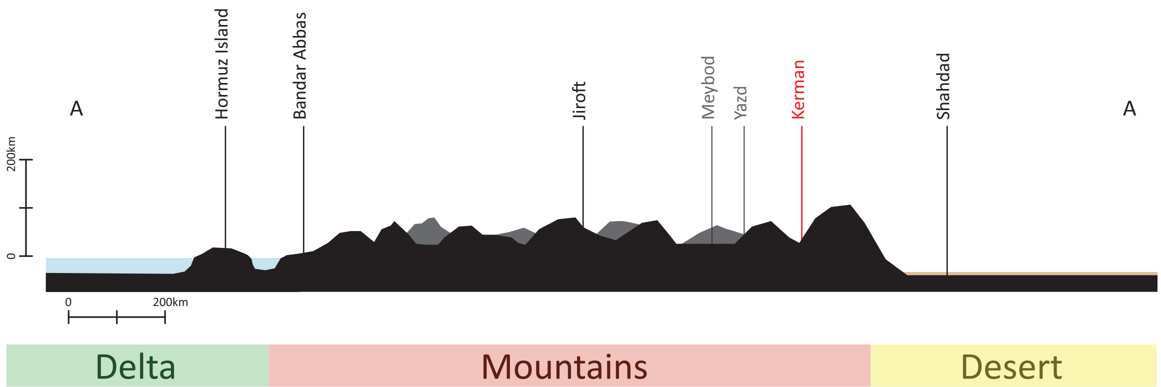


Figure 127: Section through region of study in the from the coast to the central Iranian Plateau.

Figure 128: Map of Iran with major mountain ranges, and showing the delta, mountains, and desert of region of study (UT Scan)

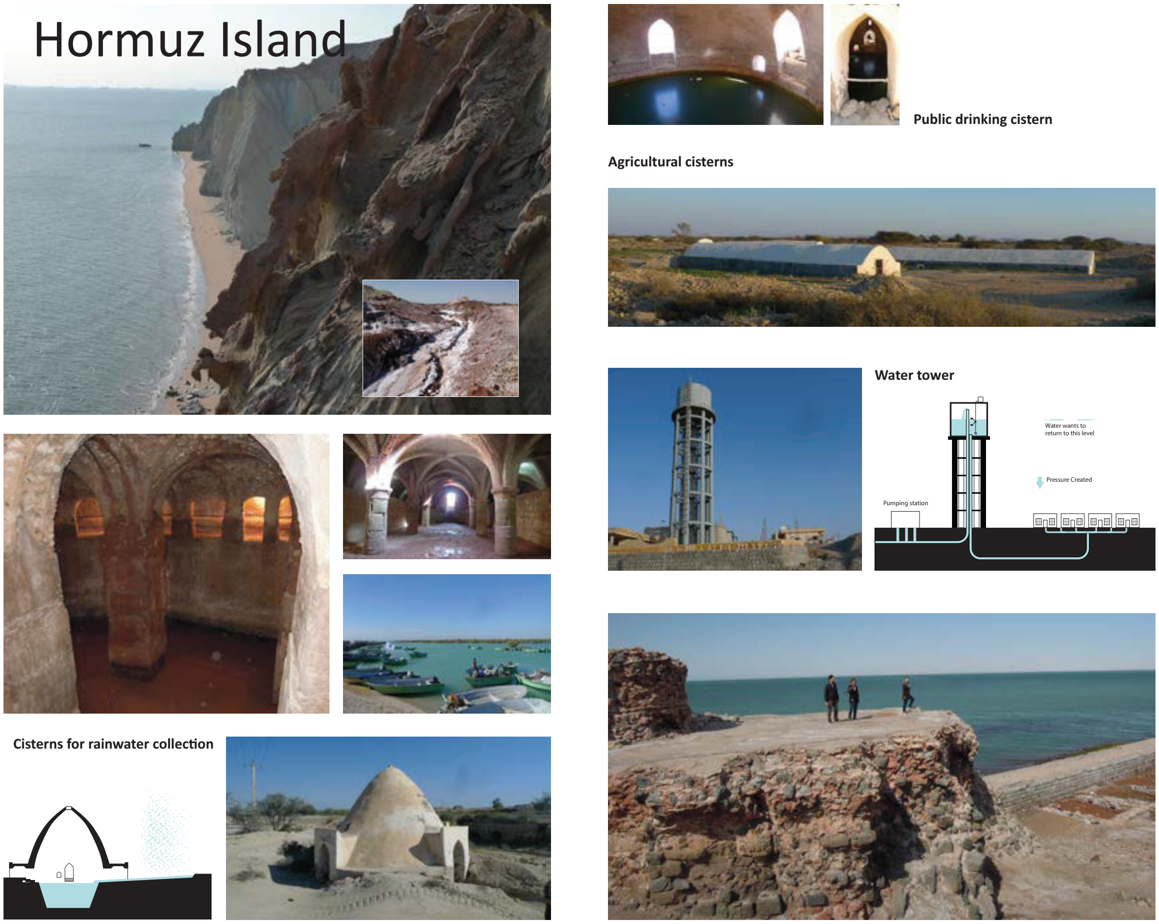


Figure 129: Rossetti Exhibition Panel 1 (October 2014)

Hormuz Island

Hormuz and Qeshm are two islands in the Persian Gulf where the salinity of the local water makes it unusable for drinking or irrigation. Instead, rainwater traditionally was collected in cisterns for use by the residents. This infrastructure still remains in place, although it is obsolete and the water in the cisterns is no longer drinkable. The cisterns take different shapes. Conical reservoirs allow for indirect reflection of sunlight while openings allow for airflow and cooling of water. Long cisterns capture more water and are used for irrigation purposes. An old Portuguese fort on the island of Hormuz has a particularly large cistern made from rocks and coral. The coral was used to filter water, as its calcium prevented mold growth. Its neighboring island of Qeshm has become a commercialized free trade zone, while Hormuz has remained relatively unaltered, although the soil on Hormuz is exported by the boatload because of its attractive colors and its use in cosmetics. The island currently has a small desalination plant that provides for the water needs of the island’s inhabitants, while water towers help maintain adequate pressure.

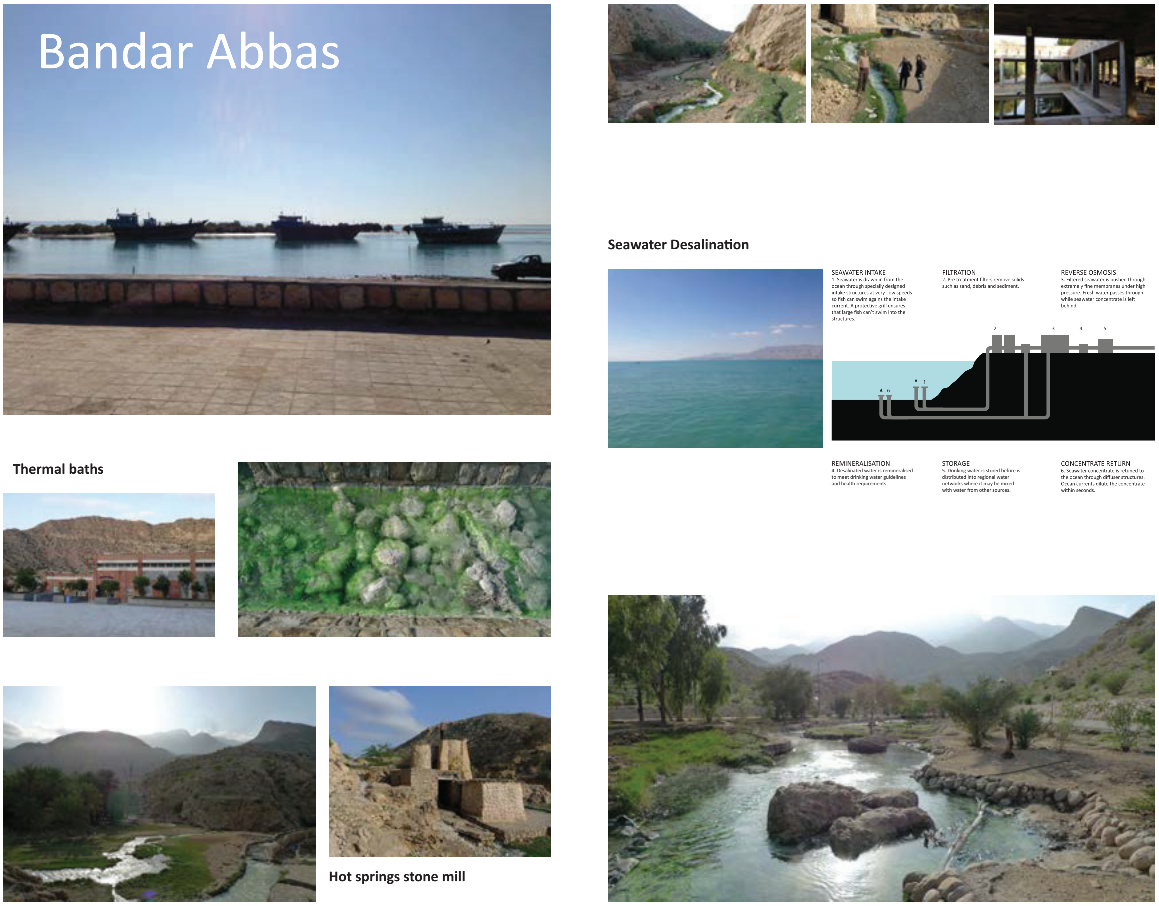


Figure 130: Rossetti Exhibition Panel 2.

Bandar Abbas

Bandar Abbas is a fast growing port city in the Hormozgan province of Iran. Due to the deterioration of water resources in many areas of Iran, a reverse osmosis desalination plant is being constructed to supply fresh water to distant cities. On the outskirts of Bandar Abbas is an area called the Geno Biosphere Reserve, with a total area of 27,500 hectares. It was designated as a protected area by the Iranian Department of Environment in 1976. The water from the hot springs in the area contains sulfur and attracts many tourists for its healing qualities.

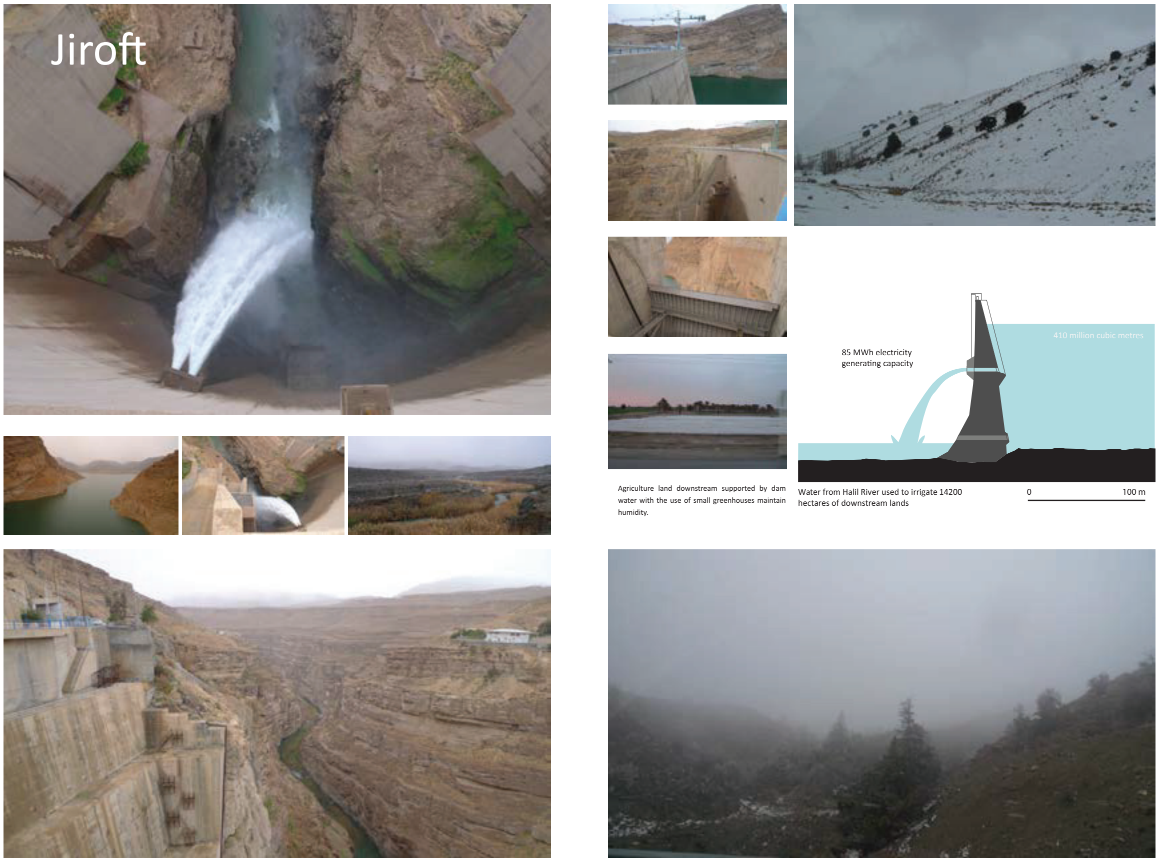


Figure 131: Rossetti Exhibition Panel 3.

Jiroft

Jiroft Dam is situated in the province of Kerman, on the Halil River 40 km northwest of Jiroft City, in the narrow valley of Narab. The dam is a hydroelectric and irrigation dam with an electrical generating capacity of 85 MWh. Construction was started in 1975 and completed in 1992. Its reservoir capacity is around 410 million cubic metres up to its normal level. The height of the dam is 134 meters and its crest length is 277 meters. In its first year of operation the dam survived an extraordinary flood with a peak discharge of 5,035 cubic meters per second. The spillways and other hydrodynamic outlets of the dam can discharge up to 6,500 cubic meters per second. Located in the mountains at an altitude of 1,185 meters above sea level, the region's microclimate creates humidity and precipitation conditions that recharge the reservoir. Large-scale concrete dam construction in Iran started in the 1950s to meet the demands of the rising population. The increased use of dams in Iran has been criticized for causing damage to sensitive ecosystems and diminishing vital water supplies downstream. Archaeological excavation of this region has revealed the remains of an ancient city and the presence of the Jiroft civilization, which dates back to at least the late third millennium BC, with its heyday from 2500 to 2200 BC.

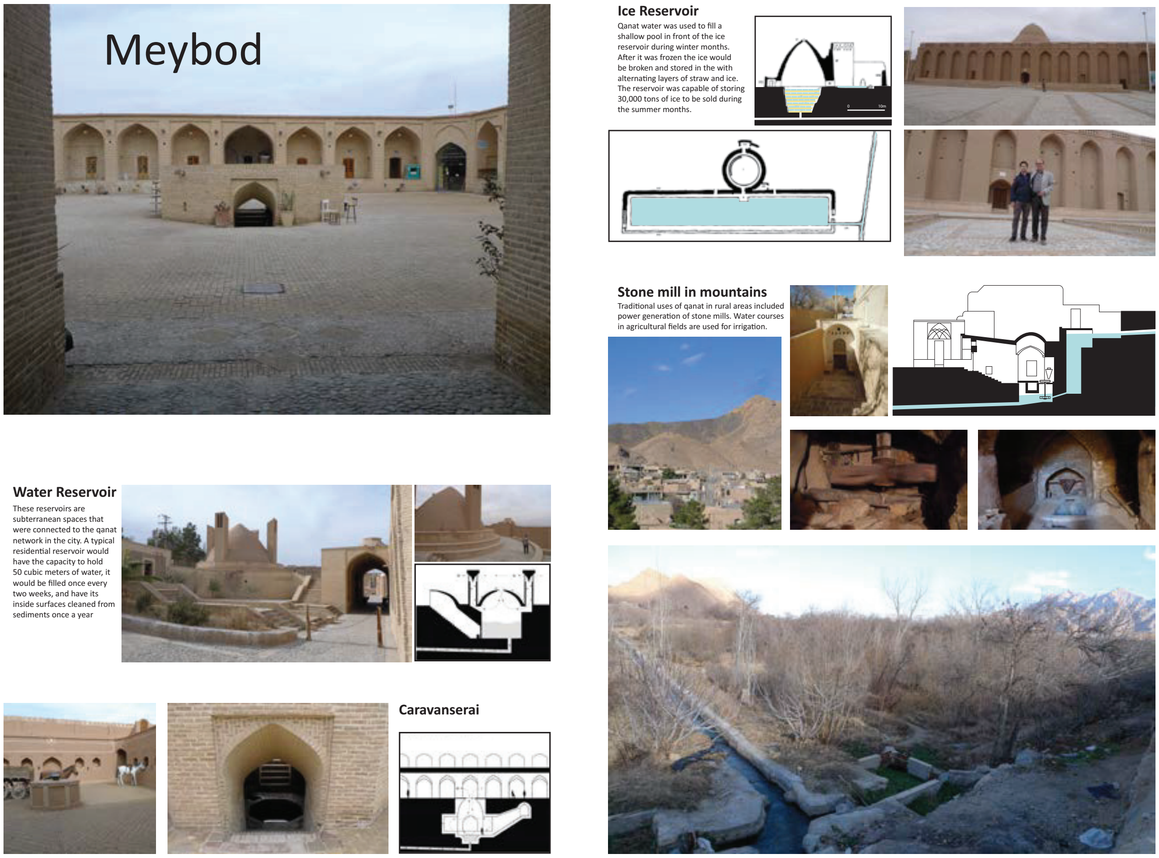


Figure 132: Rossetti Exhibition Panel 4.

Meybod

Meybod is a small town north of Yazd. It is the location of a series of well-maintained ancient water supply structures that have remained in operation until only fifty years ago. The area has a caravanserai where desert travelers traditionally would have stopped for rest, food, and water, for both themselves and the animals that travelled with them. As in Yazd, Meybod has a non-functioning water infrastructure that was once supported by qanats. It includes an ab anbar (water reservoir) that was filled every two weeks during the night to provide clean drinking water, as well as an ice house capable of storing 3000 tons of ice throughout the year, to be sold for the preparation of drinks and desserts and for storing perishable goods. The payab (access point for water) was centrally located in the caravanserai and still has water flowing through it, although it is not clear whether this water comes from pump wells or a qanat.

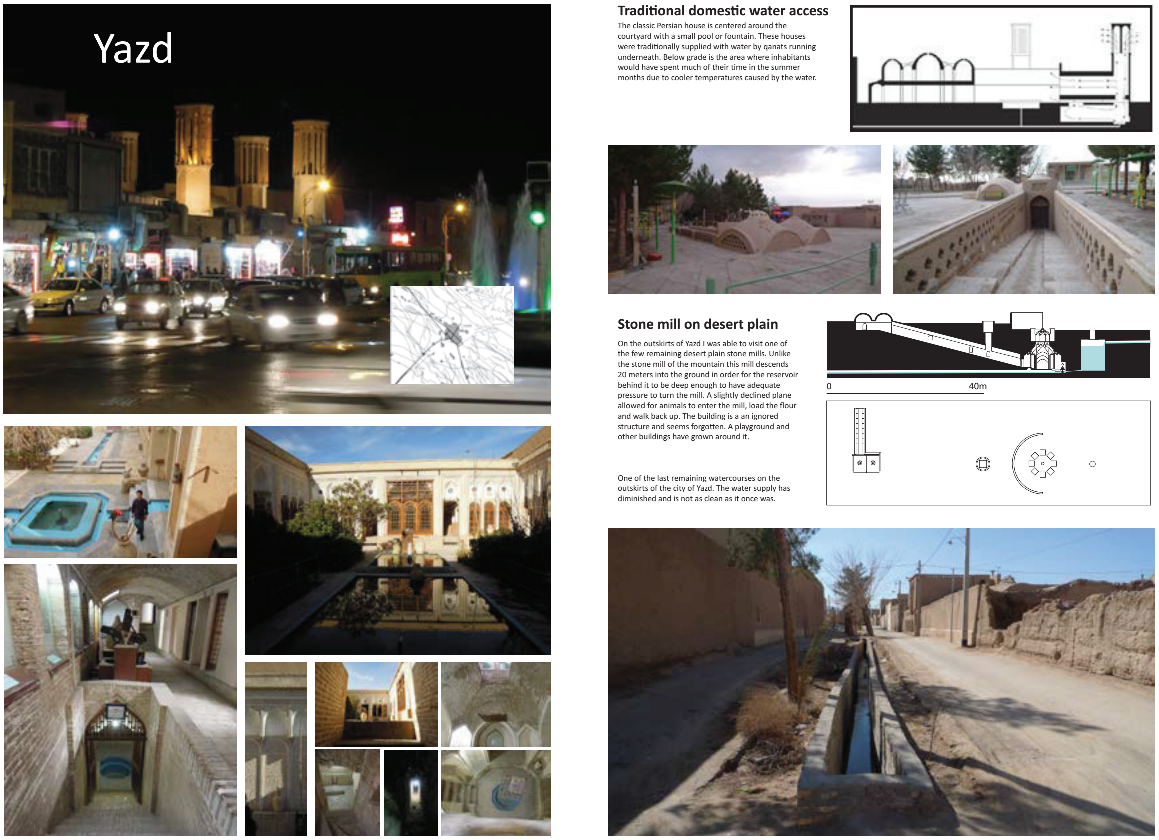


Figure 133: Rossetti Exhibition Panel 5.

Yazd

Yazd is one of the driest major cities in Iran, with an average annual rainfall of only 60mm. Qanats historically played a major role in fulfilling the city's water requirements, although they now have a diminished role, due to the modern use of deep wells and pumps. The Yazd water museum is located in the historic city core, in a house built over 120 years ago. With two qanats running underneath, it is an example of how fresh qanat water was accessed below grade in residential buildings, was used for cooling and food storage during the hot summers, and was brought to the surface in the courtyards. Unfortunately, all but one of the many underground qanat channels in Yazd have been rendered useless because of excessive deep well drilling and the lowering of the water table. From 1974 to 2013 the water table dropped twenty meters (from 1,130 to 1,110 meters above sea level), an average of .5 meter per year. Although the infrastructure for qanats still exists under the city, I was told that there is no chance of it being functional again. Over the years, people emptied sewage into them. In some places they were blocked off by new building foundations. In other areas, the qanats caved in due to lack of maintenance so none of the former qanat lines are still complete. I visited the only remaining qanat, which provides water to a rural area on the outskirts of Yazd, where it irrigates agricultural lands.

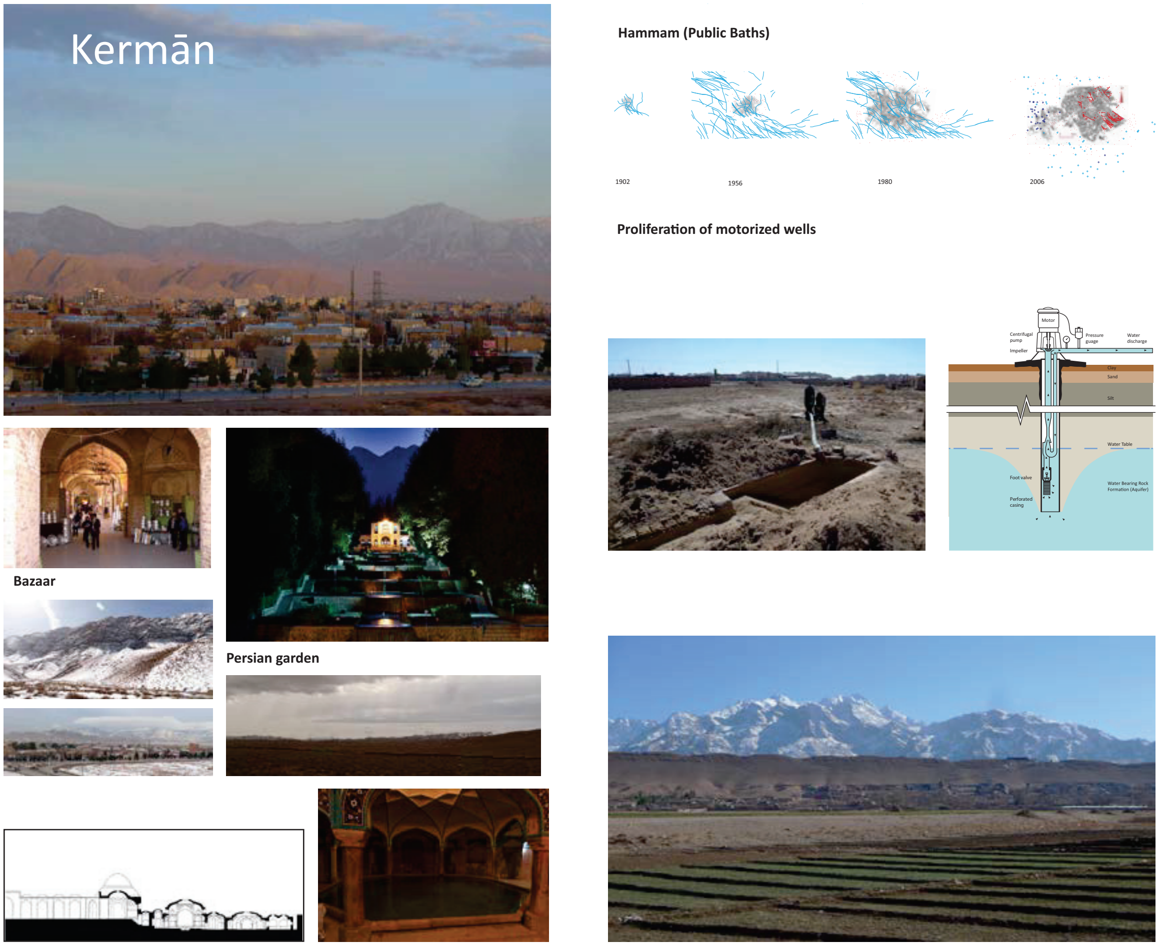


Figure 134: Rossetti Exhibition Panel 6.

Kerman

Kerman is located on a desert plain between two chains of mountains. Its qanats once passed below the urban fabric and supplied water to the city. Today there are virtually no operational qanats in the city, but some remain in the smaller surrounding towns. In the historic core the water needs traditionally were satisfied by the qanat that supplied the hammam (public bath), water reservoir, ice reservoir, and private homes. The city has grown at a rapid pace since the 1970s and has experienced a shift of water infrastructure from qanats to pump wells. Rather than having water flow from the mountains through the qanats and into the city, water is extracted directly out of the ground, using deep pump wells. The historic city core is disconnected from the water supply of its past. Inhabitants generally are not aware of the qanat network below the city. On the outskirts of Kerman is the Shazdeh Garden, a traditional Persian garden supported by qanats that flow from the mountains into the garden grounds, using gravity and water pressure to supply the fountains. This is a very popular site for local residents and tourists.

Figure 135: Rossetti Exhibition Panel 7.

Shahdad

Shahdad is located about 50 km from the Lut Desert, which has some of the highest recorded temperatures on earth, reaching 70.7°C according to NASA. I stopped at the intersection of several qanats where there is a small village surrounded by agricultural lands that grow dates and wheat. I spoke to a few locals who said that the qanats in the area are still operating because there are no wells in the area. People tried wells but the aquifer did not go deep enough. The water table was reached at 9 meters but the lower aquifer was in the range of 20-80 meters. To repair and maintain the qanats in this area, they have been lined with concrete rings to prevent them from caving in. Historically, these rings would have been made out of clay. There are a number of castles and caravanserais in a state of disrepair at Shahdad and in the surrounding area. North of Shahdad is a village where dwarf humans from the Aratta civilization are said to have existed around 6000 BC. This is also where the world's oldest metal flag was found.

Key Maps and Images from Research

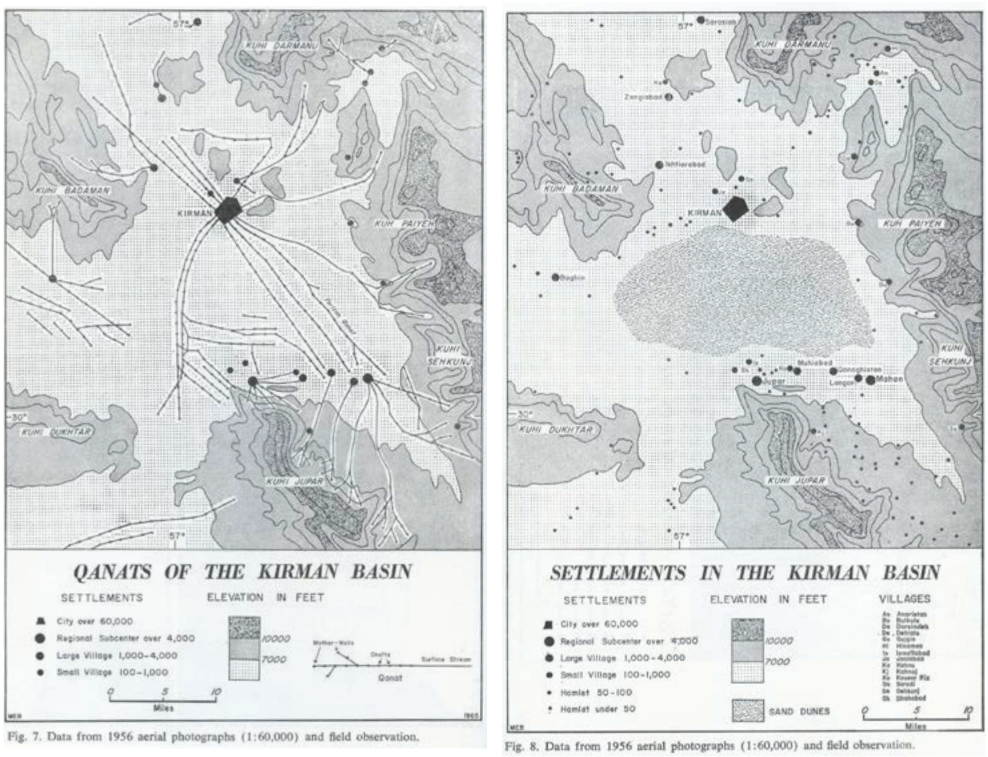


Figure 136: Qanats of the Kirman Basin and Settlements in the Kirman Basin. (Ward-English 1966)

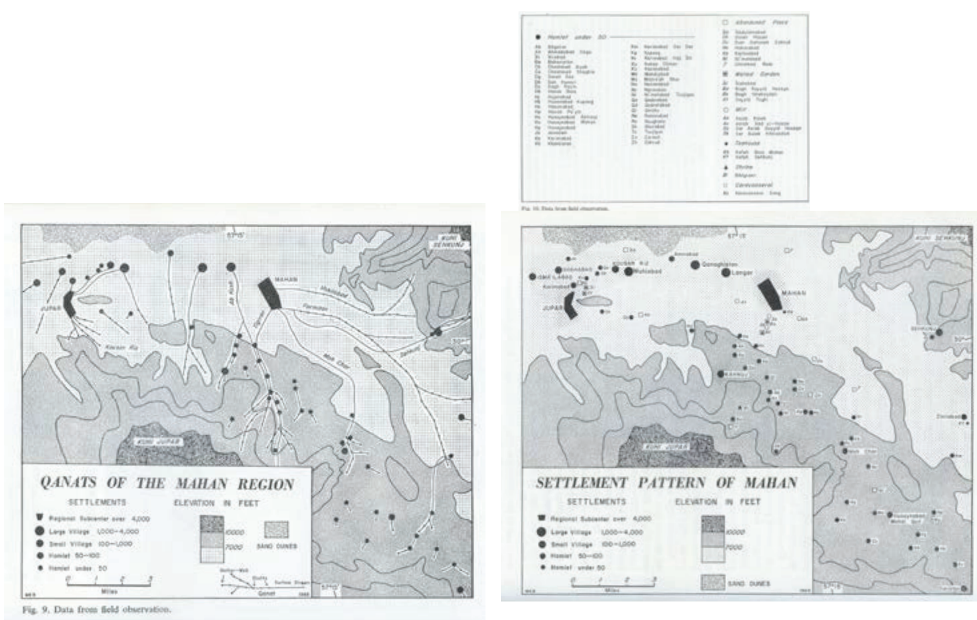


Figure 137: Qanats of the Mahan region and settlement pattern of Mahan with list of towns and populations.. (Ward-English 1966)

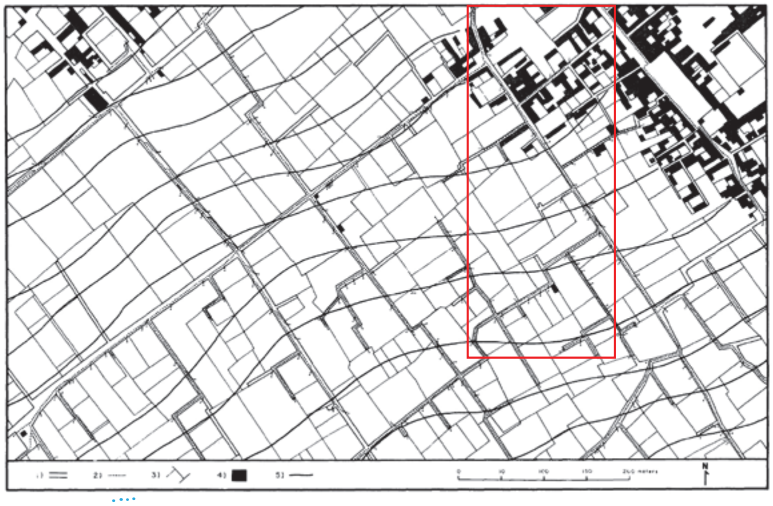


FIG. 12. Rectangular walled fields and orchards in Taft. Note also the irregular terraced fields, which are located in an area of steep topography in this dispersed valley town.

Figure 138: Streets and irrigation channels among walled fields in Mehriz. 1) streets and alleyways, including cul-de-sacs; 2) water channels, shown only in public space and where entering fields; 3) walled fields and orchards, 4) residential and public buildings; 5) contour lines, one meter intervals decreasing in elevation to the southeast. Source: Iranian national Cartographic Center, "Mehriz (Yazd)" (Scale 1:2,000), Sheet 5, 1346 [1967/68]; street pattern checked and corrected, and irrigation channels added by the author in the field; contour lines were interpolated from spot elevations on an unknown datum. (Bonine 1979)

Figure 139: Note the 20-90° rotation of water courses in relation to the slope of land. Divisions of land plots as well as dwelling formations are a result of this relationship, which allows water to flow with gravity to either the left or right direction. Such lessons about efficient siting as well as direction, redirection and continuity of water can be taken much further with new designs.

Figure 140: A major irrigation channel and street in Mehriz. (Bonine 1979)

Figure 141: Diverting water from a main channel into a walled orchard in Mehriz. (Bonine 1979)

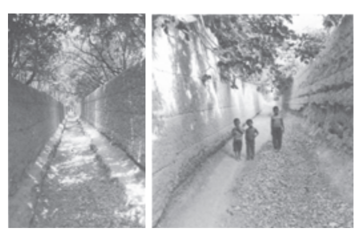


Figure 142: A minor irrigation channel and lane (cul-de-sac) in Mehriz. (Bonine 1979)

Figure 143: Typical rectangular fields of korts in central Iran. (Bonine 1979)

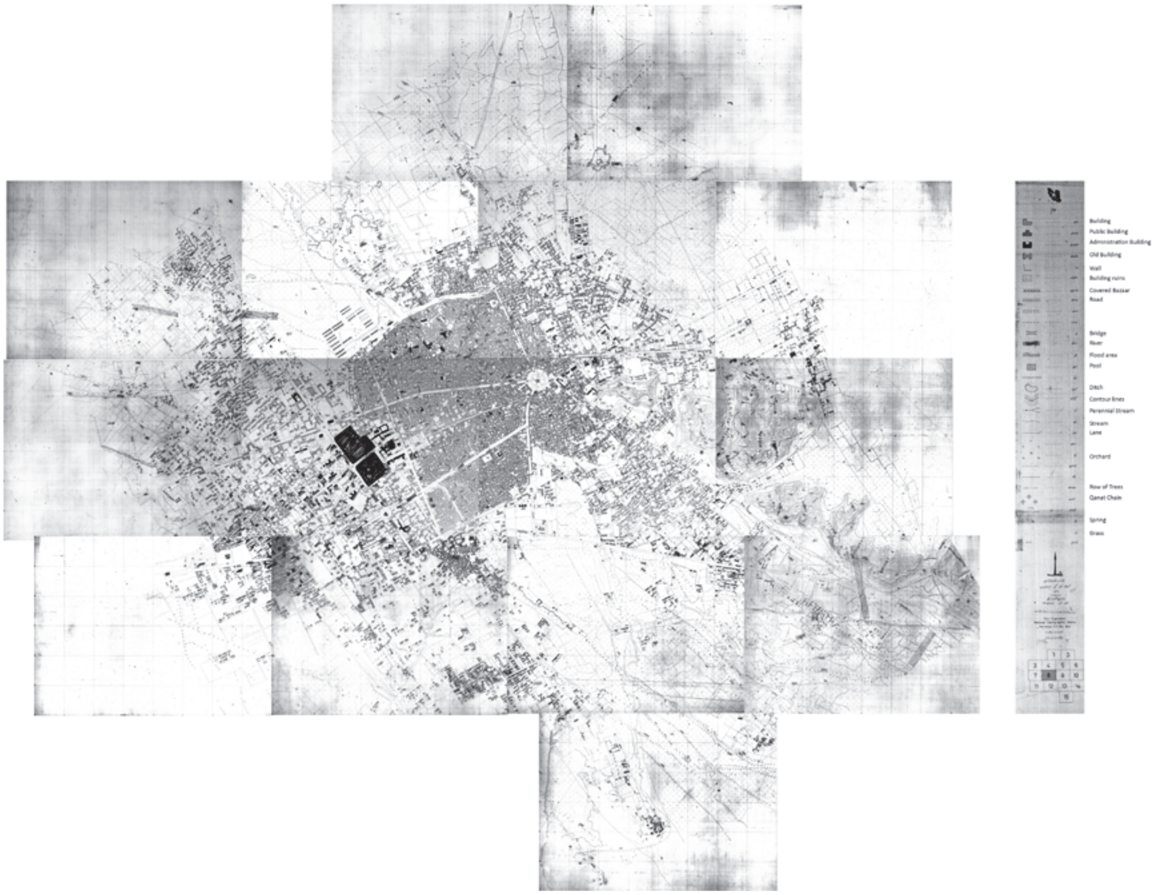


Figure 144: Map of Kerman City, The location and position of qanats as they relate to settlement patterns is visible. The agricultural roots and change in density of the newest parts of the city built over the last 50 years are also evident when comparing this with the situation today.
Original scale 1:2500 (National Cartographic Centre of Iran 1964)

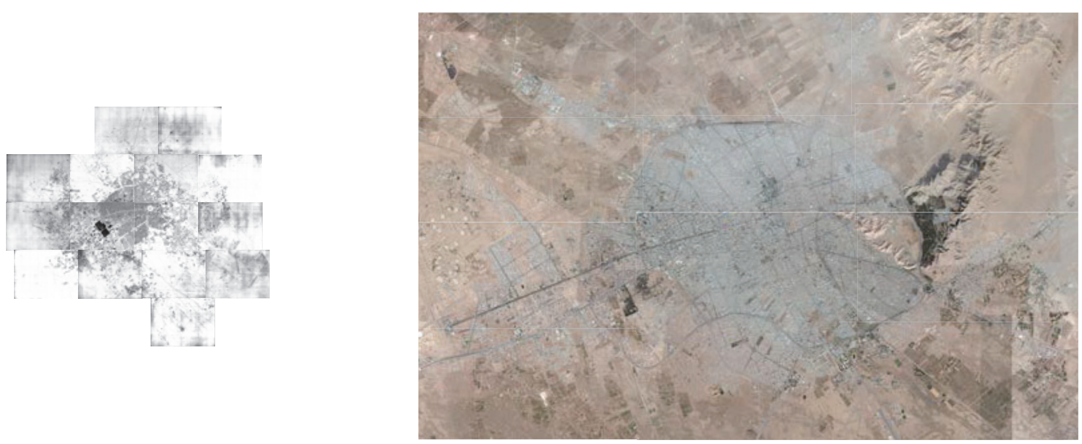


Figure 145: A comparison between the above map from 1964 to the satellite image from 2015 at the same scale shows the growth of the city over and the past 51 years. The majority of what exists today has been built during this period. As an indication of the amount of growth the new city would fall outside of this map on the left hand side.
(National Cartographic Centre of Iran 1964, Google Maps 2015)

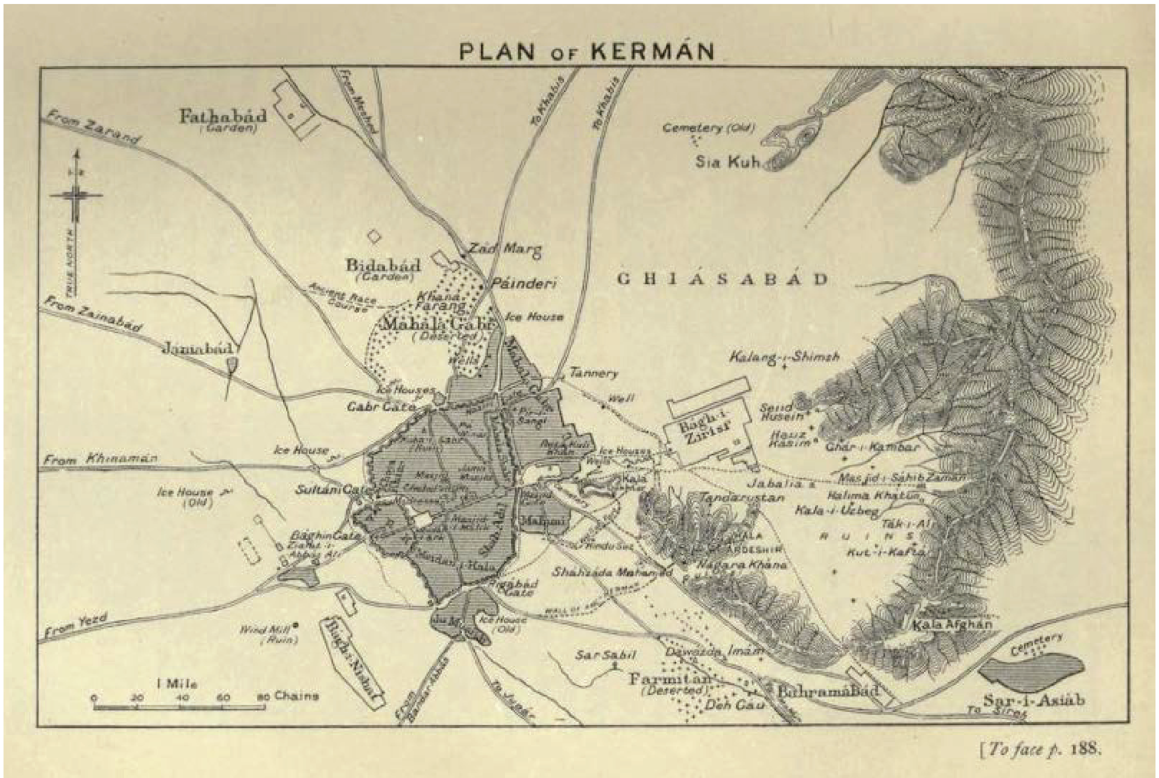


Figure 146: Plan of Kerman. This map indicates the main thoroughfares of Kerman as it was on a historic trade route. It shows the old city wall, gates, bazaar and a number of ice houses and wells outside the city walls. The Gal-e-Dokhtar (right) forms part of Kerman's recognizable foothills and is the site of ancient forts.(Sykes 1902)

Figure 147: The Ancient Forts of Kerman. (Sykes 1902)

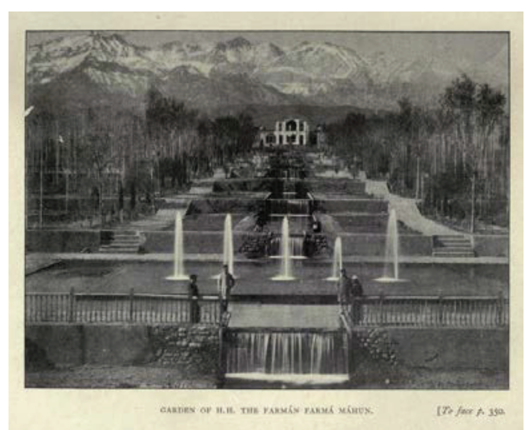


Figure 148: Garden of H. H. Farman Farma Mahan. (today called "Bagh-e-Shazdeh" meaning "Prince's Garden") (Sykes 1902)

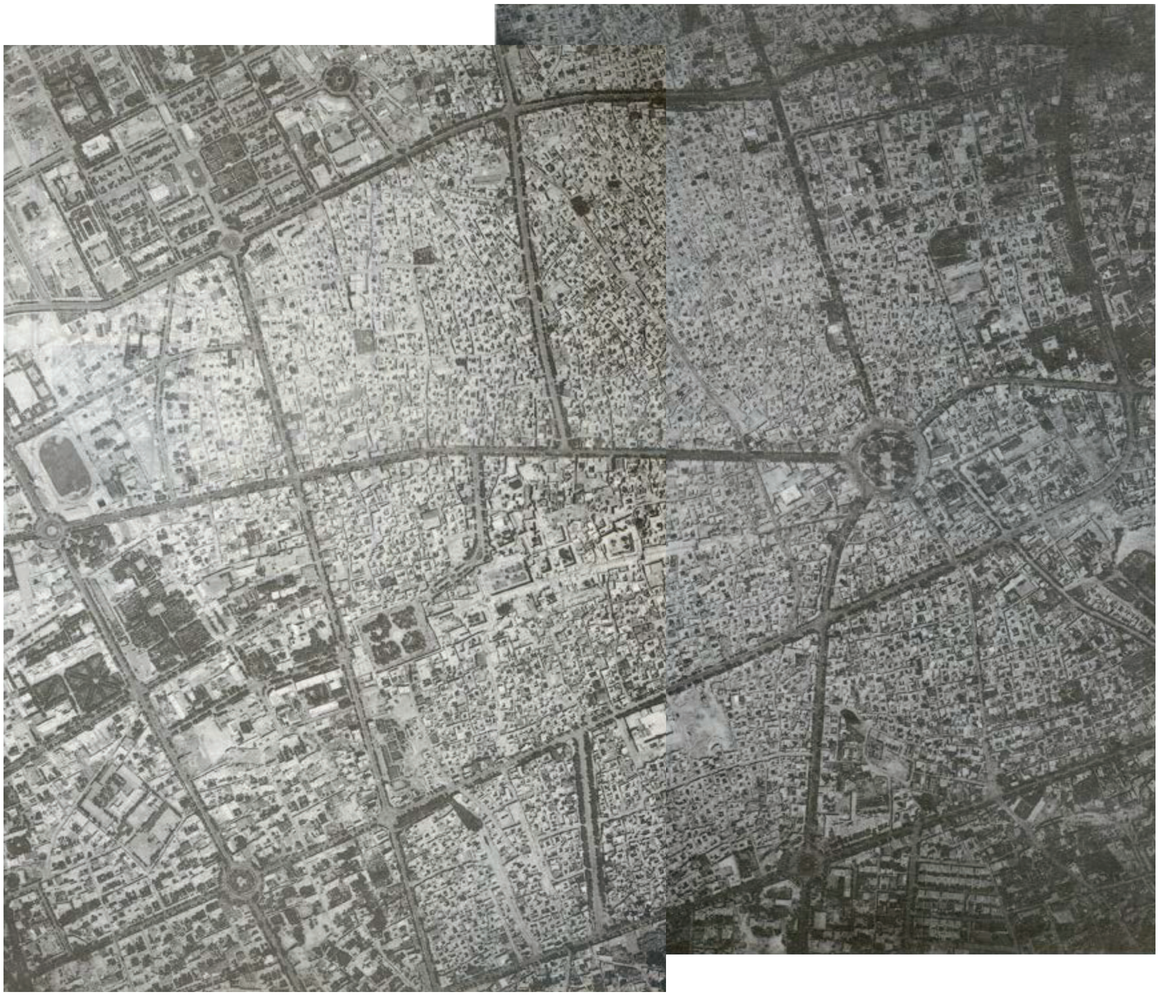


Figure 149: Aerial Photograph of Kerman city core. The bazaar which is the longest in Iran is a central and significant part of the historic urban fabric. The difference in form and scale between the old city and new developments (left) is visible. (National Cartographic Centre of Iran 1960s)

TABLE 3
Construction of Buildings, Kirman City, 1956

Dominant material	No. of units	% of total
Baked brick	445	4
Baked and sun-dried brick	8,597	68
Sun-dried brick	3,188	25
Mud	115	1
Wood	2	..
Other	3	..
Not reported	247	2
TOTAL	12,597	100

Source: Government of Iran, *Census District Statistics of the First National Census of Iran, Aban 1335 (November 1956)*. Vol. 17, Part 1 (Tehran: Department of Public Statistics, Ministry of Interior, Government of Iran, 1960), p. 51. See comparative figures for Shiraz in John I. Clarke, *The Iranian City of Shiraz* (Durham: Department of Geography, University of Durham, 1963), p. 21.

Figure 150: Construction of Buildings, Kirman City, 1956. (Ward-English 1966)

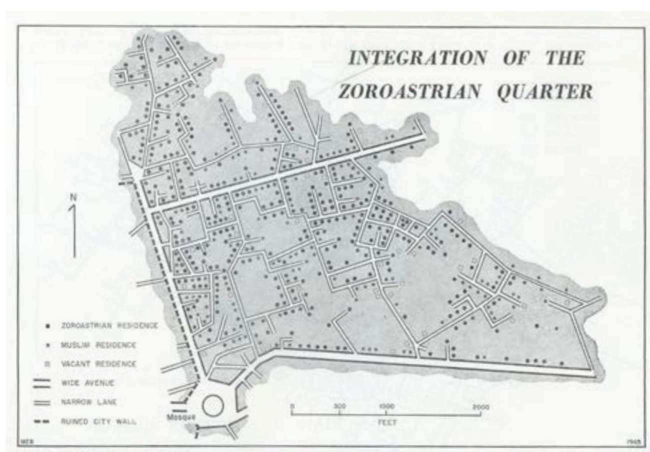


Fig. 13. Data from field observation.

Figure 151: Integration of the Zoroastrian Quarter. (Ward-English 1966)

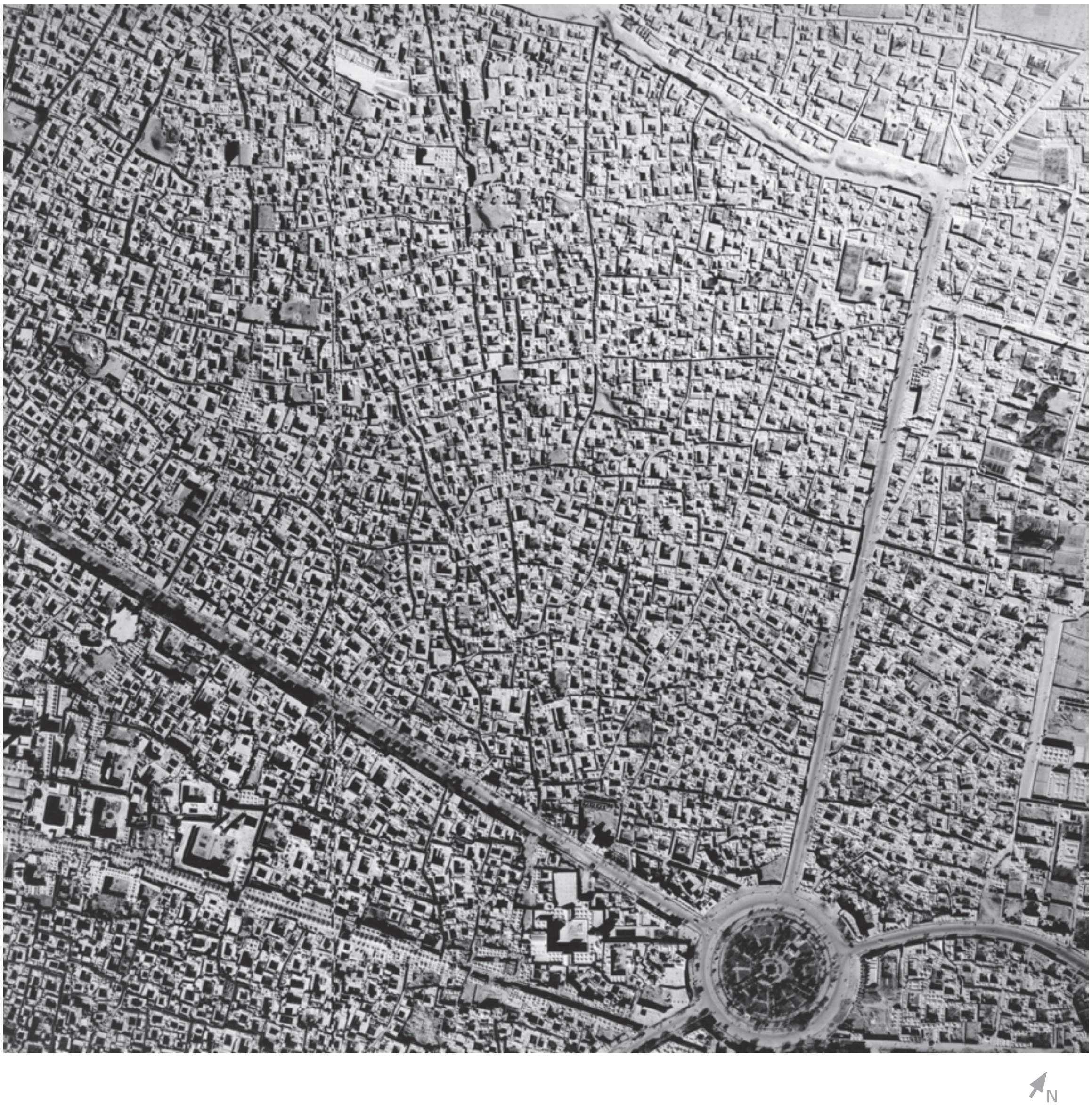


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Figure 152: Aerial Photograph of Kerman city core. The difference in scale and density of public courtyards such as caravanserais and market courtyards is visible when compared to those that are private residential. The courtyard form and domed roofing helps with climate control and heat dissipation. (National Cartographic Centre of Iran 1960s)

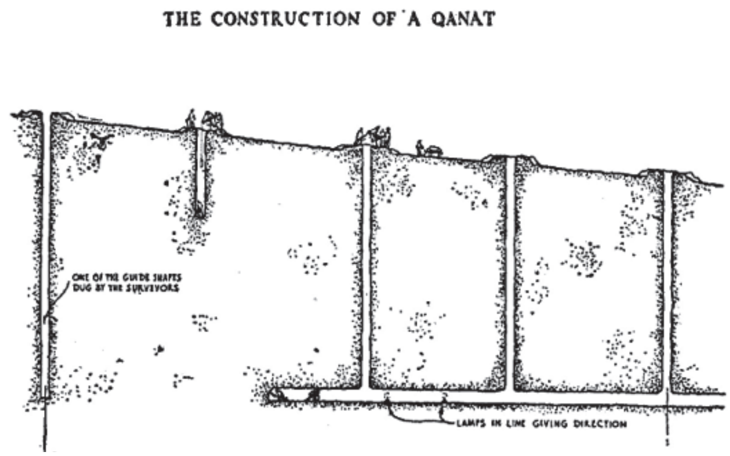


Figure 153: Stages in the construction of a qanat. (Smith 1953)

Figure 154: A winch bringing the spoil to the surface. (Wulff 1966)

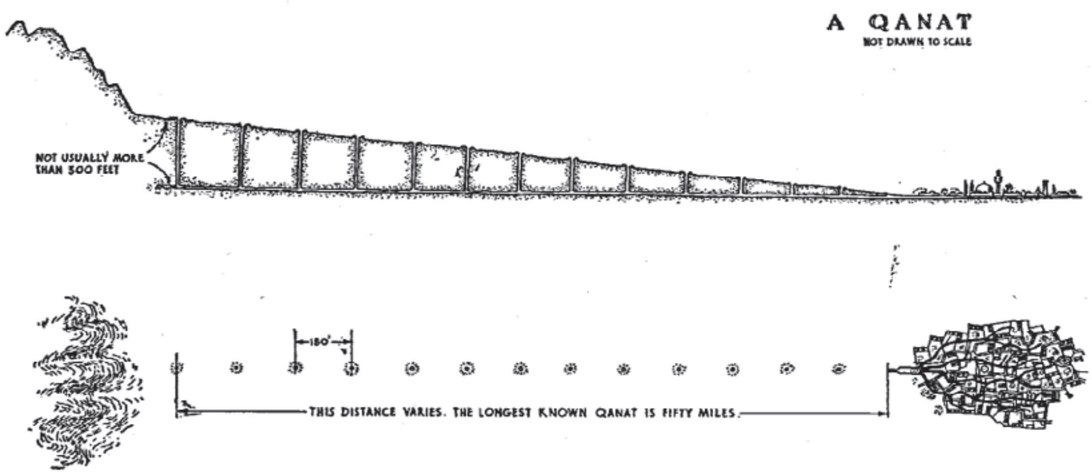


Figure 155: A Qanat. Note the depth of the mother well ~300 feet (90m) and distance between wells ~180’ (55m). The distance of the longest known qanat: 50mi (80km). (Smith 1953)

Figure 156: Qanat-lining hoops. (Wulff 1966)

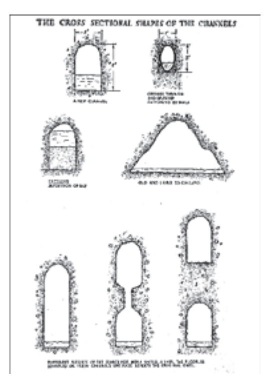
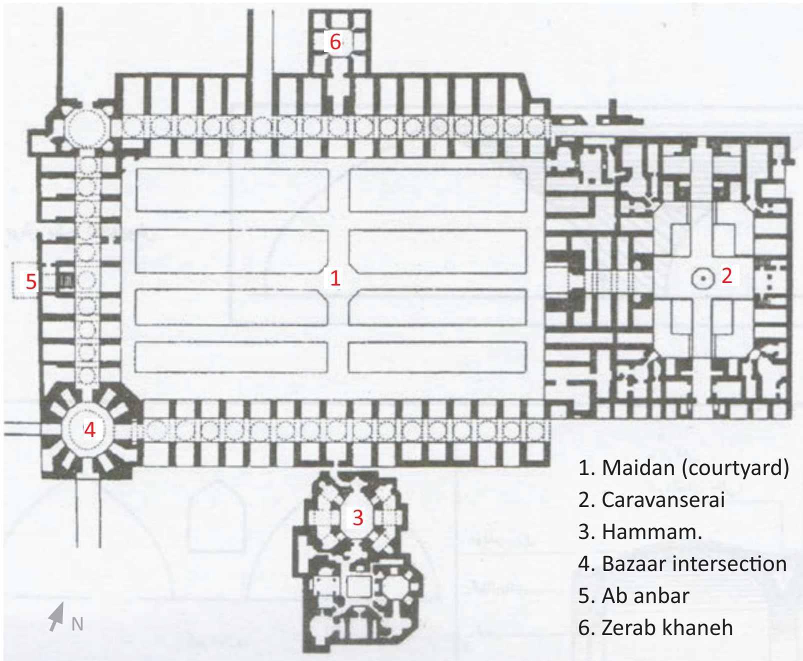


Figure 157: The cross sectional shapes of qanat channels. (Smith 1953)

Figure 158: The mouth of a qanat. (mazhar) (Wulff 1966)



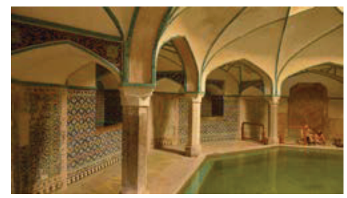


Figure 159: The Hammam in the Bazaar (Public Baths in the Market)
The Ganjali-Khan public baths can be seen at the bottom of the image. (photos from 2014, plan by Resouli 2013)

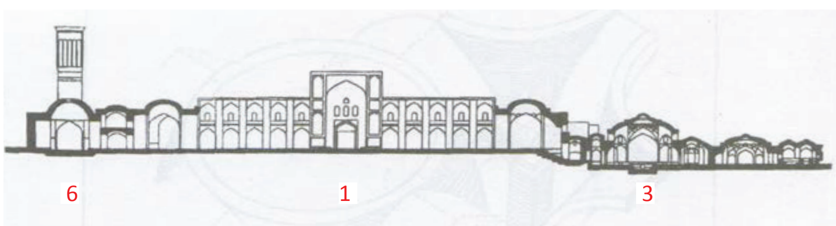


Figure 160: Section of the Hammam in the Bazaar. The bazaar courtyard, domes and windtower are features of this public space. Note the grade change in the baths (right) to access qanat water running below. (Resouli 2013)

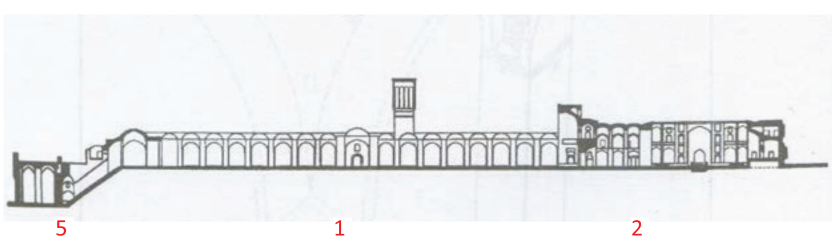
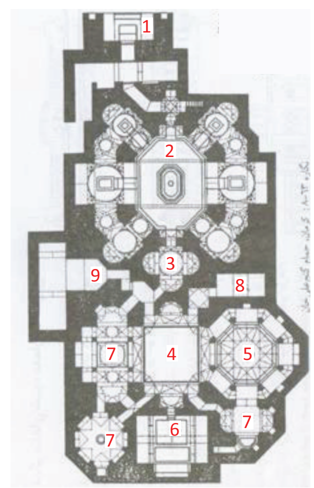


Figure 161: Section of the Ab anbar in the Bazaar section. Note the grade change in the ab anbar (left) to access qanat water running below. (Resouli 2013)



1. Entrance
2. Disrobing area
3. Foyer
4. Warm bath area
5. Cold bath area
6. Khazeeneh
7. Pool
8. Light room/wax area
9. Washrooms

Figure 161: The Ganjali Khan public baths. (plan by Resouli 2013)

Figure 162: Mahan; In the 1880s, the Governor of Kerman built Bagh-e-Shazdeh (the Prince's Garden) in the desert near Mahan. The Persian word for royal hunting gardens lives on in other languages as "paradise".
(photo taken 1977, Gerster 2008)

Figure 163: A water reservoir in the organic and tightly knit fabric of Yazd (top) and a water reservoir in a desert context on the outskirts of Yazd (below).
(photos taken 1977, Gerster 2008)

Figure 164: The tepe outside this village in the foothills of the Zagros mountains, Northwest of Ilam, testifies to an ancient settlement close to the point where two brooks exit from their respective valleys.
(photo taken 1977, Gerster 2008)

Figure 165: Active and abandoned pigeon towers, or kabutar-khaneh, in the Esfahan oasis. Pigeons are kept less for their meat than their manure, which is used to fertilize the regions melon fields.
(photo taken 1976, Gerster 2008)

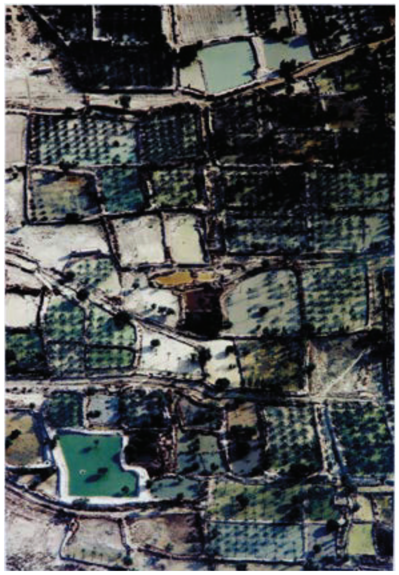


Figure 166: Date palms are grown on the northern coast of Qeshm, the largest island of the Persian Gulf. Dams hold back the winter's rainfall and guarantee moisture into the regions torrid summer.
(photo taken 1977, Gerster 2008)

Figure 167: Cisterns for conserving precious rainwater, seen here in the town of Gerash, are a key element of traditional Persian architecture.
(photo taken 1977, Gerster 2008)

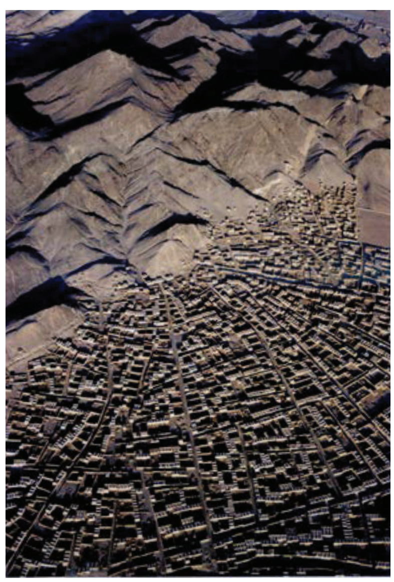


Figure 168: Zahedan, in this aerial photograph the mother wells and location of ventilations shafts in the organic city fabric is visible. (photo taken 1977, Gerster 2008)

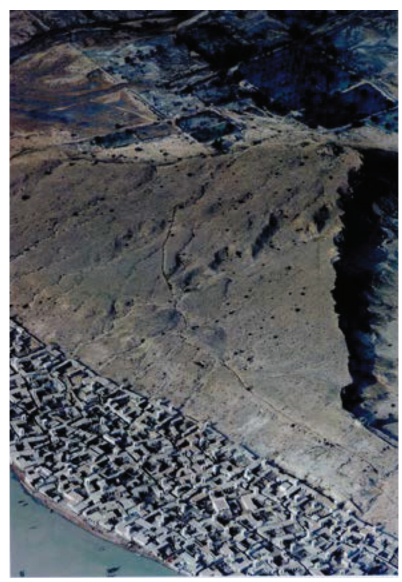


Figure 169: The village of Kuran on Qeshm Island, in the Strait of Hormuz. The village was destroyed by an earthquake on 27 November 2005.
(photo taken 1977, Gerster 2008)

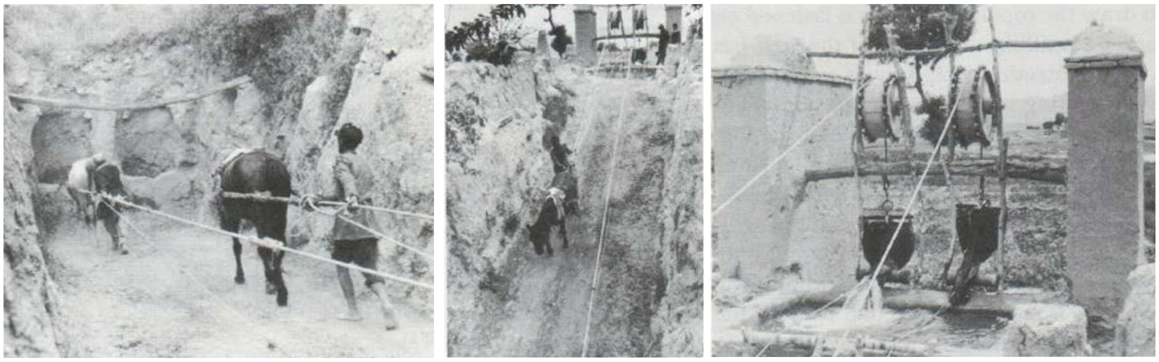


Figure 170: The well end of the main rope is attached to a hook and a ring carrying a wooden cross from which a large leather bag (*mashk*) is suspended. The bag has a capacity of about 15 gallons and runs out into a narrow spout to which the auxiliary rope is attached. A draft animal is attached to the other end of both ropes by means of a breast harness. A runway, beginning at the well head, descends at an angle of about 20 degrees. The lower end of the runway (left), runway of water well (middle), the mouth of a water well (right). (Wulff 1966)

Figure 171: Only a mud wall separates this well-planted garden near Mahan from the desert. Poplars are grown for roofing timbers. The domes of the village bath-house are surmounted by ventilators. (Beazley 1982)

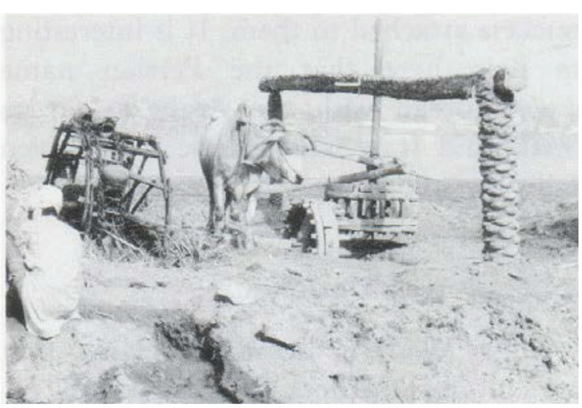


Figure 172: A Persian Wheel operating at the bank of the Indus River. (Wulff 1966)

Figure 173: A Cistern near Na'in. (Wulff 1966)

Figure 174: A watercourse in Kirman City. Members of the “traditional” commoner class (left) wash here, as two “modern” bureaucrats pass by. (Ward-English 1966)

Figure 175: A landlord’s house and courtyard garden in Kirman City. (Ward-English 1966)

Figure 176: A view of upper Mahan; trees in background mark the channel of a qanat entering the town. Note the linearity of the household compounds. (Ward-English 1966)

Figure 177: A view of Kirman City from the summit of Qal`ehi Ardashir. The foreground is a new suburb (note bricks drying in sun); the Zoroastrian quarter occupies the background. (Ward-English 1966)

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