Qanats

Background

A qanat is a horizontal underground gallery that conveys water from an aquifer in pre-mountainous alluvial fans to lower-elevation irrigated fields (see figure 1). In practice, a qanat consists of a series of vertical shafts in sloping ground, interconnected at the bottom by a tunnel with a gradient flatter than that of the ground. The first shaft is usually sunk into an alluvial fan to a level below the groundwater table. Shafts are sunk at intervals of 20 to 30 meters in a line between the groundwater recharge zone and the irrigated land. From the air, the tunnel portion of a qanat system looks like a line of anthills leading from the foothills across the desert to the greenery of an irrigated settlement.

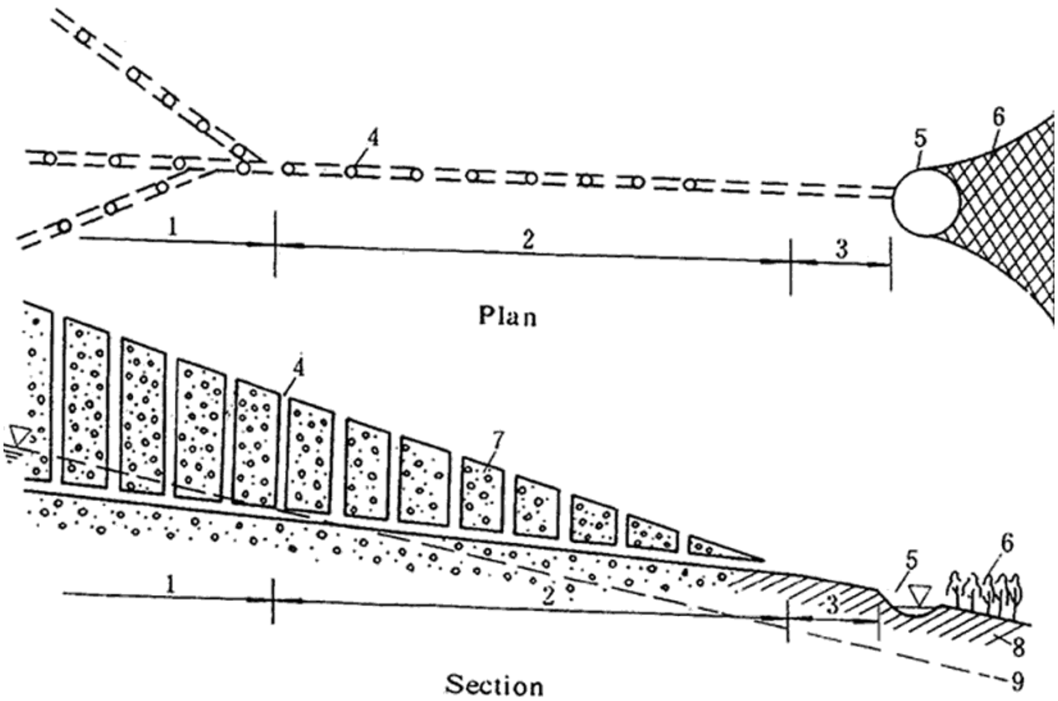

Figure 1. General Schematic for a Qanat.

(1) Infiltration part of the tunnel
(2) Water conveyance part of the tunnel
(3) Open channel
(4) Vertical shafts
(5) Small storage pond
(6) Irrigation area
(7) Sand and gravel
(8) Layers of soil
(9) Groundwater surface

There are three significant benefits of a qanat water delivery system: (1) putting the majority of the channel underground reduces water loss from seepage and evaporation; (2) since the system is fed entirely by gravity, the need for pumps is eliminated; and (3) it exploits groundwater as a renewable resource. The third benefit warrants additional discussion.

The rate of flow of water in a qanat is controlled by the level of the underground water table. Thus a qanat cannot cause significant drawdown in an aquifer because its flow varies directly with the subsurface water supply. When properly maintained, a qanat is a sustainable system that provides water indefinitely. The self-limiting feature of a qanat, however is also its biggest drawback when compared to the range of technologies available today.

Construction

Thanks to early writers, we have excellent descriptions of the techniques used by ancient qanat builders. A recently discovered book by Mohammed Karaji, a Persian scholar of the 10^{th} Century AD, has a chapter on qanat construction. The techniques he describes are basically the same as those practiced today, eleven centuries later.

Qanats are constructed by specialists. A windlass is set up at the surface and the excavated soil is hauled up in buckets (see photograph 1). The spoil is dumped around the opening of the shaft to form a small mound; the latter feature keeps surface runoff from entering the shaft bringing silt and other contamination with it. A vertical shaft 1 meter in diameter is thus dug out. A gently sloping tunnel is then constructed which transports water from groundwater wells to the surface some distance away. If the soil is firm, no lining is required for the tunnel. In loose soil, reinforcing rings are installed at intervals in the tunnel to prevent cave-ins. These rings are usually made of burnt clay (see figure 2). Mineral, salt, and other deposits which accumulate in the channel bed necessitate periodic cleaning and repair.

Photograph 1. A windlass is used to bring tunnel spoil to the surface (display at the Qanat Museum in Turpan, China).

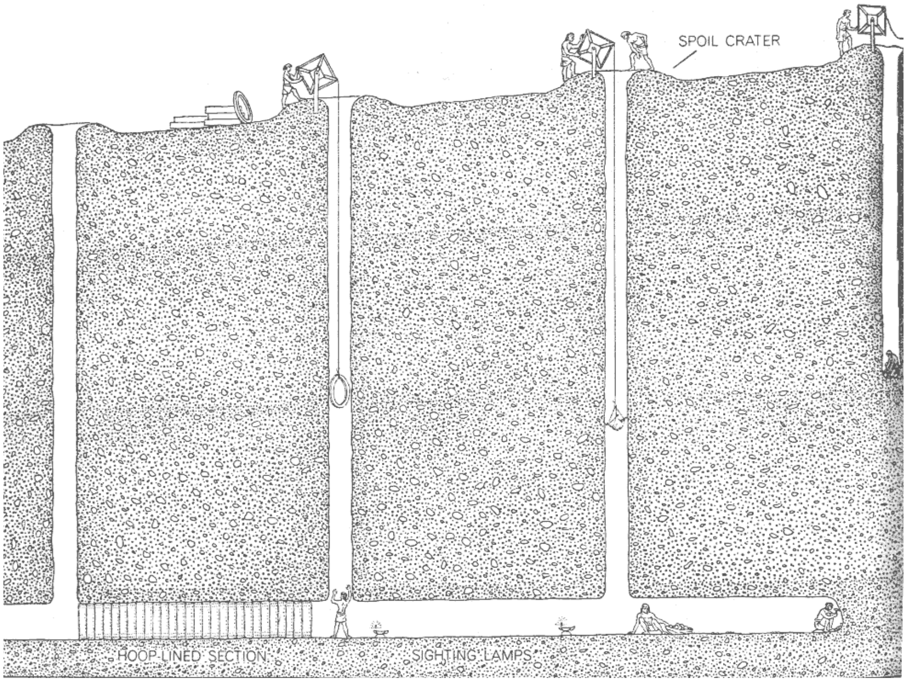

Figure 2. Constructing a qanat using reinforcing rings (from Scientific American).

History

Written records leave little doubt that ancient Iran (Persia) was the birthplace of the qanat. As early as the 7th century BC, the Assyrian king Sargon II reported that during a campaign in Persia he had found an underground system for tapping water. His son, King Sennacherib, applied the "secret" of using underground conduits in building an irrigation system around Nineveh.

During the period 550-331 BC, when Persian rule extended from the Indus to the Nile, qanat technology spread throughout the empire. The Achaemenid rulers provided a major incentive for qanat builders and their heirs by allowing them to retain profits from newly-constructed qanats for five generations. As a result, thousands of new settlements were established and others expanded. To the west, qanats were constructed from Mesopotamia to the shores of the Mediterranean, as well as southward into parts of Egypt. To the east of Persia, qanats were constructed in Afghanistan, the Silk Route oases settlements of central Asia, and Chinese Turkistan (ie. Turpan).

The expansion of Islam initiated a second major diffusion of qanat technology. The early Arab invasions spread qanats westward across North Africa and into Cyprus, Sicily, Spain, and the Canary Islands. In Spain, the Arabs constructed one system at Crevillente, most likely for agricultural use, and others at Madrid and Cordoba for urban water supply. Evidence of New World qanats can be found in western Mexico, in the Atacama regions of Peru, and Chile at Nazca and Pica. The qanat systems of Mexico came into use after the Spanish conquest.

While the above diffusion model is nice and neat (see Figure 3), human activities are rarely so orderly. Qanat technology may have been introduced into the central Sahara and later into western Sahara by Judaized Berbers fleeing Cyrenaica during Trajan's persecution in 118 AD. Since the systems in South America may predate the Spanish entry into the New World, their development may have occurred independently from any Persian influence. The Chinese, while acknowledging a possible Persian connection, find an antecedent to the qanats of Turpan in the Longshouqu Canal (constructed approximately 100 BC). The Romans used qanats in conjunction with aqueducts to serve urban water supply systems (a qanat-aqueduct system was built in Roman Lyons). A Roman qanat system was also constructed near Murcia in southeastern Spain. The Catalan qanat systems (also in Spain) do not seem to have been related to Islamic activity and are more likely later constructions, based on knowledge of Roman systems in southern France.

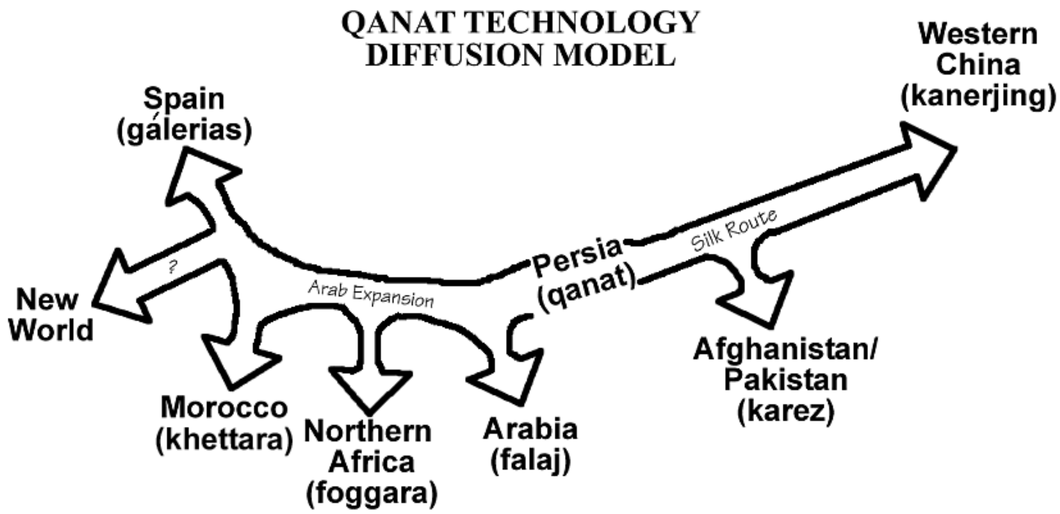

Figure 3. One possibility for the diffusion of qanat technology.

Present-Day Systems

An extensive system of qanats is still in use in Iran. According to Wulff (1968): "The 22,000 qanats in Iran, with their 170,000 miles of underground conduits all built by manual labor, deliver a total of 19,500 cubic feet of water per second - an amount equivalent to 75 percent of the discharge of the Euphrates River into the Mesopotamian plain. This volume of water production would be sufficient to irrigate 3,000,000 acres of arid land if it were used entirely for agriculture. It has made a garden of what would otherwise have been an uninhabitable desert."

Qanats are still found throughout the regions that came under the cultural sphere of the Persians, Arabs, and Romans. The qanat system in Turpan, China, is still very much in use. In the Sahara region a number of oasis settlements are irrigated by qanats, and some still call the underground conduits "Persian works."

The Palestinians and their neighbors had for some 2000 years irrigated terraces of olive groves, vineyards, and orchards with water tapped from some 250 qanat-like tunnels beneath the hills on the eastern shores of the Mediterranean. But today the terraces and tunnels are largely abandoned-unused since the day in 1948 when Palestinians vacated following the creation of the state of Israel. The demise of these irrigation systems is, according to Zvi Ron, an Israeli geographer from the University of Tel Aviv who has mapped the tunnels, a human, ecological and cultural tragedy.

Qanats are to this day the major source of irrigation water for the fields and towering hillside terraces that occupy parts of Oman and Yemen. They have for some 2000 years allowed the villages of the desert fringes of the Arabian Peninsula to grow their own wheat as well as alfalfa to feed their livestock. In these villages, there are complex ownerships of water rights and distribution canals. In Oman, their importance was underlined in the 1980s with a government-funded repair and upgrade program.

While an underground stream is called a qanat in Iran, it is called a karez in Afghanistan and Pakistan, kanerjing in China, a falaj in the Arabian Peninsula, a fogarra (fughara) in North Africa, a khettara in Morocco, and a galeria in Spain (see figure 3).

Qanats as Phreatic Barometers

Dr. Dale Lightfoot at the Oklahoma State University has been using anecdotal information on qanats to study the health of aquifers (Lightfoot, 2003). In southern Morocco, on the margins of the Sahara Desert, lies the isolated oasis of Tafilaft. In the northern section of the oasis, water for irrigation has, since the late-14th century, been provided by qanats (locally known as khettara). In all, 80 qanats once provided water for 28 villages and irrigated about 3000 hectares. Beginning in the early 1970s, the 44 remaining active qanats began to experience reduced flow, and over the next two decades many more qanats dried up and were abandoned.

The diminishing and abandonment of qanats since the early 1970s is attrbiuted to the Hassan Adahkil Dam and Reservoir. The reservoir impounds surface water that used to flow unimpeded to the Tafilalt oasis. Irrigation water is now carried to the oasis in concrete-lined canals, which do not allow for groundwater recharge. Additionally, diesel-powered wells have become very popular. This combination of a lack of recharge to the aquifer and the unregulated withdrawal of the groundwater has resulted in a rapid drop in the Tafilalt's water table since 1970 and the general abandonment of qanat irrigation.

Qanats are found over much of Syria, a "breadbasket" of the Roman, Byzantine, and the later Islamic empires. After the world price for cotton increased in the 1950s, the Syrian government encouraged farmers to produce more cotton to increase foreign exchange earnings. The widespread installation of groundwater pumping systems has successfully antiquated the old qanat technology across most of the country. A map showing the distribution of Syrian qanats, presents a picture of widespread abandonment, except in: (i) areas where commercial irrigation with diesel pumps has only recently been introduced, or was soon abandoned because of salinization problems or (ii) where rainfall is more plentiful and groundwater recharge is adequate. When qanats go dry across a wide region, within a span of only a few decades, it indicates a regional problem with groundwater stewardship.

Contemporary Experiences with Qanats

Dr. Jerry Buzzell described his experience visiting a falaj in Mahdah, Oman. "This falaj begins in the hills above town, with a very deep well to the aquifer. From there, tunnels have been dug channeling the water to the town by gravity. In town, the falaj is a concrete trough, about a foot deep and two feet wide, and the water flows swiftly."

"The falaj is communal, its water available to all, up to a (specific) point. Beyond this point, the water is distributed into different channels, owned by different families, to irrigate date palms."

"Water flow into each channel is controlled by a metal plate across the falaj, which is lifted (to allow water to flow into the channel) or lowered (to hold it back). The water is distributed to the different channels for periods of time which depend upon factors such as the contribution of the families to the construction and maintenance of the system, rents paid, etc."

"In the middle of the narrow space beside the falaj is a very basic sundial–a narrow rod stuck in the ground, with the hours marked out with stones on either side of it–which is their method of timekeeping and the basis of the distribution of the water (during daytime hours when the sun is shining)."

Dr. Buzzell was in Mahdah on a Friday and noted the falaj was being used for ritual cleaning in preparation for prayers. "A lovely old man wearing a loincloth was sitting in the water, lathering his body with soap, his white beard and the white fringe around his bald pate encircling twinkling eyes and gap-toothed grin."

"When he was satisfied with his scrubbing, he lay down lengthwise in the falaj and allowed the water to run over him, head to toe, washing the soap away with the dirt and leaving him clean enough to pray."

Qanats and Diseases

Qanats were frequently used for domestic purposes, as well as irrigation. Because of this, they could transport disease vectors (Afkhami, 1997). A chemical analysis of water, conducted in 1924, from 6 qanats as they entered Tehran revealed water of potable quality in only 2 cases. In 3 other, water purity was questionable and in 1 case the water was definitely unfit for drinking. These results were especially shocking since the samples were taken from closed qanats before they were open to contamination. It has been hypothesized that qanats were a major contributor to the cholera epidemics of the 19th century.

Throughout Iran, even if the qanat water was uninfected before entering the cities, it had ample opportunity to become contaminated while traversing the urban areas in open ditches. With the lack of proper sewage and waste disposal throughout Iranian municipalities, the cholera bacterium easily made its way into drinking water.

Passive Cooling Systems

Qanats can be used for cooling as well as water supply (Bahadori, p. 149). One technology operates in conjunction with a wind tower. The arid regions of Iran have fairly fixed seasonal and daily wind patterns. The wind tower harnesses the prevailing summer winds to cool and circulate it through a building. A typical wind tower resembles a chimney, with one end in the basement of the building and the other end rising from the roof. Wind tower technologies date back over 1000 years.

The passive cooling of a wind tower can be enhanced by connecting it to an underground stream or qanat. In the system shown in figure 4, a shaft (b) connects the qanat to the basement of the building to be cooled. Hot dry air enters the qanat through one of its vertical shafts (a) and is cooled as it flows along the water. Since the underground water is usually cold, the rate of cooling is quite high. The wind tower is placed so that wind flowing through the basement door of the tower passes over the top of the qanat tunnel. When the air flows from a large passage (the tunnel) through a smaller one (the door), its pressure decreases. The pressure of the air from the tower is still diminished when it passes over the top of the tunnel, so that cold moist air from the shaft is entrained by the flow of cooled air from the tower (c). The mixture of air from the qanat and air from the tower (d) circulates through the basement. A single qanat can serve several wind-tower systems.

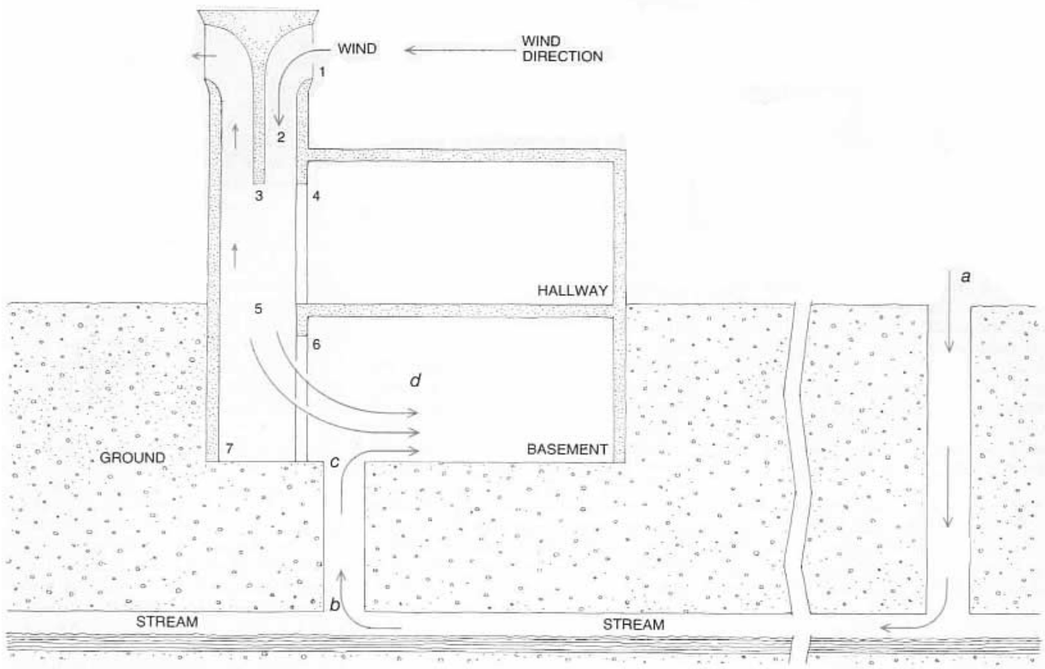

Figure 4. The air flow in a combination wind tower/qanat cooling system (from Scientific American).

Conclusion

A qanat system has a profound influence on the lives of the water users. It allows those living in a desert environment adjacent to a mountain watershed to create a large oasis in an otherwise stark environment. The United Nations and other organizations are encouraging the revitalization of traditional water harvesting and supply technologies in arid areas because they feel it is important for sustainable water utilization.

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