Thank you to give me the opportunity to tell you something about my great interest in historical waterworks.

For the Iranians I made a small introduction on aqueducts, mainly Roman ones,
For the Dutchmen I will explain the basics about Persian qanats
For all of you I will present some special topics
And I will end up with a comparison between the two systems.

**Roman aqueducts**

An *aqueduct* is a channel or pipe-line to transport water over a greater distance from a water source to its destination: often a city, sometimes a farm, industry or mill; there the water is distributed. [See Slide 3]

It starts with a need for extra water in a city, supplementary to other water sources like a river, rainwater catchment, wells, and/or springs.
Then a decision is to finance and build an aqueduct by means of a masonry channel or terracotta pipes.
But first a suitable water source must be found, not too far away, at the right level and with water of good quality.

A (military) surveyor started his work with adequate tools, looking for a good course of the aqueduct following the contour lines, with a more or less constant gradient downwards. The construction work of the channel or pipe-line was done - sometimes by the army - preferably in a trench just under the earth surface, with as few works of art as possible. I mean tunnels, bridges, substructions, arcades and siphons.
The water is conveyed in the channel or pipe-line based on gravity. [slides 4,5,6]

The Roman *empire* had almost a time span of 800 years: from 300 BCE to 400 CE, and was quite extensive: from England to Syria and from Hungary to Libya. [see slide7]

So was the *distribution* of their aqueducts. Total known aqueducts 1.000 – 1.500.[next slide 8]

When the aqueduct shows up near the city a water *distribution system* was built by means of primary and secondary castella (distribution basins); the water was brought mainly to public street side fountains and bath houses, sometimes also to selected private persons (the local elite), mainly connected by lead pipes [slide 9].

Some bigger farmers in the countryside had their own aqueducts for irrigation or tapped (legally or not-legally) a main aqueduct nearby.

The result is that up to 80% of an Roman aqueduct was subsurface and the remaining 20% are bridges, arcades etc. Some of these are still visible in the landscape, like bridges (PdG), arcades (Rome), tunnels (Cave de Curé, France). [see slides]

An aqueduct belonged to the local government or the town council; the construction of the aqueduct was often paid by a maecenas. Construction was done by contractors with sometimes support from the Emperor and/or the Army by skilled slaves and non-skilled prisoners.

**Examples** [see slide 10]:

Non-Roman:
Samos, the tunnel of Eupalinos (pre Greek: 550 BCE !!)
Aqueducts with also with pipes of Greek origin (300 BCE): Ephesus (Turkey) or Syracuse (Italy)
Roman: Rome (11x), Lyon (4x), Nimes (France), Segovia (Spain), Bologna (100% subterranean), Pompeii (It)

So the main characteristics: close to the surface, pipes (often of Greek origin), channels (0.60 x 1.2 m), works of art, public ownership, for public use (fountains and bath houses)

Persian qanats
A few days ago I got a booklet for tourists about Iran. Page 1: Geography of the country. Page 2 Fauna and Flora and already on Page 3: WATER. Water is that important for a country like the Islamic Republic of Iran!! But how to get the water where you want it to be?

The term qanat came from an ancient Semitic word meaning “to dig”, and describes an underground water channel consisting of a series of vertical shafts connected at their bottom with a sub-horizontal tunnel.
Its function is to exploit a certain aquifer which is a water bearing subterranean layer as there are thousands of these aquifers around the world, like under the Sahara desert, the Negev, Ma’an in Jordan and the Syrian desert.[slide 11]

An qanat pierces an aquifer by mean of a well (called the mother well) and a channel. Than it conveys the water to villages and towns in desert area’s at distances of 2 – 80 km. [slide 12]

The first qanats were constructed in the Iranian plateau probably 800 BCE with mining operations in NW Persia. The qanat was spread subsequently to other areas, in China, Arabia, around the Mediterranean and they bear quite different names. [slide 13]

In arid climates qanats, even the ancient ones, are easily identified in aerial photos as lines of craters formed by the deposition of excavated materials around the vertical shafts.

Qanats may reach a depth of 100 m at the so-called ‘mother well’ and a spacing of the shafts of 50 – 100 m apart. The actual channel is about 0.80 m wide and 1.2 – 1.5 m high, in which water is flowing free or in a small depression, from the ‘mother well’ to its destination.

The qanats represent often the main and only water source for thousands of persons in remote villages but also for oasis cities and major towns. In Iran about 22.000 qanats were operational with a total length of 250.000 km. Some 40 years ago Tehran was almost completely dependent of a series of qanats for its drinking water, till the advent of motorized deep pumps and the construction of dams.

The main use of qanats are for drinking water and irrigation. [slide 14] Many villages are equipped with small scale water storage sites where people can draw their water for drinking and household. Many qanat water is used for irrigating the land. There are elaborate systems how to divide the water in time and volume – using sluices, general and local laws, surveillance people, time sharing systems and alike.

The ownership of rural qanats is a quite complex affair: in many cases a group of families of farmers owns the qanat and so the water – in general qanats have 10 – 250 owners and together have to come to regulations how to manage the qanat.
The qanats are constructed by their ancestors hundred years ago and their rights are inherited from generation to generation. As you can imagine these qanats are the lifelines of the village and any disturbance can harm the fragile balance of life in deserted areas. That is why there are **special rules and regulations** about the maintenance of such vital utilities.

Because of their subterranean nature, there are **not that much works of art** attached to qanats, although there are **a few qanat bridges** known like the one in Kharanaq in the Yazd province. Some qanats are (or were) equipped with underground **water mills**! On the other hand: qanat water still is used for **cooling** of major buildings and ice storage sites – we come to that later on. [slide 15]

**Distribution**

As was said already the **timeframe** is from about 800 BCE, as a spin off from coalmining in present NW Iran, later on **spread** all over Persia and the Arabic peninsula. Around 750 CE the Islamic conquest brought the qanat knowledge to N-Africa and beyond, and many qanats are still active on the present day.

Scholars think that the spread all over the world [see slide 16] took the following routes:

- via the silk road to Afghanistan and even into China (province of Turpan)
- And to the west: to Saudi Arabia and Iraq to Egypt and North Africa. Via Jordan and Syria (there locally called ‘qanat romani’ to Cyprus and Turkey.
- Via Morocco to Spain and possibly to other European countries (see later).

Many countries use other names for the same installations like: Karez (Afghanistan and Pakistan), Kanerjing (China), Foggara (a Franch translation in North-Africa), Khattara in Morocco, Falaj (Oman) and Galería (Spain).

On the slides I will show you some examples of qanat distribution in Iran: Tehran, Isfahan, Yazd, Kerman, Bam [slide 17] [slides 18,19]

**Special subjects**

Now we come some special theme’s, mostly related to qanats. First:

**Qanats in Europe**

Many underground water structures in Europe are indicated as qanats, but are **no qanats** at all but only subterranean water-conducting channels. See later.

The best known are the ancient qanats in **Spain**, the so-called galaría’s, not only in the south (Andalusia), but also around the capital Madrid. I have been told that Madrid is derived from Madjira = Place of qanats! [slide 20]

As you may have seen also in **Germany**, close to the Czech border, some 30 small qanats were discovered, mainly 100 - 200 years old.

A real qanat can be found 1700 km to the north in a tiny country **Luxemburg**. A wealthy Roman countryman must have given order to build a qanat, less than a kilometer long with some 30 vertical shafts, some of which 30m deep. [see slide 21]

On the other hand: a **tunnel** in a Roman aqueduct in **Carhaix** (France) is called a qanat, simply because the used vertical shafts to construct the horizontal water channel. Now we do know that that has nothing to do with a qanat as such!

**The construction of qanats**

Much can be said about the construction of a qanat. I will keep it short.
Some people involved are called **muqanni**, the digger with a job from father to son, working in groups, at different places in the region, professionally skilled, well-paid. They had a **dangerous** profession because of the possibility of a **collapse** (on some places clay rings were used as reinforcements). [slide 22]

And there was the danger of **drowning** during construction work, especially when entering the ‘wet zone’ near the aquifer (as you can imagine they always dug from the lower side up!).

**How** did they find a suitable mother well and at the right level? These specialist **did knew** the essentials of geology, morphology, hydrology, vegetation, insects, moisture. Perhaps an X-factor was involved. Here the ancient Persian mathematician **Mohammed Karaji** – a native of Karadj - comes in with his treatise on “The extraction of hidden waters” (1000 BCE).

Who did the **survey work**? How to determine the optimum course (which was a real problem in case of a Roman aqueduct) and how about the almost constant but very, very modest fall??

### Interesting devices

Special attention should be paid to some special devices attached to qanats:

- **The Ab-anbar or water storage tank.** The water source of a qanat gave a constant output but under certain circumstances storage of water was necessary in huge subterranean basins, often cooled by an ingenious system, and at the same time a place to draw water. [See slide 23].

- **Wind towers or Badgir** are part of the scenery of many Iranian towns like in Kaskan, Isfahan en Yazd. These towers have a special function in cooling the air, in the basements of buildings (the summer living rooms), patio’s and courtyards. The technology involved is explained in the [next slide 24]: bringing warm air over cool qanat water.

- A third item, even more astonishing, is the **Yakh-chal or Ice-house**: people were storing ice underground in yakhchals. They would collect ice from mountain tops and put them in an underground pit insulated by a special mortar. Windcatchers could help to keep the yakhchals cool [see slide 25].

- Coming from The Netherlands with abundant water, do net tell me anything about dams: we have many, many of them. But how about **subterranean dams**! As already indicated, the aquifer gave a constant water flow but the use was seasonal: more in spring and summer and less in winter time. So there was a need of damming the flow what was done by cutting supply by means of a pierced, underground dam, [see slide 26]. The use of plugs made it possible to open and close the dam little by little. This type of mill is (or was) active in Vazvan, 100km to the north of Isfahan.

- Thinking about the landscape of my country, on several places there used to be water mills. In Persia and present Iran there are/were quite a few **underground water mills** – using the flow of qanat water as a source of energy. The horizontal mill [see slide] was attached to some millstones for grinding floor or olives etc. [slide 27]

### Dangers

As you can imagine, these ingenious qanats were **vulnerable**, although 5 – 50 m under the surface! To name a few possible **problems**:

- Flooding and Severe draughts
- Sabotage by enemies – think about the Moguls in the ... centuries
- Lack of maintenance based on changes in community feeling
- Earthquakes (Here I would call to mind the disaster in Bam next December 10 years ago),
- But the present danger **now** is the lowering of the ground water level mainly caused by 20th c deep pumping.
Qanats still have many advantages: no evaporation, no pollution, no use of external resources so they form sustainable systems and need protection. These are indeed given by the present government and other institutions like the International Center on Qanats and historic Hydraulic Structures in Yazd.

**Comparison**

For those who are mixed up now by all this information about what is what in underground water structures, we present a comparison [see the next slides 28, 29, 30]

<table>
<thead>
<tr>
<th>Element</th>
<th>Iranian qanat</th>
<th>Roman aqueducts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Mainly in arid area’s</td>
<td>Semi-arid and wet area’s</td>
</tr>
<tr>
<td>Source</td>
<td>Aquifer</td>
<td>River, Spring, Dam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>By exception: well or aquifer</td>
</tr>
<tr>
<td>Place in the landscape</td>
<td>100% subterranean</td>
<td>20% above surface</td>
</tr>
<tr>
<td>Construction</td>
<td>Shafts every 50 – 100 m plus</td>
<td>Masonry channel or pipes,</td>
</tr>
<tr>
<td></td>
<td>connecting channel</td>
<td>sometimes qanat construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(shafts)</td>
</tr>
<tr>
<td>Course</td>
<td>Straight line</td>
<td>Sinuous, following the contour lines</td>
</tr>
<tr>
<td>Works of art</td>
<td>Exceptional: subterranean</td>
<td>Bridges, tunnels, arcades,</td>
</tr>
<tr>
<td></td>
<td>dams, mills. Cooling with wind</td>
<td>siphons, distribution stations</td>
</tr>
<tr>
<td></td>
<td>towers</td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>Channels and sluices ;</td>
<td>Distribution stations (castellae</td>
</tr>
<tr>
<td></td>
<td>timesharing</td>
<td>divisoria) + lead pipes inside the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>town</td>
</tr>
<tr>
<td>Users</td>
<td>Public and Farmers [private houses, bath houses / hammams ?]</td>
<td>Public and Bathhouses. Also: privati, farmers, ornamental fountains. Sometimes grainmills</td>
</tr>
</tbody>
</table>

| Basics                   |                                   |                                    |
|--------------------------|                                   |                                    |
| - Cross-section          | 0,6 x 0,9 m                       | 0,6 x 0,9 m                       |
| - Typical length         | 20 km                             | 20 km                             |
| - Typical discharge      | 2.000 m3/d                        | 20.000 m3                         |
| - Typical depth          | 10 – 50 m                         | 5 m                               |
| - Typical fall           | 0,07 – 0,1 %                      | 0,1 – 0,5 %                       |
| Builders                 | Well paid specialists             | Slave specialists, contractors,   |
|                          |                                   | sometimes military personnel       |
| Ownership                | Cooperative (10 – 250 p)          | Town council                       |
| Finance                  | Members of the cooperation        | Local Maecenas, emperor, town      |
|                          |                                   | council                            |
| Surplus water            | ??                                 | To flush the sewers and toilets,   |
|                          |                                   | fullers                            |
| Storage                  | Local: modest volumes             | No, only behind some large bath    |
|                          |                                   | houses in Rome                     |
| Status                   | Utilitarian / Essential for life   | Additional to existing water       |
|                          |                                   | sources; luxury (baths); show-      |
|                          |                                   | case (show of pride and power)     |

**Our conclusions** [slide 31]
- Although there are similarities, qanats are quite different from roman aqueducts
- Most striking:
  - the difference in the sources
  - qanat(s) are often the only source of water
  - Roman aqueducts are all out of use
Problems?!
Where work is done, problems will occur [see slide 32]
In 150 CE an Roman army engineer, after given directions two crews started digging a tunnel for an aqueduct. He went back to Rome but was called back: the two crews missed each other altogether, since they kept on digging hopefully long after the half-way mark was passed. They almost ended up with two tunnels instead of one!

The more recent picture (Theran 2009 CE) speaks of its own: digging a hole in the ground for a street light, ended up in a crater: you can image what was below this spot!

Thank you [slide 33]
Thank you for your attention!

Wilke D. Schram
April 20, 2013

- Criteria for renovation: groundwater level, tunnel construction, social cohesion, ownership, existing rights system, willingness of the users (note: only two criteria are technical!)
- Modern dangers of old qanats (photo Tehran)
- Karaji (mathematician and hydrologist) 11th c CE
- Hidden for the enemy. Military use: to deprive the besieged and to penetrate cities.
- Water for irrigation by timesharing / example of Kashan (GIAHS): ancient rights, supervising, control, distribution and use
Useful websites:
• International Center on Qanats and historic Hydraulic Structures Yazd: http://www.icqhs.org/English/Default.aspx
• Youtube film about qanats: http://www.youtube.com/watch?v=ieBVMOPRYJ0

Teksten:
Website, text, comparison and ppt on
• Stick
• The website
• On paper
Tehran

- Iranian National Museum of Water (1999), Shahid Fallahi Ave., Shahid Taheri Ave., Sa’ d-Abad Palace This museum in an exhibition of ancient and traditional techniques and instruments for water supplement and distribution. Various water-related vernacular structures are introduced like water reservoirs and traditional icehouses. Some ancient water dams and royal orders concerning them are presented as well.
- In the Northeastern corner of the Golestan Palace, next to a reception hall, there is a building with columns in the form of a veranda. At its center there is a fountain, where water once flowed from a subterranean spring (Qanat). Named after Karim Khan Zand, this building dates back to the Zand period. It was part of the interior of Karim Khan's residence. The building is believed to have been constructed in 1759.
- Google: Water Museum Yakhchal, Tehrān, Iran
- Shahyad(Azadi) Monument Tower

Kashan

- Sultan Amir Ahmad Bathhouse incl. the roof
- Bagh-e Fin garden incl. fountains, a bathhouse and a small museum (6km to the SW)
- Abassian House
- The town has many picturesque bad girs (wind-towers)
- Boroujerdi Old House

Isfahan

- A
- B
- C
- D
- E
- F
- G
- H

Yazd

- Water museum
- Wind towers