The "karez" of the Sauran Region (Turkestan oasis)

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Abstract Few series of aligned wells have been identified by aerial surveys in the arid region near the ancient city of Sauran on the Middle Syr Darya (South Kazakhstan, Central Asia). They are locally called karez (which in Persian means 'water uplift') and initial analyses interpreted them as qanat, a groundwater collection and distribution system that is widespread in the Middle East, North Africa and Central Asia. Recent surveys discovered more than 100 km of such lines. The documentation of their geographical interaction and the renewed archaeological study of a series of them are reported in this paper: the most surprising discovery is the absence of the near horizontal gallery normally used by qanats for the transport of water between wells. The results suggest a reconstruction of the functioning of the karez systems representing a new model for water transport and delivery taking advantage of the local hydrogeology. The study has historical significance for the reconstruction of water and land use in the Turkestan oasis during the last 2000 years; and the rediscovery of this forgotten technique could have economic significance for modern land reclamation in desert zones.
Keywords Groundwater devices, Hydrogeology, Karez, Middle Ages, Turkestan.

HISTORICAL BACKGROUND OF THE TURKESTAN OASIS

Groundwater systems consisting of series of aligned wells interconnected by underground galleries have been constructed on desert sloping piedmonts for more than 2000 years in Middle East (where are called "qanat") and during the last 1000 years in Turkmenistan and Tarim (where are called "karez"). They are still active today in Iran, Turkmenistan and Tarim (Baillant, 1992; Briant, 2001; Sala, 2003).

Information about the existence of karez in the Turkestan oasis (Figure 1) is given by the historical accounts of Wasifi (Boldirev, 1957; Barthold, 1963; Akishev et al, 1973) and by the ethnographic accounts of Dingelshstedt (Dingelshstedt, 1895); and a few karez lines are documented on Soviet topographic maps.

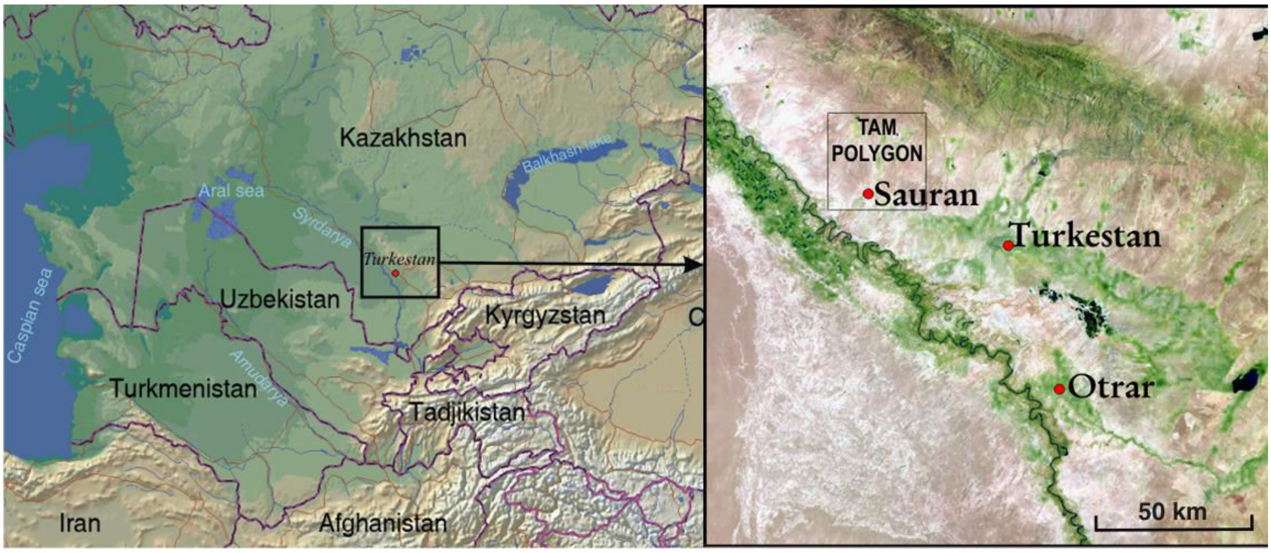

Figure 1 Location map

The XVI century Tadjik writer Makhmud Zainaddin Wasifi, in a passage of "*Amazing Events*", says that in 1510 AD the Muslim sheikh Mir-Arab, religious leader in Bukhara under the Shaybanids, offered to the town of Sauran, in the Turkestan oasis, 2 karez lines and a "charbag" (walled garden) "*similar to nothing that people travelling all around the world had ever seen neither on land* *neither on sea*" (Boldirev, 1957). The Wasifi's account inspired the first archaeological researches into the karez of the Turkestan oasis.

In 1889 by the Russian Colonel N. Dingelshstedt surveyed some of the irrigation systems of the Turkestan region. He reported that the karez had been built "*more than 250 years ago*" and that some of them have been continuously restored and are still in active use. He quoted the presence of 18 active karez systems scattered in several valleys and, following verbal reports by the local population, of 80 abandoned karez lines in the Sauran region. Like Wasifi, he was astonished by the marvellous features of the karez system and comments: "*It is rare to meet such an excellent and convenient system for agriculture. In the area of Turkestan karez are partially functioning till today*".

Wasifi doesn't provide details about the functioning of the karez but Dingelshstedt does it and points to the coexistence of different ways for favoring transport and water resurgence by aligned wells. He says that wells have a depth between 0.35 and 3.50 m and that, among the 5 lines that he analyzed, two had wells interconnected by open canals, two by underground galleries and one by both canals and galleries.

Figure 2 Karez line, relic field systems and houses (round mounds) near the city walls of Sauran (aerial photo by R. Sala)

GEOARCHAEOLOGICAL FIELDWORK IN THE TURKESTAN-SAURAN REGION

A geoarchaeological and hydrogeological study of the ancient groundwater devices of the Turkestan oasis was carried out by members of the Laboratory of Geoarchaeology of the Academy of Sciences of Kazakhstan between 2002-2004 (in the frame of the INTAS project 'Geo-archaeological investigations of land use and irrigation works in Kazakhstan in present and in historical times', INTAS 2000-0699). The study took place in the region north and west of the medieval town of Sauran (43°31'N, 67°46'E), i.e. of the Tastaksai, Aksai and Maidantal river basins (T.A.M.) (Figure 3).

Previous research and existing topographic maps had identified just three large tobe (raised townships): Karatobe (II-XIII AD), Sauran (XII-XVIII AD) and Mirtobe (XIV-XVI). An extended aerial and surface survey found an astonishing archaeological complex. Seven other mid-size townships (tobe) were discovered together with 104 isolated dwellings including Neolithic, Bronze Age, Early Iron Age and Medieval villages. Medieval agricultural fields, farms and canals were also mapped. These were surrounded by ancient fields and farms and were fed with water supplied by the karez lines and small canals (Figure 3).

Existing maps proved to be particularly useful in assisting in the detection of a few karez lines in five valleys of the Turkestan oasis. Hundreds of other lines in the basins of the rivers Tastaksai, Aksai and Maidantal rivers near Sauran were detected from low level aerial surveys. In total, 261 lines of karez with about 10000 wells were found, comprising over 124 km of water delivery systems. These figures are a preliminary estimate and as additional surveys are made, it is expected that these figures will rise.

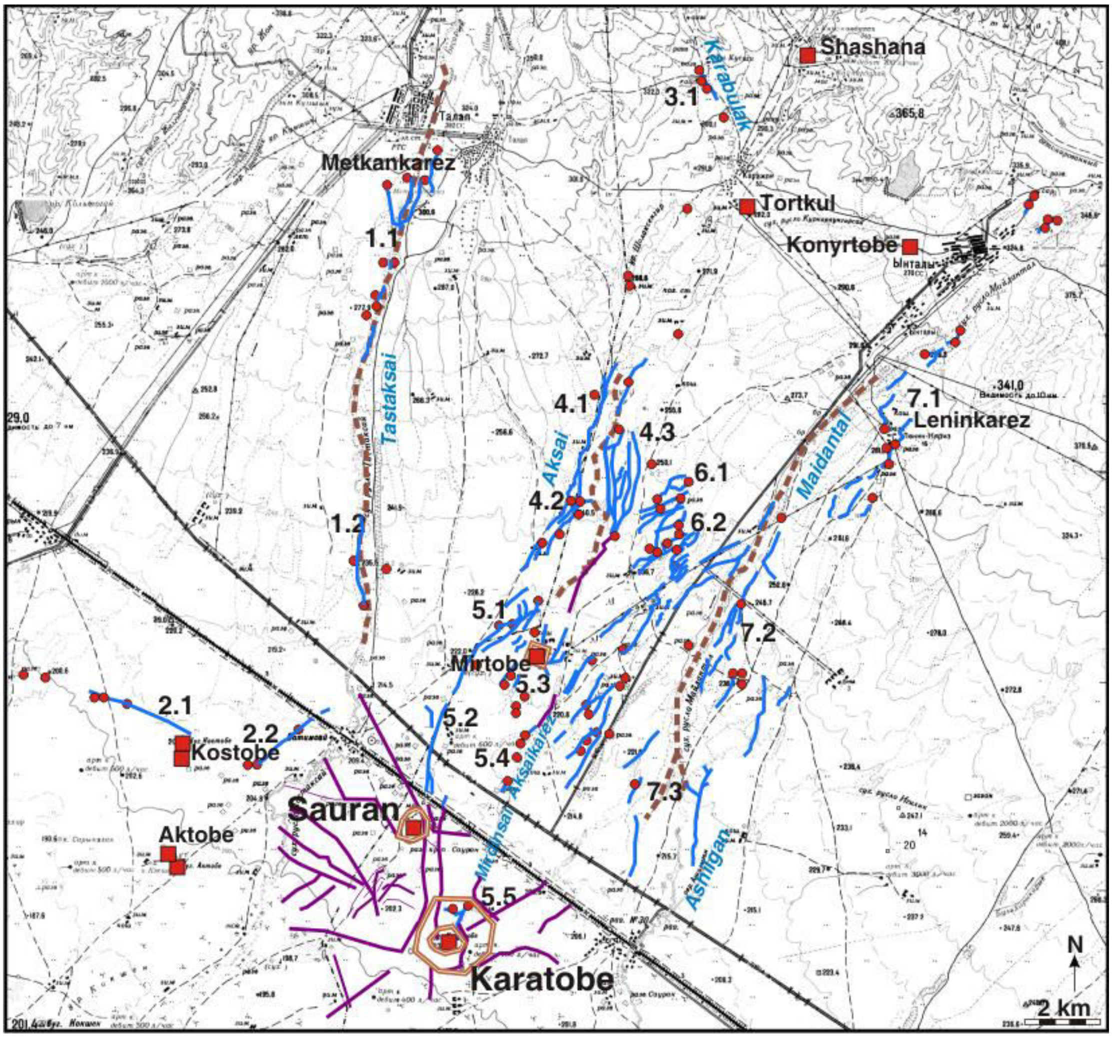

Figure 3 Archaeological map of the T.A.M. region: blue lines: karez lines / numbers: codes of karez zones / brown sequenced line: ephemeral streams / violet lines: surface canals / red round dots: villages and farms / red square dots: walled towns / light brown lines: outside walls of large towns

Few karez lines have been archaeologically studied. In 1986-88, the archaeologist V.A. Groshev detected three karez lines north of the ruins of the medieval town of Sauran (Figure 2), which interpreted as the three karez lines as the ones quoted by Wasifi. He excavated two wells and bulldozered nine others without finding any trace of underground galleries. Like Wasifi, he interpreted the karez of Sauran as an exotic rarity imported by an enlightened religious leader during the Late Middle Ages and, in spite of the archaeological evidence, had no doubts about the presence of underground galleries (Groshev, 1985; 1996).
In 2002 the Lab of Geoarchaeology, apart the extensive surface survey of all the karez complex, excavated one well 4 meter deep near Sauran, examined karez wells cut by the erosion of the Maidantal river (Figure 4) as well as sites where collapsed wells were reopened for collecting groundwater (karez 4.2, 6.2): in each case has been found no evidence of gallery connecting wells. Moreover, verbal accounts have been collected from local aged farmers reporting that "*there were no galleries, the water was flowing by itself from one well to another*".

Figure 4 Exposure of profile of karez wells by river bank erosion (aerial photo by R. Sala)

GEOGRAPHICAL AND HYDROGEOLOGICAL FEATURES OF THE TASTAKSAI-AKSAI-MAIDANTAL (T.A.M.) REGION

Geography, hydrology, geomorphology and human habitats

The study area is a zone 20 x 20 km located on the alluvial plain between the southern slopes of the Karatau mountains and the right bank of the middle course of the Syr Darya river. It is a typical desert landscape characterized by undulating relief, light brown desert soils and shrub vegetation. The area slopes gently south-south-west between 320 and 200 m asl with an average incline of 0.4%. It is crossed by three seasonal streams flowing north-south towards the river Syr Darya and converging in the area of the two largest ancient towns of the region, Karatobe and Sauran. The streams are the Tastaksai to the west; the Maidantal 10-12 km to the east; and, between them, the Aksai draining the central zone (Figure 3). The Aksai is the smallest and shortest stream being only 25 km long but it is in a deeper valley and in its middle and lower course tends to accumulate water from the other two rivers.

The geomorphological features of the alluvial plain are determined by the characters of the three river deltas and allow distinguishing, from north to south, *3 altitudinal bands* 6-8 km wide. They represent three human habitats of which the geographical and hydrogeological context, the applied water technologies and the historical development are characteristic of all the eight river basins of the Turkestan oasis.

The *northern band* (zones 1.1, 3.1, 7.1), between 320 and 260 m asl, consists of the immediate piedmont plain sloping by 1% incline and longitudinally crossed by single small streams active all year round. Starting with the I century AD it has been the object of agricultural activities based on the management, by part of three mid-size walled towns, of mildly active waters through the implementation of small lateral comb canals.

The *central band* (zones 4, 6.1-2, 7.2 and 5.1, 5.3, 6.3, 7.3), between 260 and 215 m asl, where the three river courses acquire delta-like patterns and their distributaries start to converge, has a more anomalous relief alternating positive forms and depressions. It is the driest, with surface water only existing in the form of seasonal seeps. During the Middle Ages it has been the object of intensive groundwater exploitation with the highest concentration of karez and an archaeological complex of 100 villages and a large town.

The *southern band* (zones 2.1-2, 5.2, 5.4, 5.5. 7.3), between 215 and 200 m asl, located at the final convergence of the three deltas, is very flat with poor drainage and wide seasonal marshes. Starting with the I century BC, it saw the implementation of drainage canals leading to extensive land reclamation and the building of two very large towns and four mid-size ones surrounded by farms and fields up to a radius of 3 km.

These three altitudinal bands are most clearly pronounced along the Aksai river, where correspond to its segments Karabulak, Aksai & Aksaikarez, Mirdinsai.

Geology and hydrogeology

The geological structure of the region consists of four main sedimentary units (see Figure 5). The upper layer-1 of modern origin in correspondence of the T.A.M polygon is typically 3-5 m thick and comprises sandy clay and occasional horizontal layers of pebble deposits: it is impervious or at least semi-impermeable. The second layer-2, between -5 and -15 m and of late Quaternary origin, is composed of permeable sand and pebbles. The third layer-3, 90 m thick and formed during the Eocene period, is made of impervious grey clay. The fourth layer-4, typically 130m thick, is made of sand deposited during the late Carboniferous period, and forms the deep confined aquifer of the Karatau basin which provides artesian flow in the valley floor of the River Syr Darya averaging 50 litres per second (B).

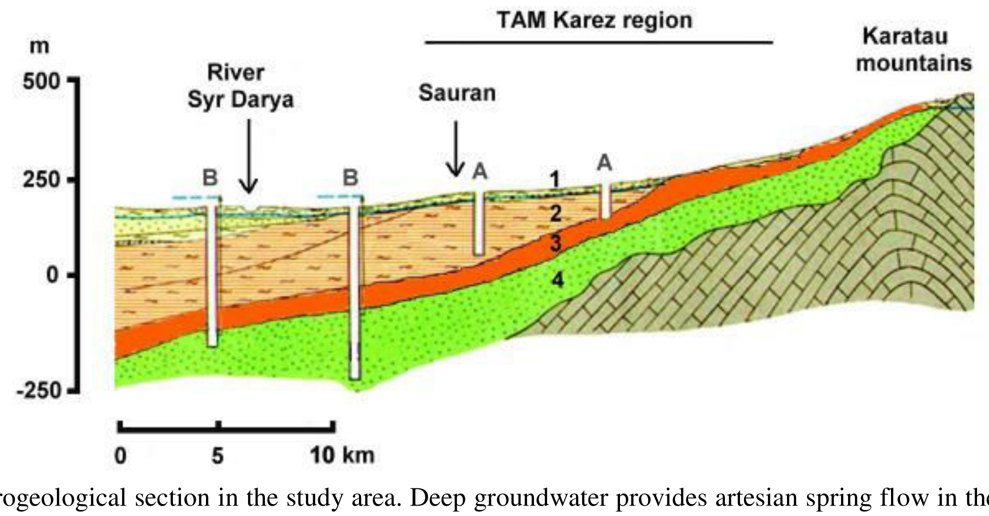

Figure 5 Hydrogeological section in the study area. Deep groundwater provides artesian spring flow in the valley floor (B) while the piezometric surface is below ground level in the T.A.M. karez region (A). (Elaborated from the Hydro-geological map K-42-II, scale 1: 200.000 and Hydro-geological profile of the Turkestan Oblast, 1975)

Modern groundwater levels in the T.A.M. region are around 4m below ground level (bgl), varying from 3m bgl near the mountains and deepening to 8m bgl the Sauran region; rising to 4m or 2.4m bgl near the Syr Darya. Mineralisation by hydrocarbonate, sulphate and chloride anions increases progressively from north to south, ranging from 0.5 g l^{-1} at the upper piedmonts to 1-1.4 g l^{-1} near Sauran and rising over 12 g l^{-1} in proximity to the river Syr Darya. Because the Soviet dams and crop fields enhancing evapotranspiration on the upper plain during the present dry climate, higher water tables must be evaluated for the middle and lower plain during past pluvial phases.

The geological structure of the two sedimentary layers covering the upper 15-20m of the T.A.M. area is the most significant for the analysis of the karez. The first layer of 3-5m, semi-impermeable, allows some percolation, which reduces water-logging and salinisation; moreover the presence of intermittent strata of pebbles deposits creates a network of subsurface horizontal waterways. The second layer, located between 5 and 15m bgl, is water-bearing: and constitutes a semi confined aquifer that is fed by percolation from the pre-mountain alluvial fans. Experimental digging of a new well in this material resulted in a water level rise from 5m to 4m bgl within 24 hours of construction.

FEATURES OF THE T.A.M. KAREZ

Karez zones, lines and systems

Lines of wells are connected with shallow aquifers and the last ones are recharged by percolation from surface streams. So, the classification of hydrological zones, basically different segments of the 3 river courses and related aquifers, constitutes the basis for the classification of karez lines and systems of lines.

By *karez zone (k-zone)* we intend the hydrological zone and aquifer where sets of different karez lines and systems are applied. Seven hydrological zones and 19 sub-zones are detected which all together cover an area of 176 km^2, i.e. 44 % of the 20 x 20 km territory that has been surveyed.

By *karez line* (*k-line*) we mean any alignment of wells longer than 30 m, i.e. having a minimum of three wells. In the T.A.M. basin 261 k-lines have been discovered and recorded, making a total development of around 124 km, which means an average k-line length of 500m and an average density of 250m per km^2. The highest concentration of k-lines happens in the central band of the Aksai depression. The central-upper band (zones 4.1 and 6.1) was the most densely populated with 117 k-lines and 4237 wells (45 % of the total) concentrated in an area of 5 x 5km. The central-lower band (zones 5.1, 5.3 and 6.3), covering an area of 5 x 3.5km, contains 45 k-lines with a total development of 16.9km. The other zones show much lower densities.

By *karez system (k-system)* we mean a set of karez lines interacting by paralleling or intersecting each other. Depending on the patterns of interaction between k-lines, k-systems can be of three different types, i.e. made of parallel, intersecting or mix-type interactions. The three types occur in different areas, depending on geomorphological features: parallel patterns along stream courses; intersecting patterns on areas crossed by complex water distributaries and presenting undulating relief; mix-type patterns on areas transitional between the former two and on very flat areas. Of the total 261 k-lines of T.A.M., 56 are isolated k-lines and 205 are grouped into *47 different karez systems* putting in interaction from 2 up to 16 lines. The average area covered by a k-system is of 400 x 700 m, although they may be made up of several converging lines of wells covering an area as wide as 1500m wide and up to 2500m long (zone 6.1). In four cases (zones 4.1, 4.3, 5.1-2, 6.1) two or more k-systems are interconnected by few k-lines into a "mega-system" (K-system) of very large proportions (up to 55 lines), including almost the totality of the k-lines of the zone.

Hydrological patterns of a karez line

The main elements of a karez line, i.e. the point of application of its head-well (mother-well), of its ending-well (day-light well), and the direction of the line, show a strict relation with surface streams.

The *head* of the k-line is applied near the bank or outlet of an upland stream bed that, during wet regimes, will supply water into the head-well and assist in groundwater recharge.

The *end* of a k-line normally happens in connection with short canals directed to fields in depressions on the sides and below the end of the line, or directed to feed the head-well of a next k-line or k-system. In fact, exceptionally, the k-systems of zones 4.3 and 6.3 end into two canals 2 km long, connecting different k-systems through surface water transport.

Concerning the *direction* of a k-line, three kinds of patterns are detected:

- the k-line parallels the course of the distributary in order to catch groundwater from that elongated corridor (the most common pattern favouring the building of parallel k-systems);
- the k-line goes from one stream course to another in order to catch the groundwater table flowing between them (only found in sub-zones 4.1, 4.2, 4.3, 5.1, i.e. the most crowded with karez lines and with intersecting k-systems);
- the k-line cuts transversely the final distributaries of the river delta, following hypsometric lines (found in just six individual cases in the flat lower altitudinal band).

Construction elements of a karez line

The main construction elements of a karez line are the following ones.

a - The *length* (metric development) of a k-line, apart two exceptional extremes of 3200 m, spans between 2,600 and 30 m, averaging 500 m. Long “classic” k-lines measuring between 2,600 (k-line 5.2.1, near Sauran) and 1,400 m are in number of 16, mainly located in the central zones 4, 6.1, 6.2 and a few in 5.2, 7.3.

b - The *shape of the single k-line* can consist of a unique straight and/or bending line; or of a main line to which are applied secondary branches less than 30 m long (otherwise the whole would be considered as a k-system).

c - The *incline* of the k-lines averages 0.5%, with a maximum of 1% in the northern altitudinal band and a min of 0.1-0.2% in the lower band. So, a k-line 500 m long will average a differential altitude of 2.5 m between the head-well and the ending-well.

d - The *relative distance between wells* is in most of the cases 15 m and averages 12 m, with maximum distances of 50 m in zone 2.1 together with the third direction pattern described above, and minimum distances of 5 m in some short k-lines of zones 1 and 5.

e - The *shape of the outer and inner rings of the wells* is round in all cases (with the exception of few oval-shaped basin-like wells). The plane of the mouth can be or horizontal or, in case of presence of a paralleling canal, inclined as if intended to discharge water into it.

f - The *diameter of the inner ring (well’s mouth)* is quite constant averaging 0.8-1 m. The *diameter of the outer ring* (i.e. of the mound deposit of the spoil of the well) averages 6 m but presents anomalies evidently connected with the well’s depth, between a maximum diameter of 12 m (sub-zone 6.1) and a minimum of 5 in the case of short k-lines or at the end of the k-line. Wells shaped like oval basins of large dimensions (9 x 12) are located either at the head of the k-line for favouring the recharge of the groundwater system by a surface distributary, either in proximity of a settlement (sub-zones 5.4, 6.2) for the application of a water-wheel. The distance between wells and the diameter of the outer ring can have different values in different segments of the same line.

g - The *height of the ring* (consisting of the spoil of the well) can reach a maximum of 1 m but is generally quite flattened, the two cases being respectively related to bigger or smaller, younger or older more eroded constructions. The same can be said for the two opposite cases of pronounced concavity or full sedimentation of the mouth of the well. The most flattened outer rings and most sedimented mouth-pits are found in the central zones of the complex (zones 4, 6.1, 6.2) independently from their diameter and so witnessing their higher antiquity. Three degrees of erosion are detected, pointing to three successive generations of karez construction, which is coherent with the stratigraphy of intersecting diachronic k-lines and with the chronological attribution of neighbour monuments of the archaeological complex.

h - The *last spoil of the dig* deposited on the very top of the ring (i.e. the material lifted from the bottom floor where the digging of the well stopped) always shows the presence of pebbles, as if the dig deliberately intended to end in the most permeable stratum.

i - The *technical construction of the mouth of the well* can consist of the simple dig or of the use of mud-bricks or baked-bricks for walling the upper 0.5-0.8 m of the mouth. The last case is represented by 20% of the wells, mainly the ones located in the southern band (zones 5.2-3-4 and 7.3) in correspondence with the largest, most recent and eventually last generation of karez in proximity of Late Medieval dwellings.

j - The archaeological studies implemented up to now, together with the hydro-geological considerations mentioned above provide an approximate estimation of the *depth of the wells*. It seems to average 3-4 m, i.e. it goes down to the top of the second water bearing sedimentary layer, or it stops at occasional pebble deposits included within the first semi-impermeable layer.

k - An open air *artificial canal paralleling* the middle and lower segments of the k-line is found in more than 50% of the cases. Ten cases are found of two canals paralleling both sides of the same k-line. In few exceptional cases of k-systems made 3-7 k-lines paralleling each other in strict proximity, 2-4 canals are located between the lines (k-system 4.3.2-12). Canals are always connected with wells having an inclined mouth-plane; and, most probably, the middle segment of the k-line where the canal begins corresponds to the starting point of water resurgence.

l - In the T.A.M. region more than ten excavations of karez wells have been implemented and none of them found any trace of *underground galleries.*

m - If wells were no deeper than 3-5 meters, the construction of the 10000 wells of the whole 124 km of development of the T.A.M. karez could have been implemented in five years by a brigade of 100 medieval workers (25 wells x person x year).

A PROPOSED MODEL OF OPERATION OF THE "KAREZ"

The remarkable feature that the karez do not have artificial underground galleries suggests that they are not qanat but constitute a now-forgotten hydraulic device working on a principal that takes advantage of the widespread occurrence of a sand-pebble layer occurring 3-8m below ground level in the confining layer. The layer was readily accessible by hand dug wells. The areas hosting karez all exhibit the following conditions:

- The karez lines are located in a depression where groundwater recharge is favoured by the convergence of underground and ephemeral surface waters from neighbouring aquifers and streams;
- The geological sedimentary structure consists of an upper semi-impermeable layer 3-5m thick resting on top of a permeable horizon, the latter bearing a semi-confined aquifer located at a depth reachable by hand dug wells (typically between -3 and -15m);
- There is no artificial gallery constructed between the wells;
- The upper confining layer contains sand-pebble horizontal strata of high permeability at 4-6m below ground level. This layer hydrologically connects adjacent wells and acts as a "natural gallery" easing further the circulation between wells.

We therefore propose the following principle of genesis and operation of the "karez of Sauran":

- The existing hydrogeology consists of a semi confined aquifer that receives recharge in the hilly areas to the north of the Turkestan oasis (which can be artificially enhanced).
- Attempts at constructing traditional wells resulted in the upwelling of water into the wells under piezometric pressure from the confined aquifer. So, the alignment of wells allowed the formation of corridors of higher water table with seasonal spontaneous outpouring of water.

– The presence of horizontal pebble strata in the shallow sand/clay upper confining stratum allows the movement of water from well to well downhill in the direction of the karez line.
– The interaction of upwelling and gravity circulation will produce water resurgence starting from a certain point of the line depending from the level of the water table (i.e. from the season and the artificial recharge).

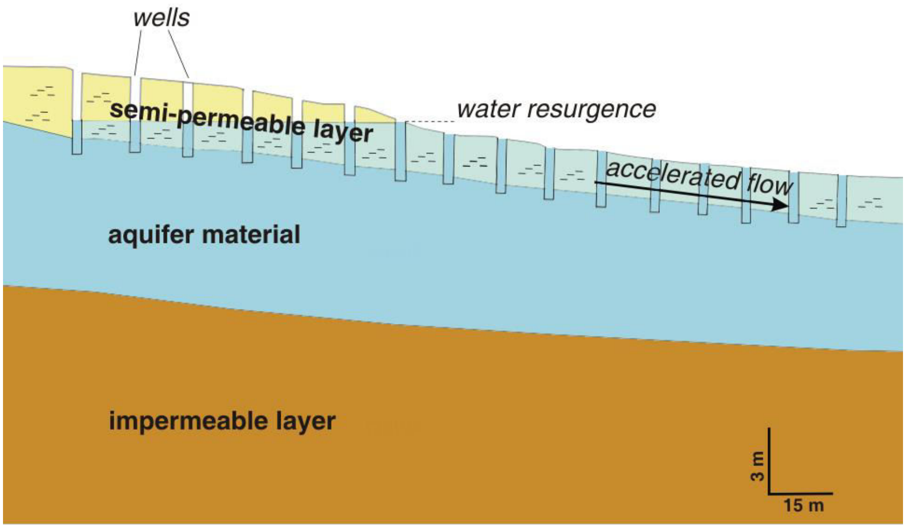

Figure 6 - Wells are constructed and fill with water to the level of the piezometric surface in the semi-confined aquifer. Then the highly permeable sand-pebble strata act as a conveyor for the water which has risen into the wells under artesian pressure.

CONCLUSION

The groundwater systems (karez) of the middle altitudinal band of the Turkestan oasis have been built on the basis of three different technologies of water transport and resurgence: by open canals, underground galleries and hydrogeological principles. The last principle has been exploited the most in the T.A.M. basin where it seems to characterize the totality of the karez. Here, during the late Middle ages, karez working on micro-artesian principles have been integrated with piedmont active streams and low plain canals into a general water system managed by the large town of Sauran.

The geo-archaeological discovery in the TAM region of 3 kinds of habitats and water technologies and of their 3-fold periodization (early, middle and late Medieval times) provides a model for interpreting the eco-economical conditions and socio-historical development of human cultures in the whole Turkestan oasis. In particular the study of the forgotten technology of the karez of Sauran has most probably scientific significance for the hydro-geological and hydro-engineering sciences, and economical significance for modern land reclamation in desert zones.

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