IRANIAN WATER HERITAGE: PAST WISDOM FOR FUTURE CHALLENGES

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ABSTRACT

In the long history of mankind, the 21st century would be very distinct from the other centuries and may be considered as the most challenging era for humanity. For the first time in human history, the 21st century is likely to see the end of world population growth. With the current trend of sophistication of technologies, it may be envisioned that by the end of the 21st century even the poorest human beings would enjoy the basic needs of life. Nonetheless reaching this status may involve unimaginable human suffering. Furthermore, according to climate scientists, more floods and droughts would be very likely in 21st century and the people living in poverty would be worst affected by the effects of climate change. The development of societies in arid and semi-arid areas in the last 5,000 years is closely connected with water management problems that have shaped the relevant society and its structures. In the course of the centuries, systems and methods worked out under these conditions have conclusively demonstrated their sustainability. Today, the knowledge and structural remains of these methods are not only interesting archaeologically and historically, but can also help solve current problems. In view of Data, Information, Knowledge, Intelligence and Wisdom hierarchy studied in knowledge management, the water wisdom of the past which was achieved in a period of hundreds of years, can be regarded as a unique and irreplaceable gift from our ancestors to our generation. The Persians of ancient times recognized the importance of irrigation to the sustenance of civilization. By excavating underground water tunnel and gallery systems (qanats) and by constructing many dams, they accomplished projects that rank among the greatest in history. This paper tries to highlight the accumulated knowledge and water wisdom of Iranian civilization by a comprehensive review of their accomplishments in water resources management in very diverse situations

Key words: Water wisdom- Iranian heritage – Qanat – Historical Dams – Climate change - Sustainability

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1- INTRODUCTION

This paper would be presented in the context of water history; still this introduction focuses on future. The 21st century would be very distinct from the other centuries in thousands years history of mankind. The 20th century was the century of explosive population growth, resulting in unprecedented impacts. In contrast, for the first time in human history, the 21st century is likely to see the end of world population growth. With the current trend of sophistication of technologies, it may be envisioned that by the end of the 21st century even the poorest human beings would enjoy the basic needs of life. Nonetheless reaching this status may involve unimaginable human suffering. Based on a report of UNICEF report entitled "THE STATE OF THE WORLD'S CHILDREN 2005, CHILDHOOD UNDER THREAT", for nearly half of the two billion children in the real world, childhood is starkly and brutally different from the ideal we all aspire to. Poverty denies children their dignity, endangers their lives and limits their potential. Conflict and violence rob them of a secure family life; betray their trust and their hope. HIV/AIDS kills their parents, their teachers, their doctors and nurses. It also kills them. A summary of horrible statistics given in the report is presented in table 1. This is the situation of in 2005. If the current trend of resources and demands continues, in coming years we would face unprecedented disasters similar to the tsunami of 2004 in south Asia. According to above discussions the influential groups should recognize that the next few decades could be critical for the whole well being of human race and adopt appropriate measures to "make poverty history" with very limit resources and in a very short time in the context of severe constrictions imposed. The challenges are immense but the eventual potentials of human being are unimaginable at the same time.

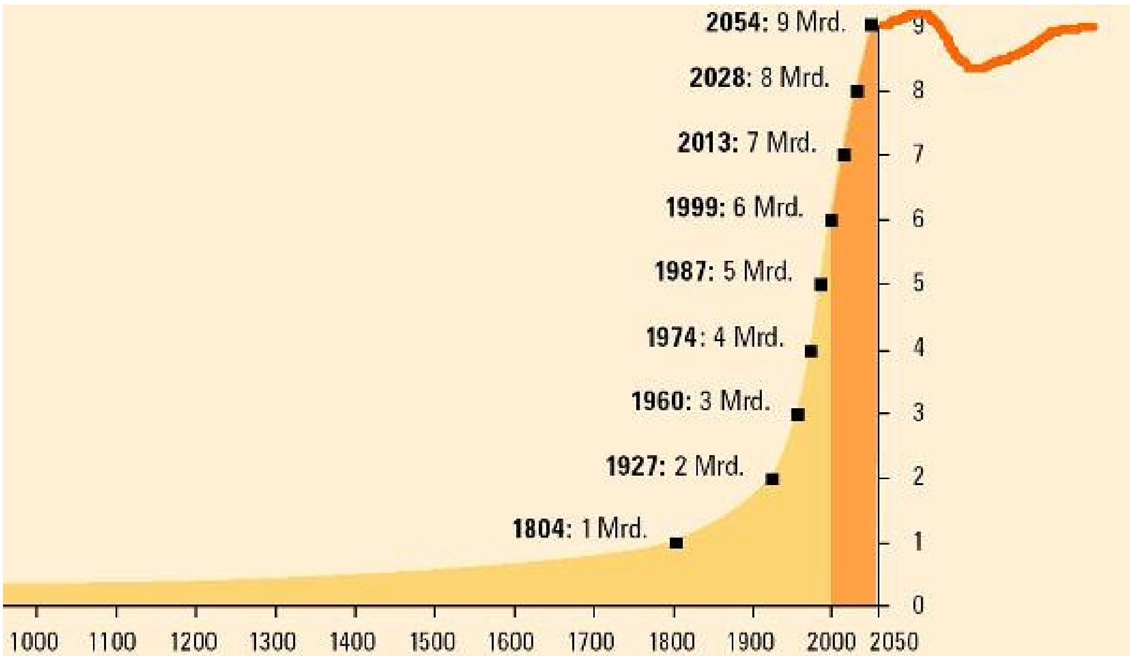

Figure (1) World population from 1000 BC to 2300 BC

Table (1) A summary of UNICEF report on THE STATE OF THE WORLD'S CHILDREN 2005

Number of children in the world:	**2.2 billion**
Number of children living in poverty:	**1 billion**
Number of children in developing countries who live without adequate shelter	**640 million**
Number of children who have no access to safe water: one in five	**400 million**
Number of children who have no access to health services	**270 million**
Number of children who are out of school	**121 million**
• Total number of children younger than five living in France, Germany, Greece and Italy: • Total number of children worldwide who died in 2003 before they were five	**10.6 million** **10.6 million**
Daily toll of children in the world who die before their fifth birthday:	**29,158**
The number of children who die each day because they lack access to safe drinking water and adequate sanitation:	**3,900**

2- WATER-RELATED CHALLENGES IN 21ST CENTURY

Based on IPCC WGII Fourth Assessment Report on climate change in 2007, climate change would be one of the key challenges of mankind in the next decades. Key findings of the report include:

- 75-250 million people across Africa could face water shortages by 2020;
- More heavy rain events are very likely and more areas are likely to be hit by drought;
- Crop yields could increase by 20% in East and Southeast Asia, but decrease by up to 30% in Central and South Asia;
- Agriculture fed by rainfall could drop by 50% in some African countries by 2020;
- 20-30% of all plant and animal species at increased risk of extinction if temperatures rise between 1.5-2.5C;
- Glaciers and snow cover expected to decline, reducing water availability in countries supplied by melt water.

The report states that the observed increase in the global average temperature was "very likely" due to man-made greenhouse gas emissions. The scientific work reviewed by IPCC scientists includes more than 29,000 pieces of data on observed changes in physical and biological aspects of the natural world. Eighty-nine percent of these, it believes, are consistent with a warming world. People living in poverty would be worst affected by the effects of climate change. The finding of the report underlines how important it is for every country to adapt to the climate change that is already under way.

This paper is trying to demonstrate that coping with the water-related challenges in the 21st century requires major technical jumps and innovations in all fields and in this context, water wisdom of the past may play a vital role.

3- DATA, INFORMATION, KNOWLEDGE AND WISDOM HIERARCHY

In knowledge management literature it is often pointed out that it is important to distinguish between data, information, knowledge and wisdom. The generally accepted view sees data as simple facts that become information as data is combined into meaningful structures, which subsequently become knowledge as meaningful information is put into a context and when it can be used to make predictions. This view sees data as a prerequisite for information, information as a prerequisite for knowledge and knowledge as a prerequisite for wisdom. In Figure 2, data are assumed to be simple isolated facts. When such facts are put into a context, and combined within a structure, information emerges. When information is given meaning by interpreting it, information becomes knowledge. At this point, facts exist within a mental structure that consciousness can process, for example, to predict future consequences, or to make inferences. As the human mind uses this knowledge to choose between alternatives, behavior becomes intelligent. Finally, when values and commitment guide intelligent behavior, behavior may be said to be based on wisdom.

With today's sophistication, the time step for a typical data to wisdom process may be a day or a week or a month in industrial cases. But in the context of water engineering, the time step may be a year or a decade or a century. Consequently the water wisdom of the past which was achieved in a period of hundreds of years can be regarded as a unique and irreplaceable gift from our ancestors to contemporary water engineers. Hopefully, the water wisdom of our ancestors would play a key role in our adaptation with the water related challenges of the 21st century. It is therefore necessary that we look back at the ancient creation of the fertile human brains that used the synergy of science and art at that moment of time to provide us with abundant food for thought. It should be remembered that foundation of the future rests on the achievement of the past. In this context, it would sustainable water management in some arid and semi-arid areas may be ensured by using traditional processes and construction methods

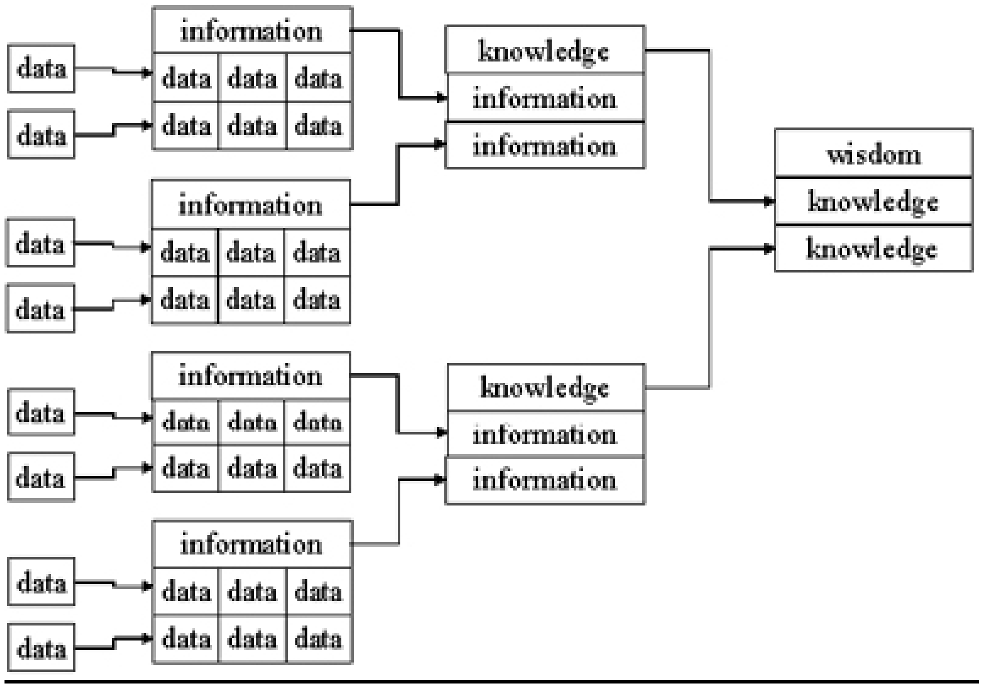

Figure 2: Building on data in the Wisdom Hierarchy.

3- THE LONG AND HONORABLE HISTORY OF IRANIAN WATER ENGINEERING

The water engineering is a vital part of the story of civilization. Reservoirs for water supply were undoubtedly among the earliest structures devised by mankind. The role that water management structures have played over the ages is documented in many records of historical lands. These structures have been linked closely to the rise and decline of civilizations, especially to those cultures highly dependent upon irrigation.

The Persians of ancient times recognized the importance of irrigation to the sustenance of civilization. By excavating underground water tunnel and gallery systems (qanats) and by constructing many large dams, they accomplished projects that rank among the greatest in history. In the ruins at Sialak, near Kashan, are to be seen traces of irrigation channels that are considered to be as much as 6000 years old, suggesting that irrigation was practiced there from very early time, even before the arrival of the Aryans in the land now known as Iran (Jansen, 1983).

With an annual mean precipitation of less than 150-mm for most regions in the country, efficient water resource management has been literally vital to sustainability of the Iranian civilization. Throughout the history of the country, ancient Iranian had to introduce many innovations to utilize the available resources such as qanat. The qanats were dug below the ground surface to intercept groundwater. They resemble under drains or culverts. At the end of the qanat, the water discharged by gravity into an irrigation canal. Along the qanat, closely spaced vertical shafts were dug during construction and were also used for maintenance and repair. More than 54000 qanats have been identified in country and some 36000 qanats are still in operation with the total annual discharge of 9000 MCM. Fig. 3 illustrates 73 historical Iranian weir, bridge-weir and dams. As mentioned above, many of these hydraulic structures are quite remarkable:

- The most ancient dams in the country were built on the River Kur south of Persepols around 500 BC. Along with the dams constructed later on the river, at least one of these dams is still in operation.
- 2500-years old Amir dam can be regarded as the world oldest dam constructed by stage construction. The dam was heightened by about 5 m around 1000 AD
- 18 m high Ezadkhast dam built around 200 AD near Shiraz may be regarded as the oldest and highest true arch dam in the world (R=18m and central angle=130 degrees). It should be mentioned that the true arch dams built by the Romans were 12 m high Vallon de Baume in southeastern France and 5.7 m high Monte Novo in southeastern Portugal.
- Amir dam mentioned above was actually a “power dam” with as many as 30 water wheels driven by the impounded water (Schintter, 1994).
- 21-m high Fariman dam near Mashhad had been the highest buttress dam in the world till 24 m high San Blas dam was constructed in Mexico in the 18th century.
- As figure 3 clearly indicates, the most important characteristic of Iranian historical dams is remarkable height. 21 historical dams higher than 15 m have been identified in Iran as shown in the figure. This is another world record in dam engineering. Spain with 10 and Solvakia with 9 historical dams higher than 15 m rank second and third respectively (Schintter, 1994). Among the Iranian historical dams, the most important and the highest is 60 m high Kurit dam.

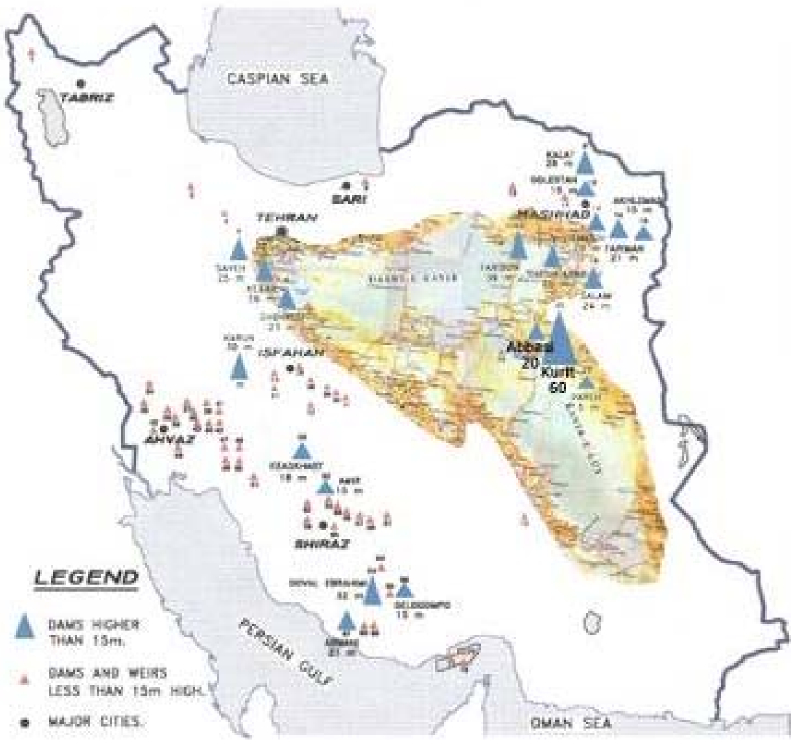

Figure (3). The historical weirs, bridge-weirs and dams of Iran (the deserts are highlighted)

4- LESSON LEARNED FROM THE HISTORICAL WATER WISDOM OF IRANIAN

This paper tries to highlight the accumulated knowledge and water wisdom of Iranian civilization by a comprehensive review of their accomplishments in water resources management in very diverse situations. Consequently the most important milestones of Iranian water heritages were reviewed and the lessons learned were classified in the following sections. It should be noted that it is just a pilot study and much has to be done on the subject.

4-1- CREATIVITY IS THE KEY TO SUCCESS

Creativity is the means to advance civilization into the future and throughout history it has played a key role in development and management of water resources especially in arid and semi-arid regions.

Creativity is vital for coping with diverse circumstances of water engineering and it can be promoted by the great challenges and limited resources. Many of the achievements of Iranian in water engineering are vivid symbols of creativity and can be considered as technical jumps:

- Qanats are probably one of the greatest hydrologic achievements of the ancient world that has made sustainable development possible in many arid and semi arid regions. Qanats were first developed in Iran but their use spread to India, Arabia, Egypt, North Africa, Spain and even to the New World. Most of the area that qanats serve to irrigate is arid and rainless. Without an effective and sustainable form of irrigation, such as is provided by the qanats, agriculture in those regions would have been impossible. For that reason, one cannot over-estimate the important role the qanats have played in Iran. To quote H. E. Wulff, "They have made a garden of what otherwise would have become an uninhabitable desert." In practice Qanat may be considered as a very intelligent scheme for conveying groundwater to the surface by gravity force. It has been proved to be an efficient and effective simple method in very diverse conditions. The great advantages of transporting water underground in this way are obvious. As the qanats are often dug into hard subsoil and, when necessary, lined with relatively impermeable clay hoops, there is little seepage, no rising of the water-table, no waterlogging, no evaporation during transit - and hence no Stalinization or alkalization in the area surrounding the conduits. Nor do they provide a niche for the vectors that transmit the water-borne diseases that so seriously affect the population of areas irrigated by modern technological means.
- To avert the construction of a diversion tunnel, a number of Iranian historical dams were built on a brick arch. The lower part of the dam would be constructed in a dry season after the completion of the upper part as shown in Figure (4). Consequently there was no need for river diversion during the construction.

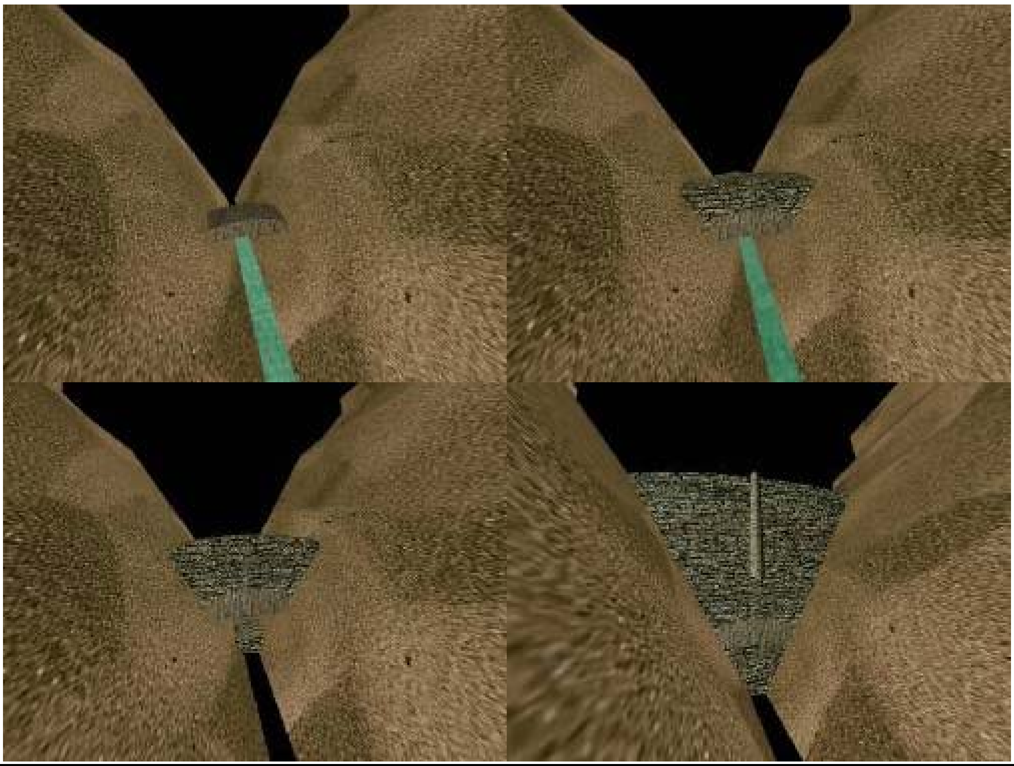

Figure (4). Construction of the dam on a brick arch to manage floods during construction

4-1- A RICH WATER CULTURE IS PREREQUISITE TO SUCCESS

Our knowledge of the past is mainly on successful water projects of the country and in practice they are just the tip of the iceberg. In comparison to successful hydraulic structures, there are many more doomed endeavors because our ancestors had to rely on trial and error. Due to the primitive technologies of past, the Iranian had to rely on their vision, intuition, imagination, creativeness, hard work and courage to accomplish these astounding achievements in water engineering. A rich water culture is prerequisite of the above mentioned characteristics and it is exactly the case of Iranian water culture. In this context it is interesting to note that In Farsi (the Iranian language), the first word in the dictionary is *ab*, water, and *abadan* -derived from it- means civilized. Throughout history Iranian water culture has motivated the people for sustainable, efficient and effective development, management and use of the limited water resources of the country. Water has been and will be a powerful cement in the organization and social cohesion of Iranian communities. This is why whenever any group has sought to destroy this country and bend them to its will; it has first attempted to wipe out their water culture and its material infrastructure. Raised to the status of a touchstone value, water has always reflected three dimensions -sacred, social and economic- in Iranian society. Fortunately Iranian water culture was further enriched by Islamic values. In the Islamic culture, Water is a gift of God. The importance of water in Islam does not derive from the facts of life in the Arabian peninsula, but directly from the revelation of God. "We made every living thing of water." (21:30). The Qur’an states that water is a source of life. The Qur’an reveals the importance of water in more than one hundred places. The

Qur'an generally link water to life and God is the giver of rain and snow. In this respect Allah says in the Qur'an: "See ye the water which ye drink? Do you bring it down from the cloud or do We?" (56:68). The importance of water is also highlighted by the traditions of the Holy Prophet Muhammad and he forbade the wasteful use of water, even when one is at the side of a river.

Finally it should be noted that Erik Swyngedow, a town-planner and geographer based at the University of Oxford, demonstrated that the modernization of the Spanish state went hand in hand with fundamental changes in the way water was used, and that water culture, water policy and water engineering played a key role in the formation of Spanish society.

4-2 RESPECTING THE YIELDS OF THE HYDRO SYSTEMS WOULD ENSURE THE LONG-TERM BENEFITS

What is particularly important about Qanats, as Pazwash points out in Civil Engineering, is that the discharge from qanats "is fixed by nature". They can only provide water produced naturally by a spring in a mountain area and then transport it by the force of gravity. As a result, the aquifer is not depleted and the quality of its water is maintained. By contrast, the amount of water extracted in a modern irrigation system by pumps and other technological means "is to some extent determined by man, who, in a modern economy, will be under pressure to extract the maximum amount possible, thereby depleting the aquifer and reducing the quality of the water." Gunter Garbrecht, former Chairman of the Working Party on History of the International Commission for Irrigation and Drainage, makes the same point. Qanats "tap the groundwater potential only up to, and never beyond the limits of natural replenishment and, as a consequence, do not unbalance the hydrological and ecological equilibrium of the region."

"If water can be withdrawn at will, regardless of the limits of natural recharge, a water supply can certainly be increased for a period of time. But sooner or later, the water potential will become exhausted and agriculture and economy will have to fall back to its original level, a process that inevitably carries serious socio-economic consequences for the society."

In this context it is not surprising to note that there are some 36,000 operating Qanats in Iran, comprising more than of thousands of miles of underground channels. Equally astonishing, much of that network is still functioning, sometimes thousands of years after the channels were originally built. Indeed, until recently, qanats still supplied 75 percent of the water used in Iran, for both irrigation and household purposes.

4-3- OOD PRACTICE CAN BE ACHIEVED BEFORE THE DEVELOPMENT OF THE RELEVANT THEORY

Some of achievements of Iranian in water resources were astounding and have only surpassed in the 20th century, such as 60 m high Kurit arch dam built in Iran around 1350. Iranian used the synergy of science and art to compensate for lack of the technologies we enjoy today. Despite their handicaps and constraints, they were ingenious enough to devise their own techniques to harness the bounty of the Mother Nature. Here are some examples:

- The application of arch, buttress and gravity dams at different dam site by Iranian clearly demonstrate the understanding of structural behaviors of dams. In this context it should be mentioned that except for the 20th century, Iran held the world record for the highest arch dam with:

- Ezadkhast, 1800 years old, 18m high,
- Kebar, 700 years, 25 m high
- and Kurit, 650 years, 60 m high.

- The deep understanding of Hydraulics by Iranian is vividly shown by many examples such as:

- Abassi Flood detention dam (Section 5 of this paper);
- Construction of water intakes in high historical dams to decrease the exit velocity of water;
- Widespread application of siphons and pipes in water transfer schemes;
- Construction of the dam on arch to eliminate the needed for a diversion system;
- Long water transfer systems;
- Construction of numerous Water wheels.

- Many considerations of modern dam site selection practice, such as topography, availability of construction materials, diversion works during construction, stream flow regime and so on, seem to have taken into account for selecting the most appropriate dam site of historical dams in Iran. So it is not surprising that the recent studies for construction of new dams have suggested the old dam axis as the best alternative. The examples are Doorodzan, Jareh, Saveh, Fariman and Kurit historical dams. Ironically, proper site selection has actually threatened the sustainability of many historical dams in Iran.

4-4 MONITORING THE HYDRO SYSTEMS, ADAPTATIONS AND NON-STRUCTURAL METHODS

Based on the existing documents, the every drop of water available, either as ground water or surface water coming from precipitation, was collected, cleaned, stored and finally used by the Iranian in arid and semi-arid areas and the water resources were closely watched during all phases. Based on the monitoring, appropriate measures (mainly non-structural) would be adopted. Some examples are presented below:

- The people of Sistan in South-East of Iran used to relocate their villages to adapt to changes of the courses of Hirmand and Sistan rivers.
- Erection of many ancient dams in remote mountainous areas where access is still difficult indicates how carefully all possible sites were investigated. This is also

indicative of closeness of Iranian engineers with the Mother Nature throughout history.

- The large spring floods of large rivers such Karun, Dez and Marun could endanger many river qanats. The villagers used to plug the qanat entrance before the floods.
- Water division is a traditional method which was institutionalized in all parts of Iran and everybody obey this method. If this method was not established or obeyed, the result of dispute would be nothing but the waste of main part of the crops. In this context, the Iranian devised accurate techniques for fair division of water.
- The most important cause for destruction of historical hydraulic structures was improper maintenance. The phenomenon was usually associated by wars and invasions.
- Community effort was required for the maintenance of qanats and historical dams and in many cases this effort has many similarities with participatory irrigation management.
- Ebrahimabad village was relocated twice to cope with the changes of the village qanat.
- A diversion channel called Gavshir was used to divert the river during the construction of 1000-years old Band Amir near Shiraz. The same channel has been used for passing large floods and sediment flushing (Figure 5).

4-5-RENEWABLE ENERGIES HAVE MUCH GREATER POTENTIALS

The future and the past would have a clear distinction from 20th and 21st centuries; there would much less use of fossil energy (relatively). The experiences of ancient Iranian clearly demonstrate that much more of the potentials of renewable energies may be captured to ensure sustainability. Some examples are as follows:

- Thousands of Qanats were and are in operation for hundreds years. The reliance of gravity force to transfer water to surface has been the key to their sustenance.
- Hundreds of Water wheels have been used in various regions of Iran to use the waterpower to rotate the stones. With 40 Watermills, the Shushtar Water wheel complex is the most important complex in Iran and it is to be included in wonders of human's cultural achievements listed by UNESCO.
- In Yazd province there has been extensive use of air conduit for cooling of the house and subterranean water reservoir.
- Iranian used ice chamber to store the freezing cold of winter as ice blocks for hot summer season without any need to fossil energy.

Figure (5). The remains of sediment flushing conduit of Amir weir (right)

4-6- THE UNIMAGINABLE POTENTIAL OF SYNERGY OF VISION, CREATIVITY AND PERSISTENCE

Due to the primitive technologies of past, the Iranian had to rely on their vision, intuition, imagination, creativeness, hard work and courage to accomplish many astounding achievements in all fields of water engineering. These milestones are indicative of potential of synergy of vision, creativity and persistence:

- It has been proposed that qanats should be listed as the Eighth Wonder:
  - Useful life (Hundreds of qanats with useful life of more than 500 years are currently in service)
  - Number (More than 54000 qanats have been identified in country and some 36000 qanats are still in operation with the total annual discharge of 9000 MCM).
  - Length (the total length of all the qanats in Iran is approximately equal to distance from earth to moon).
- The mother well of Gonabad qanat is approximately 300 meters deep! (measured by Power ministry authorities). The length of this qanat is 33 km and an underground dam near the 193rd vertical shaft, regulates the discharge of the qanat in fall and winter.
- With 21 historical dams higher than 15 m, Iran has more large historical dams than any other country in the world. Spain with 10 and Solvakia with 9 historical dams higher than 15 m rank second and third respectively (Schintter, 1994).

- The ancient Iranian constructed the earliest underground dams in the world in some qanats near Isfahan and Kashan. The largest of these underground dams is 9 m high and can store about 270000 m^3 in winter for subsequent use in dry season.
- Kurit water transfer system consisted of 60 m high arch dam, which was the highest dam in world for 550 years till early 20th century, a Qanat and a channel with a total length of 20 kms. The system regulated and transferred water from the Kurit dam site to Kurit village for irrigation for at least 600 years. Considering the dimensions of the project, i.e., the length of the transfers system (20 km) and the height of the dam (60 m), it is evident that the construction of the project required astonishing qualifications and capabilities 650 years ago.
- The 80-km long water transfer scheme from Shishpir to Shiraz in Fars province is only one of long distance historical basin to basin water transfer constructed by Iranian.

4-7- ENSURING THE HYDROLOGICAL SAFETY OF DAMS AND WEIRS BY STRUCTURAL DUCTILITY

The builders of historical dams could neither foresee the extreme floods probable during the life of the structure nor excavate a spillway in the rock. Accordingly they constructed the historical dams in such a way that could resist overtopping in large floods. To achieve this they avoid embankment alternatives, used arch configuration, protect the downstream from scour:

- The historical Kurit dam would serve as an illustrating example of structural ductility. The 60 m high dam, which was the highest dam for 550 years in world, has resisted more than 1000 overtopping ever since it has been constructed. The excellent overtopping resistance of the dam has resulted from the combined effect of arch configuration, suitable geotechnical conditions of abutments and foundation and erosion resistance of masonry (Figure (6)).
- Shushtar Bridge-weir has resisted the floods of Karun River which is the largest river in Iran for some 2000 years before its partial destruction by a flood in 1885.
- Many of the historical dams and weirs which are presently in service have resisted numerous overtopping for hundreds of years:
  - 5 dams on the Kor River near Shiraz (They are still in operation).
  - Weirs on Karun and Karkheh Rivers;
  - Bridge and weirs on Zayandehroud in Isfahan;
  - Weis on Hirmand and Sistan river in South-East of Iran;
  - 2000 years old Bahman weir near Shiraz;
  - Golestan, Fariman, Abassi and Torogh dams in Khorasaan province (They are still in operation).

Figure (6). A view 60 m high Kurit dam from the river bed (June 2004)
(The left picture is the first picture taken from the downstream river bed
due to difficult access to the downstream)

5- A HISTORICAL INNOVATION IN FLOOD MANAGEMENT

The construction of three arch dam in the 13th in Iran (Kebar, Kurit and Abbasi) was the first application of this type of dam since Romans and Iranian constructed 3 true arch dam 2000 years ago (Schnitter, 1994). Abbasi flood-retarding dam also known as Abbasi arch was constructed 600 years ago near Tabas, in Northeast Iran. The Abbasi flood-retarding dam is an illustrating example of water wisdom of the builders (Figure 7). The dam has protected the city of Tabas from floods of Nahrain River for 600 years. To avert construction of diversion tunnel, Iranian used to construct the dams on a brick arch in narrow canyons. The lower part the dam would be constructed during a dry season. This creative scheme has been used in many historical dams in Iran. At Abbasi dam site, the lower part was not constructed so during floods the outflow from the dam was automatically regulated. The scheme is so elaborate that most of the engineers visiting the site believed that the dam was uncompleted or it had suffered a wash-out because of the alluvium foundation (Schnitter, 1994). This is the first time that based on site visits by dam and flood experts and communications with the nearby villagers, the dam is called a flood-retarding dam. The dam site is located 100 m upstream of water springs that account for a considerable part of the base flow of the river. Consequently it is unlikely that the main function of the dam is water storage, otherwise they should have constructed the dam downstream of the springs. A historical document indicates that the main function of the dam is controlling the floods. Based on this document they did not construct the lower part of the dam in view of probable failure of the structures and risk to downstream. Although the area of the basin is just 200 km2, the floods have large peaks as shown in Table (2).

Figure (7) 25 m high Abbasi flood-retarding dam

Table(2). The flood peaks at Abbasi dam site

(Year)Return Period	5	10	20	50	100	1000	10000	PMF
Flood Peak (CMS)	49	92	161	286	375	632		993

10- RETARDING BASIN FOR FLOOD CONTROL

There are two basic types of flood-mitigation reservoirs - storage reservoirs and retarding basins - differing only in the type of outlet works provided. The discharge from a storage reservoir is regulated by gates and valves operated on the basis of the judgment of the project engineer. Storage reservoirs for flood mitigation differ from conservation reservoirs only in the need for a large sluiceway capacity to permit rapid drawdown in advance of or after a flood.

A retarding basin is provided with fixed, ungated outlets that automatically regulate the outflow in accordance with the volume of water in storage. The outlet usually consists of a large spillway or one or more ungated sluiceways. The Pinay retarding basin in France consists of two wing dams partially closing the river but with a gap between them for discharge the type of outlet selected depends on the storage characteristics of the reservoir and the nature of the flood problem. Generally the ungated sluiceway functioning as an orifice is preferable because its discharge equation [Q = Cd A(2gh)1/2] results in relatively greater throttling of flow when the reservoir is nearly full than would a spillway operating as a weir . A simple spillway is normally undesirable because storage below the crest of the spillway cannot be used. However, a spillway for emergency discharge of a flood exceeding the design magnitude of the outlets is necessary in any case.

As a flood occurs, reservoir fills and the discharge increases until the flood has passed and the inflow has become equal to the outflow. After this time, water is automatically withdrawn from the reservoir until the stored water is completely discharged.

An outstanding example of the use of retarding basins in the United States is the reservoir of the Miami Conservancy District in Ohio. Retarding basins were selected for this project because the small streams rise so rapidly that it would be difficult to operate storage reservoirs effectively. Moreover, the retarding basin assures the drawdown of the reservoir after a flood and prevents use of the reservoir for conservation purposes at the expense of flood control.

The planning of a system of retarding basins must assure that the basins will not make a flood worse by synchronizing the increased flow during drawdown with flood peaks from tributaries. When the entire drainage area is small, such an event is unlikely. However, separate tributaries within a large basin may be subjected to independent storms and the probability of synchronizing is greater. Hence retarding basins are preferable for relatively small streams and storage reservoirs are preferable for large streams.

11- THE ADVANTAGES OF THE PRESENT ALTERNATIVE

To control the floods of the river, there are other alternatives involving storage structure at Abbasi dam site. One of the alternatives is a dam with overflow outlet (overflow alternative). Undoubtedly the alternative of creative builders (bottom outlet alternative) has great advantages in comparison with the overflow alternative as follows:

Initial reservoir Elevation:

In overflow alternative reservoir may be partially full at the beginning of the flood. Consequently the routing of the peak of incoming flood in this alternative would be less than the bottom outlet alternative. Similarly retarding of the flood peak would be less in this case. Surprisingly the alternative constructed matches closely with modern criteria for retarding dams as motioned above.

Sedimentation

The bottom outlet alternative enjoys considerable advantage in terms of sustainability and sedimentation. A survey of the reservoir clearly indicates that there is virtually no sedimentation in the reservoir after 600 years of operation. As the Abbasi dam has been stable in many extreme events such as the Great earthquake of 1978 with maximum horizontal acceleration of 0.75g, it is virtually a sustainable dam. Very few dam in world enjoy such an advantage. On the other hand the maximum useful life of the overflow alternative would have been 50 to 100 years. Fortunately Abbasi dam is the only historical dam in Iran that has not been threatened by construction of a modern dam. It is hoped that many generations would have the privilege of visiting this outstanding human heritage than would be a source of inspiration for many engineers for centuries to come.

Risk to the downstream

As it was mentioned Tabas is located downstream of the dam near the river. Accordingly the failure of the dam would have disastrous consequences for the city. In the overflow alternative the total time that dam is full or nearly full is much more than the other alternative. So the total risk to the downstream is much less in the bottom outlet alternative. A historical document indicates that they did not construct the lower part of the dam in view of probable failure of the structures.

Overtopping Frequency

Evidently the frequency of overtopping is much lower for the bottom outlet alternative. Figures 8, 5 and 6 clearly indicate that the dam structure is intact after 600 years. With increased overtopping frequency and duration the probable damages to dam would have been more severe.

Figure (8). Flood Attenuation in Abbasi retarding dam

Passage of people

In the overflow alternative the passage of villagers is blocked because there is virtually no other way in the gorge. Still the bottom outlet alternative has allowed the passage of villagers.

Throttling of flood peak

For retarding dams the ungated sluiceway functioning as an orifice is preferable because its discharge equation results in a relatively throttling of flow when the reservoir is nearly full than would a spillway operating as a weir. The deep understanding of dam and flood hydraulics by ancient Iranian is very surprising, but it should be remembered that their survival depended on efficient water resources and flood management.

In addition to the above discussion the overtopping resistance of the masonry arch dam and application of arch, which is a superior structural element, should not be overlooked.

Figure (9). Downstream view of Abbasi retarding dam

Figure (10). A view of the arch of Abbasi dam from underneath

13. A SIMILAR CREATIVE SCHEME FOR HARMONY WITH FLOODWATERS IN JAPAN

The flood-retarding scheme of Abbasi dam has been used for solving flood control and environmental conflicts in Muko River in Japan (Hata, 2005). One of the biggest issues in the discussion on dams is the interception of biological continuity by a dam. On the other hand, it is necessary to keep the discharge less than the flow capacity of downstream. To satisfy the both conditions the following measures could be suggested. The Muko River in the Hyogo prefecture runs through the highly developed urban areas and also crosses the Japanese main road and railway, and flows into the Seto Inland Sea.

The river authority of Hyogo prefecture planned in 1983 to construct flood control dam in the valley at the middle stream to protect this important urban areas. However, as the place is famous for the beauty of the valley and is known as a scenic area, people who love the place have been against the plan for more than 20 years. The reexamination of the river plan including the design flood from the Zero Base has started in the Muko River Basin Committee. The Prefecture River Authority proposes a type of dam with orifices like a retarding basin without control gates at the outlets as shown in Figure 11 (A). Under a certain value of the design flood comprehensive flood management may be possible without dam construction. The following type of a dam may be a solution in these cases. The objective of these flood control dams is to decrease the discharge rate less than the flow capacity of the downstream. On the other hand the main problem of a dam is the interception of biological continuity as mentioned above. Therefore, a solution of this problem will be to enlarge and open the outlet of a dam along the riverbed, and preserve the continuity of the river flow (**Figure 11**(B)). If the orifice is enlarged to the size that maximum discharge rate becomes the flow capacity of the downstream, it will make it possible to keep the continuity of sediment and the migration of fishes through the dam. It seems to be important to keep the continuity of flow especially for the dam aimed for flood control.

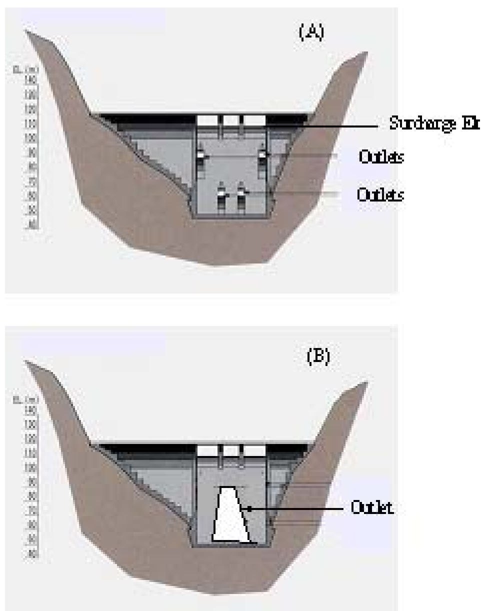

Figure (11). Modification of flood control dam in Japan
(A: Planned dam, B: Modified one)

As the stored water by the dam is quickly discharged after controlling the discharge rate, the damage to the plants will not be great. By designing the shape of the orifice the dam may harmonize with the surrounding as a well-designed bridge fits the landscape. It might be important to design a large aperture of orifice and the shape of it according to the calculated discharge to conserve ecological and sediment continuity and to decrease the damage to the landscape. The delay of runoff by the storage in the dam gives the time of warning and evacuation even in the case of exceeding the design flood when overflow of the dam crest happens and the danger of overtopping the downstream levee impends. The case study presented vividly demonstrates the main theme of this paper:

The past water wisdom can be used for coping with current and future challenges.

6- SUMMARY AND CONCLUSIONS:

Based on a comprehensive review of Iranian water heritage, the lessons learned can be classified as follows:

1. Creativity is vital for coping with diverse circumstances of water engineering and it can be promoted by the great challenges and limited resources.
2. A rich water culture is prerequisite for persistence, patience, courage and creativity required for efficient and sustainable management of limited water resources in arid regions.
3. Respecting the yields of the hydro systems would ensure the long-term benefits.
4. Good practice can be achieved before the development of the relevant theory.
5. Monitoring the hydro systems, adaptations and non-structural methods are vital for ensuring sustainability.
6. Relying on Mother Nature and her renewable energies would be the key to sustainability.
7. The synergy of vision, creativity and persistence can be used to achieve the most ambitious water management schemes with limited resources.
8. Structural ductility can be used to ensure the hydrological safety and sustainability of hydraulic structures in view of uncertainties.

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