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Identifying Karst Pattern to Prevent Bell Spring from Being Submerged in Daryan Dam Reservoir

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Abstract**—**The large karstic Bell spring with a discharge ranging between 250 and 5300 lit/ sec is one of the most important springs of Kermanshah Province. This spring supplies drinking water of Nodsheh City and its surrounding villages. The spring is located in the reservoir of Daryan Dam and its mouth would be submerged after impounding under a water column of about 110 m height. This paper has aimed to render an account of the karstification pattern around the spring under consideration with the intention of preventing Bell Spring from being submerged in Daryan Dam Reservoir. The studies comprise engineering geology and hydrogeology investigations. Some geotechnical activities included in these studies include geophysical studies, drilling, excavation of exploratory gallery and shaft and diving. The results depict that Bell is a single-conduit siphon spring with 4 m diameter and 85 m height that 32 m of the conduit is located below the spring outlet. To survive the spring, it was decided to plug the outlet and convey the water to upper elevations under the natural pressure of the aquifer. After plugging, water was successfully conveyed to elevation 837 meter above sea level (about 120 m from the outlet) under the natural pressure of the aquifer. This signifies the accuracy of the studies done and proper recognition of the karstification pattern of Bell Spring. This is a unique experience in karst problems in Iran.

Keywords**—**Bell spring, karst, Daryan Dam, submerged.

I. Introduction

KARSTIC aquifers are one of the most important water resources in the world. They supply about 25% of the water requirements [1]. About 11% of the area of Iran is covered by karstic carbonate formations [2]. Kermanshah Province is located in the west of Iran. With an average precipitation of 500 mm per annum, this province is considered as the relatively high precipitation regions of the country. There are hundreds of springs with high discharge and quality in this province. The springs' water is used for different purposes of drinking, farming and mineral water [3]. In view of the open joints and rapid penetration of water into the aquifers, they are more vulnerable than the other aquifers existing in other geological formations. Besides, due to the increasing trend of the water demand, quite a lot of dams are being constructed to collect the surface runoff even in karstic areas. This would give rise to the submergence of springs and pollution of the aquifers eventually. From qualitative and quantitative points of view, Bell Spring is one of the most important springs of the western part of the country that could be submerged under a water column of 110 m height as a result of the impoundment of Daryan Dam Reservoir. So, the rehabilitation plan of this spring was raised by the authorities. The plan entailed identifying the karst development pattern, particularly at the spring outlet. To this end, an all-inclusive engineering geology and hydrogeological study was conducted.

This paper sets out the methodology and program of the studies performed so as to recognize the karst development pattern in the spring outlet as well as the evaluation method of plugging plan.

The majority of important springs are located along the perimeter of the erosion base, i.e., at the outer boundary of karst poljes, river valleys and the seacoast. A common characteristic of these spring, whether permanent or temporary, is feature of these the direct dependence of their discharge on precipitation. In general, the capacity and hydrogeological character of the karst springs depend on number of factors such as: catchment area, retardation capacity of the aquifer, total effective porosity, geological composition and similar factors. Most of important karstic springs of the world are developed in the form of the inverted siphon (siphonal springs). Descending part of siphon for some of them reaches the depth as follows [4]:

Ombla Spring is located in Croatia. The minimum and maximum discharges of this spring are 2.4 and 106 m^3/ sec respectively. The average discharge of Ombla Spring is 23.9 m^3/ sec. The siphon of this spring is located 150 to 160 m below the sea level [5]. Ombla Spring has been investigated by the divers down to the depth of 54 m. Vaucluse Spring (Fountain of Vaucluse) is located in France. The depth of this spring is over 100 m. Ljuta Spring is located in Kotor of Monte Negro. The depth of this spring is over 80 m. Lez Spring is located in France. The depth of this spring is over 70 m reportedly.

Ombla Powerhouse constructed on Ombla Spring is one of the largest underground dams and reservoir projects. The outlet of this spring is located nearby a reverse fault placed karstic Mesozoic limestone beside the Eocene flysch deposits. The idea of constructing an underground dam or powerhouse on Ombla Spring was formed on the basis of the hydrogeological analyses done over the geological studies (1969-1974). The spring area has been explored using 19 piezometers excavating a 600 m long gallery, drilling 28 pilot boreholes and utilizing geophysical methods, caving and diving. In this project, by plugging the karstic conduits and implementing watertightening plans and connect them to the flysch, the water height behind the spring outlet could be raised for maximum 130 m.

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Four main approaches in strategy of underground water tapping are used in common applied karst hydrogeology [4]:

1- Directly from the spring outlet.
2- Using highly productive wells located behind not far from the spring outlet (from surface or from artificial underground cave).
3- Using common well technology for groundwater extraction from the karst aquifer.
4- Tapping galleries.

The first approach direct extraction from springs, has been used since ancient times but because of many reasons it is less acceptable as compared with other tapping strategies. By using this method, the optimum exploration of karst aquifer water potential is not possible in spite of a favorable water budget, because there is a discrepancy between the needs for water and natural discharge of spring.

Due to many reasons the second approach for karst spring tapping is much more acceptable. Some of those reasons are as follows:

- Minimum natural spring discharge is in many cases smaller than demand. Successfully located wells make it possible to extract more water than minimum natural spring discharge.
- Water quality is better and constant.
- Tapping structure is well protected.

In the present studies, having recognized the karstic conduits of Bell Spring, an approach similar to the second method has been resorted to for abstracting water and managing it to levels above the normal level of Daryan Dam Lake.

II. Bell Spring

This spring with an average discharge of 1.4 m^3/ sec is located in about 14 km north of Paveh and 4.5 km upstream of Daryan Dam axis (Fig. 1). This spring has its source from Zagros Mountain Range and a mountain called Darband. The spring water is used by a mineral water factory and the people living in Nodsheh and surrounding villages including Nav, Daribar and Novin.

The spring discharge ranges between 250 and 5300 lit/ sec. The high fluctuations of the spring discharge and its karstic feature in its outlet depict that Bell is a karstic spring (Fig. 2). Daryan Dam is of earth fill type with clay core. The dam height is 158 m. this dam is being constructed on the River Sirvan (Fig. 1). The spring outlet would be under an about 110 m water column after impounding the dam (Fig. 3).

III. Geology and Hydrogeology

The study area is structurally located in high Zagros zone [6]. The aquifer of Bell Spring and its catchment area have their sources from a belt-shape mountain range of Shahoo-Bell (Fig. 1). This mountain range is a part of sub-zone of Bisotoon in High Zagros Mountain Range extended with a trend of SE to NW beyond the borders of Iran and Iraq to the north of Dookan Dam in Iraq. The mountain range of Shahoo-Bell has a rough morphology including thick-bedded mass limestone of cretaceous epoch in the form of an about 2 km wide belt with a length of approximately 25 km. the maximum and minimum elevations of this mountain range are about 2500 m and 700 m (riverbed next to Bell Spring) respectively. There are lots of karstic features such as large and small caves as well as large karstic springs (e.g. Bell Spring) in the hillsides, valleys, thalweg and plains of the area under study . This mountain range has formed the aquifer of Bell Spring. The studies performed on the catchment area indicate that there is another spring in the name of Zalum in Iraq beyond the above mountain range at el. 920 masl in a distance of 28 km from Bell Spring with an outlet level of 717.6 masl. The watershed between the two springs should be above Bell and Zalum Springs at a level higher than 920 masl; whilst the normal level of Daryan Lake is 828 masl. This depicts that the aquifer of Bell Spring has even been developed at levels above the normal level of Daryan Lake. So, after the dam impoundment, water cannot flow into the Iraqi lands through the Daryan Dam reservoir whatsoever. In the interim, it was also inferred that after plugging the karstic conduits of Bell Spring, water may gravitationally flow out above the normal level of Daryan Dam Lake. The thrust faults DSF and DF are located in the northern and southern boundaries of Bell Spring Aquifer respectively (Fig. 4). These faults have caused the spring aquifer to be surrounded by the sequence of limestone and thin-bedded radiolarite (Lr1 and R Units). Geometrical characteristics of the discontinuities system of Bell limestone have been presented in Fig. 4 (b). The joint set of J1 is vertical to the bedding trend. The relatively vertical dip of the joints helps the precipitations to penetrate into the rock mass and dissolve the limestone. Most of the joints in the project area are open and without infilling. The joint apertures are mostly in the range of 2.5 to 10 mm. The bedding has fewer apertures. So, the joints and cracks in comparison with bedding have played a more important role in developing the dissolution phenomenon in the thick-bedded limestone of Bell [7].

IV. Geological Studies Around Bell Spring

Surface and sub-surface geological studies including geophysical and geotechnical investigations have been carried out around Bell Spring with the following objectives:

a) Identifying Bell Spring aquifers and determining its hydrodynamic parameters
b) Identifying type of the spring (diffuse or conduit) and its relation with the aquifer
c) Identifying the conduit(s) bringing water to the spring located in close proximity to the spring outlet
d) Study on the engineering geological parameters of the rock mass existing around the spring outlet

A. Surface Studies

These studies were performed with the aim of exploring the spring aquifer and its hydrogeological boundaries, evaluating the karstic features and preliminary recognition over type of the spring as well as managing the sub-surface studies to resolve hydrodynamic parameters of the aquifer, exploring the probable conduit(s) bringing water to the spring.

1. Fractures Around the Spring Outlet

The most important faults identified around the study area comprise CBF and F7.

- CBF Fault

The spring outlet has been formed along this strike-slip fault. The fault dip is between 75 to 80 degrees and its dip direction is NE Fig. 4 (a). The fracture zone width of CBF around the spring is about 7 m (Fig. 5).

- F7 Fault

This steeply-dipped fault is about 70 m long and has a NE-SW trend. It passes through the mouth of natural shaft above the spring. The horizontal slicken sides on the fault wall verify the strike-slip mechanism of this fault (Fig. 4 (a)).

2. Karstic Features around Bell Spring

- Bell Spring Outlet

The spring outlet is in a cave-like crack with a width of about 4 m and height of 22 m. The cave ceiling is about 26 m long with negative slope. The above crack has been formed along the semi-vertical fault of CBF. The elevation of the cave ceiling ranges between 725 and 740 masl. Water marks are observed on the cave walls and ceiling. The negative slope of the spring is the ceiling of a karstic conduit (Fig. 1).

- Natural Shaft Above the Spring

An about 4 m diameter shaft with the height of about 52 m is another karstic feature around Bell Spring. The shaft was filled by angular materials (Fig. 6). After removing the materials, it was realized that the shaft is actually the remains of the old siphon conduit of the spring which has dried as a results of the formation of new outlets at lower levels (Fig. 7). The shaft is located in the intersection of CBF and F7. The shaft outlet is located at el. 770 masl.

- Spring Old Outlet

The old outlet of the spring is located in about 28.5 m above the bottom of the present spring outlet at el. 746 masl (Fig. 8). After removing the materials via excavating G3 Gallery (Fig. 9), it was realized that the old conduit is a branch of the natural and vertical conduit of the spring or the natural shaft.

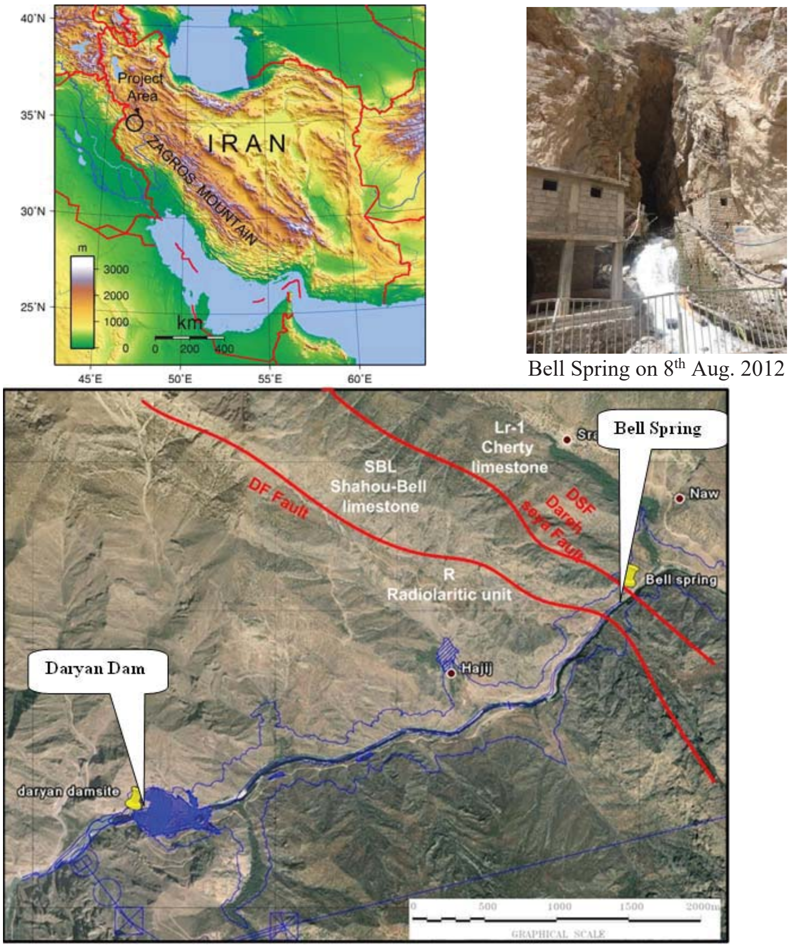


Fig. 1 Bell Spring at the upstream of Daryan Dam

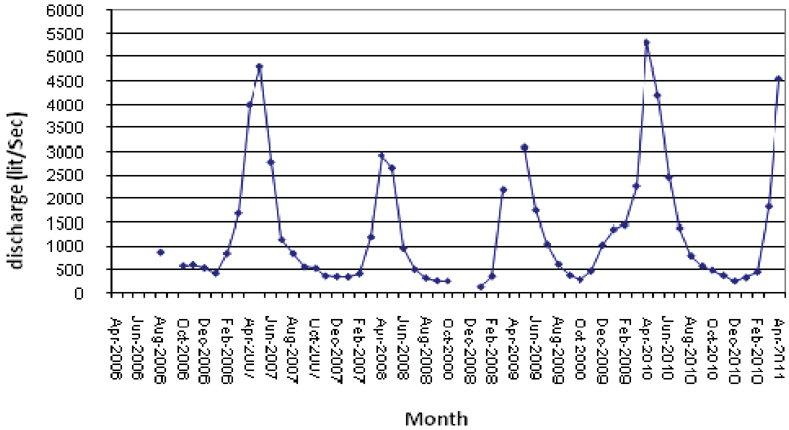


Fig. 2 Discharge diagram of Bell Spring (2006 to 2010)

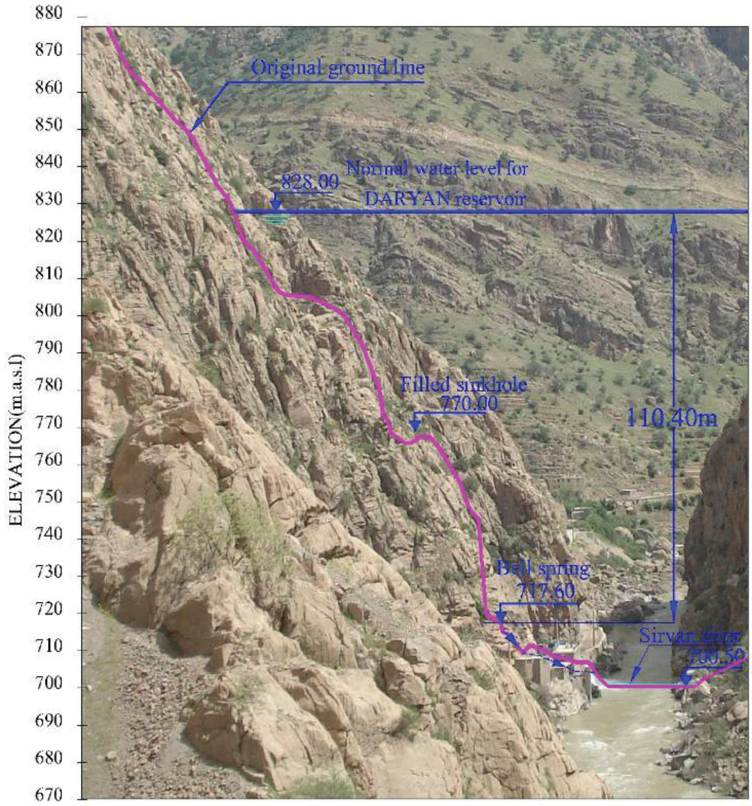
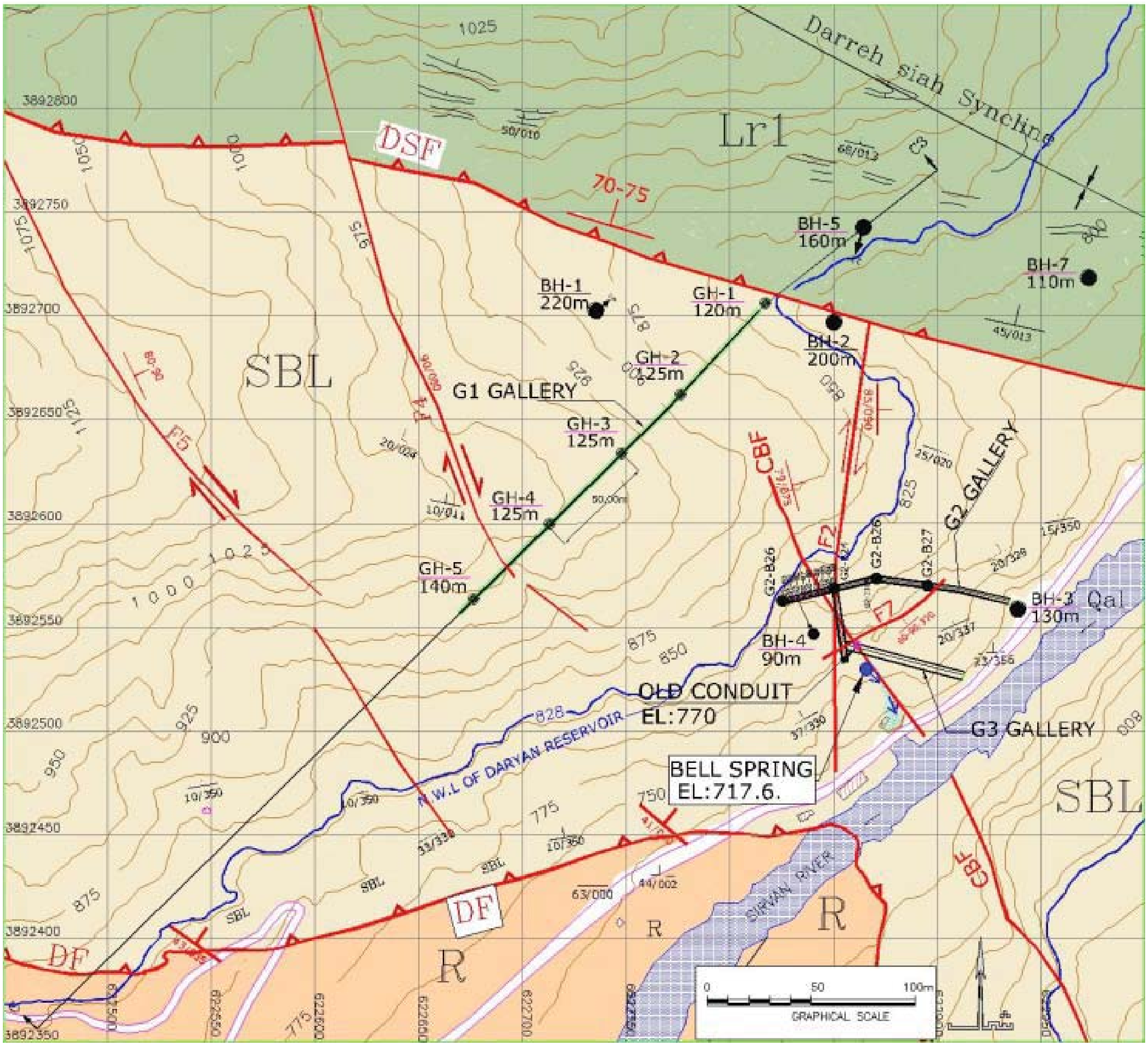


Fig. 3 Bell Spring Outlet in Sirvan Valley (Viewed from NW or upstream of the river)

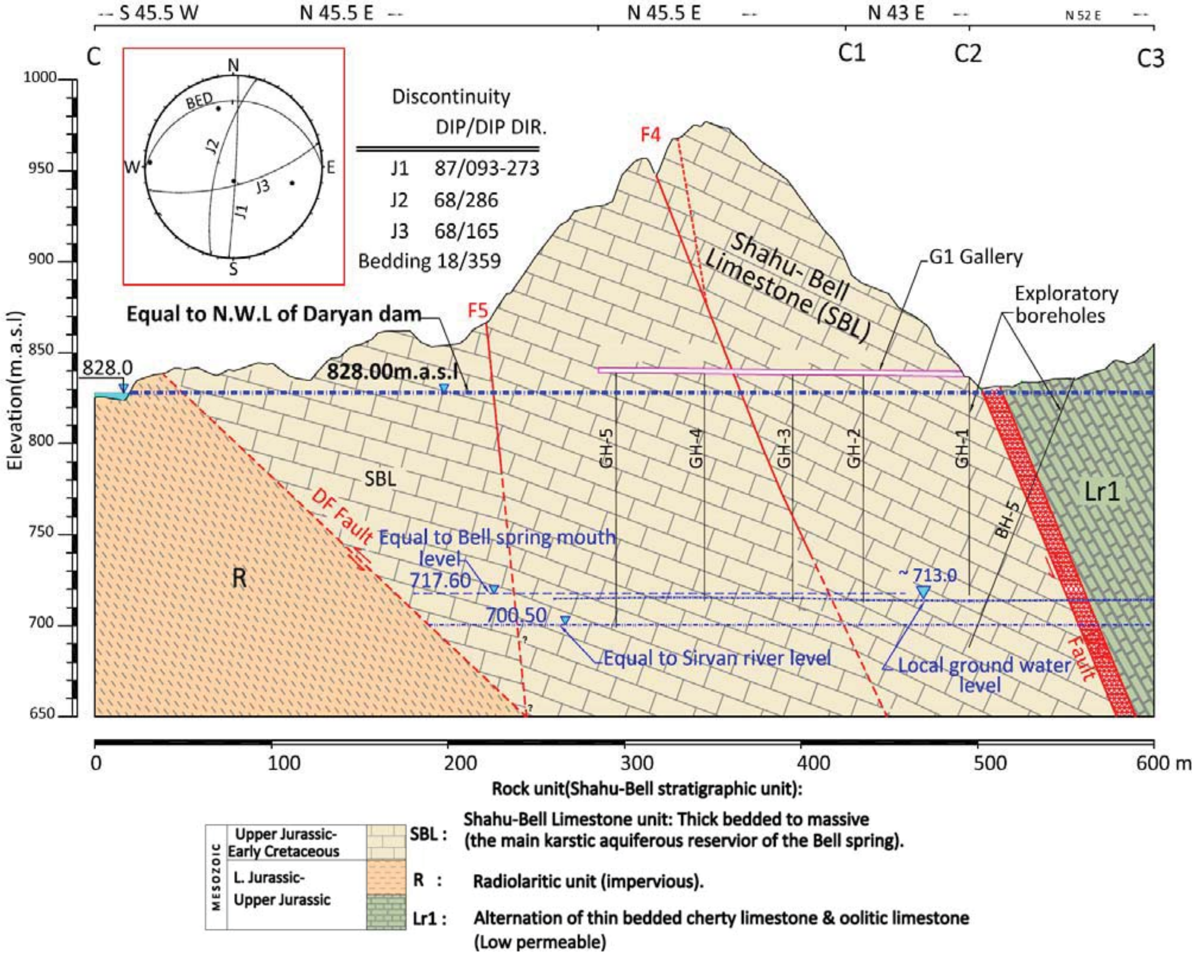
B. Sub-Surface Studies

The main objective of these studies was to recognize the characteristics and geometry of the probable conduit(s) bringing water to the spring. The studies include excavation of a gallery and shaft, drilling exploratory boreholes, field geophysical tests and diving investigation. At first, a 210 m long Gallery (G1) was excavated at el. 837 masl perpendicular to CBF and F7. Then, 5 exploratory boreholes with total length of 635 m were drilled in G1 for seismic tomography studies (Fig. 4 (b)). The spacing between the boreholes was 50 m and their depth was 120 m (up to Bell Spring Level). The geophysical study results depicted that the velocity of P waves between the boreholes ranges between 4000 and 5750 m/ sec. This indicated the intact rocks are strong. Lugeon test results showed low permeability of the above rocks as well. The investigation results indicated that the rock masses existing around the spring outlet (between G1 and outlet) have no considerable karstic feature and their average permeability is low (less than 10 Lugeon). In other words, the results showed that the spring conduit should be at a level below the spring outlet (i.e. the conduit is siphonal). Besides, 6 exploratory boreholes with total length of 910 m were drilled from the natural ground surface for studying the hydrogeological conditions around the spring. Study on the groundwater table depicted that it is mostly 3 to 4 m below the spring outlet level. This also showed that the spring is siphonal. Having realized that there is no karstic conduit at upper levels of the spring, it was to a great extent noticed that the spring is siphonal. A 112 m long gallery (G2) was excavated at el 712.5 masl about 80 m upstream of the spring to directly explore the karstic conduits below the spring level. In addition, a 24 m long adit was excavated toward the spring from chainage 87 of the gallery (Fig. 4 (a)). Some exploratory and geophysical investigations applying GPR method were performed inside G2 to identify karstic conduits. Reportedly, 27 exploratory boreholes with total length of 844 m were drilled in G2 and its adit. The exploratory drilling done in G2 proved that Bell is a siphonal spring. Some karstic conduits bringing water to the spring were also identified. The exploratory investigations of the deep siphonal conduit of Bell Spring through G2 can be divided into two parts:

1. The first part reinforced the assumption of siphonal spring.
2. The second part directly resulted in the exploration of the deep karstic conduit.



(a)



(b)

Fig. 4 Geological Plan and Profile of Bell Spring

Fig. 5 Fractured zone of CBF

In the first part, a number of shallow 10 m boreholes were drilled in the bottom of the gallery and GPR geophysical studies were performed. The water level in all above boreholes was below the spring level. The walls and bottom of G2 excavated nearby the spring were completely dry. The important point was the water level in the boreholes of G2 that was lower than the spring level. This matter does not improve the assumption that the spring's flow is gravitational. The investigations depicted that there is no karstic conduit at least down to 10 m below the spring level. In other words, Bell Spring Conduit is definitely siphonal. Then, deeper boreholes with different angles were drilled proportionate to the deep karstic conduit. Initially, some fan holes were drilled from chainage 87 of the galley towards and below the spring with different angles. When it was proved that the spring is siphonal, a 24 m long branch gallery was excavated and a number of fan holes were drilled in the branch galley towards the spring some of which encountered karstic voids and cavities in depths 16 m to 33 m below the spring level. Then. The water level in boreholes was suddenly raised and became fixed at a level close to the spring level. The adit boreholes results showed that the conduit has a steep slope (semi-vertical) at the end. In this zone, the conduit was mainly filled by angular limestone collapsed from upper levels.

Having realized that the spring is siphonal by drilling the fan holes, another borehole (BH-24) was drilled vertically in G2 at 30 m away from the spring outlet. BH-24 ran into a large karstic cavity from depth 38.5 to 42.8 m; then, the water level in this borehole raised up to the spring level (Fig. 9 (a)). The explored cavity diameter was about 4 m. The top and bottom levels of the cavity were 33 and 37 m below the spring outlet respectively. Seeing that the cavity was under pressure and saturated, it was realized that it is a part of the main conduit bringing water to Bell Spring. The cross section presented in Fig. 9 (b) has been prepared based on the latest data obtained about the spring outlet. This section indicates the old and present conduits of the spring together with the general view of the spring rehabilitation plan.

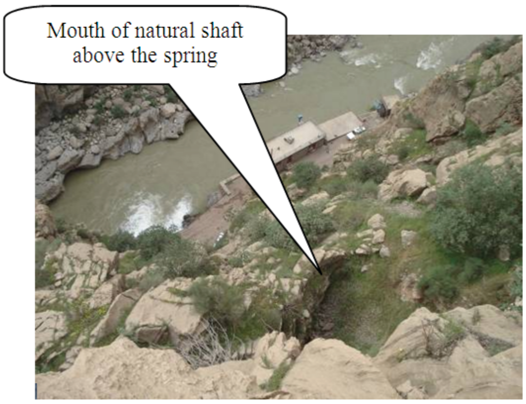


Fig. 6 Mouth of natural shaft before removing the infilling materials

Fig. 7 Natural shaft after removing the infilling materials

Fig. 8 Old spring conduit

A 38.5 m deep and vertical shaft in 2 m diameter was excavated alongside BH-24 to get access to the foregoing cavity. After that, divers explored about 120 m of the conduit bringing water to the spring in opposite direction of the water. There is only one conduit with a diameter of 3-4 m and slope of 10-15% downward along the 120 m long distance. After 120 m, the conduit continues with over 3 m diameter. In view of the high hydrostatic water pressure, it was impossible to go ahead by divers.

Allowing for the submergence head of the spring and applying the maximum pressure of about 12 bars, the Lugeon tests conducted in the boreholes of G2 showed that the rocks around the spring siphon are permeable in surface and next to the outlet. Nevertheless, they are low permeable in deeper zones.

V. Bell Spring Rehabilitation Plan

The surface and sub-surface investigations depicted that Bell is a single-conduit siphonal spring (at least for 150 m distance to the spring outlet). Hence, it was decided to study on the alternative of water abstraction from karstic conduits in a distance not so far away from the spring outlet. This is one of the methods approved as for abstracting water from the karstic springs all around the world. The low permeable surrounding rocks of the conduit gave rise to the study on plugging the spring and conveying water to the upper levels under the pressure of the aquifer. In this plan, the siphon was plugged just from the shaft constructed at BH-24 location toward the spring outlet (Figs. 9 (b) or 11 (b)).

In addition, all natural and artificial cavities including the natural shaft and old conduits connected to the shaft, exploratory boreholes drilled towards the siphonal conduit and the access galleries were plugged to leave no connection between the dam lake and the siphonal conduit. So as to manage the water outside the reservoir, a 135 m long gallery was excavated at el. 720 masl and a 100 m high shaft was constructed to discharge water from el. 837 masl (Fig. 9 (b)). In order to assess the efficiency of the proposed plan, the valves installed on the spring outlet pipes were closed to measure the spring water pressure and rising rate of water in the pipes. As per the graph presented in Fig. 10, after 10 days, the water pressure reached 12 bars and the water spilled out of the shaft which its portal level is 8 m above the normal level of the dam lake (el. 837 masl) with no pumping. Fig. 12 depicts the new fall of Bell Spring beside Daryan Dam Reservoir after plugging (in a height about 120 m above the old spring outlet).

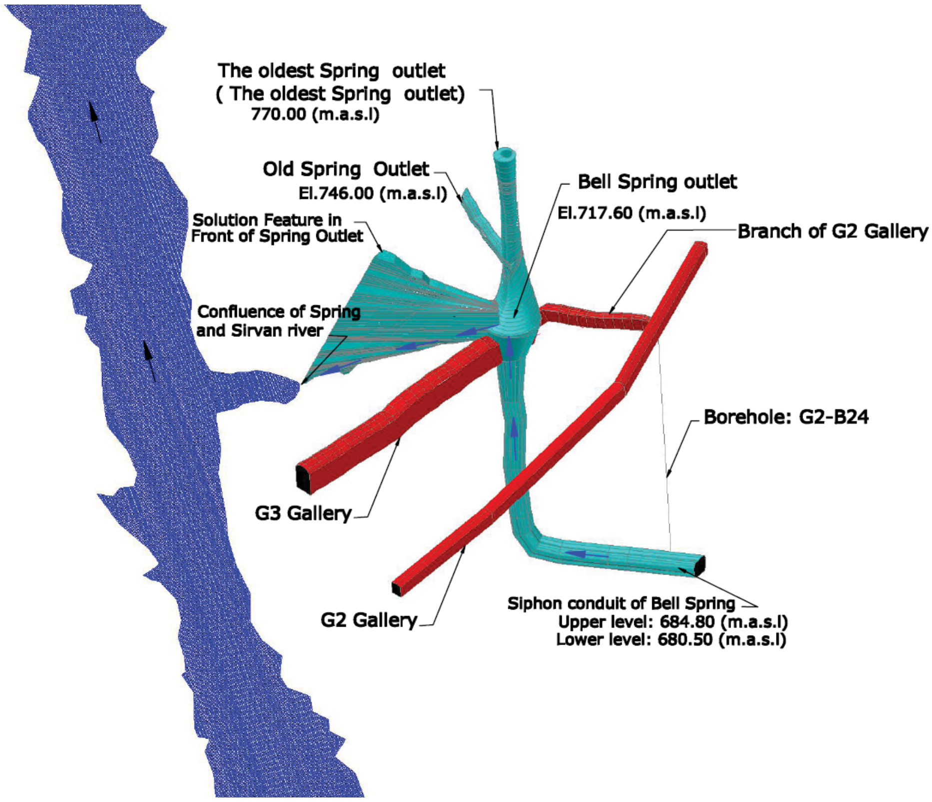
VI. Conclusion

The studies depict that Bell is a siphonal spring that its upward flow movement in the spring outlet has created a natural shaft with about 85 m height. The aquifer of this spring is a 2 km wide limestone belt with a length of approximately 25 km. this aquifer has been surrounded by some faults from both sides and has no hydraulic connection with the adjacent aquifers. The interaction between faulting and karstification has caused the karstic features around Bell Spring to be relatively regular and foreseeable. The main conduit of the spring has been formed in the intersection point of the two faults and the secondary conduits have been developed alongside the above faults.

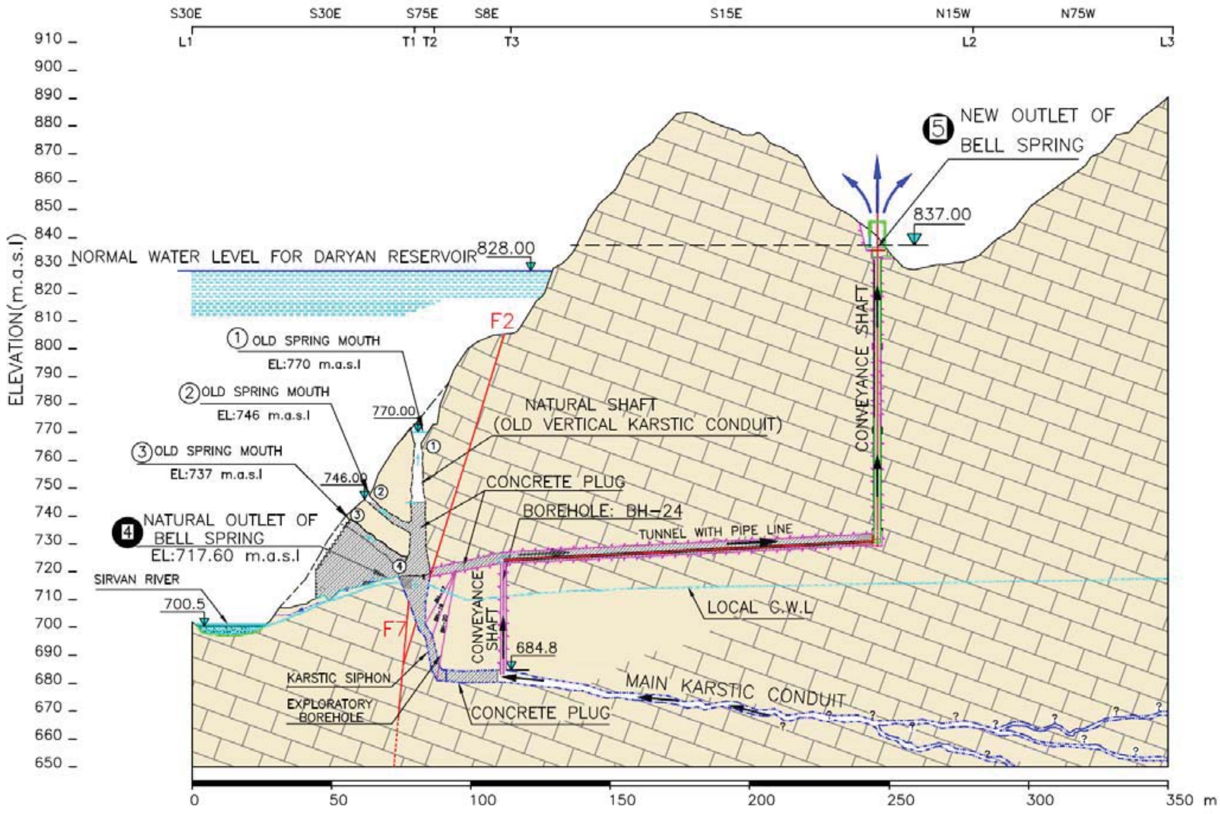
In the past, water actually went out beside Sirvan Valley through a natural and semi-vertical shaft which started from el. 685 and continued to el. 770 masl! The erosion process occurred in The River Sirvan as well as the lowering of the river water, the spring could go out from lower levels (el. 746 and 737 masl). When water was going out at el. 737 masl, the rocks underneath the siphon acted as a barrier against the spring flow. Over time, the erosion-dissolution process of the spring, the rocks vanished and the spring outlet is now observed as a fall with a false view.

The oldest natural spring outlet, which is dry now, was identified at about el. 770 masl (about 52 m above the present outlet level). This was the first indication verifying the capability of the spring aquifer to discharge out at upper levels as it did before.

Permeability tests conducted on G2 boreholes depicted that the rocks around the spring siphonal conduit are permeable in surface and close to the spring outlet. Nevertheless, the rocks of deeper zones are low permeable. The results indicated that the siphon surrounding rocks in deeper levels may play an important role in decreasing the water rush from the reservoir side into the spring conduit. In view of the low permeability of the rock mass around the siphon conduit in deeper zones, the spring water could gradually go up by plugging the conduit bringing water to the spring with the natural pressure of the aquifer.



(a)



(b)

Fig. 9 A karst pattern of Bell spring (a) 3D model of the galleries and (b) Cross section of Siphonal Conduit

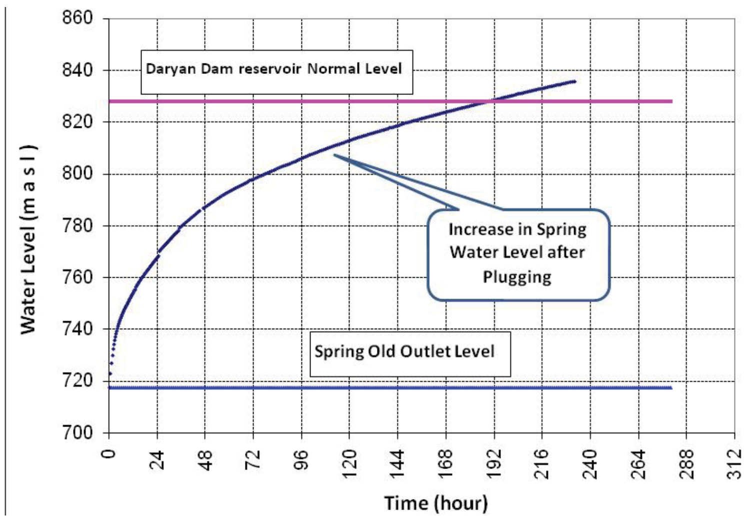


Fig. 10 Rate of Spring Raise after Plugging

Some features of the spring catchment such as high feeding level (more than 2000 masl) and its belt shape were other parameters whereby it was concluded that the spring aquifer is able to triumph over the dam normal level (828 masl). Taking into consideration the belt shape of the catchment area (about 25 km long), even by a slope of about 1% for the karstic aquifer, the water level of the karstic saturated aquifer could be over 900 masl that is above the normal level of Daryan Dam Reservoir. Zalum spring beyond this limestone in Iraq, which is located at el. 900 masl (28 km away from Bell Spring), can be served as a reason for this issue.

(a) Before plugging

(b) After plugging

Fig. 11 Natural outlet and plugging of the spring

(a) (b)

Fig. 12 A new waterfall beside the reservoir from 120 m above the natural outlet without pumping and water spilling out of the conveyance shaft

Eventually, in accordance with the accurate studies carried out on the karstic features of Bell Spring and the technical and economical evaluations, an executive solution related to the plug of the karstic conduit of Bell Spring was presented to prevent water from entering the dam lake. After plugging the spring and conveying the water to upper levels, it was proved that the plan is successful. After 10 days, the water pressure reached 12 bars and the water spilled out of the shaft which its portal level is 8 m above the normal level of the dam lake (el. 837 masl) with no pumping with a discharge of more than 650 lit/ sec. It is notable that the rehabilitation plan of Bell Spring has completely been based on the internal knowledge which resulted in a valuable successful experience for the country.

ACKNOWLEDGEMENT

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REFERENCES

[1] D. Ford, and P. Williams, "Karst hydrogelogy and geomorphology", John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, 2007.
[2] A. Afrasiabian, "Karst Water Resources Studies and Researches in Iran", Proceedings of the 2nd Global Conference Water Resources in Karstic Formations, Kermanshah – Tehran, Page 013-126, 1993.
[3] K. Taheri, E. Raeisi, "Iran Karst Resources, An Introduction on a Concept", Proceedings of the 1st National Conference on Iran Water Resources Investigations, Page 01-14, 2010.
[4] P Milanovic, "Gological engineering in karst: Dams, reservoirs, grouting, groundwater protection, water tapping, tunneling", Zebra, 347 pp., 2000.
[5] S. Misetic, "Ombla HPP environmental impact study", Zagreb, pp. 1-67, 1999.
[6] M. Berberian, G.C.P. King, "Towads a paleogeography and tectonic evolution of Iran", Can.J. Earth Sci., 18(2), pp. 210-285, 1981.
[7] Mahab Ghodss Consulting Engineering Co. "Final Geological Report and Engineering Geology of Phase II Studies of Bell Spring Rehabilitation Plan", pp. 202, 2012.