Zamzam Studies and Research Centre

20/10/2010

Unlike other geological surveys worldwide, the Saudi Geological Survey (SGS) faces a number of unique responsibilities that arise from its being the major national earth science body of the Kingdom. Foremost of these special responsibilities are the obligations it has towards the well being and prosperity of the two holiest cities of Islam, Makkah al Mukarramah (Makkah the Holy) and Madinah al Munawarrah (Madinah the Illuminated).

The Custodian of the Two Holy Mosques, His Majesty King Abdullah bin Abdulaziz, his Father His Majesty King Abdulaziz and all the kings that followed him have taken keen interest in the affairs of Muslims all over the world. Special attention was given in the matters relating to the two Holy Cities where millions of Muslims make pilgrimage; hence the various extensions of the two Holy mosques through the Saudi period. The Zamzam well, which is located within the precinct of the Holy Mosque in Makkah, is important to Muslims because of its miraculous origin. Muslims cherish water from this well, and hence Their Majesties' continued special interest in and attention to Zamzam in all its aspects.

The Zamzam Studies and Research Center (ZSRC) was created by SGS to secure the supply, in terms of quality and quantity, of Zamzam water. As a result the Center has set up a series of investigative projects to define, quantify, and monitor the water source, and provide the information needed to manage and sustain supplies in the face of increasing demand by residents and pilgrims.

The Miracle of Zamzam Well

According to Arab historians, the Zamzam Well, except for a few periods when it became dry or was buried under sand, has been in use for around 4000 years. The well marks the site of a spring that, miraculously, had issued forth from a barren and desolate wadi (non perennial stream) where the Prophet Ibrahim (Peace be upon him-pbuh), under Allah's command, had left his wife Hajar and their infant son Ismail (pbuh). In her desperate search for water,

Hajar ran seven times back and forth in the scorching heat between the two hills of Safa and Marwa to look for water for Ismail (pbuh), who was dying of thirst, and also to look for passing karawans for help.. Allah, in His mercy, sent the Angel Gabriel, who scraped the ground, causing the spring to appear. On finding the spring, and fearing that it might run out of water, Hajar enclosed it in sand and stones. The name Zamzam originates from the phrase Zomë Zomë, meaning 'stop flowing', a command repeated by Hajar during her attempt to contain the spring water. The area around the spring, which was later converted to a well, became a resting place for caravans, and eventually grew into the trading city of Makkah, birthplace of the Prophet Muhammad (pbuh).

Prophet Ibrahim (pbuh) later returned to rebuild Ka'ba, the first Bait-ul-Allah (House of Allah), originally said to have been built by Adam (pbuh). It is the holiest Muslim shrine. The Ka'ba now stands in the center of the Holy Mosque, also called Al-Haram. The Zamzam well is located within the Holy Mosque at about 20 m east of the Ka'ba.

All able-bodied Muslims with sufficient financial means are obliged to make the pilgrimage to Makkah, known as the Hajj, at least once in lifetime. During the Hajj, pilgrims perform a number of rituals in the Al-Haram and outside Makkah at Muna, Arafat, and Muzdalifa. One of the rituals known as the Umrah, includes Tawaf (seven times circling) of Ka'ba and Sai between the hills of Safa and Marwa, which is to re-enact Hajar's search for water. Hajj is performed on specific dates during Dhu Al-Hijja the last month of the Islamic year while Umrah is optional and can be performed at any time of the year. Millions of Muslims visit Makkah to perform Umrah and Hajj throughout the year; the peak season being the month of Ramadan and Dhu al Hijja. Visitors cherish drinking Zamzam water during their visit and carry it back home.

Structure and hydrogeology of the Well

Zamzam Well is hand-dug and is about 30.5 m deep, with an internal diameter ranging from 1.08 to 2.66 m. Hydrogeologically, the well lies within Wadi Ibrahim, which runs through the Holy City of Makkah, and taps groundwater from the wadi alluvium and, to a much lesser extent, the underlying fresh bedrock. The well is now housed in a basement room, protected by glass panels that allow a clear view of the well.

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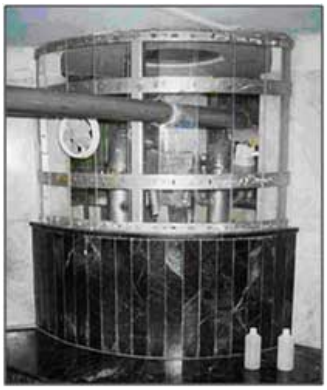

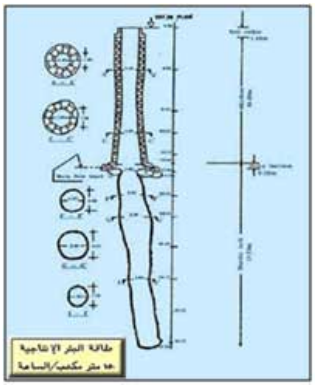

Electric pumps are used to draw water from the well, replacing the ropes and buckets of the olden days. No visitor is allowed to enter the Zamzam Well room and surroundings. Outside this room, there was a service area, where cold Zamzam water fountains and dispensing containers were provided for drinking purposes. Recently, the Al-Haram Tawaf area has been extended to cover the entrance to this area and it is no more accessible to pilgrims. Instead, cold Zamzam water fountains and dispensing containers are now placed at the periphery of Tawaf area and within the Grand Mosque, and open piazzas or Al-Sahat surrounding the Al-Haram building Moreover, a bottling plant and public distribution Sabeel have been established at Kudai, south of Al-Haram for the visitors who want to carry Zamzam home.
The upper 13.5 m of the well is excavated in the sandy alluvium of the Wadi Ibrahim, and the lower 17.0 m in the underlying diorite bedrock. In between lies a 0.5 m thick highly permeable weathered rock. Most of the alluvial section of the well is lined with stone masonry except for the uppermost 1 m, which has a reinforced concrete collar. The weathered rock section is lined with stone and it is this section that provides the main water entry into the well.

Zamzam water entering the well from the stony horizon

Research issues and objectives

Zamzam Studies and Research Center (ZSRC) at SGS is to provide the required scientific solutions for effective monitoring and management of the aquifer feeding the Zamzam well and to ensure the purity and security of supply. The Center is currently focusing on the following aspects of management of the aquifer, the well and the Zamzam supply and distribution system:

-Monitoring and managing demand to prevent depletion,
-Urbanization of the Wadi Ibrahim catchment and its effect on recharge,
-Management of storm drainage in relation to recharge,
-Maintaining groundwater movement and quality through building controls,
-Upgrading of the Zamzam pumping and storage system,
-Optimization of Zamzam supply and distribution,
-Quality control and quality assurance of operating and maintenance of filtering and storage plants at Makkah and Madinah

Monitoring and managing demand to prevent depletion

With the increasing accessibility of affordable air travel, the number of Muslims visiting the Holy City of Makkah has risen dramatically over the past 3 decades, from around 400,000 per year in the mid seventies to over several millions since the Mid Nineties.
Water levels in the Zamzam Well were formerly monitored by a simple drum hydrograph, but this has now bee ' a more sophisticated real-time multi-parameter monitoring system, which makes digital records of water level, e conductivity, pH, Eh and Temperature, etc. The Datalogger is accessible by SGS through phone cable and the d examined and downloaded without going to the well. A network of other monitoring wells has also been install t Wadi Ibrahim to monitor the response of the entire aquifer system to the recharge and discharge. Some of the

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fitted with automatic digital water level recorders.

Datalogger installed near the well to monitor water level, temperature, electric conductivity, TDS, pH, density, etc.

ZSRC member collecting water sample, and manually monitoring water level by electric dip meter for calibration of datalogger. In the background is the pumping system in the glass closet

With the increasing number of visitors, demand for Zamzam water was continually increasing. ZSRC's task is to estimate sustainable well yield and recommend measures to control further increase in demand to ensure that sustainable supply limits are not exceeded. Thus ZSRC advises Al-Haram Authority regularly on the maintenance of optimum production and the dynamic water level in the Zamzam well. In the beginning of the year SGS provides pumping schedule and the optimum monthly production depending upon demand which is the highest in the months of Ramadan and Dhu Al-Hijja and the lowest in Muharram. A threshold water level in the well is maintained. If the water level goes below this level the pumping is stopped, water level is allowed to recover, and then pumping is resumed. The annual discharge from the well is restricte
500,000 m3. However, this limit can be modified if hydrological condition so permit. For example, due to last y
rainfall the augmented aquifer recharge allowed proposed production increase by about 92000 m3 for the yea

Water Quality Monitoring

One of the mains tasks of ZSRC is to monitor the hydrochemical and microbial characteristics of Zamzam. ZSR

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monitoring Zamzam water quality for years. Every week water samples are collected from the Zamzam well and the various outlets including thermoses and water taps in Al-Haram, and Sabeel Kudai and Khazzan outlets. Samples are analyzed for chemical and microbial components. Zamzam water is filtered through a series of sand filters and cartridge filters, and then sterilized by ultraviolet (UV) irradiation at these treatment plants before distribution to consumers. Al-Haram Authority is advised to take action if and when some unexpected adverse component is detected.

Sampling Zamzam water from the thermoses in Al-Haram for microorganism analyses

Monitoring Ultraviolet irradiation for deactivating bacteria in Zamzam water

Zamzam water is supplied daily by tankers to Masjid Nabavi at Madinah Al-Munawarrah. Before, filling the thermoses and supplying to public outlet Zamzam water is again treated by UV process. ZSRC regularly inspects this treatment and distribution system and advises the managers on improvements and streamlining the system

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Inspection of quartz sleeve of UV unit Inspection of Clean cartridge Filter

Inspection of Zamzam public outlet at Madinah Al-Munawarah

Urbanization of the Wadi Ibrahim catchment and its effect on recharge

To sustain groundwater supply from wells, aquifers need to be continually recharged from direct infiltration of rainwater . In arid climate natural recharge is limited to rainfall from occasional, brief storms. Supply can be severely threatened during long dry periods, when water is effectively 'mined' from the aquifer with no source of replenishment.

The surface area of the Wadi Ibrahim alluvium covers only 60 km2. Limited recharge of the wadi alluvium aquifer occurs through infiltration of rainwater falling directly on the alluvium, supplemented by run-off from adjacent hillsides.

Urban development of Makkah has now extended over the wadi bed, diminishing the already meager amount of rainwater infiltration into the underlying aquifer due to surface sealing and channeling of rainwater into storm drainage systems. Modeling of aquifer recharge is therefore crucial to ensure that supply and demand for Zamzam water is appropriately balanced. The ZSRC is therefore assessing and quantifying the effects of urbanization on recharge, and developing recommendations for planning controls to guide further development on the wadi alluvium .

Maintaining groundwater movement and quality through building controls

Makkah is unusual among Saudi Arabian cities because of its high proportion of relatively high-rise buildings, some of which are many decades old. High-rise development continues to present a solution to urban expansion over the Wadi Ibrahim catchment area, but the deep foundations required can expose the groundwater to contamination and also restrict its movement. Strict building controls are therefore required for allowing high rise developments in sensitive areas, indicated by near real-time maps and models of the water table elevation calculated from monitoring well data, and by risk assessments of the likely impact on groundwater quality. Engineering geology maps of Makkah also help to highlight zones of lo development risk.

The ZSRC aims to present solutions to these complex and inter-related problems through a modern, integrate faceted approach to water catchment management and conservation. Through these actions, the quality and q supply from the Zamzam Well can continue to be sustained to meet the spiritual needs of the world's one billion Muslims. Wadi

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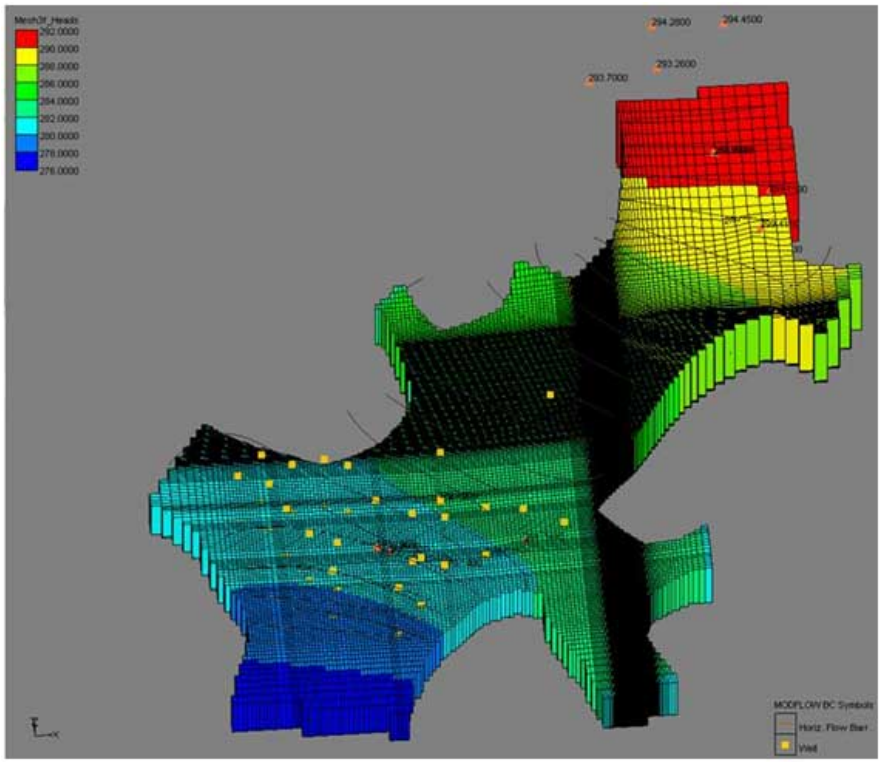
Ibrahim Environmental Management System (WIMS) project, described here below, has been designed to achieve these goals.

ZSRC is responsible to study, assess and quantify man-made activities having impacts on the groundwater environment and monitor future development projects. . In some projects consultants were also engaged. ZSRC has studied and advised on various projects on foundation design to prevent or mitigate likely present or future effect on groundwater regime in terms of quality, quantity, and flow. Groundwater modeling is the main and integral part of all such projects. Some such major projects are:

-First Project of Makkah Development Company,
-Dar Al-Tawhid Intercontinental Hotel
-Souk Al-Saghir Underpass -
-Mataf Adjustments-
-Al-Masa'a Extension
-King Abdulaziz Endowment Project -
-Haram 3rd Extension (Al-Shamiya)-
-Khandamah Development Project-
-King Abdulaziz Endowment Project 2
-Jabal Omar Development Project.
-Darb Al-Khalil Development Project
-New Ajyad Hospital
-Others



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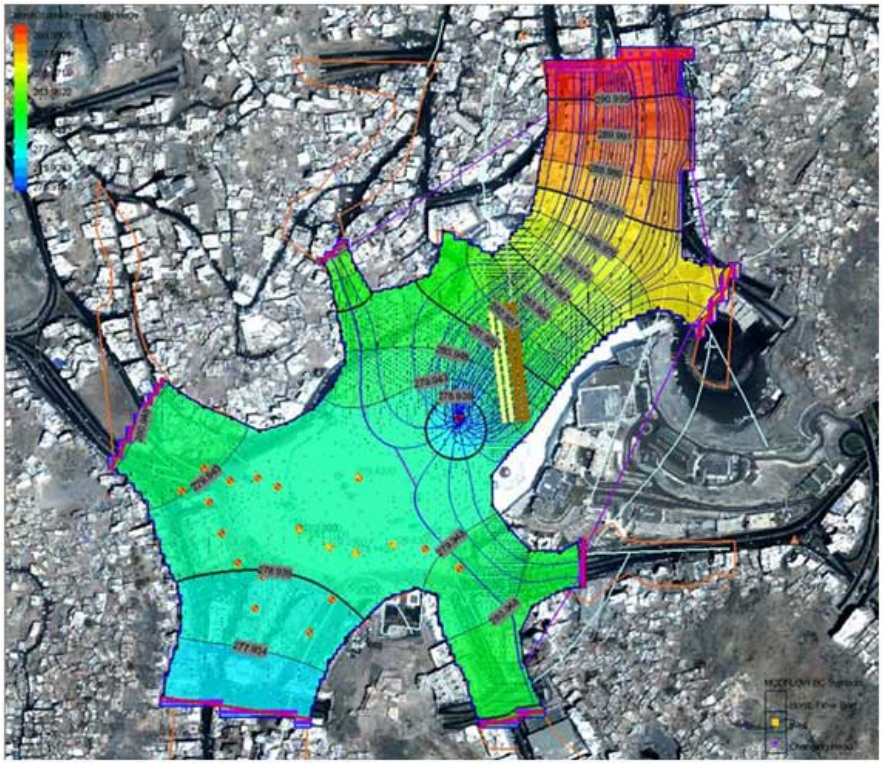

Example of groundwater modeling to study impact of piles of Al-Masa' extension foundation on Zamzam well flow regime

In addition, all the major public and private building ventures in Wadi Ibrahim, and particularly around Al-Haram, are vetted by ZSRC for their impact on groundwater regime. In some cases ZSRC facilitates this by providing consulting services to these projects.

SGS is mandated to watch all the construction activities in Wad Ibrahim and asses the foundation impact on groundwater regime. In principle, foundations are not allowed to penetrate watertable. Where slight deviation in this principle is absolutely unavoidable the builders are required to prove by carrying out groundwater modeling that there will be no adverse effect on groundwater regime. Even then, SGS requires to put a high permeability gravel layer below the foundation to compensate for the lost aquifer by the penetrating foundation. This was first done in the foundation of First Project of Makkah Development Company and Dar Al-Tawhid Intercontinental Hotel.

Excavation for foundation of King Abdulaziz Endowment Project

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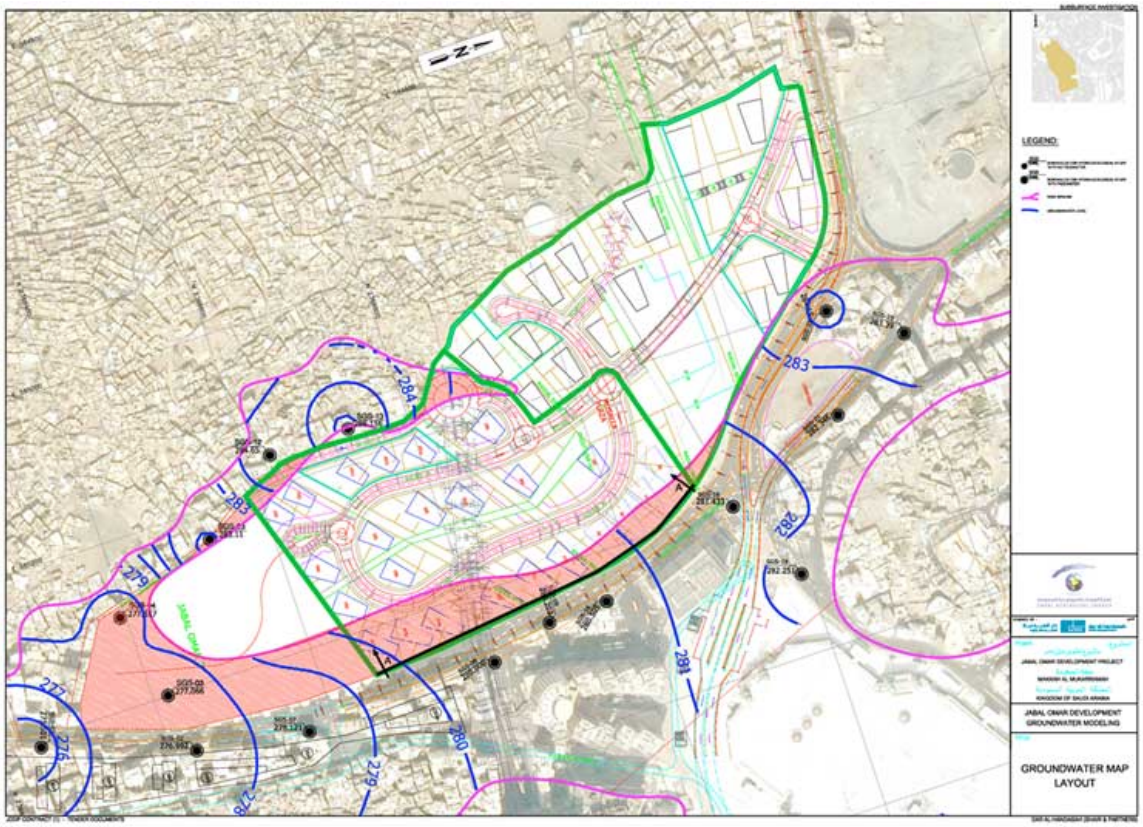
Here below is the brief description of some of the major and important projects or tasks that have either been completed or are underway under the auspices of ZSRC

Jabal Omar Development Project

Jabal Omar Development Project (JODC) is the first mega project that is being implemented under advice and supervision of ZSRC through their consultants . The scope of work for the project includes the following:

-Developing detailed scope of work for site investigations and groundwater modeling.
-The site investigations included the following:
-Geotechnical investigations;
-Hydrogeological investigations;
-Geophysical investigations;
-Laboratory tests.
-Monitoring wells/piezometers.
-Construct and evaluate groundwater model;
-Preparation of Tender Document and Bill of Quantities;
-Technical evaluation of tenders and rating of the contractors;
-Supervision of site investigations;
-Evaluation of reports from the contractors;
-Production of final report with recommendations.

ZSRC was involved in the varying degree in almost all of above tasks. ZSRC has introduced for the first time in Saudi Arabia the concept of rainfall harvesting. Removal of Jabal Omar for construction of high-rise buildings would lose the part of rainfall which would have ultimately replenished the Wadi Ibrahim aquifer through the fracture system. Therefore, a rainfall harvesting system was devised. The system, involves collecting rainfall from the building roofs and paved open spaces, conveying through piping into open-bottomed tanks for recharge to the aquifer. ZSRC has made mandatory for all the new buildings to install similar rainfall harvesting system. This new thought enables the projects to implement sustained approach of the concept green buildings.



Groundwater Contours in the alluvial aquifer in part of JODC project area

Stabilization of Abandoned Storm-water Tunnels

Two Tunnels (1B/10 and 1A/26) were originally constructed to serve as part of the Makkah storm water drainage system. Due to excessive dewatering during tunnel excavation, the groundwater table in part of wadi Ibrahim and, particularly, in Zamzam well was lowered to unacceptable levels and it was decided to suspend the construction operations in early eighties. This termination of activities occurred prior to completion of the tunnel's final lining in nearly half length of tunnels. At a later date, a program was initiated by the SGS to provide permanent stabilization of the abandoned reaches of tunnels. This project involves very delicate and sophisticated operations and technology as all the operations are done under water throughout the entire length of tunnels.

After examining various methods for feasibility, ease of implementation, and above all, effectiveness of stabilization filling of the tunnels with high permeability gravel was opted for. The gravel was to be obtained by crushing the same ki encountered in the tunnels. Before filling, the tunnels were examined and videoed by an underwater Remotely Vehicle (ROV) equipped with survey and photographic elements. Filling was first experimented in a mock real si ascertain feasibility.

Tunnel 1A/26 was completely filled. After filling part of tunnel 1B/10, which runs along Wadi Ibrahim, aquifer tests carried out

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on a specially constructed well situated at about 500 m from the Zamzam well. The tests showed some decrease in the yield from the low-permeability bedrock. No decrease was noticed in the main aquifer-the alluvium, nor any adverse impact was noticed in the Zamzam well. However, consultants advised not to take any risk with the production of Zamzam well and hence the filling was stopped. Instead, a mechanical stabilization system involving hybrid stainless steel studs and arches has been recommended and its preliminary design has been approved. Final detailed design is under preparation.

Wadi Ibrahim Environmental Management System (WIEMS)

To ensure water quantity and quality in the long term, an integrated environmental management plan for Wadi Ibrahim basin is deemed an urgent necessity by implementing a system that allows to monitor daily activities, control future development plans, and preserve the environmental integrity of the aquifer. Specific objectives of the of WIEMS include:

- Develop a GIS/RS system that includes all the relevant environmental information
- Study and assess aquifer safe yield and monitor groundwater conditions
- Assess and propose watershed management plans
- Assess water quality conditions, propose and implement the necessary monitoring and management plan
- Survey, assess and quantify man-made activities having impacts on the groundwater regime and monitor future developments
- Develop an integrated environmental monitoring plan for wadi Ibrahim basin combining all the above objectives

Under this project a very ambitious sampling of Wadi Ibrahim groundwater has recently been completed, which among others, will give isotopic signature of groundwater and help identify sources of contamination, if any. An elaborate multiwall tracer tests and several single well tracer tests were also carried out in a purpose-built well and observation wells to study dispersivity of any contaminant plumes.

Storm drains are designed specifically to prevent flooding by capturing rainwater falling on sealed urban surfaces such as roads and buildings, and carry the water away into wadis or into safe areas where it can be allowed to flood, infiltrate into the ground or evaporate. The existing system has been evaluated under WIEMS and a new modified system has been proposed to facilitate artificial recharge of stormwater to ensure natural rainfall percolation into the aquifer. ZSRC has undertaken intensive modeling of natural drainage patterns within Wadi Ibrahim catchment in order to define ways and means of harnessing storm water.

Aquifer Tests on Zamzam Well

As the number of visitors increases by the year, it is necessary to know the hydrogeological capacity of Zamzam Well so as to manage its yield in the future in a safe manner. Therefore, evaluation of potential of the surrounding aquifer system and the well with its present configuration was considered the need of the time. Although Zamzam Well has been tested many times before, the results were not conclusive. All the previous tests were carried out with paraphernalia available or in use at the time. In all the tests the drawdown was observed in the pumped Zamzam Well only. The pumping well data are not suitable for obtaining aquifer's storage parameters like storativity and specific yield, which are essential for prediction of groundwater volume availability and long term behavior. Therefore, ZSRC decided to carry out properly designed aquifer tests with observation wells at various distances in different directions, and finally evaluation of aquifer test data with the most updated methodologies and software.

Two most elaborate tests were carried out; one June 2006 and the other in June 2009. The time-drawdown data were analyzed by modern software and resulting hydraulic parameters were used in the groundwater modeling in estimation of long-term safe yield of Zamzam well. These parameters were also used in the groundwater models of other nearby urban development projects to determine foundation influence on the groundwater regime.

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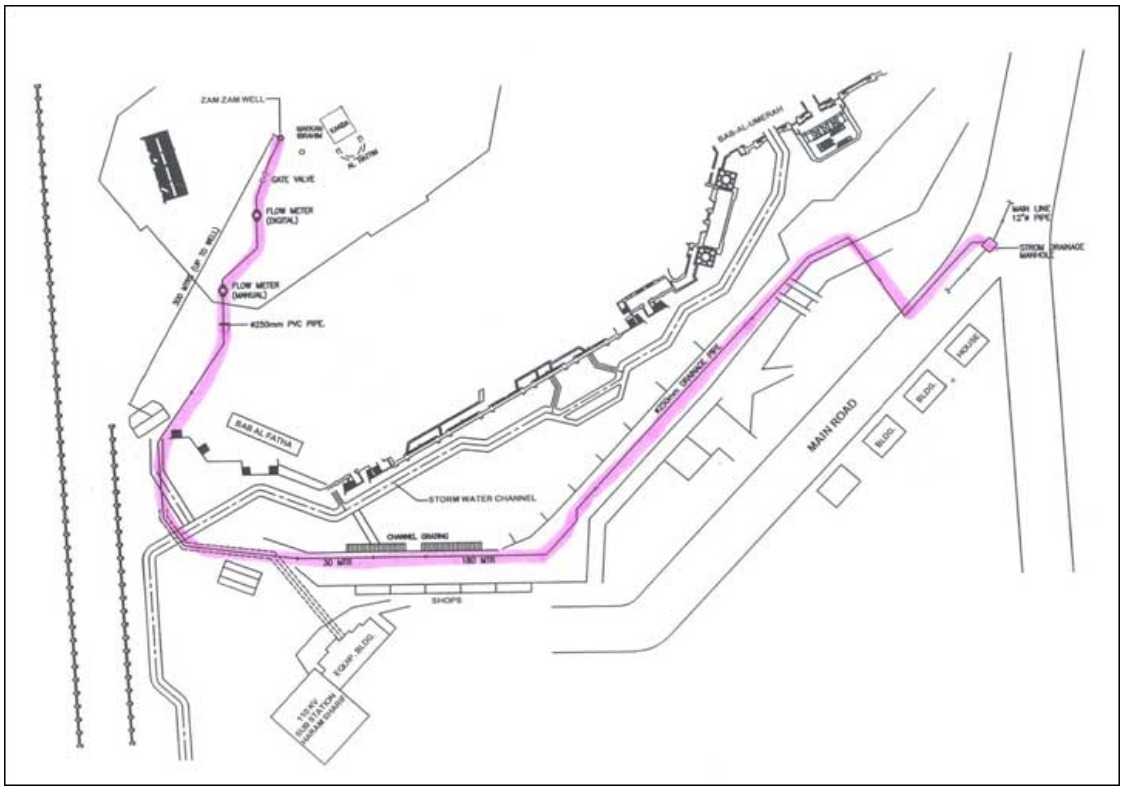

Plan of water disposal from Zamzam Well to the stormwater network

A view of part of water disposal pipe with analogue flowmeter

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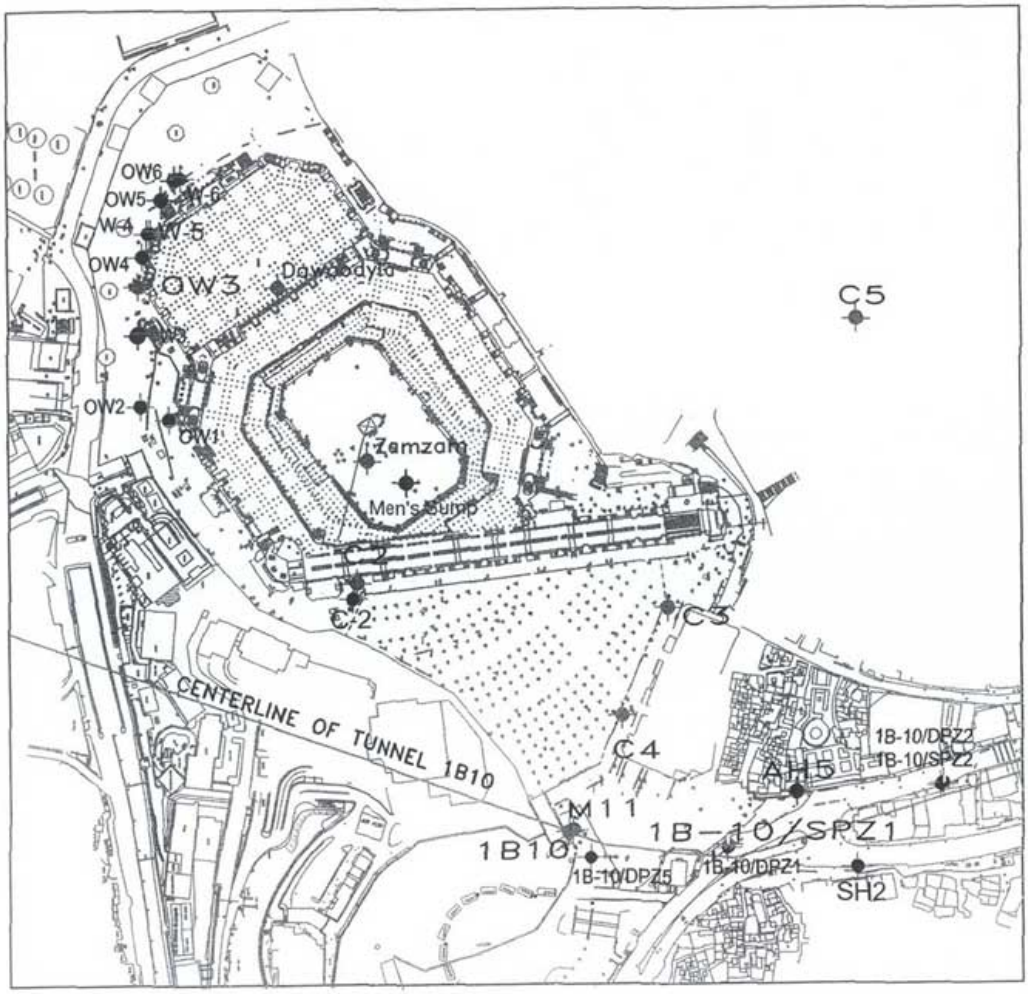
A view of part of water disposal pipe with digital flowmeter



Location of observation wells monitored during aquifer tests

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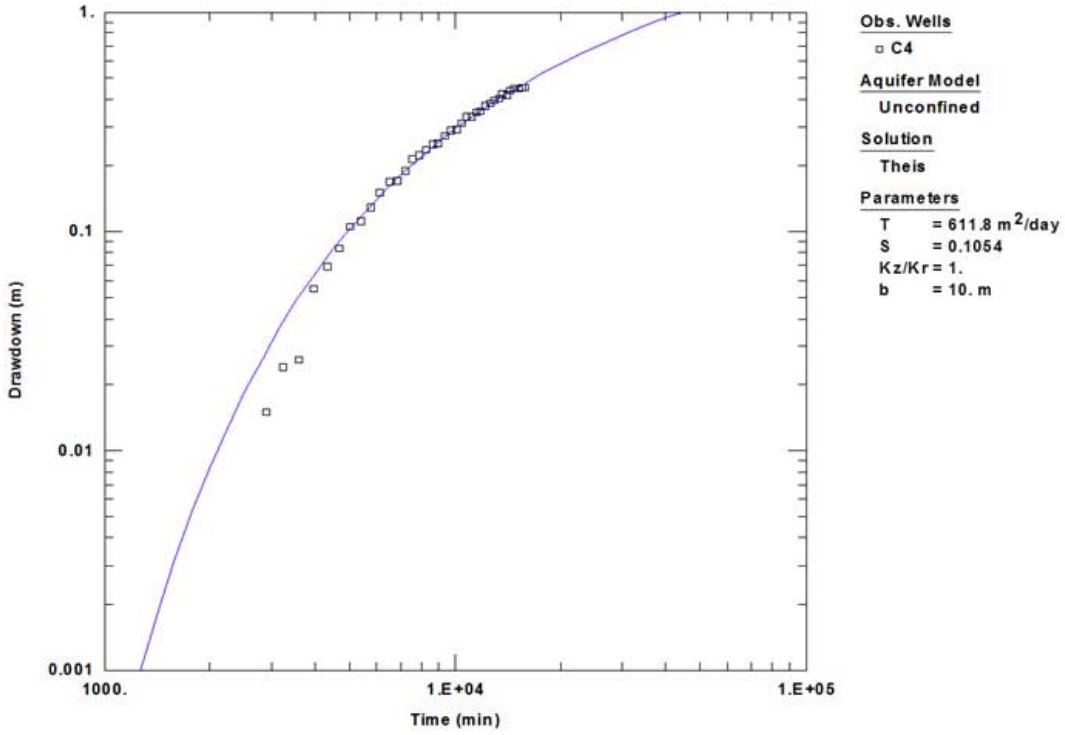

Example of analysis of data from an observation well by method

Upgrading of Zamzam pumping and storage system

In order to manage demand water from Zamzam well is pumped, treated, and stored in underground storage tanks on a continual basis. Before distribution to consumers and transportation to Madinah Zamzam water is treated by a series of sand filters, micro filters and ultraviolet disinfection. Zamzam Studies and Research Center is engaged in design of upgrading the treatment system. Already, two phases of upgrading have been completed and the third phase is in active consideration. Moreover, the Center strictly follows these activities and ensures strict quality assurance measures.

Optimization of Zamzam supply and distribution

All visitors carry Zamzam water back home usually in plastic containers of 10 or 20 liters size, which they fill themselves from several filling points, situated around the Al-Haram and at a central filling station. But, more commonly they buy the filled containers from roadside venders on the outskirts of Makkah. This distribution system is wanting in hygiene and offsets the efforts of treatment. Recently, under the instruction of His Majesty King Abdullah, Khadim Al-Haramain Sharifain, the Saudi Government has constructed a treatment and bottling plant for supplying 20-liter bottles to Umrah and Hajj visitors.

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