

## **A Sustainable Water Resources Management Plan for Wadi Hanifa in Saudi Arabia**

**Abdulaziz A. Alhamid<sup>1</sup>, Saleh A. Alfayzi<sup>2</sup>  
and Mohamed Alfatih Hamadto<sup>2</sup>**

<sup>1</sup>*Professor, Civil Engineering Dept., College of Engineering,  
King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia,  
E-mail aalhamid@ksu.edu.sa*

<sup>2</sup>*Civil Engineer, Arriyadh Development Authority,  
P. O. Box 94501, Riyadh 11614, Saudi Arabia*

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**Abstract.** Wadi Hanifah is one of the major natural landmarks in the middle part of Najd plateau. It represents the natural drain for the surface water of a very wide area. The Wadi passes through the city of Arriyadh and about 70% of the city is located within its catchment area.

In the last decade, ground water management programs in the city have contributed to the perennial flow in part of the Wadi between the confluence of Al-Aysan channel in the north to after Al-Hair in the south of the Wadi forming a river in the desert. In addition to that, treated wastewater to the tertiary stage is also discharged into the Wadi. Perennial flow is about 0.4 M m<sup>3</sup>/day and is expected to increase by 3 to 4 folds by 2021.

This paper will highlight the importance of Wadi Hanifah to Arriyadh city and shall suggest an integrated water resources management plan for Wadi Hanifah. This plan will provide sustainability to the Wadi utilizing a number of measures. These measures are anticipated to improve flood performance of the Wadi, improve surface water quality and hence protect the quality of groundwater. The plan proposes possible scenarios for water reuse to meet present and future needs of the city.

### **Introduction**

Wadi Hanifah is one of the principal wadis draining the eastern slope of the Tuwaig Mountains. It extends from north of Al-Uyaynah to south of Al-Hair city. The watershed area of Wadi Hanifah is estimated to be about 4400 km<sup>2</sup>. It flows southward from its source near the town of Al-Uyaynah until it ends into Wadi Sahba, a distance of about 150 km (Fig. 1). The main Wadi flood-channel is located slightly east of the center of the catchment area and flows northwest to southeast. Most of Arriyadh city (more than 4 million populations) is located in the Wadi Hanifah catchment area (ADA [4]). The

bed and banks of the channel are mainly composed of alluvial deposits of large to medium size sands and silts.



**Fig. 1. Wadi Hanifah location with main storm channels.**

Prior to extensive urban activities, the source of water in the main channel was seasonal rainfall. During the last two decades, a considerable urban and agricultural development occurred in the catchment area, which led to considerable disposal of sewage effluent and agricultural drainage (Siddiqui and Al-Harbi [6]). Due to the increase in consumption and disposal of industrial water, the groundwater table within Arriyadh city has risen considerably. To counter this, a dewatering scheme was implemented, leading to a continuous source of water in the southern parts of the Wadi.

Wadi Hanifah has always played a key role in the water management of Arriyadh. In the past it was used as a source of water and now as a convenient means for disposing of the city's wastewater. In the future, it has the potential to play a key role by making significant volumes of good quality water available for recycling.

The Water Resources Management Plan will provide measures for restoration of flood performance, improvement of water quality and provision of future needs of recycled water. The plan takes account of the dry weather (perennial) and flood flow conditions.

### Existing Conditions of Wadi Hanifah

The natural condition of the Wadi is that of a dry Wadi bed that floods during heavy rainfall events. To meet the rapid expansion of the city, the Wadi has been used as a source of building material and increased activities associated with construction industries such as quarries, soil removal, cement mixing, brick making, and in some parts as a dump area of wastes and refuse materials. Dramatic changes in land-use have occurred in the Wadi as good agricultural land is now being used for residential and industrial purposes. As the city has grown more and more people have tried to acquire land in the Wadi, with the result of extensive urban development onto the Wadi, some of which is now located in the flood path and presents a hazard for people and property.

The Wadi represents the natural drain to the city. Permanent flows commenced in the early 1980s when the discharges to the Wadi exceeded the natural capacity of the Wadi alluvium to absorb them. At present, water continuously flows in the southern parts of the Wadi as a result of the drained groundwater from the city, storm network system and the effluent from the wastewater treatment plant. The quantity of water flowing into the Wadi varies according to annual rainfall. This situation led to a rise of the groundwater level and to the formation of swamps in the Wadi. The pollution in the groundwater is considered high as it is drained from areas not covered by municipal sewage system.

In addition to the above, a number of service networks cross or run along the Wadi. Most of these networks lie below the present groundwater level, which creates difficulties with the maintenance and may cause hazardous problems with services such as water networks.

Most of the dry weather flows enter the Wadi along storm water channels, each draining a different sector of the city. The flows originate from dewatering of rising groundwater, from managed pumping of basements and road underpasses and the discharge from Manfouha sewage treatment plant. They are also believed to include some flows from unauthorized sewer connections, which have a water quality implication. During rainfall events, the channels perform their main function of draining flood flows from urban areas. Typical flow values are given in Table 1. Manfouha STP discharges 0.4 M m<sup>3</sup>/day, half of it is reused for industrial and agriculture purposes.

**Table 1. Main surface water flow entering Wadi Hanifah**

| Flow point                    | Flow in (m <sup>3</sup> /day) |
|-------------------------------|-------------------------------|
| North Diversion Channel (NDC) | 70,000                        |
| West Ship channel (WSC)       | 35,000                        |
| Namar (WN)                    | 8,000                         |
| Ba'tha channel (BC)           | 80,000                        |
| Manfouha STP                  | 200,000                       |

At present, intermittent dry weather flows commence above the point where the Northern Diversion Channel enters the Wadi, and major dry weather flows enter from the Northern Diversion Channel. The permanent dry weather flows continue in the Wadi forming a number of permanent lakes. Ultimately, the surface flows diminish and disappear as a result of agricultural use, evaporation and infiltration into the Wadi bed.

There are various actual and potential sources of pollution and contamination in and near Wadi Hanifah. These include irrigation returns, fertilizers and pesticides from agriculture and parks, landfill sites, leakage from sewer mains, infiltration from septic tanks, unauthorized sewage connections to storm water channels, and treatment plant bypass.

The current surface water and groundwater in Wadi Hanifah is generally in a polluted condition. Water quality data are presented in Figs. 2 & 3. The bar charts show concentrations of selected parameters that are useful indicators of pollution.

In general, surface water samples exceed many parameters with regard to drinking water standards, including total and faecal coliforms, hydrocarbons, nitrogen, nitrate and sulphate. They also exceed European Union (EU) guideline microbiological standards for bathing water (500 total coliforms/100ml and 100 faecal coliforms/100ml) and possibly for EU maximum limits (10,000 total coliforms/100ml and 2000 faecal coliforms/100ml), although the data are insufficient to determine this.

There is an evidence of a natural improvement in quality as water travels along the Wadi. There is a distinct improvement in a number of quality parameters between the North Diversion Channel and Wadi Hanifah before Sultanah Channel (Fig. 3).

The groundwater sample from the Wadi is significantly better than the Wadi surface water samples. This may be a reflection of the fact that the alluvium acts as a natural filtering and cleaning system. Thus, groundwater abstractions should, in general, be of better quality than direct surface water abstractions.

Flood flows, which occur every few years during high rainfall events, are an inevitable natural feature of the Wadi that can be damaging and hazardous. Although they cannot be stopped altogether, it is possible with careful management and appropriate engineering structures to reduce their destructive impact. Flood flows also have beneficial aspects, being a source of natural recharge and in transporting silt to agricultural areas. Generally, there were a limited flood flow data available for Wadi Hanifah in the literature. The maximum recorded flow was 400 m<sup>3</sup>/s in 1968 at Hanifah dam (ADA [2]). Alhamid and Matin [1] showed that the Wadi natural cross sections within Arriyadh city can carry up to 125 m<sup>3</sup>/s discharge, without causing over bank spills for a considerable portion of the reach.

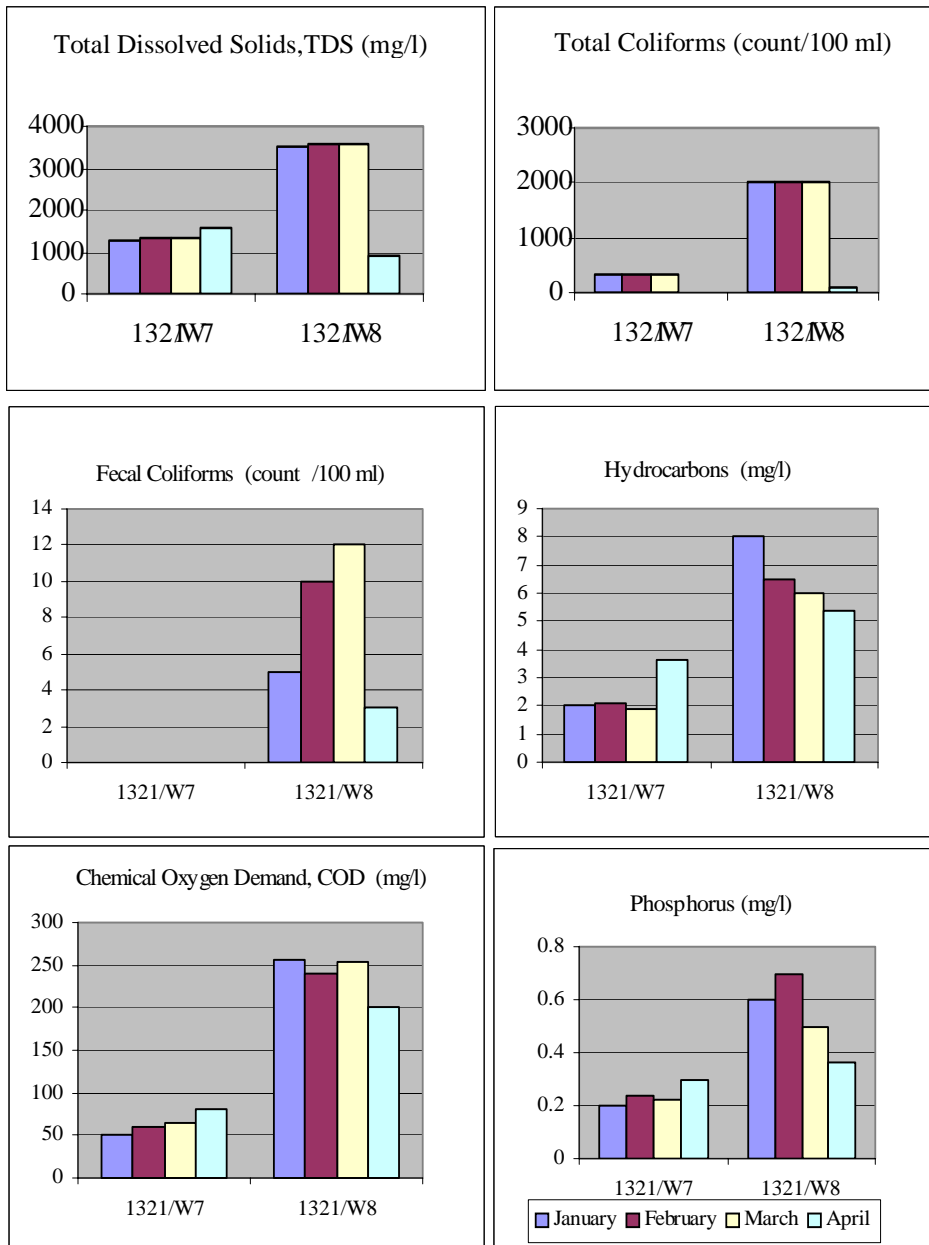


Fig. 2. Ground water quality for selected parameters.

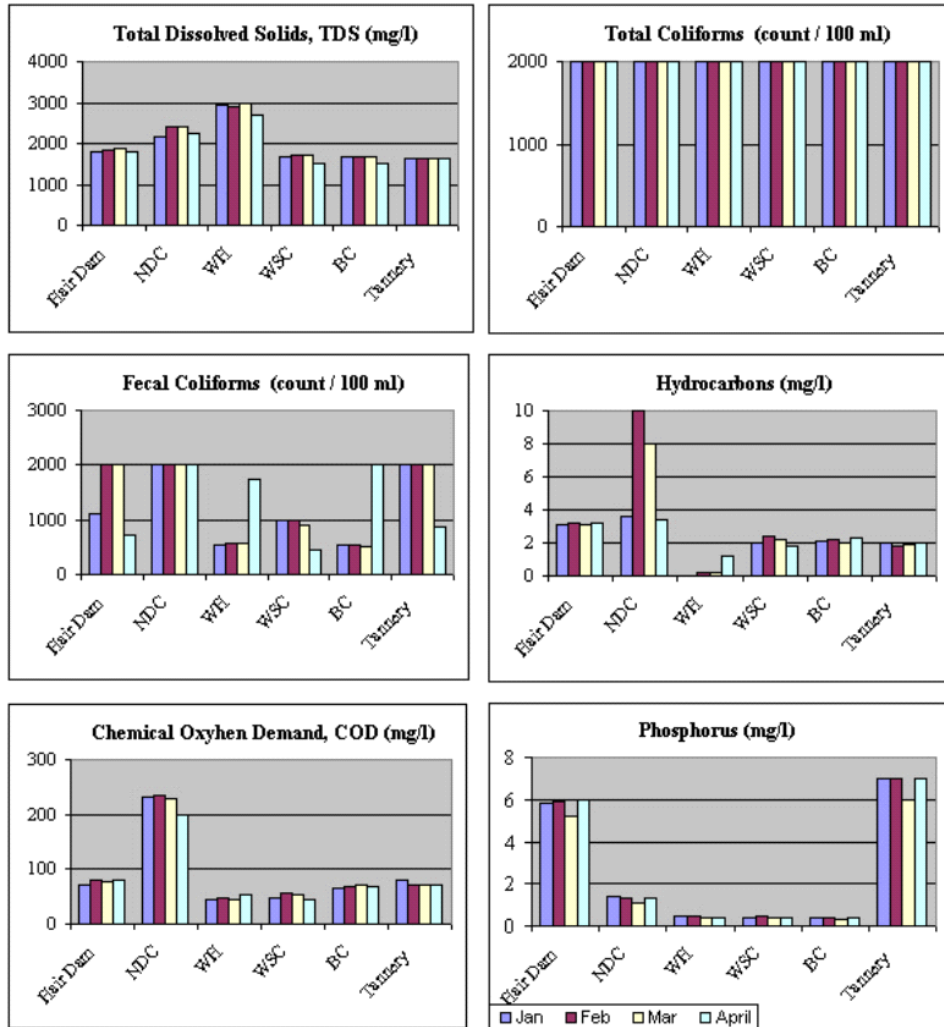


Fig. 3. Surface water quality for selected parameters.

### Water Resources Management Plan

Water management of Wadi Hanifah must be sustainable so as to protect water supplies and the environment for future generations. This means modifying some practices to achieve a target condition, combined with a management scheme that will protect this condition once achieved. However, it must also recognize that a growing population will place increasing pressure on the Wadi and its resources, requiring a balance to be struck between the interests of the current and future generations.

The Water Resources Management Plan will provide the following needs:

- Improvement of surface water quality and establishment of natural treatment processes;
- Improvement of flood performance and flood management;
- Improvement of surface flow channels and their management;
- Removal of threats to water quality;
- Prevention of unauthorized encroachments, through a strengthened planning process;
- Making available volumes of suitable quality water for recycling.

Critical issues regarding water resources management are highlighted below.

#### **Water quality**

Both groundwater and surface water in the Wadi are contaminated and not considered fit in their present state for any use, apart from supplying the natural habitats. Measures must be taken to clean up water discharges before they enter the Wadi, to further improve quality within the Wadi and to protect it from contamination. Improving water quality will be essential to ensure there is a supply of water for recycling, even if some further treatment is still required for some uses. An immediate improvement in the quality of surface water within Wadi Hanifah and the side wadis will be achieved through the following means:

- Re-grading of the Wadi bed to eliminate standing water.
- Non-inert waste poses a threat to groundwater quality and it should be removed and disposed off in a safe manner.
- Stopping of polluted discharges, in particular discharges from the Tannery and abattoir. The abattoir waste should either be directed to existing STP or an independent plant should be provided to treat this waste while the Tannery should be relocated away from the Wadi.
- Create a sufficiently diverse food web, or trophic system, to assimilate nutrients and eliminate harmful bacteria.
- Encourage oxygenation of the water. If the dissolved oxygen level can be kept high while it is being adsorbed for the breakdown of the organic material, then a healthy ecosystem can be maintained. One option is bioremediation by considering the Wadi channel as a series of bioremediation pools, similar to a continuous flow free-water-surface wetland system. The continuous flow free-water-surface bioremediation pools will reduce bacteria levels through bioconversion and other physical processes.

#### **Flood flows**

Flood flows remain the largest threat to property and human safety. These must be managed to permit efficient flow along the Wadi, while attenuating the flood peak as much as possible. One problem is that because major floods are normally separated by several years, there is a tendency to become complacent with regard to the risks.

Water Resource Management Plan proposed a range of measures to reduce flood levels, these include Wadi bed re-profiling and Road and Bridge Piers Protections. During major flood events the Wadi roads are vulnerable to damage, mainly because of inappropriate construction detailing. Edge protection is often absent, and this leads to undermining and progressive collapse. The plan proposes that roads are reconstructed to a suitable standard and provided with substantial edge protection to avoid this damage. In addition, where the road is in close proximity to the Wadi flood channel, it is proposed to armor the adjacent Wadi edge/road junction with rock to give additional protection.

Bridges are particularly vulnerable to the erosion of bed material during floods. The proposal to re-grade and lower the Wadi bed through a number of bridges will require additional protection to ensure bridge piers are not undermined. Lined bed with flat rocks or coarse riprap bed protection is proposed in these locations.

Hydraulic channel performance will be enhanced by the removal of tipping (inert waste) and the optimization of the Wadi flood channel by re-profiling. It is believed that the wadi bed is one meter higher than it was three decades ago.

Many developments within the Wadi, permitted and encroachments, create obstructions to storm flows. Where these cannot be removed, measures are proposed to improve flood flow past these to minimize hydraulic losses. These measures include training and retaining walls to direct flow in a more efficient manner past these structures.

#### **Perennial flows channel**

In order to satisfy the water quality measures, which might have a reverse impact on the hydraulic efficiency of the channel, water channel should be wide and shallow, rather than narrow and deep. This minimizes risk to humans, provides a large surface area for oxygenation to take place, and a large bed area for benthic (bed level) aquatic life. Also, the channel should be rough rather than smooth. Rough sides facilitate an escape in the event of falling into the water, provide a habitat for the natural predators of harmful organisms, provide stability from erosion, and if carefully constructed can be visually attractive. Planted vegetation along new channel construction will stabilize and accentuate channel definition. Rough bed promotes turbulence in the water, which encourages aeration, and provides habitats for a diverse range of aquatic species. This will provide a degree of in-stream bioremediation for the water that flows through the resultant rock filter. This technique is not an alternative for treatment of the total flows but as an enhancement to the overall system. The roughness can be artificially enhanced by the use of plastic media (APBS) that provides a large surface area on which an artificial periphyton can develop.

For the reach where flow is perennial, multiple options can be used for the channel design. Design takes into consideration the physical processes including hydraulics, hydrology and sedimentation and the availability of the construction materials. To enhance the water quality as mentioned above, rough channel would be preferred. Two options will be presented here as an example. The first option is to design a channel having longitudinal slope within the existing ground bed slope. The existing ground bed slope ranges from 0.0019 to 0.00256. This option would require good bed and side banks protection. Figure 4 shows a typical riprap protection. The second option uses a flatter bed slope and tackles the ground difference by introducing a number of drops. Typical drops are shown in Fig. 5. This option will increase oxidation through waterfalls and stepped drops, and hence a healthy and attractive watercourse will be maintained.

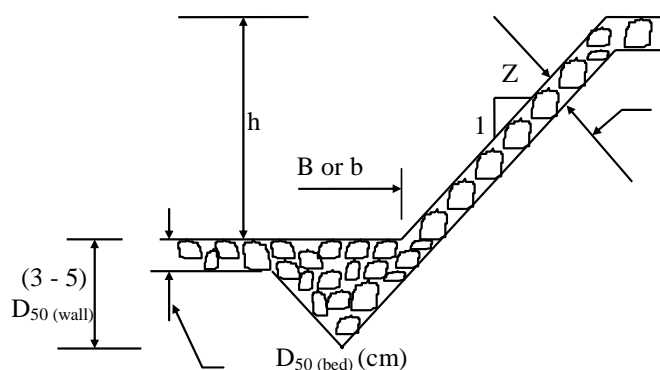


Fig. 4. Typical riprap protection.

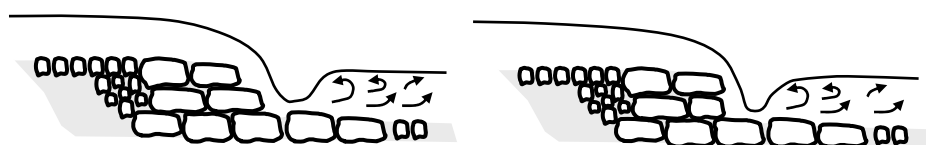


Fig. 5. Typical drops.

### Water balance

Water requirements for Arriyadh will grow as the population increases. This will result in greater volumes of leakage contributing to the rising groundwater problems. Consequently, the rates of groundwater drainage and pumping in the Arriyadh area to control groundwater levels will have to increase. If current practice continues, then most of these additional volumes will be discharged to Wadi Hanifah via the storm water channels.

The volumes of dry weather flows in Wadi Hanifah are dependent on the balance of water inflows and outflows. For this study, two water balance conditions are

considered, year 2001 condition and year 2021 condition. The purpose of the water balance is to demonstrate which are the most significant components and the scale of potential changes in the future.

In the year 2001, the daily potable water demand for Arriyadh was met by 0.754 M m<sup>3</sup> per day of desalinated water and 0.516 M m<sup>3</sup> per day of deep groundwater abstraction, totalling 1.27 M m<sup>3</sup> per day. In the year 2021, the demand is expected to increase to 3.111 M m<sup>3</sup> per day. About two thirds of this will be met by establishing a new well-field of 0.350 M m<sup>3</sup>/day capacity at Al-Hoiny and increasing desalination capacity to 1.245 M m<sup>3</sup>/day (ADA [5]). Shortages on the water supply need to be met from other resources such as recycling.

Manfouha sewage treatment plant (STP) currently serves the majority of the sewered area of Arriyadh with an approximate capacity of 0.4 M m<sup>3</sup>/day. This will be replaced by a new STP facility to treat a total of 1.444 M m<sup>3</sup>/day in 2021. In addition, a new STP south east of the city near Al-Kharj Road is under construction with a capacity of 0.427 M m<sup>3</sup>/day. Although located outside of the Wadi Hanifah catchment area, its discharge will be piped to the Wadi (ADA [3]).

Water Balance for the years 2001 and 2021 conditions are presented in Table 2. Some of the flow volumes are based on reasonably reliable measurements and data, while others have had to be estimated. However, the order of magnitude of each flow volume is considered realistic.

**Table 2. Wadi Hanifah water balance for the years 2001 and 2021**

| <b>Flow in</b>   | <b>m<sup>3</sup>/day</b> |                  |
|--|--------------------------|------------------|
|  | <b>2001</b>              | <b>2021</b>      |
| recharge from rainfall and groundwater storage in alluvium and bedrock | 10,000                   | 10,000           |
| Agricultural losses  | 170,000                  | 225,000          |
| Seepage to Wadi Hanifah from non-sewered and other network losses      | 50,000                   | 135,000          |
| Groundwater drainage   | 250,000                  | 215,000          |
| STP output to Wadi   | 200,000                  | 982,000          |
| Losses returning to Wadi Hanifah from Wadi Namar                       | 25,000                   | 90,000           |
| <b>Total in</b>  | <b>705,000</b>           | <b>1,657,000</b> |
| <b>Abstractions</b>  |                          |                  |
| Abstractions for tinkering   | 50,000                   | 0                |
| Local pumping for agriculture.   | 450,000                  | 450,000          |
| Open water evaporation   | 10,000                   | 20,000           |
| <b>Total abstraction</b>   | <b>510,000</b>           | <b>475,000</b>   |
| Other (through-flows)  |                          |                  |
| Wadi channel through-flow  | 6,000                    | 6,000            |
| Surface water flows  | 450,000                  | 940,000          |
| <b>Flow out</b>  |                          |                  |
| Balancing Flow   | <b>195,000</b>           | <b>1,182,000</b> |

The year 2021 water balance serves to demonstrate the likelihood that as much as 1.18 M m<sup>3</sup>/day will be available for water recycling schemes, provided that adequate quality can be assured.

### **Scenarios for water reuse**

Water balance showed that 1.18 million m<sup>3</sup>/day will be available for recycling by 2021. Recycled water can be used in a number of ways. The following options have been considered:

#### *1. Non-potable supplies to consumers*

Non-potable supplies could be provided to water consumers for use for irrigation, outdoor activities such as car washing and for toilet flushing. This would have the effect of reducing the demand for potable water that is currently used for these purposes. The non-potable water supply would be treated such that it was bacterially safe, and not harmful if ingested. However, it would not need to satisfy potable water standards in respect of the content of compounds such as chlorides, phosphates and nitrates.

A non-potable water supply could be provided in all areas of new development. The advantage of providing the facility in new areas of development would be that the additional pipe could be laid together with the potable water main. New housing could be built with non-potable water pipe work installed for uses as described above.

Alternatively, a non-potable water supply could be provided in some existing areas of the city to support high use of water for public or private irrigation. The non-potable water supply would be treated as described above. The disadvantage of providing the facility in areas of existing development would be the high cost of laying mains in existing streets.

The advantage of this option would be the efficient supply of recycled water for public and private irrigation, and the supply of recycled water to private users, who would otherwise have to use potable water for irrigation. A disadvantage of this system would be the introduction of more water mains from which leaks could occur.

#### *2. Bulk irrigation*

As an alternative to providing non-potable supplies to domestic consumers, a distribution network could be provided for bulk irrigation only. This could be used for irrigating parkland and road verges, and any excess could be used for agriculture.

The disadvantage of this option is that it would not reduce the demand for potable water, and therefore the supply of desalinated water would have to be increased even further.

3. *Deep aquifer recharge*

Recycled water can be treated and used for aquifer recharge. Aquifer recharge is a most desirable use of recycled water, provided it is of potable standard, as this will ensure improved sustainability of deep groundwater abstraction for Riyadh.

4. *Shallow aquifer recharge using existing dams*

There are nine dams in the Wadi system that are designed to catch flash floods and retain the water long enough for shallow aquifer recharge to take place. This option would involve constructing a distribution network to pump untreated surface water up to these dams to enable this natural recharge to take place.

A disadvantage of this option would be that if the dams were kept permanently partially full by this means, there would be reduced storage capacity available in times of flash flood, and this would defeat the original purpose of their construction. The cost of constructing and operating the necessary treatment plant and pumping network to each of the dams would be significant. There would be a very limited effect on the demand for potable water within the city, and so an increase in the desalination capacity would still be required.

5. *Shallow aquifer recharge using the Wadi*

This option is similar to Option 4 in that Wadi Hanifah itself would be used to provide the facility for water re-use. It would be proposed that water would be pumped to the head of the Wadi and allowed to flow back through the Wadi naturally where it would assist with recharge of the aquifer within the Wadi alluvium. The water so made available within the Wadi could then be abstracted where required for agriculture, irrigation or even potable use with suitable treatment.

The advantage of this option is that water would be made available along the length of the Wadi for those uses that required it. However, as with Option 4 the construction and operating costs of a pipeline to supply water to the head of the Wadi would be significant. A proportion of the water would almost certainly return to the lower end of the Wadi where it would have to be pumped again, or allowed to drain out of the system and be lost. Furthermore, this approach would exacerbate the problems of rising groundwater within the Wadi. As with Option 4 the effect on the demand for potable water would be small, so that an increase in the desalination capacity would still be required.

The recommended schemes for the re-use of water are Options 1 and 3. Both of these reduce the demand for potable water imported from the desalination plants, and so provide sustainable solutions. Option 1 supplies some existing potable water demand that does not need to be of this quality with water of appropriate quality. Option 3 provides for recharge of the deep aquifers to allow the abstraction from this source to be increased to meet the increased demand without further depleting this non-renewable resource.

For the above to be achieved an impounding dam is needed. The proposed site lies some 12 km downstream of Al-Hair, just upstream of the point where the Wadi broadens out into the lake area. This has the advantage of keeping the dam length relatively short in relation to its potential impounding volume. The creation of this impoundment will provide a substantial reservoir of water of sufficient quality to supply a range of re-uses. The volume of storage created would be about 8 million m<sup>3</sup>. This volume represents 32 days flow out of the catchment under 2001 year conditions, and over six days flow out of the catchment under the projected 2021 conditions. The volume created would provide eight days supply to Arriyadh based on the 1 million m<sup>3</sup> per day target.

### Conclusions

Wadi Hanifah played a key role in the development of Arriyadh city as a source of water and resources. It is, also, expected to continue its role if a sustainable water resources management plan is adopted. This paper suggested a water resources management plan featuring the main issues in the Wadi, which will help on the restoration of the Wadi Hanifah and its catchment. These issues include water quality, flood management, perennial flow, water balance and the utilization of recycled water. Through the application of the suggested plan and measures it is expected that a healthy watercourse will exist. Also, it is expected that Wadi Hanifah will provide more than one million m<sup>3</sup> of water daily for re-use. Different options were suggested for water re-use with emphases that the use in non-drinking potable water is a preferred option to meet the 2021-year target.

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(قدّم للنشر في ٢٠١١/٠٢/٢٥ م؛ وقبل للنشر في ٢٠٠٧/٠١/١٥ م)

**ملخص البحث.** يعتبر وادي حنيقة واحداً من المعالم الطبيعية في وسط هضبة نجد، حيث يمثل المصرف الطبيعي للمياه السطحية، ويعبر وادي حنيقة مدينة الرياض حيث يقع حوالي ٧٠٪ من مساحة مدينة الرياض ضمن حوض وادي حنيقة.

تحول الوادي خلال العقد الماضي إلى نهر جاري، خصوصاً في المنطقة بين التقاء وادي الأيسن مع الوادي شمالاً إلى ما بعد بلدة الحابر جنوباً، نتيجة لتخفيض منسوب المياه الجوفية في المدينة ونتيجة لصرف المياه المعالجة من محطة معالجة مياه الصرف الصحي إلى الوادي، وتقدر كميات المياه المتدفقة في الوادي بحوالي ٤٠٠ ألف م<sup>٣</sup> في اليوم ويتوقع أن تتضاعف هذه الكمية ما بين ثلاث وأربع مرات بحلول عام ٢٠٢١ م.

تسلط هذه الورقة الضوء على أهمية وادي حنيقة لمدينة الرياض، وتقترح خطة متكاملة لإدارة موارد المياه في الوادي. سوف تحقق هذه الخطة الاستفادة للوادي من خلال عدد من الإجراءات. ويتوقع أن تؤدي هذه الإجراءات إلى تحسين أداء الوادي في موسم الفيضانات والسيول وكذلك تحسين نوعية المياه السطحية في الوادي وبالتالي المحافظة على جودة المياه الجوفية. وتقترح الخطة عدد من البدائل الممكنة لإعادة استخدام المياه لمواجهة الاحتياجات الحالية والمستقبلية للمدينة.

