32

Groundwater Recharge and Saving in Spate Irrigation Areas
Case study, Wadi Zabid

Practical Note

Flood-Based Livelihoods Network Yemen

Introduction

Spate irrigation is a unique form of water resource management that has been practised in arid and semi-arid regions. Here, evapotranspiration often greatly exceeds rainfall (Steenbergen, Lawrence, et al. 2010). Floods are one of the important surface water resources for irrigation in Yemen's wadis, which comes as a result of rainfall. The major wadis in Yemen are located in the plain areas, while spate waters are distributed through stream beds towards diversion structures to be diverted into the irrigated fields. Spate irrigation in Yemen covers 120,000 ha (about 11 % of the average cultivated area in Yemen), where the major modern schemes cover about 90,000 ha (Al-Asbahi 2005). Spate irrigation areas depend on groundwater irrigation as complementary irrigation source (Saleh and Noman 2009).

Spate irrigation areas cover a wide range of agricultural lands with fertile soils, which makes them a reliable source to achieve food security for most parts of the country. Integration between surface water and groundwater is a major component of Integrated Water Resource Management (IWRM), that should be taken into consideration to ensure the sustainability of water resources. Unfortunately, water resources in Yemen's Wadis have been managed randomly and unfairly by the people, causing a deterioration in quality and quantity of groundwater. In addition, the cultivated areas are deteriorated and conflicts between communities over water resources have increased. Therefore, the poverty rate and unemployment has also increased.

Wadi Zabid is one of the oldest spate irrigation areas in Yemen and is located in the coastal plain between 14° 08' – 14° 13' N and 43° 14' – 43°

Table 1: Annual abstraction of groundwater irrigation according to crops patterns in spate areas in Wadi Zabid

	Upstream	Midstream	Downstream	Total
Banana area (ha)	1,900	1,700	0	3,600
Banana water consumption (MCM)	109	113	0	222
Fodder area (ha)	1,300	2,600	400	4,300
Fodder water consumption (MCM)	15	30	5	50
Other crops (ha)[1]	500	800	300	1,600
Other crops water consumption (MCM)	6	9	3	18
Total consumption of water (MCM)	130	152	8	290
Ratio of consumption (%)	45	52	3	100

1) The other crops include; Sorghum grains, maize, tomatoes, onion, cucumber, peppers, cotton, tobacco and sesame)

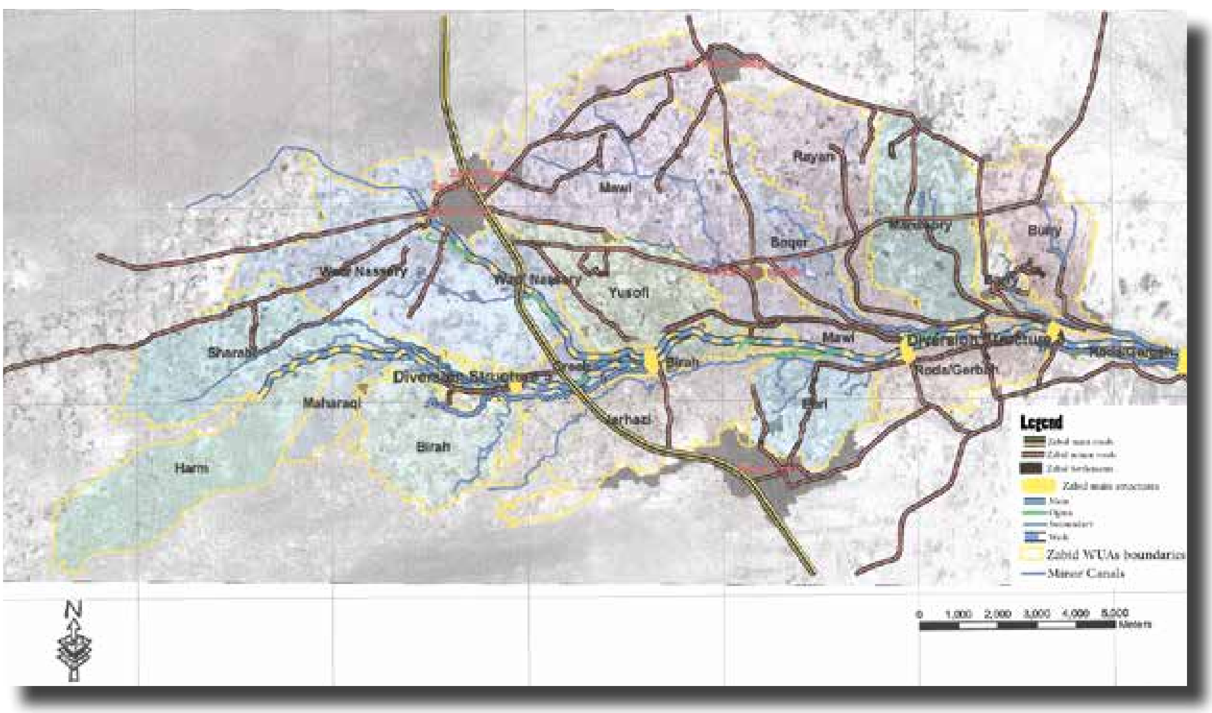


Figure 1: Map of spate irrigation areas in Wadi Zabid (source: IIP 2003)

35’ E. It has been developed with new diversion structures since 1970s. Wadi Zabid is divided into three sub-areas (upstream, midstream and downstream) with a total area of about 15,215 ha as shown in figure 1 (IIP 2002). The traditional system consists of 16 canals, most of them have an independent intake from the wadi. Water rights for the various canals and areas were established 500 years ago, and still exist nowadays (FAO, 1987).

Status of groundwater

The groundwater in Wadi Zabid is an important source for domestic, industrial, livestock and irrigation purposes. The withdrawal of groundwater is mainly for irrigation purposes (about 97 %), while both the domestic and industrial sectors use about 3 % of the groundwater. Wadi Zabid is facing a big pressure on groundwater resources for many reasons that will be explained below. The amount of the abstracted water for irrigation is 290 MCM with percentages of groundwater use of 45 %, 52 % and 3 % in upstream, midstream and downstream respectively as shown in table 1.

The first reason causing pressure on groundwater resources in Wadi Zabid is the update of modern diversion structures without taking measures into consideration, neither technically, legal or social. Some of these structures have inadvertently blocked the subsurface flow because these ‘cut-off’ weirs keyed into the bedrock or clay layers underneath the main-stream bed as show in figure 2. So, the groundwater levels increased upstream of the weir, and in the same time caused hardship for the users downstream (Steenbergen and Tuinhof 2009).

The second reason is the traditional distribution system of spate water (Al-Jabarti) which was not harmonious with the water rights (during) replacing the traditional diversion structures into modern diversion structures. This prevented the flood flow to the beneficiaries in midstream and downstream areas. Therefore, the farmers in upper areas have been benefiting from the spate water more than others. Also, they changed their crop patterns to growing the banana and mango which requires more water compared to traditional crops such as grains, fodder and cotton. While the farmers in downstream areas have been affected as a result of violating their water rights of spate water or groundwater recharge by subsurface movement of groundwater.

The third reason is the weakness of the related authorities and the non-application of a water law. Despite previous warnings by the organizations and authorities that carried out some studies and surveys of water resources in Tihama region, there is an increase in the number of unreasonable wells in Wadi Zabid.

Unfortunately, water resources have been managed in an unsustainable manner. So, the deterioration of groundwater quality began to spread from the western toward eastern parts as shown in figure 3 and 4 which show the drought of banana crops due to deterioration of the groundwater quality in midstream of Wadi Zabid as a result of over-exploitation. The groundwater level has declined during the past 20 years (1985 - 2005) by about 30 meters. Especially in the 2000s (with extensive use of groundwater for irrigation), where the groundwater level declined with an average of about 0.5 - 1.5 m each year (NWRA 2009).

Groundwater opportunities and challenges

Groundwater resources with good quality are an important source of water supply over time, especially in arid and semi-arid regions. The groundwater is reserved in the aquifer in underground layers according to characteristics of the aquifer. Its sustainability depends on the balance between two main processes; the recharge and discharge. The study of groundwater is very important and complex at same time, especially in Yemeni’s Wadis which depend on the

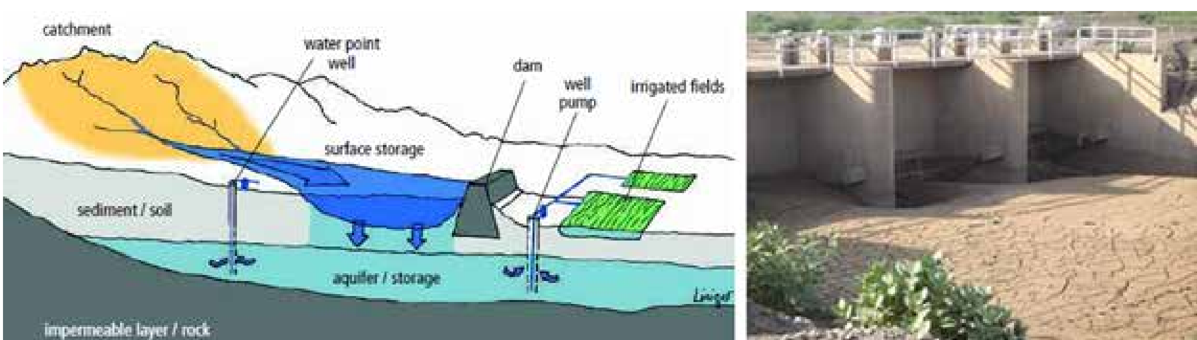


Figure 2: Model of diversion structures which affect subsurface flows in the wadis

Figure 3: Drought of banana crops due to deteriorating the groundwater quality in midstream of Wadi Zabid as a result of over-exploitation.

Figure 4: Increase the slat on the ground because of deterioration of groundwater quality in midstream of Wadi Zabid .

availability of several data including hydrology and hydrogeology information which should be measured continuously.

Groundwater is an insured source of water supply in spate irrigation areas, which can meet the crops water requirements when the spate water is unavailable. As a result, the availability of groundwater in spate irrigation areas often a problem; there is a shallow water depth and the opportunities of farming have changed. The farmers depended on the groundwater as a safe water supply for their production. They took its advantages and harnessed the water in a more productive way than expected from traditional spate systems. (Steenbergen, Lawrence, et al. 2010)

The groundwater used in spate irrigation areas promoted on a more controlled basis, offers a major opportunity for increasing agricultural production (through improvements in overall cropping intensity and irrigation water productivity) without compromising groundwater use sustainability (GWP 2012).

The over-exploitation of groundwater resources is one of the most important challenges for the groundwater sustainability, as a result of the increasing in the irrigated area with crops that required huge amounts of water such as banana. Therefore, the imbalanced use of groundwater in spate irrigation areas led to the decline of groundwater levels in most of wells and consequently deterioration of the quality as a result of saline intrusion in the coastal zones.

Sources of groundwater recharge

According to Todd and Mays (2005), a variety of methods have been developed to artificially recharge groundwater. The most widely practiced methods can be described as the ones spreading-releasing water over the ground surface in order to increase the quantity of water infiltration into the ground and the percolation into the water table.

Recharge from wadi beds or canals

The infiltration of flood water into the aquifers through alluvial beds is the most important mechanism for groundwater recharge in Yemeni's Wadis, which happens in the main streams and channels. Typically, the measurement process for infiltration from a wadi bed requires several measuring stations distributed in different places in order to have accurate measurements. For example, first station upstream, the second station midstream and the third station downstream. However, there is only one measurement station called Al-kolah, which is located in the upstream reach of Wadi Zabid.

Furthermore, the water losses from the wadi bed were estimated with different rates, which included about 10 - 15 % between the measuring station at Al-kolah station and weir 1 for about 10 km distance (IIP 2003). In other words, the losses of water by infiltration were estimated 3 % per km for the length in upstream course between Al-kolah and weir 3 (which is about 20 km). While the losses in the midstream canal were estimated 1.2 % per km for the length between weir 3 and weir 4. Moreover, at the downstream canal it was estimated to be about 1.6 % between weir 4 and weir 5 (IIP 2002).

According to the flood water distribution system called Al-Jabarti, the upstream area has 52% from the amount of total floodwater, while midstream area has 40 % and downstream area has only 8%, as shown in table 2.

Table 2: Floods loss by infiltration through wadi bed in Wadi Zabid

Area	Allocation %	Average of flood allocated MCM	Length of main canal Km	Ratio of losses per Km (%/Km)	Wadi bed Recharge MCM
Upstream	52	61.41	20.0	3.0	36.85
Midstream	40	47.24	28.0	1.2	15.87
Downstream	8	9.45	32.5	1.6	4.91
Total	**100%**	**118.10**			**57.63**

Recharge from the fields

The infiltrated water from irrigated fields by floods in spate irrigation areas have a big importance in the groundwater recharge. This process depends on many factors which include soil characteristics, climatic conditions, land use and water sources. In Wadi Zabid, the percentage of groundwater recharge from the fields was estimated 30 % according to size of fine soils in cultivated lands and water requirements ET according to area conditions.

Table 3 shows the annual amount of groundwater recharge from the wadi bed (channels) and fields. They are 57.63 MCM and 18.14 MCM respectively, with a total of 75.77 MCM, which constitutes about 64 % of the total amount of water entering.

Methods of recharge improvement

Groundwater recharge within streambed

A streambed is generally called a wadi bed where many human interventions are done to improve the groundwater recharge process. There are various technologies that can be implemented to enhance groundwater recharge according to the conditions of the area such as the diversion weirs, check dams, and pits and trenches as shown in table 4.

Groundwater recharge within spate irrigated fields

Flood waters flowing to spate irrigation areas across the main-streams that called wadi beds or channels, are diverted from the main canals or sub-canals towards irrigated fields through the traditional or modern diversion structures. In this case, the infiltration of water often occurs in those places mentioned above (main canals or sub-canals), while the rest of the floods move to be infiltrated in the fields during the spreading process within the bounds as shown in table 4.

Groundwater demand management

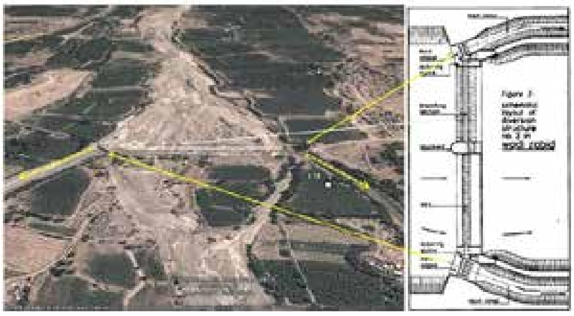
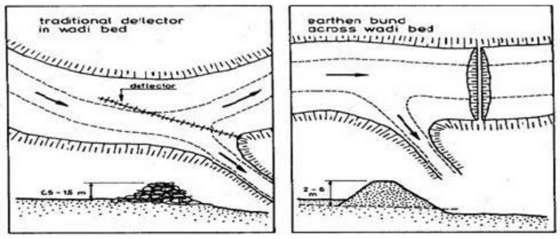
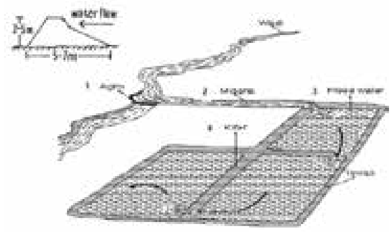
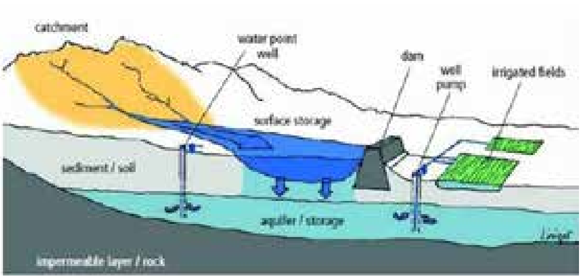
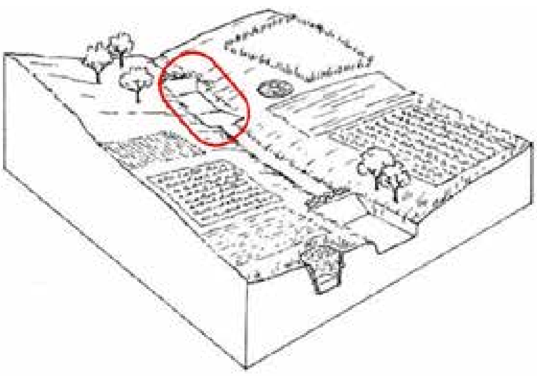
Groundwater demand management must be accomplished in a balanced manner in order to meet water requirements for future generations. However, the water balance of Wadi Zabid has a calculated annual deficit of about 110 MCM. This study estimated the predicted age of Wadi Zabid aquifer in order to find good solutions to avoid the big problem in this vital source; the depletion of groundwater resources.

So, in this study a hypothetical scenario has been made for Wadi Zabid aquifer to estimate the aquifer age if this situation will be continued along. The aquifer size has been estimated about 3,000 MCM according to the physical characteristics. The porosity of the aquifer has been estimated about 20 % for an area of 300 km^2 and the thickness of the freshwater layer has been estimated 50 m. So, the aquifer age has been calculated according to water balance equation which takes into account the population growth. Therefore, according to the relationship between withdrawals and recharge of groundwater curves as shown in figure 5, the age of Wadi Zabid Aquifer has been estimated to be 26 years.

Table 3: Groundwater recharge from irrigated fields by floods water

Area	Allocation %	Average of flood allocated MCM	Wadi bed Recharge MCM	Irrigation water MCM	Water infiltrated by fields MCM
Upstream	52	61.41	36.85	24.56	7.37
Midstream	40	47.24	15.87	31.37	9.41
Downstream	8	9.45	4.91	4.54	1.36
Total	**100%**	**118.10**	**57.63**	**60.47**	**18.14**

Table 4: Forms of artificial recharge techniques in the wadis

Artificial Recharge within streambed	Groundwater recharge within spate irrigated fields
	
	
Weirs diversion	Traditional diversion structures (Ogmas)
	
Check dams	Water spreading bunds
	
Pits and trenches	Pits and trenches

Sources: IFAD 2013, Saleh and Noman 2009 and Steenbergen and Tuinhof 2009

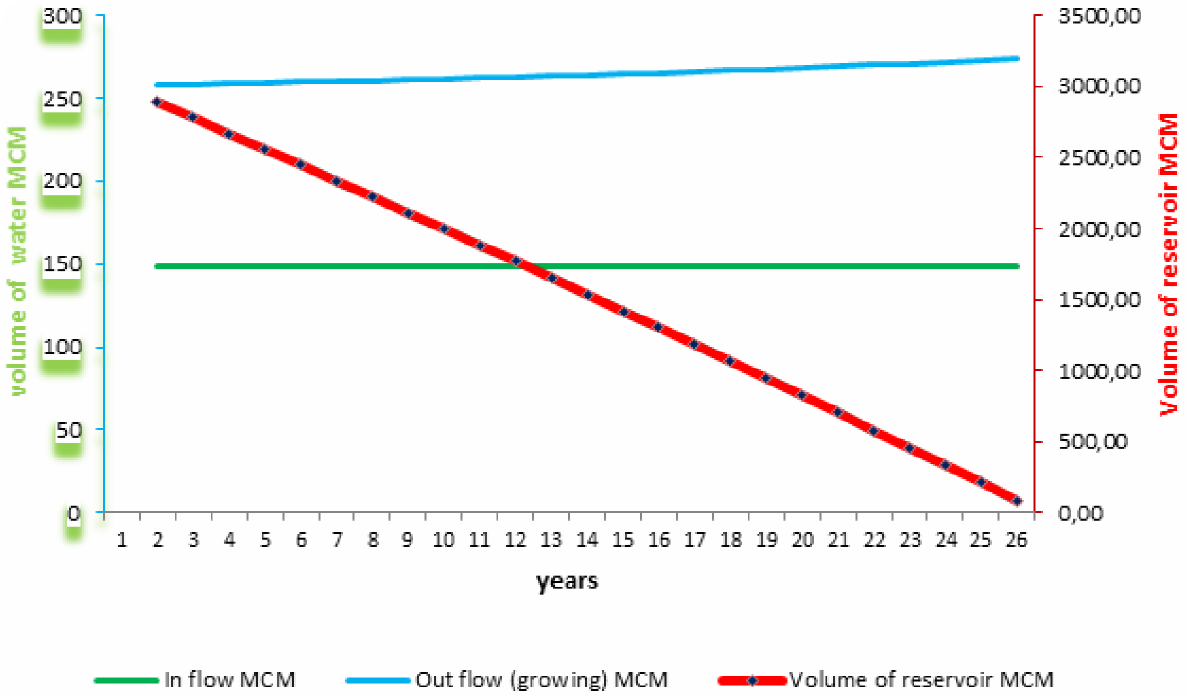


Figure 5: A schematic form for aquifer age in Wadi Zabid

Farmers awareness about groundwater

The issue of groundwater in Wadi Zabid indicates that there is weakness of the society role in groundwater sustainability as a result of lack of awareness on the importance of this precious resource. Also, there are many reasons which encourage to increase the groundwater abstraction by the wells, e.g. over pumping to irrigate the banana crop in upstream areas in Wadi Zabid (see figure 6), this includes income (profitability), competition between farmers and absence of water rights. In addition, there is a difference between the community on economic and social levels.

Topographic variation encouraged the beneficiaries upstream to get more water, either from their share or from others share at midstream and downstream. Also, most WUA leaders and powerful people in upstream areas are large landholder farmers at the same time who make them dominants on water distribution. The inequity in the distribution of flood waters caused increased pressure on groundwater in these areas, which prevents flood waters from reaching midstream and downstream areas.

The decline in groundwater level, required high costs to further deepen the wells which some farmers are not able to afford. Also, the increase of groundwater scarcity happened

Figure 6: Role of farmers in deterioration of groundwater resources by over-exploitation in Wadi Zabid

Figure 7: Example of unregulated drilling of the wells in Wadi Zabid

due to unregulated drilling as shown in figure 7 (where the distances between wells is adjacent), led to an increase in conflicts between farmers. Moreover, there is deterioration of agricultural fields and unemployment increases which forces many farmers to look for other sources of income. Because of this, many farmers migrate to the cities or neighbor countries.

Achieving groundwater balance and sustainability

The groundwater requirements for domestic use, drinking and livestock purposes are the most important priorities which must be taken into consideration. The groundwater requirements for the irrigation should focus on the crops that have low water requirements such as a grains, fodder, vegetables and some fruits. However, achieving the water balance between water supply and demand in Wadi Zabid is a complex process to be applied. The balancing needs further efforts through the various parties, including all stakeholders, to avoid depletion and salinization of the groundwater reservoir.

As mentioned previously, the gap between recharge and abstraction is about 110 MCM annually and could easily be increased with population growth continuation and urbanization. This gap is an annual deficit in the aquifers, where banana crop occupied 76 % of the groundwater extraction which is estimated about 222 MCM annually. About 67 MCM returned to aquifer and 155 MCM, is the net of groundwater consumption. So, the replacement of banana crops has been proposed. This process takes time and hard work to remove 3,600 hectares of banana fields and replace it with other crops such as grains, fodder, fruits and vegetables that depend on spate waters as a major source of irrigation and can be irrigated from groundwater.

The process of removal and replacement banana crop suggested to be gradually applied at several stages through twelve years period in order to replace 300 hectares banana fields annually with crops that consume less water. All this will save about 11 MCM per year, which is repeated every year to reach the total savings which is estimated about 93 MCM at end of the changing period for cropping pattern.

From figure 8, assuming the aquifer size is 3,000 MCM (as shown in groundwater inflow and outflow curves), the required time to achieve water balance is a period of 9 years from the beginning of the applied plan. The next period is a recovering period for aquifer past deficit. This process needs to be updated over time according to climate changes as well as changes in water use patterns by future generations. However, sustainable of groundwater resources requires serious coordination between the relevant authorities and the society, based on IWRM principles.

Conclusions

- Groundwater is a safe source of water supply in spate irrigation areas, which supports the agricultural production as supplementary irrigation with spate irrigation.
- Over-exploitation of groundwater resources is one of the main challenges which harms the groundwater sustainability in spate irrigation areas due to the increase in irrigated areas with crops that required huge amounts of water such as banana.

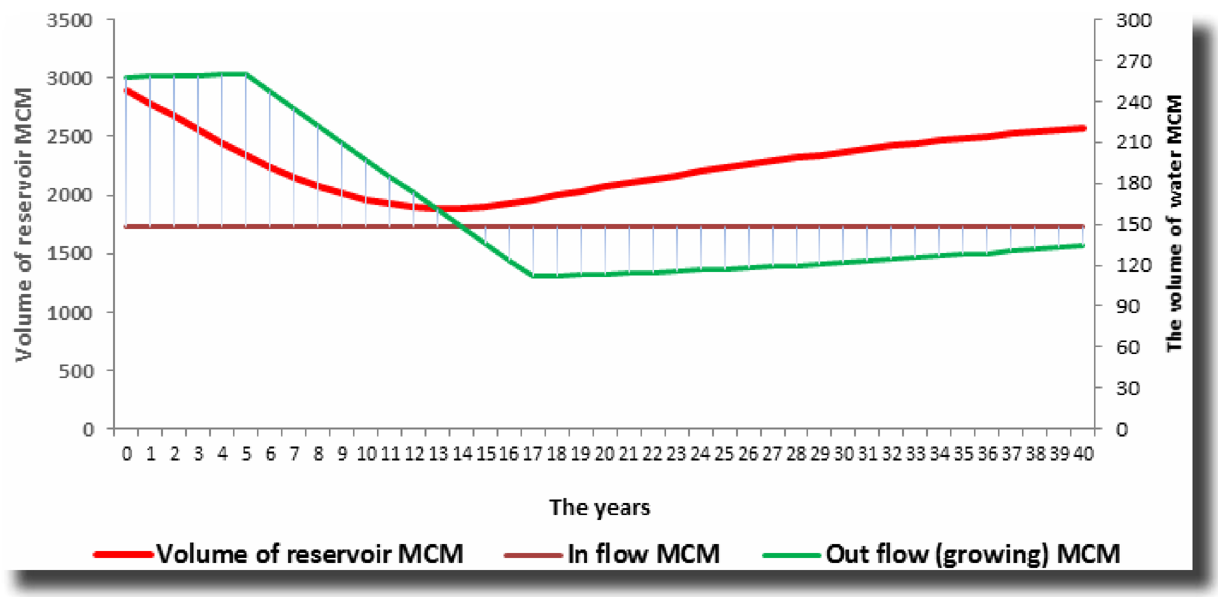


Figure 8: Form schematic shows the aquifer age for groundwater future use

- There are many factors affecting groundwater recharge in spate irrigation areas:
  Technical: Structures block the subsurface flow.
  Regulatory: Water rights are inappropriate with modern diversion structures.
  Socially: The violation of water rights among the beneficiaries of flood water in Wadi Zabid has led to pressure on groundwater sources.
- There is a gap between recharge and discharge of groundwater resources in spate irrigation areas, especially Wadi Zabid which led to annul deficit with about 110MCM.
- Techniques of groundwater recharge either from the wadi bed or from irrigated fields have good potential to increase the recharge, but with the problem of imbalanced use of groundwater.
- There is weakness of the society role in groundwater sustainability as a result of lack of awareness on the importance of this precious resource.
- Absence of IWRM played a big role in deterioration of groundwater resources in spate irrigation areas.

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Colophon

This practical note is prepared by Eng. Adel Mohamad Zolail and Dr. Sharafaddin A. Saleh for the Flood-Based Livelihoods Network.

The Flood-Based Livelihoods Network (FBLN) supports and promotes appropriate programmes and policies to improve flood-based livelihoods systems (FBLS) through a range of interventions, assists in educational development and knowledge-sharing, creates networks and supports the implementation of projects on FBLS.

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