4th International Conference on Water Resources and Arid Environments (ICWRAE 4): 871-878
5-8 December 2010, Riyadh, Saudi Arabia

Water Harvesting and Groundwater Recharge in the Catchment of Wadi Wateir - South Sinai

Mohamed Ali Soinbol

National Water Research Center, Water Resources Research Institute,
El-Qnater EL-Khairia, Cairo, Egypt

INTRODUCTION

Due to the limited water resources and the rapid increase of population in Egypt and their high concentration in the Nile valley and Delta, the Egyptian Government has implemented great efforts to develop new settlements and communities. The development of these new communities is a must to strengthen their role in national economy and strategic development. This can be achieved through a comprehensive research works and studies of the different water resources. Groundwater recharge is the replenishment of an aquifer with water from the land surface. It is usually expressed as an average rate of millimeters of water per year, similar to precipitation. Thus, the volume of recharge is the rate times the land area under consideration and is typically expressed in millions of cubic meters per year. Groundwater Recharge is the total volume of water entering aquifers within a watershed's borders from endogenous precipitation and surface water flow. Groundwater resources are estimated by measuring rainfall in the catchment area where rainfall is assumed to infiltrate into aquifers.

Quantifying recharge and spatially identifying recharge distribution is important for evaluating groundwater sustainability, especially in such arid regions. The quantity of recharge to an aquifer can be considered equivalent to the "safe yield" or quantity of water that could be removed from an aquifer on a sustainable basis. It is believed that the "sustainable yield" of an aquifer is almost always appreciably less than recharge. Nevertheless, a sustainable yield figure is derived from a recharge determination and any sustainable yield study will usually involve the determination of recharge as a necessary first step. However, recharge is not well understood, so it is difficult to estimate aquifer sustainability unless the recharge-related processes are carefully studied.

Although a rock formation may have properties favorable for storage of water, it must be in contact with a source of water for replenishment (recharge) to provide a continual supply of water. Recharge is generally highest in the mountainous northern part of the region where precipitation is greatest. The percentage of annual precipitation recharging the aquifers is dependent on the rates of evaporation, transpiration to plants, runoff and soil permeability. In places where the withdrawal of water is more than the rate of recharge an imbalance in the groundwater reserves is created. Recharging of aquifers is undertaken with the following objectives:

- maintain or augment natural groundwater as an economic resource
- conserve excess surface water underground
- combat progressive depletion of groundwater levels
- combat unfavorable salt balance and saline water intrusion

Natural replenishment of groundwater in such arid regions can take place through two mechanisms: 1) direct or diffuse infiltration of rainfall via the soil and unsaturated zone; and 2) local recharge by surface runoff via permeable wadi beds.

This study has been carried out mainly for the estimation of the rates of recharged water into the catchment of Wadi Wateir in South Sinai and the variation of groundwater levels and conditions. It also gives a brief description for the recharge rates at the area of Delta wadi Wateir and the effects of the floods and surface runoff.

The natural hydrological aspects in such arid and semi-arid regions like Eastern South part of Sinai,

Corresponding Author: Mohamed Ali Mohamed Metwalli Soinbol, Professor, National Water Research Center, Water Resources Research Institute, EL-Qnater EL-Khairia, Cairo, Egypt.

where Wadi Watier basin located is formed from different components. These include, among others, the existence of seasonal flash floods, groundwater recharge, sediment transport, flow of the natural springs and water table. Rain and flash floods are considered the main natural resources in this desert lands especially in case of increasing of water requirements for sustainable development. However, the characteristic trends imparted by evaporation can be useful in understanding the mechanisms of recharge, as well as determining recharge rates, which ranges between 1% to 2% of the precipitation. Water can be lost by evaporation from surface waters during runoff prior to infiltration, from the unsaturated zone or from the water table. Evaporation during runoff and infiltration in arid landscapes is generally associated with groundwater in alluvial aquifers along drainage networks (wadis). For groundwater recharged by direct infiltration through the soil or sand, evaporation from the unsaturated zone occurs. Hence, it was found that the recharge of the Quaternary aquifer depends mainly on the intensity of rainfall and infiltration rate of runoff water.

Groundwater Conditions in Wadi Wateir

Groundwater Level Variation and Conditions: Although all the recharge occurs in the Wadi due to the rainfall and flood of the eastern and western Waids, wells in the wadis did not show a clear seasonal variations, this may be due to the pumping effect and the broad area of the Wadi.

The water depth indicates a tight relation with the topography. The wells in the Delta Wateir are of relatively shallow water depths, ranging from 7 to 13 m below ground surface. At some wells, the water level ranges from 1.5 to 7.7m with average level 4.0m (a.m.s.l.) and in only two wells, water level ranges from 0.8 to 4.7(b.m.s.l.).

At El Sheik Attia area, the depth to water are relatively shallow ranging from 3 to 15 m below ground surface and the water level ranges from 700 to 890 m (a.m.s.l.).

At Wadi Sheira, the depth to water are relatively deep and ranging from 85 to 350 m below ground surface and the water level ranges from 560 to 835 m (a.m.s.l.), with an average level is 735 m (a.m.s.l.).

The flow direction of groundwater is northwestern to southeastern and the flow mainly from the southeastern to the northeastern towards the Gulf of Aqaba, with an average hydraulic gradient of 13 m/km. The water level for each well is shown in Figure (1) at EL-Sheikh Attia area for the period from 2000 to 2005.

Potential Recharge of Groundwater: The recharge of the aquifer is mainly encountered through its area of outcropping along the southern and eastern margins of El-Egma and El-Hazim plateaux and by the down word flow from the overlying aquifers (Quaternary and Upper Cretaceous). The amount of recoverable water into this aquifer was estimated at 38 x 10^9 m^3 JICA [1], taking into consideration that the extension of aquifer area is equal to 8000 km2, the average thickness is equal 160m and

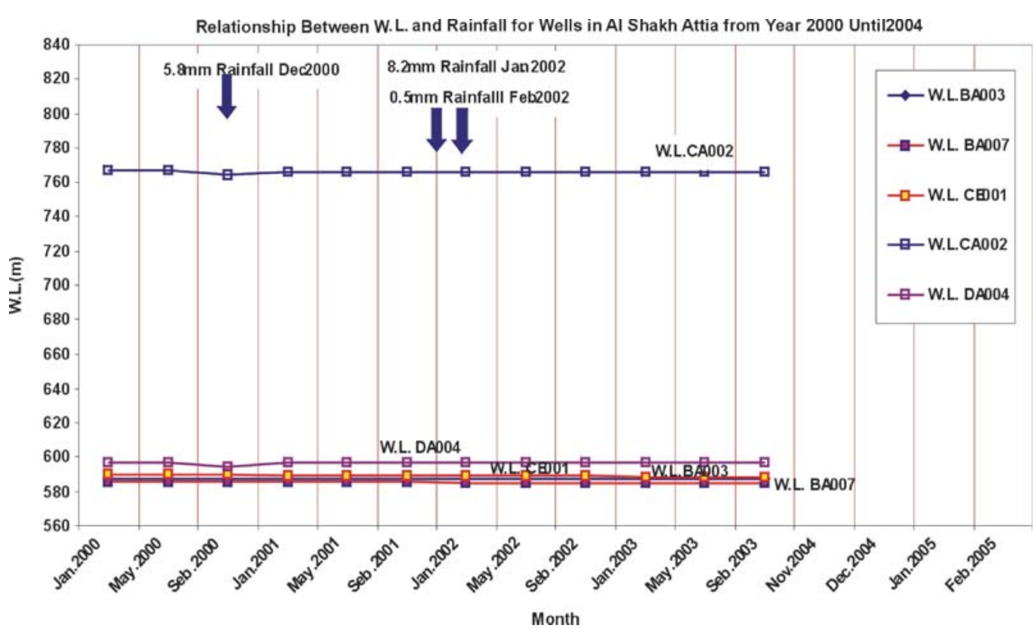

Fig. 1: Water Level for Wells in El Sheikh Attia from Year 2000 to 2005

the effective porosity is 3 %. The total inflow was estimated through the southern and eastern fronts as 51 x 10^6 m^3/year WRRI [2].

Water balance models were developed in the 1940s by Thornthwaite [3] and were later revised. The method is essentially a bookkeeping procedure, which estimates the balance between the inflow and outflow of water. Here, the volume of water required to saturate the soil is estimated from the part of average daily rainfall depth which does not produce surface runoff. This soil water balance volume can be represented as:

$$Rt = \sum_{i=1}^{n} Av(Ii - E) + \sum_{i=1}^{n} Ad(Ii - D)$$
$$where: (Ii - E) and (Ii - D) \geq zero$$

Where:
Rt: Net potential recharge (m^3);
D: Surface detention (m);
I: Average daily rainfall depth (m);
Av: Area of the flat parts (m^2);
E: Average daily evaporation depth (m);
n: No. of rainy days;
Ad: Area of the mountainous parts (m^2);
At= Av + Ad

The upstream part of the studied area is considered as a flat area which is subjected to evaporation, while the mountainous and hilly parts are found at the downstream part which more subjected to surface retention. From the topographic analysis of the catchment, it can be noticed that both flat and mountainous area more or less are equal to 0.5 of the total area. The average daily rainfall depth which does not produce surface runoff was estimated to be less than 13 mm based on the analysis of the land-use and soil type of the Wadi Wateir area. The measured daily average precipitation at St. Kathatrine; Ras EL-Naqab meteorological stations from1982 to 2005 and EL-Sheikh Atteia station form 1982 to 1995 have been used with the measured daily evaporation to estimate the potential recharge in million m^3 according to the above equation.

Analysis of Results: The recharge of the aquifer is mainly encountered through its area of outcropping along the southern and eastern margins of El-Egma and El-Hazim plateaux and by the down word flow from the overlying aquifers (Quaternary and Upper Cretaceous).

Table 1: Average potential recharge at the selected stations

	Recharge (Million m^3)		
Year	St. Katherine	EL-Sheikh Attia	Ras EL-Naqab
1982	49	38.5	41.65
1983	4.2	19.95	4.55
1984	28.7	79.8	13.3
1985	22.75	24.5	43.05
1986	19.6	83.3	21.35
1987	37.1	45.15	20.65
1988	61.25	5.6	75.25
1989	4.2	7.35	23.45
1990	17.15	9.1	11.2
1991	79.1	0.7	45.5
1992	15.75	85.75	49.7
1993	25.2	17.85	41.3
1994	84.35	17.15	95.9
1995	11.2	6.65	21.7
1996	52.85	-	16.8
1997	91	-	21.7
1998	14.35	-	24.15
1999	17.5	-	42.7
2000	23.1	-	8.05
2001	17.85	-	17.5
2002	45.5	-	38.5
2003	22.05	-	21
2004	19.6	-	16.45
2005	27.65	-	26.95

It was found that the net annual potential recharge ranges between 4.2 million m^3 at year 1989 and 84.35 million m^3 at year 1994 in the St. Katharine station and between 0.7 to 75.25 million m^3 (year 1991 and 1992) at EL-Sheikh Attia station and between 8.05 to 85.75 million m^3 (year 2000 and 1988) at Ras EL-Naqab station. Table (1) gives the average potential recharge at the three selected meteorological stations.

It can be observed that the recharge rate matches the high rates of infiltration in the high rainfall region at St. Katharine where the strata of the upper aquifer complex have its outcrops. It is recommended to conduct a continuous monitoring of the groundwater levels from the available wells or using some piezometers, in order to approximately estimate the depth of the recharged water from the rainfall storms during the rainy season.

Groundwater Recharge at Delta Wadi Wateir: Recharge of the unconfined Quaternary aquifer at delta wadi Wateir depends mainly on the intensity of rainfall and infiltration rate of runoff water. It is estimated to be 0.75x10^6 m^3/year, WRRI/Cairo University [4].

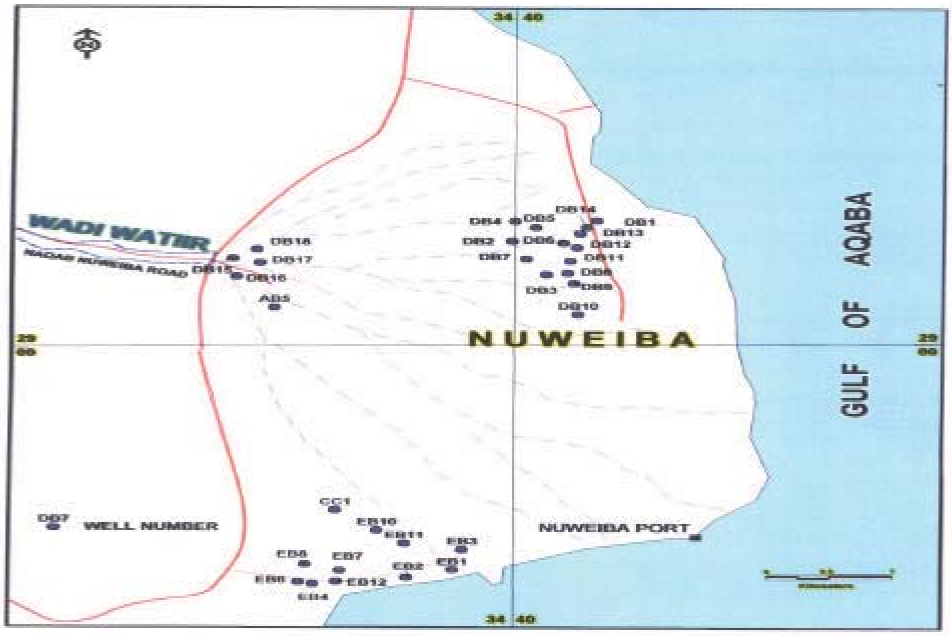

Fig. 2: Location of Wells in Delta Nuweiba

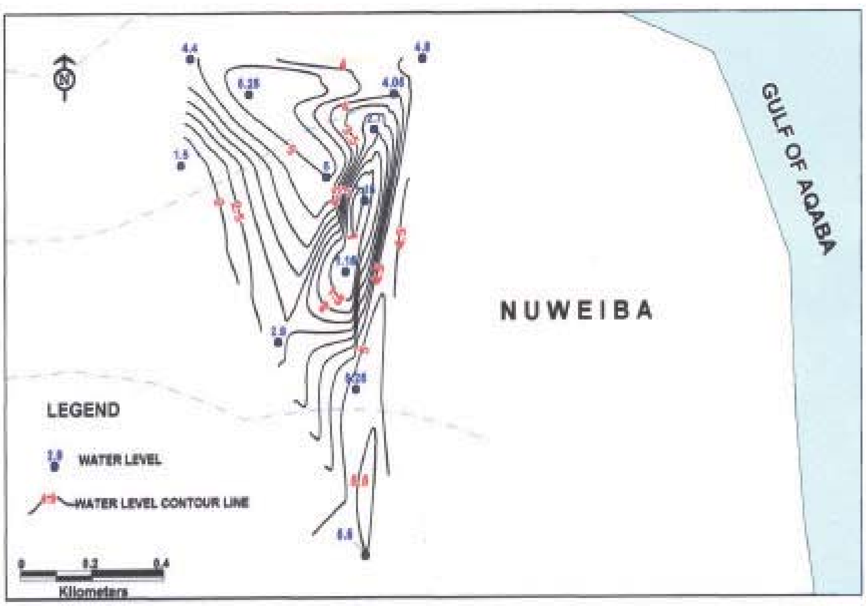

Fig. 3: Isohyetal Contour Lines for Water Level of Wells In Delta Nuweiba

The tranmissivity ranges from 5-6 m^2/day in El Sheikh Attia and 800-1500m^2/day in the delta of wadi Watir (Nuwieba). Although, the wells at El-Shiekh Attia show rather low productivity of 0.2 - 0.4 m^3/h, but the wells at the delta are of high yield (35-50 m^3/h).

The groundwater level in Delta Nuweiba, are recorded for 17 dug wells as shown in Figure (2). These data are described in well inventory. The ranges of groundwater level from 6 to 16 m, with average level of 10.55 m below ground surface level (B.G.L), Seven dug wells are exploiting groundwater under the sea level (a.m.s.l.). The water level ranges from 1.5 to 7.7m with average level 4.0m (a.m.s.l.).

The groundwater in the southwestern part of delta Nuweiba moves in the northeastern direction towards the Gulf of Aqaba as shown in Figure (3). Figure (4) shows the water level for wells in delta Wadi Wateir from year 2000 to 2005 and Figure (5) shows damped increase in

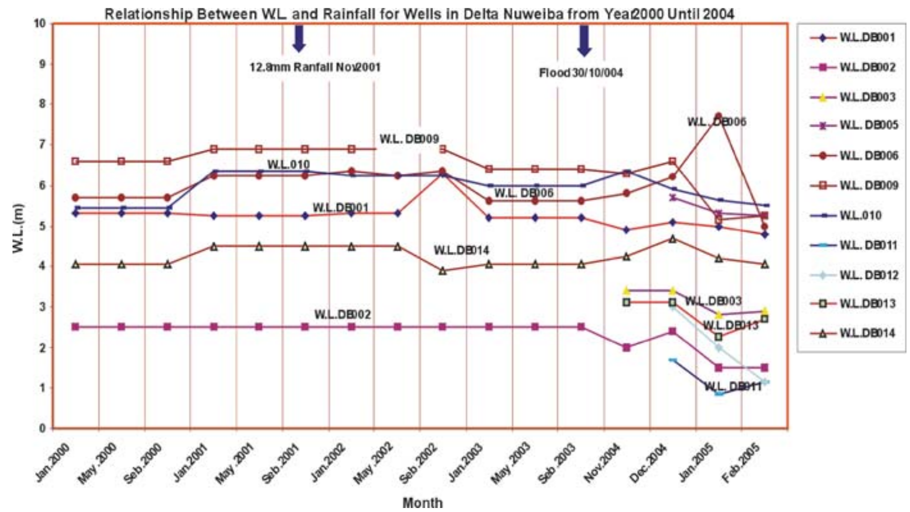

Fig. 4: Water Level for Wells in Delta Wadi Wateir From Year 2000 to 2005

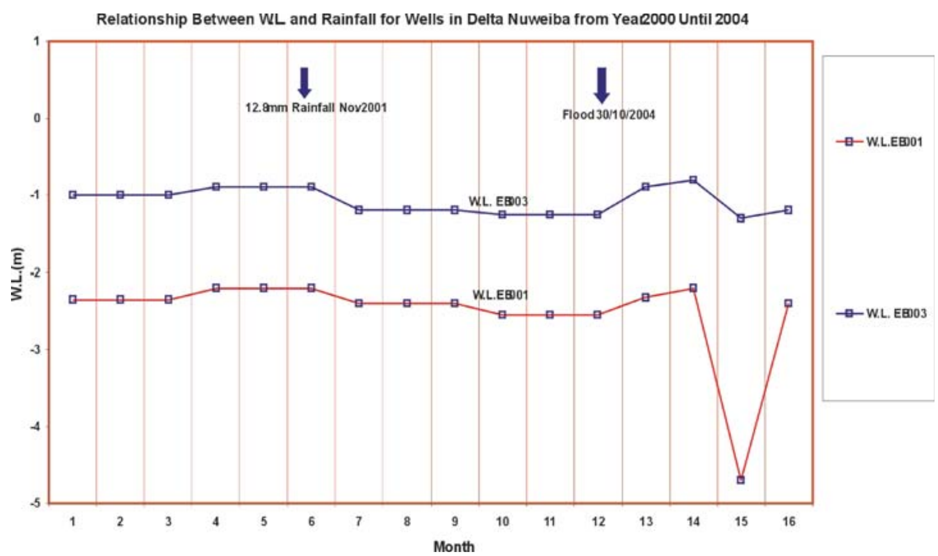

Fig. 5: Variation of Water Level After the Flood of 30/10/2004 (Wells 66EB001 and 66EB003) in Delta Nuweiba

water levels of two selected wells in the recharge area and the effects due to the flood of October, 2004. The response in the water levels resulted after a lag time of about two months. This lag according to Wright [5] is affected by two factors; firstly the thickness, permeability and porosity of the unsaturated zone; secondly the horizontal propagation of the flood wave in the saturated zone which is related to the diffusivity of the aquifer Abd Al Rahman H., [6].

It can be observed that positive fluctuation is observed to occur in the southern part of the Wadi after the flood of 30/10/2004. The increase in water level ranges between 0.1 to 2.15 m. This means that the surface runoff and floods increase the recharge rate at the area of the delta of wadi Wateir.

Water Harvesting at Arid and Semi Arid: The catchments systems used in the RWH are those where runoff is concentrated, stored and productively used by plants. The coefficient of runoff depends upon the shape, size, soil properties, temperature and geological conditions of the area of the catchment. In summary RWH may occur naturally or by intervention. Natural RWH can be observed after heavy storms, when water flows to depressions, providing areas for agriculture. RWH by intervention involves inducing runoff and either collecting it, or directing it, or both, to a target area for use. Table (2) summarizes the main rainwater harvesting techniques.

All rainfall harvesting systems have three components: a collection area, a conveyance

Table 2: The main rainwater harvesting techniques

Water Source	Objectives	Water Harvesting Techniques
Rainfall	- To increase rainfall effectiveness - To conserve water and soil	Terraces Contour-ridge terracing Dams Harrabas
Local Runoff	- To collect water - To store harvested water	Micro-catchment Cisterns
Wadi Flow (Flood and Base Flow) Wadi–bank	- To protect land against flood	Earth dykes (spate irrigation and small-head pumps and earth canals) enforcement
Spring Water	- To deliver water to participants within water rights limits - To store limited quantities forr short periods	Earth canals, Cisterns
Groundwater	- To abstract water from shallow aquifers - To exploit ground-water stored in the coastal sand dunes.	Shallow dug wells and pits, Galleries

Fig. 6: Rainfall harvesting system at the landscapes

Fig. 7: Rainfall harvesting system at the topographic depressions

system and a storage area. In this application, collection and storage are provided within the landscape as shown in Figures (6) and (7), respectably. In many situations, such areas are impermeable, being underlain by clay soils that minimize infiltration.

The concentrated, stored and productively used runoff of such catchments systems in the RWH as shown in Figure (4) can be worked out by one of the hydrological models (e.g. HEC-1), or the simple formula of the Rational Method as follows:

Fig. 8 Rainwater in sub-surface reservoirs "Haraba"

Fig. 9: Example of the improved water harvesting system

$$Q = C\,I\,A$$

Where:
Q = Discharge m^3/time,
C = Coefficient of Runoff,
I = Total annual rainfall in m and
A = Catchment area in m^2

One of the methods frequently used in rainwater harvesting is the storage of rainwater in sub-surface reservoirs which is called "Haraba" as shown in Figure (8). Topographically low areas are ideal sites for collection and storage of rainfall which has been used primarily for domestic and irrigation purposes.

Water harvesting initiatives and interventions need projects aimed at improving existing individual farmer practices on water harvesting as shown in Figure (9). Promotion of water harvesting should be done in conjunction with crops, which can be sold for cash. Micro-catchment approach to RWH has a high potential for improving land conservation. Macro- Catchment may, to some extent, increase the risk of erosion on the area used for yielding runoff. Individually based water Conservation/harvesting systems to a large extent have been more successful than collective based systems. Communally owned systems such as rain water harvesting and storage reservoirs were found to suffer from lack of protection, care and maintenance.

The only effective source of renewable water supply for Wadi Wateir basin is the recharge that takes placed during the few annual wadi floods and the rainfall. Surface runoff and rainfall saturate the wadi sediments and then infiltrate the shallow, perched aquifer system. There is a seasonally rainfall mechanism that lead to groundwater recharge. The majority of recharge most likely occurs during winter frontal and orographic rainfall. However, the recharge tends to be overestimated or underestimated in some areas according to the availability of the climatic data; the boundary conditions and the geological stratification.

The main direct recharge takes place in the high rainfall regions where the stratum of the upper aquifer complex has its outcrops. Along the mountain ridge a water divide has developed in this complex separating the water flow in an easterly and westerly direction. The lower aquifer complex receives its replenishment by vertical indirect recharge from the overlying aquifer systems.

CONCLUSION AND RECOMMENDATION

Conclusion: Regular monitoring of the water levels in the upper and lower areas of the wadi through monitoring; piezoelectric or observation wells is very important and more accurate way to estimate the groundwater recharge rates at different locations in the wadi. However, the groundwater recharge can be modeled by many different ways as follows:

- Simulated rainfall or recharge series within the idealized arid zone catchment for the conditions of Wadi Watiar catchment. Rainfall can be modeled within MODFLOW by applying a steady-state or temporally varying recharge rate to the upper active soil layer. Intensities can be varied over the modeled domain. The evaporation rate on a saturated surface layer is specified as a constant for the entire catchment.
- Runoff Modelling of Wadi Watiar The methodology for the flood hydrological study of Wadi Watier is based on the use of a deterministic conceptual model that converts precipitation to runoff asImplemented in HEC-1 model for the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1990).

Recommendations: The Soil Water Assessment Tool (SWAT) can provide meaningful recharge rates. SWAT generates recharge that is subsequently used in two transient MODFLOW simulations; one with the recharge distributed according to sediment unit location and one with the recharge concentrated in cells adjacent to the mountain fronts surrounding the basin. The model results should be compared with the historic well hydrographs for the calibration. A deterministic analytical model like SWAT is helpful in estimating recharge in arid basins and can create meaningful input parameters for numerical models like MODFLOW.

The isotopic composition of groundwater in arid regions can be considerably modified from that of local precipitation. The cause is the strong isotopic enrichment in water during evaporation. Unlike evaporation is a highly fractionating process. This complicates the use of isotopes as tracers of recharge origin, as well as the calculation of surface runoff vs. infiltration. However, the characteristic trends imparted by evaporation can be useful in understanding the mechanisms of recharge, as well as determining recharge rates.

REFERENCES

Abd El Rahman Hatem, 1996. Water resources assessment and utilization in El Qaa Plain, Sinai, PhD Thesis, faculty of engineering, Cairo university, EGYPT.

JICA, 1999. South Sinai Groundwater Resources Study in the Arab Repubic of Egypt.

Thornthwaite, 1948.

U.S. Army Corps of Engineers, (1990). HEC-1, Flood hydrograph package: User's manual. Hydrologic Engineering Center, Davis, California.

Wright, 1990.

WRRI/Cairo University, 1989.