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Evaporation Modeling for Sub-surface Reservoirs

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Abstract

Evaporation losses are the major problem effects on small dam's reservoirs in water harvesting systems. In this paper, evaporation modeling for sub-surface reservoirs was developed. The physical model contains four squares cross section tanks of (91.4) cm length and (46.2) cm depth (Colorado Sunken Pan). Three tanks were filled with different types of earth fill materials while the forth one filled with water. New instrument was **developed** to measure the amount of evaporation losses from gravel and sand, then comparing with free surface evaporation losses in order to estimate the amount of water that can be saved by using these types of small dams. The field study was achieved with the model during the period (Dec 2010-Feb 2012). The evaporation losses was reduced about 60 % when the water table below gravel surface by 10 cm only, while at 20 cm depth of the water table the evaporation reduction was about (85 % to 89%) from cores gravel and fine gravel respectively .

Key words: - Evaporation, Sub-surface Reservoirs, Modeling.

1-INTRODUCTION

Water resources management are raised to be one of the most important subjects in the human's life, particularly in arid and semiarid regions , since precipitation is extremely limited and spatially distributed, with poorly available ground water in quantity and quality. The evaporation losses from dam's reservoirs and lagoon forms very huge losses in water resources, for example, annually evaporation losses from Mosul dam and Haditha dam was more than two Km^3. The annual evaporation depth losses in Iraqi Western Desert is about (2.25 -3) meter (Kamel, 1999), this depth store the highest percentage of the small dams. For example, if the surface area of the small dam is one square kilometer, the annual evaporation loss for this dam is equal to 3 * 10^6 m3, which may be exceeds 75% of annually small dam storage (Alabaid, 2008).

Water harvesting systems is used to overcome water scarcity and improve water productivity in rain fed agriculture in arid and semi-arid climates. Harvesting water rainfall in storage reservoir may result in wastage of large volumes due to evaporation. This is particularly important in arid and semi-arid regions where the amount of evaporation greatly exceeds the amount of rainfall. More recent efforts include small-scale projects in many parts of the world, notably India, Africa and Brazil (Barrow, 1999). Such dams store sufficient quantities of water for livestock, minor irrigation and domestic use. The technology might be considered ‘simple’ but ‘effective’, reason why many Non-Governmental Organizations (NGO) consider it an interesting instrument to provide drinking water to poor, rural communities (Nilsson, 1988; Van Haveren, 2004).

Efforts were directed toward sub-surface storage to reduce evaporation losses and to maintain the quality of water. The newly suggested method to sub-surface storage is storing water by sand storage dams, which are small concrete check dams built in the valley bed perpendicular to the flow direction. Upstream of the sand dam fast sedimentation occurs, which is regarded a problem considering surface water dams. However, sand accumulating behind these dams has a large grain size diameter, thereby enlarging the natural aquifer. An enlargement of groundwater storage capacity compared to a situation without a sand dam is the result.

The sand reservoirs are replenished by rainwater, either directly or, more generally, through flash floods originating at higher elevations in the catchments. The larger part of the flash floods volume will pass over the dam, but a small part of one single and short-lived flash flood may completely fill a reservoir with water. A few hours after a flash flood has passed over a dam, the surface of the sandy riverbed may look dry again, but water will have been stored in the reservoir. This water then starts to seep into the river banks, which tend to have a much lower infiltration capacity than the sediments collected in the river bed. This seepage into the riverbank is expected to be slow. It may take many flash floods, or even many seasons, before the water levels in the surrounding soil come into equilibrium with the water level immediately upstream of the dam.

There is enough practice based evidence that sand storage dams can be an effective water source, providing a possible solution for soil and water conservation challenges in the drier areas of Iraqi western desert. There is also a clear need, however, to gain better understanding of the hydrological processes around dams. The goal of the modeling effort discussed in this paper was to show the general effect of a sand storage dam on evaporation losses at different level of water tables.

Rainfall will have a certain effect on water tables levels in the wider area, although the effectiveness of sand storage dams may be less sensitive to the amount of rainfall than one would expect (Borst and De Haas, 2006). Only when rainfall drops below a certain threshold, dependent on the location, volumes stored in dam reservoirs would be affected. The geometry of the impermeable layer, often assumed flat (as in this model), is in reality quite undulating and is one of the hardest variables to get accurate data on.

The objectives of present study are:

1- Develop a physical model to study the effects of sub-surface reservoir on evaporation from water table below the soil surface, and comparing it with evaporation from free water surface.

2-Simulating the relation between soil type and amount of evaporation to determine the best type that minimize the evaporation losses from sub-surface storages.

2-PHYSICAL MODEL DEVELOPMENT:-

The field study was started in Dec. 2010 and ended in Jul. 2011 in the city of Ramadi (University of Anbar), and the field study was extended from Oct. 2011 to feb.2012 in order to improve the model results. Hydrological station was constructed and provided by four evaporation tanks, three filled with gravel, sandy gravel, and fin gravel, while the forth one filled with water. The target of this experiment is to observe evaporation at different depth of water table within the gravel storages in comparison with surface evaporation. Eventually to determine the effectiveness of sub-surface storage and determination of the best soil type to reduce the losses of evaporation.

2-1DESCRIPTION OF HYDROLOGICAL STATION:-

Hydrological station with dimension 4x4 m of wood frames was constructed. It is protected by chicken wire to prevent against animals and birds as shown in figure (1).

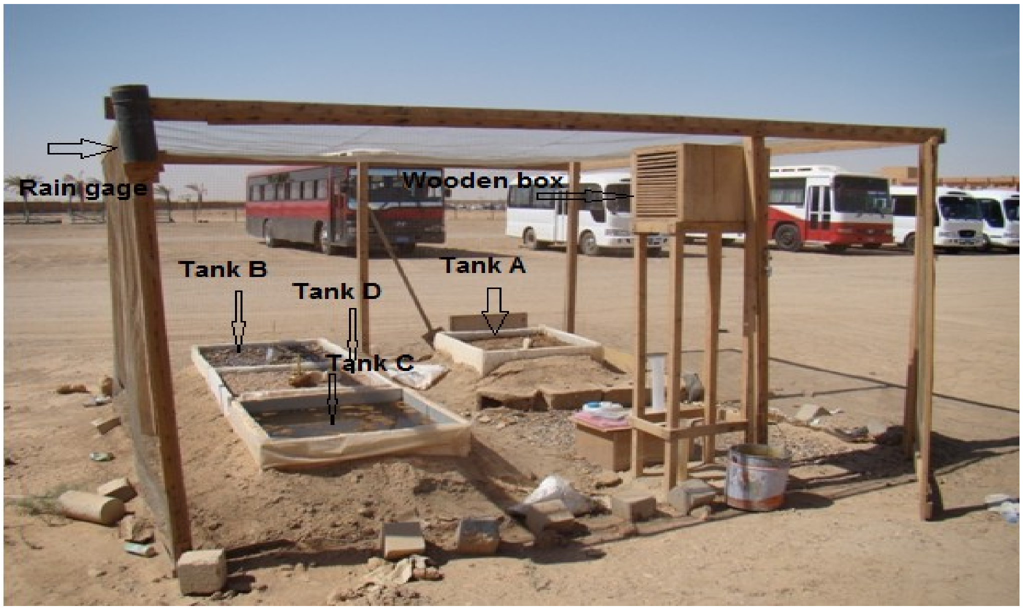

Figure (1) the Hydrological Station (evaporation physical model)

The station was provided with standard rain gauge, which is used to correct the reading of evaporation in case of the presence of rain by deleting the amount of recorded rain from measured evaporation. The station also, provided with thermometers for measuring temperature and fixed in airy and sun covered by wood box. For measurement of wind speed, relative humidity, air pressure and dew point, the station was provided with a manual digital anemometer. Figure (2) shows the wooden box and anemometer.

2-2 EVAPORATION TANKS:-

Four tanks were made locally by using the ironsmith, according to standard specification of " Colorado sunken pan". These specifications include the cross-section is a square of 914 mm with dimensions and 462 mm depth; it is buried into the ground within 100 mm of the top. The chief of advantage of the sunken pan is that radiation and aerodynamic characteristics are similar to those of a lake, (Patel and Shah, 2009).

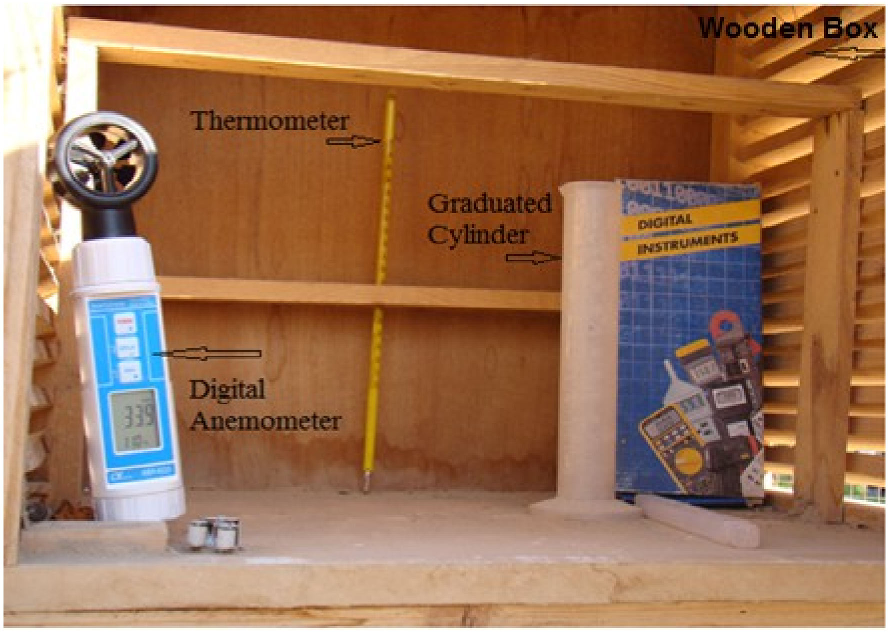

Figure (2) Thermometer and Digital Anemometer.

All tanks were fixed above the land surface after being covered and lining the internal and external surface with nylon to prevent erosion by rust, and then they were surrounded with soil and cork to maintain the tanks from temperature effect, as shown in figure (3). The tanks were labeled as tank A, tank B, tank C and tank D as shown below:-

2.2.1-TANK A (SANDY SOIL WITH GRAVEL): -

This tank filled with soil classified according to standard specification of Unified Soil Classification System (USCS) as a Poorly Graded Sand with Gravel (sp). (Figure 3-a).

2.2. 2. TANK B (COARSE GRAVEL):-

This tank is filled with gravel classified according to the Iraqi specification number 45 in 1988, as limited gradation from 5 to 40 mm. (Figure 3-b)

Porosity of the gravel sample was calculated in the field by adding ten liters of water to this tank(B) and adding the same water volume to the tank C (filled with water only). The water level was measured in both tanks, then the porosity estimated using the following equation:-

Porosity (n) = …(1)

n = = 34 %

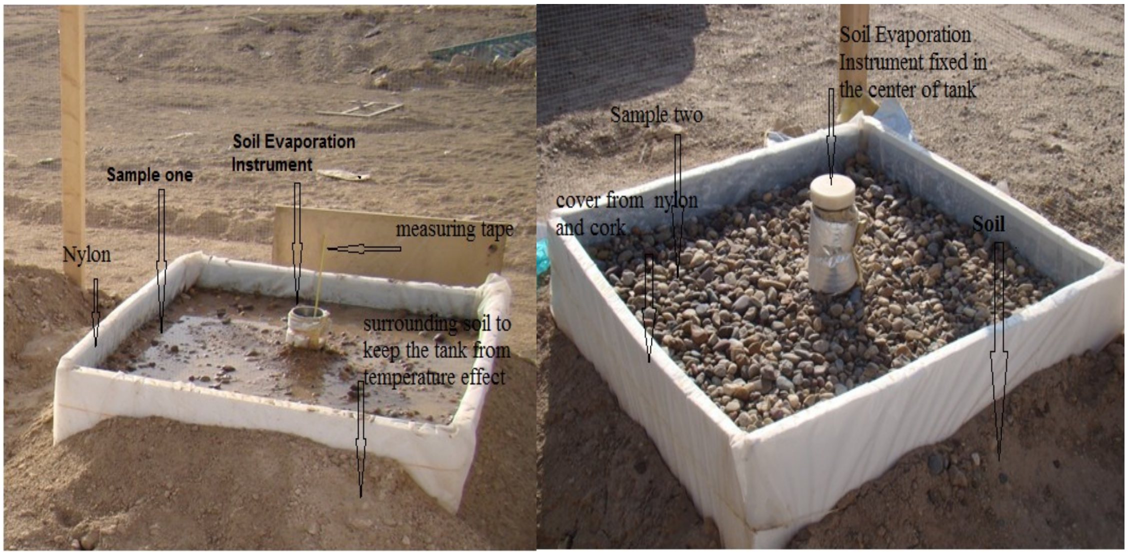

Figure (3), a- Tank A. (sand gravel) b- Tank B Coarse Gravel

2.2. 3. TANK C (PAN EVAPORATION):-

This tank filled with water to measure the surface evaporation which represents the standard evaporation level. (Figure 4-a).

2-2-4- TANK D (FINE GRAVEL): -

This tank sample was classified according to the Iraqi specification number 45 in 1988, as a gradient region's number one. (Figure 4-b)

The porosity of gravel was calculated using equation (1) as follows:-

$$n = \; = 44\ \%$$

Figure (4), a- Tank C (filled with Water) b- Tank D (fine Gravel)

3- EVAPORATION MEASUREMENT:-

A simple instrument is manufactured (by researchers) to determine the water table in the tanks that filled with soil, represents a small well, and easily for operation, (Figures 5- 7). This instrument is consists of an outer stainless steel cylinder which is multi-perforated; its end is sharpened to facilitate the planting in the soil. Inside the cylinder, there is another perforated stainless steel cylinder surrounded by latticed mineral wire to prevent the entry of sand and gravel granules.

The instrument was covered with a white plastic cover to prevent the direct evaporation from the free surface of cylinder. On the other hand the plastic cover prevents the direct sun light from heating the internal cylinder because the cover is made of a special material characterized as heat isolation.

The whole instrument is made of stainless steel (except the plastic cover) to maintain the two cylinders from corrosion by rust. The diameter of the outer cylinder is three inches (7.5 cm) and its height is 50 cm, while internal cylinder measurement is1.5 inch (3.75 cm) diameter .It was fixed by an axial rivet by wilding in the tipped end of the outer cylinder. Figure (7) shows shape of the outer, inner cylinder and latticed.

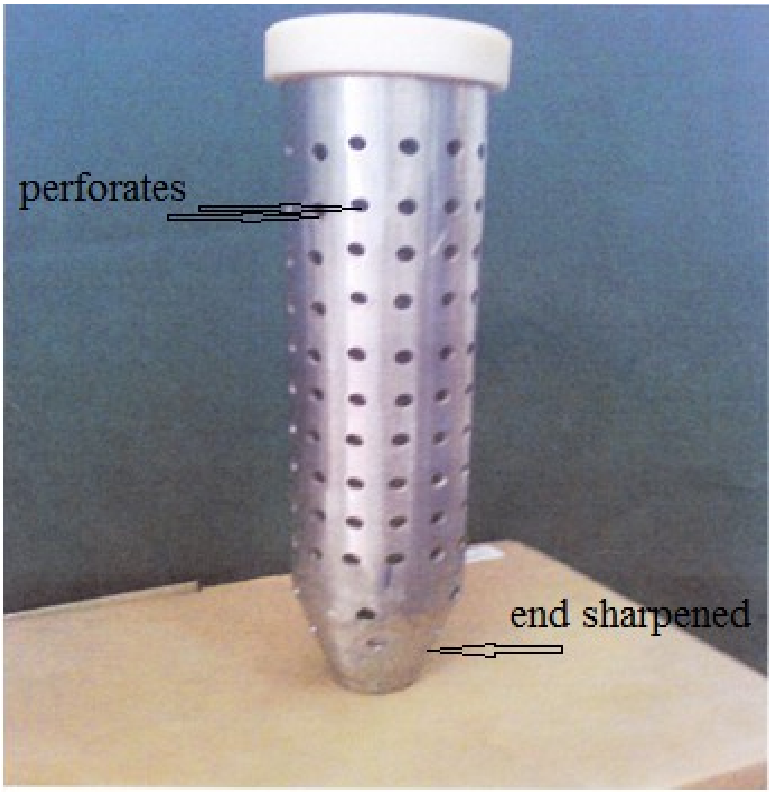

Figure (5) the Outer Shape of Instrument

The measuring tape is fixed to cork float which is cork cylinder with dimension 1.4 inch in diameter and 2 inch in height .Both the measuring tape and the cork float are fixed by an axial rivet inside the inner cylinder, the cork float in working situation is shown in figure (6).

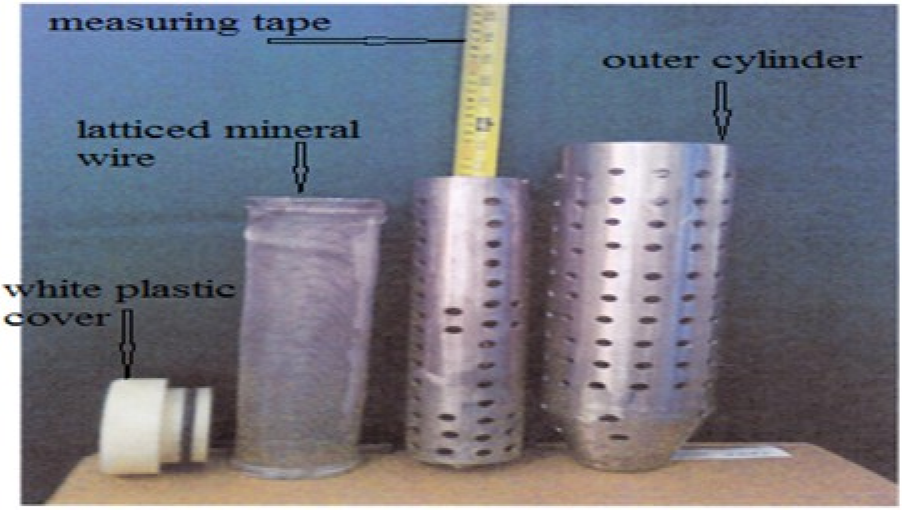

Figure (6) Outer and Inner cylinder & latticed Silk

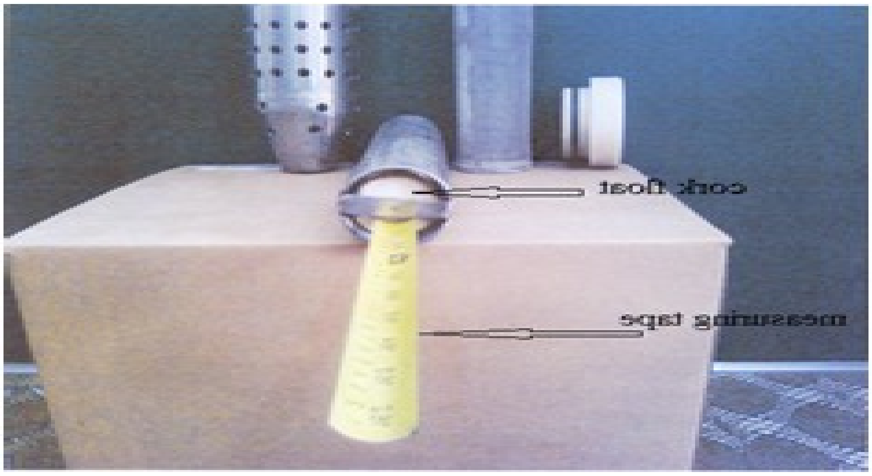

Figure (7), Cork Float and the Measuring Tape.

4-RESULT AND DISCUTION:-

The collected data for the four tanks were subjected to statistical analysis in order to give a scientific background to interpret the variation or fluctuation in evaporation readings.

It is a good idea to cast light on the average evaporation readings with respect to month for the four tanks. Table (1) shows the average evaporation and standard deviations for each experiment according to the months mentioned above.

Table 1. Averages and Standard Deviations of the Experiments According to Months.

Months	Evaporation from tank B (C.G)		Evaporation From Tank C(Pan)		Evaporation from Tank D (F.G)	
	Avg.	Sd	Avg.	sd	Avg.	Sd
Dec.	1.1022	0.785	2.042	0.679	1.147	0.388
Jan.	0.3948	0.2231	1.333	0.589		
Feb.	0.952	0.566	2.852	0.985		
March	0.5733	0.2904	4.397	0.886		
April	0.5913	0.3583	5.395	0.510		
May	2.1001	2.0328	7.241	1.431	2.611	3.506
June	1.8242	0.913	9.631	1.432	1.489	1.050
July	2.1614	0.4677	11.707	1.184	1.244	0.982

To explain the relation between evaporation and the depth of water table at different temperatures, the collected data from hydrologic station were distributed according to the average temperatures. These relations can be illustrated as follows:-

4-1EVAPORATION DEPTH RELATED TO WATER TABLE DEPTH

The daily average soil surface evaporation was plotted against the water table depth at different temperatures. These relations can be shown in figure 8 for cores gravel.

4-2EVAPORATION DEPTH RELATED TO THE TEMPERATURE

The daily average soil surface evaporation was plotted against the temperature at different water table depth. These relations can be shown in figure 9 gravel compared with free surface water evaporation. It is clear that as temperature increase, the difference between free evaporation and under gravel evaporation was increased, that mean more amount of water saved in gravel.

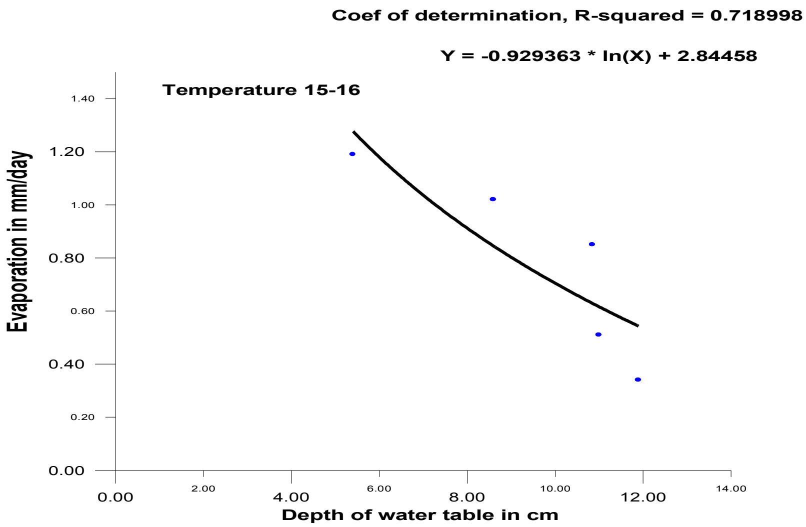

Figure (8), Relation between depth of water table and evaporation at temperature 15-18°C for tank B (C.G).

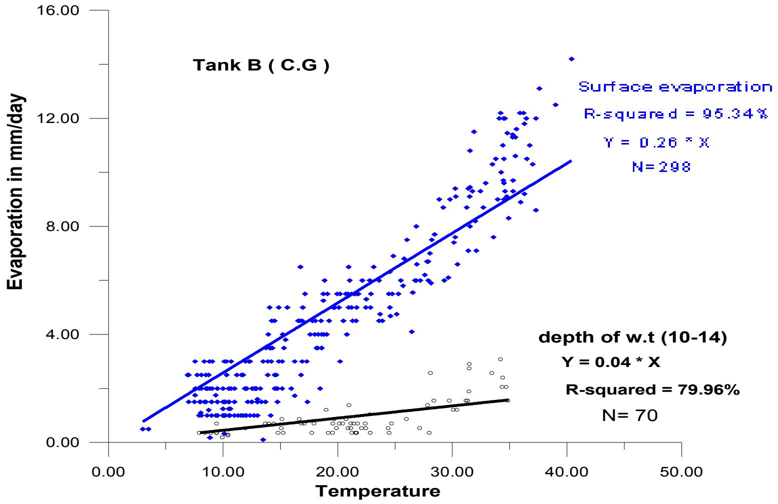

Figure (9), Relation between temperature and evaporation for sample (C.G) at depth of water table 10-14cm

4-3EVAPORATION RATIO AT DIFFERENT WATER TABLE DEPTH:-

Evaporation ratio will be introduced and defined as a ratio of sub-surface evaporation depth to the surface evaporation depth at the same temperature, at given water table depth (table 2).

Table (2) evaporation ratio for different water table depth.

N	Depth of W.T in cm	Tank B	Tank D
		Ratio of evaporation	Ratio of evaporation
1	0	1	1
2	<5	0.46	0.42
3	5-9	0.23	0.23
4	10-14	0.15	0.11
5	15-23	0.15	0.11

The relation between water table depth and evaporation ratio can be shown in figure (10) below. This figure shows a very important relation that can be used to find the ratio between sub-surface evaporation and free surface evaporation at any water table depth. The first point in this figure represents the 100% evaporation at zero depth of water table (at depth zero the evaporation from gravel tanks equal to evaporation from free surface tank).

The good correlated (R2 >= 84%) for two relations between evaporation ratio and water table depth for cores and fine gravel respectively are:-

$$Y = \exp(-0.083 * x) * 0.72 \ \ldots\ldots\ldots\ldots\ldots\ldots \ (2) \quad (\text{C.G.})$$
$$Y = \exp(-0.098 * x) * 0.73 \ \ldots\ldots\ldots\ldots\ldots\ldots \ (3) \quad (\text{F.G.})$$

Using these equations to estimate evaporation at any water table depth leads to very important conclusion, the effect of porosity. For example, if water table depth equal to 20 cm, the evaporation ratio for C.G. tank (from improved equation 2):-

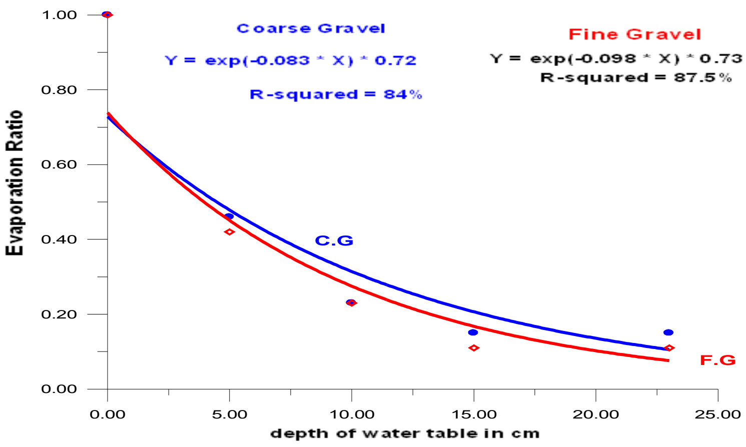

Figure (10), Relation between depth of water table and evaporation ratio.

$$Y = \exp(-0.083 * 20) * 0.72 * 100\% = 13.7\ \% \quad \ldots\ldots\ (4)$$

Evaporation from F.G. tank (from equation 3)

$$Y = \exp(-0.098 * 20) * 0.73 * 100\% = 10.3\ \% \quad \ldots\ldots(5)$$

Multiplying both results in equation 4 and 5 by corresponding porosity, which equal 34% for C.G and 44% for F.G.

$$13.7\ \% * 0.34 = 4.658\ \% \ \ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$
$$10.3\ \% * 0.44 = 4.532\ \% \ \ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

The difference between equations 6 and 7 above as a ratio to the minima (equation7) calculated below:-

$[(4.658 - 4.532) / 4.532] * 100\% = 2.78\ \%$

So the average ratio calculated from these two equations (6 and 7) can be used to predict the evaporation ratio from the porosity of the filling material :-

$$ER * n = 4.595 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

ER :- Evaporation Ratio
n :- Porosity

If a filling material porosity equal 50% , then evaporation ratio at water table depth 20cm can be estimated from equation 8 and equal to 9.19% which mean that more than 90% of evaporation losses can be saved in this reservoirs technology.

5- CONCLUSIONS:-

1- Evaporation from water table in the gravel affected by depth of water table, average temperature, and wind speed,

2 – The logarithmic relation between evaporation from pan can also be used for evaporation from shallow water table,

3- For a different depth of water table there is a linear relation between temperature and evaporation,
4- There is an exponential relation between depth of water table and evaporation ratio which is defined in this study as a (ratio of subsurface evaporation depth to surface evaporation depth) for the soil type that consider in this study,
5- The soil evaporation ratio at depth of water table 10 cm was 0.32 when using C.G sample and 0.28 when using F.G sample, whereas at 20 cm depth the evaporation ratio was 0.15 and 0.11 when using C.G and F.G sample respectively.

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