Hydro engineering Feasibility Study of Surface Runoff Water Harvesting in Al-Ajeej Basin, North West Iraq

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Abstract

The hydro engineering characteristics of Al-Ajeej basin which was located within south Sinjar plain north west Iraq was analyzed to predict the possibility of surface runoff harvesting during rainfall season in the upstream sites in this basin using watershed modeling system (WMS). The hydrological feasibility of constructing small dam on Al-Ajeej valley with some preliminary design calculations were presented. The best optimum dam site was selected to be located (3.95) km downstream the confluence of Al-Badee branch with Al-Ajeej valley ($35^{\circ}\ 46'\ 6''$ Latitude and Longitude $41^{\circ}\ 36'\ 11''$) having a catchment's area of (3043)km^2. The proposed dam height was (12.5) meter with a dam length of (1277)m, while the normal storage volume of the reservoir is (38.8) million m^3. Construction a dams in such sites characterized by water shortage during all around the year will give an aid in the sustainable development of such area by increasing the cultivation lands, the agricultural products and also modify the income of the villagers living in this area leading to prevent them leaving their lands to other places.

Keyword: Sustainability; Water harvesting; Small dams; Al-Ajeej Basin, WMS, GIS.

الجدوى الهيدروهندسية لحصاد مياه السيح السطحي لحوض وادي العجيج شمال غرب العراق

الخلاصة

تم دراسة وتحليل الخواص الهيدروهندسية لحوض وادي العجيج الذي يقع ضمن سهل سنجار الجنوبي شمال غرب العراق لتحديد أمكانية حصاد مياه السيح الناتجة عن الأمطار الساقطة في المواقع المتقدمة للحوض باستخدام نظام WMS، حيث اعتمدت بيانات الأمطار اليومية المسجلة في محطتي سنجار والبعاج للسنوات (1994-2006) في حساب معدل كميات السيح السطحي السنوية للحوض والتي بلغت حوالي 53144784 متر مكعب. كما تم دراسة الجدوى الهيدرولوجية لإنشاء سد إملائي صغير على وادي العجيج وعرض تصميم أولي لهذا السد واختير الموقع الأمثل له الذي يقع على بعد 3.95 كم من موقع التقاء فرع وادي البديع مع وادي العجيج ويقع على خط طول 11 36 41 وخط عرض 6 46 35 حيث بلغت المساحة المغذية له 3043 كم^2.

بلغ ارتفاع السد الإملائي المقترح 12.5 متر وطول 1277 متر وخزين حوالي 38.8 مليون متر مكعب عند المنسوب الاعتيادي للخزان. أن أنشاء سدود صغيرة في مثل هذه المواقع والتي تتصف بشحة في المياه خلال معظم أيام السنة سوف يؤدي إلى دعم التنمية المستدامة لهذه المنطقة وذلك بزيادة مساحات الأراضي الزراعية والإنتاج الزراعي وتحسين دخل الفلاحين الساكنين فيها مؤديا إلى منع هجرتهم إلى مواقع أخرى تتوفر فيها المياه.

الكلمات الدالة : استدامة، حصاد المياه ،سدود صغيرة ، حوض العجيج

Introduction

Due to the water scarcity for different uses in the area south sinjar mountain specially in the residential groups in Baaj district and due to the importance of this area in the cultivation of strategic crops such as wheat in which the Iraqi country depends on, it is mandatory and essential to conserve, stabilize these population groups and satisfy sustainable agricultural and dairy resources development. The main expects states that water is available in the area during

certain limited period during the year (few months) but the actual input indicates a water shortage almost the year as a result of non-homogenous distribution of water resources in different places and large amount of surface runoff flowing draining towards main valley called (Al- Ajeej valley) leading to natural salty depression across the Iraqi boarder to Syria called Al-Raudha depression.

Motivation and Aim of the study

The study area (Al-Ajeej basin south sinjar plain) survive from the water shortage without existing any permanent surface water resources, in-addition this area did not included into any engineering previous study and will not served by the proposed south Al-jazeera irrigation project. The basin of Al-Ajeej valley drains the surface runoff water quantities of the western north of south AlJazeera plain out of the Iraqi boarder to Syria without any use. Another reason is the arid climate of the basin lead to the idea of rain fall these water quantities behind proposed embankment dam constructed on this valley of (176 km length).

The aim of the research work is to present a hydrological and topographical feasibility study for water resources development in Al-Ajeej basin by surface water harvesting during rainfall season which drain and flow in the perennial Al-Ajeej valley in addition to selecting the best optimum site on this valley for constructing embankment dam which is feasible and satisfy little economic cost with high usage coinciding with the water harvesting aspect.

Location of the study area

The Al-Ajeej basin is located within the area of south Sinjar plain and Al-Baaj cities in Ninavah governorate including western north part of Al-Jazeera plain in Iraq near the Iraqi-Syrian boarder. The total basin area is (5189) km^2 and extends between (41° $10'$ – 42° $60'$) long. and between (35° 20 - 36° $25''$) lat., 4050 km^2 of this area is located in Iraq and 1139 km^2 in Syria. Sinjar mountain east Al-tharthar valley, snaissla salty depression from the south ,while Al-Khabour river basin in the Syrian lands from the west, (Figure 1).

The Climate

The Al-Ajeej basin is located within the arid and semi-arid climate with high average air temperature, high temperature difference between the day and the night summer and winter with little rainfall and humidity (Al-Qassab , et.al. 1987). The rainfall quantities increases during oct. till may with snowfalls in the Sinjar mountain in the north, the maximum rainfall in Sinjar is 667 mm in 1954 while the minimum is 92 during the year 1947. Table 1 shows average monthly rainfall in Sinjar and Al-baaj hydrological stations which are located within the study area for the years (1960-2001).

Literature Review

Most of the previous studies concerning water availability within the study area like Abdulkadir 1993; Al-Sawaf 1997; Sharif 1981; Awad 1994;Al-Muhsin 1985; Al-Talabani 1986 and Sam 1989 focus on the geological formations storing water and types and characteristics of rocks and the ground water investigation except the study conducted by (Abdulkadir, 1973) which focuses on the preliminary evaluation of some northern valleyes of south Sinjar plain against the feasibility of check dams construction to store

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rainfall water on their basins and also the study conducted by (Rafiq, et.al, 2000) on the possibility of rain water harvesting through the basin of Sinjar mountain.

The demographical distribution

The interested study area is characterized by good population distribution represented by small medium villages and large residential camps as in Alsaggar, Almusharaf and Alhamdania camps which were located near the Al-Hamal, Al-khazrajia and Al-badee branches respectively as shown in Figure 1. According to the recorded information during the year 2002, the habitants of those camps were estimated to be (1955), (6896) and (2255) respectively, (Rafiq, 2000).

Geomorphological Description of Al-Ajeej Basin

Al-Ajeej basin is classified as plainy lands except Sinjar Mountain and some high lands north the basin. The basin extends from north to the south, consists of about eleven main valley within Iraqi lands and three other main in Syria. Al-Ajeej basin consist of three main branches (Al-Hammal, Al-Khazrajia and Al-Badee) which originate from the south side of Sinjar mountain and extends between the water divide of Al-Khabour basin from the west and between Al-tharthar basin from the east. Al-Hammal branch intersects with Al-Khazrajia branch at a distance about 27.5 km south Al-Baaj city forming Al-Ajeej valley, while Al-Badee valley intersects with Al-ajeej valley south west Al-Baaj city at a distance about 28.8 km and 1.38 km south west the intersection Al-Hamal with Al-Khazrajia branches. The geomorpological characteristics of those branches of Al-Ajeej valley was investigated using the watershed modeling system (WMS 7.1) with the aid of the geographical information system as listed in Table 2.

Al-Ajeej Basin Soil

One of the essential parameters which must be taken into consideration during the design and construction of any hydraulic engineering project like a dam is the soil type. The soil in Iraq differs from place to another according to the material and existed geological formation and also the climatic conditions and vegetation cover in the site. The most soil type of Al-Ajeej basin contains calcarious, gypsum with organic material due to the existed geological formation of Injana and Al-fatha in the basin. The soil characteristics and its components describes the permeability degree which in-turn affect on the hydrological elements starting from the surface runoff, infiltration to the ground water storages.

Surface Water Sources in the Basin:

The water resources are characterized by the main valleys and their tributaries distributed through the basin. In-addition to the springs existed in the north of the basin at the foothills of south side of Sinjar Mountain such as Jaddala spring. The ground water quantities cover the surface water shortage and its existence differs in Al-Ajeej basin according to the climate, topography, and geological formations. The rainfall is the more essential climatic parameter existed in the area in which it considers the only water source in the area for it's feeding a large quantity through north zone of the basin. The topographical features of the basin and drainage pattern play an important role in the ground water. The increasing of the numbers of valleys, narrowness, closeness between them

and their parallel drainage pattern leading to direct fast flash flow during rainfall without any time for infiltration processes which in-turn increase the opportunity of harvesting those surface runoff quantities by constructing a small dam.

Figure (2) shows longitudinal cross-section of Al-Ajeej valley from the beginning of its formation to the outlet of the three main branches.

Calculation of the Annual Runoff in Al-Ajeej Valley

(Rafiq, et.al, 2000) estimated the surface runoff in Al-Ajeej basin as (10000-15000) m^3/km^2 using Berkly equation. In the present study the flowing runoff depth within Al-Ajeej basin was estimated using the daily rainfall recorded data in Sinjar and Al-Baaj metrological stations for the years (1994-2006) applying the SCS curve number method as follows:

$R = (p-0.2S)^2/ (p+0.8S$ ...……..(1)

$R = 0$ if $p <$ $(0.2*S)$

Where:
R= runoff depth (mm); P = precipitation (mm).

$S= (25400/CN) – 254$ ……(2)
Where:
CN = curve number
Curve number was derived from hydrological soil group and, land use and land cover. It was provided for moderate antecedent soil moisture conditions (ASM-II) then converted to ASM-I and ASM-III conditions reaching to the following regression equations, (Chow, 1988) :

$CN\text{-}I = 0.3358 * 1.009^{CN\text{-}II} * CN\text{-}II^{1.038}$ …… (3)

$CN\text{-}III=3.5610 * 0.9961^{CN\text{-}II} * CNII^{0.8101}$ …….(4)

Where; CN-I,II,III are the curve numbers for antecedent moisture condition I, II,III.

Applying the above equations taking into consideration all the hydrological and physiographical factors of the Al-Ajeej basin, the average curve number value of 82 was found.
Watershed modeling system (WMS) was fed with all the hydrological and physiographical characteristics of the catchment area of Al-Ajeej valley for the years (1994-2006), the annual runoff volume (Table 3) was calculated at the confluence of the three main branches of Al-Ajeej valley (Al-Hammal, Al-Khazrajia and Al-Badee) as follows:

$V \text{ in } m^3 = (R/1000) * \text{area in m}$……(5)

Selection of Dam Site

Using topographical topo-sheet map 1: 2500 and the 90*90 m DEM of the study area, the dam site was proposed to verify the criteria of less dam length, less amount of earth works and higher storage volume with a minimum ratio of surface area to the storage volume. The essential hydrological conditions and factors such as available storage volume, geomorphologic characteristics of the site, the engineering nature of the site including bed slope, availability of the depression valley was taken into consideration too. The proposed dam site was located (3.95) km downstream of the confluence of Al-Bade branch with Al-Ajeej valley having a coordinate of ($35^\circ 46' 6$ Latitude and Longitude $41^\circ 36' 11''$) as shown in Figure 3. Figure 4 shows a topographical cross-section of the proposed dam site.

Storage Volume of the Proposed Dam

Depending on the storage volume, surface area stage curve shown in Figure 5 the normal water level in the reservoir was proposed to be (261) m.a.s.l. taking into consideration the available calculated annual surface runoff of the basin and the demand for water from the residential population groups in the area to cover their domestic and agricultural purposes.

The maximum water level of the dam was predicted depending on the maximum probable flood wave in the Al-Ajeej valley which was calculated using Synthetic unit hydrograph (Snyder method) which can be used in un-gauged basins as follows:

$$Q_p = (640 C_p A)/ t_p \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where :

Q_p is the peak flow in (cfs); C_p is peak coefficient and A is the basin area in (mil^2).

$$C_p = P_e C_t A^{0.15} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$P_e = 0.00245 I_a^2 - 0.012I + 2.16 \ldots\ldots\ldots(8)$$

$$C_t = -0.0037 I_a + 0.163 \quad \ldots\ldots\ldots\ldots(9)$$

Where:

P_e is peak parameter; C_t is time to peak coefficient and I_a is the percentage of impervious land surface.

The duration of the excess rainfall for any storm was calculated as:

$$D = t_p / 5.5 \quad \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

$$t_p = C_t (LL_{ca} / S^{0.5})^{0.48} \quad \ldots\ldots\ldots\ldots(11)$$

where:

t_p is basin lag time in hours; L is length of main stream from outlet to the water divide line in (mile); L_{ca} is the length along the main stream to a point nearest to watershed centroid (mile) and S is the average bed slope of the stream.

To convert Snyder unit hydrograph (D) to any rainfall duration (D_1), a new basin lag time (t_{p1}) was calculated as follows:

$$t_{p1} = t_p + 0.25 (D_1 - D) \quad \ldots\ldots\ldots\ldots(12)$$

The base time of the synthetic hydrograph in hours $(T_b) = 5\, t_{p1}$

The width of the hydrograph was calculated at 50% and 75% of the peak as follows:

$$W_{50\%} = 770/(Q_p/A)^{1.0} \ldots\ldots\ldots\ldots(13)$$

$$W_{75\%} = 440 /(Q_p /A)^{1.08} \ldots\ldots\ldots\ldots(14)$$

The width of the hydrograph were located between the 1/3 of the width before the peak and 2/3 of the width after the peak. The time of concentration of the basin was calculated using the following equation:

$$T_c = 0.00013\, m\, (L_f^{0.77} / S_f^{0.385})\, t_{cc} \quad \ldots\ldots\ldots\ldots(15)$$

Where:

L_f is length of overland flow in (ft); S_f is the average overland slope and t_{cc} is coefficient of concentration time.

Using Gumbels distribution method to predict the probable flood wave in Al-Ajeej valley for 100 year return period was predicted as follows:

$$P_T = P_{avg} + K_T \sigma_{n-1} \ldots\ldots\ldots\ldots(16)$$

$$K_T = Y_t - Y_n / S_n \quad \ldots\ldots\ldots\ldots(17)$$

$$Y_T = -[\ln.\ln (T/T-1)] \ldots\ldots\ldots\ldots(18)$$

Y_n is function of the size of the used data.

S_n is the standard deviation and function of the size of data.

Applying Snyder method on Al-Ajeej basin, the following parameter values was calculated as follows:
A = 3302.22 km^2 ; S =0.001; L =103.6 km^2; L_{ca} = 39.17 km^2; Ia =5% ; C_t =0.144; t_p =14.06; C_p =0.9; D=2.5 hour ; Tc= 12 hour, t_{p1} =16.36 hour; T_b =82 hour ; P_{100} = 3 inches (76mm) and R_{100} = 1.378 inch.
The peak discharge of the unit hydrograph is 1191 m^3/sec while the design peak discharge of Al-Ajeej basin is 1101*1.378 = 1642 m^3/sec.
Figure (6) shows the synthetic flood hydrograph of Al-Ajeej basin.

Design of dam embankment

1. The height of dam was selected depending on the calculated storage runoff volume. The net height of the dam = height up to normal water level in reservoir + F.B+ settlement allowance(3% of dam height)
   F.B = height of wave (hw)
   $hw = 0.014 (Dm)^{0.5}$
   Fetch of the reservoir = 7100 meter
   at 261 m.a.s.l.
   hw = 1.17≈ 1.2 = F.B

Height up to normal water level=
261-250= 11
Net height of dam = 11+ 1.2 +
(0.03*12.2) = 12.56 m

2. Width of crest (b) = 0.45 (H)
   Width of dam base (B) = b +5.5 (H)
   Where (H) is the dam height

The embankment volume of the dam was calculated using Trapizoidal method assuming the upstream slope of 1:2.5 and downstream of 1:2 according to the proposed type of available material used in the embankment (Homogenous coarse silty clay) with dam height less than 15 m as follows:
Table 4 shows proposed dam specification while table 5 and figure 7 shows the hydraulic characteristics of the reservoir behind the proposed dam.

Proposed Type of Spillway Structure

To release the probable maximum flood wave passing in Al-Ajeej valley (1642 m^3/sec for 100 year return period) above the proposed normal water level in the reservoir, two options may be presented: the first is constructing an ogee gated type spillway (6 gates with 10 meter length and 4.5 meter height) fixed on the crest of the spillway at elevation 256.5 m.a.s.l.
The second option is to construct rectangular weir across the whole cross-section of the proposed dam site (1277 m) with a crest elevation 261 m.a.s.l. Figures 8 and 9 shows a schematic diagram for the proposed options of the spillway structure.

Engineering Conclusions

From the analysis of the hydrological and topographical data for the Al-Ajeej basin it to test the feasibility of surface runoff water harvesting during rainfall season in the Al-Ajeej valley by proposing constructing small dam on this valley, it was concluded that it is feasible to construct a hydraulic structure either small dam or weir in the selected site along Al-Ajeej valley in which the average annual surface runoff volume is about (53.144) million m^3 at the proposed dam site which is located (3) km downstream the connection of Al-Badee branch with Al-Ajeej valley. The dam length is (1377) km while the dam height is (12.5) m with the normal storage volume of (38.8) million m^3.
It is essential to construct an earth dam at this best optimum site on Al-Ajeej valley to verify the following:

a. Make use of surface storage volume in the proposed dam to cover the water demand from the population groups in the area and extend the cultivation lands and eliminate the

probable desertification processes in the area.

b. Ground water recharge which will in turn increase the water yield of the wells in the surrounding area which may used as a supplemental water source in the drought periods.
c. Transfer large agricultural areas depending on rainfall to surface and supplemental irrigation.
d. Transfer many pasture areas to agricultural lands due to the availability of irrigation water.

The existing of the water surfaces behind the dam will lead to develop the tourist sector in the area and may in-turn modify the income of the villagers and the people living their.

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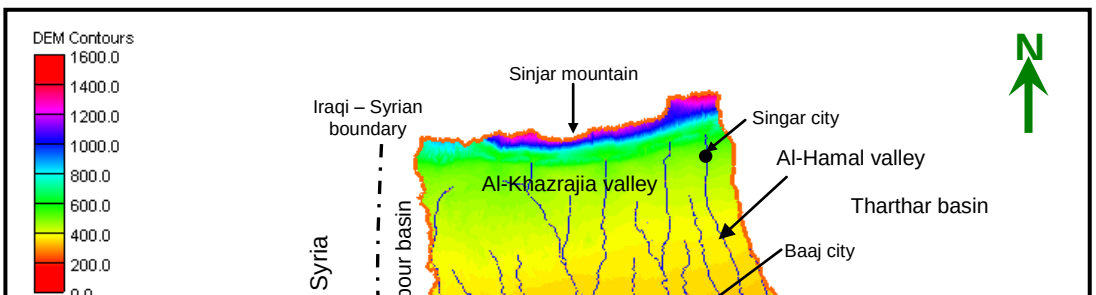
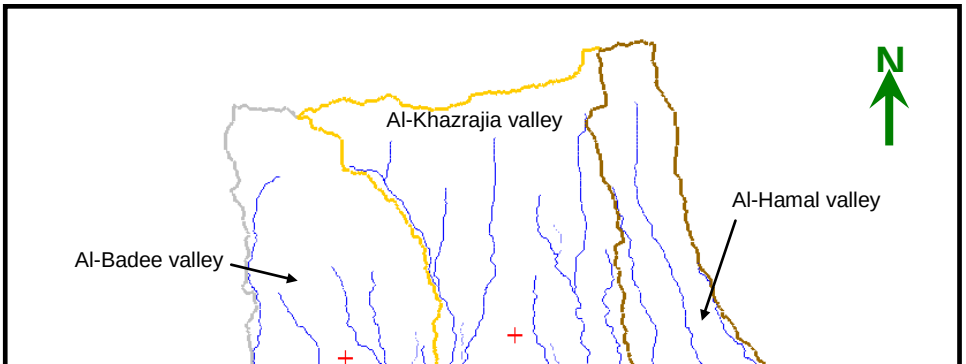
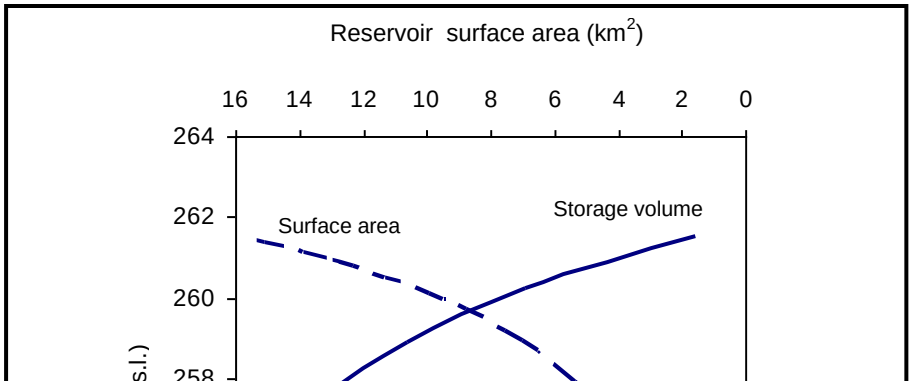
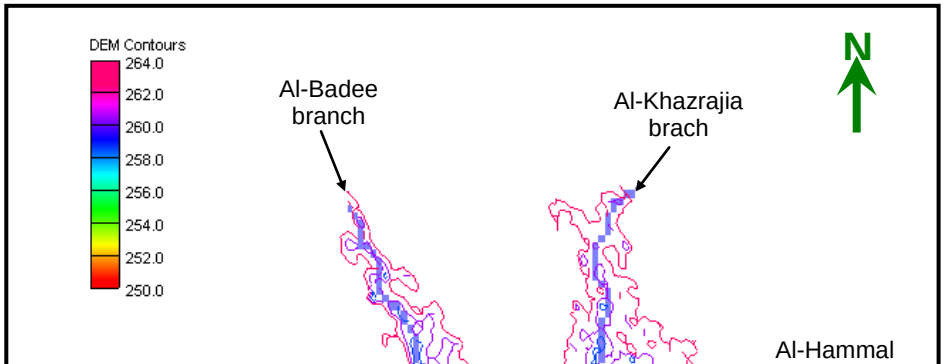



N
Al-Khazrajia valley
Al-Hamal valley
Al-Badee valley


Reservoir surface area (km2)
16
14
12
10
8
6
4
2
0
264
262
260
Surface area
Storage volume


DEM Contours
264.0
262.0
260.0
258.0
256.0
254.0
252.0
250.0
Al-Badee branch
Al-Khazrajia brach
N
Al-Hammal

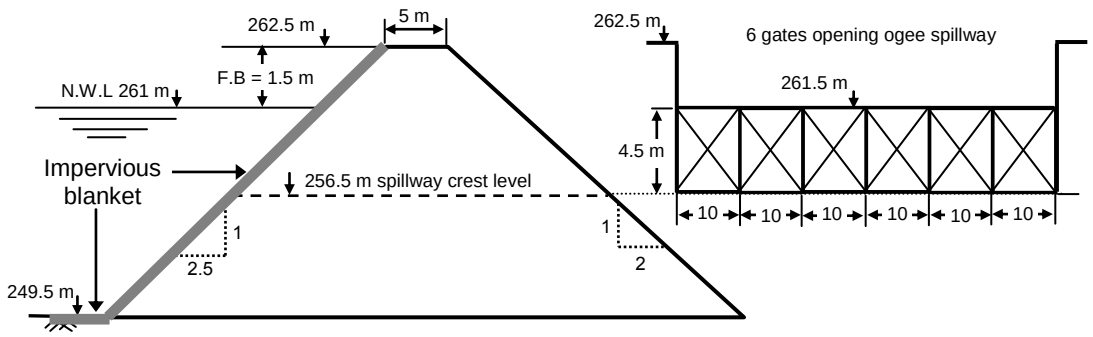


Fig.(8): Schematic cross-section of earth fill embankment dam.

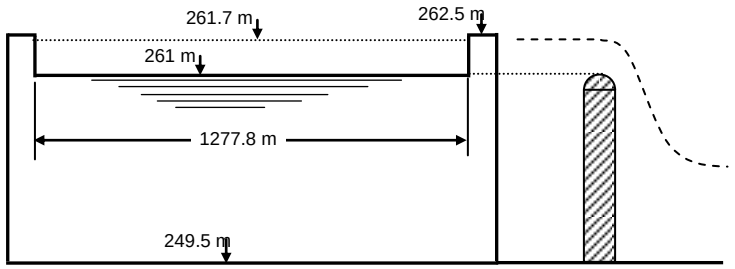


Fig.(9): Schematic cross-section of rectangular weir

Table (1): Average monthly rainfall in Sinjar and Al-baaj hydrological stations.

Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual (mm)
Sinjar	67.7	63.4	64.7	45.3	23.1	0.72	0	0	0.5	12.2	37.1	67.6	382
Baaj	57.8	44.5	47.6	24	21.1	2.5	0	0	0.24	10.8	37.9	37.9	311

Table (2): Geomorphologic Parameters for the study area.

Geomorphologic Parameters	Al-Hamal Basin	Al-Khazrajia Basin	Al-Badee Basin
Cachment Area (km^2)	885.48	1280.73	877.24
Basin slope (m/m)	0.0166	0.031	0.018
Average overland flow (km)	5.06	5.19	5.64
Basin length (km)	68.66	66.75	65.4
Basin Perimeter (km)	279	258.5	211.7
Shape factor (mi2/mi2)	5.32	3.48	4.88
Basin Sinuosity Factor	1.28	1.09	1.12
Average Basin Elevation (m. a. s. l.)	353	402.3	366.8
Max Flow Distance (Km)	96.86	81.84	84.09
Max Flow Slope (m/m)	0.0111	0.0128	0.0066
Average basin width (km)	14.07	20.96	18.75
Time of concentration (hr)	13.9	10.5	12.7

Table (3): Annual volume of runoff.

Year	Annual Runoff volume (m^3)
1994	63,867,086
1995	51,436,209
1996	136,989,336
1997	21,165,293
1998	23,742,186
1999	9,045,001
2000	28,881,158
2001	81,531,890
2002	95,957,754
2003	25,423,839
2004	8,515,427
2005	70,542,827
2006	73,784,186
Average	**53,144,784**

Table (4): Proposed characteristic of Al-Ajeej dam.

Dam	Bed Level (m.a.s.l.)	Dam length (m)	Dam height (m)	Dam width (m)	Dam base width (m)	Crest Dam level (m.a.s.l.)	Volume of earth work (m^3)
$35^{\circ}\ 46'\ 6''$ Latitude $41^{\circ}\ 36'11''$ Longitude	250	1277	12.5	5	63.5	262.5	215217

Table (5): Hydraulic characteristic of Al-Ajeej dam.

Normal water level (m.a.s.l.)	Reservoir length (km)	Average reservoir width (km)	Reservoir surface area (km)	Normal Reservoir storage volume (million m^3)
261	7.1	2.1	15.5	38.8