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HYDROLOGICAL STUDY AND ANALYSIS FOR PROPOSED SARTIK DAM PART 2: RESERVOIR CHARACTERISTICS, SIMULATION MODEL, AND FLOOD ROUTING CALCULATIONS

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ABSTRACT

This research is the part 2 of hydrological study and analysis for proposed Sartik dam which located on the Lesser Zab River, the second largest tributary of Tigris River at 18 km northeast of Altun Kopri town, within Erbil governorate of Iraqi Kurdistan Region. In this part water demand from the dam is calculated, the dam power generating facility with an installed capacity amounting to 156 MW with a maximum discharge of 300 m^3/sec. The characteristics of the dam reservoir were calculated, from reservoir sedimentation calculation the dead storage level and capacity was determined and was equal to (309 m.a.s.l., and 104,304,031 m^3) respectively. The monthly and annual water losses due to evaporation were calculated from daily recorded evaporation using an equation based on area, volume and elevation curve, and the annual losses were equal to (51,132.366 m^3), also the normal reservoir water level (NWL) was fixed at 325 m.a.s.l. which gives live storage capacity equal to (384,846,885), and flooded area equal to (34.184 km^2). The simulation model of the dam reservoir, prepared from the calculation of water inflow into the reservoir and water demand including evaporation losses. The inflow was taken for different types of water years, dry (deficit) years (1984, and 1999), average water years (1981, and 1995) inflow, and maximum (flood) water years (1969 and 1988) inflow. From the curves, it is clear that the reservoir starts full at month April and ends full at month March during one year taking into account that the maximum water storage in the reservoir is (489,150,916)m^3 and minimum storage is (104,304,031) m^3. The flood routing study was done using the (PMF, 1000, 100, 50, and 25) years return periods inflow hydrographs, and stage and volume curve by fixing the crest level of ogee spillway will at 320 m.a.s.l., choosing the number of gated spans equal to 7, the length of each span equal to 12m, and the initial water level of the reservoir was 325 m.a.s.l. The results of this routing will be used to determine the design parameters of the spillway and to determine the actual need of the emergency spillway.

KEYWORDS: Reservoir Characteristics, Water Demand, Sedimentation, Evaporation Losses, Simulation Model, Flood Routing

1. INTRODUCTION:

Kurdistan region of Iraq is frequently subjected to a severe drought, which causes shortages for the region population, as the available water resources to not satisfy water demands for domestic, livestock consumption, agriculture, tourism and environment requirements. Therefore, the water resources management becomes one of the most important issues at the same time intensive rain causes runoff at times that take substantial amounts away from where it falls and after lost. Water harvesting is a useful practice to capture runoff and utilize in situ for various uses especially supplemental irrigation during drought spells [3].

In order to satisfy water management of the area, investigations and studies started for water harvesting through the construction of small and medium dams everywhere feasible, that aims at collection of excess water and in conservation of the eroded soil, in addition to ground water recharge. Many locations in Erbil Governorate were proposed for conducting feasibility studies and design of small and medium dams in order to reclaim water resources of Erbil Governorate. Sartik location in Altun Kopri District is one of the areas was selected for the above object in order to reclaiming water resources of the area.

2- CALCULATION OF WATER DEMAND:

The possibility of meeting the expected future demand with its seasonal variations will be greatly dependent on the possibility of arranging sufficient storage capacity in the river Tigris and its tributaries.

The amounts of precipitation in the dam site are between 300-400 mm/year. Most precipitation occurs from October to March. Such precipitation depths are not sufficient for all daily requirements (especially for irrigation). Thus, agricultural

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development in these areas depends on the amount of surface water available for irrigation. The existing Dokan reservoir allows for a fairly high degree of regulation of the water flow in the Lesser Zab. The yearly average regulated discharge at Dokan is 208 m^3/sec of which a firm irrigation discharge of about 110 m^3/sec can be obtained at present. The planned Sartik reservoir may increase the firm irrigation discharge up to 125 m^3/sec.

The power generation is considered as a by-product of irrigation. The power output for the Sartik dam is computed on the basis of monthly flows, total irrigation requirements and average monthly heads.

The firm power from the Sartik dam is the minimum power output. That is, the power that could be produced with the flow covering the monthly minimum (irrigation and non-irrigation water demands desired below Sartik dam) that passes through the turbines at the minimum head.

Sartik dam may have a power generating facility with an installed capacity amounting to 156 MW with a maximum discharge of 300 m^3/sec. This is governed by the seasonal variations of river Lesser Zab flow, power generation in Dokan dam and irrigation demands downstream.

For better flexibility of operation, 3units are found the optimum number to be installed, each having a capacity of 52 MW and a maximum discharge of (100 m^3/sec).The total monthly water requirements for irrigation and other (domestic, industrial supplies, power product and others) are given in Table (2-1).

Table(2.1):- Water requirement for downstream users – monthly distribution

Month	Total Water Requirements	
	m^3/sec	(m^3x1000)
January	102	273,196
February	108	261,273
March	120	321,408
April	141	365,472
May	151	404,438
June	300	803,520
July	300	803,520
August	300	803,520
September	300	803,520
October	151	404,438
November	104	269,568
December	88	235,699
Total	2165	5,749,572
Mean	180	479,131

3- SARTIK DAM RESERVOIR CHARACTERISTICS

3-1 Reservoir Area - Volume Capacity Curves:

Water management calculations require reservoir characteristics in the form of curves relating volumes, levels, and water surface areas. These relationships are based on topographic descriptions of the reservoir expressed as a relationship between its water surface area and level. The surface areas of the reservoir at various elevations for a contour interval of (1m) up to an elevation of (340 m.a.s.l.) were obtained by the surveying team. The volumes of the reservoir between the contours were obtained by the following equation (1) [4], and then the calculated volumes for each contour were accumulated as shown in the table (3-1).

$$\mathbf{V} = \left(\frac{\mathbf{H}}{\mathbf{3}}\right) * \left(\mathbf{A_1} + \mathbf{A_2} + \sqrt{\mathbf{A_1} * \mathbf{A_2}}\right) \ldots\ldots\ldots\ldots \mathbf{(1)}$$

Where: H is contour interval (m), A_1 = Area of top contour (m^2), and A_2 = Area of bottom contour (m^2).

Figure (1) shows Elevation, Area-Storage curves, while figure (2) shows Area-Storage curve, From the below data a non-linear regression analysis has been made and a suitable equation, is formulated to fit the Area-Storage curve as shown in the figure (2).

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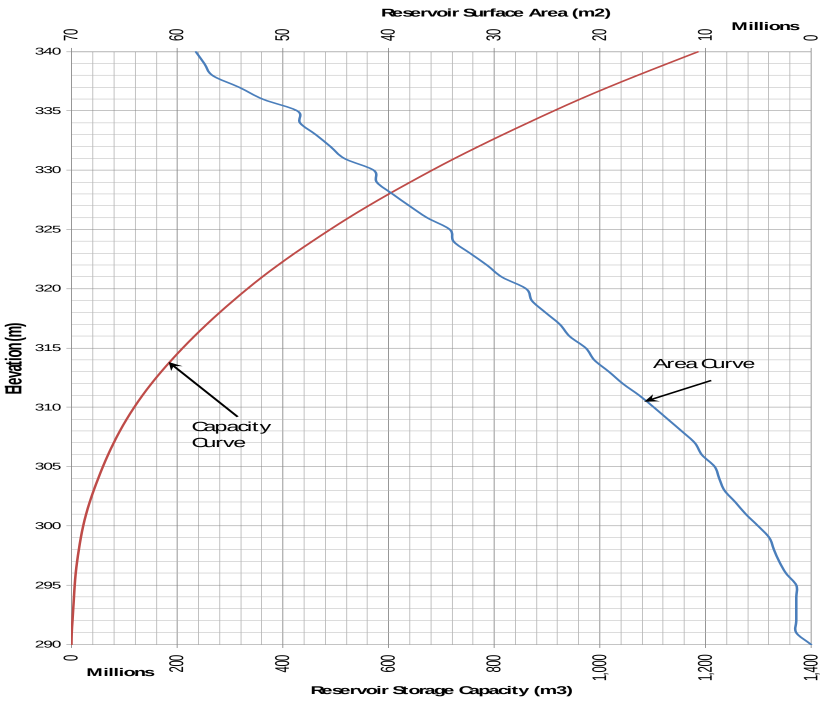
Table (3-1): Sartik Dam Elevation, Area, and storage capacity calculation

Elevation (m)	Area (A) (m^2)	SQR (A_1 + A_2)	Volume (m^3)	Accum. Volume (m^3)
290	0	0	0	0
291	1,405,413	0	468,471	468,471
292	1,405,413	1,405,413	1,405,413	1,873,884
293	1,405,413	1,405,413	1,405,413	3,279,297
294	1,405,413	1,405,413	1,405,413	4,684,710
295	1,405,413	1,405,413	1,405,413	6,090,123
296	2,368,285	1,824,395	1,866,031	7,956,154
297	3,018,258	2,673,592	2,686,712	10,642,866
298	3,518,602	3,258,842	3,265,234	13,908,100
299	3,952,291	3,729,147	3,733,347	17,641,446
300	5,014,556	4,451,852	4,472,900	22,114,346
301	6,184,477	5,568,878	5,589,304	27,703,650
302	7,161,044	6,654,871	6,666,797	34,370,447
303	8,200,803	7,663,309	7,675,052	42,045,499
304	8,693,512	8,443,564	8,445,960	50,491,459
305	9,126,816	8,907,530	8,909,286	59,400,745
306	10,334,444	9,711,878	9,724,379	69,125,124
307	10,999,971	10,662,016	10,665,477	79,790,601
308	12,246,849	11,606,678	11,617,833	91,408,434
309	13,555,412	12,884,529	12,895,597	104,304,031
310	14,869,013	14,197,028	14,207,151	118,511,182
311	16,239,905	15,539,349	15,549,422	134,060,604
312	17,809,080	17,006,404	17,018,463	151,079,067
313	19,117,202	18,451,552	18,459,278	169,538,345
314	20,517,943	19,805,193	19,813,446	189,351,791
315	21,317,234	20,913,770	20,916,316	210,268,107
316	22,853,687	22,072,095	22,081,005	232,349,112
317	23,771,575	23,308,113	23,311,125	255,660,237
318	25,127,898	24,440,330	24,446,601	280,106,838
319	26,421,725	25,766,692	25,772,105	305,878,943
320	26,958,134	26,688,582	26,689,480	332,568,423
321	29,262,350	28,086,622	28,102,369	360,670,792
322	30,669,667	29,957,746	29,963,254	390,634,046
323	32,265,032	31,457,237	31,463,979	422,098,025
324	33,831,241	33,038,857	33,045,043	455,143,068
325	34,184,760	34,007,541	34,007,847	489,150,916
326	36,331,363	35,241,721	35,252,615	524,403,531
327	38,010,234	37,161,319	37,167,639	561,571,169
328	39,603,202	38,798,543	38,803,993	600,375,162
329	41,103,188	40,346,225	40,350,872	640,726,034
330	41,389,747	41,246,219	41,246,385	681,972,418
331	44,162,862	42,753,827	42,768,812	724,741,230
332	45,482,562	44,817,855	44,821,093	769,562,323
333	46,858,960	46,165,632	46,169,051	815,731,374
334	48,365,022	47,606,036	47,610,006	863,341,380
335	48,599,902	48,482,320	48,482,415	911,823,795
336	51,876,662	50,211,559	50,229,374	962,053,169
337	54,111,578	52,982,337	52,990,192	1,015,043,362
338	56,642,681	55,362,667	55,372,309	1,070,415,670
339	57,420,470	57,030,250	57,031,134	1,127,446,804
340	58,226,771	57,822,215	57,823,152	1,185,269,956



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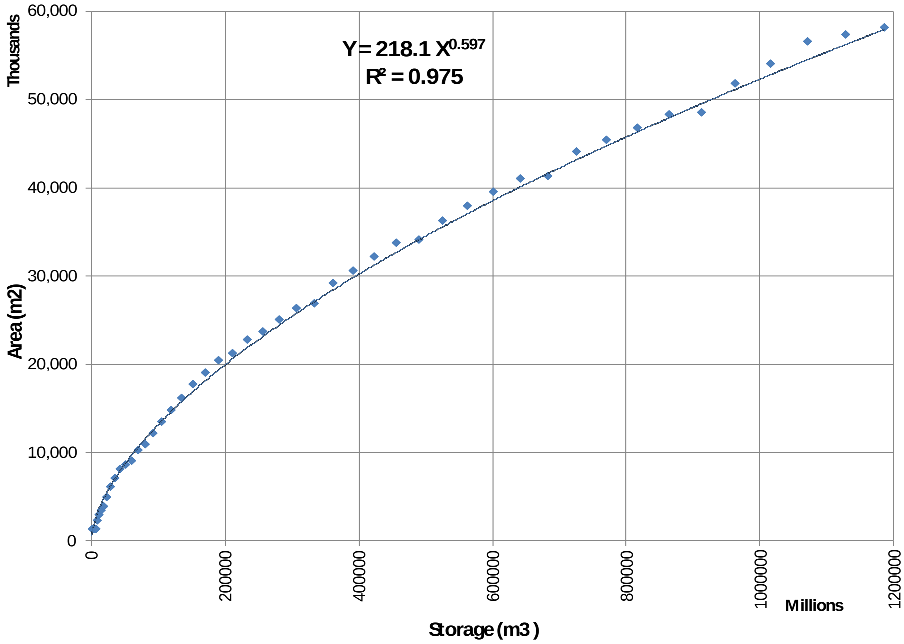

Fig. (2): Area and Storage capacity curve for Sartik Dam

3-2 Reservoir Sedimentation:

The material transported in a river can generally be divided into suspended load, carried in the suspension by the water, and bed load moved along the bottom by the water. The maximum sediment transport takes place during periods of high flows, often during a few flood days each year. Measurements of suspended load are regularly undertaken, in the Lesser-Zab River at Altun Kopri/Goma Zerdala gauging station. Observation of suspended load concentration and corresponding discharge values for the period 1971- 1980 are given in the table (3-2) [13]. These values refer to regulated conditions.

The regression equation between suspended sediment load and daily average discharge is: -

$$\mathbf{SSL = 0.000376 * q^{1.366}} \quad \ldots\ldots (2)$$

Where, SSL = Suspended sediment load in million kg/day, and q = Daily average discharge in m^3/sec at Goma Zerdala gauging station.

With the use of the above equation and the duration curve for the dam site, the mean annual suspended sediment load had been calculated (by SWECO, 1982) [13] to be about 1.1 million tons. No bed – load measurements are available for the Lesser-Zab River. The amount of the bed – load is difficult to estimate, but for rivers with catchment displaying similar erosion proneness, it is of the order of (20 – 30) % of the suspended load. Assume a bed load concentration of 30%, the total sediment load is 1.45 million ton / year. Based on sediments density of 1.2 ton/m^3, the total volume of deposited sediments is 1.2 Million m^3 /year.

The deposition of sediment gradually reduces the available storage capacity of the reservoir. When the useful capacity is reduced that is not able to serve the required purpose, the useful life of the reservoir is considered to be over. The sedimentation of a reservoir is measured in terms of trap efficiency (Te), is defined as the percent of the inflowing sediment which is retained in a reservoir and it's a function of the ratio of the reservoir capacity to average annual water inflow(equation 3) [4].

$$\mathbf{T_e = f\left(\frac{Resesvoir\ Capacity}{Average\ annual\ inflow}\right)} \quad \ldots\ldots.. (3)$$

The probable useful life for the proposed dam reservoir is shown in the table (3-3) below of an initial capacity of 681,972,418 m^3, the average annual inflow of 7,379,424,000 m^3, and the average annual sediment inflow is 1,200,000 m^3. Assuming that the useful life of the reservoir will terminate when 80% of its initial capacity is filled with sediment. From above one can show the trap volume of sediment for 100 year = 104,304,031m^3, this volume will be considered as reservoir dead storage.

Journal of University of Duhok, Vol. 20,No.1(Pure and Eng. Sciences), Pp 776-789, 2017
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Table (3-2) :-Records of suspended sediment concentration for period (1971-1979)

Date	Average daily discharge (m^3/sec)	Average sediment concentration (ppm)	Sediment load (10^6 kg/d)	Date	Average daily discharge (m^3/sec)	Average sediment concentration (ppm)	Sediment load (10^6 kg/d)
19/5/ 1971	64	286	1.58	1/7/1974	87	62	0.47
5/1/ 1972	107	67	0.62	27/7/1974	288	123	3.06
3/2/1972	119	210	2.16	1/9/1975	294	80	2.03
14/2/1972	197	302	5.14	5/11/1975	259	33	0.74
8/3/1972	287	212	5.26	31.12/1975	233	1069	21.52
8/4/1972	273	210	4.95	4/2 / 1976	101	137	1.20
5/9/1972	284	243	5.96	23/9 /1978	433	480	17.96
3/10/1972	314	221	6.00	30/11/1978	326	287	8.08
9/12/1972	215	116	2.15	27/12/ 1978	354	453	13.85
11/1 /1973	303	136	3.56	4/1/ 1979	286	357	8.82
18/2/1973	259	362	8.10	13/1/1979	293	337	8.53
9/3/1973	260	341	7.66	20/1/1979	508	3345	146.82
19/4/1973	113	802	7.83	27/2/1979	112	1233	11.93
12/6/1973	72	97	0.60	16/4/1979	28	225	0.54
13/7/1973	225	535	10.40	21/5/1979	54	73	0.34
13/8/1973	363	175	2.46	28/8/1979	258	33	0.74
11/9/1973	269	175	4.07	2/10/1979	345	103	3.07
4/10/1973	290	164	4.11	30/10 /1979	255	440	9.73
1/11/1973	251	2345	50.85	30/12 /1979	112	220	2.13
7/2/1974	93	115	0.92	31/1 /1980	97	897	7.52
21/2/1974	101	312	2.72	6/3 /1980	51	383	1.69
24/10/1974	242	5142	107.51	4/3 /1980	92	173	1.38
23/2/1974	289	2120	52.94	30/4 /1980	214	6213	114.88
1/4/1974	110	374	3.55	2/10 /1980	68	143	0.84
3/6/1974	89	278	2.14				

Table (3-3):- Sartik Dam Reservoir Useful Life Calculation

Capacity		Capacity-inflow ratio	% Te	Average % Te	Volume of sediment (m^3)	Volume of capacity interval (m^3)	Years to fill
%	m^3						
100	681,972,418	0.09	85.67				
90	613,775,177	0.08	84.33	85.00	1,019,994	101,504,336	99.51
80	545,577,935	0.07	83.00	83.67	1,003,998	101,504,336	101.10
70	477,380,693	0.06	71.75	77.38	928,500	101,504,336	109.32
60	409,183,451	0.055	71.13	71.44	857,250	101,504,336	118.41
50	340,986,209	0.05	70.50	70.81	849,750	101,504,336	119.45
40	272,788,967	0.04	69.25	69.88	838,500	101,504,336	121.05
30	204,591,726	0.03	68.00	68.63	823,500	101,504,336	123.26
20	136,394,484	0.02	68.00	68.00	816,000	101,504,336	124.39
10	68,197,242	0.01	45.00	56.50	678,000	101,504,336	149.71
Total							966.70

3-3 Reservoir Water Losses Due To Evaporation:

The monthly and annual Evaporation losses were calculated from daily recorded evaporation using the following equation based on area, volume and elevation curve [8].

$$\mathbf{Y = a * V^b * E} \quad \ldots\ldots \quad (4)$$

Where, Y is monthly water losses from reservoir due to evaporation in (m^3/sec), V is water storage in the reservoir in specified month (m^3), E is monthly recorded evaporation for Dokan station in (m), and a and b are area, and volume curve equation parameters (from figure2), a = 218.1, and b = 0.597

The results of the calculations are presented in table (3-4) below:

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Table (3-4): Mean Monthly Losses Due to Evaporation from Sartik Dam Reservoir

Month	Evaporation (mm)	Losses (m^3/month)
Jan.	34.1	1,410,246
Feb.	41.0	1,695,604
March	66.4	2,746,051
April	98.8	4,085,991
May	160.1	6,621,125
June	258.7	10,698,845
July	301.8	8,227,525
Aug.	275.5	5,342,794
Sept.	210.7	4,450,114
Oct.	118.0	2,391,220
Nov.	61.8	1,887,181
Dec.	38.1	1,575,671
Year	1664.9	51,132.366

3-4 Reservoir Storages:

From above mentioned losses calculations the Sartik proposed dam reservoir levels and storages were fixed. The dead storage elevation was provided at **309 m.a.s.l.** this level gives dead storage volume equal to (104,304,031m^3),and the normal reservoir water level (NWL) is fixed at 325 m.a.s.l. which gives live storage capacity equal to (384,846,885)and flooded area equal to (34.184 km^2) as shown in table (3-5).

Table (3-5) :-Storages of Sartik Proposed Dam Reservoir

Dead Storage			Live Storage			Dam crest level
Level (m.a.s.l)	Volume (m^3)	Flooded area (km^2)	Level (m.a.s.l)	Volume (m^3)	Flooded area (km^2)	(m.a.s.l)
309	**104,304,031**	**13.555**	**325**	**384,846,885**	**34.184**	**335**

3-5 Reservoir Simulation Model:

The Sartik Dam consists of a multi-purpose dam for, flood control, regulation of the Lower-Zab River below Dokan Dam, Irrigation, and power generation. Reservoir operation is necessary to be made in such a manner that it functions according to the respective purposes of its design. At Sartik Reservoir, the storage capacity of (384.846 MCM), between normal operation water level of (325 m.a.s.l.) and minimum operation water level of (309) m.a.s.l, is to be utilized for irrigation and power generation. The operation rules for Sartik Reservoir are to be fixed on the bases of the following factors:

1. Irrigation and power generations are carried out within the range of the storage capacity of (384.846 MCM).

2. Maximum discharge from Power outlet is fixed, which is equal to 300 m^3/sec.

3. Operation is done in a manner that waste spillage from the reservoir is minimum.

4. High-water-level operation is performed as a rule to ensure stable output over a long period. In addition, this will maximize the energy production.

5. Operation for power generation is performed in such a manner that the necessary irrigation water is secured even in fairly dry years.

In this section, the real time monthly operation of the Sartik reservoir has been obtained by using historical monthly inflow data for the period October 1960 to September 1999. These forty years inflow data represent the input of the model. This period has been chosen because it includes the flood years 1969 and 1988, the deficit years 1989 and 1999, and the average years 1981 and 1994.

The monthly operation procedure depends on the monthly inflow data, as well as on the water demand, and evaporation data. This is an accounting of the inflow-outflow activity of the reservoir and can be stated as [4]:

Volume for next month = Stored Volume + Inflow Volume – Demand Volume – Evaporation losses … … (5)

For all other months, the storage in the reservoir should belong to the set of admissible storage it means that the storage for any month should not be less than minimum storage and should not exceed range of the storage capacity of (384.846 MCM).

Journal of University of Duhok, Vol. 20,No.1(Pure and Eng. Sciences), Pp 776-789, 2017
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Figures (3), (4), (5), (6),(7) and (8) shows the simulation model of the Sartik reservoir, prepared from calculation of water inflow into the reservoir and water demand including evaporation losses from the reservoir surface for each month .The inflow was taken for different types of water years, dry (deficit) years (1984,and 1999), average water years (1981,and1995) inflow ,and maximum (flood) water years (1969 and 1988) inflow. From the curves it is clear that the reservoir starts full at month April and ends full at month March during one year taking in account that the maximum water storage in the reservoir is (489,150,916)m^3 and minimum storage is (104,304,031) m^3.

Months	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar.
Monthly Evaporation (mm)	98.8	160.1	258.7	301.8	275.5	210.7	118	61.8	38.1	34.1	41	66.4
Area-Vol. Parameters	218.104595	0.597466037										
INITIAL VOLUME	489,151			PROJECT:Sartik Dam								
FINAL VOLUME	125,068			RESERVOIR SIMULATION MODEL								
SUMSURPLUS	993,073			DATA IN THOUSANDS OF M^3								
SUMDEFICITS	0.000											
Month	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STORED VOLUME	489,151	281,033	132,501	136,257	310,941	489,151	489,151	489,151	391,151	207,890	150,950	126,069
INFLOWS	54,432	56,246	59,616	380,333	656,208	570,240	894,586	173,664	53,568	77,674	48,384	53,568
DEMAND	259,200	200,880	51,840	200,880	267,840	259,200	404,438	269,568	235,699	133,920	72,576	53,568
EVAP	3,350	3,899	4,020	4,769	7,126	7,145	4,001	2,096	1,130	693	689	1,002
SURPLUS	0	0	0	0	203,032	303,895	486,146	0	0	0	0	0
DEFICIT	0	0	0	0	0	0	0	0	0	0	0	0
Volume next month	281,033	132,501	136,257	310,941	489,151	489,151	489,151	391,151	207,890	150,950	126,069	125,068

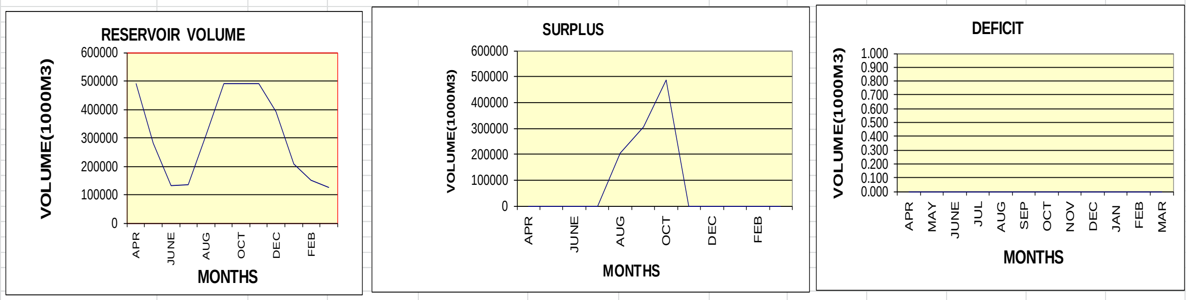

Fig. (3):- Simulation model of the Sartik reservoir for dry year inflow data (1984)

Months	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar.
Monthly Evaporation (mm)	98.8	160.1	258.7	301.8	275.5	210.7	118	61.8	38.1	34.1	41	66.4
Area-Vol. Parameters	218.104595	0.597466037										
INITIAL VOLUME	489,151			PROJECT:Sartik Dam								
FINAL VOLUME	425,296.175			RESERVOIR SIMULATION MODEL								
SUMSURPLUS	1,440,107			DATA IN THOUSANDS OF M^3								
SUMDEFICITS	0											
Month	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STORED VOLUME	489,151	452,105	401,393	341,758	306,714	256,791	174,169	386,282	489,151	489,151	489,151	489,151
INFLOWS	225,504	222,307	207,360	241,056	224,986	181,440	618,710	645,408	846,374	782,093	314,496	259,805
DEMAND	259,200	267,840	259,200	267,840	267,840	259,200	404,438	269,568	235,699	273,197	261,274	321,408
EVAP	3,350	5,179	7,795	8,260	7,068	4,861	2,159	1,820	1,292	1,156	1,390	2,252
SURPLUS	0	0	0	0	0	0	0	271,152	609,383	507,740	51,832	0
DEFICIT	0	0	0	0	0	0	0	0	0	0	0	0
Volume next month	452,105	401,393	341,758	306,714	256,791	174,169	386,282	489,151	489,151	489,151	489,151	425,296

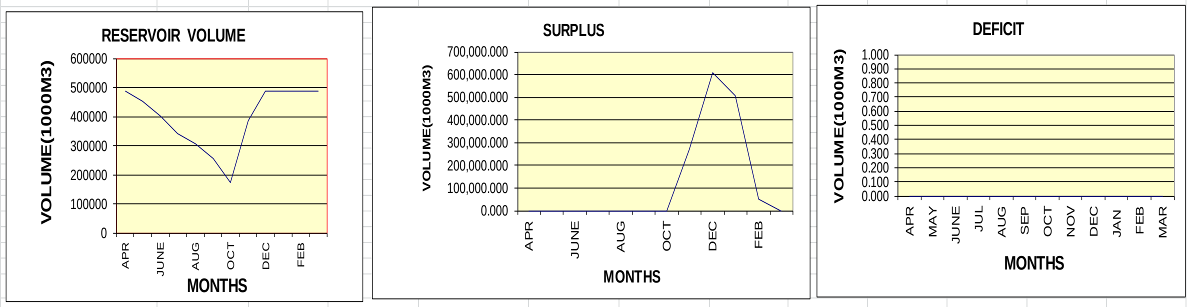

Fig.(4):- Simulation model of the Sartik reservoir for dry year inflow data (1999)

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eISSN: 2521-4861 & pISSN: 1812-7568
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Months	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar.
Monthly Evaporation (mm)	98.8	160.1	258.7	301.8	275.5	210.7	118	61.8	38.1	34.1	41	66.4
Area-Vol. Parameters	218.104595	0.597466037										
INITIAL VOLUME	489,150.916			PROJECT:Sartik Dam								
FINAL VOLUME	489,150.916			RESERVOIR SIMULATION MODEL								
SUMSURPLUS	2,935,516.474			DATA IN THOUSANDS OF M^3								
SUMDEFICITS	0.000											
Month	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STORED VOLUME	489,150.916	395,080.731	216,206.315	148,612.369	392,681.191	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916
INFLOWS	274,752.000	230,342.400	391,392.000	918,691.200	1,352,592.000	1,397,088.000	1,033,862.400	565,056.000	554,428.800	350,870.400	263,692.800	495,504.000
DEMAND	365,472.000	404,438.400	453,600.000	669,600.000	669,600.000	518,400.000	404,438.400	269,568.000	235,699.200	273,196.800	261,273.600	321,408.000
EVAP	3,350.185	4,778.416	5,385.946	5,022.377	8,192.822	7,144.574	4,001.233	2,095.561	1,291.923	1,156.288	1,390.259	2,251.541
SURPLUS	0.000	0.000	0.000	0.000	578,329.454	871,543.426	625,422.767	293,392.439	317,437.677	76,517.312	1,028.941	171,844.459
DEFICIT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Volume next month	395,080.731	216,206.315	148,612.369	392,681.191	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916

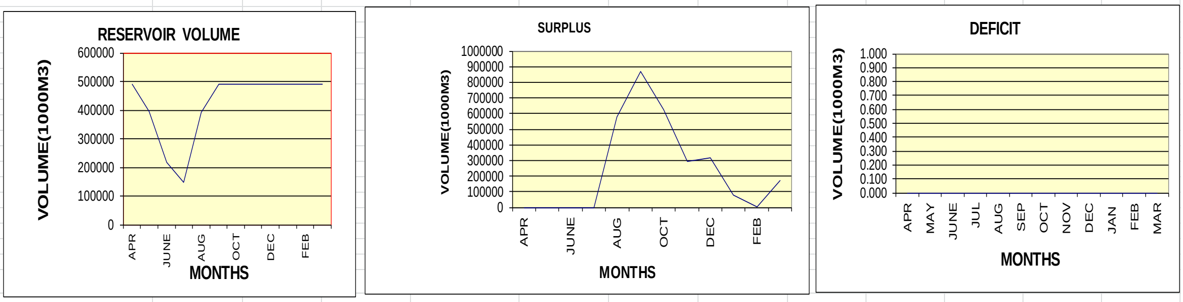

Fig. (5):- Simulation model of the Sartik reservoir for average year inflow data (1981)

Months	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar.
Monthly Evaporation (mm)	98.8	160.1	258.7	301.8	275.5	210.7	118	61.8	38.1	34.1	41	66.4
Area-Vol. Parameters	218.104595	0.597466037										
INITIAL VOLUME	489,150.916			PROJECT:Sartik Dam								
FINAL VOLUME	489,150.916			RESERVOIR SIMULATION MODEL								
SUMSURPLUS	1,758,542.269			DATA IN THOUSANDS OF M^3								
SUMDEFICITS	0.000											
Month	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STORED VOLUME	489,150.916	489,150.916	489,150.916	353,370.722	202,988.745	253,711.589	222,965.034	402,593.961	489,150.916	489,150.916	489,150.916	489,150.916
INFLOWS	461,376.000	474,076.800	520,992.000	661,564.800	591,926.400	492,480.000	586,569.600	780,192.000	474,076.800	629,424.000	619,315.200	554,428.800
DEMAND	365,472.000	404,438.400	648,000.000	803,520.000	535,680.000	518,400.000	404,438.400	269,568.000	235,699.200	273,196.800	261,273.600	321,408.000
EVAP	3,350.185	5,428.791	8,772.194	8,426.777	5,523.556	4,826.555	2,502.273	1,865.388	1,291.923	1,156.288	1,390.259	2,251.541
SURPLUS	92,553.815	64,209.609	0.000	0.000	0.000	0.000	0.000	422,201.657	237,085.677	355,070.912	356,651.341	230,769.259
DEFICIT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Volume next month	489,150.916	489,150.916	353,370.722	202,988.745	253,711.589	222,965.034	402,593.961	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916

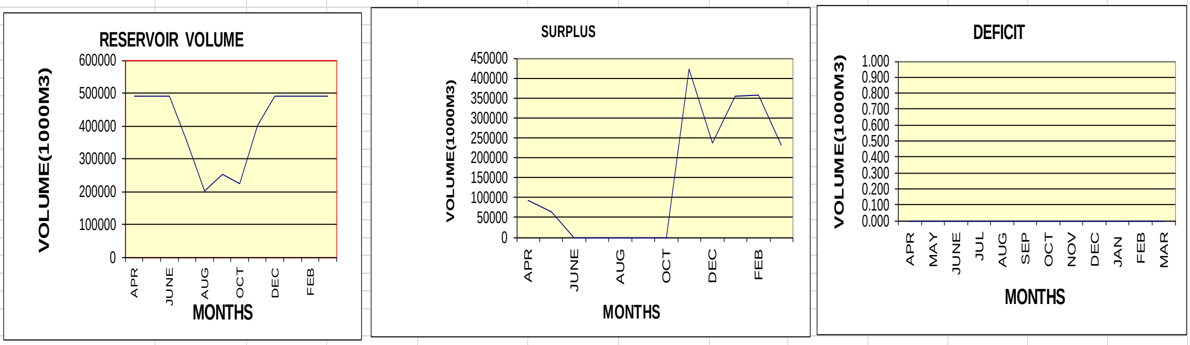

Fig. (6):- Simulation model of the Sartik reservoir for average year inflow data (1995)

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Months	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar.
Monthly Evaporation (mm)	98.8	160.1	258.7	301.8	275.5	210.7	118	61.8	38.1	34.1	41	66.4
Area-Vol. Parameters	218.104595	0.597466037										
INITIAL VOLUME	489,150.916			PROJECT:Sartik Dam								
FINAL VOLUME	489,150.916			RESERVOIR SIMULATION MODEL								
SUMSURPLUS	10,336,789.066			DATA IN THOUSANDS OF M^3								
SUMDEFICITS	0.000											
Month	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STORED VOLUME	489,150.916	489,150.916	489,150.916	433,722.722	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916
INFLOWS	3,696,192.000	1,952,553.600	730,944.000	1,315,094.400	1,848,096.000	977,184.000	583,891.200	505,440.000	527,644.800	557,107.200	1,175,731.200	2,220,393.600
DEMAND	365,472.000	404,438.400	777,600.000	803,520.000	803,520.000	777,600.000	404,438.400	269,568.000	235,699.200	273,196.800	261,273.600	321,408.000
EVAP	3,350.185	5,428.791	8,772.194	9,524.123	9,341.861	7,144.574	4,001.233	2,095.561	1,291.923	1,156.288	1,390.259	2,251.541
SURPLUS	3,327,369.815	1,542,686.409	0.000	446,622.083	1,035,234.139	192,439.426	175,451.567	233,776.439	290,653.677	282,754.112	913,067.341	1,896,734.059
DEFICIT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Volume next month	489,150.916	489,150.916	433,722.722	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916

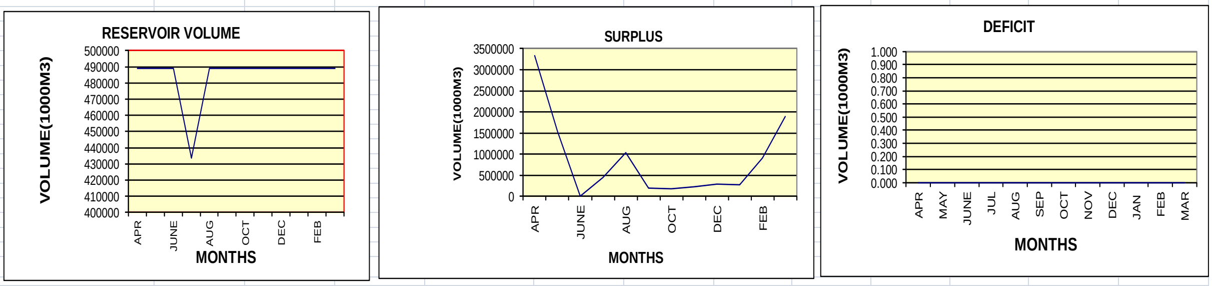

Fig. (7): Simulation model of the Sartik reservoir for wet year inflow data (1969)

Months	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar.
Monthly Evaporation (mm)	98.8	160.1	258.7	301.8	275.5	210.7	118	61.8	38.1	34.1	41	66.4
Area-Vol. Parameters	218.104595	0.597466037										
INITIAL VOLUME	489,150.916			PROJECT:Sartik Dam								
FINAL VOLUME	489,150.916			RESERVOIR SIMULATION MODEL								
SUMSURPLUS	10,809,724.327			DATA IN THOUSANDS OF M^3								
SUMDEFICITS	0.000											
Month	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
STORED VOLUME	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916
INFLOWS	1,998,086.400	1,738,281.600	1,137,888.000	1,328,486.400	1,475,798.400	1,342,656.000	784,771.200	539,136.000	712,454.400	514,252.800	1,153,958.400	3,838,147.200
DEMAND	365,472.000	404,438.400	777,600.000	803,520.000	803,520.000	777,600.000	404,438.400	269,568.000	235,699.200	273,196.800	261,273.600	321,408.000
EVAP	3,350.185	5,428.791	8,772.194	10,233.661	9,341.861	7,144.574	4,001.233	2,095.561	1,291.923	1,156.288	1,390.259	2,251.541
SURPLUS	1,629,264.215	1,328,414.409	351,515.806	514,732.739	662,936.539	557,911.426	376,331.567	267,472.439	475,463.277	239,899.712	891,294.541	3,514,487.659
DEFICIT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Volume next month	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916	489,150.916

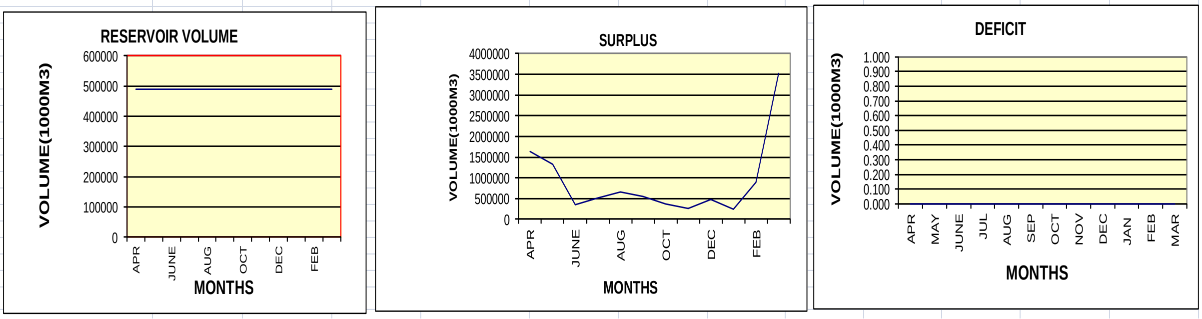

Fig. (8): Simulation model of the Sartik reservoir for wet year inflow data (1988)

4. RESERVOIR FLOOD ROUTING

The flood routing was used to check the maximum head over the spillway weir crest and to find the routed outflow discharge over the spillway crest using puls method, equation(4) [8] .

$$\left(\frac{2S_{n+1}}{d_t} + O_{n+1}\right) = I_n + I_{n+1} + \left(\frac{2S_n}{d_t} - O_n\right) \quad \ldots\ldots (4)$$

Where: dt is routing time interval (6hrs), I_n is inflow discharge (m^3/sec) at time t, I_{n+1} is inflow discharge (m^3/sec) at time (t+dt), O_n is outflow discharge (m^3/sec) at time t, O_{n+1} is outflow

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eISSN: 2521-4861 & pISSN: 1812-7568
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discharge (m^3/sec) at time (t+dt), S_n is reservoir storage (m^3) at time t, and S_{n+1} is reservoir storage (m^3) at time (t+dt)

The flood routing study was done using the following data:-

1. The crest level of ogee spillway will be fixed at 320 m.a.s.l. as shown in the figure (9).

2. Number of gated spans = 7 and the length of each span = 12m.

3. Initial water level of the reservoir is 325 m.a.s.l.

4. The (PMF, 1000, 100, 50, and 25) years return periods inflow hydrographs of Sartik dam site are to be used.

5. Stage and volume curve, which is given in the figure (1) are to be used.

6. The results of this routing are used to determine the design parameters of the spillway and to determine the actual need of the emergency spillway.

Spillway discharge capacity for free overflow is presented in the following figure (10) and discharge capacity for different partial openings of gates (Y) is presented in the following table (3-6).

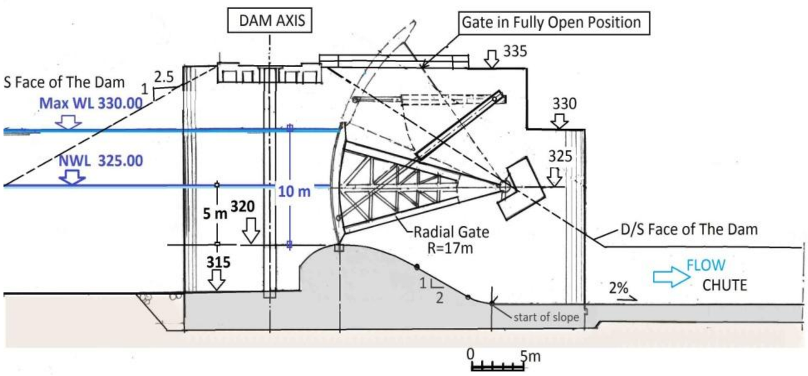

Fig. (9):-Sartik Dam Spillway Radial Gate Elevations

Reservoir Elev. (m.a.s.l.)	Q (m^3/s)
320.0	0.0
320.5	66.1
321.0	186.9
321.5	343.4
322.0	528.6
322.5	738.8
323.0	971.2
323.5	1223.8
324.0	1495.2
324.5	1784.1
325.0	2089.6
325.5	2410.8
326.0	2746.9
326.5	3097.3
327.0	3461.4
327.5	3838.9
328.0	4229.1
328.5	4631.7
329.0	5046.3
329.5	5472.6
330.0	5910.3

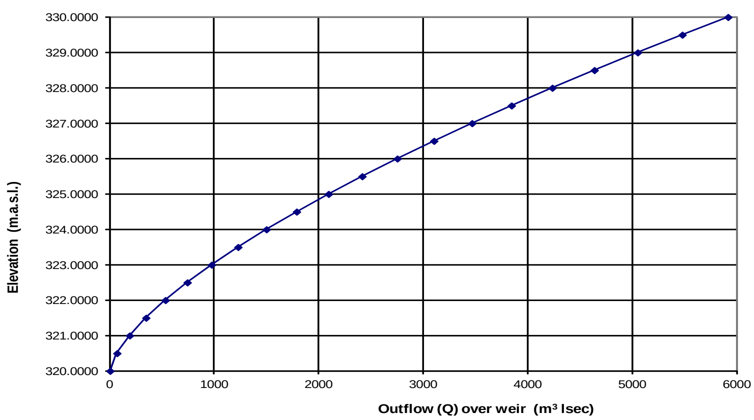

Fig. (10):- Sartik Dam Spillway Free Flow Discharge VS Elevation

Journal of University of Duhok, Vol. 20,No.1(Pure and Eng. Sciences), Pp 776-789, 2017
eISSN: 2521-4861 & pISSN: 1812-7568
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Reservoir Elev. (m.a.s.l.)	Gates Opening (Y) (m)									
	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
320.0										
320.5	66.1	66.1								
321.0	186.9	186.9								
321.5	228.9	343.4			free overflow discharge zone					
322.0	264.3	528.6								
322.5	295.5	591.0								
323.0	323.7	647.4	971.1							
323.5	349.6	699.3	1048.9							
324.0	373.8	747.6	1121.4	1495.1						
324.5	396.5	792.9	1189.4	1585.8						
325.0	417.9	835.8	1253.7	1671.6	2089.5					
325.5	438.3	876.6	1314.9	1753.2	2191.5					
326.0	457.8	915.6	1373.4	1831.2	2289.0	2746.7				
326.5	476.5	953.0	1429.5	1905.9	2382.4	2858.9				
327.0	494.5	988.9	1483.4	1977.9	2472.4	2966.8	3461.3			
327.5	511.8	1023.7	1535.5	2047.3	2559.1	3071.0	3582.8			
328.0	528.6	1057.2	1585.8	2114.4	2643.1	3171.7	3700.3	4228.9		
328.5	544.9	1089.8	1634.6	2179.5	2724.4	3269.3	3814.2	4359.0		
329.0	560.7	1121.4	1682.0	2242.7	2803.4	3364.1	3924.7	4485.4	5046.1	
329.5	576.0	1152.1	1728.1	2304.2	2880.2	3456.2	4032.3	4608.3	5184.4	
330.0	591.0	1182.0	1773.0	2364.0	2532.9	3546.0	4137.0	4728.0	5319.1	5910.1

Table (3-6):- Sartik Dam Spillway Discharge capacity for Partial Opening Gates (Orifice Flow)

For the case of flood coming into the Sartik reservoir, radial gates will start opening keeping the water level at NWL (325 m.a.s.l.). After the full opening of the radial gates the water level will continue rising till the Maximum Water Level (MWL).The maximum water level during the flood routing should not go beyond the level of 330 m because of the level Taq Taq bridge and the main road at upstream, if we passed this level the bridge and the road will submerged.

Results of PMF ,1000,100,50 and 25 years return periods flood routing through the reservoir are presented in two types of figures the first is inflow and resulting outflow hydrographs figures (11-a),(12-a),(13-a),(14-a),and (15-a). The second is water level fluctuation in the reservoir with the time during flood routing figures (11-b), (12-b), (13-b), (14-b), and (15-b)

Coordinates of inflow, outflow, water level, head over spillway weir ,and spillway gates opining of each time period flood routing are shown in tables (3-7),(3-8),(3-9),(3-10)and (3-11).

The probable maximum (PMF) Flood routing results as shown in above mentioned figures (11-a),(11-b) and table (3-7) showed that the maximum outflow from Sartik reservoir was (6456.42 m^3/s), and maximum elevation reached 330.21 m.a.s.l. which is somewhat higher than 330 m.a.s.l. ,the difference 21 cm is not significant if covered the Taq Taq bridge and this elevation occurs only during PMF ,we can increase number of gates to 8 gates instead 7 but economically 7 gates needs less cost.

Table (3-7): Sartik Dam Inflow, Outflow, and Water levels For PMF flood routing

T (hr)	inflow (m3/s)	outflow (m3/s)	Elevation (m a.s.l.)	Head over spillway (m)	Gate opening (m)
6	628	1737.39	324.48	4.48	10
12	889	1501.04	324.06	4.06	10
18	2092	1337.64	323.76	3.76	10
24	5753	1277.15	323.65	3.65	10
30	8368	1598.25	324.24	4.24	10
36	9100	2727.18	326.05	6.05	10
42	8472	4149.2	328.01	8.01	10
48	7322	5294.93	329.42	9.42	10
54	5962	6271.39	330.15	10.15	10
60	4393	6456.42	330.21	10.21	10
66	3452	5745.47	329.95	9.95	10
72	2406	5327.9	329.46	9.46	10
78	1674	4798.33	328.82	8.82	10
84	1151	4201	328.07	8.07	10
90	732	3604.72	327.29	7.29	10
96	523	3046.31	326.51	6.51	10
102	314	2541.13	325.77	5.77	10
108	209	2112.35	325.1	5.1	10
114	157	1748.06	324.5	4.5	10
120	105	1448.9	323.97	3.97	10

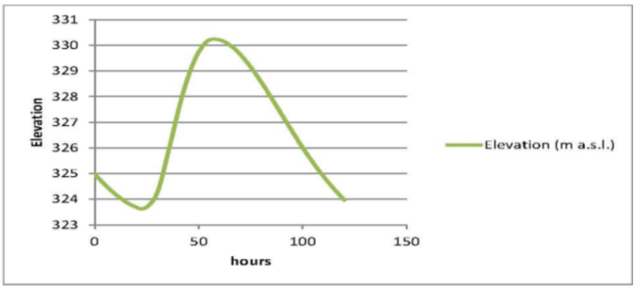

Fig.(11-a) : PMF Flood Time & Water Elevation relation for Sartik Dam Spillway

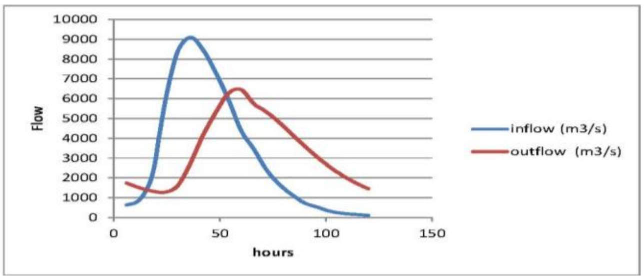

Fig.(11 - b) : PMF Flood Inflow & Outflow Hydrographs &Water Level for Sartik Dam Spillway

Journal of University of Duhok, Vol. 20,No.1(Pure and Eng. Sciences), Pp 776-789, 2017
eISSN: 2521-4861 & pISSN: 1812-7568
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Table (3-8): Sartik Dam Inflow, Outflow, and Water levels for 1000 year return period flood routing

T (hr)	Inflow (m^3/s)	Outflow (m^3/s)	Reservoir Elevation (m.a.s.l.)	Head over weir (H) (m)	Gate Opening (Y) (m)
0	100.0	100.0	325.0	5.0	6.0
6	200.0	100.0	325.0	5.0	6.0
12	360.0	150.0	325.0	5.0	6.0
18	1100.0	300.0	325.0	5.0	6.0
24	2560.0	1000.0	325.7	5.7	6.0
30	3800.0	2000.0	326.8	6.8	6.0
36	4100.0	2500.0	327.7	7.7	6.0
42	3900.0	2650.0	328.3	8.3	6.0
48	3280.0	2750.0	328.8	8.8	6.0
54	2620.0	2600.0	328.9	8.9	6.0
60	2050.0	2300.0	328.7	8.7	6.0
66	1520.0	2000.0	328.5	8.5	6.0
72	1075.0	1700.0	328.2	8.2	6.0
78	770.0	1500.0	327.8	7.8	6.0
84	540.0	1250.0	327.5	7.5	6.0
90	400.0	1100.0	327.1	7.1	6.0
96	260.0	900.0	326.7	6.7	6.0
102	165.0	800.0	326.4	6.4	6.0
108	110.0	750.0	326.1	6.1	6.0
114	90.0	700.0	325.8	5.8	6.0
120	50.0	650.0	325.4	5.4	6.0

Table (3-9): Sartik Dam Inflow, Outflow, and Water levels for 100 year return period flood routing

T (hr)	Inflow (m^3/s)	Outflow (m^3/s)	Reservoir Elevation (m.a.s.l.)	Head over weir (H) (m)	Gate Opening (Y) (m)
0	100.0	100.0	325.0	5.0	3.5
6	150.0	150.0	325.0	5.0	3.5
12	300.0	300.0	325.0	5.0	3.5
18	750.0	500.0	325.0	5.0	3.5
24	1800.0	1000.0	325.1	5.1	3.5
30	2600.0	1300.0	325.7	5.7	3.5
36	2850.0	1600.0	326.4	6.4	3.5
42	2700.0	1750.0	327.0	7.0	3.5
48	2300.0	1700.0	327.3	7.3	3.5
54	1825.0	1600.0	327.5	7.5	3.5
60	1430.0	1500.0	327.5	7.5	3.5
66	1050.0	1400.0	327.4	7.4	3.5
72	700.0	1250.0	327.1	7.1	3.5
78	500.0	1100.0	326.8	6.8	3.5
84	350.0	900.0	326.5	6.5	3.5
90	250.0	700.0	326.2	6.2	3.5
96	180.0	600.0	325.9	5.9	3.5
102	100.0	500.0	325.7	5.7	3.5
108	80.0	400.0	325.5	5.5	3.5
114	50.0	300.0	325.4	5.4	3.5
120	25.0	200.0	325.2	5.2	3.5

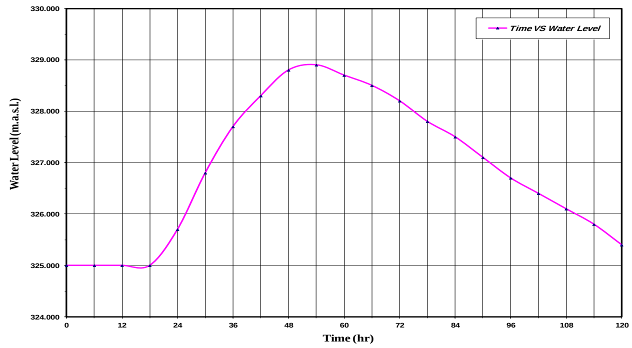

Fig.(12-a) : 1000 Years Return Period Flood Time & Water Elevation relation for Sartik Dam Spillway

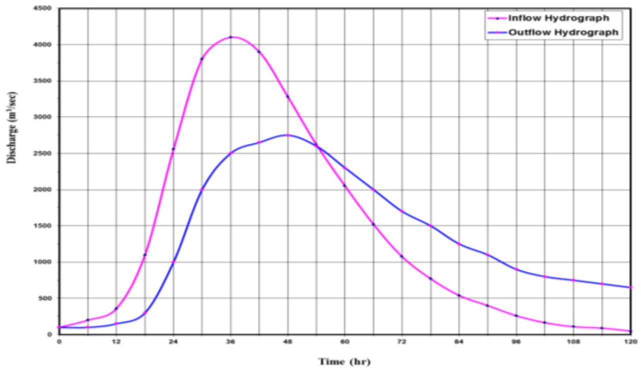

Fig.(12 - b) : 1000 Years Return Period Flood Inflow & Outflow Hydrographs for Sartik Dam Spillway

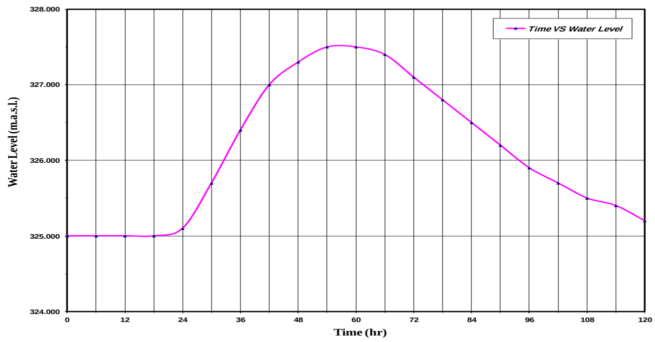

Fig.(13-a) : 100 Years Return Period Flood Time & Water Elevation relation for Sartik Dam Spillway

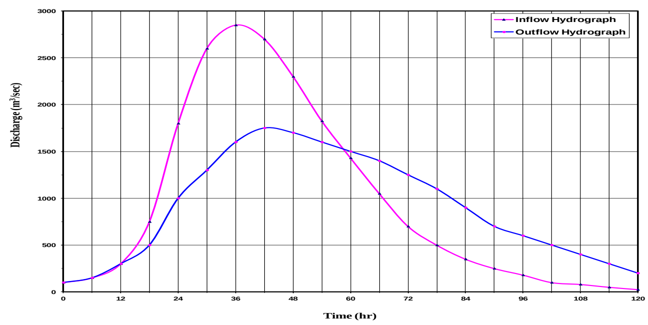

Fig.(13 - b) : 100 Years Return Period Flood Inflow & Outflow Hydrographs for Sartik Dam Spillway

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Table (3-10): Sartik Dam Inflow, Outflow, and Water levels for 50 years return period flood routing

T (hr)	Inflow (m^3/s)	Outflow (m^3/s)	Reservoir Elevation (m.a.s.l.)	Head over weir (H) (m)	Gate Opening (Y) (m)
0	95.0	50.0	325.0	5.0	3.0
6	190.0	50.0	325.0	5.0	3.0
12	280.0	100.0	325.0	5.0	3.0
18	560.0	400.0	325.0	5.0	3.0
24	1435.0	800.0	325.1	5.1	3.0
30	2130.0	1000.0	325.7	5.6	3.0
36	2330.0	1200.0	326.0	6.2	3.0
42	2175.0	1300.0	326.7	6.7	3.0
48	1850.0	1250.0	327.0	7.0	3.0
54	1435.0	1200.0	327.0	7.2	3.0
60	1110.0	1100.0	327.0	7.3	3.0
66	835.0	1000.0	326.8	7.2	3.0
72	580.0	900.0	326.5	7.0	3.0
78	395.0	800.0	326.3	6.9	3.0
84	280.0	750.0	326.0	6.7	3.0
90	190.0	700.0	325.6	6.4	3.0
96	120.0	650.0	325.4	6.2	3.0
102	95.0	600.0	325.1	5.9	3.0
108	70.0	550.0	325.0	5.6	3.0
114	35.0	450.0	325.0	5.2	3.0
120	25.0	300.0	325.0	5.0	3.0

Table (3-11): Sartik Dam Inflow, Outflow, and Water levels for 25 years return period flood routing

T (hr)	Inflow (m^3/s)	Outflow (m^3/s)	Reservoir Elevation (m.a.s.l.)	Head over weir (H) (m)	Gate Opening (Y) (m)
0	90.0	50.0	325.0	5.0	2.0
6	105.0	50.0	325.0	5.0	2.0
12	190.0	70.0	325.0	5.0	2.0
18	470.0	100.0	325.0	5.0	2.0
24	1230.0	500.0	325.1	5.1	2.0
30	1820.0	700.0	325.6	5.6	2.0
36	1990.0	900.0	326.2	6.2	2.0
42	1865.0	1000.0	326.7	6.7	2.0
48	1590.0	950.0	327.0	7.0	2.0
54	1275.0	900.0	327.3	7.3	2.0
60	955.0	850.0	327.4	7.4	2.0
66	685.0	800.0	327.3	7.3	2.0
72	500.0	750.0	327.2	7.2	2.0
78	365.0	700.0	327.1	7.1	2.0
84	260.0	670.0	327.0	7.0	2.0
90	185.0	640.0	326.7	6.7	2.0
96	100.0	600.0	326.4	6.4	2.0
102	80.0	570.0	326.2	6.2	2.0
108	45.0	530.0	326.0	6.0	2.0
114	35.0	500.0	325.7	5.7	2.0
120	25.0	400.0	325.1	5.1	2.0

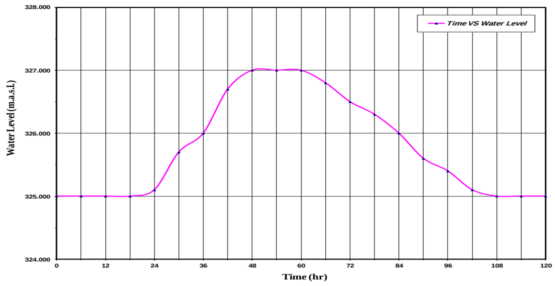

Fig.(14-a) : 50 Years Return Period Flood Time & Water Elevation relation for Sartik Dam Spillway

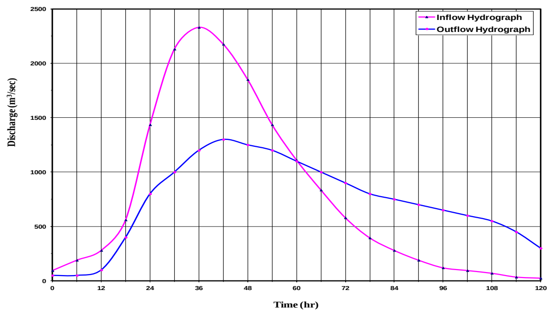

Fig.(14 - b) : 50 Years Return Period Flood Inflow & Outflow Hydrographs for Sartik Dam Spillway

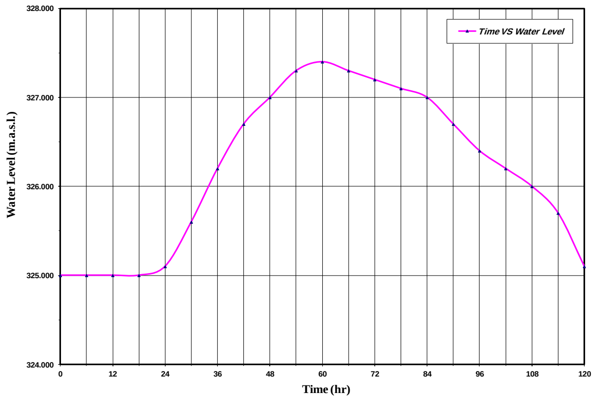

Fig.(15-a) : 25 Years Return Period Flood Time & Water Elevation relation for Sartik Dam Spillway

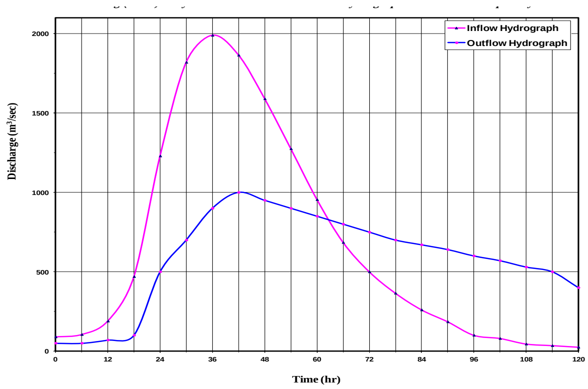

Fig.(15 - b) : 25 Years Return Period Flood Inflow & Outflow Hydrographs for Sartik Dam Spillway

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CONCLUSIONS

1 - Construction of Sartik Dam aims to increase the firm irrigation discharge up to 125 m^3/sec. The dam may have a power generating facility with an installed capacity amounting to 156 MW with a maximum discharge of 300 m^3/sec.

2- The height of proposed dam reservoir storage is 40 m. The dead storage elevation was provided at 309 m.a.s.l. this level gives dead storage volume equal to (104,304,031m^3),and the normal water level is fixed at 325 m.a.s.l. which gives live storage capacity equal to (384,846,885)and flooded area equal to (34.184 km^2).

3- From the simulation model of the Sartik dam reservoir, for different water (dry, average, and wet) years inflow hydrographs, it was clear that the reservoir starts full at month April and ends full at month March during one year taking in account that the maximum water storage in the reservoir is (489,150,916)m^3 and minimum storage is (104,304,031) m^3

4- Flood routing was conducted to find outflow hydrographs and maximum water level in the dam reservoir for (25, 50, 100, 1000 years and PMF) return period's inflow hydrographs. The probable maximum flood (PMF) routing results showed that the maximum outflow from Sartik reservoir was (6456.42 m^3/sec), and the maximum water level reached 330.21 m.a.s.l.

5- According to hydrologic study it is recommended to built the dam because the project will active the agriculture system in the area and solving the draught action in the area by producing different types of summer crops during draught season and producing Electricity, increasing the animal production and fish breeding, also there is indirect benefit of this project by recharging the ground water.

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