Water Balance of Haditha Reservoir

Majd Ahmed Al- Bayati
Civil Engineering Department
Engineering College, Babylon University.
majd _alBayati @ yahoo. com

Nariman Yahya Othman
Civil Engineering Department
Engineering College, Babylon University.
narimanyahay @ gmail. Com

Abstract:

The water balance procedure was applied on Haditha reservoir in the present research work for the year (2000) to (2011). The ground water flow was assumed to be the residual in the water balance equation. All the supply terms, reservoir level changes and water losses except seepage losses were estimated either from direct measurements from dam meteorological station or from the calculation using pertinent data.

The water balance of the Haditha reservoir for the whole studied period indicated that the inflow to the reservoir and the outflow from the reservoir dominated the water balance in seasonal succession. Also it was observed that the reservoir had been losing water during the years from (2000) to (2011) in an average of $(1.18*10^9)\ m^3$, while it was feeder with an average amount of $(1.34*10^9)\ m^3$.

In general, the water balance of the reservoir for the whole studied period indicated that the reservoir was feeder by an amount of $(192.82*10^9)\ m^3$. This amount of water feeding may be related to the ground water in the adjacent area and to some of the unrecorded sources of reservoir that came from another source.

Key words: water balance, dam, reservoir, water balance equation.

الخلاصة

تم استخدام طريقة الموازنة المائية على خزان سد حديثة للسنوات من (٢٠٠٠) الى (٢٠١١) م. وقد تم افتراض عامل المياه الارضية على اساس المتبقي من معادلة الموازنة المائية. ان جميع مصادر المياه الداخلة للبحيرة والتي تشمل تصاريف نهر الفرات، الامطار و السيول الاتية من المساحة الجانبية للبحيرة وكذلك جميع مصادر المياه التي تطلق من السد وجميع الفواقد ماعدا فواقد التسرب (seepage) قد جمعت اما باستخدام قياسات مباشرة من المحطة الهيدرولوجية او من بعض الحسابات باستخدام بيانات معينة.

ان الموازنة المائية لخزان سد حديثة اعطت مؤشرا على ان كميات المياه الداخلة والخارجة من الخزان عن طريق النهر هما العاملان المؤثران في معادلة الموازنة. ولقد استنتج من البحث ان الخزان المائي قد فقد من المياه (من ٢٠٠٠ الى ٢٠١١) بمعدل (١,١٨*١٠^٩) م^٣ بينما كان قد تغذى من المياه بمعدل (١٠^٩* ١,٣٤) م^٣ وهذه المياه قد تعود الى المياه الارضية المتغلغلة من مرر وجوانب الخزان وقد تعود كذلك الى بعض مصادر المياه غير المقاسة التي تأتي من مصادر اخرى.

الكلمات المفتاحية: الموازنة المائية، السد، الخزان، معادلة الموازنة المائية.

Introduction:

The water balance of an open reservoir is expressed by an equation indicating that the rate of change of reservoir volume is equal to the rate of inflow from all sources less the rate of water losses. The sources of income are:

1- Precipitation falling on the reservoir surface.
2- Water from surface influents.
3- Ground water contribution.

The source of outcome is:

1- Evaporation
2- Surface water effluent.
3- Ground water seepage.

Reservoir losses may be classified into absorption losses, percolation or seepage losses in addition to the evaporation losses usually small but may be quite significant where there may be continuous seem of porous strata or cavernous fissured rock. Many reservoirs in semiarid regions lie in basins without any kind of effluent loosing water only by evaporation **Hutchinson (1957).** Such lakes may be termed closed in contradistinction to open lakes having an effluent. Basically the water balance method for reservoir with no open ends involves one input (rainfall), two outputs (seepage and evaporation). The volume lost from the reservoir seepage and evaporation must by rainfall and with drawl from land storage otherwise the lake level would fall. While the water balance for the reservoir with two open ends involves two inputs (seepage, evaporation and outflow). Haditha Reservoir is an example of the above second mentioned types of reservoirs.

The water balance for Haditha reservoir is expressed by the following hydrological equation:-

Where:

I = The discharge rate that inflow to the reservoir from Euphrates river (m^3/sec).
P =The monthly precipitation that fall to the reservoir (m).
R = Runoff from the catchment area of the reservoir (m)
O = The rate of discharge that out from the reservoir (m^3/ sec).
E = The monthly evaporation from the reservoir (m)
Δs = The change in storage volume of the reservoir (million m^3).
G = Ground water discharge or recharge from or to the reservoir.

All the supply terms, reservoir level changes and water losses except seepage losses are estimated either from direct observation in Haditha dam metrological station or from the calculation using pertinent data, so the unknown term in the present water balance equation is the ground water which will be estimated in the present study as the residual term in the water balance equation due to the difficultly to assess than the rainfall or surface runoff or even evaporation. It has been treated often as the residual term in the water balance calculation.

For lake Michigan one of the earliest estimate of ground water flow was made by [**Bergstrom(1962)]** who used a water budget approach to calculate the ground water component as the residual term in the water balance equation.

Detailed hydrological study has been done at six sites along lake Michigan shoreline in [**Wisconsin** by **Cherkauer (1986)]**. At each site flux of ground water to the lake has been calculated for both natural conditions and the existing conditions created by pumping. Recently [**Cartwight (1979)]**made direct measurement of hydraulic gradients in the southern portion of Michigan reservoir, combined with measured and approximated hydraulic conductivity of the lake bed sediments to calculate the seepage rate.

The water -balance for **Georgian Bay** and water exchange through main channel has been estimated primarily from (**1974)** hydrological data by [**Schertzer (1979)].** This water balance was dominated by the exchange occurred through main channel assuming negligible ground water contribution. The water balance of Lake Victoria was explanted by piper **(1986)** in detail over the period (**1965- 1978)**, and in particular the sharp rise of the lake level during the years **(1961 -1964)** assuming in their work negligible ground water flow.

The reservoir water- balance for Kajakai reservoir was developed to simulate the change in reservoir storage using the data generated by sub watershed water –balance models for the Helmand River above Kajakai reservoir and the river gage stations. Monthly reservoir contents and gage station information for water years(**1956-1979**) were used in the model. Continuous elevation- capacity and elevation- area curves describing by [**Vecchia** (**2002**)] were used to compute approximate storage volumes and surface areas for kajakai reservoir.

[**Dittmann *et al.*,(2009)**] used Weisseritz River Basin, located in the low mountain ranges of eastern Germany and equipped with three multipurpose reservoirs, as a case study. They presented a reservoir management system which is capable of determining optimal operating rules both for flood event based and normal operation while at the same time attempting to achieve ecologically oriented operation. In order to maintain the variability of the natural flow regime, a new dynamic operating policy is introduced for normal operation. Flood event based operation is managed by a two-part step function. Both operating policies are optimized using a state-of-the-art multi-objective evolution strategy algorithm.

The aim of the present research work is to present the annual water balance for Haditha reservoir for the years (**2000-2011**) and to observe whether the Haditha reservoir was losing water or feeder from other source during this period, the data from meteorological station for year (2012) are not available. The importance of the present work will aid in many future studies concerning future plane of Haditha reservoir operation.

The case study "Haditha reservoir ":-

Haditha dam is a multi- hydro development to control the Euphrates River in the interest irrigation, electric power generation and for partial accumulation of extreme Euphrates river inflow into Haditha reservoir. Haditha reservoir was constructed on the Euphrates River in the middle west of Iraq (7km) upstream from Haditha town; the project was completed at **(1988).**

Haditha dam contains of six hydropower stations, two bottoms out lets for empty water which are not worked until the water level is less than [129.5 (m.a.s.l.) which is the minimum operation level], a spillway to be established with six orifices controlled by radial gates and two bottoms outlets.

The main purpose of design the dam project is to store and regulate the abundant water of Euphrates River by creating large scale reservoir to supply irrigation water required in the area downstream and the other purpose of design is to control the danger of flood and then use it satisfy for water requirement .

In addition to the above mention purpose, the discharge and head level obtained by the dam are to be utilized for hydraulic energy there by making this multi-purpose for irrigation and power generation.

The project generates **(660)** Mw of electrical power aside from performing its flood function. Central and southern parts of Iraq get the benefit of irrigation water from its reservoir.

The dam lake was formed at latitude (**1988)** for storage water. It is be located at the West part of Euphrates River between (**27°- 42°)** Eastern latitude and **(34°- 40°)** Northern longitude. The lake is extended for **(100 km)** south of **Abu-Shabour** region and direction to the North- west towards (Rawa City). The minimum width of the reservoir was (2) km and maximum width (11) km with average depth (17) m. The surface area of the reservoir is about (500 km^2) at the design- operation level **(147)** m.a.s.l and with design- operation Storage volume of **($8.28*10^9$)**m^3, where[**($8.05*10^9$)m^3** of their is life storage and **($0.23*10^9$)**m^3 is dead storage] for a level **(112)** m.a.s.l. The bed of the reservoir is covered with recent sediments consist from the silt, sand and gypsum deposition.

The region of the reservoir was under hot desert climate with average annual precipitation (127) mm and amount of rain (45-200) mm. The wet period extend between two months (November and April) while the dry period extend between (May and October).

Water balance components:-

Water-balance models can provide effective means for evaluating the sensitivity of water availability or flood risk to historical and hypothetical future climate conditions by relating runoff and reservoir storage to climatic inputs and hydrologic processes within a watershed. Monthly inflows to Haditha Reservoir were modeled using estimates of monthly precipitation and temperature for the Upper watershed and runoff for two historical gage stations on the Euphrates River. Monthly changes in storage of Haditha Reservoir were modeled to simulate possible reservoir sedimentation and storage-release scenarios. The effects of possible climate change and increasing downstream irrigation demand on water volumes in Haditha Reservoir were modeled using hypothetical future scenarios that included changes in monthly precipitation and temperature and increases in reservoir sedimentation and downstream irrigation demand.

The component of Haditha reservoir water -balance are rainfall over the reservoir, inflow to the reservoir (Euphrates river), surface runoff from the catchment area, outflow from the dam, evaporation from the reservoir surface, change in reservoir storage and groundwater flow into or out of the reservoir. The data available for each of these components is discussed separately blow:

1- **Precipitation (p)** : is based directly on daily rain gauge records at Haditha dam meteorological station .
2- **Inflow (I)** : is the daily measurements of Euphrates river discharge At **Abu – shabour** metrological station .
3- **Runoff (R)**: from the tributaries in the catchment area of the Haditha reservoir was estimated using the rational formula; R = c*p where c is the runoff coefficient which was calculated to be 0.3 according to **Chow (1988).**The estimated value of R is being very small.
4- **Out flow (0):** is the daily measurements of the out flowing discharges from all the exits exist in the Haditha dam such as bottom outlet, powerhouse and spillway.
5- **Evaporation (E):** comprises real reservoir evaporation. The reservoir evaporation is estimated using a model had been developed and used by Morton (1979). This model needs a field climatologically data such as air, temperature, dew point, vapor pressure and sunshine radiation. The land evaporation amount was assumed to be included indirectly in the estimated value of runoff coefficient during the estimation of the surface runoff.
6- **Change in reservoir level (Elv.):** Representing difference in storage which is the difference between successive staff gage readings. The sign convention is positive for arise in reservoir level Haditha reservoir level change were recorded daily at the metrological station. The capacity , surface area- stage curve for the reservoir was used to find the change in storage volume .The stored volume and surface area of the Haditha reservoir was related with the reservoir stage by equations denoted below.
7- **Ground water (G)**:flow into or out of the reservoir was assumed to be equal to the residual of the water balance equation.

<u>Water balance devoted to Haditha dam reservoir:</u>

The water balance of the dam reservoir is be calculated by found the amount of water that inflow and outflow from the reservoir at period of time (t) by using the following equation:

$$\boxed{S(I,j+1)= S(I,j) +\{I(I,j) -O(I,J)\}*t +\{p(j) -Ev(j)\}*A} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:
J=1,2,3,……….12
I = 1,2,3,………n
S(i,j) = The volume of storage water (m^3) at month j year I .
I(i, j) = The discharge rate that inflow to the reservoir (m^3/ sec) at month j year i .
O(i,j) = The rate of the discharge that out from reservoir (m^3/sec) at month j year i.
P(j) = The monthly precipitation that fall on the reservoir (m).
Ev(j) = The monthly evaporation from the reservoir (m).
A = The surface area of reservoir (m^2). Its changing depends on the water level of reservoir.

t = Period time in (sec).
n = Operation year number.

Area capacity curves:

It's basically depended on the land topography of reservoir, where the amount of storage water and surface area can specification by showing to the water level of reservoir.

Elevation- storage relationship:

Many relationships were derived between the elevation, area, and storage of Iraqi reservoirs system by several researches. One of these is due to **(Ishaq (1998)**, he suggests this relation between the storage volume and the elevation of water level at Haditha dam:

$$\boxed{S = a1 * (Elv + b1)^{c1} + d1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

S = Storage volume in million (m^3) at elevation of water (Elv.).
Elv. =The water level at (m.a.s.l.).
a1= Constant from non -liner equation= 0.24
b1= Constant from non- liner equation = -100.062.
c1= Constant from non – liner equation = 2.7114
d1= constant from non-liner equation = 0

Elevations -surface area relationship:-

For obtain the amount of water that losses due to evaporation or added to the reservoir due to precipitation must find the surface area of reservoir for different water level. **Ishaq (1998)** used the non – linear relation method to find the relation between the surface area of Haditha reservoir and water level by using this equation:-

$$\boxed{A = a2*(Elv + b2)^{c2} + d2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

A = Surface area of reservoir in $(km)^2$ at any elevation of water.
Elv = Water level of reservoir in (m. a. s. l .)
a2 = Constant from non- liner equation =0.000588.
b2= Constant from non- liner equation = -81.992.
c2= Constant from non- liner equation = 3.252.
d2= Constant from non- liner equation= 37.018.

Results and discussion:

The collected and the calculated data of the inflow, outflow reservoir stage, rainfall, runoff and evaporation were feeder to personal computer to solve the water balance equation of Haditha reservoir for the study period **(2000-2011).**

According to the operation policy of Haditha reservoir and due to the hydrological regime of the reservoir, the maximum rise in reservoir level occurred in March, April and May while the maximum fall was in November and December. The range of the reservoir level fluctuation was about (**14.78, 6.4, 4.5, 2.5, 6.8, 4.3, 7.7, 19.62, 19.62, 26.66, 5.2, 0.2 and 1.8)** meter for the **years (2000 -2011**) respectively, **Fig (4**) it's clear from figure that the year (2009) was abnormal ,because in this year the max water level was (**131.06**) **m** and the Minimum water level was (**116)m** and that less of the Min. water level of operation of reservoir **(129.54)m**, this can be attributed to the small amount of Euphrates river discharges during the flood period of this year especially in October and November.

Figure **(5**) shows the water balance components expressed in m^3 per month for the studied period. It can be concluded from the figure that the inflow and the outflow components dominate the water balance of Haditha reservoir in seasonal succession. Also it is evident from **Table (2**) that the total amount inflow to the reservoir through Euphrates river represents about **(96)%** of the total income to the reservoir while the outflow from the dam represents about **(98)%** of the total outcome from the reservoir.

The analysis of the results shows that the average monthly volume of inflow and into or outflow of the reservoir for whole studied period are equal **to (1.3 $*10^{9}$)** m^3 **and (1.1$*10^9$**)m^3 respectively. While the average monthly volume of rainfall plus runoff and evaporation are equal to **(0.0034$*10^9$) m^3** and **(0.0618$*10^9$)** m^3 respectively. These values indicated the amount of evaporation from the reservoir is more than the amount of rain that fall on the reservoir.

The variation of the residual term in the water balance equation with the inflow and out flow terms is shown in Fig**.(6-[a,b,c,d]**) . From these figures, two important points are appeared; **First**; when the inflow discharges were greater than the outflow, the residual term appeared in the water balance equation in a positive sign which means that the reservoir was losing water ,while the residual term appeared in a negative sign when the outflow discharges were greater than the inflow discharges which means that the reservoir was feeder at that period. So it can be concluded from the figure that the reservoir loses some of its water storage during the increasing of the reservoir as bank storage. As the reservoir stage decreases, the stored water began to feed the lake again. This process was true for all the studied period except the year **(2009)**due to abnormal conditions of small amount of discharges that entered the reservoir during flood period at that year. Those amounts of large discharges were not recorded accurately due to the unavailability of accurate hydrological instrumentation at Abu- Shabour meteorological station.

Second; there was only one month in the studied period in which the total amounts of inflow and outflow discharges were approximately equal. In this month **(December 2011)** the residual term was approximately equal to zero and the reservoir level was almost constant this may confirm that the variation of reservoir stage is as significant factor in determining the residual term in the water balance equation (ground water seepage).

In general, it was observed that during the studied period the reservoir had been max losing of water in average **(1.41$*10^9$)** m^3 while it was feeder at an average with max amount of water at January and February **(1.82$*10^9$)**m^3 and **(1.9$*10^9$)**m^3 respectively . These results indicate that the reservoir was feeder by a total amount of **(192.42 $*10^9$)** m^3 during the whole studied period (this may need more field observation and investigation for the ground water). **Table(2)** gave an evidence assuring the existence of groundwater contributions in which the total amount of inflow to the reservoir and the outflow from the reservoir was approximately equal for the studied period while there was a large difference in the reservoir stage between the beginning period of the study (**January 2000**) and the end of the (**December, 2011**). Those amount of feeder water may be related to the ground water in the adjacent area and to some of the unrecorded sources of the reservoir s inflow like springs and subsurface streams, also it is important to note that the used rainfall records in the water balance equation doesn't represent the actual rainfall records due to the unavailability of rainfall stations within the catchment area.

For the whole study period (2000- 2011)

Total inflow (Euphrates river) to the reservoir =191.936 $*10^9$ m^3

Total outflow from the dam = 157.596 * 10^{9} m^3

Total rainfall and runoff = 0.492$*10^9$ m^3

Total reservoir evaporation = 8.899$*10^3$ m^3

Total residual (feeding) = -0.7573 $*10^3$ m^3

Total change in storage volume = -2.942 * 10^8 m^3

Recommendation:

As result of the present work two recommendations may be written as follows:

1- An accurate meteorological station must be constructed at Abu- Shabour on Euphrates River including fixed continuous discharge measurements.
2- Number of fixed rain gauge station must be constructed different location in the catchment area of Haditha reservoir give an accurate and real values of the runoff amount which reaches the reservoir during rainy season.

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Table (1) :The basic information of Haditha Reservoir

Property	The value	Property	The value
(design – operation) storage volume (m^3*10^6)	8200	Max. water level(m)	150.2
Natural operation level	143	Max .volume of storage (m^3*10^6)	9850
Natural(design- operation) storage volume (m^3*10^6)	6591	The dead water level(m)	112
Min .operation level (m)	129.5	Min. volume of storage (m^3*10^6)	188
Min. (design- operation) storage (m^3*10^6)	2362	Design- operation level(m)	147

Table(2): Average Haditha Reservoir balance water for the years (2000-2011)

Month	Inflow (m^3)	Precipitation (m^3)	Total supply	Outflow (m^3)	Evaporation (m^3)	Total loss
Jan.	1.81E+09	6063598	1.82E+09	9.48E+08	14191401	9.63E+08
Feb.	1.89E+09	5999697	1.9E+09	1.11E+09	23430769	1.14E+09
Mar.	1.55E+09	7573413	1.55E+09	1.18E+09	40837030	1.22E+09
Apr.	1.05E+09	8228251	1.06E+09	8.83E+08	57078860	9.4E+08
May	1.14E+09	2115901	1.14E+09	8.88E+08	81666355	9.69E+08
Jun.	9.72E+08	0	9.72E+08	1.07E+09	1.04E+08	1.18E+09
Jul.	1.15E+09	0	1.15E+09	1.25E+09	1.13E+08	1.36E+09
Aug.	1.38E+09	0	1.38E+09	1.31E+09	1.01E+08	1.41E+09
Sep.	1.12E+09	0	1.12E+09	1.25E+09	84239486	1.34E+09
Nov.	1.04E+09	1678409	1.04E+09	1.16E+09	58302626	1.22E+09
Oct.	1.33E+09	2794846	1.33E+09	1.15E+09	37644863	1.18E+09
Dec.	1.6E+09	6618985	1.61E+09	9.38E+08	25887585	9.64E+08

Fig.(1) : Location of Haditha lake

Fig.(2): Haditha dam

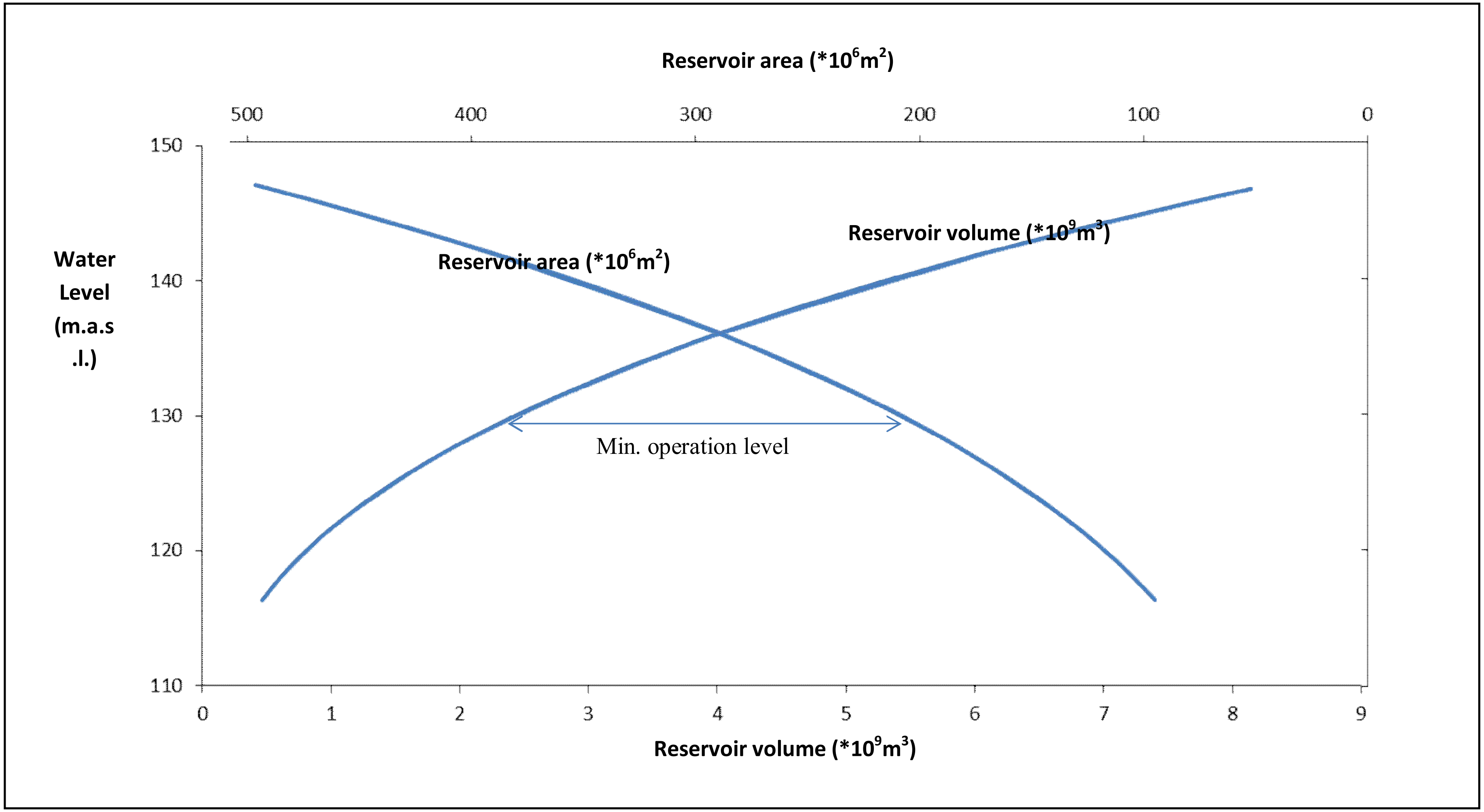


Fig.(3): Haditha Reservoir volume and area curves

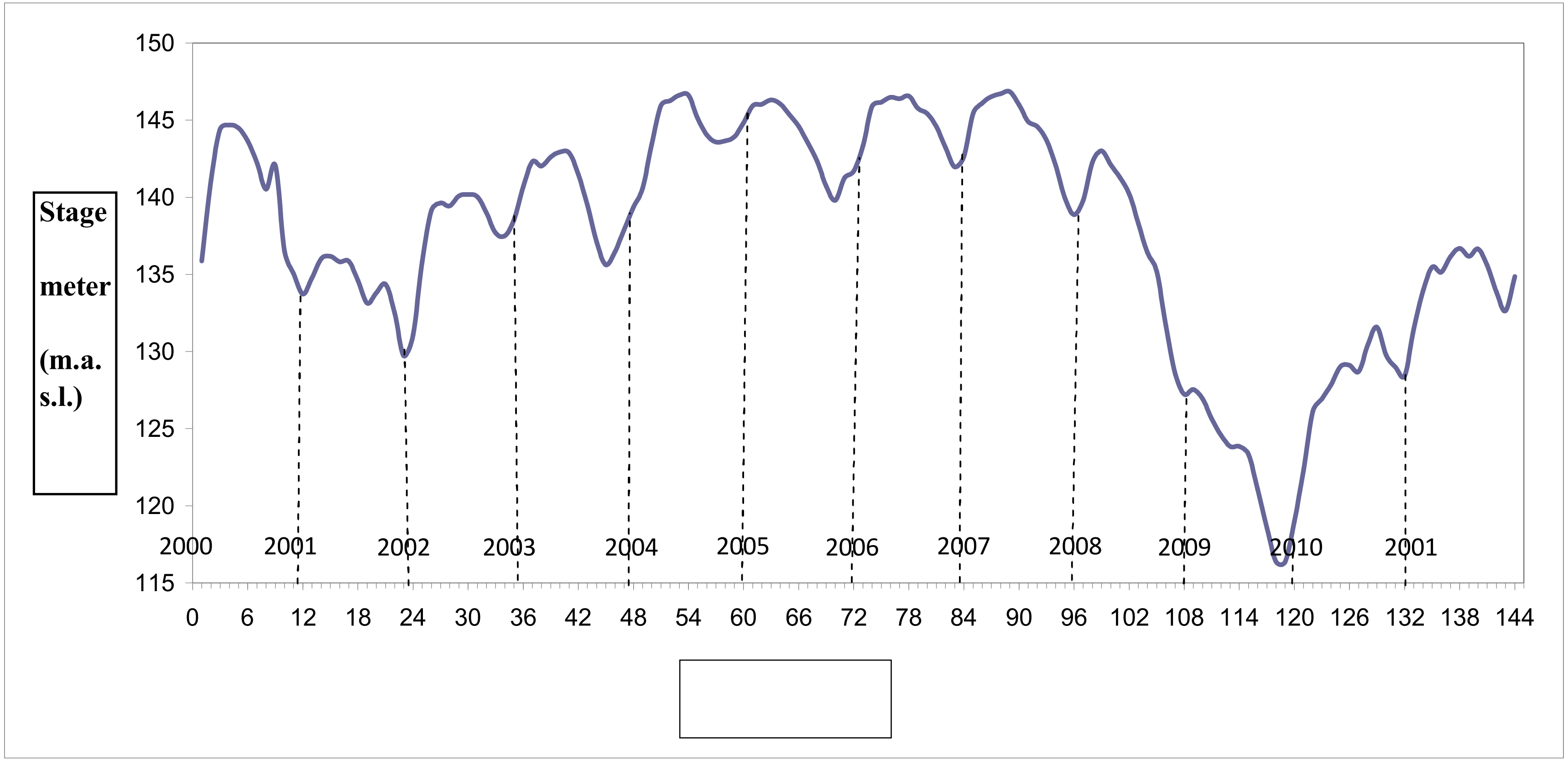
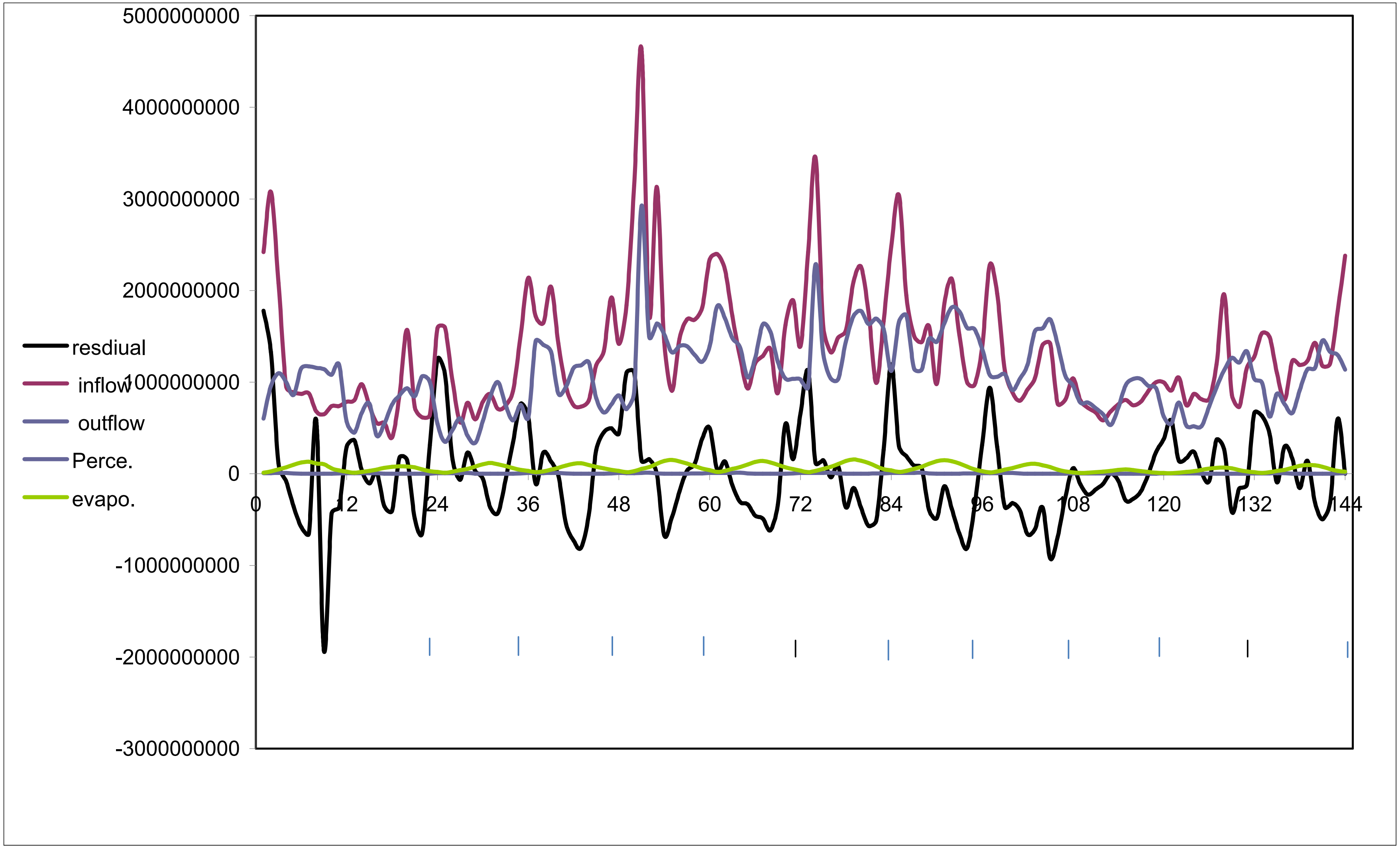
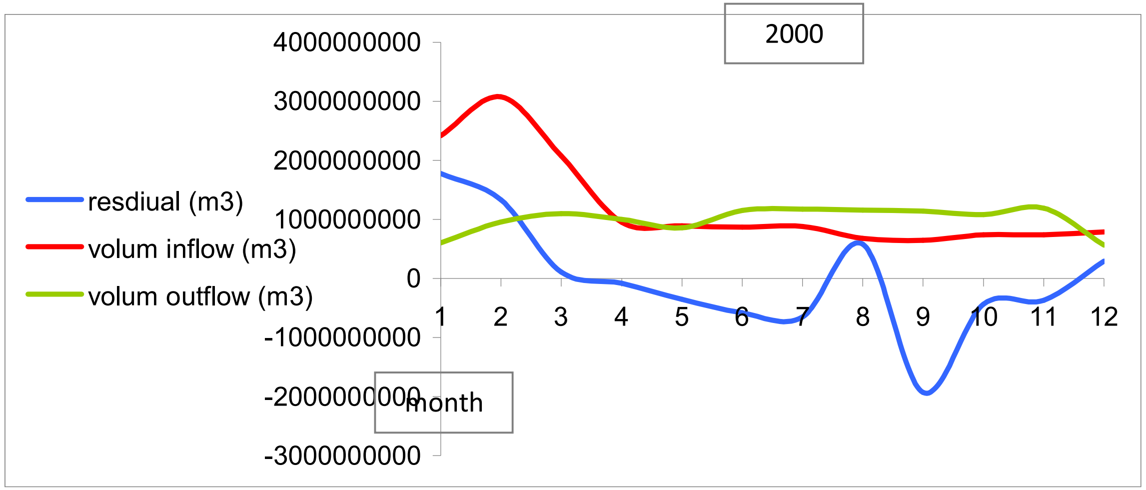
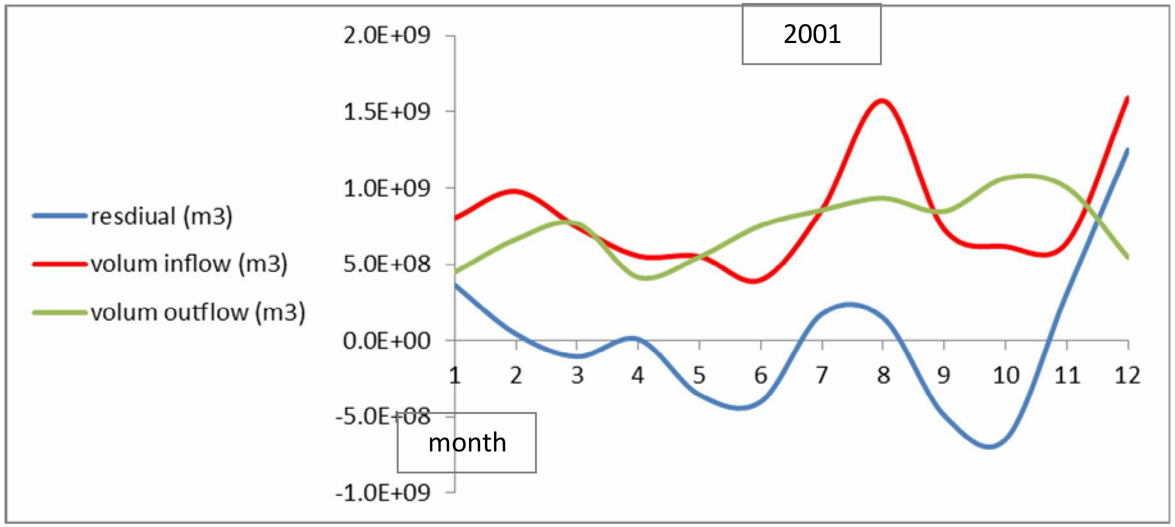


Fig.(4): Haditha lake stage (m) in period (2000-2011)



Fig(5): Water balance of Haditha Reservoir


2000
4000000000
3000000000
2000000000
1000000000
0
-1000000000
-2000000000
-3000000000
resdiual (m3)
volum inflow (m3)
volum outflow (m3)
1 2 3 4 5 6 7 8 9 10 11 12
month


2001
2.0E+09
1.5E+09
1.0E+09
5.0E+08
0.0E+00
-5.0E+08
-1.0E+09
resdiual (m3)
volum inflow (m3)
volum outflow (m3)
1 2 3 4 5 6 7 8 9 10 11 12
month

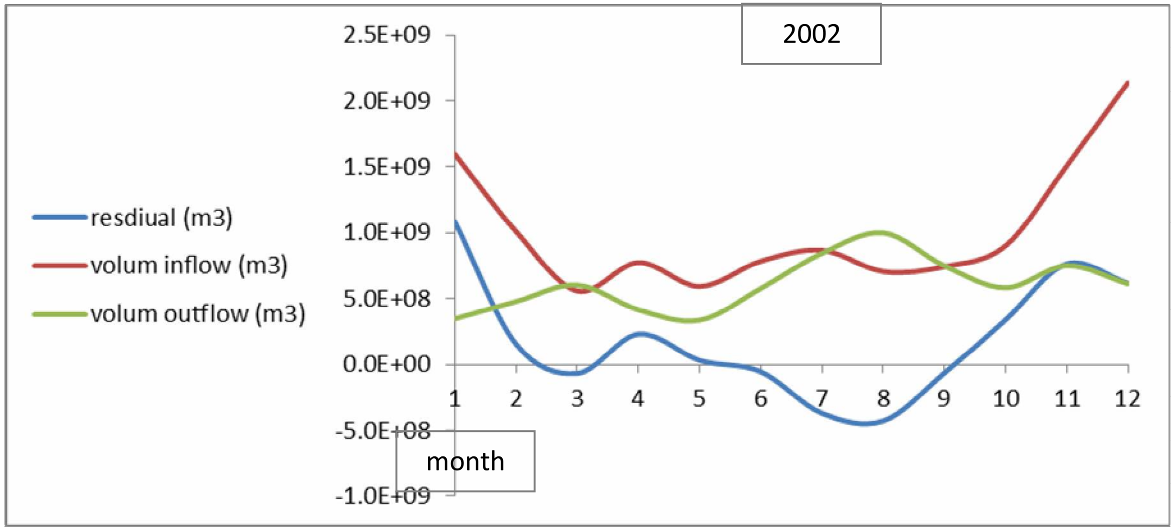
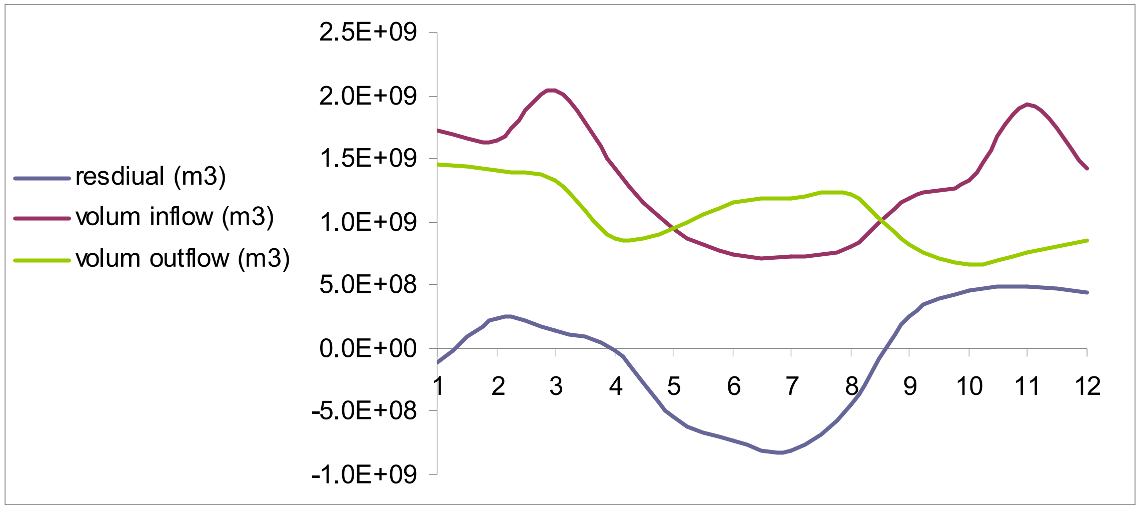
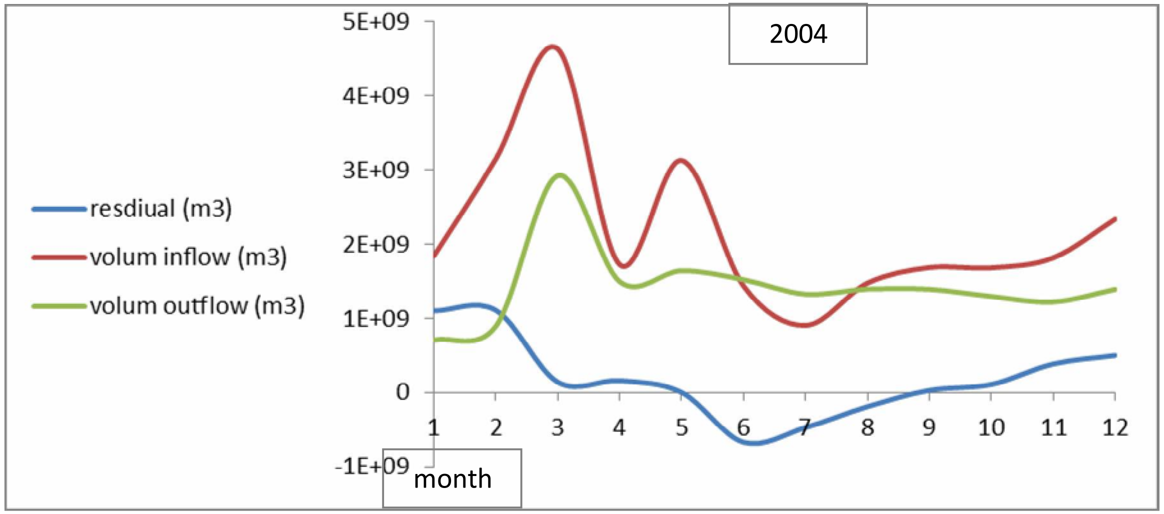
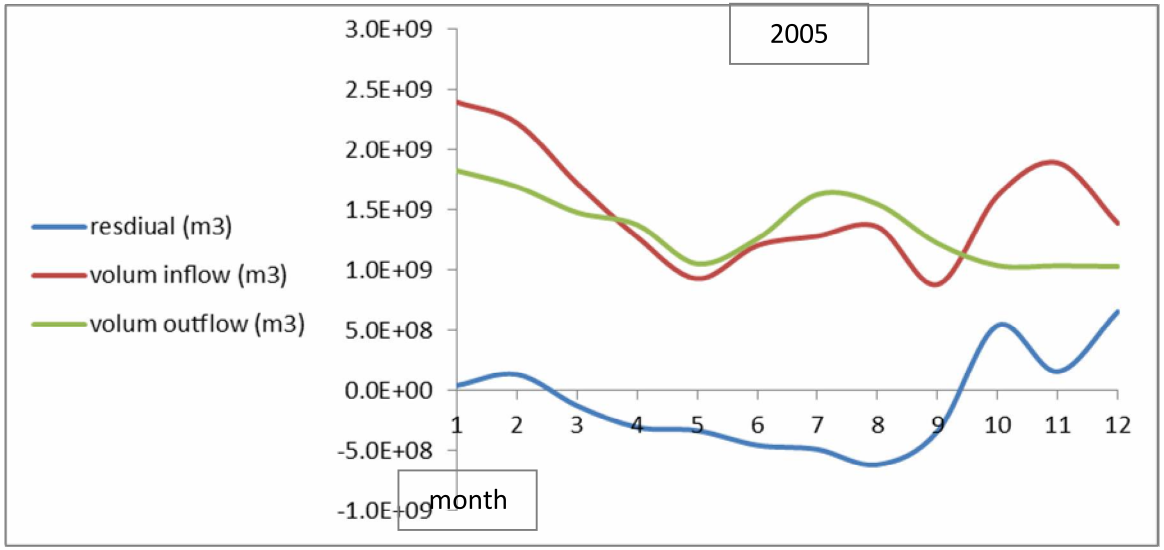


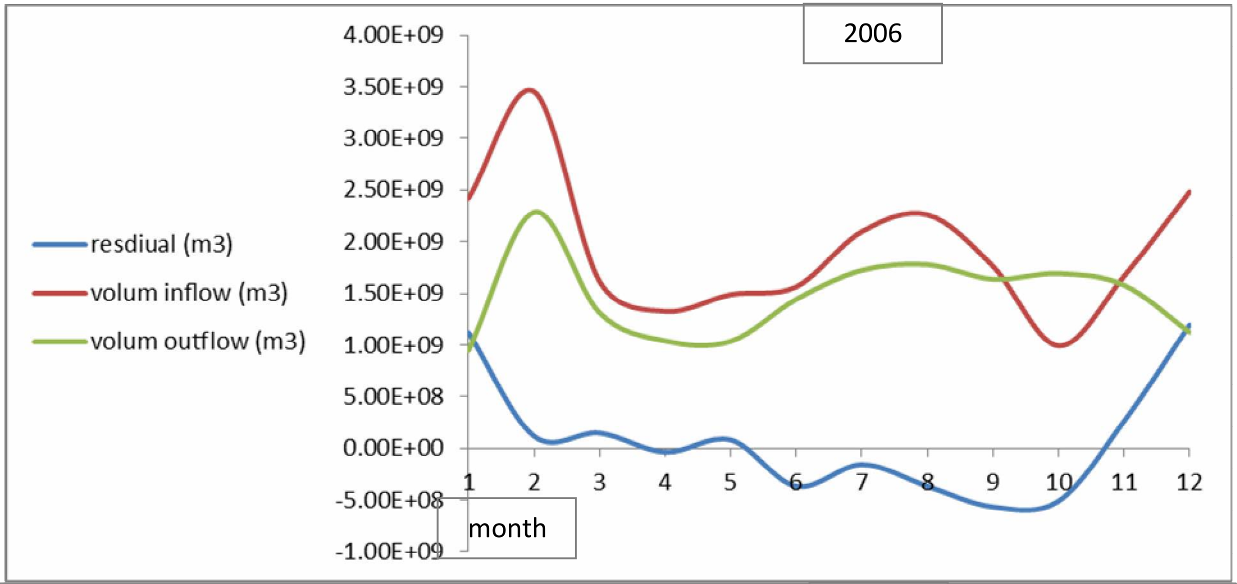
Fig.(6-a) : Variation of residual with respect to inflow and outflow relationship

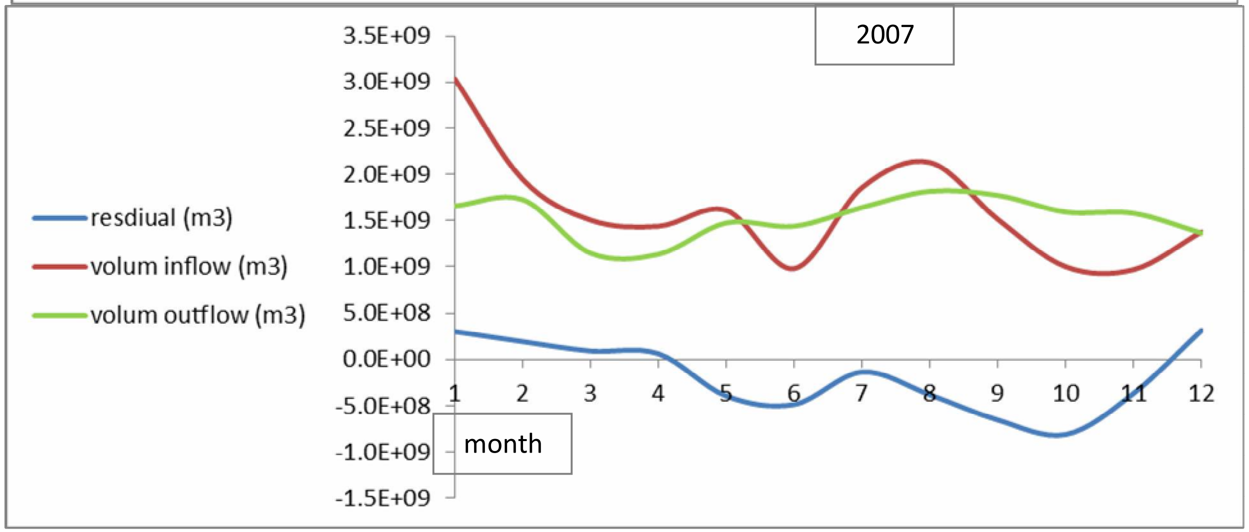


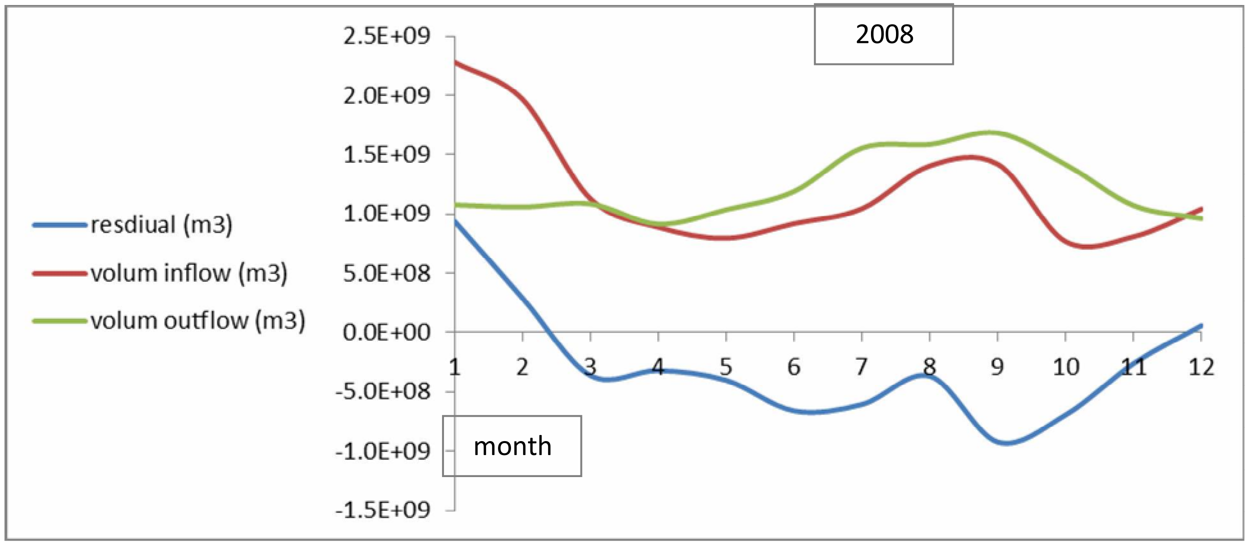




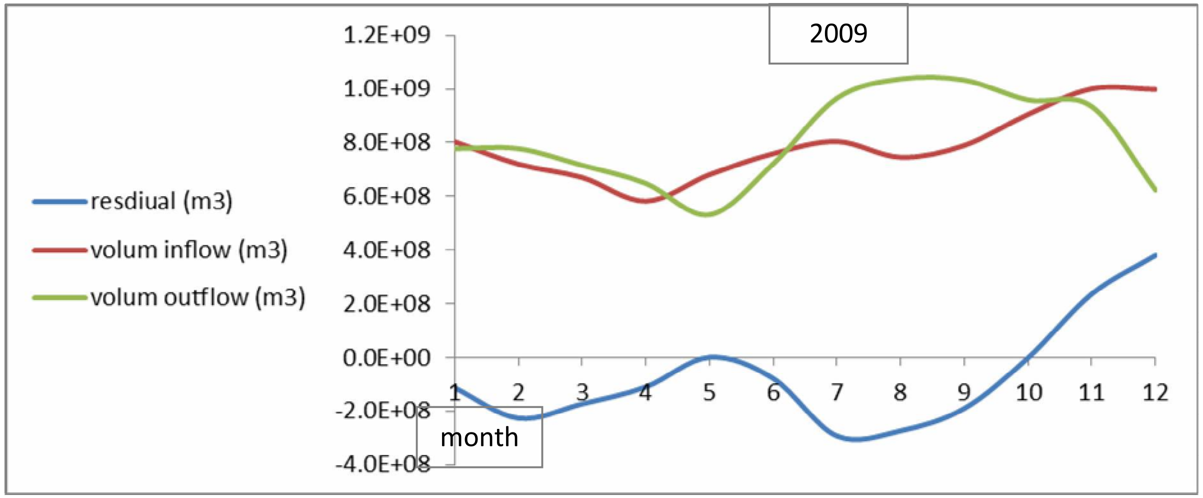
Fig(6-b): Variation of residual with respect to inflow and outflow relationship

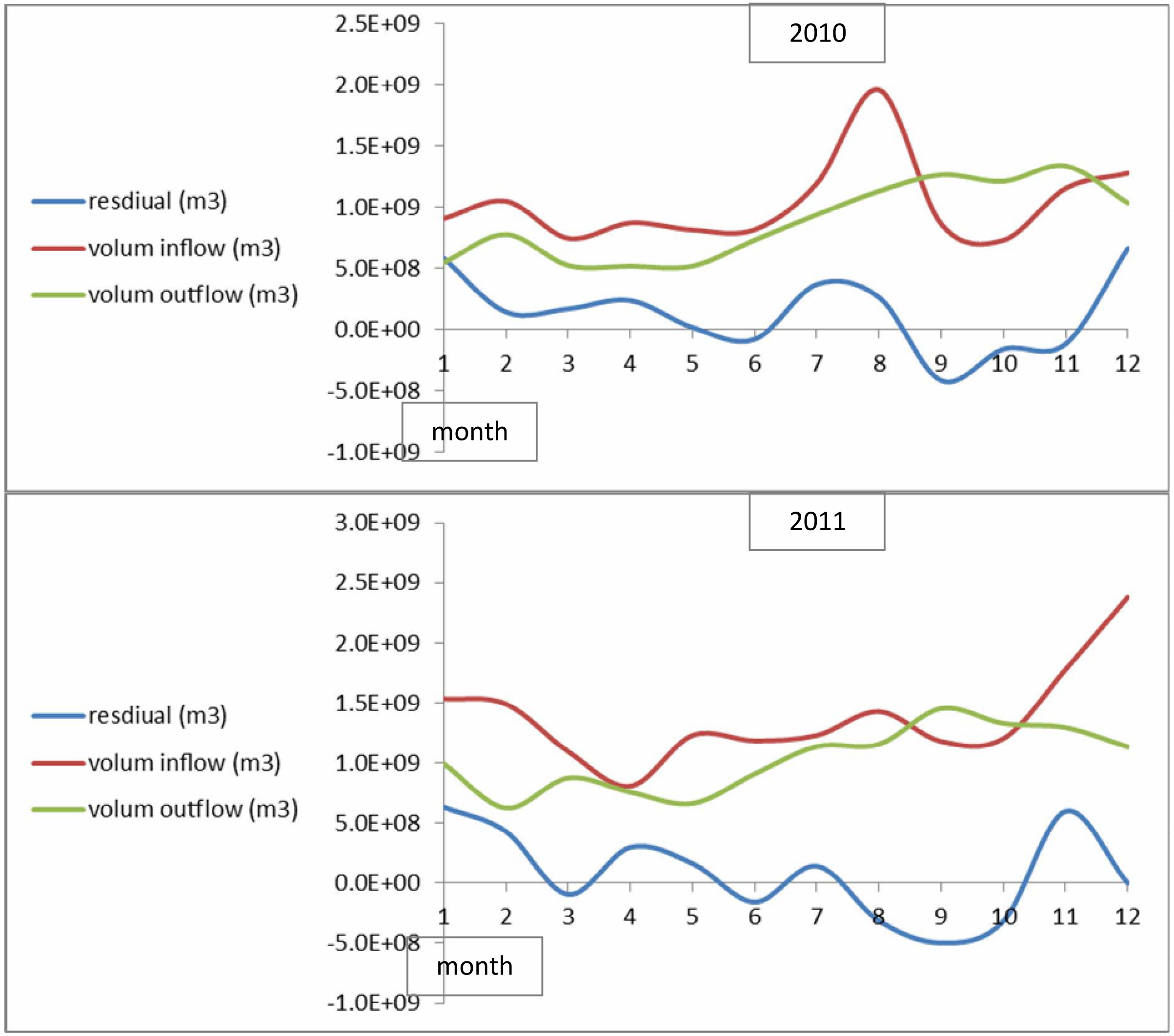

2006
4.00E+09
3.50E+09
3.00E+09
2.50E+09
2.00E+09
1.50E+09
1.00E+09
5.00E+08
0.00E+00
-5.00E+08
-1.00E+09
1 2 3 4 5 6 7 8 9 10 11 12
month
resdiual (m3)
volum inflow (m3)
volum outflow (m3)


2007
3.5E+09
3.0E+09
2.5E+09
2.0E+09
1.5E+09
1.0E+09
5.0E+08
0.0E+00
-5.0E+08
-1.0E+09
-1.5E+09
1 2 3 4 5 6 7 8 9 10 11 12
month
resdiual (m3)
volum inflow (m3)
volum outflow (m3)



Fig(6-c): Variation of residual with respect to inflow and outflow relationship





Fig(6-d): Variation of residual with respect to inflow and outflow relationship