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Calculation of Optimal Height and Number of Small Dams Series At Upper Euphrattes River (In Iraq) Using Hec-Ras and Vba.

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ABSTRACT

Small dams represent an adequate tool to manage fresh water storage and its timely distribution and use. The construction of small reservoirs in larger numbers and well spread throughout a region reaches a wide population and facilitates its water demands. This, in turn, has feedback effects on the environment that need not to be waved away. A 58000 m long of Euphrates River reach between Haditha and Al-Baghdadi cities at Anbar province was selected to evaluate the usefulness of constructing system of small dams series by calculating the range of improvements in reducing evaporation and cost of pumping of water for demand. A geometric numerical model has been created with geographic information system (GIS) based program called Global Mapper (Ver. 10) by using digital elevation model (DEM) combined with surveyed cross-sections of the river bed. The numerical model simulated with (HEC-RAS 4.1) to estimate surface area (SA) of reservoir dams with max. discharge (500 m^3/s) .A computer program was established with visual basic programming to evaluate the optimal height of dams according to economical methodology based on less of cost of evaporation and cost of pumping through a group of equations .The study area was evaluated and the results recommended establishing a system of four dams with height of (6.75 m).

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INTRODUCTION

Water is a very important resource, which makes its management one of the greatest challenges facing us globally; therefore, the human beings constructed dams to have a most benefit from water (Nariman, 2013).

The overall increase in water demand, accompanied by climate change predictions, has resulted in global water scarcity issues (McCully, 1996; Bates *et al*., 2008). It has been suggested that 1.8 billion people (23% of the world's projected population) will be living in areas with absolute water scarcity by 2025, with almost 6 billion people (75% of the world's projected population) living under conditions of water stress (FAO, 2007).

The benefits brought by dams are considerable. They not only provide electricity to growing economies, in many cases they also secure the availability of safe drinking water and sufficient quantities of irrigation water. During the 20th century a huge number of dams was built to satisfy the needs of water resources management. It is estimated that around 30% to 40% of the irrigated land worldwide is dependent on dams. About 19% of the world's electricity production is generated by hydropower. Thus, more than 60% of the rivers are affected by dams (WCD, 2000).

The use of dams to facilitate irrigation through water storage in times of scarcity in developing countries has had a long and varied history. Traditionally much of the funding by international donors was for large dam construction (Hathaway and Pottinger, 2008). However, in the 1990s, considerable concern emerged over the fact that the actual distributional environmental and economic impacts of large dams had been largely ignored (Elodie and Eric, 2013).

Small dams represent an adequate tool to manage fresh water storage and its timely distribution and use. The special appeal of small dams is that their construction requires comparably little expenditure. The use of dams to facilitate irrigation through water storage in times of scarcity in developing countries has had a long and varied history (Elodie and Eric, 2013).Dam development needs to be pursued in a strategic manner and requires water resources management and planning that takes into account these effects. While their widespread

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distribution has the advantage of serving many people, in turn it complicates the evaluation of their environmental effects (Diekkruger.B., 2002). Water quality can determine success or failure of use of a small dam, water may be of limited usefulness as it may be fit for irrigation or stock purposes but not for human consumption (Nelson, 1985).Computer modeling techniques have assisted engineers in determining the hydraulic changes in natural streams and rivers affected by hydraulic constructs. One of the most commonly used one-dimensional modeling tools is HEC-RAS. The main objective of HEC-RAS program is to compute water surface elevation at locations of interest for a given flow value (Hydrologic Engineering Centre, 1991). Geographic information system (GIS) based program called (global mapper 10) is used to extract information from digital elevation models (DEM) then combined with surveyed river bed cross-section to build the geometric model of the study reach which is used with HEC-RAS and visual basic (VB) model to predict the effect of the recommended small dams system on the river behavior .

Methodology:-

The methodology of this paper is based on modeling the geometric extracts from the study area with HEC-RAS to examine the hydraulic and spatial variation due to water surface change in case of establishing a group of sequence dams with number and height specified by the Small Dams for irrigation Evaluating Model which makes the calculates within economical optimality to estimate height potentials with less evaporation and pumping cost in the selected reach of the river.

The achievement of research objectives through HEC-RAS program and the VBA model arises from the type of data required. Three types of data are used: geometric, hydraulic, and economic, which are used in reach geometry, the hydraulic model, and the visual basic evaluating model. Also as in most engineering programs some data are selected to be user defined especially in VBA model for more engineering choices.

Digital Elevation Model:

A surface created from elevation point data to represent the topography. Often a DEM is more easily used in a geographic information system (GIS) or computer-aided design (CAD) application than the raw point data it is constructed from (NOAA,2012).

The DEM used in the study is obtained through The Shuttle Radar Topography Mission (SRTM) which is an international research effort that obtained digital elevation models on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. This model was processed by a program known (global mapper-10) on which a Geographic information system (GIS) is based and has many features used to extract geometric details of the study area.

Global mapper-10, has a capability of identifying the elevation of any point and delineation of cross-section at any given location, but unfortunately the digital elevation model did not include information about water covered surfaces and it considers the water surface as the ground surface, so on site surveying process for the stream bed on the specified locations of the cross-sections is required to establish relatively accurate geometry of the study stream.

The Study Reach:-

The study reach is located at Euphrates River uppers starts at station (0) [(66400) m] NW of Hit hydraulic station, and ends at station (58000) upstream; the number is equal to the distance [in meters] of the specified station from the reach start figure (1). The cross-sections invested in this study were surveyed through a previous study by (Al-Fahdawi, 2009) along Euphrates River between Hit and Haditha through 197 stations.

Cross-Sections Geometry:-

Coupled with the hydrological data, the geometric data determine the conveyance of water downstream, both within the channel and across the floodplain. The boundary geometry for the analysis of flow is specified in terms of ground surface profiles (cross sections) and the distance between them (reach lengths). The cross-sections are located at intervals along the river in order to characterise and accurately represent the flow carrying capacity and geometry of the channel and its floodplain. Cross-sections are required where changes to roughness, discharge, shape and slope occur, as well as before and after weir and bridge structures. In HEC-RAS the cross-sections extend across the entire floodplain, perpendicular to anticipated flow (Catherine *et al*,2010).

Each cross-section is labelled with a river, a reach and a river station label. The cross section is described by entering the station and elevation (x-y) data from left to rightright, with respect to looking in the downstream direction figure (2). All cross-section data are defined looking in the downstream direction. The specific points at which ‘overbank flow’ is defined along the channel cross-section are called ‘left and right overbank stations’. The reach lengths between cross-sections must be specified for the left bank, right bank and channel. Channel lengths are typically measured along the thalweg and overbank distances along the expected centre of mass of the overbank flow. These values differ more greatly as river bends (Catherine *et al*,2010).

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

Extracting Reach Geometry:-

Reach geometry in its final shape is established from combination of survived cross-sections and extracted elevation cut line which is obtained from DEM processed in global mapper according to the following procedure:

1. Locate the interesting stations of the surveyed cross-sections on the study reach using Google earth by entering its coordinates, and then save the file in (.kml) format, figure (3).
2. Open the study area DEM with Global mapper, then open the (.kml) format file, draw the reach centerline from upstream to downstream across the located stations, figure (4).
3. Draw cross-sections cut lines across the reach starting from the left side bank to the right side looking downstream, figure (5)
4. Extract cross section profile using (generate path profile along line) feature, figure (6), and then save the generated drawing in .xz format to be processed with Microsoft excel, figure (7) to be combined with the surveyed part (River bed surface).
5. It's obviously that the minimum elevation in the cross-section is the water surface figure (6) in the center of the stream which will be replaced with the surveyed surface using excel,figure (8).
6. The combination of numerical and surveyed cross-sections is illustrated in figure (9), and the resulted cross-section is in Excel format as shown in figure (10) to facilitate importing process with HEC-RAS.

Data that are required for each cross section** in **HEC-RAS:-

1-Reach length

The measured distances between cross sections are referred to as reach lengths .the reach lengths for the left overbank, right overbank and channel are specified on the cross section data editor .channel reach lengths are typically measured along the thalweg. Overbank reach lengths should be measured along the anticipated path of the center of mass of the overbank flow often, these three lengths will be of similar value. there are, however, conditions where they will differ significantly ,such as at river bends,or where the channel meanders and the overbanks are straight(USACE, 2010-a).

2-Roughness coefficient:

The Manning coefficient values were assumed for each cross-section depending on previous studies in this region of Euphrates River whose system verification shows a good agreement between the stage of river observed in Hit gauge station and those calculated by using the numerical model, for river channel = 0.033 and for the floodplain roughness = 0.05 (Al-Fahdawi S. A., 2009).

3-Expansion and contraction coefficients:

The energy loss is calculated by multiplying the coefficients by the absolute difference in velocity heads between one cross-section and the next one downstream. If the change in cross-section is small or gradual, the contraction and expansion coefficients are typically 0.1 and 0.3 respectively. These values are recommended by the HEC-RAS manual to account for gradual changes in river cross sectional area (U. S. Army Corps of Engineers, 2008).

4-Cross section Interpolation:

Occasionally it is necessary to supplement surveyed cross section data by interpolating cross section between two surveyed section.

Interpolated cross section are often required when the change in velocity head is too large to accurately determine the change in the energy gradient an adequate depiction of the change in energy gradient is necessary to accurately model friction losses as well as contraction and expansion losses. when cross section are spaced too far apart , the program may end up defaulting to critical depth.

The HEC-RAS program has the ability to generate cross section by interpolating the geometry between two user entered cross section.

The geometric interpolation routines in HEC-RAS are based on string model ,as shown in figure(11), figure(12)**.**

Structures: Weirs:

HEC-RAS has the ability to model broad-crested, ogee shape and sharp-crested weirs as inline structures across the main river. Like bridges, weirs have an effect on flow as water backs up behind them causing a localised increase in width and depth. The presence of a weir also has an effect on river-floodplain interaction and both the bank and bed can be subject to erosion. In HEC-RAS the flow over a weir is computed using the standard weir equation:

$$Q = CLH^{\frac{3}{2}}$$

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

Equation 1.1:

where Q is discharge, C is the weir flow coefficient (typical values range from 2.6 to 4.0 depending upon the shape of the spillway crest), L is the length of spillway crest and H is the upstream energy head above the spillway crest (Catherine *et al*,2010).

The shape of the weir selected determines how HEC-RAS calculates submerged weir flow. In order to model inline structures it requires the cross-section framework. The geometry of the weir is entered using elevation and station data across the river. The contraction and expansion coefficients apply for weirs figure(13) (Catherine *et al*,2010).

Visual basic model

The model processes to extract and evaluate the optimal height and number of dams with less evaporation and cost of pumping of water go through the general steps described below which is illustrated in figure (14):

1- Selecting reasonable maximum and minimum heights of dams depending on the geographical survey of the site, the minimum height is important as a limit for the maximum number of dams especially if there is any adventitious for constructing a dam in the selected distribution , in present study was selected the minimum and maximum height (3m) (9m) respectively .

2- This height will be iterative within the selected range in steps of 50 cm each time of calculation.

3- The height will be processed in two deferent paths, the first is to find the evaporation water price, and the second is to find the estimated costof pumping water for irrigation .

4- One of the basic inputs in this system is the cost ($/Kwh) of energy consumed by the pumps used to lift water from the river to meet the demand for irrigation and other uses , and this energy is consumed mainly rely on head of suction.

5- The annual energy cost to pump water can be calculated from the following equation :(*Lori* , 2009)

C = (DR/GPM) x HP x 4.5 x cost of energy ($/kWh)…………… *Eq.* (1)

Where:
C = annual energy cost, dollars
DR = daily water requirement, gal
GPM = flow rate, gpm
HP = pump size, hp
4.5 = unit conversions.

6- The estimated cost of EVAPORATION WATER from reservoir of dams calculated from the following equations .

V = (E / 1000) * SA)…………………………. Eq. (2)
Cost of water evaporated=V* C_w…………… Eq. (3)

Where:
E=Evaporation rate (mm).
SA=surface area of reservoirs (m).
C_w=cost of water.

7- The comparison between the cost of the evaporated water from the reservoirs and the cost of energy used to pump water from the river of both single large dam and series of small dam at the same reach and are choosing the optimal high dams based on minimum cost of them.

Formulation of the Optimization Model for Dam height:

One of research objectives is to evaluation the best high dams in study reach, so that the minimum cost energy to pump water from the river for irrigation and other uses and minimum cost for the evaporation of water from the surface area of the lake dam.

Optimal high of Small Dams Model (OHSDM) is windows program established through the study process to deal with a set of equation.

The equations are function of the dam height (h) and solved for optimal height using Microsoft visual basic programing within economical optimality.

Where is the use of a set of equations by which compared to the expected benefits of small dams through repetition of the high dams within the range specified by the user, and is measured surface areas for each rising through the program (HEC-RAS) is insert these surface areas in the program (VBA) where they are from which account the amount of water evaporated from each high dams are also calculate the cost of pumping power of the river is where the comparison between them is best choice for high Small Dams so that it is minimum cost to water evaporated and minimum cost to pump water from the river. The program interface, figure (14)

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

RESULTS AND DISCUSSION

Reach Simulation:

The max. discharge value (500 m^3/s) is used in ***OHSDM*** to design the system of small dams because it reflects the normal variation of the dam releases . The Thalweg line profile which is extracted from the HEC-RAS Model is represented in figure (15). The elevations and horizontal spacing were processed using Microsoft excel to determine the average slope of the study reach (= 0.0003) which is used as a boundary condition for the reach downstream in normal depth option with HEC-RAS, figure (16).

Estimation of Optimal high of Small Dams (OHSDM):-

Input Geometric Data:-

The extracted geometric data from the water profile (MedWS) which are calculated through the same simulation and analyzing process above are, Maximum reach elevation(98.70) Minimum reach elevation (71.7), The difference between Maximum and Minimum elevation(27m) was used as single large dam. The maximum dam height of small dams assumed (9 m), beside this value is user defined; it matches the general definition of small dams. The minimum dam height assumed (3m), also this value is user defined but it has engineering sensitivity to the average water depths calculated in reach simulation beside this option it can provide a good solution to fix the maximum number of small dams in cases of limitation like but not limited to geological, economical, and social reasons.

Hydraulic Data:-

The hydraulic data are represented by the discharge value (500 m^3/s),the discharge of pump value(1170 *l/sec)* and the centrifugal pump and the AC induction motor. The centrifugal pump converts mechanical energy into hydraulic (flow, velocity, and pressure) energy and the AC motor converts electrical energy into mechanical energy. Many medium and larger centrifugals offer efficiencies of 75-90% and even smaller ones usually fall into the 50-70% range. Large AC motors, on the other hand, can approach an efficiency of 97% and any motor, five hp and above, can be designed to break the 90% barrier (Joe Evans,2005). But we recommend efficiency of pump(70%) for modeling as reasonable value for present electro-mechanic equipment.

Economical Data:-

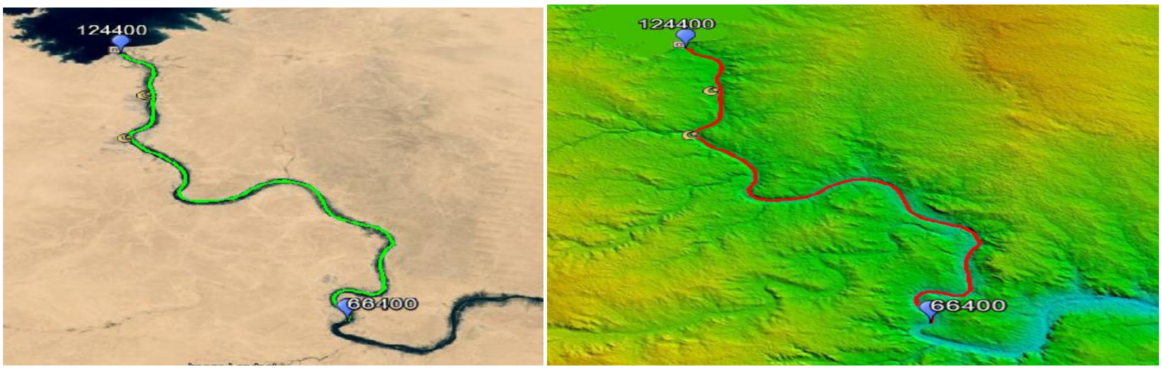
The economical data includes the price of water, which represents the cost of the water evaporated from the reservoirs of small dams .It assumed (0.0012$/m^3)(Baghdad Municipality,2013). Both intensive grazing and water quality protection programs are increasing the need for pumping water to demand from locations where commercial electricity is not readily available. It will generally be the most cost-effective method for pumping water. However, there may be instances where the distance from existing power lines to the desired pump location makes it cost-prohibitive to obtain electricity from the utility. A rule of thumb is that alternative energy sources may be economically justified if the distance to commercial power exceeds one-third of a mile. In this case, the livestock producer can select from a range of alternative power methods (*Lori*, 2009). The unit selling price of electric power fitted to pumps to pump water for demands have a direct impact on the optimal height of small dams. It assumed (0.015 $/Kwh) which matches the international electricity selling prices (Wikipedia, 2012).

Input data for model (OHSDM):

The Figure (17) shows the program interface .It can be clearly seen that this program has used to calculate the cost of water evaporated and the cost of energy to pump water from the reservoirs of small dams. The saturated vapour pressure at the water surface temperature (ew)effect directly on the value of evaporation ,because of this ,the value of evaporation increase with a rise (ew) the Figure(17a) demonstrate the insert of value(ew) . By contrast ,the partial vapour pressure in the air at a specified location height (ea) also detect the value of evaporation where this value increase with the drop of (ea), the Figure(17b) shows input the value of (ea). While the Figure(17c) represents the value (U) is wind speed . Surface area for each small dam and for each height (SA) ,it represent a key factor influencing evaporation rate due to the increase in humidity and resultant decrease in local evaporation rates with distance downwind from a shore, Figure(17d) refers to the input values (SA). daily water requirement for irrigation and another demand (DR), Figure(17e) explains input of daily water requirement (DR). After calculating the cost of water evaporated from reservoirs of small dams and the cost of pumping power using OHSDM as in Figure (17) and when you transfer these values to the Excel program appeared the following figure (18). The figure (18) shows that the optimal height of small dams is (6.75m) and recommended number of dams to be installed along the reach (4 dams) . At this height the cost less of the water evaporated from the surface areas of Small dam reservoirs as well as the cost less of the pumping power needed to pump water to the demand. At this height the minimize cost of the evaporated water from the surface areas of Small dam reservoirs as well as the minimize cost of the pumping power needed to pump water to the demand. In this

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

present study the range of height of dams was (3-9)m which larger from range (3-7)m in study of (AL-dulaimi,2012) was evaluated and the results recommended establishing a system of dams with height (4.3m) for each with the to generate expected power. In figure (18) the equation of pumping cost($y = 0.0003x^2 - 2955.9x + 35470$) the coefficient of ($x^2$) is very small so it can be neglected.



(a) (b)

Fig. 1: (a) - satellite image for the study reach via Google Earth),(b) - DEM for the study reach

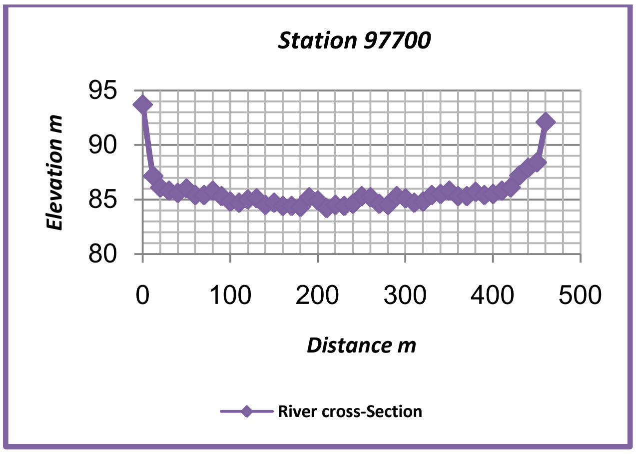
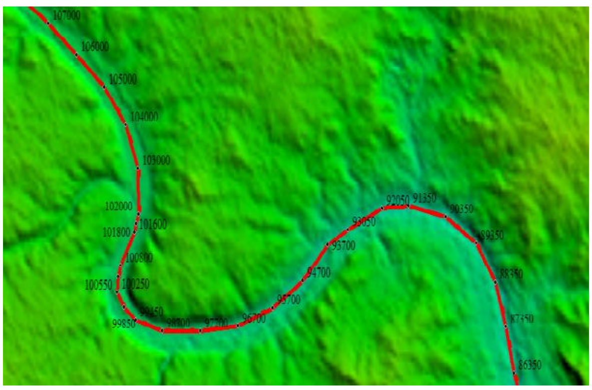


Fig. 2: surveyed cross-section in station (97700) **Fig. 3:** stationing the reach using Google earth



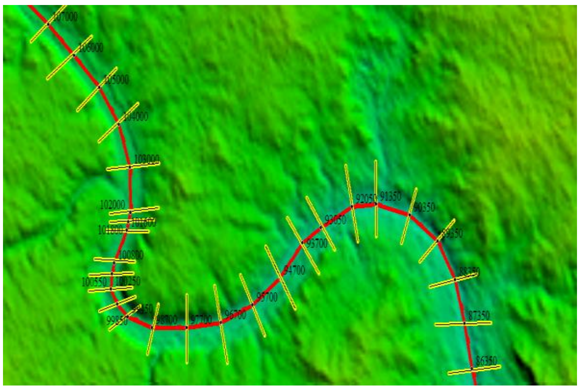


Fig. 4: stationed stream centerline, global mapper v 10 **Fig. 5:** cross-sections cut lines along the river reach global mapper v 10

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

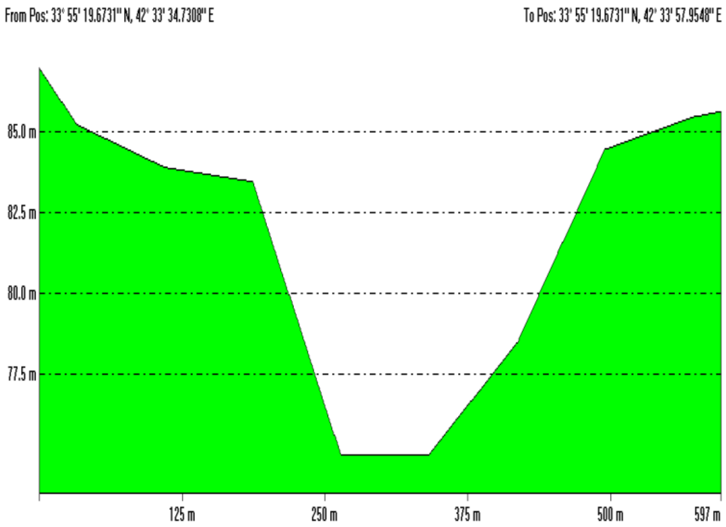


Fig. 6: generated cross-section at station (107000) by global mapper

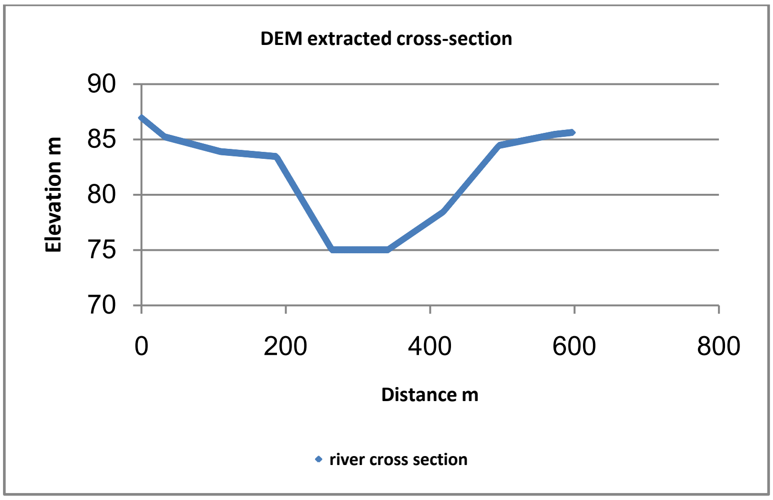


Fig. 7: DEM extracted cross-section for station(107000) processed with Excel

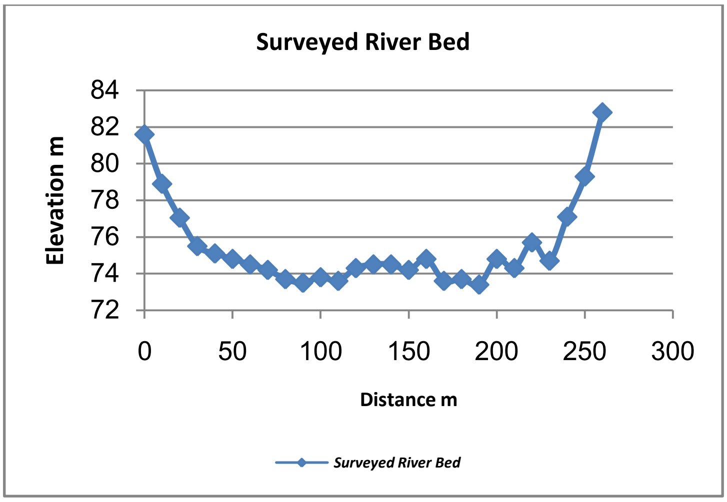


Fig. 8: the surveyed River bed for station(107000) processed with Excel.

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

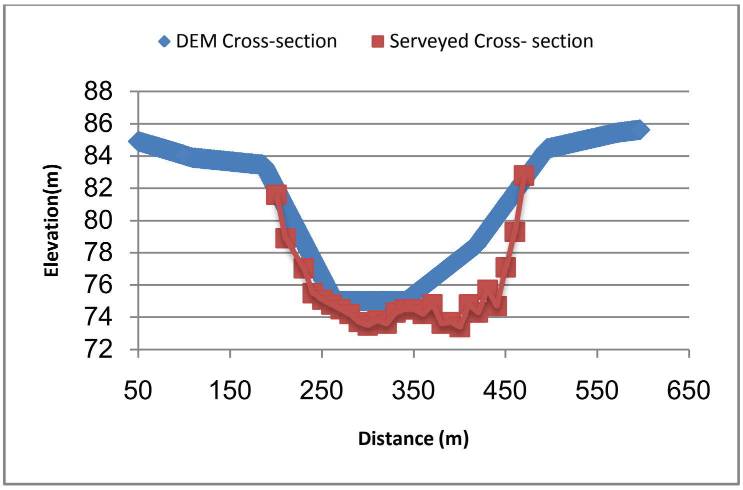


Fig. 9: the combined cross-section for station (107000).

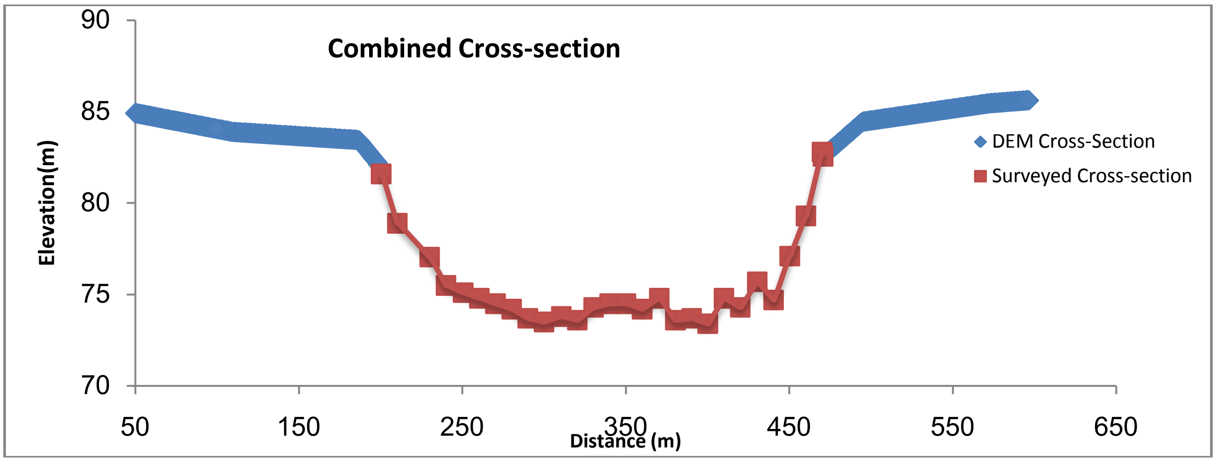


Fig. 10: the final cross-section for station (107000) processed by Microsoft Excel and ready to be entered to HEC-RAS

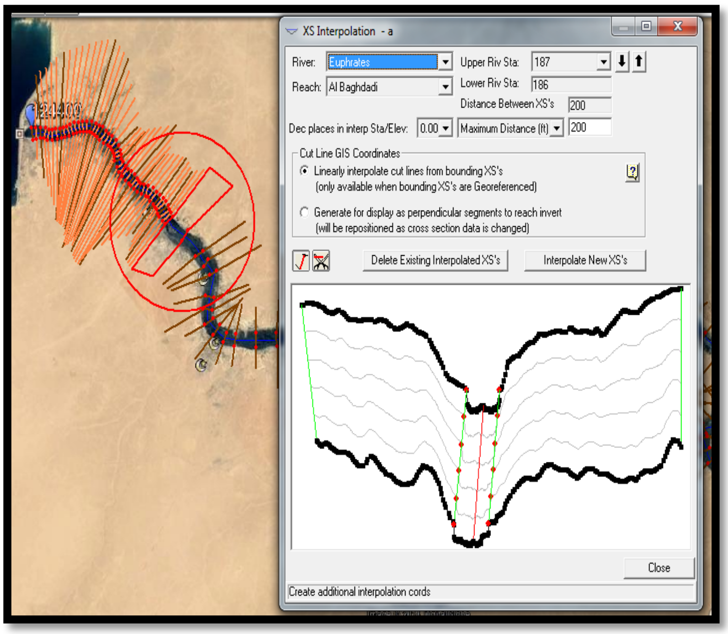


Fig. 11: cross-sections interpolation, HEC- RAS

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

Fig. 12: the study reach with complete cross- section set.

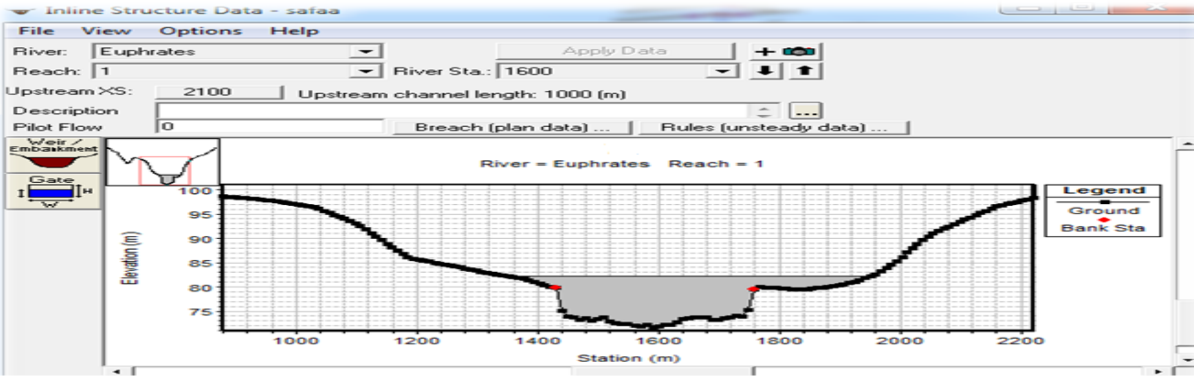


Fig. 13: inline structure data, HEC-RAS

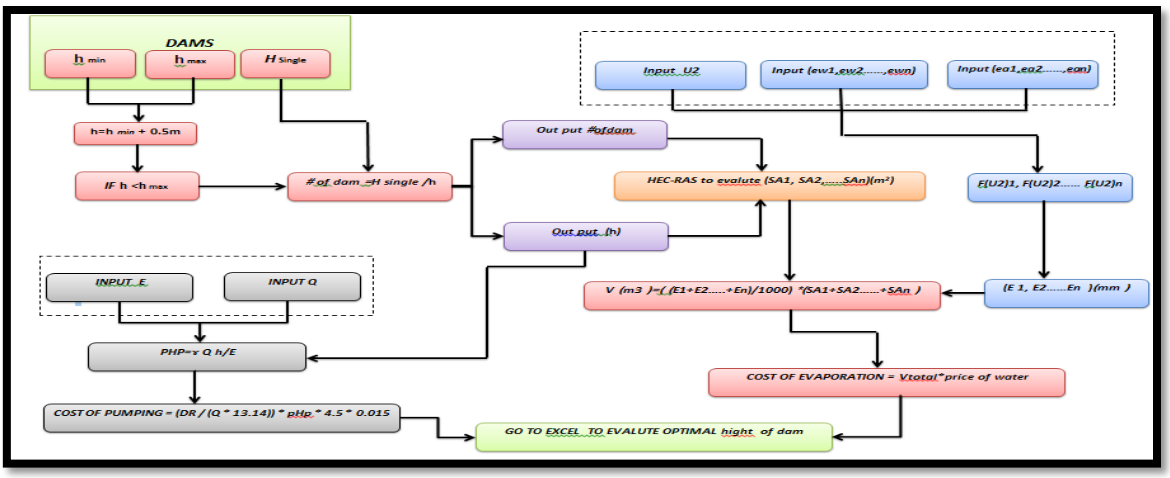


Fig. 14: OHSDM logic flow chart for VBA program

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

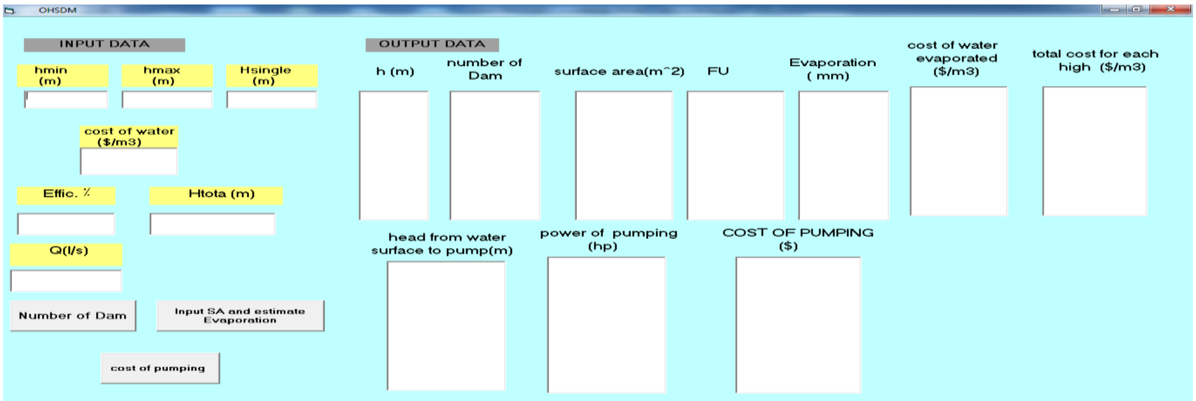


Fig. 15: OHSDM interface

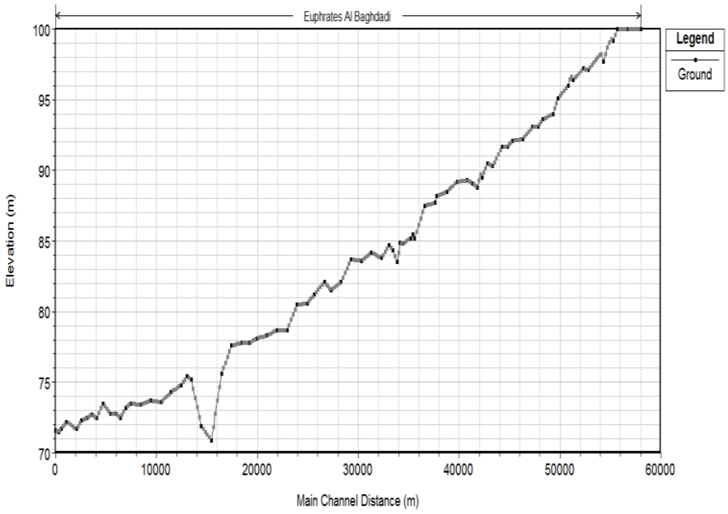


Fig. 16: study reach profile, HEC-RAS

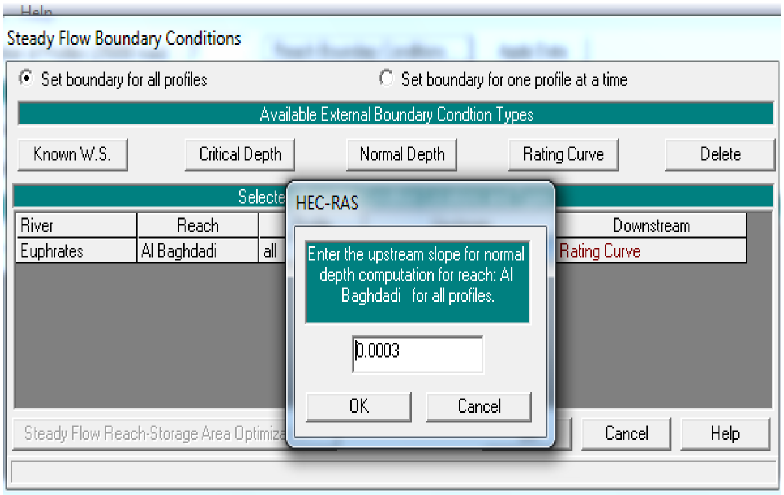


Fig. 17: normal depth boundary condition

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

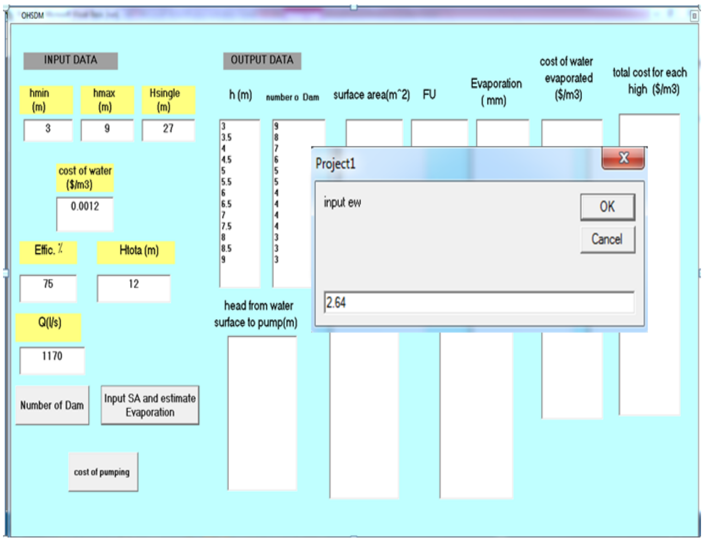


Fig. 18a: input the value of saturated vapour pressure (ew)

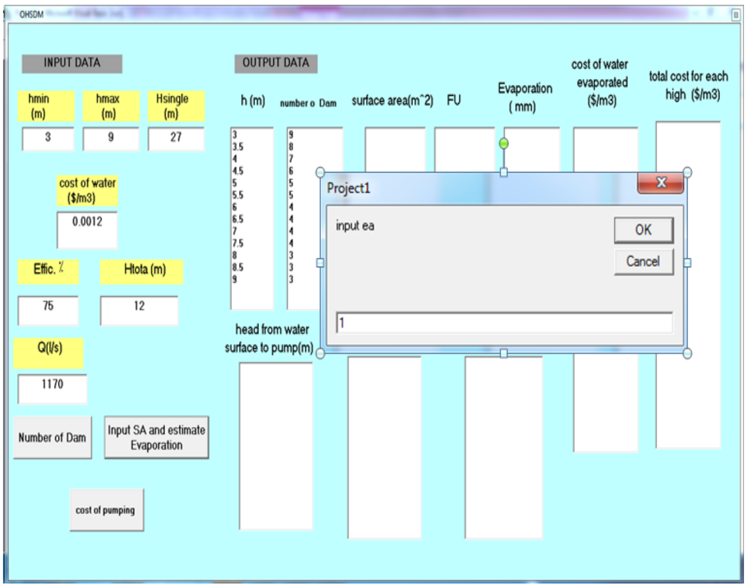


Fig. 18b: input the value partial vapor pressure of (ea)

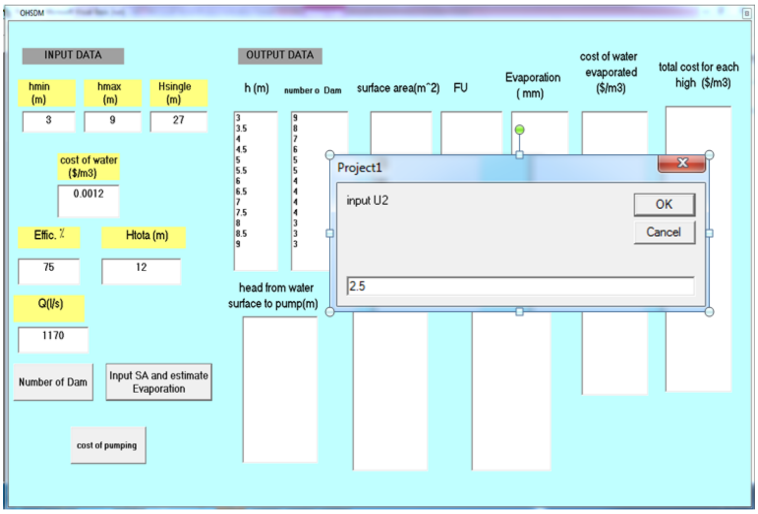


Fig. 18c: input the value of wind speed (U m/sec.)

Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

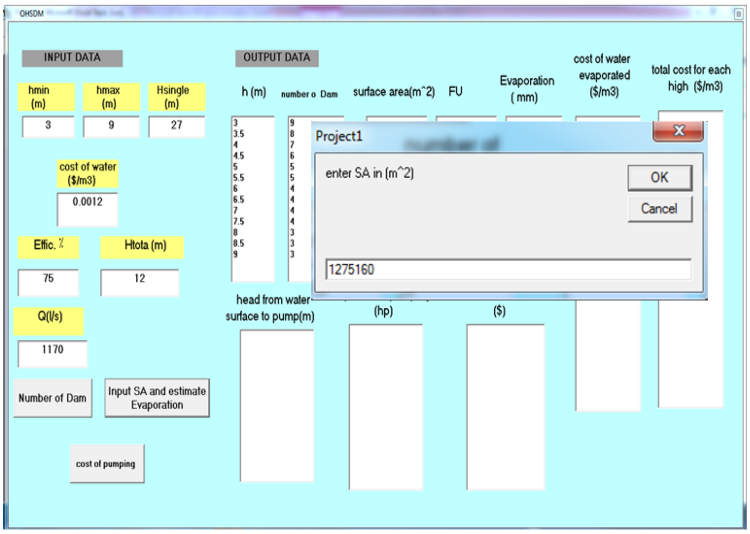


Fig. 18d: input the values of values Surface areas (SA) m^2

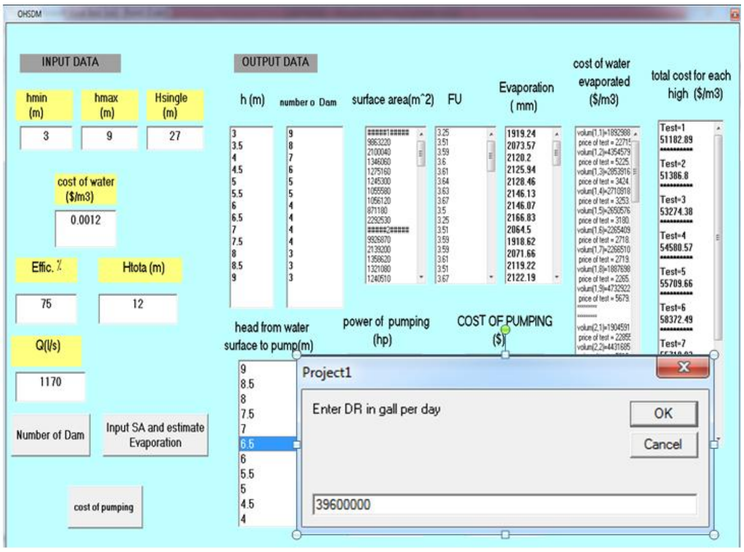


Fig. 18e: input the values of daily water requirement (DR).

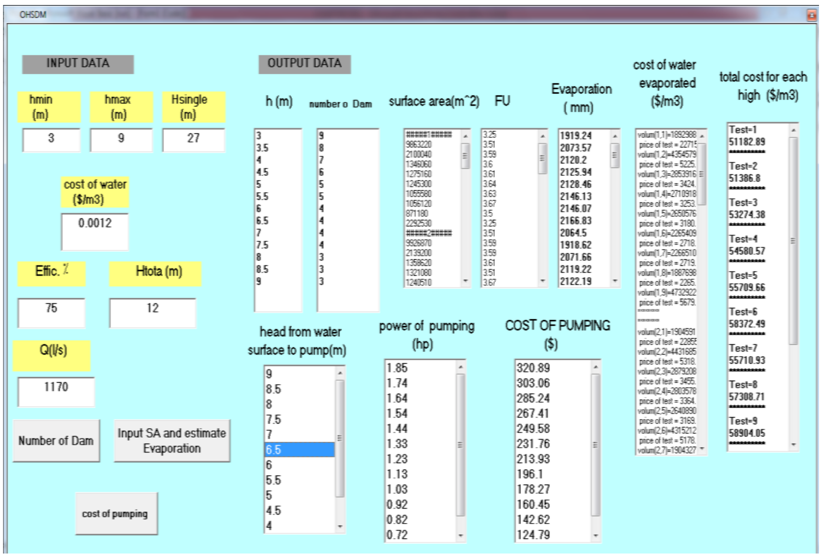


Fig. 18: OHSDM model RUN interface.

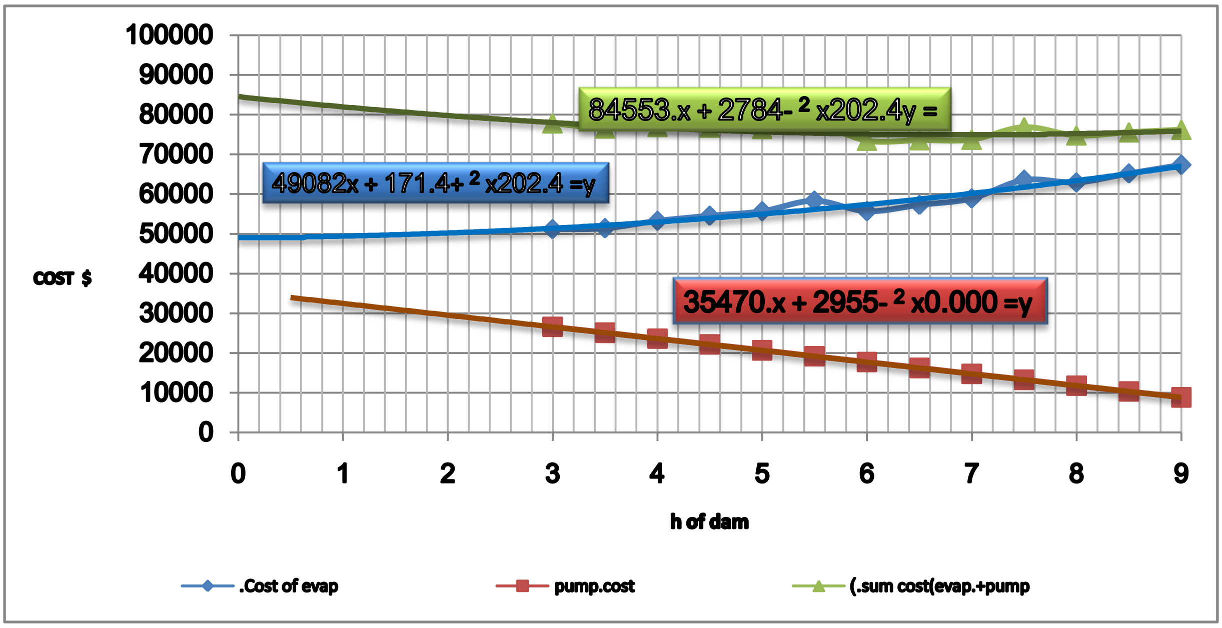


Fig. 19: Cost$ -height of small dams / with Excel 2010.

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Australian Journal of Basic and Applied Sciences, 8(18) December 2014, Pages: 672-685

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