Saving on Energy of and Determining the Best Location of Water Treatment Plant along Rivers Depending on the Effect of Broad Crested Weir on Dissolved Oxygen Concentrations in Water

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Abstract—**This research is concerned with studying the effect of installing a weir on dissolved oxygen (DO) concentrations in water at different water depths. The study was done using a laboratory flume to be under controlled conditions; i.e constant temperature and no pollution sources. Then a mathematical simulation part is done – using Streeter-Phelps equation- to the study to relate it to real life conditions and thus determine where is the best location to install a water treatment plant on a river. Although many studies were done on examining the effect of hydraulic structures on air entrainment in water, bubbles captures in water, rate of transfer of oxygen to the water, rarely was the direct effect of hydraulic structures on dissolved oxygen concentration values in water investigated. This study will be investigating the effect of broad crested trapezoidal weirs on the dissolved oxygen (DO) in water at different longitudinal stations along the same water streamline; as well as, at different water depths. The study was done on a flume in the hydraulics laboratory at the American University in Cairo. It was found that installing the weir increased the values of the DO in water (comparing its upstream side with the downstream side) by an average of 5.3% comparing all depths. It was also found that installing a weir on a river will result in shortening the time the DO takes to recover after a pollutant was dropped in a river by 39.5%.**

Index Terms—**Broad crested weir, dissolved oxygen, flume, hydraulic jump, hydraulic structures.**

I. Introduction

When a water treatment plant's location is chosen, one condition within the criteria of choosing is letting this treatment plant operate under the least energy operating conditions. This means that the treatment plant (and the intake from the river to the treatment plant) has to be located at a point on the river where the dissolved oxygen (DO) concentrations are high enough (around the 5 mg/l) in order for the treatment plant to save on cost and energy to treat this water and to make it contain the desired DO levels after treatment. When a hydraulic structure (i.e weir, barrage, control gate .etc) is placed in a waterway it will create difference in water levels between its upstream side and at its downstream side: a backwater curve is created at the upstream side and a hydraulic jump is formulated at the downstream side. The hydraulic jump causes turbulence in water and thus causes more air to be transferred to the water and hence the dissolved oxygen concentrations will rise in water because of the existence of that jump.

There are two broad categories of hydraulic jump, namely a) the free jump , and c) the submerged jump. [1]. The type of jump generated in this research is a free jump because it drags more air and hence DO into water more than the submerged jump. Extensive research in this area concerning the effect of the jump types on air entrainment was done by Brett [2]. Many studies were done to investigate the effect of various weir types and shapes on air entrained in water. Other studies were examining the effects of accessories that are installed with a weir (i.e. turbines) on the DO concentrations. But rarely were studies done examining the effects of weirs directly on the concentration values of dissolved oxygen. As for the studies done on the effect of weirs on air entrainment; the study done by Baylar was examining the free overfall jets from triangular sharp-crested weirs and their effect on the air entrainment rate and aeration efficiency. [3] Another study done by Kibel was investigating the effect turbine installation on dissolved oxygen concentrations within the weir pool. [4] .As for the studies done on the direct effect of hydraulic structures on dissolved oxygen concentrations in water, was the study done by El Baradei. But this study was investigating the effect of gates and not weirs on the DO concentrations in water. [5] The following study is addressing something new which is studying the effect of broad crested trapezoidal weirs on the Dissolved Oxygen (DO) concentrations in water. The study was done at two different water depths. The research was done in the laboratory flume that simulates real life open channel flow conditions. Based on the DO concentrations that where generated downstream the weir, a mathematical simulation was done to calculate the travelling time the water needs to reach these DO concentrations. It was found that installing a weir will reduce this travelling time.

II. Equipment

Three main equipment were used namely: a) The Open Channel Flow Simulator (Flume) Fig. 1, b) a broad crested weir (Fig. 2), and b) The Dissolved Oxygen measuring device (Fig. 3)

As for the flume, it is located in the hydraulics lab of the American University in Cairo. The flume is rectangular in shape and has the following specifications:

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The cross section is 10 cm in width (wetted width), and has a maximum water depth of 30 cm. The length of the flume it is 4 meters. The flume has two differential manometers attached to it to measure the flowing water head. One is a mercury manometer and the other is a water manometer. The water (tap water) inters the flume from a main source and after flowing along the 4 m flume, the water is discharged into a tank. Here water is collected and is pumped again to the flume. So it is a closed system where the water will circulate through the flume and the tank (Note: the main source valve is closed after reaching the desired depth of water in the flume and the system is left to be closed, ie water circulates through the flume and the tank). As will be noted at the coming section on methods, the flume will be working as open not closed system for some important reasons that will be discussed. Also it is important to mention that the tank itself where the water discharges has an outlet connected to a valve through which the water could be emptied. The emptied water discharges through the outlet to the drain of the laboratory. A broad crested trapezoidal weir is installed in the flume. As mentioned the weir is trapezoidal in shape with a height of 150 mm and 9 cm thickness. The top width is 18 cm whereas the bottom width is 25 cm.

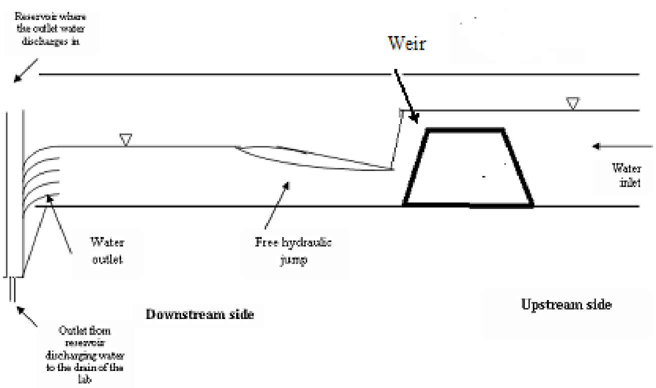

Fig. 1. Schematic sketch showing the flume system with the weir installed in it and the hydraulic jump generated downstream that weir.

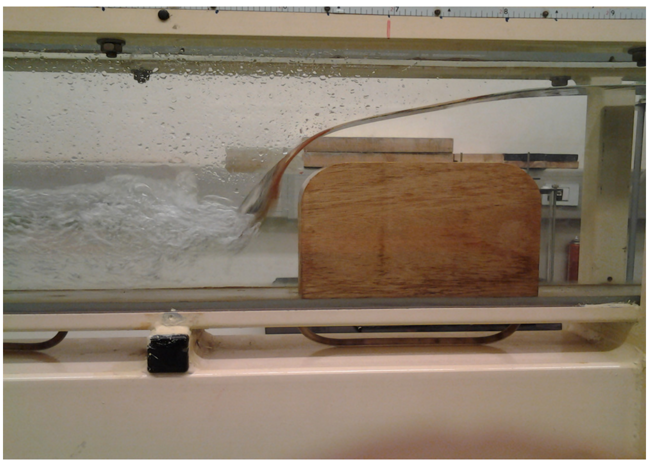

Fig. 2. The weir and the hydraulic jump generated at its downstream side

As for the DO measuring device; it is of the portable type "HANNA HI 9146". It is used to measure the DO concentrations in water. The probe is of the type HI 76407/4F with 4 m cable.

Fig. 3. The DO concentration measuring device HANNA HI 9146

III. Experimental Methods and Procedures

Tap water enters the flume from the main source. Water is left to fill the flume to the desired depth (the upstream and downstream depths that would ensure creating a free hydraulic jump downstream of the weir).

The jump is created by controlling a valve that would control in turn the discharge (volume flow rate) of water and hence the desired depths.

As mentioned before the flume system is supposed to be a closed system, but actually in this research it is functioning as an open system; meaning the water is going to be fed via the inlet (source) constantly (at a constant controlled flow rate) and it will discharge in the tank that is constantly discharging the water out to the lab drain. This is so because if the flume is left to work as closed system, then the water that is stored in the tank is going to be under the septic action of the tank and thus the dissolved oxygen will decrease in concentration with time. This was experimented on, namely the DO was measured in the closed system and was observed to decrease with time, but when the system operated as open system, this problem was get rid of. So to avoid this decrease in DO values with time, the water is kept running in an open system as was previously mentioned.

1) The weir was placed in the flume at the horizontal station referred to in the results' section.
2) The experiment was done at two water depths; namely: 26 mm and 46 mm measured from the bed of the flume.
3) Readings of the DO was taken via the DO measuring device HANNA at both previously mentioned depths and at many horizontal stations (longitudinal direction: parallel to the water flow) as will be clarified in the results section.
4) The depth at which the DO concentrations are measured , were measured by a vertical scale that is attachable to the flume.
5) The DO concentrations and the temperature at each horizontal station and at each vertical depth were measured. It was noted that the variations in water temperature at various station were very negligible so they do not affect the DO concentration. The temperature was around 27 degrees C.

6) The upstream (of the weir) and downstream water depths were measured. Also the reading of the differential water manometer was taken; this is so because there is an equation in the manual of the flume calculating the discharge "Q" from the manometer reading (see the results section).

IV. Results

For both experiments, namely at depth 26 mm and 46mm, the water manometer was adjusted to read the same reading and this is to ensure having the same discharge " Q " at both experiments. The reading of the differential water manometer was ΔH = 5.5 cm. [6]. The discharge is calculated via the following equation (which is provided within the manual of the flume as previously mentioned):

$$Q= 0.917\Delta H^{0.5} \quad (1)$$

Thus Q = 2.15 l/s

The horizontal stations (along the flume) that were taken in the case of both depths are:

At 3.3 m (upstream side of the gate), 2.85 m (beginning of the weir), 2.65 m (end of the weir), 2.5 m, 2.52 m (beginning of free hydraulic jump), 2.25 m (end of the free hydraulic jump), and 1.3 m (at the downstream side of the weir and after the hydraulic jump is finished with about 1 m as horizontal distance).The upstream depth (at station 3.3 m) was measured to be 23 cm and the downstream depth (at station 1.3 m) is 12 cm . The hydraulic jump starts downstream the weir at station 2.52 m and ends at station 2.25m. The depth at the end of the hydraulic jump was measured to be 5.5 cm (at station 2.25 m). The end of jump has depth of 11 cm. The depth of water at the beginning of the weir (station 2.85 m) is 7.5 cm. All depths are measured from the bed of the flume. The dissolved oxygen concentration readings were taken at each station at two vertical depths namely at a depth of 46 mm and a depth of 26 mm from the bed of the flume (see Table I):

TABLE I: DO Concentrations at Various Stations and Depths

Station in meters	DO concentrations in mg/l at depth 46 mm	DO concentrations in mg/l at depth 26 mm
3.30	6.00	6.00
2.65	6.27	6.27
2.50	6.35	6.33
2.52	6.34	6.31
2.25	6.39	6.39
1.3	6.27	6.27

The results revealed that the weir has an effect on the DO concentrations in water; namely the existence of the weir resulted in increasing the values of DO at the downstream side of the weir. This increasing effect could be seen particularly at the end of the hydraulic jump. Actually at the upstream side of the weir the DO concentration was 6 mg/l (for both depths, namely the 26 mm and the 46 mm), as the water flew over the weir the DO starts to increase till it reaches its peak at the end of the jump as mentioned before. These results could be interpreted as follows: as the water flows over the weir and goes through the hydraulic jump it will be aerated due to the turbulence that the jump creates and thus the DO values increase. As the water reaches the end of the jump; it would had been went through the utter most effect of the jump aeration and thus the DO values at the end of the jump are the highest. After the end of the jump and its effect the DO in water decreases again but still it remains higher than the upstream side of the weir. When comparing the DO concentrations at both depths. It was found that at depth 46 mm (measured from the bed of the flume) the DO levels were at two stations higher than at depth 26 mm. This is due to the fact that water at the higher depth (46 mm) is nearer to surface (air-water interface surface) than at the lower depth. This causes water to be aerated easily at depth 46 mm than at depth 26 mm. Because both depths are close to each other this difference in DO was only depicted in two points. Other depths couldn't be taken due to the operating rules of the DO measuring device probe (very near at the bed of flume there are lots of vibrations and hence the probe will not be able to measure well. As for the higher depths that are near to the air-water surface, the probe will not be covered with enough water so the readings will be not accurate).

To relate the experiment and the findings to real life conditions, a mathematical simulation was done (as if the weir is placed in a river but with same measured DO concentration as the laboratory) to calculate the travel time needed by water to reach the DO levels and the DO deficit levels measured downstream the weir at each station and at both depths. To do so, a point source of biochemical oxygen demand (BOD) of 11.9 mg/l was introduced to the simulation along with a DO saturation concentration to be assumed as 13 mg/l; the decay rate and the reaeration rate were taken to be 0.048/day and 0.052/day respectively. DO initial was taken to be 7mg/l and it is assumed that it happens (of course in the river at the point source) at the upstream of the weir. To do this simulation, the Streeter-Phleps equation was used. The simulation was done on depth 26mm as it has lower DO concentrations than depth 46mm, so depth 26mm is the critical case. See Table II.

TABLE II: Travelled Time to Reach Desired DO Levels at Various Stations and Depth 26 MM

Stations in meters	DO conc. in mg/l at depth 46 mm	DO conc. in mg/l at depth 26 mm	Travelled time in days at 26mm depth
3.30	6.00	6.00	4.13
2.65	6.27	6.27	2.70
2.50	6.35	6.33	2.42
2.52	6.34	6.31	2.51
2.25	6.39	6.39	2.16
1.30	6.27	6.27	2.70

V. Discussion and Conclusion

This research is done to examine the effect of a broad crested weir on the DO concentrations in water at different water depths. The study was made in the flume of the hydraulics laboratory of the American University in Cairo. A mathematical simulation was done on the experimental results to see the travel time needed by water to reach the DO levels measured downstream the weir if a BOD source was entered to the water. The following findings were reached:

1) It could be concluded that the DO concentration in water increases with decreased depth (measured from the surface of the water). So at depth 46 mm the DO concentrations were higher than at 26mm depth. It has to be noted here that those two depths are measured from the bed of the flume and hence the 46 mm depth is shallower (measured from the surface of the water) than the 26 mm depth. This finding agrees with the logic because as the depth (measured from water surface) increases it is harder for the gas (oxygen coming from air as part of the reaeration procedure) to enter the water and dissolve into it.
2) It could also be concluded that the DO concentration started low at the upstream side of the weir and it started to increase as the measurements were at the hydraulic jump. The DO concentrations reached their peak at the end point of the free jump. After that the concentrations started to decrease again. At both depths (26 mm and 46 mm) installing the weir increased the values of the DO in water (comparing its upstream side with the downstream side) by an average of 5.3% comparing all depths.
3) It was also found that installing a weir on a river will result in shortening the time the DO takes to recover after a pollutant was dropped in a river by 39.5% on average.

To conclude it was found from this in vitro conducted research that the weir and the free hydraulic jump generated at its downstream increase the value of DO concentrations in water. Thus if a water treatment plant (or its intake to the river) is installed at the river downstream a weir this will increase on the DO concentrations in the water to be treated and as a result will save on energy and cost of the water treatment plant.

REFERENCES

[1] R. H. French, *Open Channel Hydraulics*, Mc Graw Hill, 1985.
[2] B. L. Vallé and G. B. Pasternack; "Air concentrations of submerged and unsubmerged hydraulic jumps in a bedrock step-pool channel," *Journal of Geophysical Research*, vol. 111, F03016, PP. 12, 2006.
[3] A. Baylar, K. Ozgur, and E.M. Emiroglu, "Modeling air entrainment rate and aeration efficiency of weirs using ANN approach," *G. U. Journal of Science*, vol. 22, no.2, pp. 107-116, 2009.
[4] P. Kibel and C. Toby, "Castleford mill hydro power proposal River Aire fisheries assessment," Report by: Fishtek consulting, 2009.
[5] S. El Baradei; "Effect of free hydraulic jump on dissolved oxygen concentrations in water at different vertical control gate openings," A study done in vitro," *ICASTOR Journal of Engineering*, vol.4, no.3, pp. 281-291, 2011.
[6] S. A. El Baradei, "Effect of broad crested weir on dissolved oxygen concentrations in flume water at different water depth," *ICASTOR Journal of Engineering*, vol. 5, no. 3, pp. 185 – 193, 2012.

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