HYDRAULIC PERFORMANCE OF INLAND PONDS CIRCULATION SYSTEMS

Ashraf M. El-Moustafa[1] **Mohamed H. Elgamal**[2] **Hesham Badry**[3]

Abstract

Treatment of golf course ponds has recently received a lot of attention as a result of the vast recreational development in the Arab region. Generally these ponds experience some water deterioration problems. Accordingly developers usually use different treatment approaches including the chemical, surface circulation and aeration techniques. In this study, the surface circulation and the bottom aeration were investigated using two different hydrodynamic models. Two dimensional hydrodynamic model (RMA2) was used to study the ponds system under surface circulation technique while a well known CFD model "FLUENT" was used to investigate and study the bottom aeration technique. The results of the two models lead to the best arrangement to be implemented in the pond system to improve the pond water quality and to decrease or minimize the ponds deterioration. The study also concluded that the circulation technique will require high capital and operation cost while the bottom aeration techniques require lower capital and operation cost. More studies are required to better evaluate the two systems from the quality point of view where the water quality should be studied rather that the hydrodynamics only.

Introduction

Tourist and recreational related developments have expanded considerably in the whole Arab region especially in the last century as a result of gas price booming. Example of these developments includes the construction of recreational and/or tourist resorts that usually contain some attractive landscaping water-bodies such as closed ponds or a cascade of inland artificial lagoons.

Golf Course ponds serve many purposes. They increase the added value of the project area and they work as water traps to golfers as they make golf courses more challenging which increases the popularity of the course and attracts more golfers to the project area.
Golf course ponds work also as nutrient catchment basins. This is where the problems occur. Due to the necessity of high nitrogen and phosphorous fertilizers used to keep turf grass looking in good conditions; the ponds are the recipient of these nutrients and they could quickly start to grow algae and other invasive plants.

1 Assistant Professor Irrigation and Hydraulics Department - Faculty of Engineering – Ain Shams University. elmoustafa010@yahoo.co.uk
[2] Assistant Professor Hydraulics Department - Faculty of Engineering – Cairo University
[3] Associate Professor Irrigation and Hydraulics Department - Faculty of Engineering – Ain Shams University.

Inland and closed pond systems are vulnerable to lack of aeration and the stagnant water problems which result in misbehavior of the objective water bodies. The poor aeration problem helps in the formation of algae that consumes all the available nitrogen then it dies and falls to the bottom of the pond, where they decompose using oxygen which is not replaced. The absence of oxygen in the water allows plant nutrients to dissolve into the water causing general water quality deterioration, change of water pond color and bad odor release. Therefore, one of the major concerns for pond owners all over the world is to keep their ponds clear and algae free.

For a long time, pond chemicals are being used to make golf course ponds look pretty and to get rid of algae problems. However, chemicals have a dramatic affect on the environment due to the seepage of these chemicals into nearby water ecosystems.

Stagnant water in golf course ponds is unpleasant to look at and could produce a terrible smell. It can also be extremely dangerous. Stagnant water is not only an unsuitable from the environmental point of view; it could also lead to unhealthy conditions that provide an excellent breeding ground for mosquitoes.

In order to get rid of the aforementioned problems, different treatment techniques have been proposed and applied. These techniques include chemical treatment techniques, bottom aeration techniques, surface aeration techniques and circulation techniques. This paper aims to evaluate and study the surface circulation technique and the bottom aeration technique.

Circulation Technique

This system is based on circulating the water in the pond by taking the water from the pond, passing it through a filter then pumping it back to the pond. This process increases the aeration rate at the surface and minimizes the stagnation zones within the pond, Figure 1.

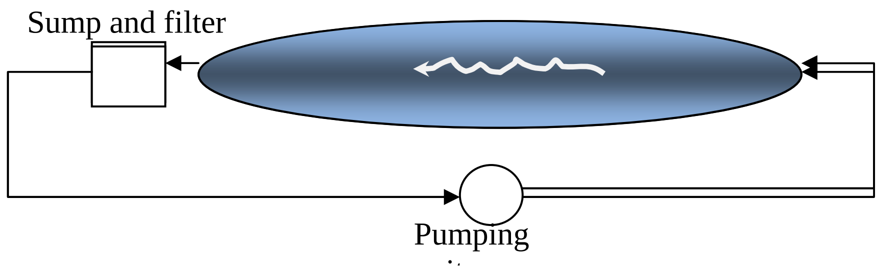


Figure 1: Schematic diagram of the main elements in the circulation system

In order to enhance the circulation efficiency and to eliminate the dead stagnation zones, some of the designers propose to use several nozzles for feeding water into the pond and a fewer number of drains for taking water out of the lagoon as per a circulation manner, refer to Figure 2.

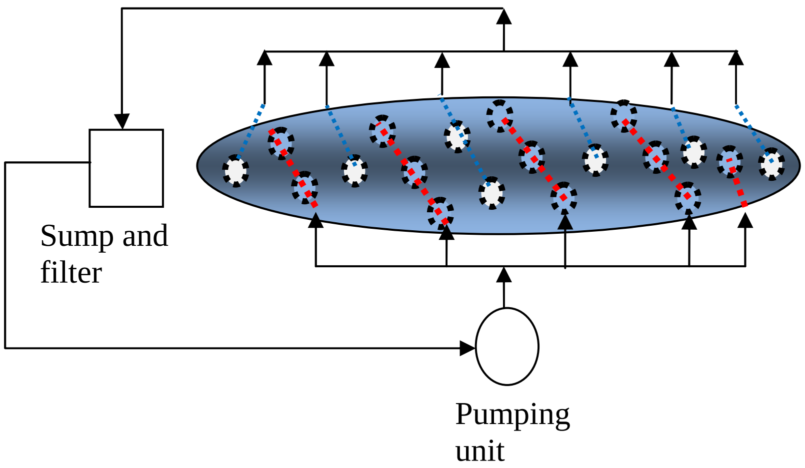


Figure 2: Distribution of sink and source nozzles for best flow circulation efficiency

Aeration Techniques

Bottom aeration Technique

Bottom aeration concept is based on maintaining a minimum level of oxygen within the whole water depth so as to get rid of the nutrients and bacteria needed for algae and weeds bloom.

Different bottom aeration methods are applied including the use of electrical aerators or the use of windmill aerators. In these aeration techniques, compressors are being used to directly pump or inject air in a continuous manner within the water body of the pond. The pumped air will continuously help in raising the concentration of the dissolved oxygen in the nearby hood of the injection air point moreover, it will help in generating secondary current and big water eddies of length scales comparable to the pond depth and this will create water circulation in the whole pond and thus the high concentration of the dissolved oxygen will be transported via diffusion and advection due to the created circulation, refer to Figure 3.

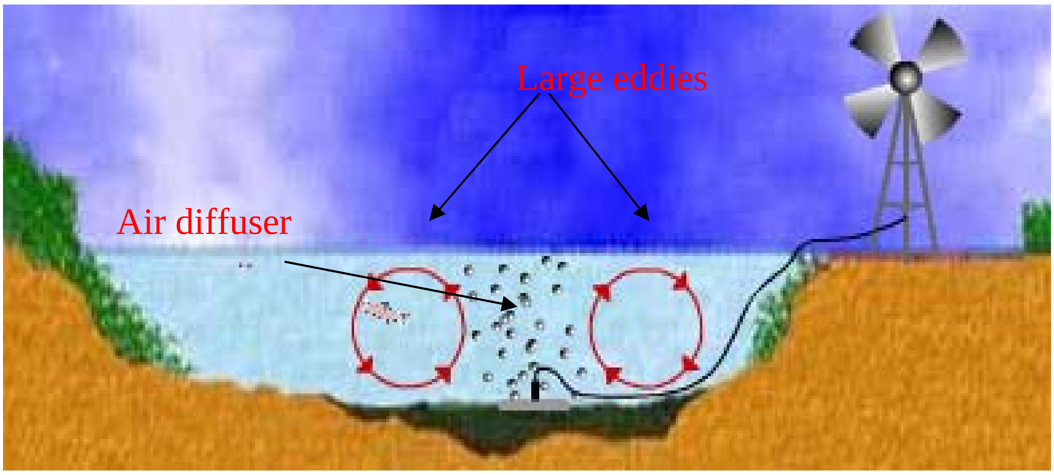


Figure 3: Generation of large scale eddies due to air injection (aeration process)

Pond Circulation using 2 Dimensional Modeling

Horizontal two dimensional hydrodynamic model was built for the pond studied, Figure 4.

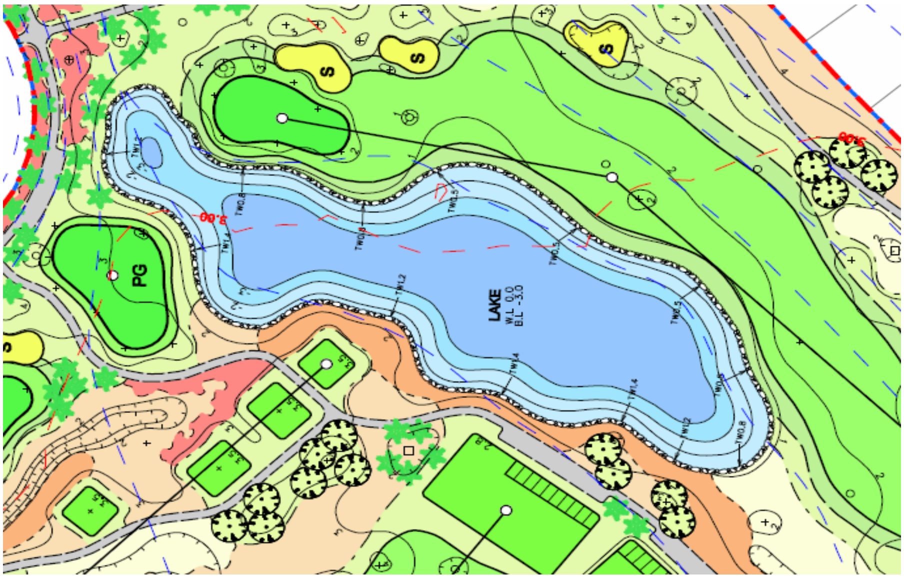


Figure 4, Selected pond for hydrodynamic performance test

The RMA2 model was used in the development of the pond model. The original RMA2 was developed by Norton, King and Orlob (1973), of Water Resources Engineers, for the Walla Walla District, USA Corps of Engineers, and delivered in 1973. Further development was carried out by King and Roig at the University of California, Davis. Subsequent enhancements have been made by King and Norton, of Resource Management Associates (RMA), and by the USA ERDC at the Waterways Experiment Station (WES) Coastal and Hydraulics Laboratory.

RMA2 is a two-dimensional depth averaged finite element hydrodynamic numerical model for subcritical, free-surface two-dimensional flow fields. RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows.

RMA2 Mesh Generation

After creating a polygon, which encloses the study area, a mesh was generated to fill the interior of a polygon. This technique used for mesh generation uses the existing spacing on the polygons to determine the element sizes on the interior.

The mesh size was determined based on the capability of the available hardware as increasing the mesh density will cause the solution time to increase. The spacing between nodes was chosen to be at an average of 20 meters, Figure 5.

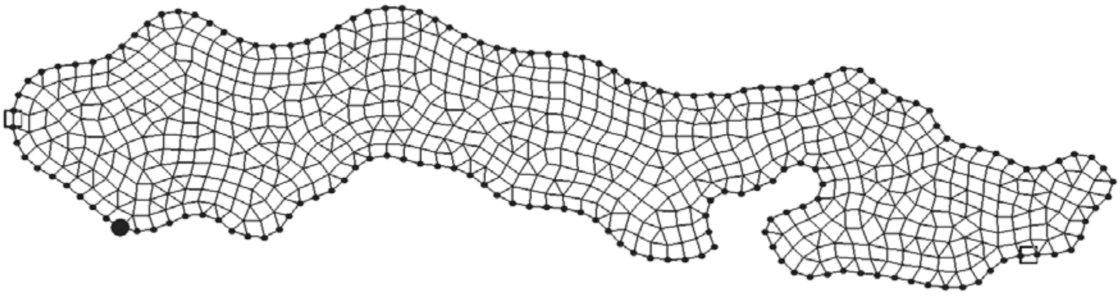


Figure 5, The generated mesh

Bathymetry Interpolation

The contours of the pond bathymetry were used to form digital terrain surface of the bed using a GIS software. This surface will be used as a source of levels on scatter points grid. After the mesh generation, the scatter points obtained from the GIS were used to form a triangles irregular net (TIN) which was used in the interpolation of the bed levels. One of the most commonly used techniques for interpolation of scatter points is the inverse distance weighted (IDW) interpolation method. Inverse distance weighted methods are based on the assumption that the interpolating surface should be influenced mostly by the nearby points and less by the more distant points. The interpolated surface figure 6 is a weighted average of the scatter points and the weight assigned to each scatter point diminishes as the distance from the interpolation point to the scatter point increases.

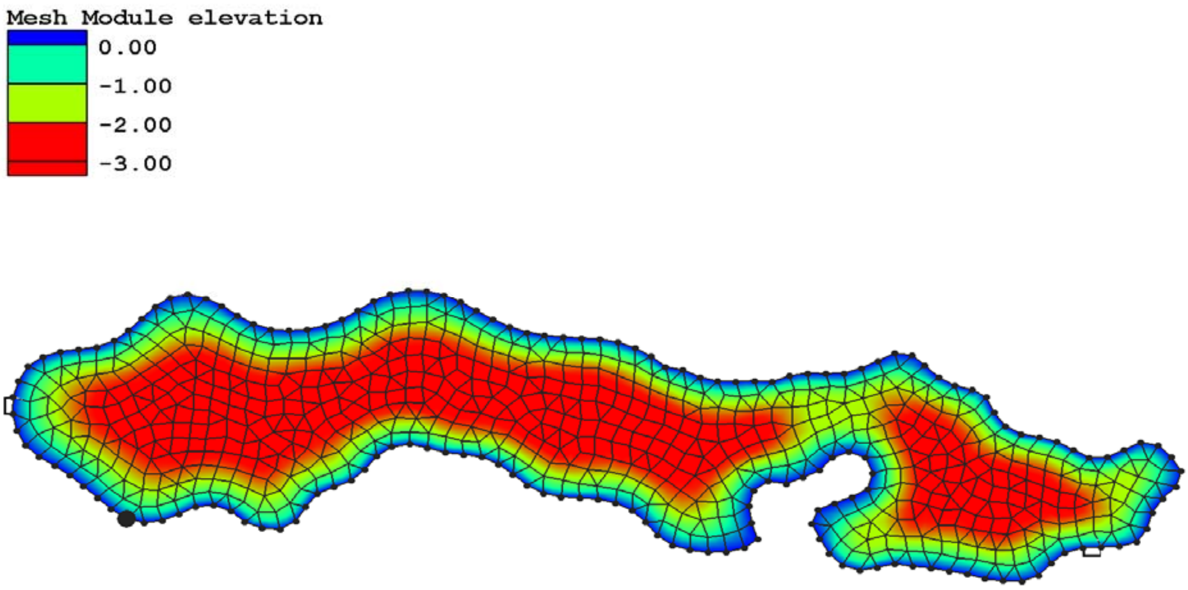


Figure 6, Interpolated Bathymetry

Specifying Initial and Boundary Conditions

Boundary conditions usually take the form of a specified total discharge at inflow sections and fixed water surface elevations or rating curves at outflow sections. All boundary conditions hold from one time step to the next unless they are specifically modified. RMA2 does not permit a new boundary condition location to be specified in mid-run, nor does it allow a change in the type of boundary condition at a previously specified boundary location.

Initial Conditions

Initial conditions are important, even for steady flow, since they are usually used as the initial guess in the iterative solution procedure. A good guess will significantly reduce the total run time and may make the difference between a stable run and an unstable one. The flow was assumed stagnant (at rest) with a water level equal to zero at the beginning of the simulation as this is the condition that the pond will have before the start of the circulation system.

Upstream Boundary

The upstream boundary was proposed as an inflow from a weir with linear distributed flow along its crest length, the flow rate was calculated based on the following equation;

$$Q = \frac{Volume \times No.\ of\ circulation / day}{pump\ operating\ hours / day} \tag{1}$$

Where; Q is the pumping flow rate in m^3/s

The recommendations of North America Lake Management Society (NALMS) is to circulate the water volume of the pond 7 times every day in this hot weather area as high temperature water cannot hold oxygen efficiently and the need of circulating the flow to allow for oxygen to penetrate the inflow and maintain the oxygen level at its acceptable range. The 10 pumping hours per day for the pond under study, 30025 m^3 in volume, allowed a pumping rate of 5.84 m^3/s. The location of the weirs where proposed in several locations as alternatives to test the hydraulic performance of the flow field inside the pond. The objective of changing the weir location is to find the best velocity vector inside the pond that insure no formation of dead zones (stagnant flow area).

Downstream Boundary

The water level at the downstream was assumed to be equal to 0.20 m as a generated head U.S. the overflow weir, Figure 7. The circulation of flow will keep the system in its original case and the overflow weir should be dimensioned to assure that the generated afflux will cause no flooding to the surroundings.

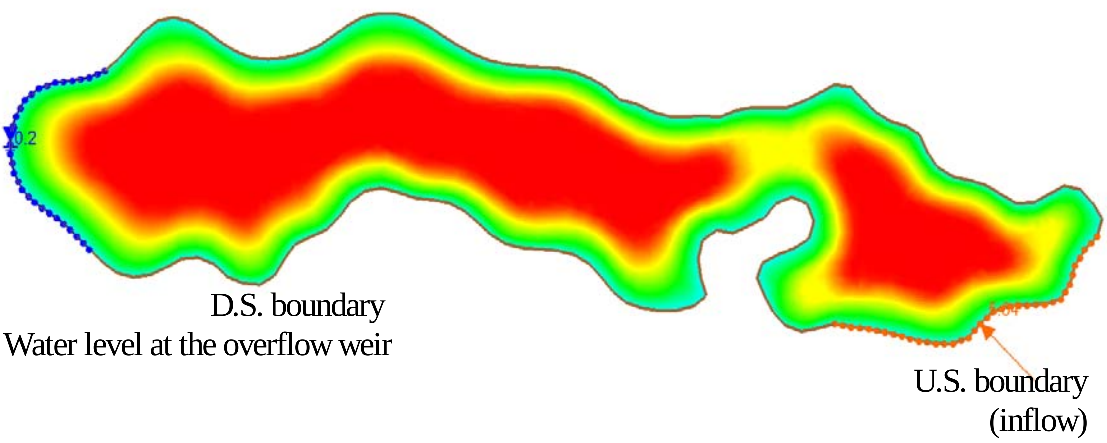


Figure 7, Model boundaries

RMA2 Model Results

The pumped flow caused a velocity magnitudes ranging between almost stagnant flow and 0.8 m/s however the legend displayed in Figure 8 shows the maximum value of 0.1 m/s as most of the high velocity occurred at the upstream and down stream boundaries.

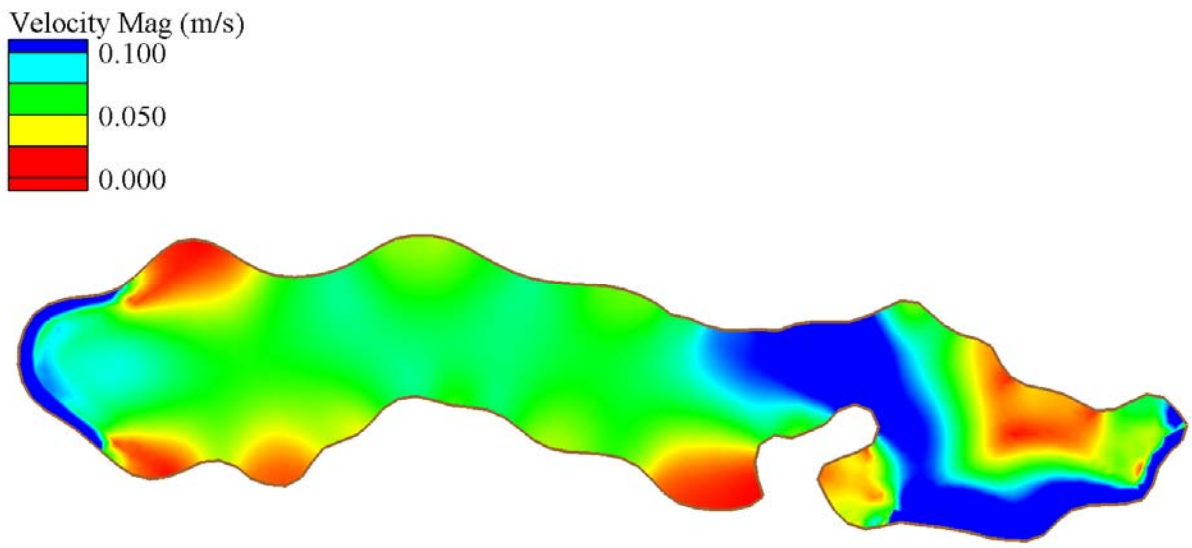


Figure 8, Velocity magnitudes for an inflow of 5.84 m^3/s

Stagnant flow areas, identified by the dark orange colour, may cause water quality problems to the water pond therefore many other inflow weirs distribution layouts along the pond boundary were tested. The aim is to assure the continuous flow all over the pond and to limit the stagnant flow areas as much as possible. Based on the results of those alternatives, it was decided to distribute the flow along the sides in four locations. The first is discharging the water parallel to long axe of the pond with 0.75 of the pumped water the other quarter is distributed in 4 locations where stagnant flow is expected. The velocity field resulted, Figure 9, and velocity vectors, Figure 10, show almost no stagnant area.

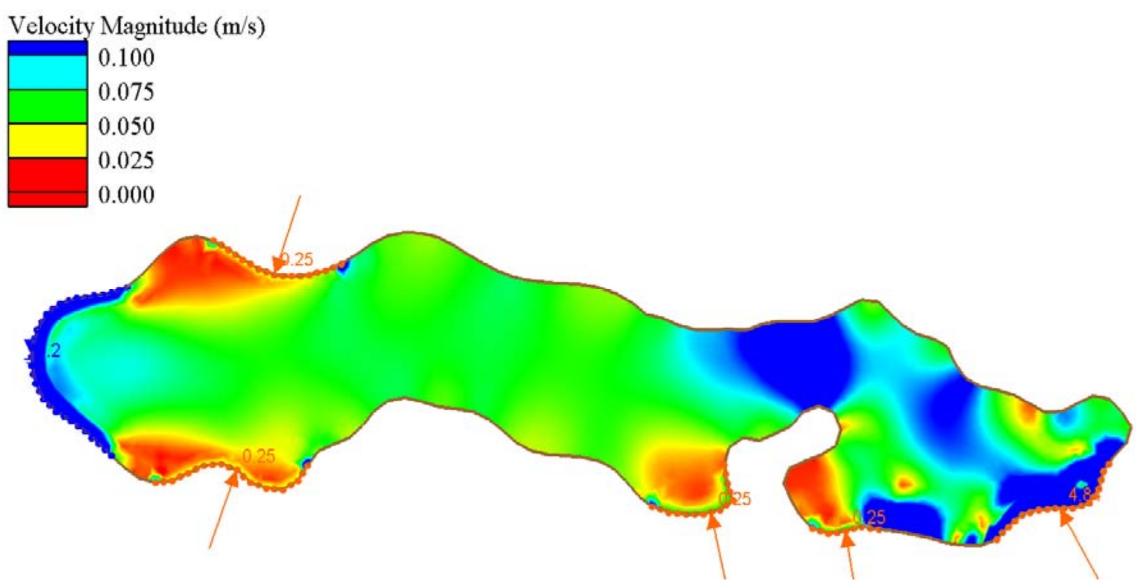


Figure 9, Velocity magnitudes for the chosen weirs layout

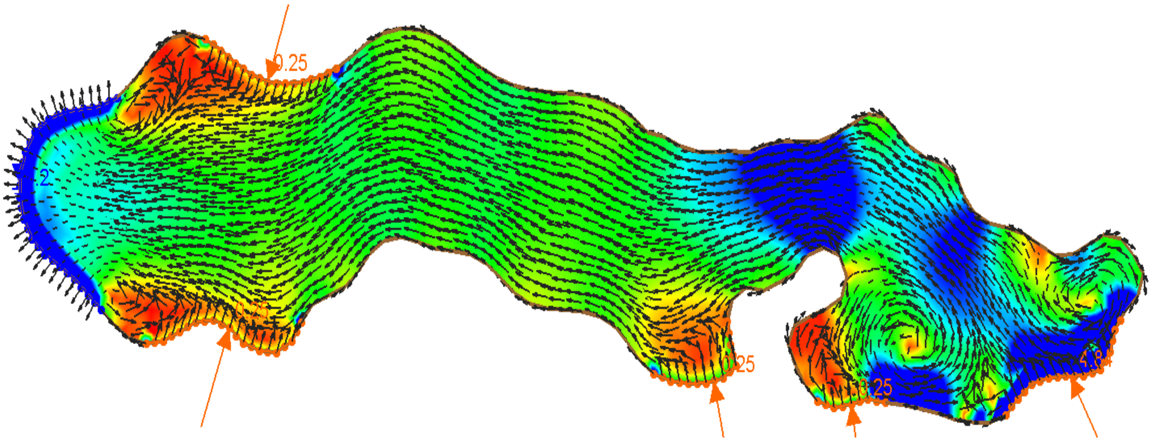


Figure 10, Velocity vectors for the chosen weirs layout

Pumping power reduction

The problem of the pumping horse power was then addressed. To reduce the pumping power and in the same time insure flowing water along the day it was proposed to pump the required volume through two time intervals of 8 hrs each during the day with a break of another 8 hours in between to facilitate the maintenance if required. The pumping rate for this scenario was found to be equal to 3.65 m^3/s which will reduce the pumping power to 62.5 %. This scenario was tested and the results are represented in Figures 11 and 12.

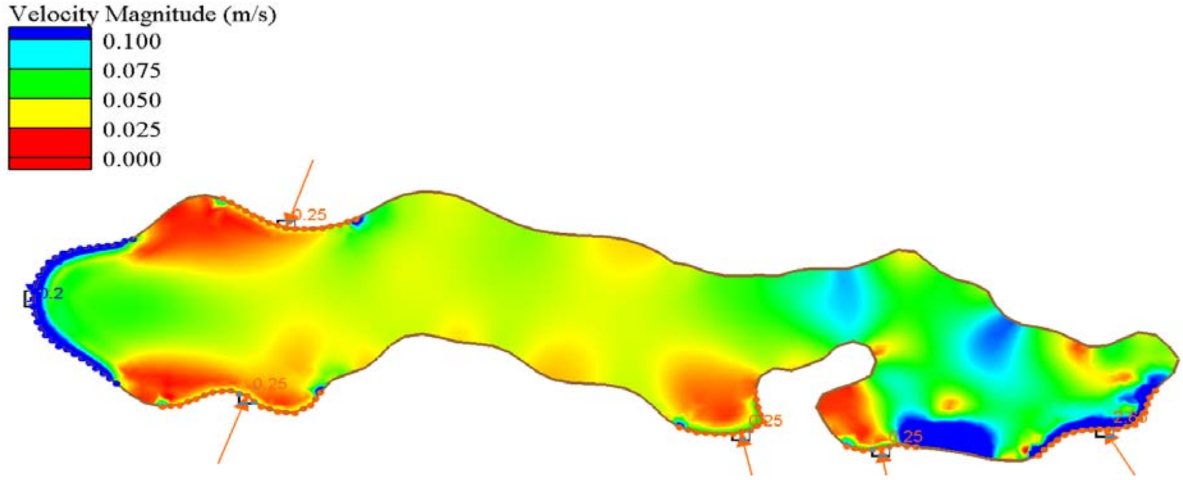


Figure 11, Velocity magnitudes for the reduced pumping rate scenario

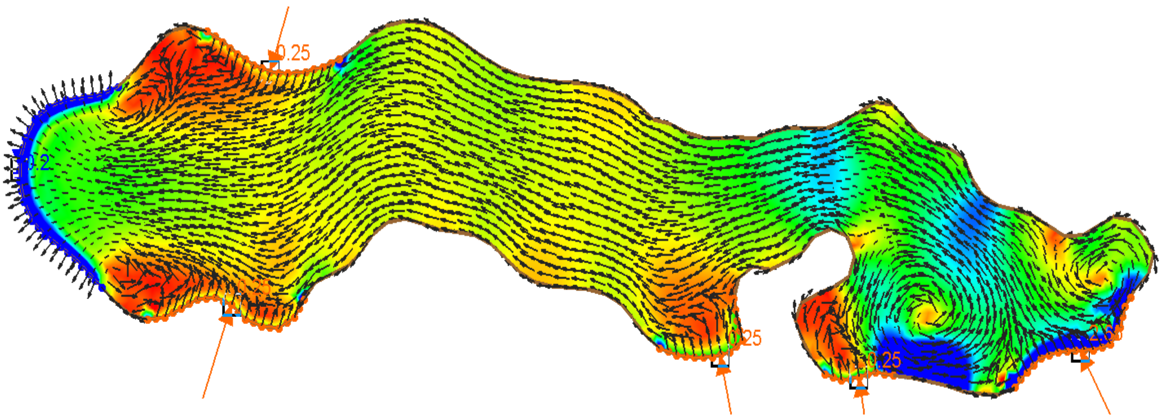


Figure 12, Velocity vectors for the reduced pumping rate scenario

Modeling Aeration technique Using Fluent

In order to check the efficiency of the proposed aeration system and to determine the exact spacing of the air diffusers, a Computational Fluid Dynamic model was used. One of the objectives of this analysis is to investigate the water circulation produced as a result of the air injection. The Fluent package has been chosen because it is capable to solve multiphase flow that comprises the interaction between the injected air and the water. Moreover, it can model transport species and nutrients as a result of the air-injected induced velocity field.

Fluent package

The broad physical modeling capabilities of FLUENT have been applied to industrial applications ranging from air flow over an aircraft wing to combustion in a furnace, from bubble columns to glass production, from blood flow to semiconductor manufacturing, from clean room design to wastewater treatment plants. The ability of the software to model in-cylinder engines, aeroacoustics, turbomachinery, and multiphase systems has served to broaden its reach.

Today, thousands of companies throughout the world benefit from the use of this important engineering design and analysis tool. Its extensive range of multiphysics capabilities makes it one of the most comprehensive software tools available to the CFD community. With its long-standing reputation of being user-friendly and robust, FLUENT makes it easy for new users to come up to productive speed.

The capabilities of Fluent can be summarized as follow:

- The model solves laminar as well as turbulent flow;
- The model can solve gravitational as well as pressurized induced flow;
- The model can handle free surface flow problems;
- The model is powered by different turbulence models including mixing length and eddy viscosity models; k-e models, k-w models, Reynolds stresses model and LES models;
- The model can handle multiphase flow and nutrient transport.

Model setup and problem idealization
General assumptions

In order to simulate the induced circulation and the generated eddies as a result of air injection, the pond has been idealized as 2D vertical domain and the lateral flow variations have been neglected.
The following assumptions have been considered:

- All the air diffusers are similar therefore part of the domain needs only modeling. This assumption is highly crucial to minimize the number of nodes and the time of computation in the solved domain.
- The flow is assumed turbulent and k-e model is adopted as a closure to the conservation equations.
- The standard “universal” coefficients of the k-e model have been adopted.
- The size of the air diffuser and the air holes are assumed 20 cm and 1mm respectively.
- The rate of air injection is assumed constant and equals 1.5 ft^3/min.

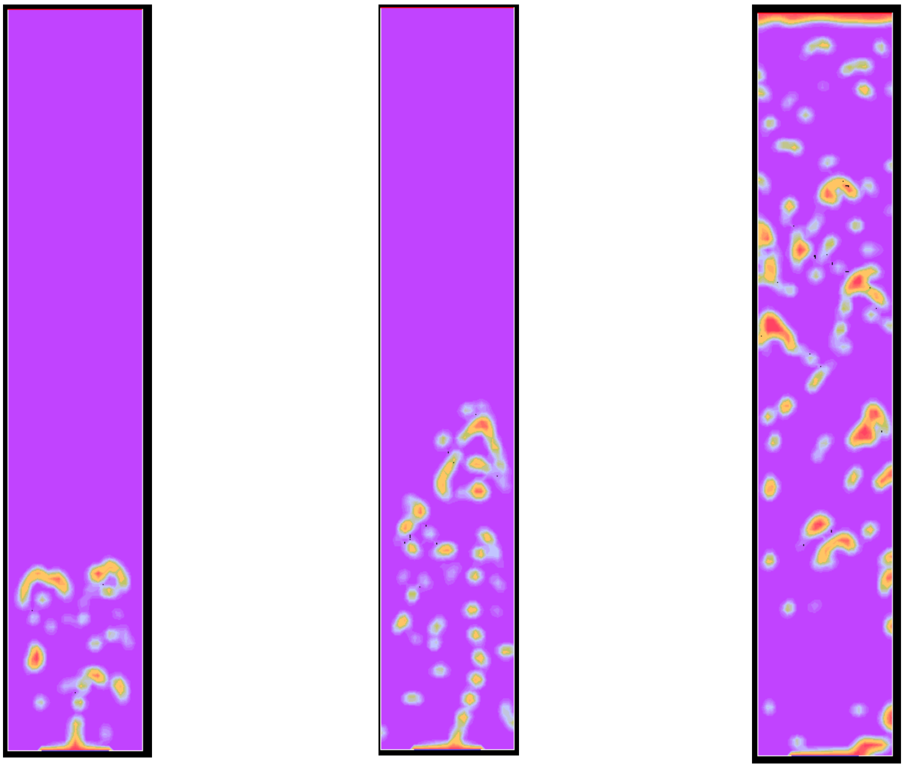
- It has been assumed that the maximum spacing between the adjacent air diffusers is less than 85m.

Near flow field of the air diffuser

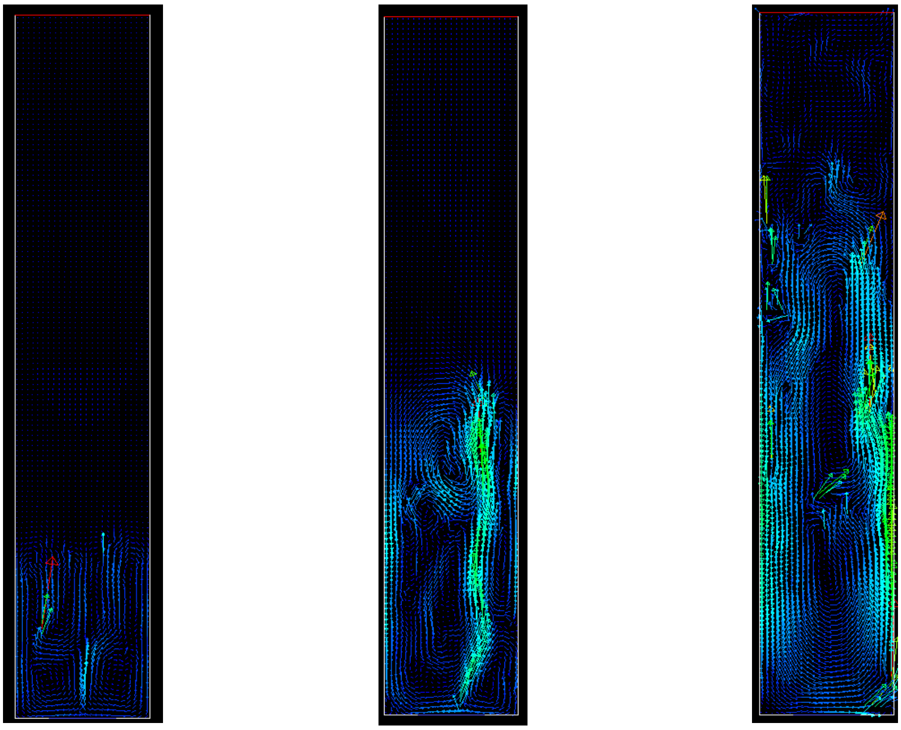
As a first step and in order to study the near flow field of the air diffuser, a numerical model has been constructed to simulate the flow field in the nearby-hood of the air diffuser. To acheive this objective, a water column of 25cm in width has been considered and the diffuser is located in the middle of the domain.
This step was developed to investigate the following:

1- The model performance as two phase flow
2- The speed of particles movement to the pond surface and
3- The possibility of the model to be used in an average scene.

Figure 13 presents the Fluent simulation of the transportation of air bubbles from the diffuser and the corresponding induced velocity fields.



a) Sequence of release of air bubbles from the air diffuser (t=1 sec, 1.7sec, 5 sec)



b) Velocity vector

Figure 13. Effect of air bubbles release in the near field (t=1 sec, 1.7sec, 5 sec)

The model showed the flow pattern in two phase flow where the air bubbles reach the surface of the pond in 5 seconds. The model also showed that the system can be averaged which leads to the second step.

The second step simulates the pond area between any two successive air diffusers as presented in the next item.

Numerical grid and boundary conditions

Based on the similarity assumption, the model was used to simulate the domain shown in Figure 14. The adopted boundary conditions are: specified velocity (velocity-inlet) at the diffuser holes; pressure outlet at the water surface and wall boundary elsewhere.

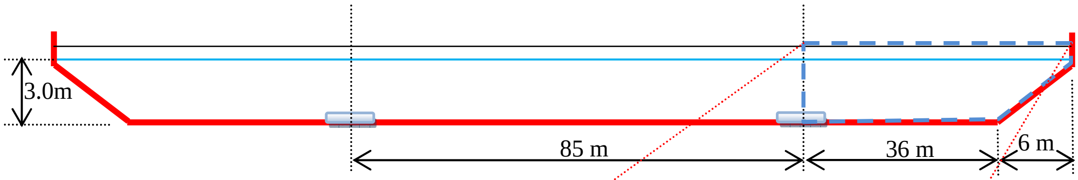


Figure 14. Typical air diffuser arrangement and chosen domain

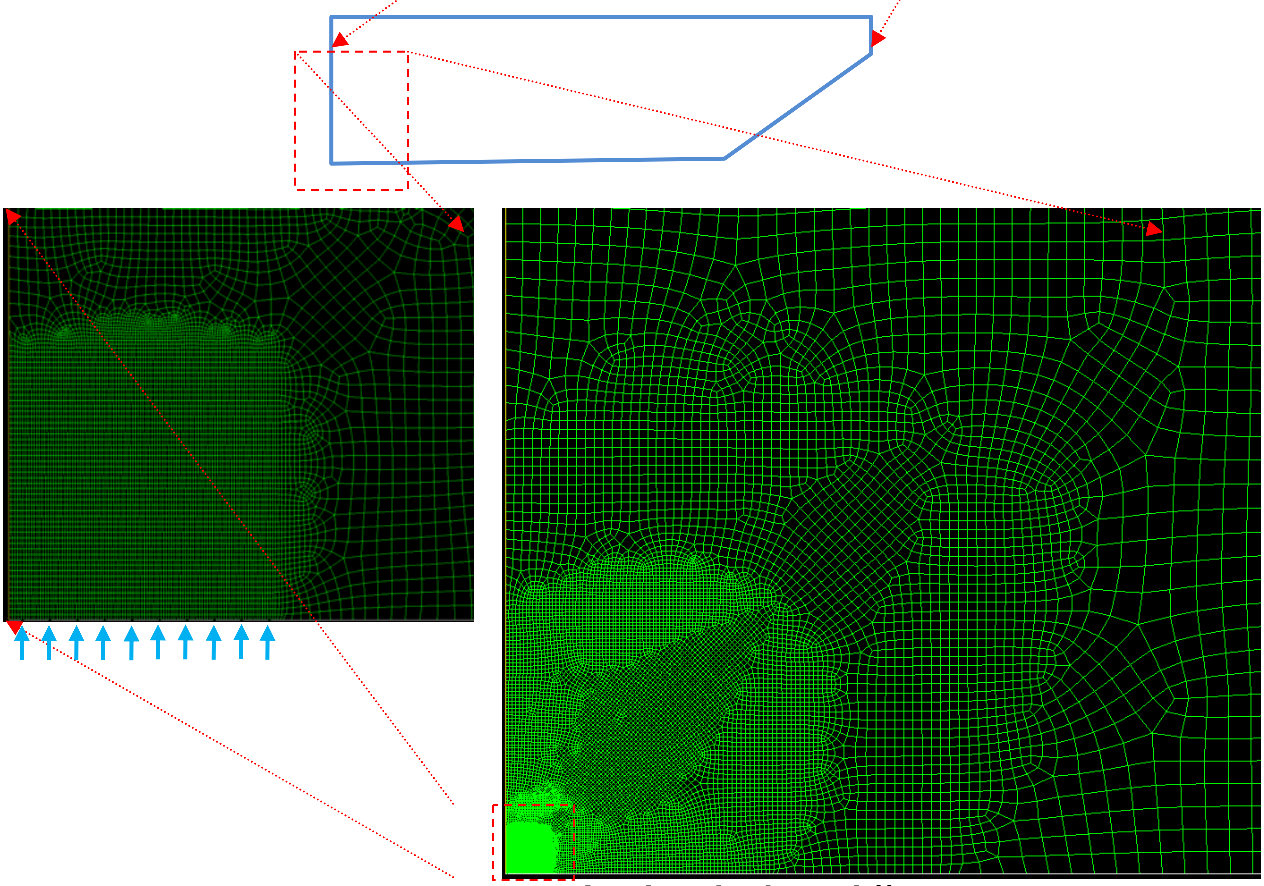


Figure 15. Numerical grid nearby the air diffuser

The numerical grid describing the simulated part of the pond is made out of more than hundred thousands of quad elements and nodes. The grid is shown in Figure 15. The grid developed was finer as it approaches the air diffusers. Clearly visible in the grid are the inlets of the diffuser and the grid mesh has been refined to match with the air holes of the diffuser (size of 1.0 mm).

Induced velocity field

This sub-section presents the outcomes of Fluent simulation for the domain described in Figure 14.

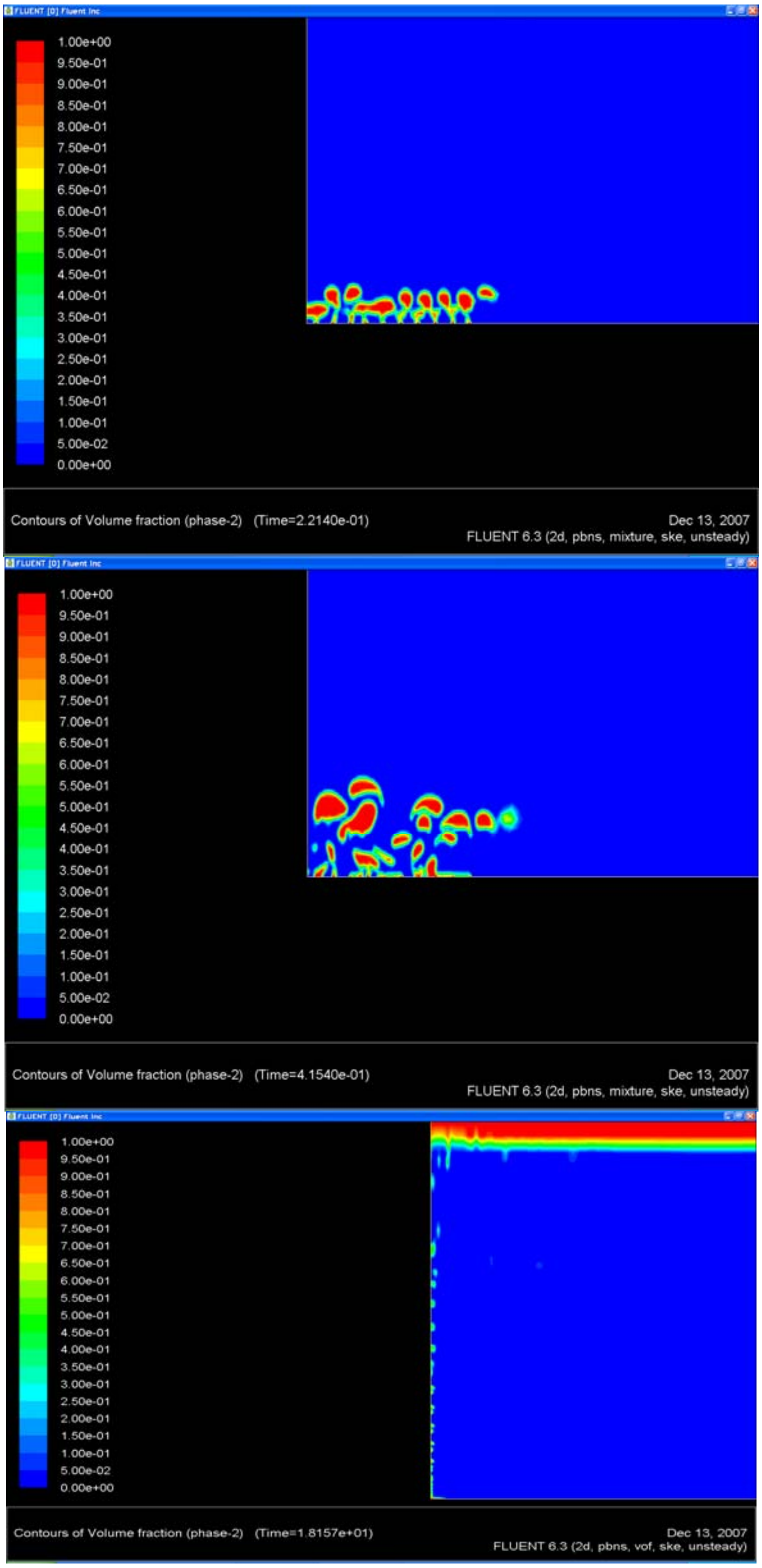


Figure 16. Progress of air bubles release from the diffuser throughout the pond

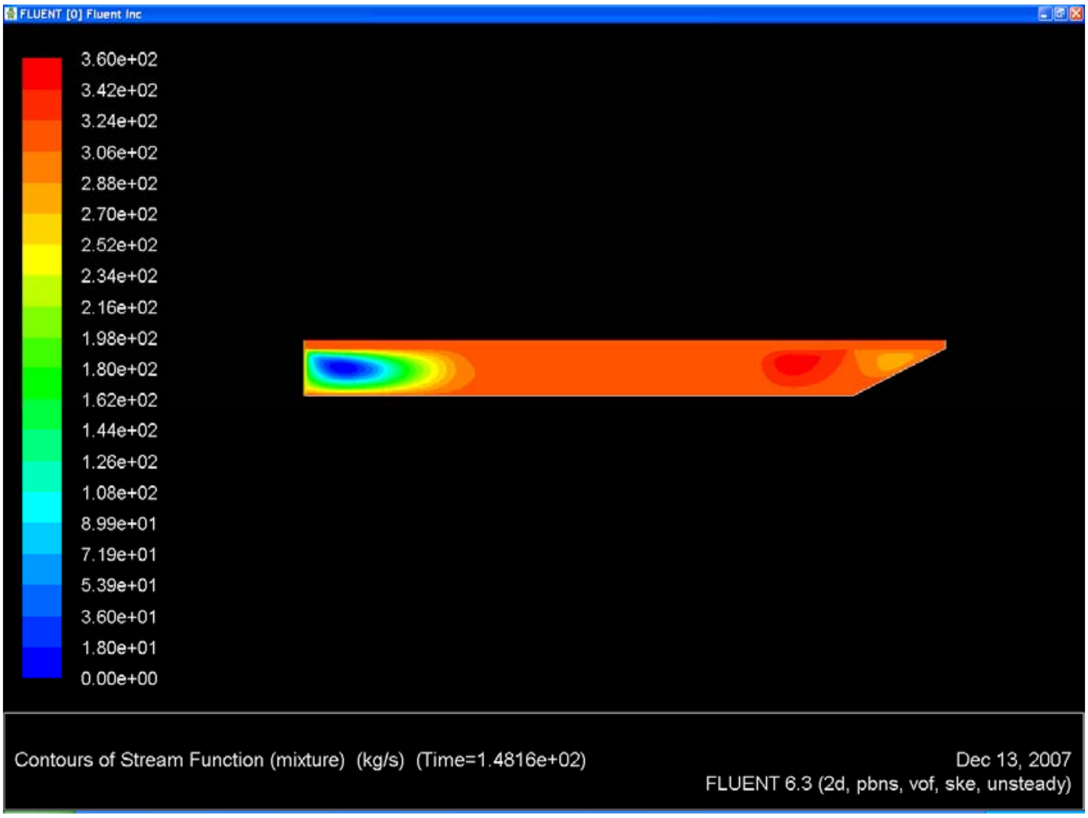


Figure 17. Contours of stream function for the whole simulated pond domain (t=2.5 min)

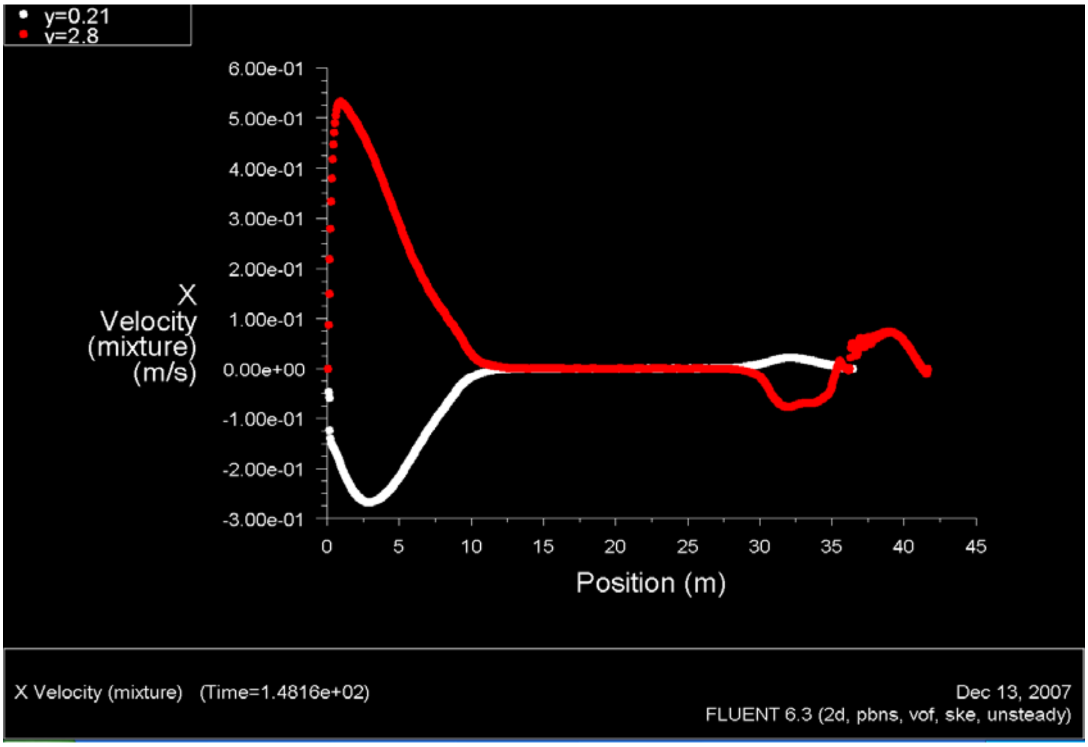


Figure 18. Spatial variation of x-velocity with distance (at depths 0.2m, 2.8m, t=2.5 min)

From the previous results, figures 16, 17 and 18, it has been noted that the released air bubbles have generated at least three large eddies (as shown in Figures 13a and 13b). The strongest eddy takes place nearby the diffuser with a velocity scale of the order of 0.5m/s whereas the other two eddies exist close to the pond edge with a velocity scale of the order of 0.1m/s and less. The extent of the strong nearby eddy is about 12.5 to 15m from each side of the diffuser axe which corresponds to about 4-5 times the pond height. Based on the aforementioned rational, it could be concluded that the recommended spacing between diffusers is of the order of 10 times the pond height. This conclusion neglects the effect of week eddies and it should be also mentioned that the diffuser spacing is expected to get bigger in case of applying higher air injection rate (greater than the default value of 1.5 fpm).

Results Discussion

The study in hand investigated the hydraulic performance of a system of inland ponds under two water quality enhancement techniques. The hydraulic module of RMA2 package has been applied to study the circulation technique and simulate the hydrodynamics fields of the pond. While the CFD, Fluent, model has been applied for the simulation of the bottom aeration technique.

The two dimensional hydrodynamic model showed the most appropriate sinks and sources arrangement and resulted with a system that requires a large pumping station and associated pipe networks to circulate at least $3.65m^3/s$. This system will require high initial capital cost which will comprise of the following:

1- Pipe network,
2- Pumping station units to pump $3.65m^3/s$, and
3- Sinks and sources which may comprise of weirs, water diffusers and water collection systems/structures.

In addition this system will require around 25 HP to operate the system. This Hp power is required 16 hours a day.

The CFD simulation has been carried out to simulate the flow structure of the near field as well as the far field from the diffuser axes. The numerical simulation resulted with the best number of diffusers in the pond and the best arrangement of these air diffusers. This system requires low capital cost which will comprise of the following (Figure 19):

1- Air diffusers,
2- Air compressor,
3- Air Ducts, and
4- Electrical power supply which could be a wind mill or an electrical motor.

The required operation cost of this system is small as it only used for compressed air to be supplied to the air diffusers. The power required is about 1 to 5 HP.

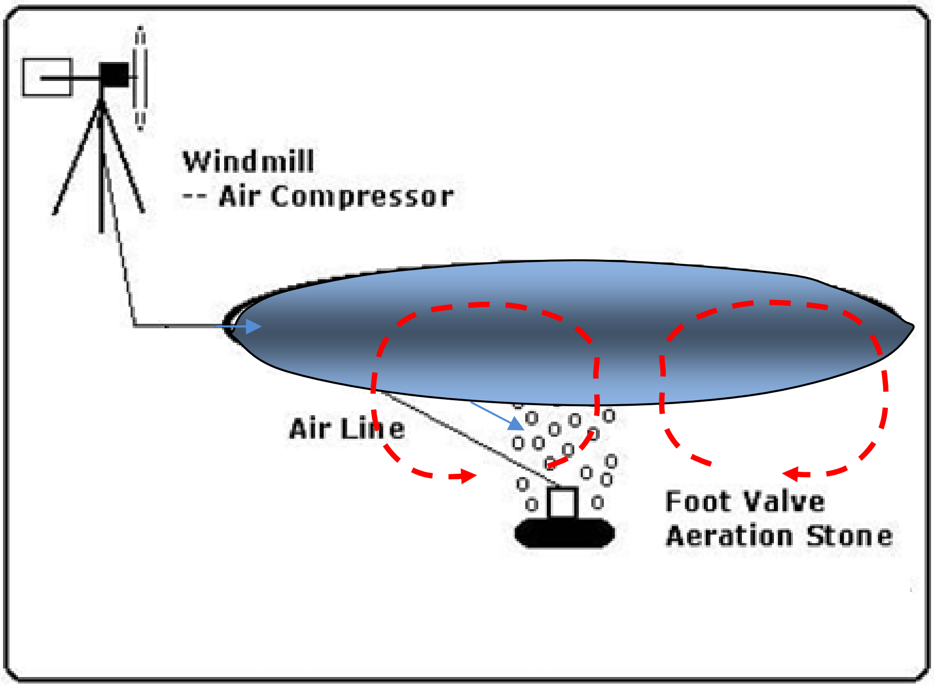


Figure 19: Schematic of the aeration system components

Conclusions and Recommendations

The study performed and the results analysis showed that both techniques improve the water circulation in the pond.

It showed that the aeration technique is much cheaper and more environmental friendly. The bottom aeration system is simple and does not require a high capital cost and only requires very low operation cost.

The study did not perform water quality calculation it did not compare the water quality resulted from both system/techniques. This is an interesting point to be studied so as it will help the decision makers/developers to choose the appropriate system to improve the water quality of the closed ponds used in the recreational developments.

References

1. Vincent Hulla et al., 2008, "Modelling dissolved oxygen dynamics in coastal lagoons", Ecological Modeling 211, 468–480.

2. Tsihrintzis and Hamid, 1998 "Runoff quality prediction from small urban catchments using SWMM", Hydrological Processes, Vol. 12, 311-329.

3. Culberson, S.D., Piedrahita, R.H., 1996. "Aquacultural pond ecosystem model: temperature and dissolved oxygen prediction-mechanism and application" Ecol. Model. 89, 231–258.

4. Gelda, R.K., Effer, S.W., 2002, "Estimating oxygen exchanges across air–water interface of a hypertrophic lake", Hydrobiologia 487, 243–254.