MANAGEMENT OF DIFFUSE POLLUTION BY THE CONSTRUCTION OF WET RETENTION BASINS : A NEW DEMAND FOR THE SANITARY ENGINEERING

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ABSTRACT
The main objective of this paper is to perform an ecological evaluation of about 50 retention ponds located in the French region of Ile-de-France, specially under the aspect of their water quality. The paper emphasizes the necessity of developing well fundamented principles about the ecological functioning of the system in order to allow a sound management of these water bodies. The large data base used in this research shows that retention basins are limnologically quite similar to small lakes. Their efficiency in the removal of pollutants depends strongly on the configuration of a well structured aquatic system, with their inherent physical, chemical and biological characteristics. Besides giving a general view about the water quality in the surveyed ponds, the paper stresses the need of an intensive monitoring of these almost unknown aquatic environments. Since their use is strongly coupled with recreational activities the ecological study of retention ponds represents a new demand for Sanitary Engineering and other related sciences. The surveyed retention ponds generally present a good water quality according to the traditional physico-chemical and biological parameters. Since they are usually very shallow (2 to 3 meters depth), they can easily circulate, which is a quite positive feature for the enhancement of the water quality.

Keywords Ecological behavior, monitoring program, retention ponds, water quality

INTRODUCTION
The final destination of rainwater constitutes a significant and complex issue in the study of diffuse pollution in urban areas. In this aspect the construction of retention ponds is one of the most frequent alternatives for the management of urban stormwater. Basically these wet ponds act as a storage tank for events of high pluviometry, allowing the temporary retention of large volumes of water, which otherwise would be directly discharged to rivers or other exutories. The water storage in these open systems contributes efficiently to an enhancement of its quality, since coarse particles are easily sedimented and also a nutrient assimilation takes place as a consequence of biological activities. The main aspects regarding the design of these ponds have been extensively explored in the technical literature (Wanielista, 1978, Whipple et.al., 1989, WEF/ASCE, 1992, Urbonas and Stahre, 1993, Azzout et.al., 1994, STU, 1994, ASCE/EPA, 2002), including the configuration of inlet and outlet structures, pond bottom and slope protection. In this sense attention should be drawn to the design procedures regarding the determination of the water residence time. It should be long enough to allow nutrient uptake by the algae, which is one of the ecological functions of retention basins, but not so long as to induce long term stagnation or the formation of anaerobic bottom sediments. Neverthless very little information has been gathered or published regarding the ecological quality of the aquatic environment. Under the aspect of water quality the available knowledge is restricted to studies about the efficiency of retention ponds in the removal of some pollutants. It can be stated that the *hydraulical* behavior of retention ponds has been far more intensively studied than their *ecological* behavior. This assumption is not surprisingly, since the main objective of these ponds is to function primarily to store and release water, i.e. they fulfill a hydrological demand concerning the infra-structure of urban waters. However the creation of new aquatic systems in urban areas should be followed by a careful monitoring of the water quality, since these systems, besides being subject to several pollution problems (eutrophication, silting, salinization), can be conveniently destinated to other uses. Actually the retention ponds are ecologically similar to small natural lakes and should hence be studied as such.

Besides performing a well understood hydrological function, the retention ponds are prone to several other uses, most of them coupled with landscape requirements. Also recreation can be carried out in a very intensive way. With the exception of swimming, which is generally not recomended due to possible bacteriological contaminations, the retention ponds can be widely used for fishing, or even for sailing in the case of large surfaces. Other uses can be accomplished in the drainage basin or in the immediate vicinity of the ponds. Examples are walking, jogging and contact with nature. These sites can be well destinated as spaces for activities for environmental education, since the ponds represent also an important habitat for wildlife. In winter the frozen surface can be conveniently used for skating. The calming function of the water mirror and its integration in the landscape harmony are valuable features of retention ponds. Under this aspect it can also be expected an inverse relationship between the cost of the terrain and its distance to the retention basin.

HISTORICAL BACKGROUND
During the 19th century, which saw the first steps in the direction of a well consolidated sanitation structure in the large cities, the prevailing idea, mainly in Europe, was to proceed to the fastest possible evacuation of rain waters, since these could carry pathogens and other nuisances. This deep established concept, known as hygienist principle, encouraged to transport the run-off far away from urban areas. In the well known and documented hystorical evolution of Sanitary

Engineering, some countries inovated by the implementation of separate sewers for collecting run-off and waste waters, increasing obviously the installation costs, but aliviating the onerous and extremely sensible functionning of waste water treatment plants.

After the end of the Second World War, many European countries initiated a monumental reconstruction program, which included the creation of new urban settlements. In many cases these new villages were not situated close to large water bodies, as had been so far in the history of mankind. In this boom of installation of modern urban equipments, many small cities have been constructed in plains that were distant from natural exutoires. This situation could be observed frequently in France and mainly in the province of Ile-de-France. The absence of near receiving waters led the local administrators and the correspondingly water agencies to the creation of retention basins in the new urban areas. These water bodies had also the important task of bringing the nature inside the urban, according to the environmental conscience that was flourishing during the 70's.

METHODS

All the 50 retention ponds evaluated in this paper are situated in the region of Ile-de-France, France, in the following communities : Aulnay-sous-Bois, Blanc-Mesnil, Champs-sur-Marne, Croissy-Beaubourg, Dugny, Elancourt, Emerainville, Guyancourt, La Coumeuve, Le Bourget, Livry-Gargan, Lognes, Magny-les-Hameaux, Montigny-le-Bretonneux, Noisiel, Torcy, Trappes,Voisins-le-Bretonneux.The names of the surveyed ponds are : Arche, Bailly, Bassin du Château, Beaubourg, Beauregard, Bois de Grace, Bouvalais, Celie, Croissy, Ecluse, Etang de La Madeleine, Gendre, Grand Parc, Ibis, La Boissière, Lac de Villaroy, La Croix au Buis, La Muette amont, La Marechale, La Mare d'Auvergne, La Mole, La Muette intérmediaire, La Nouvelle Amsterdam, L'Armanderie, La Soubriarde, La Blondeau, Le Grand Bassin, Le Manet amont, Le Manet aval, Les Coudrays, Les Graviers, Les Roussières, Malnoue Nord, Malnoue Sud, Mare du Monastère, Maubuée, Moulin à Renard, Moulin à Vent, Nesles, Pecheur, Pissaloup, Pont Yblon, Savigny, Segrais Nord, Segrais Sud, Sevigne, Val d'Or, Vieilles Vignes.

These retention ponds present areas between 0.2 and 27 ha, with 70 % of them under 3 ha, 50 % under 2 ha and just 8 % over 10 ha. Their maximum depth varies between 0.6 and 6 m. Most ponds are quite shallow, with 75 % under 2 m depth and 95 % under 3 m, while just 5 % are deeper than 3 m.

There is a large data base gathering all the physico-chemical and biological results of the several monitoring programs that have been carried out since 1996. The database serves the same purposes as the US National Stormwater Best Management Practice Database (ASCE & EPA, 2002), but focussed only on retention ponds. It is developed in Microsoft Access 97 and made of 55 interconnected tables which cover following aspects :

Design of the retention pond **: location, picture, morphometric data, design criteria ;**

- *The retention pond in its catchment*: geographical description of the various subcatchments, as well as their land use, description of the entries and of their treatment equipments ;
- *The retention pond and its neighbours*: hydraulic connections with other retention ponds, organisation of clusters of ponds ;
- *Water quality of the retention pond*: monitoring of classical physico-chemical and hydrobiological parameters ;
- *Sediment quality of the retention ponds*: physico-chemical parameters, including heavy metals and micropollutants in the sediment ;
- *Ecological quality of the retention pond*: trophic network in the retention pond, from phytoplankton and macrophytes to fishes and birds ;
- *Management of the retention pond*: maintenance and exceptional events (accidents, dredging) and their corresponding costs.

The sampling frequency is variable, but it happens generally 3 to 4 times a year. Only for the physico-chemical set over 13,000 entries can be counted, covering following parameters : *temperature, dissolved oxygen, pH, suspended solids, turbidity, Secchi depth, BOD, COD, ammonium, nitrate, phosphate and ortophosphate, sulphate, chlorine and conductivity*. The biological parameters that have been analyzed, but not for all retention basins, are *phytoplankton, zooplankton, zoobenton, macrophytes* and *fishes*. Other informations are related with the morphology of the retention basins, their inlet and outlet structures, main uses of the aquatic system and of its drainage basin and organization responsible for the management. For some selected parameters the samples have also been taken in several depths, allowing therefore the construction of vertical profiles. Some of them, as is the case of temperature and dissolved oxygen, are extremely important for the comprehension of the functionning of the aquatic system.

The *morphology* of lentic aquatic systems, among which retention basins can be included, has a strong influence on nearly all physical, chemical and biological parameters of the water body (Wetzel, 1983). Besides the classical morphological parameters (area, volume, depth, perimeter), there is the group of the so called secondary parameters, which are obtained from the primary ones. These secondary morphological parameters are indeed the most useful for the prediction and characterisation of the water quality. One of the most significant parameters is the *relative depth,* which is defined as the relationship between lake maximum depth and the mean diameter of the lake (i.e., diameter of a circle that has the same area as the lake).

$$Z_r = Z_{max} / \theta_{mean} = 88,6 \,.\, Z_{max} / \quad A \quad [\%] \qquad (1)$$

The ecological importance of the relative depth is to provide informations about the circulation potential of the water body. Aquatic systems with low relative depths (large and shallow) can easier circulate than those which present high relative depths (small and deep).

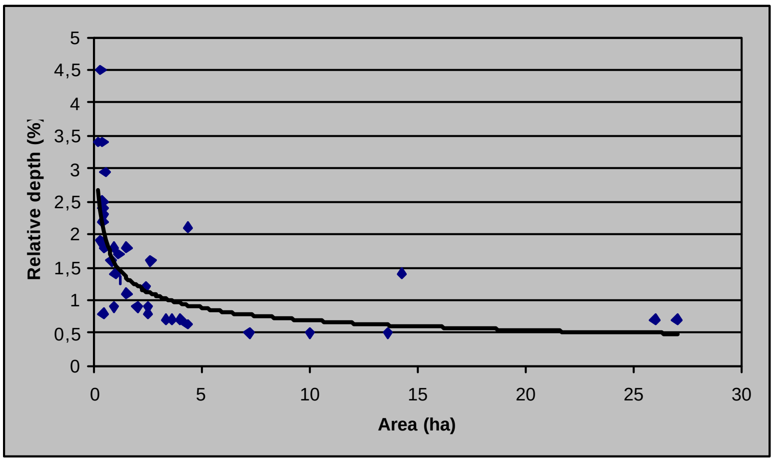

Figure 1 *Relationship between area and relative depth*

It can be seen in Figure 1, that there is a clear inverse relationship between the area of the retention pond and its relative depth. This indicates that larger ponds can usually easier circulate. In the very small lakes the high relative depth can eventually prevent the onset of circulation. In terms of water quality this means that these aquatic systems can suffer from the consequences of very long stratification periods, which can lead to the formation of anaerobic layers at the bottom of the ponds. Another possible occurrence in the case of large relative depths is the so called *meromixis*, i.e. the pond does not circulate completely, but just till a certain depth. As pointed out before, the existence of a circulation process should be considered as a positive feature for the ecological integrity of a water body.

The curve in Figure 1 applies also generally for the case of lakes and reservoirs. It can be easily understood why large relative depths are only found in small lakes. For example, to reach the high value of relative depth of 5 %, a lake of 300 km^2 (at least 500 lakes in the world are larger than this, Herdendorf, 1990), would need a maximum depth of approximately 1000 m (only 3 lakes are deeper than 1000 m: Baikal, Tanganika and Caspian); on the other hand a lake of 3 km^2 would demand a maximum depth of 100 m, which is far more common than the previous situation.

RESULTS AND DISCUSSION

The main features that could be extracted from the explored data base are summarized below.

Temperature

There are very clear seasonal variations in the water temperature, with higher values being obtained in July and August. In the study of the aquatic ecology not only the absolute values of temperature are important, but also their variation along the vertical profile of the water body. Different values of temperature imply obviously in distinct degrees of density, leading to the configuration of two possible situations regarding the vertical hydrodynamics of the retention basin : period of *stratification* or period of *circulation*. While in the first case there is a quiescent phase in the water body, which enables the accumulation of dissolved oxygen in the upper layers, during the second period a complete turn over of the vertical structure of the water body takes place, leading to a healthy exchange of gases and particles between upper and bottom layers.

One very practical way of determinating the strength of the stability of a water body is to calculate its RTR (Relative Thermal Resistence) (Wetzel, 1983). The RTR gives the numerical expression of the stability of the thermal vertical profile of the lake; it is obtained by dividing the density difference of upper and bottom layers by a standard value, adopted as the water density difference between the temperatures of 4 and 5 ^{0} C, i.e. 0.008. Hence :

RTR *(adimensional) = DDensity between upper and bottom layer / 0.008* *(1)*

From the explored data base, the RTR values have been calculated, reaching their maximum during the months of July and August. The highest registered value was 323, recorded in August. From a broad analysis of the 50 retention basins, it seems that, most of them, present a *dimitic* behavior, as it is typical for lakes situated in temperate regions. This means that they circulate twice a year (spring and autumn), being stratified in summer and winter periods.

pH

The pH values ranged from 6,2 to 10,8 .Generally higher values are obtained in the period July- September, as consequence of the algae metabolic activity. During the photosynthesis there is an absorption of carbonic acid and a consequent elevation of the pH. The differences of pH between surface and bottom oscillated between 0,6 and 4,1.

Transparency (Secchi depth)

The measurement of the Secchi depth, which is operationally quite simple, gives important informations about the optical properties of the water column, specially in relationship to the depth of light penetration and the consequent development of photo-autotrophic aquatic life. The so called *euphotic* zone, in which primary producers (algae, plants) can live, reaches a depth of about two times the Secchi depth or transparency (Cole, 1983). In the surveyed retention basins the Secchi depth oscillated from 12 to 200 cm, showing the wide range of variation of this useful parameter.

Turbidity

The values ranged from 2 to 190 unities.

Dissolved Oxygen

The results of dissolved oxygen are presented as % of saturation, which is a very comprehensive way for expressing the presence of this gas in the liquid mass. The mere information about the dissolved oxygen concentration does not allow a clear view of its ecological meaning, since the gas dissolution is strongly influenced by water temperature, but also by atmospheric pression and by water salinity. Hence it is more convenient to inform how near is the dissolved oxygen concentration from the possible saturation value.

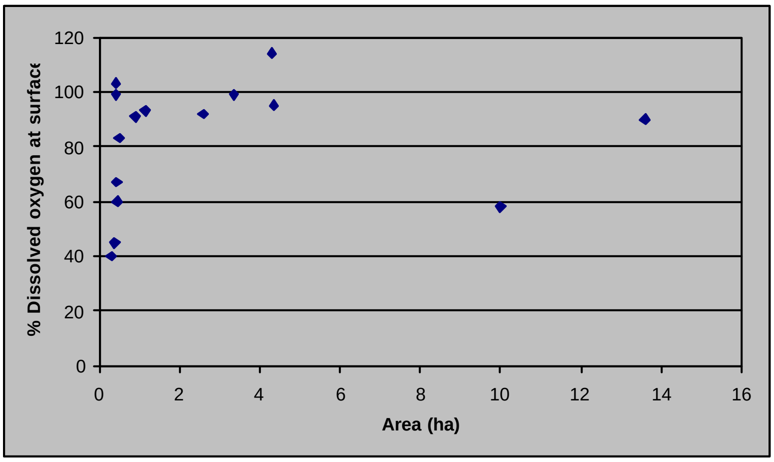

Figure 2 *Relationship between DO and area*

The maximum concentration found in the surveyed retention basins was 139 %, which means a supersaturation in dissolved oxygen caused by algae photosynthetic activity. This kind of oxygen surplus is usually found at the upper layers of productive water bodies during periods of strong development of vegetation. On the other hand low values of dissolved oxygen are generally found in the bottom layers of the retention basins, including the eventual establishment of anoxic conditions during the stratification period It can be observed in Figure 2 that, beyond a certain area (around 2 ha) there is an homogeneization in the concentration of dissolved oxygen at the surface of the retention ponds; on the other hand, the graph shows that very small ponds may present both high and low oxygenation at the surface (mean values in the 1 m-layer).

Ammonium (NH_4^+)

The ammonium concentrations oscillated between 0.08 and 3.5 mg l^{-1}

Chlorine

The registered range was from 3 to175 mg l^{-1}

Conductivity

It has been observed a quite broad variation in the conductivity results (130-1550 µS/cm). Higher values were frequently obtained during the winter period, as consequence of the utilization of salt for snow defrosting.

Phosphate: 0,05-2 mg l-1 ;

Orthophosphate: 0,015-1,53 mg l-1

CONCLUSIONS

The surveyed retention ponds present generally a good water quality, in spite of a clear trend to the onset of eutrophication processes. Phosphorus concentrations are high, while nitrogen levels exhibit strong variations. Neverthless it seems that primary production is rather phosphorus limited. The ponds generally circulate twice a year, which can be considered as a positive feature in order to avoid oxygen depletion in the bottom layers. Due to the high poductivity of the ponds, BOD and COD do not describe properly the organic pollution arriving from the catchments. Bacteriological indicators, like faecal coliforms and *E. coli* are much more efficient for this purpose. Ammonium, which is also an indicator of waste water contamination, enables the detection of highly polluted ponds. The feasibility of the use of retention ponds for recreational activities should be evaluated on an individual basis.

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