OPTIMUM ARRANGEMENT OF PONDS IN A GIVEN AREA

[1]Agunwamba, J. C., [2]Ukpong, E. C., [3]lbrahim, A. and [4]Tanko, J. A.
[1]Department of Civil Engineering University of Nigeria, Nsukka, Enugu State.
[2]Department of Civil Engineering University of Uyo, Akwa Ibom State
[3]Agricultural Engineering Unit Department of Soil Science University of Calabar, Cross River State
[4]Department of Civil Engineering Federal University of Technology, Yola Adamawa State.

ABSTRACT

Several factors that affect the arrangement of ponds in a given area are presented and the weaknesses of the current pond orientation highlighted. The concept of orthogonality in pond layout is also introduced. It is illustrated that non-orthogonal pond arrangement could result in optimal land use. Efficiency, cost of inter-pond pipe connections and maintenance of orthogonal and non-orthogonal systems were discussed. Land area and cost of inter-pond connections could further be reduced if pond shapes other than rectangular shapes are used.

Introduction

The Waste Stabilization Pond (WSP) has gained wide popularity as a result of its ability to achieve high efficiency in wastewater treatment at minimum maintenance and operational cost (Mara and Pearson, 1983; Agunwamba, 1992a; 1992b). Waste stabilization pond is versatile and could be applied in treating not only domestic wastewater but also agricultural and industrial wastewater. Besides, in water scarce areas, the use of WSP system has attracted more attention in its treated effluent reuse for irrigation (Shuval et a1., 1986). The major limitations in the utilization of a pond system is its large area requirement which makes its use difficult in congested urban centers and industrial layouts. In addition, the large area utilized by the pond system may also limit the size of the land adjacent to the ponds for other activities, especially agricultural practices using the treated effluent. In such cases, use of WSP for wastewater treatment in order to meet effluent discharge standards while achieving savings in cost seems unattainable.

Therefore, research on reduction of land space requirement of WSP is important (Hosetti, 1987; Oragui et a1., 1987; Agunwamba, 1992a). Attempts have been made by several researchers from different approaches to reduce WSP area requirement (Oragui et a1., 1987; Shin and Polprasert, 1987; Agunwamba, 1991). However, whether or not the commonly used orthogonal method of point arrangement is optimal, is not known to have been investigated.

The aim of this research is to investigate how the total gross land occupied by a pond system could be reduced by appropriate arrangement and utilization of shapes other than rectangular. Given a typical land area, it is to be shown how a certain number of rectangles could be arranged both orthogonally and non-orthogonally in order to minimize land area while allowing minimum space between the ponds for monitoring and maintenance.

Pond Arrangement

Conventional pond design is aimed at determining the pond area and the detention time under an assumed depth of flow. A pond’s cross-sectional shape is usually rectangular or trapezoidal, and the ponds are arranged orthogonally. The layout of the pond system will certainly affect the land area used. Hence, it is worthwhile to investigate methods of improving pond layout especially in urban areas where land is scarce and expensive.

It must be noted that the investigation is on pond arrangement only, given the same pond geometry and topography. Hence, the issue of the effect of economy on the waste treatment and effluent quality does not arise.

Ponds of exactly same geometry as was used in the work will always have the same treatment efficiency.

The factors that affect pond layout are land topography and geometry, prevailing wind direction, facilities and communities around the site and so on. These factors are discussed below.

Land Topography and Geometry

Land geometry and topography will determine whether or not a series or parallel arrangement is better. Little rigorous work has been done in determining optimal pond shapes. However, it is obvious that the optimal pond shape is site specific, and cannot be specified without consideration of the layout of inlet and outlet structures and other treatment facilities.

Prevailing Wind Direction

It is recommended conventionally that a pond be located so that its longest dimension (diagonal) lies in the direction of the prevailing wind in order to encourage wind-induced mixing. Besides, the wastewater should flow in the pond against the wind in order to minimize hydraulic short-circuiting (Mara and Pearson, 1987). The whole arrangement is meant to discourage stratification. However, since it seems that stratified pond water column aids development of a high pH zone which in turn encourages high bacterial degradation, maturation ponds should be designed to stratify rather than be well mixed (Mara et al., 1983). Hence, the conventional method of pond orientation should be reviewed in light of recent findings and ideas.

Facilities and Communities around the Site

The pond system should be not less than 200m from the community to minimize the effect of odour, mosquitoes and flies. Besides, it should be sited such that the prevailing wind does not blow from it to the community. All these factors in addition to the effluent discharge point will affect the optimal pond layout.

Land Requirement for Future Expansion

Provision of land for future expansion of a pond system will affect the present layout. The consideration of this is very important in communities and cities because of population growth.

Apart from the above factors, ponds are also arranged in a particular order. For instance, anaerobic ponds should be followed by facultative ponds, and facultative ponds by maturation ponds. Within each group, wastewater is designed to flow from bigger to smaller ponds. At present, ponds are arranged orthogonally. For a given depth, the problem is essentially a two dimensional one. Pond arrangement need not be orthogonal since non-orthogonal arrangement may lead to minimum land wastage. Different pond layouts are illustrated below with a hypothetical example.

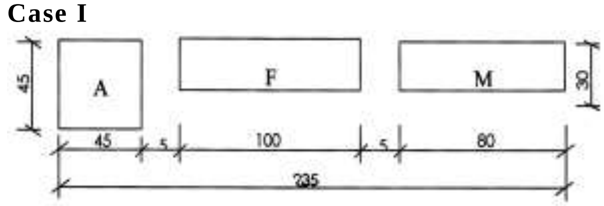
POND LAYOUT EXAMPLE

Consider a certain pond system which comprises Anaerobic Pond (A), 45m H 45m; Facultative Pond (F), 100m H 30m; and Maturation Pond (N), 80m H 30m arranged in series. Compare orthogonal and non-orthogonal layout if 5m is allowed between ponds.

Solution

A. Orthogonal Arrangement (all dimensions are in m)

Case I

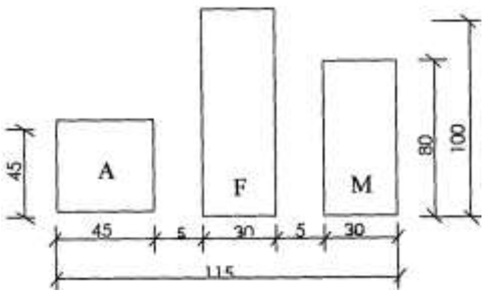


Total gross area = 10575m^2

Total net area occupied by ponds = 7425m^2

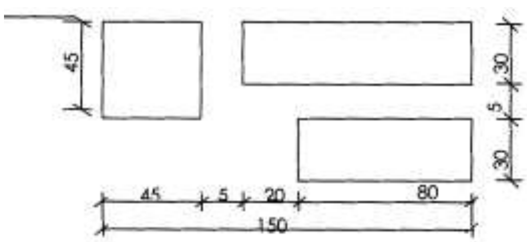
Unused land area = 3150m^2

Case II



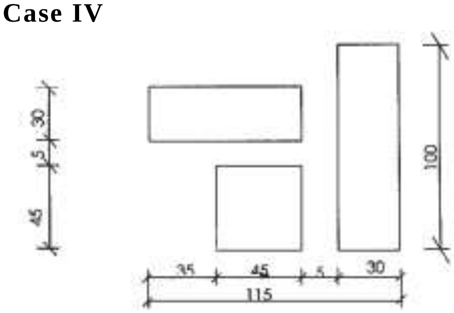
Total gross area = 11500m^2
Unused land area = 4075m^2

Case III



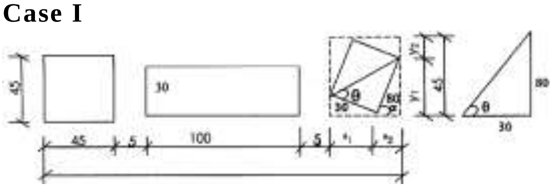
Total gross area = 9750m^2
Unused land area = 2325m^2

Case IV



Total gross area = 11500m^2
Unused land area = 4075m^2

B. Non-Orthogonal Arrangement
Case I

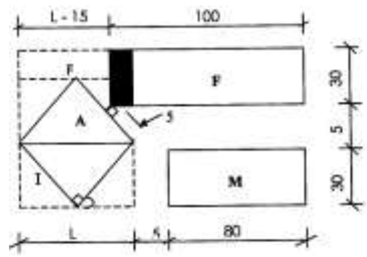


$y_1 + y_2 = 45$
i.e. 80 sin α + 30 cos α = 45
But 80 = 85.44 sin θ, 30 = 85.44 cos θ

$$\Rightarrow \sin\theta\sin\alpha + \cos\alpha\cos\theta = \frac{45}{85.44}$$

∴ cos (θ ! α) = 58.2182°
∴ But θ = 69.444°
α = 11.2258°
∴ $x_1 + x_2$ = 30 sin + 80 cos = 84.3097m
∴ Gross area = 10768m^2
∴Unused land area = 3343.9m^2

Case II



Unused land area W = 4 (area of I) + Area of F ! 30(15) + 5(35) + 80(5)
but L = (cos θ + sin θ) ! 15[65 ! 45 (cos θ + sin θ)]
= 3600 (cos θ + sin θ) ! 3000 ! 2025 sin θ

$$\text{Area of I} = \frac{1}{2}(45^2)\sin\theta\cos = \frac{1}{4}(45^2)\sin 2\theta$$

∴ W = 3600(cos θ + sin θ) ! 2875

$$\frac{\partial w}{\partial\theta} = 3600(\cos\theta + \sin\theta) = 0$$

⇒ cos θ = sin θ or θ = 45°

This is the lowest in all the cases both for orthogonal and non-orthogonal arrangements.

Discussion and Conclusion

The example considered showed that non-orthogonal arrangement could result in the lowest unused land area. However, non-orthogonal arrangement will not be the best for every system. The relative sizes and number of the ponds will also affect the optimal arrangement.

Non-orthogonal arrangement could lead to additional cost in pipe connection works. The arrangement has to be such that available land is optimally utilized while the connection cost and short-circuiting are kept minimum. The shape of the pond surface need not be rectangular or square (Mara and Pearson, 1987). Apart from adding to the aesthetics of the system it helped reduce the pipe connections while the extra land is utilized to advantage for treatment (Mara and Pearson, 1987). Hence, ponds with rectangular surface may not always be the best.

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