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Sedimentation retention basin utilization for best management practice

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Abstract: Approaches to the artificial impoundment and theoretical design of sedimentation retention basin are reviewed with particular attention to best management practice(BMP) to control agriculture and surface runoff. Sediments retention basins are the small version of farm pond used where a criteria of farm pond is not met. Such basin traps the pollutants and suspended solids prior to entry into streams and lakes. The study is focused with special reference to the assessment and control of non-point source pollution(NPSP) from the sub-basin area of Tai Lake in the Xishan County of Wuxi City of China. The author suggested two different approaches to conduct this study including theoretical design for sedimentation retention basin and computation of flow, sediment transport and deposition during the artificial impoundment of retention basin for BMP's utilization. Theoretical design will provide a useful function as a first line defense against the movement of sediments and transport of pollutants into the Tai Lake while the assessment of sediments deposition will help to make its proper use and periodic cleanup.
Keywords: agriculture runoff; artificial impoundment; best management practice; sediment retention basin; Tai Lake sub-basin; non-point source pollution

Introduction

Modeling and monitoring ate two complementary procedures are being used for the assessment and evaluation of environmental pollution of the watershed for the last decades. The modeling of diffuse sources of pollution is rather complicated comparing with point sources of pollution. In this regards various modeling procedure are interacted including mathematical techniques integrates with geographical information system(GIS) have been used for the evaluation of NPSP in the watershed(Zaheer, 2002). Traditionally monitoring has been focused on point sources, while monitoring of non-point source pollution (NPSP) has been more or less neglected and usually taken as the deficit pollutants load between total watershed and point sources loads. However, precise and more prompt method is required to evaluate and control NPSP during the planning and management of watershed. A major concern in watershed planning and management is the sources of pollution including nutrients and sediments from land uses.

In the more recent, best management practice(BMP) is commonly used as cost effective mechanism to prevent water quality problems related to agriculture NPSP and surface runoff by reducing soil loss and sediments control providing numerous procedures including sediments retention basin, land forming, contour farming, filter striping and so on. Among all these BMP's, sediment retention basin is recommended because the existence of 28 number of wetlands varying from small to medium size(2000—10000 m^2) in the Xishan County. This paper describes the theoretical design of retention basin and modeling procedure for the transport of sediments and deposition of non-point pollutants from the surface runoff of Xishan County during artificial impoundment. Theoretical design of retention basin is proposed followed by practical example in the real basin area. The purpose of adopting such procedure and methodology is to reduce non-point sources pollutants from the surface runoff in Xishan County, which will provide temporally retention for pollutants reduction and improvement of down stream water quality. The objective of selecting designing parameters helps for the treatment of pollutants settling potential during artificial impoundment of surface runoff. The approach also leads for the computation of runoff volume, area and depth of basin under the required physical conditions regarding basin volume, soil infiltration capacity and bottom elevation. The overall approach for the sediment retention basin utilization for BMP's in this study is in cooperated either in the form of aerial features(GIS data) or specific site to simulate

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PLOAD version 3.0 for the quantification of NPSP in this county.

1 Existing scenario of study area

Sedimentation retention basin is used as one of the tools for the best management practice providing as defensive line for the protection of Tai Lake against the flow of pollutants from NPS in Xishan County and to regain deficient pollutants load. Xishan County is covering a total area of 878 km^2, which makes about 3% of whole Tai Lake watershed. Tai Lake is one of the biggest lakes in China covering total area of 36355 km^2 including 18500 km^2 of lake catchments located on Yangtze River Delta. Topographic map of Tai Lake watershed is shown in Fig.1. Predominant soil is loamy and sandy. The climate is tropical with warm wet

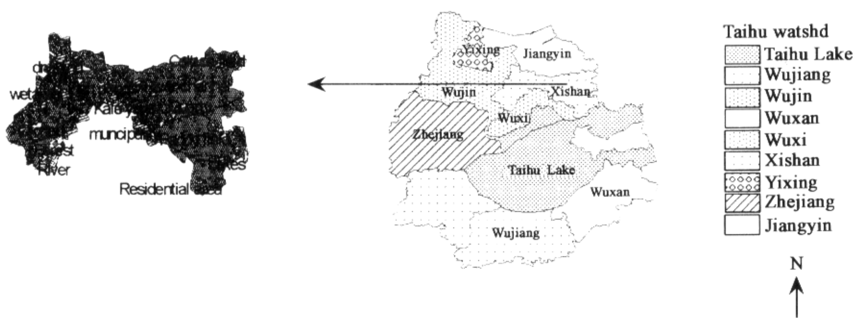

Fig.1 Topographic map of Xishan County in Tai Lake watershed

summer and cold dry winter with average rainfall of 1050—1240 mm. The average flow from the catchments is about 8.7×10^9 m^3 including 30% of rainfall directly falls into the lake. The rapid economic growth due to agriculture and industrial development in the county is causing severe impairment in the two rivers named as Wangyu River and Xichengyun River flowing from Yangtze River to Tai Lake and vice versa depending upon the flood season. Ma Lishan *et al*. (Ma, 1997) have developed net pollution load concept, describing the pollutants concentration (N, P) from agriculture non-point sources pollution in the Tai Lake watershed is increasing with rising trend of fertilizer application, irrigation and annual rainfall. It shows the negative correlation between the net load of phosphorus from agriculture non-point sources and phosphorous content in irrigation water. The most

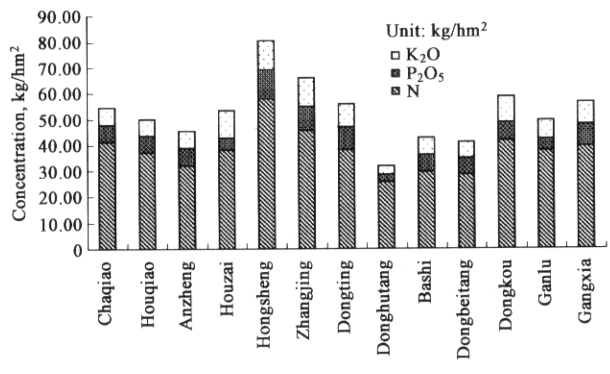

Fig.2 Estimated amounts of fertilizers components applied for agriculture field in the Xishan County

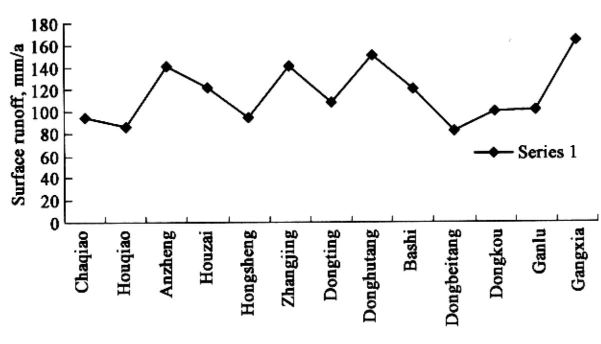

Fig.3 Simulation of annual surface run off from each sub-county of study area

common fertilizers are including urea, ammonium carbonates, potassium chloride and mixed form, having the main components estimated during the period 2000—2001 is shown in Fig.2. The major non-point source pollution are agriculture, urban, live stock and fisheries, which are and industrial, releasing COD and nutrients including nitrogen and phosphorus from each sub-county of Xishan County is estimated and shown in Table 1. Most of the area is plain having extensive agriculture including pastureland, paddy fields, kale yards, urban and livestock where most of the pollutants are concentrated. The dominant crop in the study area is paddy field, which is calculated as about 72% of total area(Fig.3).

Table 1 Estimated concentration of non-point pollutants released from the Xishan County

Name of sub-counties	Total area, km^2	Pollutants from agriculture sources, mg/L		Pollutants from domestic/urban sources, mg/L			Pollutants from livestock sources, mg/L		
		TN	TN	COD	TN	TN	COD	TP	TN
Chaqiao	25.68	0.39	54.77	39.53	3.31	7.91	10.71	0.11	5.50
Houqiao	23.44	3.09	56.57	36.68	3.09	7.38	8.27	0.10	4.19
Anzheng	38.19	0.21	110.42	55.87	4.68	11.17	25.56	0.33	13.03
Houzai	33.07	0.49	91.27	59.62	4.99	11.92	15.11	0.21	7.92
Hongsheng	25.58	0.77	69.55	43.72	3.68	8.74	8.50	0.12	4.43
Zhangjing	37.91	4.42	58.27	48.14	4.03	9.63	18.15	0.21	9.48
Dongtin	29.42	0.18	30.13	57.64	4.82	11.53	20.36	0.24	10.39
Donghutang	40.80	0.31	118.68	52.78	4.42	10.56	13.56	0.18	7.03
Bashi	32.67	0.78	95.35	67.35	5.64	13.47	27.90	0.31	14.48
Dongbeitang	22.30	1.71	58.27	58.84	5.01	11.97	19.85	0.17	10.27
Dongkou	27.03	3.49	62.16	37.76	3.16	7.55	8.83	0.12	4.48
Ganlu	27.53	0.24	61.33	41.74	3.49	8.35	9.32	0.15	5.16
Gangxia	44.17	0.86	120.82	81.93	6.86	16.39	18.37	0.24	9.37

2 Methodology and modeling strategies

2.1 Best management practice

Best management practices are known as those management practice considered most effective, efficient and cost effective actions identified to particular activity or address specific problem. There are numbers of BMP's utilized in Texas through Texas Natural Resources Conservation Commission(TNRCC, 2001) for agriculture NPSP, land development and urban surface runoff. Particularly, for agriculture surface run off, BMP's includes erosion and sediment control practices, vegetation stabilization and drainage water management. Sedimentation retention basin is utilized in the form of small ponds. It provides pretreatment of runoff in order to remove suspended solids, which can impact other primary treatment of BMPs. Such basin has no "permanent pool" volume; runoff is detained so that particulates can settle out before being discharged to another BMP. Runoff treated by retention basin must be further treated by a water quality filtration BMP, a wet pond-type BMP, or a bio-filter. Presetting basins may need to be located "off-line" from the primary conveyance/detention system if used to protect infiltration or filtration BMPs from siltation(Urbonas, 1993).

2.2 Sedimentation retention basins as BMP's utilization

Sedimentation retention basins are simply defined as surface water management practice that captures storm water runoff during artificial impoundment and does not allow to discharge directly into the lakes and reservoirs. The terms detention and retention many times are considered to have the same meaning. However, the water that is "retained" is "discharged" from the basin either by infiltration or evaporation. Retention basins will typically have minimal impact on 100-year flood peaks, since they are usually not designed to retain the 100-year runoff. The two driving forces in the design of a retention basin are the amount of runoff that will be retained, and the infiltration capacity of the soil. The use of retention basins in the Xishan County would result in a high percentage of NPSP removal. Table 2 indicates estimated removal rates for a retention basin for two types of sizing requirements. The larger basin is proposed for the study area to make more efficient the basin will be at removing pollutants. However, since larger basins cost more, which needs to be pointed, that additional cost of a larger basin will not translate into a significant increase in the efficiency of the basin.

2.3 Procedures adopted for artificial impoundment

Maximum impounding time is adopted about 72 h, if the impounding time exceeds 72 h(depending upon the size of basin), the basin probably will be continually wet. Specially, the basin having more infiltration capacity, continually wet cannot be maintained properly, and may turn into an eye sore. Moreover, it is advise to be placed at least 10 feet from the nearest basement wall. Certain BMP's proposed to treat surface run off before entering the basin such as grass filter strips to avoid the sealing of basin bottom. To avoid compaction of bottom, it needs to excavate from the sides of the basins, rather than placing the equipment on the basin bottom. Similarly, during cleaning process, the sedimentation should be allowed to dry before light equipment is used to remove the sedimentation. Once the sediments are removed down to the basin floor, the floor should be tilled and re-vegetated to restore infiltration rates.

Table 2 Estimated long-term pollutant removal rates (%) for retention basins

Pollutants	Sizing rule, 1.54 cm/impervious hm^2	Sizing rule, 2-y runoff volume
Sediment	75	99
Total phosphorous	50—55	65—75
Total nitrogen	45—55	60—70
Trace metals	75—80	95—99
BOD	70	90
Bacteria	75	98

2.4 Flow and sediments transport

Keeping in periodic cleaning process of basin, a computer based mathematical model is used for the simulation of flow, sediment/pollutants transport and deposition in the retention basin. It is one-dimensional, quasi steady state model that solve water and sediment transport equation in three different stages using sediment deposition law that enables impressive modeling for the formation of delta in the retention basin. In first and second stage flow continuity, energy and sediment discharge equation are solved using standard step method(Chow, 1959). The bed roughness is related to the medium size by a Strickler-type equation. Next, the sediment deposition equation is solved for each sediment size fraction. In the third phase the sediment continuity equation is solved starting with known value of sediments production load before entry to the retention basin and proceeding downstream(Lyn, 1987; Chauldry, 1986). Annual surface runoff from each sub-county in the study area is simulated(Fig.3).

2.5 Theoretical design of sedimentation retention basin

Sedimentation basins are the principal BMP recommended on earth disturbance sites requiring Erosion and Sediment Control (E&SC) Plans (TNRCC, 2001). In this context treatment means letting the suspended sediment settle, under the influence of Stoke's law, from the runoff water before it is discharged to a receiving water bodies. For any clay-sized or larger particle suspended in a fluid, the settling rate is a function of the gravitational force(downward) and the frictional resistance(opposite). In order to calculate the critical velocity of the smallest consistently removed particle using Stoke's law(for small Reynolds numbers), it needs particle density, fluid viscosity, and the drag coefficient. In practice, a retention column experiment is often used to determine the settling velocity of the different fractions of a suspension, along with the mass of sediment in each fraction. A theoretical design of retention basin is shown in Fig.4. The retention basin is sized for smallest particle to be removed, using the following equation:

$$Q = AVc.$$

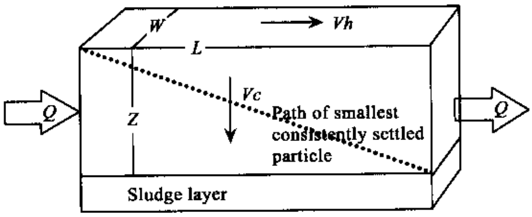

Fig.4 Theoretical design of sedimentation retention basins

Where, Q is the flow rate, A is the surface area of basin and Vc is the terminal settling velocity of the smallest particle for which settling is desired. Principally, the size of the basin required is a function of area but not depth; so shallow systems are most efficient (and are therefore sometime stacked in municipal and industrial applications). Practically, it needs to adjust the resulting Q/A ($= Vc$) for the effects of inlet and outlet turbulence, non-uniform fluid flow, and sludge storage. The retention basins is designed to achieve a 5 to 10 min residence time, which should settle 50% to 75% of the solids from open feedlot runoff. At 6 min residence time, the nominal size of the smallest consistently separated particulate matter is 35 microns, with a calculated terminal velocity Vc of 0.4 cm/s. Physical parameters are required to be adjusted for theoretical design of retention basin.

2.5.1 Volume requirements

Particularly, for water quality purpose, the most widely applied runoff methods include: (1) storage of 1.27 cm of runoff per impervious hectare; (2) storage of 1.27 cm of runoff from the entire drainage basin and; (3) storage of the volume of runoff from a 2 year storm. If the basin is to provide water-quantity benefits, the retention volume has to be significantly higher, which may not be feasible. It would be more appropriate to use a retention basin to capture the "first flush" and use a detention basin for water quantity control.

2.5.2 Infiltration capacity

The infiltration capacity of the soil is required greater than 2.54 cm/h. Soil boring is needed at least 1.524 m below the bottom of the proposed basin to evaluate soil type accurately. Infiltrations rate of certain soil group is given in Table 3. Soil group A and B is feasible then C or D because of high infiltration capacity. The design of retention basins is typically based only on a design runoff; the everyday rainfall and runoff events are not considered(WEF/ASCE, 1993). As a factor of safety, it is suggested that the infiltration capacity of the basin floor be multiplied by at least 0.5 when designing the basin. The factor of safety is to try to account for the compaction of the basin floor and the accumulation of sediments on the basin floor. Factor of safety of 50% in combination with minimum infiltration capacity helps to minimize the potential of standing water occurring in the retention basin.

Table 3 Infiltration capacities for various soil groups

Soil class	Infiltration capacity hydrologic soil group, in/h	Conservation service
Sand	8.0	A
Loamy sand	2.0	A
Sandy loam	1.0	B
Loam	0.5	B
Silt loam	0.3	C
Sandy clay loam	0.2	C
Fine sand	0.1	C

2.5.3 Basin-bottom elevation

To ensure that the basin will be able to function properly, the basin bottom should be at east about 3 m above the seasonal high-water table or bedrock.

3 Practical design of sedimentation retention basin

Retention basin is proposed to design for retaining the surface runoff from the 500 hm^2 agriculture and pasture land use of study area in the Xishan County, sub-basin of Tai Lake keeping in view of higher pollutants potential to control non-point sources pollution. The dimensions of various basin parameters are collected from Jiangsu Water Resources Bureau, which are used given as below:

(1) The basin is developed in cropland and pastureland use having impervious factor about 2%. Percent impervious factor associated with each land use can be obtained from literature (Table 4)(Laurens, 2001).

(2) Retention capacity is 1.27 cm of runoff from impervious land(including rice field).

(3) Duration of impounding is within 72 h following the storm.

(4) Infiltration capacity of basin floor area soil is 2.54 cm/h(predominant soil of basin floor is considered as sandy).

Table 4 Impervious factors of various land uses

Land uses	Impervious factor
Residential	25
Commercial and service	85
Industrial	70
Trans communications and utilities	65
Industries and commercial complex	75
Mixed urban and build up	60
Cropland and pastureland	2
Orchards	2
Water resources	0

* Source TNRCC, USEPA, 2001

(5) Safety factor is taken as 0.5 due to varying soil texture of Xishan County(loamy and sandy) and moisture content of soil because of wet summer and dry winter(Table 3).

Computation method:

(1) Calculation of runoff volume: Total basin area × (% impervious) × retention requirement

$500\ hm^2 \times 0.02 \times 1.27\ cm/hm^2 = 0.127\ hm^2$-m.

(2) Calculation of required depth of basin:

Infiltration.time × infiltration capacity × factor of safety

72 h × 0.0254 m/h × 0.5 = 0.9144 m in 72 h.

(3) Calculation of surface area of the basin:

Volume of runoff/infiltration available, i.e.:

$0.127\ hm^2 - m/0.9144\ m = 0.1388\ hm^2 = 561.50\ m^2$, say about $562\ m^2$.

It should be noted that this sizing computation is excluded the value of infiltration that may be occurring through the sides of the retention basin. For shallow retention basins such as this one, the infiltration through the sides will be much less, can be neglected comparing with the value if infiltration occurring through the basin floor.

4 Conclusions

The present study described the utilization of best management practice to address the non-point pollution sources in the watershed. The computation of flow, sediments transport and deposition during artificial impoundment of retention basin helps to increase the efficacy during periodic cleaning up process of the basin. Theoretical design of the basin shows that any given flow the surface area will determine the critical settling velocity and thus the effectiveness of the retention basin. Moreover, the proper use, design, operation and maintenance during artificial impoundment of retention basin in the study area, the watershed of Tai Lake would provide the useful function for management of sediments and nutrients transport from non-point pollution sources. The essence of the design process is to determine a specific residence time, dependent on a particle size removal goal with a velocity > V_c plus that fraction of the slower(smaller) particles that enter low enough in the column to settle in the sludge layer before passing out of the basin. Practical design of retention basin for small area ($500\ hm^2$) has provided the provision for the formulation to design the various retention basins in the Xishan County(particularly in agriculture and pasture land use) depending upon the potential of NPSP in the surface runoff. Practical design of sediment retention basin shows that about $500\ hm^2$ of agriculture / pasturelands required about $0.1338\ hm^2$ of area, i.e. about 0.02% of total agriculture land for the construction of basin to impound $0.127\ hm^2$-m of surface runoff. The larger the basin, the more efficient the basin will be at removing pollutants. However, since larger basins cost more, there will be a point at which the additional cost of a larger basin will not translate into a significant increase in the efficiency of the basin. To limit the possibility of contamination, the basin is proposed to be located at least 30 m from the nearest water supply well. Safety factor is taken as 0.5 because of varying soil texture of Xishan County(loamy and sandy) and varying moisture content of soil because of wet summer and dry winter. The factor of safety in combination with a minimum infiltration rate of 25.4 mm/h should minimize the potential for standing water occurring in the retention basin. Results obtained from the practical example would help to setup optimum design parameters regarding flow, depth and surface area of the retention basin at various locations within the county. Results obtained from practical design of sedimentation retention basin for BMP's utilization showed that area of the basin is directly related to runoff volume and basin depth including safety factor and land use impervious factors.

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