Dissolved Loads of Rivers and Surface Water Quantity/Quality Relationships
(Proceedings of the Hamburg Symposium, August 1983). IAHS Publ. no. 141.

The role of detention basins for stormwater quality control

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ABSTRACT A comprehensive analysis of the effectiveness of detention basins for storm water quality control is reported herein. The study consisted of three phases: (a) a field monitoring programme identifying influent and effluent water quality, (b) laboratory storm water pollutant settleability tests, and (c) mathematical modelling of detention basins. The first phase provided data on time-variable influent and effluent concentrations, and therefore yielded a measure of the actual pollutant reduction obtained via detention. Phase two identified the appropriate detention time to achieve maximum particle removal through sedimentation. Phase three developed a methodology for design and analysis of storm water detention basins for both quantity and quality control.

Le rôle des bassins de détention pour le contrôle de la qualité des écoulements d'averses
RESUME On présente une analyse compréhensive de l'efficacité des bassins de détention pour régler la qualité des écoulements d'averse. L'étude comprends trois phases: (a) des mesures effectuées dans un réservoir pour identifier la qualité des eaux affluentes et effluentes, (b) des recherches en laboratoire sur la sédimentation des polluants dans des écoulements d'averse, et (c) la construction d'un modèle mathématique du bassin de détention. La première phase présente des résultats d'analyse sur les variations temporelles des concentrations des eaux affluentes et effluentes, et donne une mesure de la réduction de la pollution obtenue par la détention. La deuxième phase détermine le temps de détention approximatif pour obtenir l'élimination maximale des particules en suspension par sédimentation. La troisième phase présente une méthode de dessin et d'analyse des bassins de détention pour la contrôle de la quantité et de la qualité des eaux.

NOTATION

C	pollutant concentration in basin
C_i	influent pollutant concentration
COD	chemical oxygen demand
H	mean depth of water in basin
Q_e	effluent flow rate

Q_i	influent flow rate
t	time
TKN	total kjeldahl nitrogen
TP	total phosphorus
v_s	settling velocity
V_T	total volume of water in basin
μ	micron

INTRODUCTION

Reduction of storm water runoff pollutant loadings transported to receiving waters can be accomplished in detention basins. The portion of the runoff load which exists in particulate form can be removed via sedimentation. In this respect, detention basins may be designed for the dual purpose of storm water quantity and quality control. Methods of analysis for the former are well established, but the degree of improvement in storm water quality is not well known.

The present study consisted of three phases. Phase one involved a data collection programme at an actual storm water detention basin. Samples were collected at discrete time intervals over the duration of individual storms at both the influent and effluent of the basin. As a result, the time-variable storm water runoff pollutant load and the detention basin discharge load were identified. This enabled computation of the actual pollutant removal efficiency. Phase two involved laboratory settling column tests aimed at determining storm water particle settling velocities. The findings of this phase of the study may be used to develop guidelines on the length of detention time required for maximum pollutant removal via sedimentation. Finally, phase three undertook development of a mathematical modelling approach for simultaneous analysis and design of detention basins for storm water quantity and quality control.

DATA COLLECTION

The facility chosen for data collection is an on-stream, continuously wet detention basin which was created by impounding a small intermittently flowing channel. Outflow rate is controlled by two weirs. Samples were collected at both the influent and effluent of the basin at discrete time intervals. The samples were tested for solids, chemical oxygen demand, total kjeldahl nitrogen, and total phosphorus. Concentrations were measured in three separate particle size ranges for each of the four parameters. The size ranges chosen represent the settleable fraction (>105 μ), suspended fraction (>1 μ), colloidal plus dissolved fraction (<1 μ), and the supra-colloidal fraction (<105 μ but >1 μ). Particle size distribution is an important consideration since it provides an indication of the fraction of the pollutant load which may be removed via sedimentation. Table 1 presents the average particle size distributions observed during the sampling programme. These data are representative of storm water runoff quality from a basin with land use as follows:

TABLE 1 Storm water pollutant particle size distribution

Particle size	*% of pollutant concentration in size range:* *Solids*	*COD*	*TKN*	*TP*
>105 µ	*14.9*	*10.3*	*23.3*	*6.8*
<105 µ, >1 µ	*13.5*	*16.9*	*14.5*	*21.8*
<1 µ	*71.6*	*72.8*	*62.2*	*71.4*

residential 42%, construction 22%, pasture/grassland 10%, cropland 7%, forest 19%. The data demonstrate that the majority of the pollutant load for each of the four parameters is in the smallest and therefore most slowly settling particle size range, limiting the practical effectiveness of pollutant load reduction through sedimentation.

A detailed presentation of the sampling programme data is provided in Ferrara & Witkowski (1983). Two additional significant conclusions were found. The percent reduction in pollutant concentrations is a function of two processes, namely flow equalization and sedimentation. Effluent concentrations from the detention basin were fairly constant over the duration of discharge for all storms and were not significantly different from concentrations in the basin at the start of the storm. Therefore, water quality in the basin preceding a storm and the ratio of the storm volume to detention basin volume are important in determining discharge load. Finally, the detention basin monitored was generally effective in reducing solids, COD, and total phosphorus. However on the average, TKN concentrations increased from influent to effluent.

SETTLEABILITY TESTS

Laboratory experiments were conducted to determine actual settling velocities for the particle size ranges observed in the data collection programme. Theoretically derived equations relating the vertical forces acting on a discrete particle in a quiescent fluid have been used in the past to compute settling velocities. Application of these equations is limited since they assume a uniformly shaped particle which settles discretely, and that all particles of a given size have the same density. These assumptions are violated in the case of storm water runoff in detention basins. Rather, within any particle size range, a settling velocity distribution exists. This is demonstrated in Fig.1 which summarizes the laboratory experimental results. Details of the experiments are provided in Ferrara & Salvage (1983).

The results suggest that for all practical purposes, total removal of particles greater than 1 µ can be achieved. Under quiescent conditions, essentially complete removal of these particles occurs fairly rapidly, taking from several minutes to less than an hour. Turbulence will of course increase the required settling time. For particles less than 1 µ, approximately 20% removal is achieved.

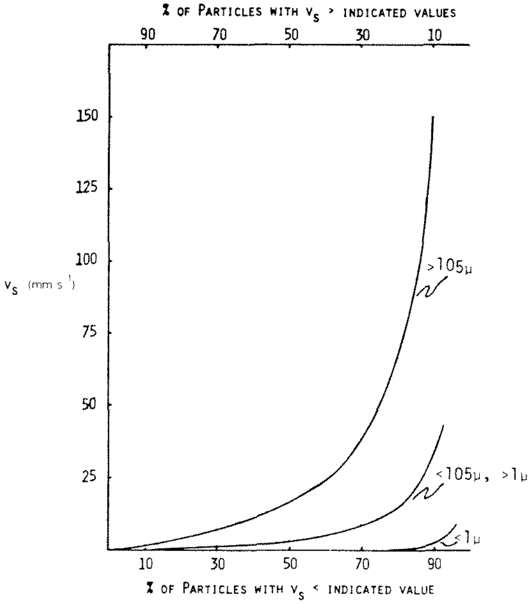

FIG.1 Settling velocity distribution curve.

Because of irregularities in shape and density, the experimentally determined settling velocities demonstrate that there exists an overlap between the three particle size ranges. A portion of the particles in a larger size range will have a settling velocity less than that for some of the particles in a smaller size range. Indeed these results prove that a distribution must be used rather than one specific value for the settling velocity at any given particle size range.

Coupling the settling velocity results with the particle size distributions observed in the sampling programme leads to conclusions regarding the extent of storm water pollutant load reduction which may be obtained with sedimentation alone. While complete removal of all particles greater than 1 µ can be accomplished, total removal of a particular parameter is limited by its fraction in the <1 µ size range of which only 20% removal may be obtained. Therefore maximum removal is limited to 43% for solids, 42% for COD, 50% for TKN, and 43% for total phosphorus given storm water quality as observed in the data collection programme.

MATHEMATICAL MODELLING

An integrated approach for storm water quantity and quality control via detention basins has been developed (Ferrara & Hildick-Smith, 1982). The time variable conservation of mass equation for volume of water in the basin is:

$$dV_T/dt = Q_i - Q_e \tag{1}$$

Q_e for a given basin outlet structure can be expressed as a function of depth of water in the basin, and for a given basin geometry, a relationship between V_T and depth is known enabling solution of equation (1). The conservation of mass equation for any pollutant is:

$$d(V_T\ C)/dt = Q_i\ C_i - Q_e\ C - (V_T\ C\ v_s/H) \tag{2}$$

Flow rate, volume and depth are known from solution of equation (1). Appropriate values for settling velocity must be specified. Thus for a given runoff hydrograph and its associated pollutant concentrations, equations (1) and (2) provide the outflow hydrograph and pollutant load to the receiving water.

Figures 2 and 3 illustrate a sample model output. The model has been utilized to design a detention basin which for the 100 year storm would control the post-development peak rate of flow equal to that of the pre-development peak rate of flow as illustrated in Fig.2. The effluent solids concentrations corresponding to this particular storm are illustrated in Fig.3. Note that effluent concentrations for the two smaller particle size ranges vary

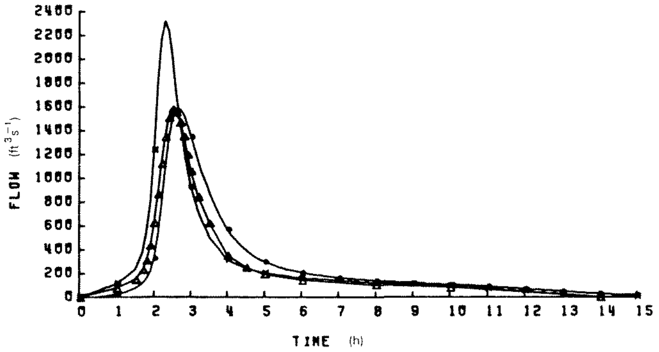

FIG.2. Hydrographs for pre-development runoff (Δ), post-development runoff (x), and detention basin outflow (•) for a 100 year storm.

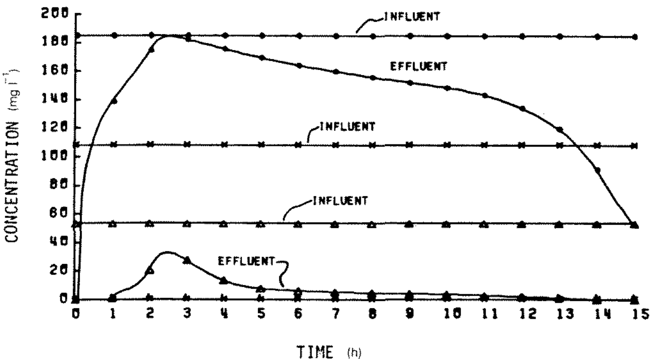

FIG.3 Detention basin influent and effluent solids concentrations for >105 µ (x); <105 µ but >1 µ (Δ); and <1 µ (•) size ranges during a 100 year storm.

considerably with time even though the influent concentrations were assumed constant. This is a result of the variation in detention time and settling depth over the simulation period. Pollutant removal is least at the time of maximum depth and minimum detention time. This occurs at the time of peak effluent flow rate. For the largest size range, total removal occurs at all times during the simulation. Although not specifically demonstrated in this case, the model is capable of designing a detention basin to meet any specified pollutant reduction requirement within the maximum levels prescribed above by the settleability tests.

ACKNOWLEDGEMENT Support for this study was provided by the National Science Foundation and the Department of Civil Engineering at Princeton University.

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