COMPARISON OF BASIN PERFORMANCE MODELING TECHNIQUES[a]

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Abstract: A comparison of methods used for analyzing the long-term pollutant removal efficiency in a stormwater detention basin points out some fundamental differences between simulation, using EPA's Storm Water Management Model, and a statistical technique advanced by Hydroscience, Inc. For the 24.6-yr record of Atlanta, Georgia hourly rainfall, the mean runoff event volume predicted by each method is similar. However, the inability of the statistical method to account for the reduction in the number of events (due to indigenous catchment storage) results in an estimate of total runoff 30% greater than the simulation results. The statistical technique employs a pollutant removal expression applied to the total flow captured in the detention basin, as contrasted to the simulation's utilization of intra-event pollutant kinetics for removal within the basin. Solution surfaces of runoff flow capture and pollutant removal efficiencies are developed for each method as a function of basin volume and drawdown rate. The differences in performance estimates between the two methods increase as the basin volume and drawdown rate increase, with the statistical technique yielding the lower estimate of flow capture. An optimal combination of basin volume and drawdown rate was determined for each technique by incorporating a cost constraint. For a long-term pollutant removal efficiency of 70%, the annual cost associated with a basin designed by the statistical technique is approximately twice that of a basin designed by simulation. The program SYNOP generates rainfall event statistics which may be incorporated with simulation, providing a coordinated approach for analyzing the performance of stormwater detention basins.

INTRODUCTION

Combined and separate storm sewer overflows contribute similar magnitudes of contaminant loads to receiving waters as does secondary treatment effluent (5). Simple storage/treatment devices provide a cost-effective measure for quantity as well as quality control of storm flows. While the design of these devices has traditionally been based upon a single design storm event, the additional information provided by long-term analysis of the rainfall record has recently encouraged its adoption as a viable method. The engineer concerned with the design of a detention facility for the quality control of stormwater runoff has a variety of solution methodologies available: (1) Empirical approaches utilizing fundamental hydraulic parameters; (2) analytical methods based on solutions to the governing flow equations; simulators amenable to rigorous search techniques; and (3) statistical techniques involving rainfall-runoff parameter distributions. No one method has been documented to be the most cost-effective for all applications. This is in part due to the lack of long-term data base, but also reflects the lack of comparative studies. This study presents estimates of the performance of stormwater storage/treatment devices as obtained by computer simulation and a statistical technique. The optimal design of a control device will depend on problem-specific constraints such as discharge quality standards and economic considerations.

Traditional Design of Stormwater Basins.—The sizing of stormwater detention facilities has been based on a single "design" storm event. These basins are designed to capture the runoff from a storm expected to occur for a given duration on the average once every *N* years (3). Incorporation of downstream risk assessment governs the value of *N*, which typically ranges from 1 yr–50 yr. The traditional design storm analysis employs ranking storms (e.g., annual maximum 60-min or 24-hr duration rainfalls) over a time period and assigning an extreme value probability distribution to the resultant sequence. This method does not retain information on the time between events. One unobtainable parameter whose value is necessary for accurate flow routing is the effective volume, defined as the storage volume within the basin available at the beginning of a storm, which is a function of antecedent conditions. While the single storm method has been used for flood control design, no criteria have been established for determining a design storm for quality control.

STUDY CASE

In the study case, the control unit was a single basin which receives stormwater runoff from an adjacent urban catchment. As indicated in Fig. 1, the watershed contains no streams, lakes or groundwater interaction. The flow routing geometry was kept as simple as possible. Runoff from the entire catchment was routed to the stormwater basin and subsequently discharged to a receiving water. The catchment characteristics are presented in Table 1.

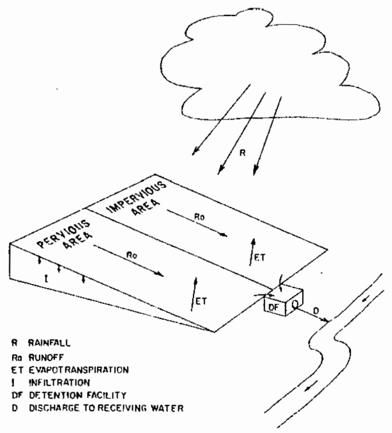

FIG. 1.—Schematic of Study Catchment

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TABLE 1.—Catchment Characteristics of Study Case

Total area = 24.7 acres (10 hectares)
Imprevious area = 37%
No depression storage
Average catchment slope = 0.040 ft/ft (0.040 m/m)
Maximum infiltration = 2.5 in./hr (64 mm/hr)
Minimum infiltration = 0.5 in./hr (13 mm/hr)
Evaporation = 0.1 in./day (2.5 mm/day)
Population density = 3,000 people/square mile (12 people/hectare)

Runoff Quantity.—A comparison of rainfall and runoff time series reveals two phenomena characteristic of the rainfall-runoff process: (1) A reduction in the number of events due to the complete capture of low volume storms by the indigenous catchment storage capacity, e.g., depression storage and soil moisture capacity; and (2) a reduction in the volume of the events due to the catchment storage and flow interception, e.g., depression storage and infiltration rates. Analyses that deal with single runoff events are not sufficient to characterize these phenomena because the catchment storage and interception capacities are functions of antecedent soil moisture conditions, and hence, are not constant. It becomes necessary to retain as much information as possible on the time between successive events.

Basin Characterization.—The long-term series of runoff flows is a sequence of flow pulses separated by relatively long periods without flow, suggesting two realms of kinetics in the basin: rapid, relatively well-mixed during the runoff event, followed by slower kinetics (with less dispersion and turbulence) and relatively quiescent conditions during the subsequent dry weather period. Characterizing this time series of discontinuous flows entering the basin and subsequent kinetics within the basin has been a major obstacle in solution methods.

SIMULATION ANALYSIS

Several computer models are available for the simulation of the rainfall-runoff process in an urban system, e.g., SWMM (10), STORM (1) and DEPOSITS (4). This study utilized Version III of the EPA Storm Water Management Model (SWMM). While the SWMM allows for extensive watershed simulation, this study restricted the analysis to a simplified Runoff Block and concentrated on the Storage/Treatment Block. No gutter or pipe networks were used in the example catchment; all runoff exited at a single outlet.

The Storage/Treatment (S/T) Block of SWMM modeled the flow and pollutant routing through the detention basin. Basin geometry, hydraulic characteristics and incoming flows were included as data input for the S/T block. As a reference, basin volumes V_b were divided by mean event runoff volume V_{ro}, yielding normalized volume ratio V_b/V_{ro}. The rainfall data source utilized for this study was the National Weather Service (NWS) record for 24.6 yr (June 1948–December 1972) of hourly rainfall at Atlanta, Georgia. The hourly rainfall data was analyzed with SYNOP, a computer package developed by Hydroscience, Inc. (1,10) to determine synoptic statistics of rainfall time series. Rainfall event volumes, intensities, durations and interevent times are the principal parameters evaluated in SYNOP. Available options include complete statistics on an event or time basis, e.g., storm or yearly averages. Cumulative conditional probabilities (i.e., given that rain has occurred) and return periods for hourly rainfall volumes are also calculated. SYNOP incorporates the assumption that storm events occur as a Poisson process and that the time between events is exponentially distributed. The exponential distribution is a special case of the gamma distribution having the coefficient of variation equal to unity. The grouping of hourly data into storm events was determined by the minimum intervent time—a user-defined input variable establishing the minimum number of dry hours between rainfall events. The minimum interevent time was varied to obtain a value close to unity for the coefficient of variation c_v associated with the interevent time. The results of the SYNOP runs, presented in Table 2, give some idea of the sensitivity of the results to the choice of the minimum interevent time. With eight hours specified as the minimum number of dry hours defining an event, the coefficient of variation for the mean interevent time was 1.004. Values for the event means of the parameters were taken from this run, e.g., mean volume V_r of a rainfall event was 0.495 in. Notice that V_r does not equal the product of event mean event intensity I_r and duration D_r. This is because V_r is the mean of the products of individual events' intensity i_r and duration d_r, which is not necessarily equal to the product of I_r and D_r.

Currently, the SWMM does not define runoff event statistics, so the SYNOP program was employed. This involved running the Runoff Block with the complete 24.6-yr rainfall record and generating 24.6 yr of runoff data which were subsequently transformed to the format of the NWS rainfall data to be compatible with the SYNOP input format. As with the rainfall data, the minimum interevent time was varied to obtain coefficient of variation c_v for the interevent time close to unity. A minimum interevent time of 8 hr resulted in a c_v of 0.999. The mean runoff event volume was determined to be 19,492 cu ft. The total number of events was reduced from 2,381 rainfall events to 1,760 runoff events. Mass continuity was checked by comparing the product of the mean runoff event

TABLE 2.—Results of SYNOP Analysis of 24.6 yr of Atlanta, Georgia Rainfall

		Rainfall Volume, V_r		Rainfall Duration, D_r		Rainfall Intensity, I_r		Interevent Time, T_i	
Minimum number of dry hours (1)	Number of events per year (2)	Mean, in inches (centimeters) (3)	Coefficient of variation (4)	Mean, in hours (5)	Coefficient of variation (6)	Mean, in inches per hour (centimeters per hour) (7)	Coefficient of variation (8)	Mean, in hours (9)	Coefficient of variation (10)
3	130.7	0.367 (0.932)	1.540	4.642	1.126	0.078 (0.198)	1.372	66.73	1.269
5	105.5	0.454 (1.153)	1.424	6.646	1.124	0.077 (0.196)	1.348	82.62	1.067
8	96.8	0.495 (1.257)	1.384	7.824	1.134	0.077 (0.196)	1.356	90.10	1.004
12	86.7	0.552 (1.402)	1.332	9.817	1.143	0.074 (0.188)	1.334	100.55	0.917

volume and the total number of events (as determined by SYNOP) with the amount of runoff generated by the Runoff Block. Continuity was found to be preserved within one percent. Test basin volumes were obtained to closely approximate volume ratios of 0.5, 1.0, 2.0, 4.0, and 10.0. A V_o/V_{ro} ratio of 0.50 implies that the empty basin volume is 50% of the mean storm event volume. The S/T Block utilized the runoff values generated from the Runoff Block. To save execution time and money, the Runoff Block was run once and the output stored in an interface data file. The interface data set served as the input to S/T for the subsequent simulations. A constant suspended solids concentration of 100 mg/L was assigned to the influent. This was chosen as opposed to generating pollutants from the catchment area for three reasons: (1) It avoids concern over how the pollutants are generated; (2) it provides a base value for future comparisons; and (3) a constant influent concentration establishes that the percent of flow bypassed is numerically equivalent to the percent of the pollutant bypassed.

The actual storm flow condition in a basin is neither plug flow nor completely mixed, but somewhere between, termed intermediate mixing. The complete mixing option of the S/T block was chosen as the flow regime for its computational simplicity. A constant outflow basin was simulated by using the pumping option of S/T and the drawdown rate was normalized as Q_c/Q_{ro} in which Q_c = drawdown rate; and Q_{ro} = quotient of mean runoff volume V_{ro} and mean interevent time T_i. V_{ro} and T_i are constants determined from SYNOP runs; thus, various values of the discharge ratio reflect different drawdown rates. Pumping rates were calculated to yield ratios of 1, 2, 4, 7, and 10. Drawdown occurred whenever water was in the basin. As a separate investigation, the effects of drawdown height (H_d) and drawdown rate on capture and removal efficiencies were analyzed.

Pollutant removal was characterized by treatment time in the basin. The removal kinetics were defined by the hydraulics within the basin, as determined by basin geometry and the inflow and discharge characteristics; these are the major influences on control efficiency and became the design parameters. A pollutant removal equation was utilized of the form

$$R = R_{\max}[1 - \exp(-kt)] \quad \text{(1)}$$

in which R = pollutant removal efficiency; $R_{\max}$ = maximum removal efficiency; k = first-order removal rate coefficient; and t = treatment time. Values of $R_{\max}$ = 1.0 and k = 0.6 per hour were arbitrarily assigned. In the S/T Block, removal is accounted for once per time step, with the treatment time defined as the length of the time step. Because the time step was held constant throughout the simulation a constant percentage of pollutant was removed per time step. A comparison of effluent concentrations for three flow regimes, in an ideal plug flow basin, an ideal completely mixed basin and the S/T complete mixing regime, is presented in Fig. 2. As shown, the S/T results lie within the extremes of pollutant removal efficiency defined by ideal plug flow and complete mixing.

Simulation Results.—On the example catchment, the Runoff Block estimated that 60% of the total 1,177 in. (2,990 cm) of rain left via infiltration. A total of 33% accumulated as runoff, while 7% was lost to evaporation. Mass continuity was preserved within 0.3% over the total 24.6-yr simulation. The costs of the analysis were reduced an order of magnitude by simulating runoff during a single year of record which adequately reproduced long-term basin performance. A surrogate year, 1953, was chosen on the basis of similar synoptic statistics, as determined by the SYNOP run of the 24.6-yr runoff data. A comparison of 1953 runoff parameters with those of the 24.6-yr time series is presented in Table 3. Performance results from the S/T Block simulations are presented in Figs. 3 and 4 and in Table 4. The 1953 simulations duplicated the performance results of the 24.6-yr simulations within five percent over the entire spectrum of basin volumes and discharge rates. Fig. 3 presents the solution surface for flow capture efficiency as a function of drawdown rate and basin volume. Isopleths of capture efficiency were drawn by linear interpolation between calculated values. As expected, flow capture was greater as the drawdown rate increased, due to an increase in the effective volume. Also, as the basin volume increased, the capture efficiency increased due to less bypass. The vertical distance between the isoquants represents the sensitivity of capture performance to basin vol-

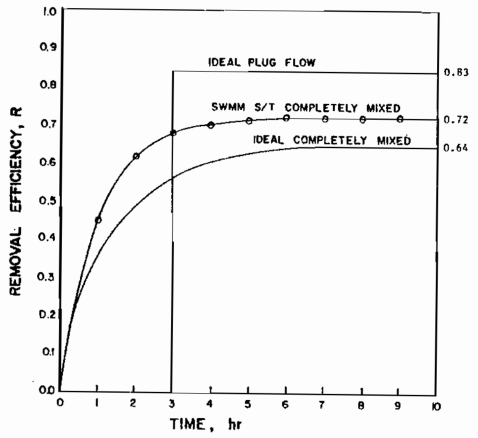

FIG. 2.—Comparison of Flow Routing Techniques

TABLE 3.—Comparison of Mean Runoff Event Parameters for 1953 with the 24.6-yr Record (Minimum Interevent Time = 8.0 hr)

		Runoff Volume, V_{ro}		Runoff Duration, D_{ro}		Runoff Intensity, I_{ro}		Interevent Time, T_i	
Rainfall data set (1)	Number of events per year (2)	Mean, in inches (millimeters) (3)	Coefficient of variation (4)	Mean, in hours (5)	Coefficient of variation (6)	Mean, in inches per hour (millimeters per hour) (7)	Coefficient of variation (8)	Mean, in hours (9)	Coefficient of variation (10)
24.6-year record	72	0.217 (5.51)	1.194	6.438	1.030	0.040 (1.02)	1.073	122.32	0.999
1953	71	0.223 (5.66)	1.102	6.887	1.121	0.040 (1.02)	1.103	124.30	0.937

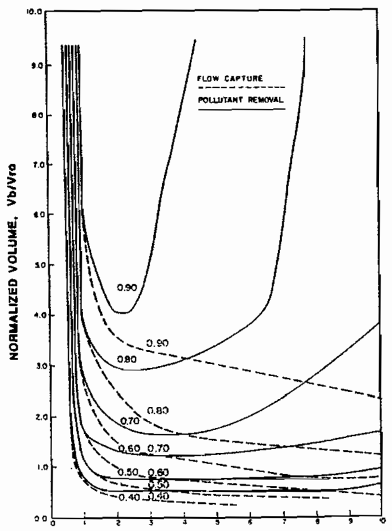

FIG. 3.—Solution Surface of Basin Performance; Simulation Results

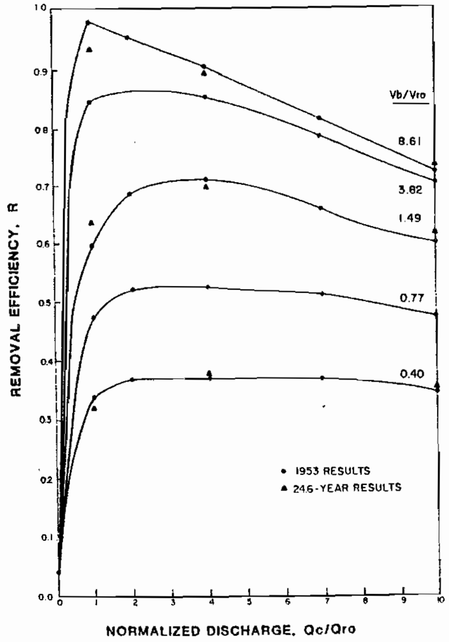

FIG. 4.—Pollutant Removal Efficiency; Simulation Results

ume; the smaller the distance, the greater the sensitivity. For drawdown rates greater than 4.0, there was a uniform sensitivity to basin volume. The lowest sensitivities occurred at the lower drawdown rates, where Q_c/Q_{ro} was less than 2.0. The isoquants converge slightly toward the upper end of the abscissa. The horizontal distance separating the isoquants represents the sensitivity of capture performance to the drawdown rate. The isoquants become parallel to the ordinate above Q_c/Q_{ro} of 4.0, implying relative insensitivity to drawdown rates as the drawdown rate is increased.

Fig. 3 also presents the solution surface for pollutant removal efficiency as a function of basin volume and drawdown rate. Unlike the solution surface of flow capture performance, the pollutant removal isoquants slope upward after an initial negative slope. The result is a solution surface which allows the same removal performance for more than one drawdown rate at a specific basin volume. This demonstrates the performance tradeoff of providing a larger effective volume by emptying the basin quicker versus providing a longer treatment time, although bypassing more flow. The greatest removal occurred in the region of basin volume ratios greater than 4.0 and at drawdown ratios less than 4.0. The sensitivity of pollutant removal to drawdown rate increases as the volume ratio increases, as shown in Fig. 4. Combinations of basin volume and drawdown rates yielding equivalent removal as well as the sensitivity of the removal performance to drawdown rate are demonstrated. The sensitivity of performance to drawdown is represented as the slope of the curves, and is seen to increase as the volume ratio increases. Also as the volume ratio increases, the maximum removal efficiency for each volume occurs at decreasing drawdown rates. The performance curve for a V_b/V_{ro} of 8.6 is depicted as a straight line. This represents a maximum divergence of 5% from the 24.6-yr results, possibly due to the lack of a large storm during 1953. All of the curves

TABLE 4.—Estimates of Flow Capture Efficiency (C) and Pollutant Removal Efficiency (R) as a Function of Basin Volume and Constant Discharge Rate: Simulation Results

Normalized discharge ratio, Q_c/Q_{ro}		NORMALIZED VOLUME RATIO, V_b/V_{ro}							
		0.40		0.77	1.49		3.82	8.61	
		1953 (2)	24.6-yr (3)	1953 (4)	1953 (5)	24.6-yr (6)	1953 (7)	1953 (8)	24.6-yr (9)
(1)									
1	C	0.344	0.331	0.476	0.613	0.640	0.852	1.000	0.952
	R	0.343	0.322	0.476	0.598	0.638	0.847	0.989	0.941
2	C	0.398	—[a]	0.552	0.721	—[a]	0.945	1.000	—[a]
	R	0.373	—[a]	0.527	0.690	—[a]	0.906	0.961	—[a]
4	C	0.468	0.461	0.621	0.804	0.795	0.962	1.000	0.993
	R	0.373	0.383	0.532	0.712	0.705	0.864	0.905	0.896
7	C	0.542	—[a]	0.699	0.839	—[a]	0.971	1.000	—[a]
	R	0.365	—[a]	0.524	0.661	—[a]	0.792	0.817	—[a]
10	C	0.611	0.608	0.744	0.868	0.876	0.982	1.000	0.999
	R	0.342	0.351	0.483	0.603	0.619	0.713	0.728	0.736

[a] Indicates that simulation was not run.

converge to 4.3% removal at Q_c/Q_{ro} of zero, i.e., in the case where there is no basin outlet. Long-term removal efficiency for this case would tend to zero percent.

Technically Efficient Basin Design.—The height at which discharge begins (drawdown height) combines with the discharge rate to regulate basin performance. Intuitively, increasing the height would decrease the capture efficiency, but due to the completely-mixed flow regime, the remaining volume would dilute the influent pollutant load. Combinations of drawdown height (H_d) and rate (Q_c) were simulated to develop guidelines for a technically efficient design of detention facilities. A basin with a V_b/V_{ro} of 1.49 was utilized for these simulations. Results from the previous simulations indicate that a basin with this ratio had the greatest performance sensitivity (26% flow capture and 11% pollutant removal) over the range of drawdown rates and should be sensitive enough to reflect the effect of various drawdown height and discharge combinations on basin performance. The results of the simulations, presented in Fig. 5 and Table 5, indicate that maximum performance was achieved by a normalized discharge ratio of 12.0 with a drawdown height of one foot. Removal efficiencies for basins with complete drawdown (in the previous simulations) were lower than limited drawdown (H_d greater than zero) for all but the lowest discharge rates. The general trend of the isoquants indicates that similar performance can be achieved by a low drawdown ratio and low drawdown height as well as a higher discharge ratio and a corresponding higher drawdown elevation. As the drawdown height increased, maximum removal occurred at higher drawdown rates. As the drawdown rate increased, removal efficiency increased until a maximum was reached, after which, further increase in drawdown rate yielded decreased removal. These results suggest that a basin with a large outlet, possibly a weir near the top of the basin, offers a feasible solution for good flow capture and pollutant removal performance. This is a different case than a basin with no outlet. With no outlet the maximum depth is maintained (minus evaporation, etc. losses) and any runoff is immediately bypassed with no treatment. With a large outlet just below the maximum depth, the runoff will pass through the basin and receive some degree of treatment by dilution. Extrapolating these results to areas outside the solution surface, the limiting maximum removal configuration might be a drawdown rate as high as the maximum inflow rate, with the discharge height at the top of the basin, i.e., no bypass, but all the runoff would be diluted to some degree as it passed through the basin.

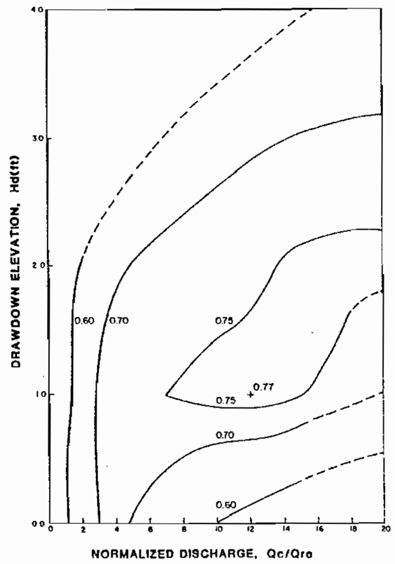

FIG. 5.—Solution Surface of Removal Efficiency as Influenced by Drawdown Height; Simulation Results

TABLE 5.—Estimates of Flow Capture Efficiency (*C*) and Pollutant Removal Efficiency (*R*) as a Function of Drawdown Height and Rate (V_b/V_{ro} = 1.49): 1953 Simulation Results

Normalized discharge ratio, Q_c/Q_{ro} (1)		Drawdown Height, *H*, in Feet (Meters)				
		0 (2)	1 (0.305) (3)	2 (0.610) (4)	3 (0.915) (5)	4 (1.220) (6)
1	*C*	0.613	0.578	0.517	—[a]	—[a]
	R	0.598	0.578	0.517	—[a]	—[a]
2	*C*	0.721	0.679	0.610	—[a]	—[a]
	R	0.690	0.679	0.610	—[a]	—[a]
4	*C*	0.804	0.756	0.687	—[a]	—[a]
	R	0.712	0.734	0.687	—[a]	—[a]
7	*C*	0.839	0.804	0.749	—[a]	—[a]
	R	0.661	0.752	0.728	—[a]	—[a]
10	*C*	0.686	0.837	0.778	—[a]	—[a]
	R	0.603	0.761	0.738	—[a]	—[a]
12	*C*	0.883	0.860	0.795	0.717	—[a]
	R	0.570	0.766	0.744	0.694	—[a]
15	*C*	0.900	0.874	0.831	0.745	0.610
	R	0.520	0.749	0.763	0.713	0.597
18	*C*	—[a]	0.885	0.845	0.765	0.648
	R	—[a]	0.730	0.758	0.727	0.621
20	*C*	—[a]	—[a]	0.851	0.776	0.663
	R	—[a]	—[a]	0.761	0.731	0.636

[a] Indicates that simulation was not run.

STATISTICAL ANALYSIS

Independently, two groups have developed combinations of statistical and empirical approaches for designing urban stormwater detention facilities. Howard (8) presented the theoretical framework for analyzing the interevent times and volumes of combined sewer overflows resulting from various storage/treatment configurations. His derivation was based on approximating intensity, duration and interevent time as independent and exponentially distributed random variables.

As part of a study evaluating the long-term performance of urban stormwater control devices, Hydroscience, Inc. derived an analytical expression for the effective volume of a stormwater detention facility available at the beginning of a storm event (1,10). Like Howard's method, this technique retains information on the time between events, an important parameter for flow routing analyses. The associated methodology was published in the Journal by Di Toro and Small (2). The method is based on the SYNOP results for rainfall event statistics. The result is a set of graphs which enable the user to plot the solution surface for percent of flow captured (C) and effective volume (V_e), as a function of the constant drawdown rate (Q_c) and the empty basin volume (V_b). The algorithm requires repetitive application to obtain an optimal basin size for maximum capture efficiency.

Data Input.—The Atlanta, Georgia rainfall event statistics were obtained from the previous runs of SYNOP. Magnitudes of the runoff event parameters were obtained from the rainfall values via a linear conversion factor. The STORM runoff factor equation was used to determine the runoff volume conversion ratio, based on the percent imperviousness for the catchment

$$C_{ro} = 0.15 + 0.75I \quad \text{(2)}$$

in which C_{ro} = runoff conversion factor; and I = percent of the catchment area that is impervious. With $I = 0.37$ for the catchment data, $C_{ro} = 0.4275$, and the conversion produced a mean runoff volume of 18,973 cu ft (53 cu m). The mean event runoff volume is similar to the value obtained by the SWMM simulation, yet as mentioned earlier, the conversion method does not account for the reduction in the number of events resulting from catchment capture. The result is a total of 504 in. (1,280 cm) of runoff for the entire 24.6-yr record, as compared with the 388 in. (986 cm) obtained in the Runoff Block simulation. V_b/V_{ro} ratios were calculated to correspond to the volumes used in the S/T simulations.

Pollutant Removal.—An inherent limitation of using the Hydroscience statistical method for estimating quality control is the assignment of an absolute pollutant removal efficiency. In the design of a detention facility for quality control, the determination of a removal efficiency is a primary objective. It was difficult, therefore, to assign a removal expression. It was tempting to use the constant removal value incorporated during each time step in the S/T simulation; however, the two terms are not conceptually equivalent. Simulation employs time steps to route the flow through the basin, and the constant removal term applies only to the volume within the basin during that time step. This implies that for any runoff volume which remains in the basin longer than one time step, the total removal efficiency will be greater than the constant removal term. The Hydroscience statistical method essentially treats the removal mechanism in the basin as a black box process in which the constant removal term is applied to the total flow captured during the complete time history. Di Toro and Small (2) compare this method with STORM simulations as a comparison of basin pollutant removal efficiency estimates. Similar results were obtained because the STORM model also uses an assigned removal expression, rather than simulating the pollutant removal processes as does SWMM.

Approach.—A solution surface of capture performance was prepared as a function of basin volume and pumping rate. The grid was created by using Fig. 6 as follows: (1) Enter the lower graph at the respective volume ratio V_b/V_{ro}; (2) move horizontally until intersecting with the normalized discharge curve ($Q_c T_i/V_{ro}$); (3) move to the upper graph at the effective volume ratio V_e/V_{ro}, the common side between the graphs; (4) continue up until intersecting the runoff volume coefficient of variation curve c_v; and (5) move horizontally and exit at the estimate of capture efficiency C. This process was repeated for the combinations of basin volumes and drawdown rates which were incorporated in the simulation analysis.

Results.—The results are presented in Fig. 7 and Table 6. Isopleths of flow capture efficiency were drawn, and they emphasize the apparent insensitivity of the performance results to varying pumping rates. This relationship exists due to the combined shapes of the upper and lower curves. The capture efficiency is most sensitive to the coefficient of variation and effective volume ratio at the lower end of the V_b/V_{ro} axis. However, at the lower end of the V_b/V_{ro} axis, the effective volume ratio is relatively insensitive to the pumping rate, for the lines converge near $Q_c T_i/V_{ro}$ of 1.0. Conversely, where the effective volume is most sensitive to the pumping rate, at the upper end of the V_b/V_{ro} axis, the percent capture is least sensitive to effective volume, for the slopes are the flattest. The greatest overall sensitivity lies in the middle region of the graphs. The maximum variation for any given volume ratio was a 10% increase

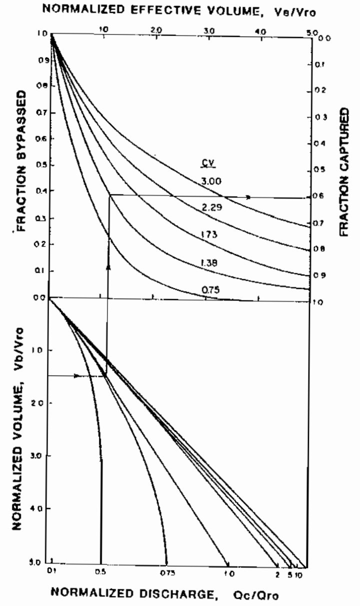

FIG. 6.—Determination of Long-Term Flow Capture Efficiency (Modified from Hydroscience, Inc.)

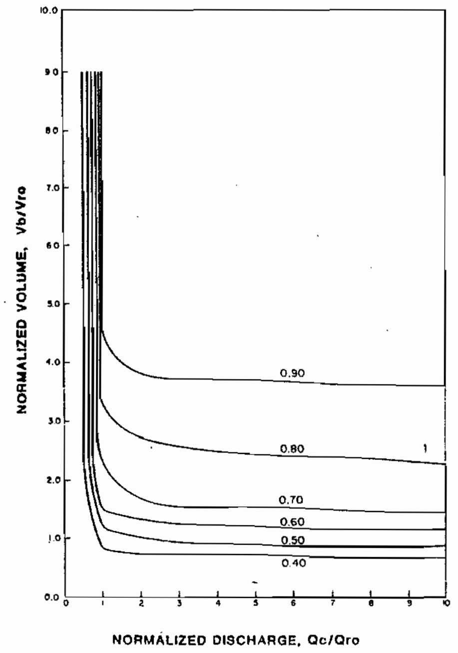

FIG. 7.—Solution Surface of Basin Performance; Statistical Results

from 61%–71% for a V_b/V_{ro} of 1.49. The largest V_b/V_{ro} ratio available in Fig. 6 is 5.0. This limitation precluded a complete comparison with simulation results, where V_b/V_{ro} ratios up to 8.6 were analyzed.

To make an estimate of removal efficiency would be presupposing the solution in this analysis. However, an estimate of removal efficiency can be obtained by taking the product of the percent capture and an assigned constant removal percentage. The resulting solution surface will have the same shape as the flow capture performance presented in Fig. 7, but the values of the isoquants will be altered by the pollutant removal factor.

TABLE 6.—Estimates of Flow Capture Efficiency (C) as a Function of Basin Volume and Constant Discharge Rate: Results of Hydroscience Statistical Method

Normalized discharge ratio, Q_c/Q_{ro} (1)	Normalized Volume Ratio, V_b/V_{ro}			
	0.40 (2)	0.77 (3)	1.49 (4)	3.82 (5)
1	0.22	0.40	0.61	0.86
2	0.23	0.47	0.68	0.90
4	0.24	0.48	0.70	0.91
7	0.30	0.49	0.70	0.92
10	0.30	0.49	0.71	0.92

COMPARISON OF METHODS

In comparing the methods, it is necessary to recognize that the Hydroscience statistical technique is a first-cut approach, while the SWMM can be employed to obtain greater design and analysis flexibility, although requiring a larger data input. As emphasized earlier, no established data base was available to definitively assess the results obtained. However, certain aspects of the statistical and simulation methodologies can be compared. Both techniques utilize the same rainfall data. The simulation generates its own runoff data, while the statistical technique relies on a rainfall to runoff conversion factor. Both methods allow calibration of results with observed data when available, although this feature is more limited in the statistical technique. Mean event runoff volumes obtained from the two methods differed by only 5%, but the different number of events, 2,381 for the statistical method versus 1,760 for the simulation, resulted in the statistical method predicting 30% more total runoff over the 24.6 yr record.

The flow capture solution surfaces obtained from the simulation and statistical methods are compared in Fig. 8. For discharge ratios less than 1.0 the two methods are in reasonable agreement. However, at discharge ratios above unity the estimates diverge, with the statistical estimates predicting up to 20% less capture than the simulation results. Removal efficiencies obtained from the simulation and statistical methods are compared in Fig. 9, where r is the constant removal term employed by the statistical technique. The most striking difference is the

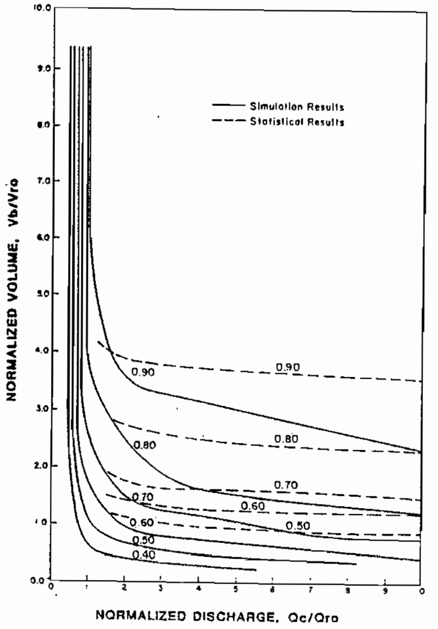

FIG. 8.—Comparison of Flow Capture Efficiency Estimates

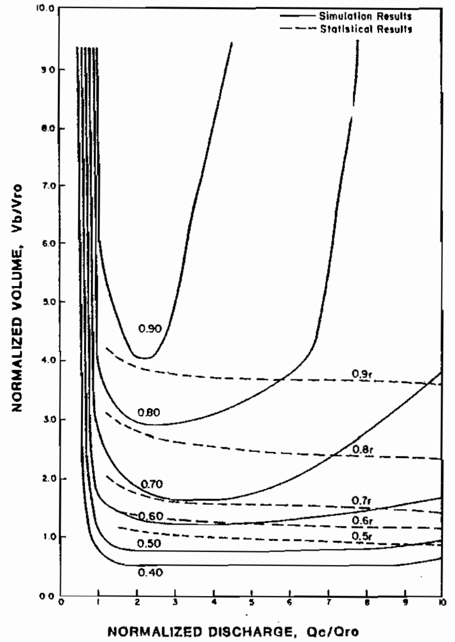

FIG. 9.—Comparison of Pollutant Removal Efficiency Estimates

shape of the isoquants. The simulation estimates reflect the combined effect of flow capture and treatment time on the slopes of the isoquants. The ability to depict this fundamental property of storage/treatment devices is relinquished by the statistical method with the direct inclusion of a removal expression, r. Estimates of r yielding pollutant removal comparable to the simulation results ranged from near unity at discharge ratios less than 1.0 to less than 0.8 at higher drawdown rates.

OPTIMAL SIZING

As an additional basis for comparing the methodologies, optimal basin designs were evaluated from their respective performance solution surfaces. In general, optimization criteria may include water effluent quality standards, long-term pollutant removal efficiency and economic constraints. The solution surfaces prepared in this study facilitate optimization based on the latter two constraints. The performance isoquants developed by each method define combinations of basin volume and drawdown rate yielding equivalent performance. However, another constraint was necessary to determine the optimal combination. An economic constraint was employed for this purpose. Cost functions for wet-weather control devices developed by Heaney et al. were modified to estimate amortized costs of detention facilities (5). The total annual cost was estimated as $TC = a\ V^b + c\ Q^d$ in which TC = total annual cost (1980 dollars); a, b, c, d = cost coefficients; V = basin volume; and Q = drawdown rate.

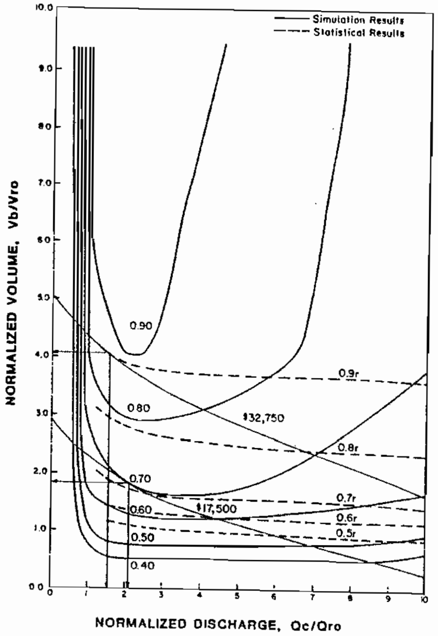

FIG. 10.—Determination of Least Cost Combination of Basin Volume and Drawdown Rate

Results.—An effluent constraint of 70% long-term removal was evaluated. An assigned removal efficiency of 77.8% was chosen for the statistical method to allow a 70% removal when applied to the 90% capture isoquant. Tangent cost curves were constructed on the combined solution surface shown in Fig. 10. For 70% removal, the statistical analysis determined the basin volume to be 2.28 times larger than the simulation estimate; coupled with a drawdown rate two-thirds of the simulation estimate, the total cost of the statistical optimum control facility was 1.87 times the cost of the simulation designed optimal basin. The discrepency is largely attributed to the inability of the statistical technique to account for intra-storm pollutant removal.

SUMMARY AND CONCLUSIONS

This study compared methodologies available to determine the long-term pollutant removal efficiency of stormwater detention basins. The relative effectiveness of the Hydroscience statistical technique in estimating flow capture performance for the hypothetical catchment was analyzed by comparison with the results from simulation using the SWMM. The statistical method in the form utilized precludes determination of pollutant removal efficiency. Modifications are needed to account for various removal characteristics within the detention facility. Simulation permits a sensitivity analysis of basin parameters and operating policies, while there is limited mechanism for this in the statistical technique. Simulation provided an interesting relationship between the overall removal efficiency and the basin parameters, demonstrating multiple drawdown rates at most basin volumes to achieve equivalent pollutant removal efficiencies. There was a noticeable removal performance trade-off between increasing the effective volume at the beginning of a storm and increasing the pollutant treatment time. These relationships were closer to observed results than the constant removal results of the statistical method (6). The use of SYNOP on the simulated runoff data facilitated the determination of a surrogate year of runoff which served as the input for subsequent simulation runs. An optional combination of basin volume and drawdown rate was determined for each technique by incorporating a cost constraint. For a long-term pollutant removal efficiency of 70%, the estimated annual cost associated with a basin designed by the statistical technique was approximately twice that of a basin designed by simulation.

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PREDICTING ALGAL STIMULATORY PROPERTIES OF WASTEWATER

By Neil M. Ram[1] and Patricia E. Austin[2]

ABSTRACT: The growth response of the green alga, *Selenastrum capricornutum* to varying additions of either sewage or reconstituted water containing equivalent levels of inorganic nitrogen and phosphorus, was compared to algal growth levels calculated from the inorganic nutrient concentrations of these additions using the algal yield factor of the test alga. The additions resulted in a linear increase in algal growth with percent of sewage or chemical equivalent solution addition which was in close agreement to the values predicted from the total soluble inorganic nitrogen concentration in the algal cultures alone. Thus, the Algal Assay: Bottle Test (AA:BT) did not permit sufficient organic mineralization during incubation, owing to the exclusion of heterotrophic bacteria and protozoa by the test procedure. This occurrence could result in an underestimation by the AA:BT of the algal growth potential occurring from the entry of a wastewater containing inorganic and organic nitrogen and phosphorus compounds into the aquatic environment.

INTRODUCTION

Discharge of wastewater effluent into the aquatic environment is of environmental concern because of the resulting eutrophication or nutrient enrichment of receiving waters leading to decreased water quality. One method to assess this impact is to predict the level of phytoplankton growth induced by the addition of a nutrient-rich wastewater by determining the gram N:P ratio [equal to (NH_3-N + NO_2^--N + NO_3^--N)/(Ortho-P)] of the receiving water, and the nitrogen and phosphorus added by the wastewater input. It has been shown that nitrogen and phosphorus are taken up by the alga *Selenastrum capricornutum* in a ratio of approximately 11.3:1 (12). Miller, et al. (12), therefore, defined a water to be nitrogen limiting for algal growth at an N:P ratio of less than 10:1, and phosphorus limiting for algal growth at an N:P ratio of greater than 12:1. The predicted level of algal biomass arising from additional nutrient input can then be calculated using Eqs. 1 or 2 from Miller (12), i.e.:

$$\begin{bmatrix}\text{Predicted algal}\\ \text{biomass (mg/L) for}\\ \text{a nitrogen limiting}\\ \text{receiving water}\end{bmatrix} = \begin{bmatrix}\text{Total soluble}\\ \text{inorganic}\\ \text{nitrogen}\\ \text{(mg/L)}\end{bmatrix}\begin{bmatrix}\text{Algal yield}\\ \text{factor}\end{bmatrix} \pm 20\% \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$\begin{bmatrix}\text{Predicted algal}\\ \text{biomass (mg/L) for}\\ \text{a phosphorus limiting}\\ \text{receiving water}\end{bmatrix} = \begin{bmatrix}\text{Orthophosphorus}\\ \text{(mg/L)}\end{bmatrix}\begin{bmatrix}\text{Algal yield}\\ \text{factor}\end{bmatrix} \pm 20\% \quad \ldots\ldots \quad (2)$$

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