PARKING LOT STORAGE MODELING USING DIFFUSION WAVES

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ABSTRACT: The feasibility of temporarily holding storm water in parking lots is examined by using a diffusion wave model of catchment dynamics. Four extreme storm types are applied to four typical parking lot sizes to assess the sensitivity of the resulting storm hydrograph to the choice of design slope. Results show the promise of parking lot storage in urban storm water management.

INTRODUCTION

Urban development decreases surface roughness and infiltration rates, thus decreasing the time of concentration and increasing surface runoff. When taken in the aggregate, these effects result in an increase in the magnitude and frequency of floods at downstream sites, at any scale.

To counter this trend, runoff detention and retention is now being seen as an alternative strategy (Stahre and Urbonas 1990). The rationale behind this change of approach is the recognition that the conventional drainage strategy has its pitfalls: While it effectively reduces the local flooding risk, it results in an increase in the regional flooding risk.

Herein we define ''kinematic drainage'' as the strategy that produces a storm hydrograph rising at the fastest possible rate. ''Diffusive drainage,'' on the other hand, is that which produces a storm hydrograph rising at rates lower than kinematic.

The calculation of diffusive drainage is possible with the diffusion wave model of catchment dynamics (Ponce 1986; Orlandini and Rosso 1996). The diffusion effect reduces the rate-of-rise of the outflow hydrograph, increasing the time base, spreading the flow in time, and reducing the flood risk downstream.

In this note, we use the diffusion wave model to quantify runoff detention in parking lots. Four extreme storms for San Diego County, California, are applied to four typical parking lot sizes to assess the sensitivity of the resulting storm hydrograph to design slopes ranging between 1.0 and 0.1%. The aim is to determine the effect of slope on parking lot storage.

DIFFUSION WAVE MODEL

The diffusion wave model used herein is an extension of the Muskingum-Cunge method of flood routing (Cunge 1969; ''Flood'' 1975) to overland flow phenomena (Ponce 1986). The geometric configuration follows Wooding's (1965) open book. The input to the planes is effective rainfall intensity, which is converted into lateral inflow into the center channel draining the two planes. In turn, the lateral inflow into the channel is routed to the outlet and expressed as an outflow hydrograph.

Because its hydraulic diffusivity is a function of the Vedernikov number (Vedernikov 1945; Chow 1959), the catchment model has a significant dynamic component (Dooge 1973; Dooge et al. 1982; Ponce 1991). Thus, diffusion vanishes if the Vedernikov number approaches one. However, under the flow conditions normally encountered in overland flow, the Vedernikov number is usually well below one.

The Muskingum-Cunge method works by matching physical and numerical diffusivities. Numerical stability and convergence are preserved by setting the Courant number at one, and varying instead the number of spatial increments. This technique avoids the infamous dip in the calculated hydrograph (Hjelmfelt 1985) and makes possible a simulation that is both stable and convergent. In addition, the linear formulation conserves mass exactly, while precluding kinematic shock development.

Unlike the kinematic wave model, which is a one-parameter model, and therefore, responsive only to wave celerity (Seddon 1900; Chow 1959), the diffusion wave model is a two-parameter model and is responsive to both wave celerity and hydraulic diffusivity (Hayami 1951). In essence, this means that the diffusion wave model can simulate a perceptible hydrograph feature such as flow spreading, which is directly traceable to the hydraulic diffusivity. On the other hand, a comparable kinematic wave model is unable to effectively account for the flow diffusivity, resulting in simulations that are dependent on grid size (Ponce 1986).

Because the hydraulic diffusivity is inversely related to plane and channel slope, the diffusion wave model is suited to applications where slope plays a major role. The steeper the slope, the more kinematic and less diffusive the flow is; conversely, the milder the slope, the more diffusive and less kinematic the flow is. For a sufficiently steep slope, the flow becomes kinematic and the resulting outflow hydrograph rises at the fastest possible rate. For the milder slopes, the outflow hydrograph rises at rates lower than kinematic.

The above reasoning led to the formulation of a testing program designed to determine the sensitivity of overland flow hydrographs to plane and channel slope. The aim is to assess the feasibility of using slope as a design parameter in urban storm water management.

TESTING PROGRAM AND MODEL RESULTS

The testing program was designed to vary storm intensity, catchment area, and design slope for a wide range of conditions. Four extreme storm types shown in Table 1 were established for the San Diego urban area (''Rainfall'' 1982).

Four typical parking lot sizes were selected, ranging from 0.105 to 6.88 ha (*Architectural* 1988). The parking lot types were classified as follows: A = very small, 0.105 ha; B = small, 0.83 ha; C = large, 3.44 ha; and D = very large, 6.88 ha.

Equilibrium outflows for each storm and parking lot type are shown in Table 2 (Ponce 1989). For simplicity, the chosen geometry is Wooding's (1965) open book, including a properly sized triangular drainage channel in the middle of the two planes. The surface roughness in planes and channel was set at $n = 0.1$ (*HEC-1* 1990) and $n = 0.013$ (Chow 1959), respectively.

Four design slopes were chosen to reflect a wide range of flow conditions, from kinematic to diffusive. Slopes less than 0.1% were judged to be impractical due to the possibility of excessive ponding, which could impair drivability. The selected slopes were: (1) 1%, kinematic; (2) 0.5%, mildly dif-

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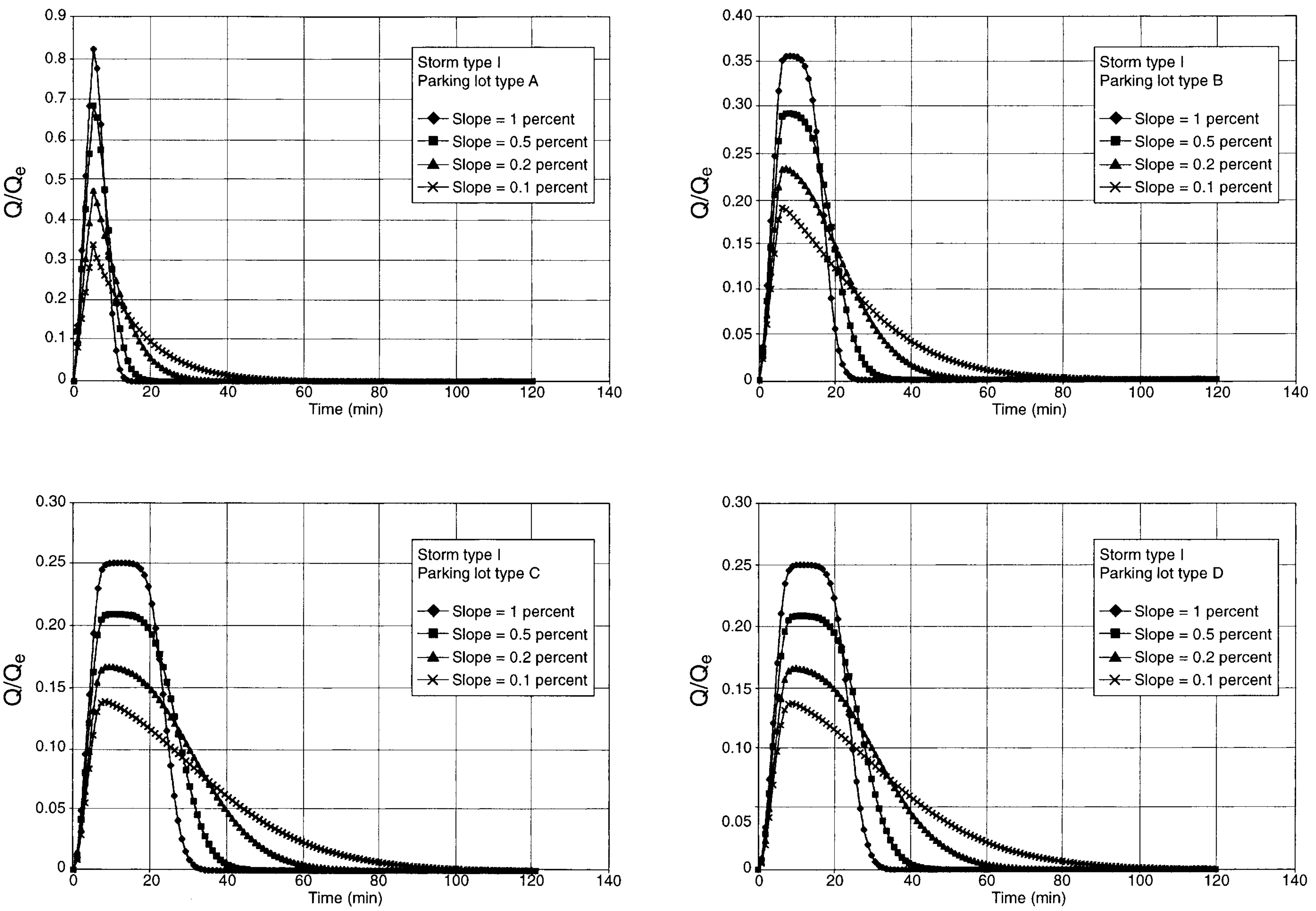

FIG. 1. Outflow Hydrographs for Storm Type I

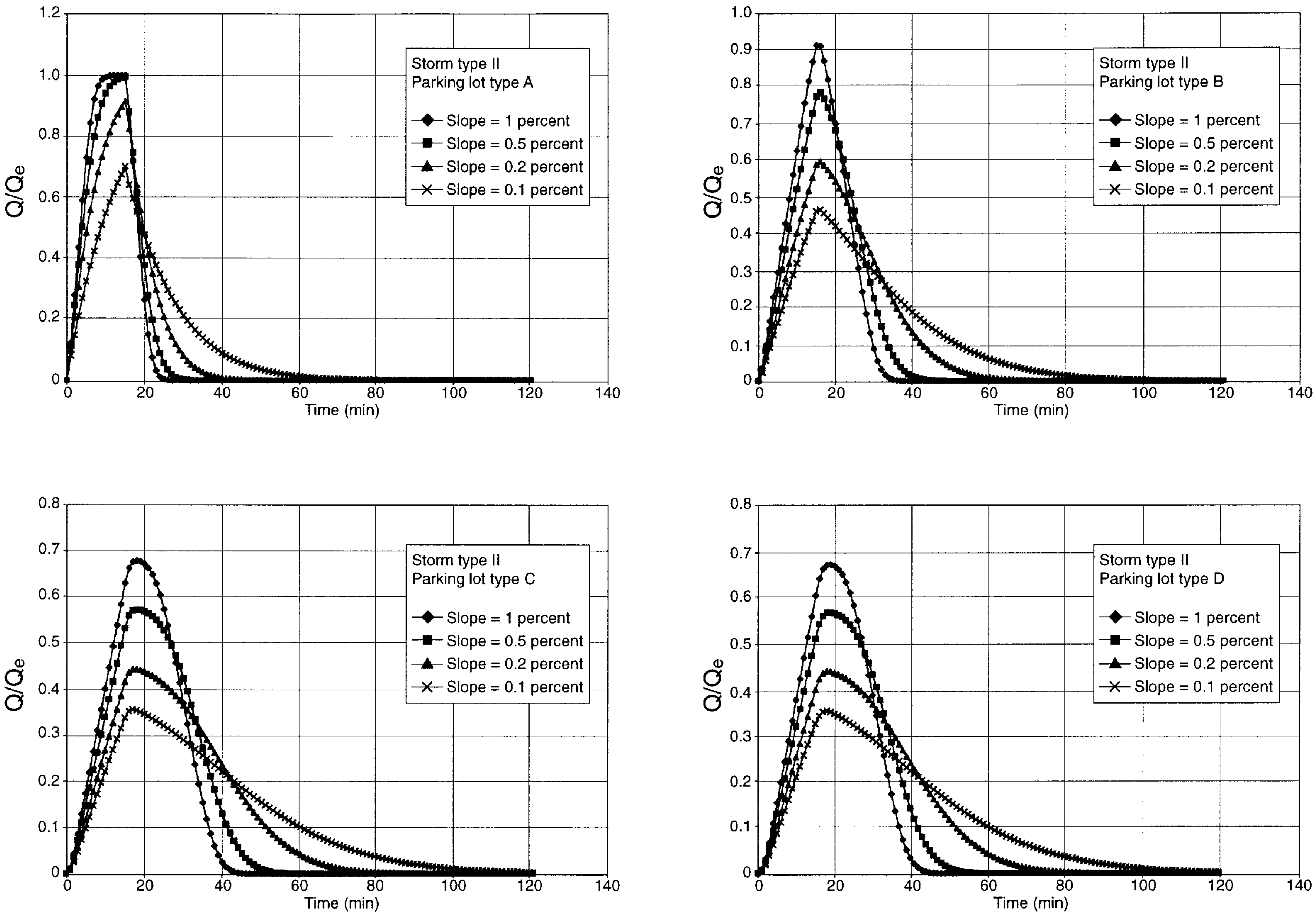

FIG. 2. Outflow Hydrographs for Storm Type II

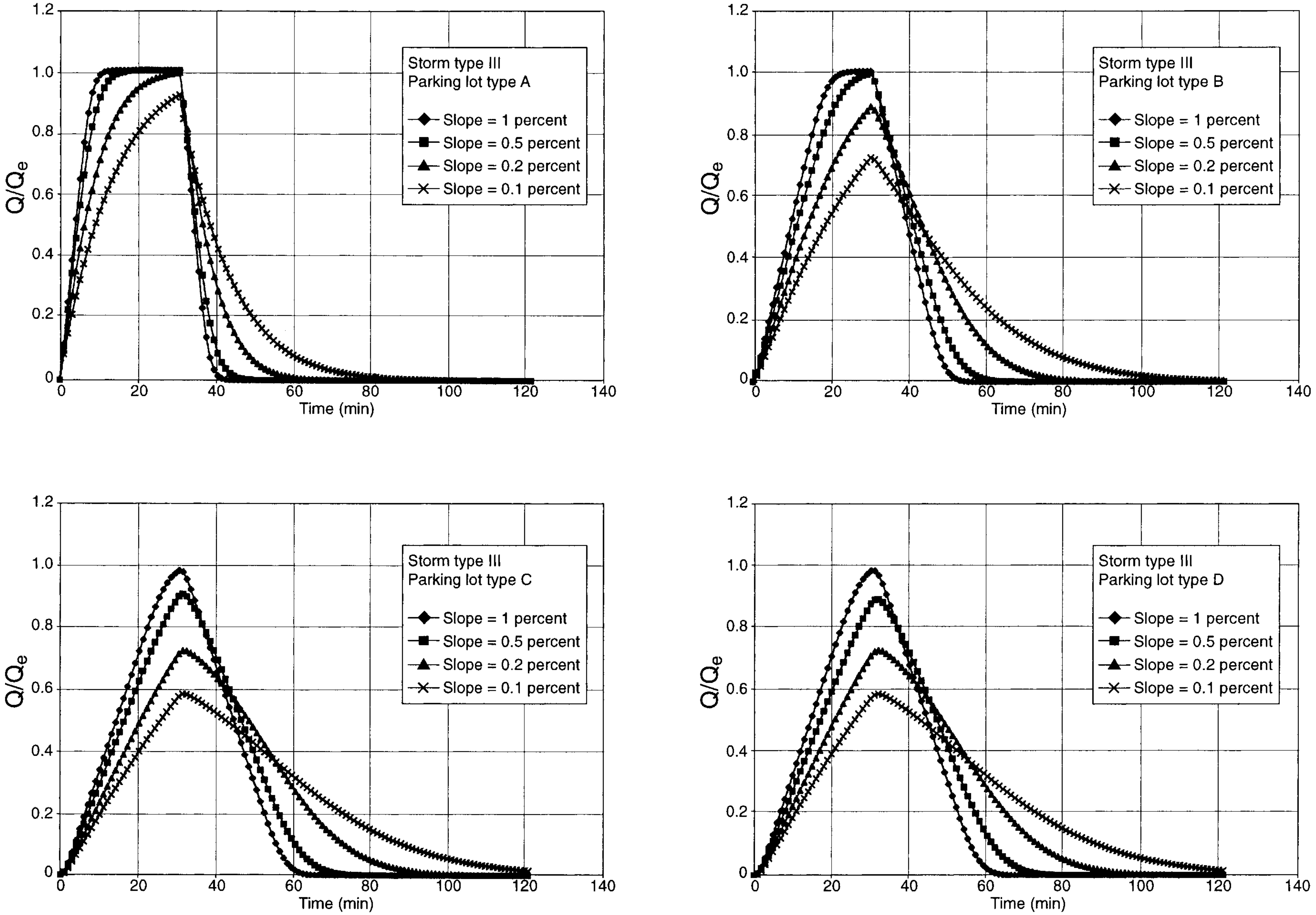

FIG. 3. Outflow Hydrographs for Storm Type III

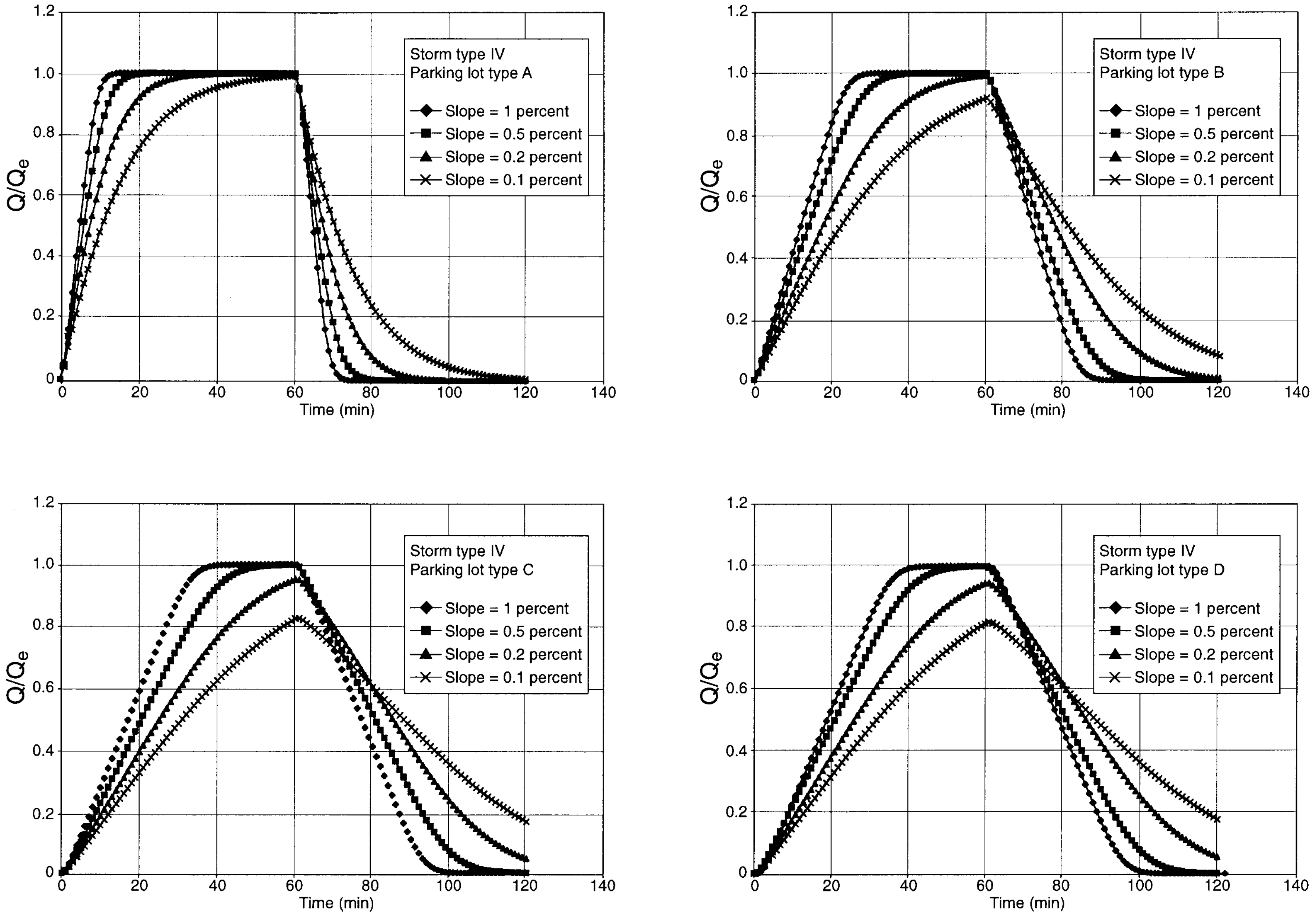

FIG. 4. Outflow Hydrographs for Storm Type IV

TABLE 1. Extreme Storm Types for San Diego Urban Area

Storm type (1)	Depth (mm) (2)	Duration (min) (3)	Intensity (mm min^{-1}) (4)
I	15.24	5	3.048
II	37.59	15	2.506
III	55.12	30	1.837
IV	67.82	60	1.130

TABLE 2. Equilibrium Outflows Q_e[a] for Each Storm and Parking Lot Type

	Parking Lot			
Storm type (1)	A (2)	B (3)	C (4)	D (5)
I	0.0533	0.422	1.748	3.495
II	0.0439	0.347	1.437	2.874
III	0.0321	0.254	1.053	2.106
IV	0.0198	0.156	0.648	1.296

[a] In $m^3 s^{-1}$.

fusive; (3) 0.2%, moderately diffusive; and (4) 0.1%, strongly diffusive.

Figs. 1–4 show the results of the simulation. For each storm type, four parking lot types and four design slopes led to 16 runs. The discharges shown are normalized discharges, i.e., the outflow discharges Q divided by their respective equilibrium outflow Q_e (Table 2).

Analysis of Figs. 1–4 leads to the following conclusions:

1. As slope decreases from 1 to 0.1%, the rate-of-rise of the outflow hydrograph decreases. This delays the attainment of equilibrium outflow, increases the time of concentration from kinematic to diffusive, and spreads the outflow hydrograph [see, for example, Figs. 3(d) and 4(d)].
2. For a storm duration less than the diffusive time of concentration, the delay in the attainment of equilibrium outflow produces subconcentrated catchment flow (Ponce 1989) and results in effective diffusive behavior [Figs. 3(c) and 4(c)].
3. For the shorter storms (5 and 15 min), the equilibrium outflow is not attained in most cases. The spreading of the outflow hydrograph results in effective diffusive behavior [see, for example, Figs. 1(c) and 2(c)].
4. For the longer storms (30 and 60 min), the equilibrium outflow is attained in most cases. However, the delay results in the spreading of the outflow hydrograph, i.e., in effective diffusive behavior [Figs. 3(b) and 4(b)].

SUMMARY

A diffusion wave model of catchment dynamics is used to assess the feasibility of using slope as a design parameter in urban storm water management. Parking lot storage is defined as the strategy to temporarily detain storm runoff in parking lots to provide an appreciable amount of storm water detention instead of fast and immediate drainage.

The testing included one kinematic case (1% slope) and three diffusive cases (0.5, 0.2, and 0.1% slopes). Model results show that the smaller the slope, the slower the rate-of-rise of the outflow hydrograph. This delays the attainment of equilibrium outflow, resulting in lower peak flows and/or longer time bases, i.e., in effective diffusive behavior. Thus, a parking lot can provide a substantial amount of storm water storage if it is specifically designed for this purpose.

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