IMPROVING UPON CONVENTIONAL STORM WATER DETENTION ORDINANCES

Brett A. Cunningham, P.E. and Michael F. Schmidt, P.E.
Camp Dresser and McKee; Jacksonville, Florida 32216

ABSTRACT

Ordinances designed to control post-development stormwater impacts are common among most municipalities. The requirement of detention storage to maintain the post-development peak flow of a given return period to no greater than the corresponding pre-development peak flow is often used as a means to achieve this objective. In many instances, however, this requirement is insufficient for maintaining downstream pre-development flood elevations under post-development conditions due to the increased discharge volume over the period of time critical to peak flood stage conditions from the post-development hydrograph.

An alternative (and more effective) method of maintaining pre-development downstream flood elevations under post-development conditions is to require the volume from the controlled post-development hydrograph over the period of time critical to peak flood elevations in downstream reaches to be no greater than the volume from the pre-development hydrograph over the same critical time period. The critical time period varies from basin to basin. The determination of the time period requires a comprehensive, basin-wide study.

This paper contains two examples of detention facilities designed to meet a volumetric discharge criterion. These two facilities are compared to similar facilities designed under a conventional peak discharge criterion. Performance of the volumetric and peak discharge criteria on an example basin is also presented.

INTRODUCTION

Urbanization of watersheds results in increased stormwater flows, primarily because of the increased levels of impervious area. Increased stormwater flows result in increased flood damages and erosion problems (1). One measure that is typically taken to control these adverse impacts is to require (e.g., through an ordinance) that the post-development peak flow be no greater than the pre-development peak flow for a given storm event (2). In many cases, this criterion is best achieved by use of detention storage. The peak flow criterion is a presumptive criterion in that it is presumed that if peak flows are controlled, then peak stages will be controlled. However, many communities have experienced flooding problems due to development, even with this requirement in place. Modeling studies have also verified the inadequacy of this requirement at controlling downstream impacts due to hydrograph timing, duration, increased volume, and dynamic channel routing effects.

Examination of several hydrographs from a large basin may illustrate the inadequacy of controlling peak flows in order to control peak stages. Figure 1 shows three hydrographs from a basin that is approximately 20 square miles. The two tallest hydrographs are the flow and stage hydrographs near the mouth of the basin from a 100-year synthetic rainfall event (essentially, a 24-hour SCS Type III distribution). The shortest hydrograph is a flow hydrograph from a 200 acre sub-basin within the basin. Two features are important to note on Figure 1. First, there is an extended period of time during which the stage hydrograph at the downstream end of the basin is at peak or near-peak conditions. This period of time plus the period of time where the stage hydrograph is rising sharply will be

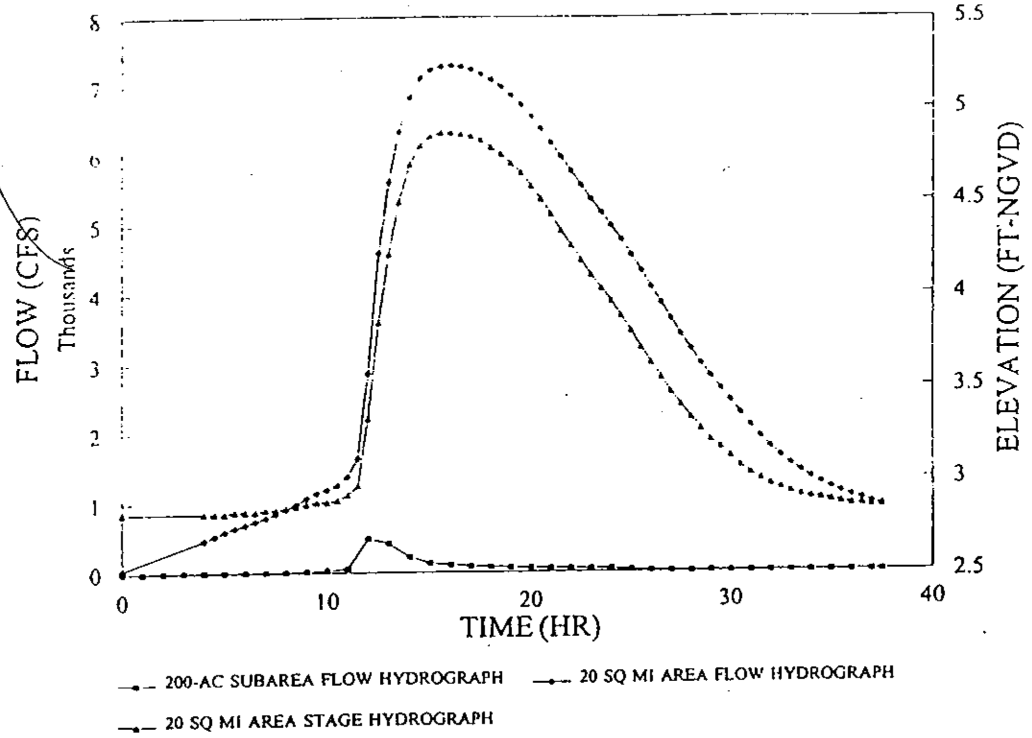

Figure 1. Response to synthetic 24-hour, 100-year rain event.

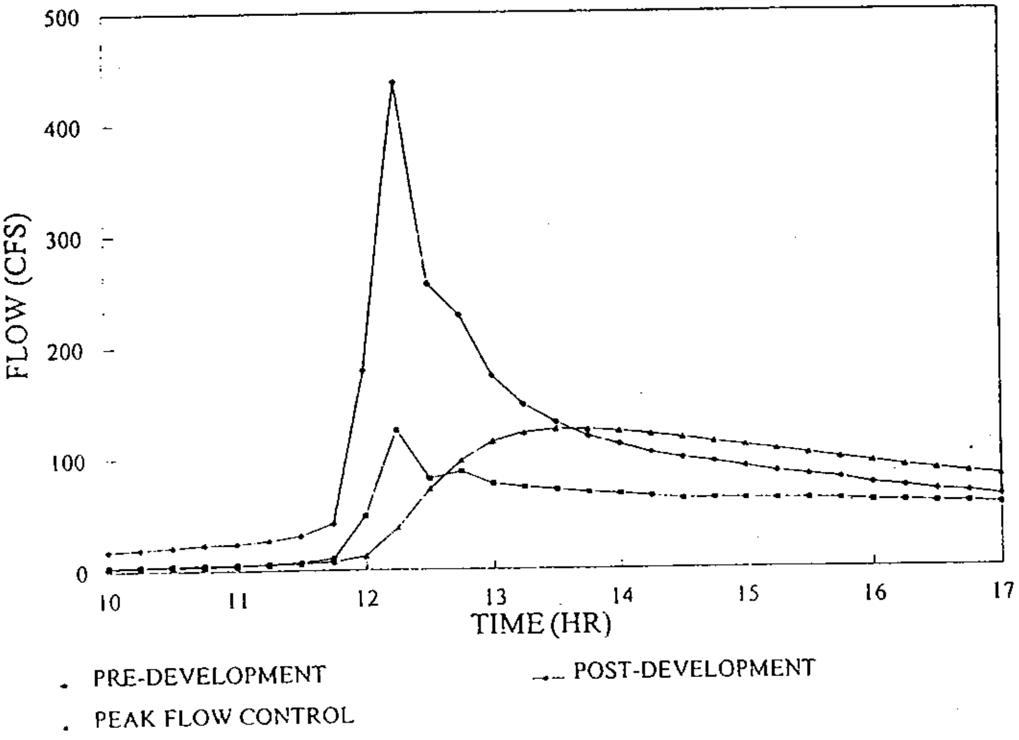

Figure 2 Comparison of hydrographs over critical time period

referred to as the "critical time period". Second, the total flow volume discharged over the critical time period from the 200-acre sub-basin will have a greater effect on the downstream stage hydrograph than will the peak flow from the 200-acre sub-basin.

Three hydrographs from the 200-acre sub-basin are shown in Figure 2 for the critical time period, which, for this example, is defined as hour 10 to hour 17 of the 24-hour storm event. The tallest hydrograph is the post-development hydrograph with no detention. The earlier peaking of the two other hydrographs is the pre-development hydrograph. The third hydrograph is the post-development hydrograph from a peak flow control detention pond. Basing the effectiveness of the detention pond on the volume of flow discharged over the critical time period, the hydrographs in Figure 2 illustrate that the detention pond will provide some reduction in downstream peak stage over providing no controls, but that some increases in downstream peak flood stages over pre-development conditions will occur because a greater volume is discharged over the critical time period.

STUDY SITES

Calculations for the design of two detention facilities designed to meet the volumetric discharge criterion are given in this paper. The purpose of presenting the calculations is to show that designing a detention pond under the volumetric discharge criterion is not significantly more difficult than designing a detention pond under the peak discharge criterion. Characteristics of the two areas for which these two facilities are designed are shown in Table 1. The two areas differ only in size--one is 200 acres and the other is 10 acres.

Performance of the volumetric discharge criterion and the peak flow criterion in an example basin is also presented in this paper. The example basin is West Branch, which is shown in Figure 3 (3). The West Branch basin was subdivided into four subareas. Characteristics of these four subareas are shown in Table 2. In order to evaluate the performance of the criteria on West Branch, it was necessary to predict peak flood stages along the primary stormwater management system (PSWMS). The junctions in Figure 4 show the locations where peak flood stages were predicted along the PSWMS.

Table 1 - Example Design: Area Characteristics

Size	10 acres and 200 acres
Predominant Pre-Development Land Use	95% forest/open
Pre-Development Imperviousness	6%
Predominant Post-Development Land Use	86% medium density residential
Post-Development Imperviousness	27%
Soils	Hydrologic Class C

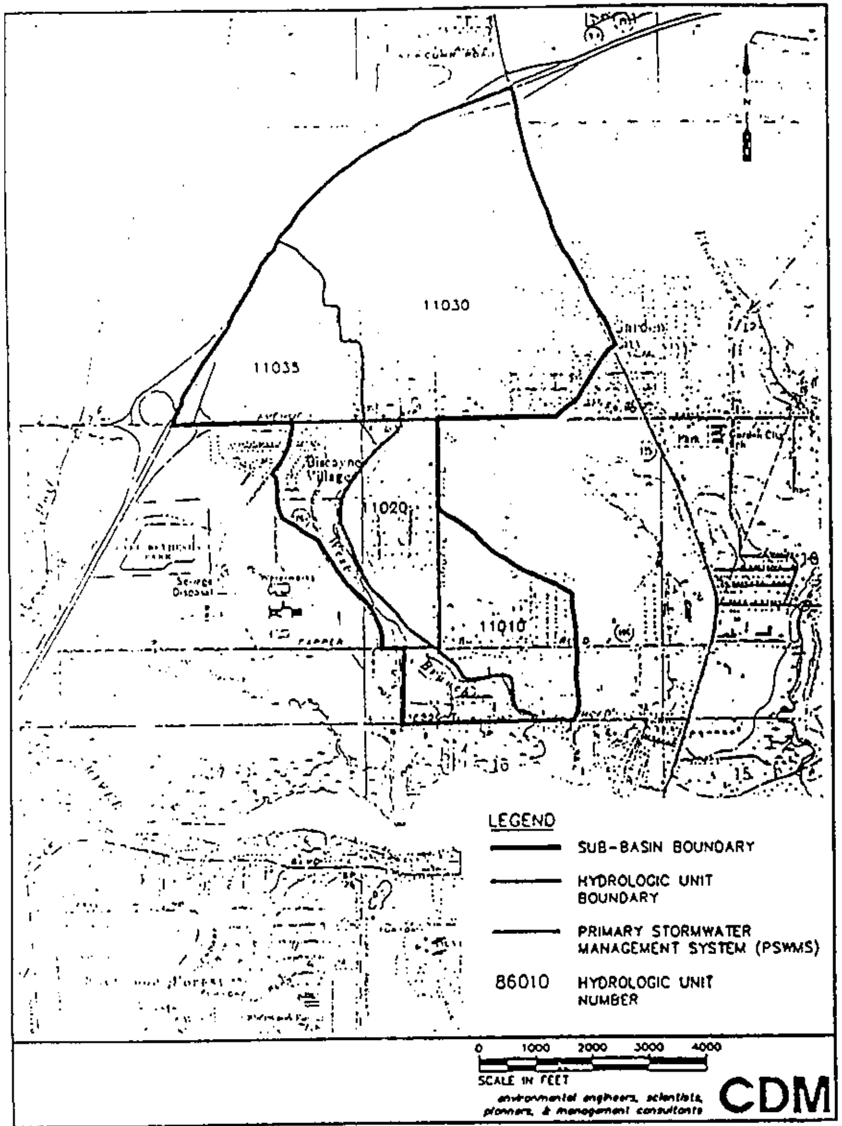

Figure 3. Example basin: West Branch.

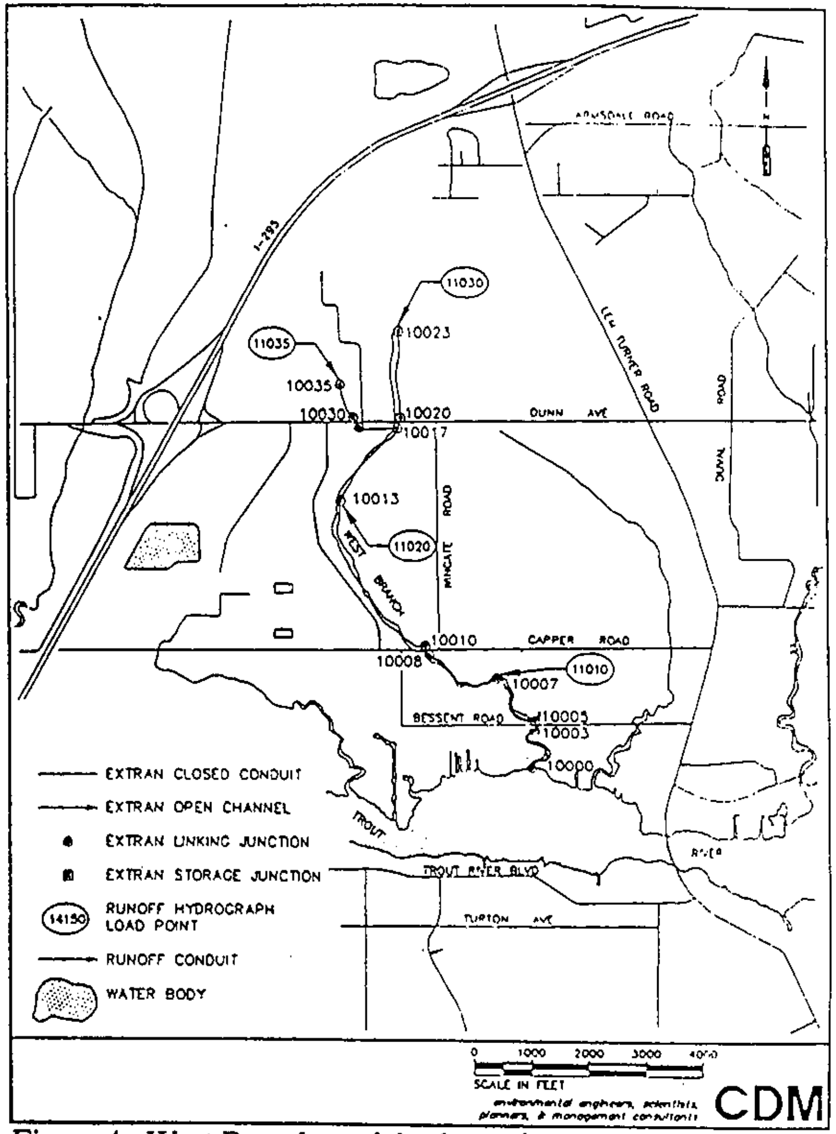

Figure 4. West Branch model schematic.

Table 2 - Characteristics of the West Branch Subareas

Subarea	Area (acres)	Overland Slope (ft/ft)	Soils	Pre-Dev. Imp	Post-Dev. Imp
11010	173	0.065	C and D	9%	29%
11020	190	0.0100	C and D	8%	28%
11030	503	0.0028	D	21%	41%
11035	150	0.0037	D	6%	56%

METHODOLOGY

In order to properly evaluate the performance of the two criteria, the use of a model with dynamic flow routing capabilities was necessary. A modified version of the EXTRAN block of the Environmental Protection Agency (EPA) Stormwater Management Model (SWMM) was used for the hydraulic simulation portion of this study (4). A modified version of the RUNOFF block of SWMM was used for the hydrologic portion of this study (5). The most significant modification of RUNOFF for this study was the addition of a lake routing routine. The routine is based on the storage-indication method.

One important aspect to any detention ordinance is implementability. For a detention ordinance to implementable, the the detention ponds must not be too difficult to design or review. The following steps explain how detention ponds are designed for two areas under the volumetric discharge control:

- Establish hydrologic parameters
- Calculate runoff hydrographs under pre-post-development conditions
- Calculate the difference between the pre-and post-development runoff volumes over the critical time period (hour 10 to hour 17 for this example), and multiply this difference by 1.5 as a first guess of the detention pond size
- Determine the allowable depth in the pond (3 ft for this example)
- Vary the pond volume and outlet size until the peak pond depth is equal to the allowable depth and the volume restriction is satisfied. A V-notch weir is recommended for combined volume/peak and water quality control structures.

RESULTS

Table 3 summarizes the pre- and post-development hydrographs over the critical time period for the two example areas. As shown in Table 3, the goal for the 10-acre area is to design a pond that discharges no more than 4.1 acre-feet over the critical time period under post-development conditions. Likewise, the goal for the 200-acre area is to design a pond that discharges no more than 51.6 acre-feet over the critical time period under post-development conditions. Table 4 shows the iterations that were required to design the two example ponds. Table 5 shows a comparison of the two example ponds using the volumetric discharge criterion as a basis for design and using the peak discharge criterion as a basis for design. Figure 5 illustrates the pre-development, post-development with no control, the post-development with peak flow control, and the post-development with volumetric discharge control hydrographs over the critical time period.

Table 3 - 100-Year Flows For Critical Time Period

	10-acre		200-acre	
	Pre	Post	Pre	Post
Total Volume (ac-ft)	4.1	5.2	51.6	88.3
Peak Flow (cfs)	21.8	49.2	184.0	586.0

Table 4 - Iterations For Pond Sizes and Outlet Capacities

Iteration	Area	Volume at 3 ft (ac/ft)	V-notch Weir Angle (degrees)	Depth (ft)	Critical Outflow Volume (ac/ft)	Peak Outflow (cfs)	Comments
1	10-ac	1.64	15.0	3.32	4.7	22.8	inc vol, dec weir
2	10-ac	2.56	13.0	3.03	4.2	16.0	inc vol, dec weir
3	10-ac	2.58	12.9	3.00	4.1	15.8	okay
1	200-ac	55.0	100.0	2.92	49.3	148.0	dec vol, dec weir
2	200-ac	48.5	95.0	3.02	53.1	159.0	inc vol, inc weir
3	200-ac	50.3	96.0	3.00	51.8	155.0	inc vol, dec weir
4	200-ac	50.5	95.5	3.00	51.6	154.0	okay

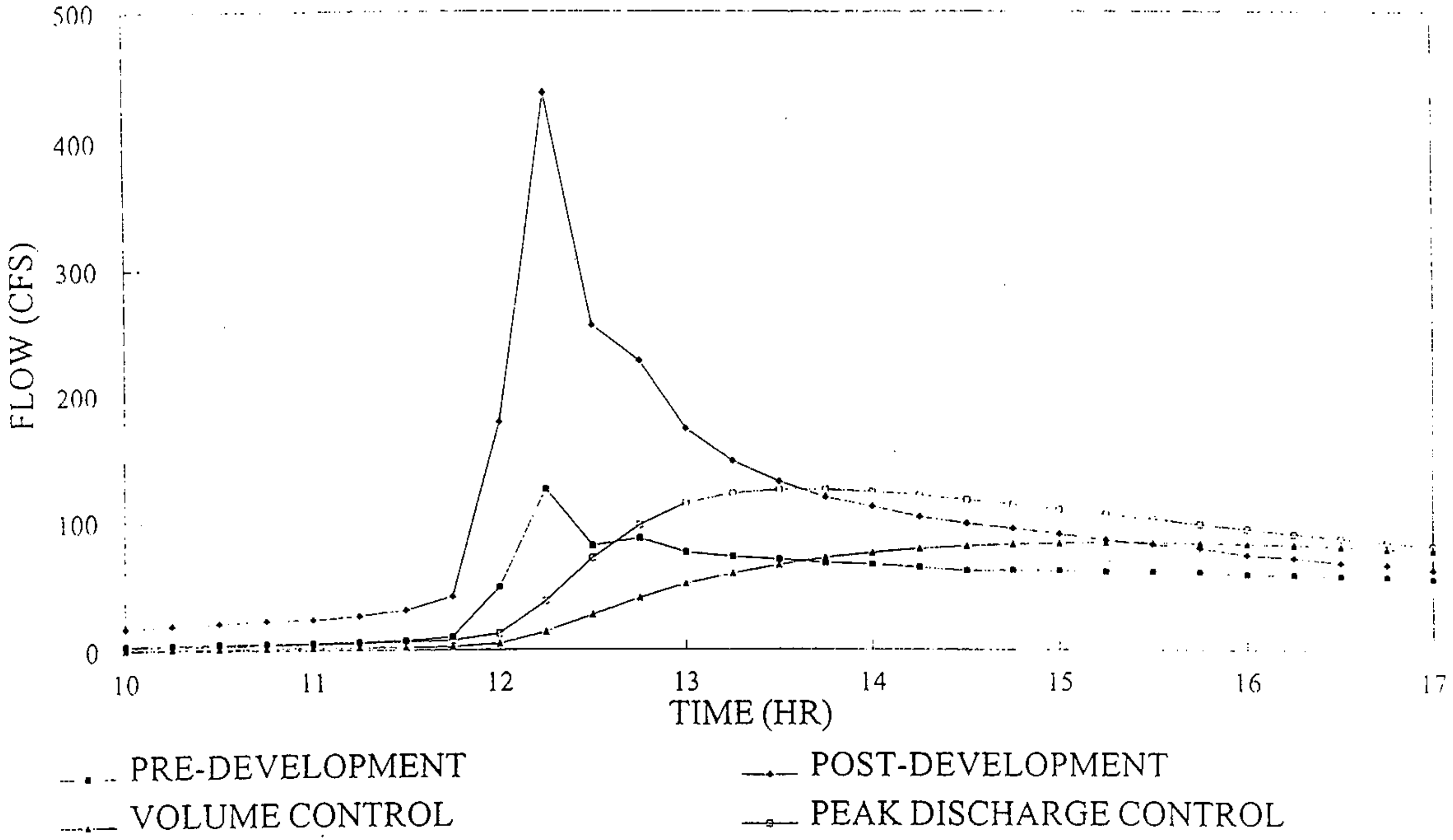

Figure 5. Comparison of hydrographs under various controls.

Table 5 - Pond Design Under Volumetric and Peak Flow Criteria

Area	Volumetric Control				Peak Flow Control			
	Pond Volume (ac-ft))	Pond Surface Area (ac)	V-notch Weir Angle (degrees)	Percent of Land Area	Pond Volume (ac-ft)	Pond Surface Area (ac)	V-notch Weir Angle (degrees)	Percent of Land Area
10-ac	2.58	0.97	45.5	9.7%	2.09	0.79	18.3	7.9%
200-ac	50.5	17.3	152.0	8.7%	37.2	12.80	115.0	6.4%

As stated previously, the two detention criteria were applied to the West Branch basin in order to examine their performance at minimizing increases in downstream flood stages. A summary of peak flood stages under pre-development, post-development with no control, the post-development with peak flow control, and post-development with volumetric discharge control conditions is given in Table 6. Note that the junctions numbers in Table 6 correspond to the junction numbers in Figure 4.

Table 6 - West Branch: 100-Year Flood Level Comparison

Node	Undeveloped (ft)	Developed With No Controls (ft)	Developed With Volumetric Controls (ft)	Developed With Peak Controls (ft)
10000	2.9	2.9 (0.0)	2.9 (0.0)	2.9 (0.0)
10003	3.0	3.2 (0.2)	3.0 (0.0)	3.1 (0.1)
10005	3.3	3.8 (0.5)	3.3 (0.0)	3.5 (0.2)
10007	4.6	5.5 (0.9)	4.6 (0.0)	5.0 (0.4)
10008	5.3	6.4 (1.1)	5.3 (0.0)	5.8 (0.5)
10010	5.4	6.8 (1.4)	5.4 (0.0)	6.0 (0.6)
10013	10.2	11.3 (1.0)	10.2 (0.0)	10.7 (0.5)
10017	11.3	11.9 (0.7)	11.2 (0.0)	11.5 (0.3)
10020	12.3	14.5 (2.2)	12.1(-0.1)	13.2 (0.9)
10023	15.0	15.6 (0.5)	14.5 (-0.6)	15.1 (0.1)
10030	13.3	17.0 (3.7)	13.3 (0.0)	13.4 (0.1)
10035	15.1	17.5 (2.4)	15.0(-0.1)	15.1 (0.0)

( ) - change from undeveloped

DISCUSSION

The design of the detention ponds for the two example areas illustrates two points. First, the design process under the volumetric discharge criterion is not significantly more complicated than the design process under the peak flow criterion. Second, the size of the ponds and the amount of area required under the volumetric discharge criterion is reasonable when compared to the size and amount of area required under the peak flow criterion.

The West Branch basin example illustrates that the volumetric discharge criterion is more effective at controlling the downstream impacts of development, which is part of the intent of most detention ordinances. Conventional methods of controlling downstream flooding that are based on controlling peak flows may not provide the desired level of control.

The bleed-down times for the detention ponds designed under the volumetric discharge criterion are on the order of a half-day to one day longer than those designed under the peak discharge criterion. This extended detention time coincides well with the longer detention times required for water quality control. The benefit of this is that the bleed-down volume required for water quality control can be incorporated into the flood control volume.

The effectiveness of this volumetric discharge criterion is limited to basins where the use of a 24-hour design storm is appropriate. For large riverine systems, this volumetric detention criterion, like most any detention criterion, will likely be ineffective at controlling peak stages where the contributory drainage area is very large.

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