Sensitivity of Detention Basin Volume to Rainfall Input

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Abstract

In the Midwestern United States, four major rainfall depth estimation methods are used to determine runoff depths and volumes. The purpose of this study is to analyze the difference in detention basin volumes computed by using these rainfall depths. The four rainfall depths used in this study are calculated from Chen’s Method, the National Weather Service (NWS), the depths published by the Indiana Division of Natural Resources (DNR) in Technical Paper Number 40 and the depths published in the “Rainfall Frequency Atlas of the Midwest” (Huff-Angel). One of these four depths is used to determine the detention volumes required for residential developments in Indiana. However, there are not always guidelines as to which rainfall depth should be used.

The rainfall depth analysis was performed for three locations in Marion County, Indiana. The rainfall depths determined by Chen’s Method were calculated based on the location in Indiana to find the corresponding coefficients. The depths from the National Weather Service, Indiana Division of Natural Resources and “Rainfall Frequency Atlas of the Midwest” were read from figures provided in these publications. The Marion County Stormwater Specifications Manual requires that a detention basin be large enough to hold runoff from the post-developed 100-year storm and discharge this runoff at a rate no larger than the runoff from the pre-developed conditions for a 10-year storm. From these ordinance requirements, detention volumes were calculated. Two hydrologic models, TR-20 and HEC-HMS, were used for this analysis. The changes in detention volumes obtained by using different rainfall depths are discussed. The rainfall depths from the “Rainfall Frequency Atlas of the Midwest” (Huff-Angel) usually gave the largest detention storage volumes and that from TP-40 (DNR) the smallest.
Introduction

Many rainfall depths and rainfall distributions are used in hydrology to model runoff volumes from watersheds. These depths and distributions are also used to model detention basins for residential, commercial and industrial developments. These different rainfall depths can differ by as much as 20 percent for certain storm durations and recurrence intervals. The temporal distributions of the rainfall depths also can differ based on the method used to generate them. The purpose of this study is to analyze the effect of four rainfall depths and three temporal rainfall distributions on detention volume sizing for three different developments in the Indianapolis area using. The three developments analyzed in this study are called Whispering Pines, Fox Chase and Benjamin Crossing.

The rainfall depths evaluated in this study come from four different sources: Chen’s method, the National Weather Service website, the Indiana Department of Natural Resources (Hershfield, 1961), and the Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992). The rainfall depth provided by Chen’s method was calculated from equations which were developed from figures and coefficients (Chen, 1983). The other three rainfall depths were determined from tables and rainfall isohyets maps, based on location in the State of Indiana. Table 1 shows the rainfall depths that were used in this study to determine detention basin discharges and volumes. As shown in the table, the four methods provide fairly close estimates for the 10-year storm but a larger difference for the 100-year storm.

Table 1: Rainfall Depths for 10-year and 100-year Recurrence Intervals

<table>
<thead>
<tr>
<th>Method</th>
<th>10-year, 2-hour storm event (in)</th>
<th>100-year, 2-hour storm event (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huff-Angel</td>
<td>2.46</td>
<td>3.97</td>
</tr>
<tr>
<td>NWS</td>
<td>2.43</td>
<td>3.69</td>
</tr>
<tr>
<td>Chen</td>
<td>2.44</td>
<td>3.58</td>
</tr>
<tr>
<td>DNR</td>
<td>2.38</td>
<td>3.34</td>
</tr>
<tr>
<td>Max. % Difference</td>
<td>3.25%</td>
<td>15.87%</td>
</tr>
</tbody>
</table>
Three different hyetographs were used in this study: constant rainfall, a Huff 3rd quartile 10% curve, and a scaled SCS Type II curve, which was normalized to a two-hour rainfall duration. For all of the distributions, a two-hour rainfall event was assumed. Figure 1 shows the cumulative hyetographs used in the study.

For the three proposed residential developments, curve numbers were provided for the pre- and post-development conditions (to be referred to as the given $CN$ throughout the paper). However, these curve numbers were not realistic, as many pre-developed curve numbers were higher than their corresponding post-development curve numbers. Hence, an assumption was made that the land use for the pre-developed condition was agricultural crops in good condition. The curve number selected for this condition corresponds to $CN = 73$ (to be referred to as the new $CN$ throughout the paper).

Two software programs, HEC-HMS and TR-20, were used to estimate the detention volumes. To determine the volume of a detention basin, the runoff rate for the pre-developed 10-year, 2-hour storm was found for each rainfall distribution and rainfall depth. The detention basin was then sized to discharge the post-developed 100-year, 2-hour storm at the pre-developed 10-year, 2-hour runoff rate. This discharge requirement follows the Marion County Stormwater Drainage Ordinance, where each of these developments is located. The smallest 10-year, 2-hour flow rate was used as the allowable peak flow rate to provide the most conservative estimate of detention volume for all of the rainfall depths. For simplified geometry and program inputs, a box shaped detention storage facility was used with a square base in all calculations. The orifice equation was used to find the stage-storage-discharge relationship required for each program. A constant outflow is assumed in this study. To find the storage volume in the basin, the difference between the water elevation and the basin elevation was multiplied by the base area. For these calculations, no initial storage was assumed.
Whispering Pines Subdivision

The Whispering Pines development (Fig. 2) was the first case analyzed. This development consisted of one watershed draining to one outlet point. The post-developed area also discharges to the same point. For this development a fairly obvious trend in detention storage volume was found for every distribution. Different rainfall depths yielded significant differences in detention storage volumes. The rankings of rainfall depths providing the largest required detention volumes were Huff-Angel, Chen, National Weather Service and Indiana Division of Natural Resources, from highest to lowest. This pattern is seen for all rainfall distributions and for both given and new CN values. The difference between Chen and National Weather Service detention volumes was small because the rainfall depths were almost the same.

There was also a trend in detention volume size with respect to rainfall distribution. For both given and new CN values, the constant rainfall depth provided
the largest detention storage volumes. The Huff 3rd quartile storm provided the second highest volume, while the SCS Type II distribution provided the smallest detention volume. The same trends were seen for both HEC-HMS and TR-20. Figure 3 shows the required storage for the different rainfall depths and distributions using HEC-HMS and Figure 4 shows the same information using TR-20.

Fig. 2: Schematic of the post-development case in Whispering Pines Subdivision

Fig. 3: Storage Volume Computed Using HEC-HMS for Each Rainfall Distribution and Depth
Fox Chase Subdivision

The Fox Chase development consists of two watersheds draining to one outlet (Fig. 4). After development, two detention basins will be located onsite. One basin, Pond A, will drain into another basin, Pond B. Pond B will drain to the outlet defined in the previously defined. These two basins were both sized based on discharging the post-developed 100-year, 2-hour runoff at the pre-developed 10-year, 2-hour peak runoff rate. For Pond A, the peak outflow was defined solely from watershed A. For Pond B, the peak outflow was defined from the combination of watersheds A and B. The same trends in detention volume sizing that were seen for Whispering Pines were also found for each basin in Fox Chase. The Huff-Angel rainfall depth gave the largest required storage followed by the National Weather Service and Chen’s method. The Indiana Division of Natural Resources’ depth gave the smallest storage of all four rainfall depths. Additionally, the rainfall distributions followed the same pattern seen in Whispering Pines, with constant rainfall generating the largest volume and the SCS Type II generating the smallest volume. Figure 5 shows the required storage volumes for Pond A from the TR-20 model.

Fig. 4: Schematic of the post-development case in Fox Chase Subdivision
Benjamin Crossing Subdivision

The Benjamin Crossing development consists of four watersheds labeled, A, B, C and D (Fig. 6). Watershed A is an offsite watershed that drains onsite to watershed B. These watersheds both drain to watershed C. The addition point of all three watersheds was used as the point of analysis. Watershed D drains to a separate outlet point. After development, this site will contain three detention basins. Pond A was designed to accommodate runoff from watersheds A and B. Pond B was designed to accommodate runoff from watersheds A, B and C. Pond C was designed for runoff from watershed D only. For all three ponds in the Benjamin Crossing development, the trend between detention volume and rainfall depth was consistent with the two previously discussed developments. The Huff-Angel rainfall depths provided the largest required storage volumes followed by the National Weather Service and Chen’s method. The Division of Natural Resources’ depth provided the smallest required storage volumes.
For pond A, similar detention volume trends were seen with respect to rainfall distribution and curve number. The given CN values provided smaller required storage volumes than the new CN values. This is similar to the trends found in the previously discussed cases, where the new CN values provided larger detention volumes. Pre-developed conditions given CN values were always higher than pre-developed new CN values, except for the Benjamin Crossing watershed D (pond C). For pond A, (Fig. 7 and 8) the constant rainfall distribution provided the largest volumes, the Huff 3rd quartile provided the second largest, and the SCS Type II provided the smallest.

For Ponds B and C, the trend between detention volume and rainfall distribution was different than the previous two developments. For TR-20 computations with new CN values, the Huff 3rd quartile rainfall depth provided the largest volume, while the constant rainfall provided the second largest volume and the SCS Type II distribution provided the smallest required volumes. For TR-20 computations with new CN values, the SCS Type II method provided the largest volume, while the Huff 3rd quartile rainfall distribution provided the second largest volumes and the constant rainfall provided the smallest required volumes. This is a notable departure from the previously discussed cases. The given CN values, however, seemed to follow the same trend for both HEC-HMS and TR-20 which was seen in the earlier subdivisions. This could be due to the fact that the Pond B had inflow from another basin, and the effect of the rainfall distribution multiplied for higher runoffs (as was the case with the new CN computations).

For Pond C, the SCS Type II distribution provided the largest required volume. Constant rainfall distribution provided the second largest volume and Huff 3rd quartile provided the smallest volume. This is unusual because this basin only had one watershed. It would seem that this basin should follow the same pattern seen in the other two developments. Also, for this case, the given CN provided a larger required storage volume. This is because the new CN value, which is larger than the given CN value, provided a larger allowable discharge. Figures 10 and 11 show the required storage volumes for Pond B from the HEC-HMS and TR-20 computations as an example.
Fig. 6: Schematic of the post-development case in Benjamin Crossing Subdivision

Fig. 7: Storage Volume Computed Using HEC-HMS for Each Rainfall Distribution and Depth for Pond A
Fig. 8: Storage Volume Computed Using TR-20 for Each Rainfall Distribution and Depth for Pond A

Fig. 9: Storage Volume Computed Using HEC-HMS for Each Rainfall Distribution and Depth for Pond B

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Conclusions

The results of this study show that, rainfall input has a significant effect on detention storage volume. The storage volumes produced by Huff-Angel and Indiana Division of Natural Resources rainfall depths are significantly different and sometimes considerably higher than the storage volumes given by the other two rainfall depths (NWS and Chen’s method). Storage volumes produced by the Huff-Angel rainfall depth seem to be an overestimate and provide large storage volumes, whereas the storages computed by Indiana Division of Natural Resources rainfall depth appear to be too small. The National Weather Service and Chen’s rainfall depths give storage volumes between these extremes. The results of this study also show that the temporal distribution of rainfall has an effect on the storage volume; however, this effect is not as large as that provided by the rainfall depth. A constant rainfall distribution, although unrealistic in practice, consistently provided the largest storage volumes. The Huff 3rd quartile and SCS Type II distributions usually...
provided intermediate and smaller detention volumes, respectively. These distributions are more realistic and probably provide a better estimate. The two hydrologic models used, TR-20 and HEC-HMS, provided very similar results. Overall, the largest effect came from the rainfall depths, not the temporal rainfall distributions.

The most important conclusion from this study is that rainfall depths and distributions have a large effect on storage volumes and hence, on the cost of building these facilities. However, some ordinances and codes do not have any specifications about these inputs. This aspect deserves better delineation in practice. Another important conclusion is that the data in the Midwest Climate Atlas (Huff-Angel) gives the largest, and hence, the most expensive detention storage volumes.

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References

