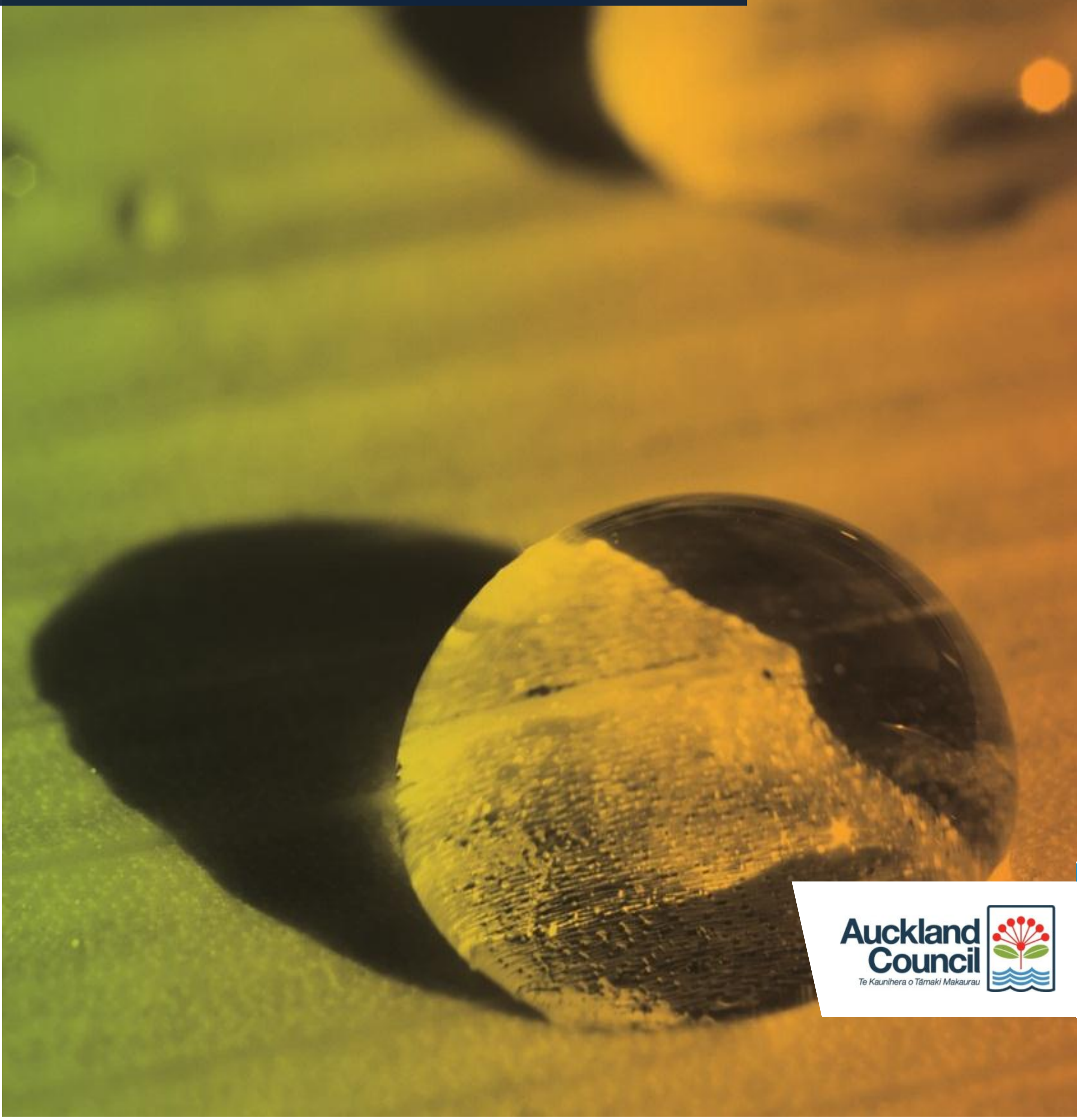
Review of Approaches for Stormwater Detention Sizing

April 2014 Working Report 2014/003



Review of Approaches for Stormwater Detention Sizing

April 2014 Working Report 2014/003

This report has been peer reviewed by the Peer Review Panel using the Panel's terms of reference.
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Review of Approaches for Stormwater Detention Sizing

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AECOM New Zealand Limited

Executive Summary

The purpose of this study was to undertake research and modelling to try and determine appropriate approaches for sizing of stormwater detention basins.

In particular this study covers the following key areas:

a. Review and summary of the strengths and weaknesses of a design storm approach and a continuous simulation approach.
b. For the design storm approach, research was carried out to determine an appropriate storm duration for a given catchment size, and how this duration could be justified. Limited high-level modelling was undertaken to illustrate the problem and included consideration of the influence of the design hydrology (rainfall temporal pattern, loss method and duration) on required detention volumes and peak runoff.

As a result of the research and modelling, it became clear that the rainfall temporal pattern, duration and loss method all have an effect on both peak runoff and the storage volume required to reduce peak flows to pre-development levels. The purpose of this research was *not* to recommend a preferred loss method or temporal pattern for use in rainfall modelling. However, some recommendations *can* be made as to an appropriate approach for determining critical duration and sizing detention basins – as follows:

General recommendations regarding critical storm duration:

1. Council could further investigate using design storm durations based on critical duration for the catchment. This 'critical' duration should be carefully determined, and should be relevant to a specific point (or points) of interest within the catchment.
2. This 'critical' duration is not necessarily the 'time of concentration (Tc) for the entire catchment, and instead may be governed by other factors, such as downstream network features or existence of online storage or flow restrictions.

Specific recommendations regarding an appropriate approach to sizing detention basins:

1. When using a nested (Chicago type) rainfall temporal pattern and either the SCS or Initial and Constant loss method, required storage volumes remain relatively constant for different duration events *when comparing the same ARI storm events*. As such, there is no apparent need to consider the impacts of storm duration when using this approach for sizing detention basins.
2. When using a triangular or constant rainfall temporal pattern, storm duration does have an impact on the required size of detention basin. Generally speaking, the longer the duration, the higher detention volume required to return post-development flows to pre-development levels for the same duration event. As such, it is important to determine what duration is appropriate, and this in turn relates to what an appropriate 'critical' duration is. The following recommendations are made:
    a. If the detention basin is located upstream of a network with a fixed capacity, or there is an established target discharge limit (for other reasons), then a range of increasing durations should be tested until a maximum storage volume is determined (the maximum will be determined by that duration at which the post-development un-attenuated flow is less than the pre-development flow).
    b. If the detention basin is discharging to a natural watercourse then an appropriate duration equal to the time of concentration (Tc) of the 'point of interest' within the downstream watercourse. This may be at the very downstream end of the catchment (in which the whole-of-catchment Tc will apply) or a shorter Tc for a point of interest further up the catchment. As discussed in 2. above, if there are additional

flow restrictions and/or storage areas downstream of the detention basin, then longer duration events may need to be tested to determine maximum flood levels.

3. For modelling using the SCS loss method and nested temporal pattern, peak flows were shown to increase with increasing duration. As such, if sizing detention basins for a fixed downstream capacity constraint, 2a. above would apply. Additionally, if a catchment modelling exercise is being undertaken it is likely that different durations of nested storm event may have an impact on flood levels and peak flows if there are storages within the network being modelled. As such, it is recommended that various, increasing duration storms are tested to determine an appropriate 'worst case' – as per 2b. above.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The purpose of this study is to undertake research and modelling to try and determine appropriate approaches for sizing of stormwater detention basins.

In particular this study covers the following key areas:

- Review and summary of the strengths and weaknesses of a design storm approach and a continuous simulation approach.
- For design storm approach, research was carried out to determine an appropriate storm duration for a given catchment size, and how this duration could be justified. Limited high-level modelling was undertaken to illustrate the problem and included consideration of the influence of the design hydrology (rainfall temporal pattern, loss method and duration) on required detention volumes and peak runoff.
- Recommendations on further work.

2.0 Detention Basins

A detention basin/pond is an excavated area installed on, or adjacent to, tributaries of rivers or streams to reduce post-development peak flows and in some cases, downstream erosion by storing water for a limited period of a time. The basins are typically built during the construction of new land development projects. These projects alter the hydrologic characteristics of a catchment through a range of means, such as:

- Removal of natural vegetation (thus eliminating interception storage),
- Grading the land surface (which greatly reduces depression storage),
- Covering over of part of the land surface with impervious materials (thus decreasing the availability of storage in the soil matrix, and increasing the runoff volume and velocity), and
- Altering the natural drainage paths, including channels (which reduces channel storage and response time).

The reductions in natural storage can have significant hydrologic consequences such as flooding, downstream channel erosion, and increased velocities, which in turn impact communities, structures, and habitats.

Detention ponds help manage the excess runoff generated by newly constructed impervious surfaces, and the loss of natural storage through land development. Detention basins can also be designed for additional purposes, including:

- Provision of extended detention, which aims to mitigate downstream erosion by storing and releasing runoff over a much longer period (typically, 24 hours),
- Provision of water quality treatment, by including permanent wet pool areas which allow suspended solids to settle out.

The focus of this study is on the functioning of detention basins as it applies to *peak flow reduction*. This occurs typically as illustrated in Figure 1, where peak discharge control provided by a detention basin provides a reduction in peak flows back to pre-development levels; however, the duration of elevated peak flows is much longer, and, typically, the total runoff volume is also greater.

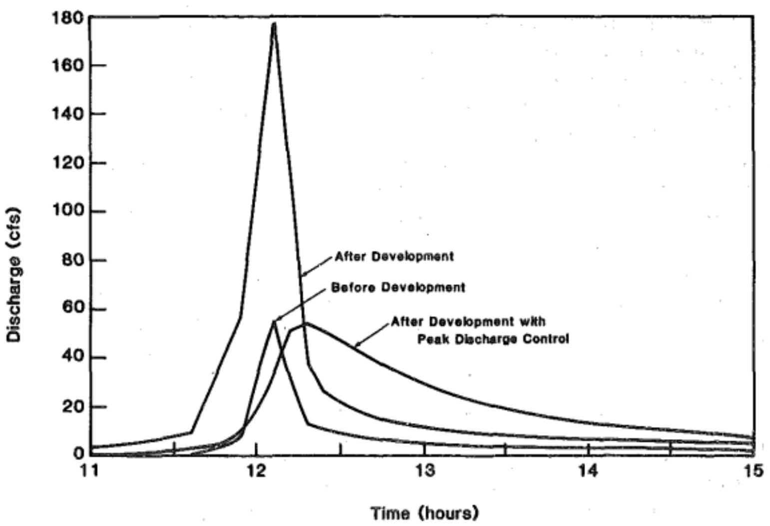

Figure 1 Runoff hydrograph for three catchment conditions (McCuen et al, 1988)

2.1 Detention Basin Design Approaches

In general, there are two possible approaches to sizing detention basins: sizing based on design storms and sizing using continuous simulation (using long term rainfall time-series).

In New Zealand and internationally, design guidelines typically follow the design storm approach, and require sufficient storage volume to reduce post-development peak flows back to pre-development peak flows for a range of Average Return Interval (ARI) design storm events (typically, 1 in 2 year, 1 in 10 year and occasionally 1 in 100 year).

Both these approaches have advantages and disadvantages, summarised in the table below:

Table 1 Summary of advantages and disadvantages

Approach	Advantages	Disadvantages
Design Storm	While there are a large range of design storm approaches, they are (in general) relatively simple to implement and can be applied by designers with the use of inexpensive analysis tools (software)	There is considerable uncertainty in: - Rainfall hyetographs (distribution, duration). These are not based on 'real' storms - Loss methods used - Initial storage volume - Effect of antecedent conditions
Continuous Simulation	- Input data is often based on real rainfall and therefore can more accurately model the effect of antecedent conditions - Explicitly accounts for long duration events, as well as the antecedent conditions prior to major short term storm events - Can allow more detailed examination of wetlands and ponds whose water level regime is often more dependent on seasonal runoff that 24hr runoff. - Allows investigation of flow/duration data to test impacts of development on stream erosion and morphology	- This approach is much more complicated to implement; it also requires more time and more complicated modelling software, especially in relation to the small time steps and long duration of modelling. However this is likely to become less of an obstacle in the future as computing power increases. - Requires robust input data and sufficiently long time series to capture extreme events - Requires a range of model parameters to be estimated that again, have a large degree of uncertainty. Calibration could potentially be undertaken to gauged flows data; however, this again is complex

2.2 Design Storm Approaches

There are a range of design storm approaches which are used by authorities in New Zealand

a. Loss method, transformation method
b. Rainfall hyetograph distribution and duration
c. Required ARI events to be mitigated
d. Approach to establishing a 'target' critical storm duration

Some examples of this variance in approaches are illustrated below:

Table 2 Summary of design storm approaches

Region / publication	Hyetograph and duration	Loss method & transformation	Critical duration approach used in sizing detention basins
Auckland, TP108 (ARC 1999) and TP10 (ARC, 2003)	24hr nested storm	SCS Method	No assessment of 'critical' duration. A single 24 hour event is required.
New Zealand Transport Agency (2010) guidance	Variety accepted (rational, TM61, SCS)	Variety accepted	A 1 hour duration storm is suggested.
NZWERF (2004)	As above	As above	Recommends considering the range of points within the catchment where peak flows may be critical and testing each of these (e.g. local drainage, main pipe system, watercourse).
Christchurch – Waterways, Wetlands and Drainage Guide (2012)	Triangular hyetograph with peak at 70% of duration	Rational	Critical storm required to be determined for the receiving waterway. Example given for one stream of 36 hours. Various durations then required to be tested.
Australia (general)	Specified in 'Australian Rainfall and Runoff'	Varies	Analysis of a range of durations is required, when outflows must be limited to a certain flowrate.
USA (general)	Range of methods including 24hr nested storm and others	SCS and rational	For SCS methods, only the 24 hour event is used.

An important observation in the various methods above, and a key consideration as part of this study is the importance of the design storm duration. This links directly to the concept of 'critical' duration.

1. How do you determine/justify an appropriate design storm duration for a given catchment when sizing a detention basin?
2. Is this related to a 'critical duration' for a catchment, and moreover, how do you determine a 'critical duration' and what factors influence criticality?

These questions are explored further below.

2.2.1 Critical Storm

A critical storm is generally defined as the storm which creates the largest flowrate, volume, or flood level from a catchment. This often relates to a storm of equal duration to the 'time of concentration' for the catchment.

For detention sizing, in many jurisdictions, a **target** pre-development flowrate is established based on the critical 'peak' flow for the catchment in question, and a range of increasing post-development storm durations are routed through a detention basin to determine the *maximum* storage volume required to ensure that post-development peak flows do not exceed the **target** for any duration.

This assumes, however, that the concept of 'critical' duration is relevant to the context of the problem being investigated. A number of examples are illustrated in the table below which demonstrate a variety of potential approaches related to different contexts.

Table 3 Critical duration contextual examples

Context / Problem	**Critical duration discussion**
A. Flood analysis to establish peak water levels in a watercourse – with no storage	Critical duration would correspond to that which generated the highest water level, and for a given ARI event would typically correspond to the time of concentration (Tc) for the catchment.
B. Flood analysis to establish peak water levels in a watercourse – with storage	Critical duration would correspond to that which generated the highest water level, for a given ARI event. Various durations may require testing as depending on how the storages functioned, water levels may vary.
C. Sizing of a pipe or channel for peak flow	Critical duration would correspond to that which generated the highest peak flow, and for a given ARI event would correspond to the time of concentration (Tc) for the catchment.
D. Sizing of a detention basin discharging to a piped system	Critical duration would correspond to that which generated the largest required storage volume in order to not exceed the established capacity of the downstream network. Various, increasing durations would require testing to determine the maximum storage volume required to ensure that post-development peak flows did not exceed the target for any duration.

A recent study by Lau and Gali (2011) further highlights the concept of critical duration. They modelled two large catchments within the Chicago area and compared peak flows at different stations along the main streams (each around 20km in length), for a range of storm durations from (3, 6, 12, 24 and 48 hours). They concluded as follows:

1. In general, the critical duration increases with location, moving from upstream to downstream in a catchment.
2. In urbanised areas without major on line detention, the differences between peak flows from short and long duration events can be significant and can become even more pronounced when moving downstream in the catchment. As a result, longer duration events must be considered when sizing conveyance and storage facilities, especially in downstream reaches.
3. The significance of event duration on peak flows is much less in catchments with major in-stream detention storage. However, significant detention storage will require much longer event durations to achieve the highest peak flow in a given stream reach.
4. When evaluating flood hazards with design rainfall events and when sizing flood storage facilities, the critical duration of the event must be considered in order to identify the highest peak flow. This will allow both the development of maximum flood levels and the appropriate volume for sizing flood management facilities.
5. When evaluating flood hazards with design rainfall events and when sizing flood storage facilities, the critical duration of the event must be considered in order to identify the highest peak flow. This will allow both the development of maximum flood levels and the appropriate volume for sizing flood management facilities.

These results highlight the complexity inherent in modelling and understanding urban drainage systems, where often a variety of natural and piped conveyance elements exist, along with natural and man-made depressions and storage areas.

The figure below (from Lau and Gali, 2011) illustrates that for the studied catchment (Butterfly Creek) with a stream reach of over 20km in length, from the head of the catchment to station ~17,000m, the critical duration event is the 12 hour duration. From this point onwards, the 48 hour duration becomes the critical one. The authors comment that for the upper reaches one would expect the shorter duration (3 and 6 hour) events to be critical; however, due to a significant flow restriction and storage at the 18,000m location, all events were concentrated in a narrow range with the 12 hour being slightly higher.

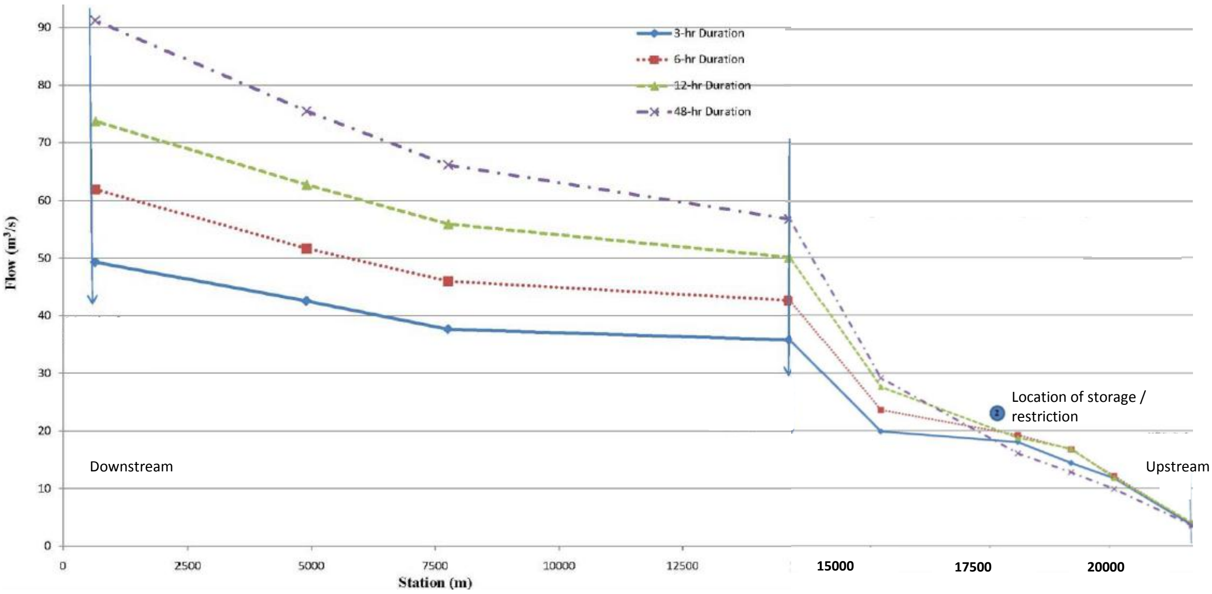

Figure 2 Butterfly Creek (Illinois) example (Lau and Gali, 2011)

2.3 Example Modelling

2.3.1 Introduction

To test the impact of duration on the required detention volumes, and hopefully assist in determining an appropriate duration of storm, some modelling was undertaken using HEC-HMS. A range of design storm temporal patterns, loss methods and durations were analysed for a standard catchment size and ARI event. Model set up parameters are summarised in the section below.

2.3.2 Model set up

The general catchment/hydrological details were as follows:

- Catchment area: : 10ha (0.1km^2)
- ARI event: 1 in 10 year
- Rainfall depths for different durations as follows: 1hr – 26mm, 6hr – 50mm, 24hr – 82mm
- RI event: 1 in 10 year
- Loss Methods:
  - Initial and Constant: Initial = 5mm; Constant = 5mm/hr
  - SCS curve number method: Initial abstraction (Ia) = 5mm; Curve number (CN) (pervious) = 74; CN (impervious) = 98
- Transformation method: SCS unit hydrograph

- Catchment lag times (2/3 of Tc): Pre-development 20mins, post-development 10 mins
- Pre-development imperviousness: 0%
- Post- development imperviousness: 65%
- Detention basin set up with an orifice outlet
- Model set up as per schematic below

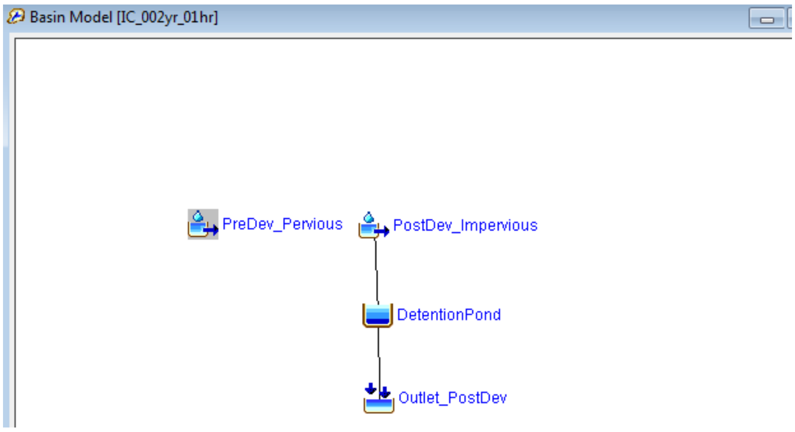

Figure 3 Typical HEC-HMS model set up

A range of rainfall events were evaluated as per Table 3 and Figure 3 below, including nested (Chicago type), triangular and constant rainfall temporal patterns, with both *initial and constant* and *SCS* loss methods.

Table 4 Summary of modelled rainfall events

Temporal pattern:	**Nested**		**Triangular**		**Constant**	
Loss method:	Initial & Constant	SCS	Initial & Constant	SCS	Initial & Constant	SCS
Durations:	1hr, 6hr, 24hr	1hr, 6hr, 24hr	1hr, 6hr, 24hr	1hr, 6hr, 24hr	1hr, 6hr, 24hr	1hr, 6hr, 24hr

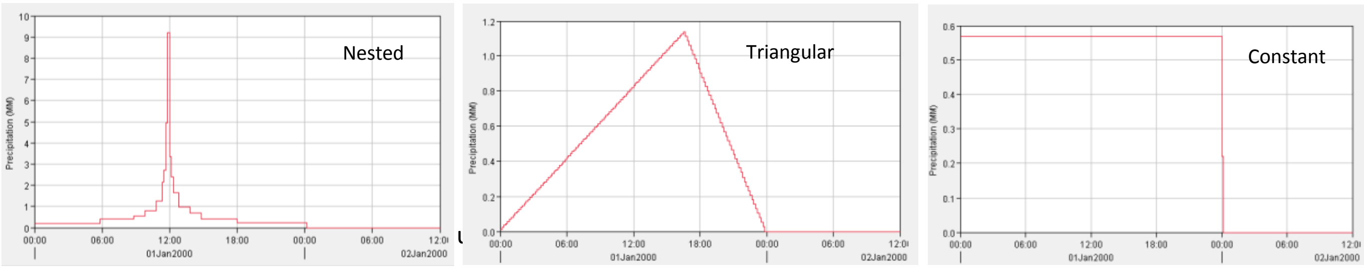

Figure 5 Example of temporal patterns used in modelling (24 hour duration only)

2.3.3 Model results

The HEC-HMS models were run, the detention volumes adjusted, and outlet orifice pipe sizes modified to achieve a post-development peak flow roughly equal to the pre-development peak flow. The following table summarises the model results and storage volume requirements.

Table 5 Summary of model results for 10yr ARI event

Storm Profile	Loss Method	Storm Duration (hour)	Peak Pre-Development Flow (m^3/s)	Peak Post-Development Flow into Basin (m^3/s)	Peak Post-Development Flow out of Basin (m^3/s)	Peak Storage Volume (m^3)
Nested	Initial & Constant	1	1.247	1.824	1.24	1.431
		6	1.295	1.829	1.289	1.382
		24	1.295	1.829	1.289	1.382
	SCS	1	0.386	1.329	0.378	2.082
		6	0.66	1.508	0.65	2.041
		24	0.879	1.619	0.874	1.772
Triangular	Initial & Constant	1	1.163	1.641	1.16	1.395
		6	0.526	0.632	0.525	1.542
		24	0.149	0.241	0.148	3.346
	SCS	1	0.356	1.189	0.348	2.019
		6	0.373	0.575	0.367	2.283
		24	0.209	0.262	0.209	2.138
Constant	Initial & Constant	1	0.85	0.98	0.849	1.403
		6	0.204	0.295	0.204	3.355
		24	0.008	0.098	0.008	8.421
	SCS	1	0.326	0.787	0.321	1.989
		6	0.227	0.303	0.221	2.586
		24	0.12	0.137	0.118	3.043

Refer Appendix A for further detail

The above results are summarised in the following bullet points:

Nested Storms

- The peak flow rates using the *initial and constant* loss approach are effectively equal for the range of storm durations. This is to be expected, as the loss will be taken up during the early part of the storm, well prior to the peak. The same peak intensity is nested within all storm profiles, hence the same peak flows occur. The slightly lower peak flow for the 1 hour storm duration is likely due to the early initial losses affecting the peak intensity.
- The peak flow rates using the *SCS* loss approach *increase* for increasing duration. This is to be expected, as the losses proportionally have a *greater* effect for the shorter duration (and lower depth) storms, therefore decreasing the amount of runoff during the peak. The increase in peak flows with duration is more pronounced in the pre-development scenario, as the losses have a much larger effect in the more pervious catchment, and are a larger percentage of overall rainfall in the shorter duration events. For example, in the pre-development scenario losses as a percentage of total rainfall are approximately as follows: 1 hour: 76%; 6 hour: 58%; 24 hour: 44%).
- The required storage volumes for both loss methods remain relatively constant; however the 24 hour duration SCS storm requires slightly less volume. This is likely due to a smaller difference between pre and post development flows due to the reasons described above.

Triangular Storms

- The peak flow rates using both the *initial and constant* loss approach and SCS approach decrease with increasing duration. This is to be expected, as the peak rainfall intensity decreases with increasing duration for the same ARI event, and given the short Tc of the catchment; the 1 hour duration storm will give the greatest peak flow.
- As occurs for the *initial and constant* approach, the peak flow rates using the *SCS* loss approach decrease with increasing duration for the post development scenario. However, for the pre-development scenario, the 6 hour storm is slightly higher than the 1 hour. This is likely due to the opposite effects of decreasing peak intensity (reducing peak flows), and lessening impact of losses (increasing runoff and peak flows).
- The required storage volumes to mitigate the post development peak flows back to pre-development are shown to increase with increasing storm duration for the *initial and constant* approach, and are relatively constant for the *SCS* approach.

Constant Storms

- The peak flow rates using the *initial and constant* loss approach decrease with increasing duration. This is to be expected, as the peak rainfall intensity decreases with increasing duration for the same ARI event, and given the short Tc of the catchment; the 1 hour duration storm will give the greatest peak flow. While the *SCS* approach did have a significant effect on reducing peak flows for the short duration (1 hour) event, it did not cancel out the effect of decreasing intensity, as occurred for the triangular storm.
- The required storage volumes to mitigate the post development peak flows back to pre-development are shown to increase with increasing storm duration for both the *initial and constant* approach and the *SCS* approach, with the *initial and constant* approach showing marked increases in required storage with increasing duration.

Comparison of peak flows across the different approaches

A comparison of peak flows is presented below in Figure 6. Salient points are as follows:

- Peak flows using a nested storm (hyetograph) are generally higher than those for triangular or constant distributions. This is to be expected, as the peak 10min and 20min intensities will be higher than the peak intensities for the triangular and constant hyetograph.
- The nested, SCS storms are the only ones that *increase* in peak flow with increasing duration. This has interesting implications for flood modelling or detention sizing as discussed in Section 3.0.
- Peak flows generated using the SCS method are generally lower than those generated from the Initial and Constant (I&C) method. While recognising that this is dependent on the parameters set for each loss method, it implies that the SCS method assumes more rainfall is lost, and less is converted to runoff. However, further testing and investigation would be required to form any conclusions in this regard, due to the comparability between the SCS curve number and the initial loss and constant infiltration parameters for a given catchment. This was not part of the scope of this study.

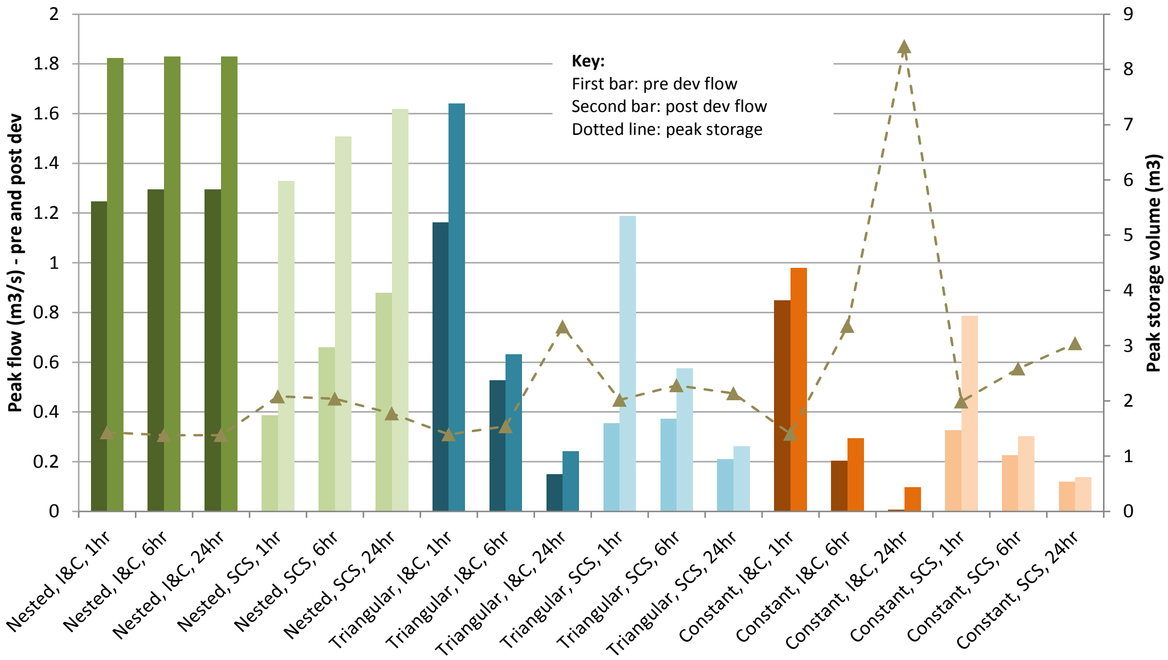

Figure 6 Summary of peak flows and storage requirements

3.0 Discussion

From the above results a number of conclusions can be drawn.

1. The storm profile, duration and loss method can all have a potential impact on the peak flow runoff from a catchment and the storage volume required to attenuate flows to pre-development levels.
2. In general, when using nested storm profiles, the required storage volumes to attenuate a given duration storm event to pre-development levels remain relatively constant for different duration events when using both *initial and constant* and *SCS* loss methods.
3. The nested SCS storm peak flows are shown to increase with increasing duration. If detention was required to reduce post-development flows to a fixed *target* flow then the required storage volumes would logically increase with increasing duration. Similarly, if catchment modelling (flood modelling) was undertaken for a network with restrictions and storages present, then it is possible these increasing durations could result in corresponding increasing water levels (volumes) within these storage areas/flood plains (depending on location within the catchment).
4. In general, when using the triangular or constant storm profiles, the required storage volumes to attenuate a given duration storm event to pre-development levels *increase* with increasing storm duration for both the *initial and constant* and *SCS* loss methods. This is less pronounced for the SCS loss method.

The resulting question arises then: *When using a triangular or constant storm profile to size detention basins, or when using SCS/nested storm approach to model catchment flooding or size detention for a fixed target outflow, which duration is appropriate to use?*
To try and answer this question, a literature review was undertaken and summarised below.

3.1 Literature Review

A number of authors and local government guidance refer to what can be called a 'critical duration' approach to sizing detention. This methodology would entail:

a. Determining a **target** pre-development (greenfields) peak flow for the given ARI event. Typically this is based on a storm of duration equal to the time of concentration of the area being assessed.
b. Trialling a *range* of increasing storm durations for the given ARI event and determining the storage volumes required to bring the peak post-development flow back to the **target** pre-development flow.
c. Selecting the largest storage volume required.

However, as discussed in Section 2.2.1, there are a variety of contexts in which a 'critical duration' can be assessed.

Argue (2005) makes a number of points in regards to sizing detention basins for a critical duration:

- Basing the size of the detention basins on duration equal to the time of concentration (Tc) of a *site* within a wider catchment produces storage volumes which are, typically, undersized; and
- Current practice in applying detention technology at a site level leads to minimal, if any, reduction in catchment-wide flood peaks and, indeed, may produce increased peak flows downstream (due to co-incidence of peak flows from various sub-catchments).

Argue goes on to recommend an approach based on a critical duration relevant to a '*singular points of interest'* within a catchment. These points of interest may include the site discharge point itself, a receiving stream channel/watercourse, or the downstream discharge into a receiving water body. Each of these points will have its own Tc and critical duration. He recommends that storage is sized based on the largest Tc values which typically require the largest volumes.

Similarly, NZWERF (2004) makes the following point: "*Because an on-site device changes the response characteristics of the catchment in which it is located, an issue arises in respect to selecting the applicable storm duration (D) value to be used in generating the design hydrograph to be used in sizing an on-site device".* NZWERF suggests that duration of the design event be reflective of the Tc of the relevant receiving point, whether this be the immediate pipe network, downstream reticulation, watercourse or outfall. Each of these would have a correspondingly larger Tc value. *Generally speaking, the largest storage volume would relate to the longest Tc value.*

Based on the above research and discussion, as well as the model testing undertaken, a number of conclusions and recommendations are made, as summarised in the following section.

4.0 Background

As a result of the research, it is clear that the rainfall temporal pattern, duration, and loss method all have an effect on both peak runoff and the storage volume required to reduce peak flows to pre-development levels. The purpose of this research is *not* to recommend a preferred loss method or temporal pattern for use in rainfall modelling. However, some recommendations *can* be made as to an appropriate approach for determining critical duration and sizing detention basins.

General recommendations regarding critical storm duration:

1. Council could further investigate using design storm durations based on critical duration for the catchment. This 'critical' duration should be carefully determined, and should be relevant to a specific point (or points) of interest within the catchment.
2. This 'critical' duration is not necessarily the 'time of concentration' (Tc) for the entire catchment, and instead may be governed by other factors, such as: downstream network features or existence of online storage or flow restrictions.

Specific recommendations regarding an appropriate approach to sizing detention basins:

1. When using a nested (Chicago type) rainfall temporal pattern and either the SCS or Initial and Constant loss method, required storage volumes remain relatively constant for different duration events *when comparing the same ARI storm events*. As such, there is no apparent need to consider the impacts of storm duration when using this approach for sizing detention basins.
2. When using a triangular or constant rainfall temporal pattern, storm duration does have an impact on the required size of detention basin. Generally speaking, the longer the duration, the higher detention volume required to return post-development flows to pre-development levels for the same duration event. As such, it is important to determine what duration is appropriate, and this in turn relates to what an appropriate 'critical' duration is. The following recommendations are made:
   a. If the detention basin is located upstream of a network with a fixed capacity, or there is an established target discharge limit (for other reasons), then a range of increasing durations should be tested until a maximum storage volume is determined (the maximum will be determined by that duration at which the post-development un-attenuated flow is less than the pre-development flow.
   b. If the detention the detention basin is discharging to a natural watercourse, then an appropriate duration equal to the time of concentration (Tc) of the 'point of interest' within the downstream watercourse. This may be at the very downstream end of the catchment (in which the whole-of-catchment Tc will apply) or a shorter Tc for a point of interest further up the catchment. As discussed in 2) above, if there are additional flow restrictions and/or storage areas downstream of the detention basin, then longer duration events may need to be tested to determine maximum flood levels.
3. For modelling using the SCS loss method and nested temporal pattern, peak flows were shown to increase with increasing duration. As such, if sizing detention basins for a fixed downstream capacity constraint, 2a. above would apply. Additionally, if a catchment modelling exercise is being undertaken it is likely that different durations of nested storm event may have an impact on flood levels and peak flows if there are storages within the network being modelled. As such it is recommended that various, increasing duration storms are tested to determine an appropriate 'worst case' – as per 2b. above.

Next Steps

It is understood that Auckland Council are reviewing stormwater rules as part of the Unitary Plan process. Depending on the final rules developed, and the requirements to provide attenuation of peak flows, some more formalised guidance on storm duration may be worthwhile developing.

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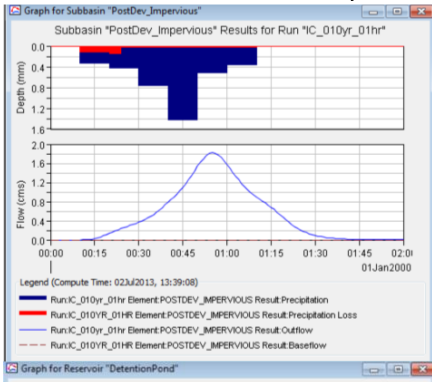
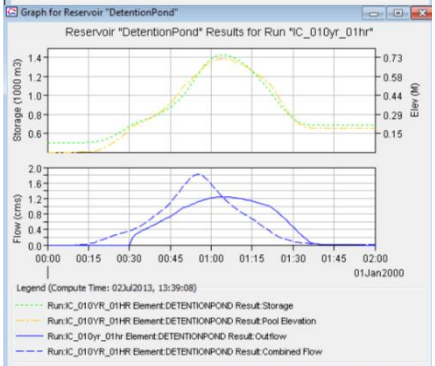
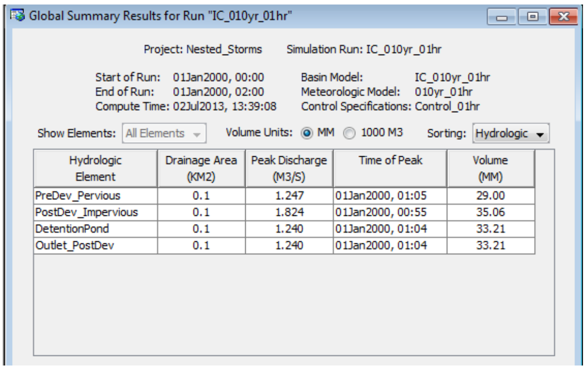
Appendix A HEC HMS Modelling Results

Nested Storm Results

Nested - Initial and Constant, 1 hour:







Global Summary Results for Run "IC_010yr_01hr"

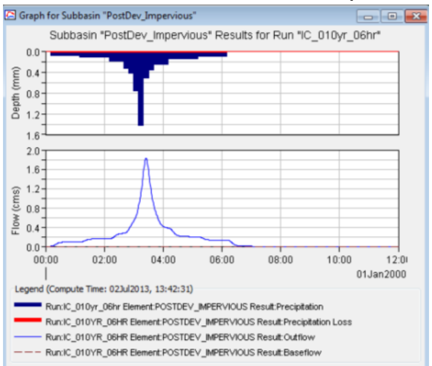
Project: Nested_Storms Simulation Run: IC_010yr_01hr

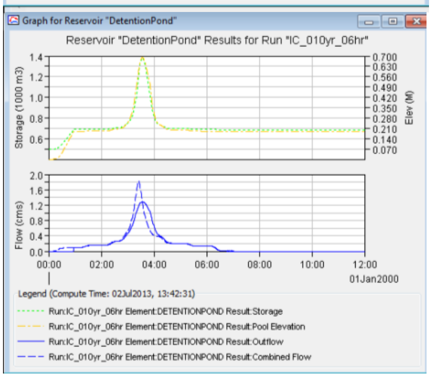
Start of Run: 01Jan2000, 00:00 Basin Model: IC_010yr_01hr
End of Run: 01Jan2000, 02:00 Meteorologic Model: 010yr_01hr
Compute Time: 02Jul2013, 13:39:08 Control Specifications: Control_01hr

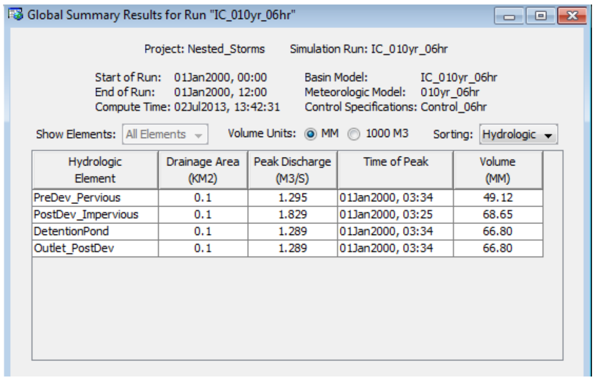
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	1.247	01Jan2000, 01:05	29.00
PostDev_Impervious	0.1	1.824	01Jan2000, 00:55	35.06
DetentionPond	0.1	1.240	01Jan2000, 01:04	33.21
Outlet_PostDev	0.1	1.240	01Jan2000, 01:04	33.21

Nested - Initial and Constant, 6 hour:







Global Summary Results for Run "IC_010yr_06hr"

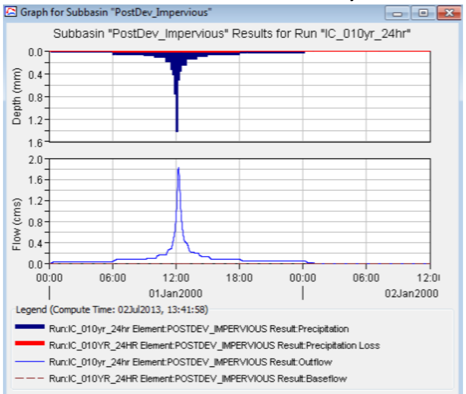
Project: Nested_Storms Simulation Run: IC_010yr_06hr

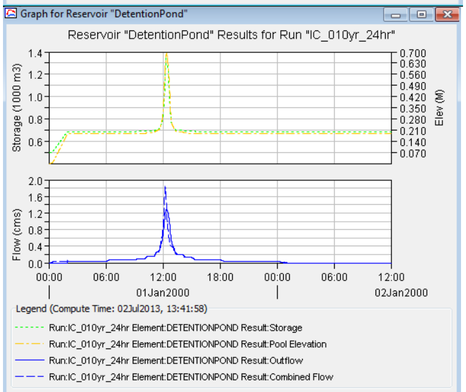
Start of Run: 01Jan2000, 00:00 Basin Model: IC_010yr_06hr
End of Run: 01Jan2000, 12:00 Meteorologic Model: 010yr_06hr
Compute Time: 02Jul2013, 13:42:31 Control Specifications: Control_06hr

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	1.295	01Jan2000, 03:34	49.12
PostDev_Impervious	0.1	1.829	01Jan2000, 03:25	68.65
DetentionPond	0.1	1.289	01Jan2000, 03:34	66.80
Outlet_PostDev	0.1	1.289	01Jan2000, 03:34	66.80

Nested - Initial and Constant, 24 hour:





Global Summary Results for Run "IC_010yr_24hr"

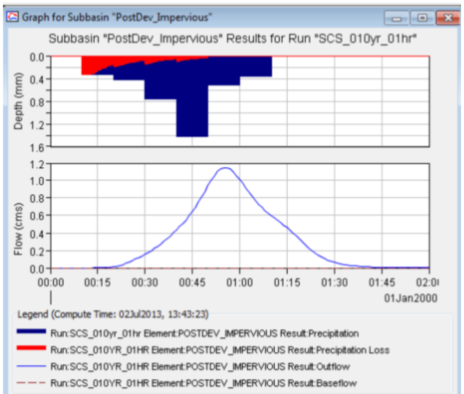
Project: Nested_Storms Simulation Run: IC_010yr_24hr

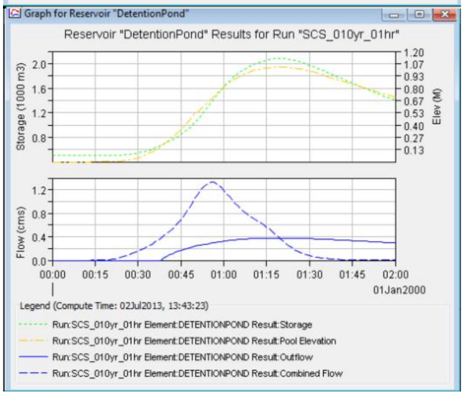
Start of Run: 01Jan2000, 00:00 Basin Model: IC_010yr_24hr
End of Run: 02Jan2000, 12:00 Meteorologic Model: 010yr_24hr
Compute Time: 02Jul2013, 13:41:58 Control Specifications: Control_24hr

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	1.295	01Jan2000, 12:24	49.23
PostDev_Impervious	0.1	1.829	01Jan2000, 12:15	99.30
DetentionPond	0.1	1.289	01Jan2000, 12:24	97.45
Outlet_PostDev	0.1	1.289	01Jan2000, 12:24	97.45

Nested - SCS, 1 hour:





Global Summary Results for Run "SCS_010yr_01hr"

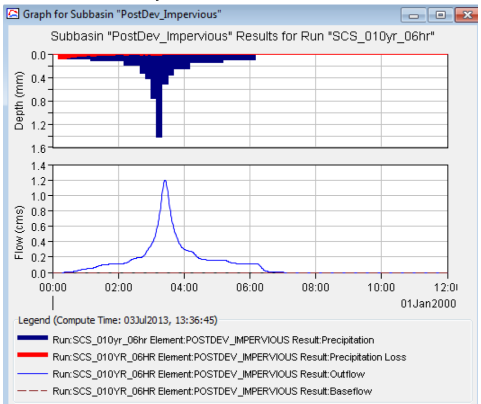
Project: Nested_Storms Simulation Run: SCS_010yr_01hr

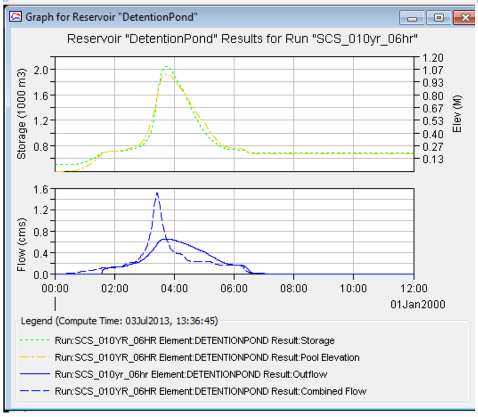
Start of Run: 01Jan2000, 00:00 Basin Model: SCS_010yr_01hr
End of Run: 01Jan2000, 02:00 Meteorologic Model: 010yr_01hr
Compute Time: 02Jul2013, 13:43:23 Control Specifications: Control_01hr

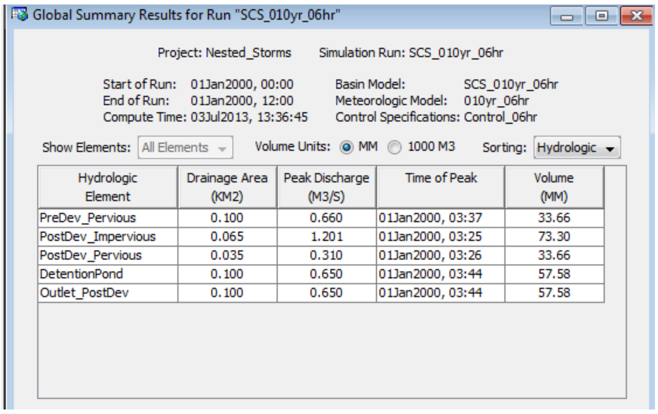
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.386	01Jan2000, 01:11	8.84
PostDev_Impervious	0.065	1.149	01Jan2000, 00:55	32.61
PostDev_Pervious	0.035	0.183	01Jan2000, 00:58	8.98
DetentionPond	0.100	0.378	01Jan2000, 01:20	15.33
Outlet_PostDev	0.100	0.378	01Jan2000, 01:20	15.33

Nested - SCS, 6 hour:






Global Summary Results for Run "SCS_010yr_06hr"

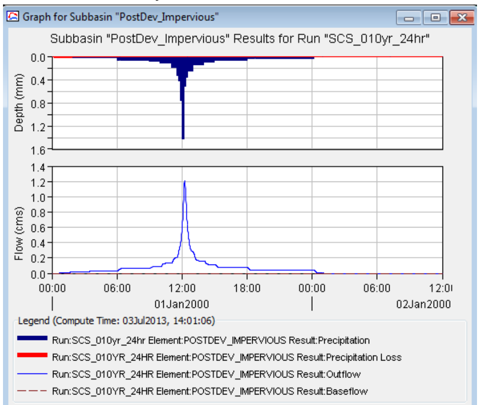
Project: Nested_Storms Simulation Run: SCS_010yr_06hr

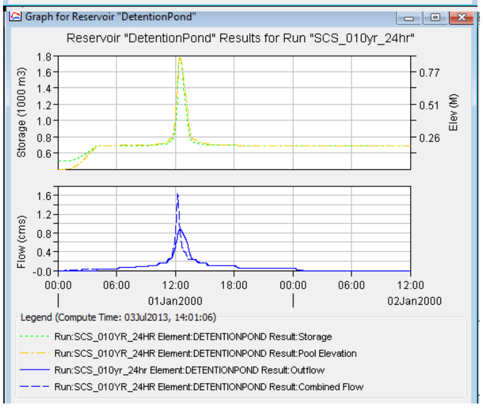
Start of Run: 01Jan2000, 00:00 Basin Model: SCS_010yr_06hr
End of Run: 01Jan2000, 12:00 Meteorologic Model: 010yr_06hr
Compute Time: 03Jul2013, 13:36:45 Control Specifications: Control_06hr

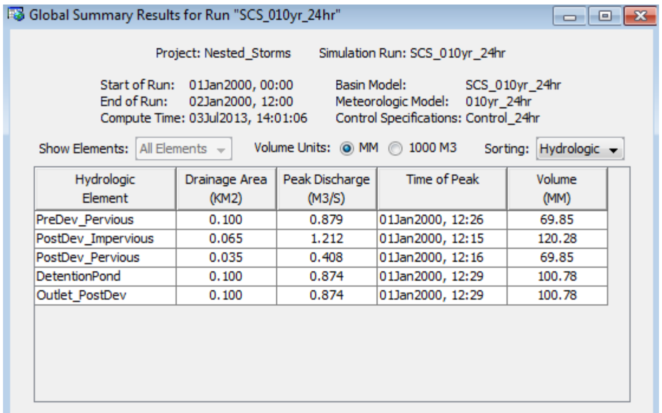
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.660	01Jan2000, 03:37	33.66
PostDev_Impervious	0.065	1.201	01Jan2000, 03:25	73.30
PostDev_Pervious	0.035	0.310	01Jan2000, 03:26	33.66
DetentionPond	0.100	0.650	01Jan2000, 03:44	57.58
Outlet_PostDev	0.100	0.650	01Jan2000, 03:44	57.58

Nested - SCS, 24 hour:






Global Summary Results for Run "SCS_010yr_24hr"

Project: Nested_Storms Simulation Run: SCS_010yr_24hr

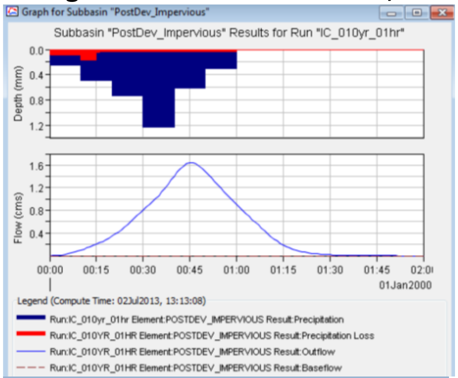
Start of Run: 01Jan2000, 00:00 Basin Model: SCS_010yr_24hr
End of Run: 02Jan2000, 12:00 Meteorologic Model: 010yr_24hr
Compute Time: 03Jul2013, 14:01:06 Control Specifications: Control_24hr

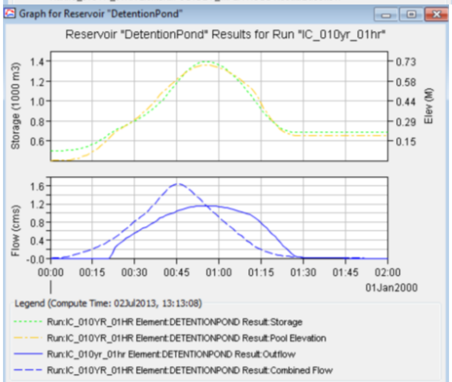
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

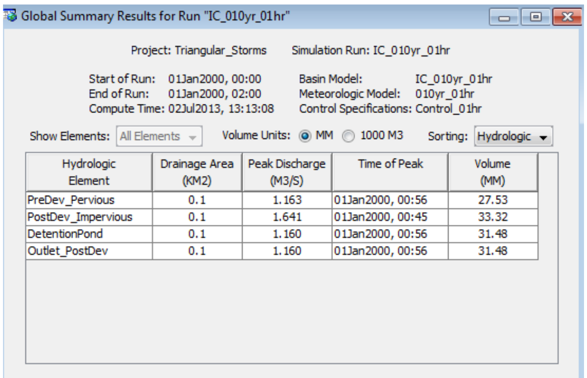
Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.879	01Jan2000, 12:26	69.85
PostDev_Impervious	0.065	1.212	01Jan2000, 12:15	120.28
PostDev_Pervious	0.035	0.408	01Jan2000, 12:16	69.85
DetentionPond	0.100	0.874	01Jan2000, 12:29	100.78
Outlet_PostDev	0.100	0.874	01Jan2000, 12:29	100.78

Triangular Storm Results

Triangular - Initial and Constant, 1 hour:






Global Summary Results for Run "IC_010yr_01hr"

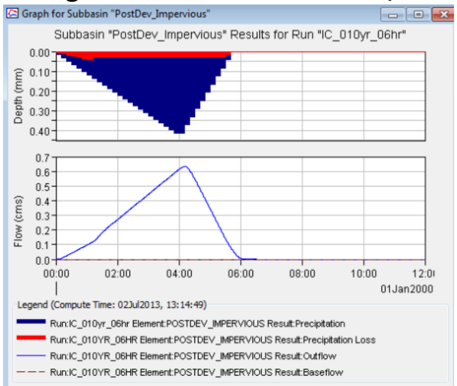
Project: Triangular_Storms Simulation Run: IC_010yr_01hr

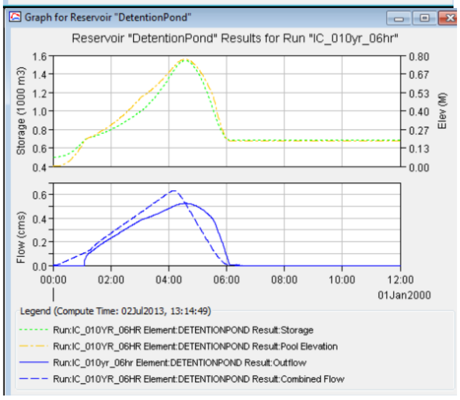
Start of Run: 01Jan2000, 00:00 Basin Model: IC_010yr_01hr
End of Run: 01Jan2000, 02:00 Meteorologic Model: 010yr_01hr
Compute Time: 02Jul2013, 13:13:08 Control Specifications: Control_01hr

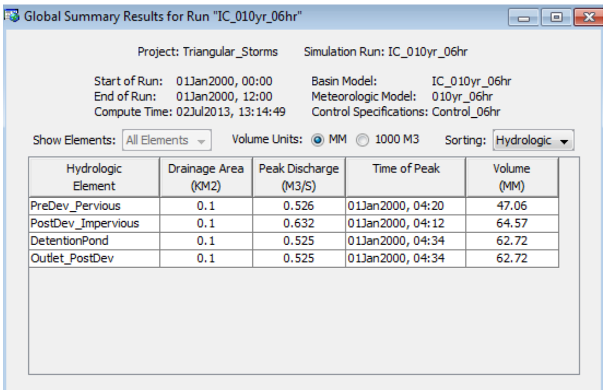
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	1.163	01Jan2000, 00:56	27.53
PostDev_Impervious	0.1	1.641	01Jan2000, 00:45	33.32
DetentionPond	0.1	1.160	01Jan2000, 00:56	31.48
Outlet_PostDev	0.1	1.160	01Jan2000, 00:56	31.48

Triangular - Initial and Constant, 6 hour:






Global Summary Results for Run "IC_010yr_06hr"

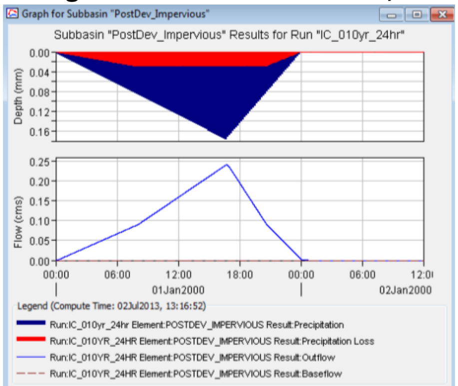
Project: Triangular_Storms Simulation Run: IC_010yr_06hr

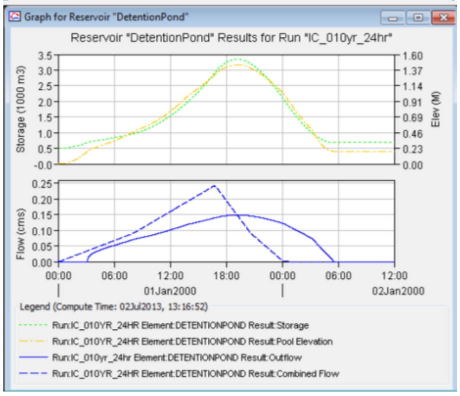
Start of Run: 01Jan2000, 00:00 Basin Model: IC_010yr_06hr
End of Run: 01Jan2000, 12:00 Meteorologic Model: 010yr_06hr
Compute Time: 02Jul2013, 13:14:49 Control Specifications: Control_06hr

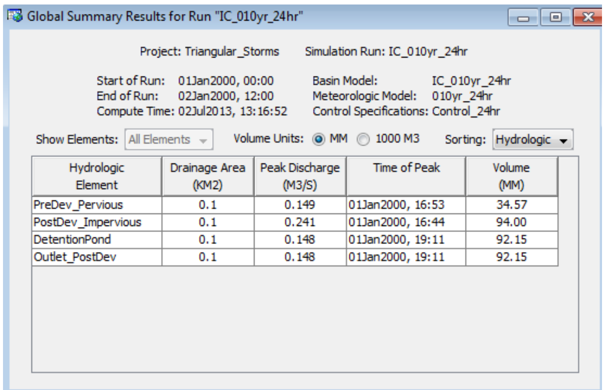
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	0.526	01Jan2000, 04:20	47.06
PostDev_Impervious	0.1	0.632	01Jan2000, 04:12	64.57
DetentionPond	0.1	0.525	01Jan2000, 04:34	62.72
Outlet_PostDev	0.1	0.525	01Jan2000, 04:34	62.72

Triangular - Initial and Constant, 24 hour:







Global Summary Results for Run "IC_010yr_24hr"

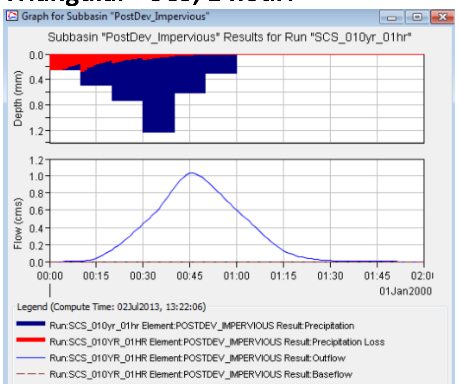
Project: Triangular_Storms Simulation Run: IC_010yr_24hr

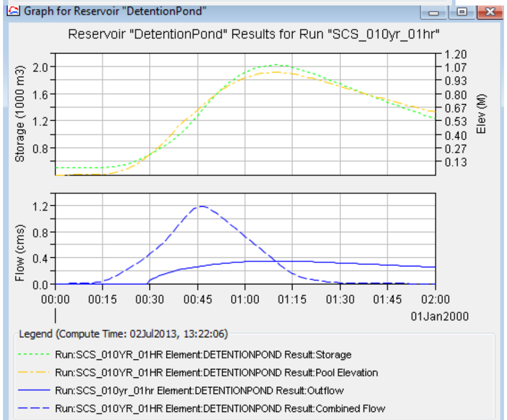
Start of Run: 01Jan2000, 00:00 Basin Model: IC_010yr_24hr
End of Run: 02Jan2000, 12:00 Meteorologic Model: 010yr_24hr
Compute Time: 02Jul2013, 13:16:52 Control Specifications: Control_24hr

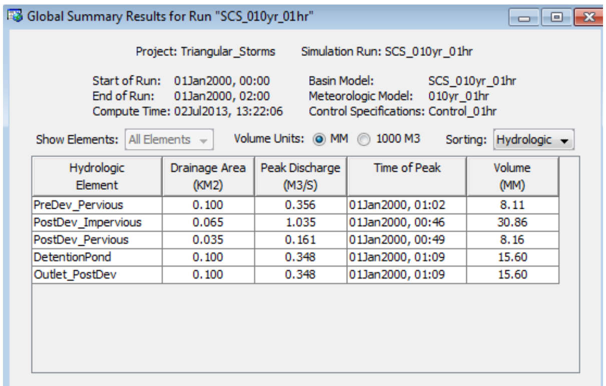
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	0.149	01Jan2000, 16:53	34.57
PostDev_Impervious	0.1	0.241	01Jan2000, 16:44	94.00
DetentionPond	0.1	0.148	01Jan2000, 19:11	92.15
Outlet_PostDev	0.1	0.148	01Jan2000, 19:11	92.15

Triangular - SCS, 1 hour:







Global Summary Results for Run "SCS_010yr_01hr"

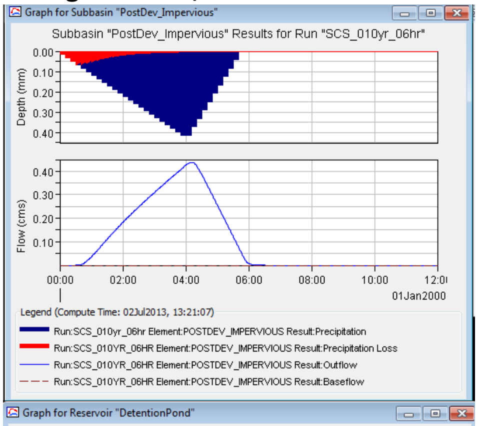
Project: Triangular_Storms Simulation Run: SCS_010yr_01hr

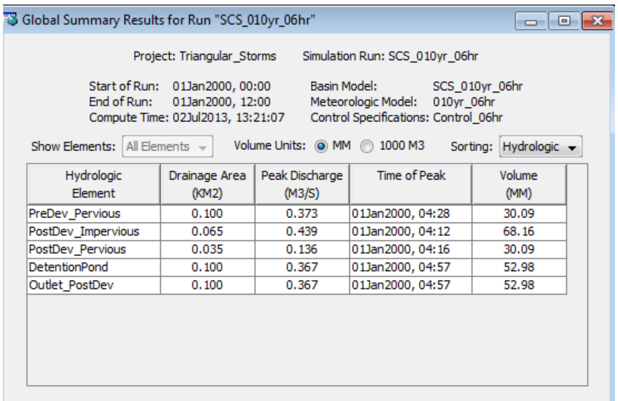
Start of Run: 01Jan2000, 00:00 Basin Model: SCS_010yr_01hr
End of Run: 01Jan2000, 02:00 Meteorologic Model: 010yr_01hr
Compute Time: 02Jul2013, 13:22:06 Control Specifications: Control_01hr

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.356	01Jan2000, 01:02	8.11
PostDev_Impervious	0.065	1.035	01Jan2000, 00:46	30.86
PostDev_Pervious	0.035	0.161	01Jan2000, 00:49	8.16
DetentionPond	0.100	0.348	01Jan2000, 01:09	15.60
Outlet_PostDev	0.100	0.348	01Jan2000, 01:09	15.60

Triangular - SCS, 6 hour:



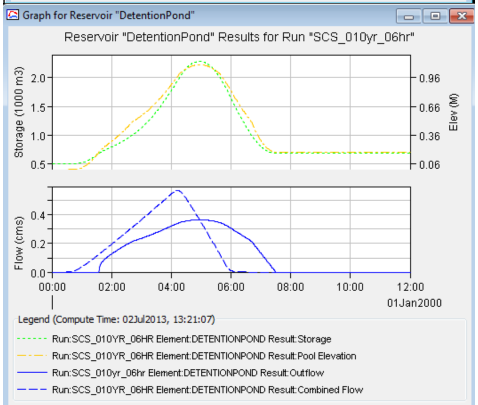

Global Summary Results for Run "SCS_010yr_06hr"

Project: Triangular_Storms   Simulation Run: SCS_010yr_06hr

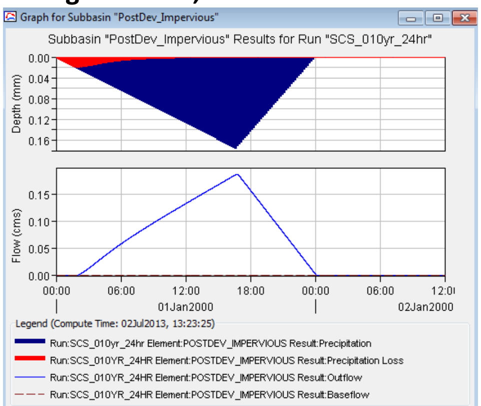
Start of Run: 01Jan2000, 00:00   Basin Model: SCS_010yr_06hr
End of Run: 01Jan2000, 12:00   Meteorologic Model: 010yr_06hr
Compute Time: 02Jul2013, 13:21:07   Control Specifications: Control_06hr

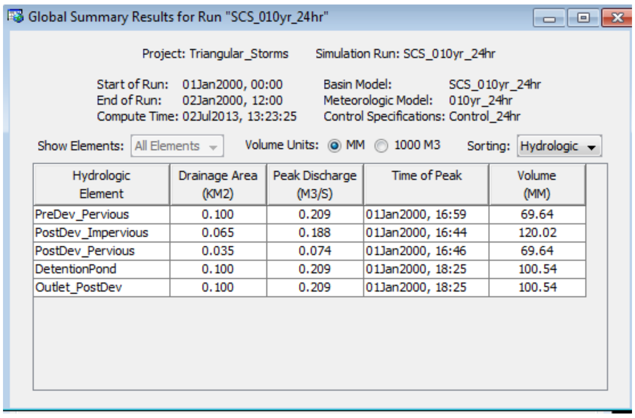
Show Elements: All Elements   Volume Units: MM 1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.373	01Jan2000, 04:28	30.09
PostDev_Impervious	0.065	0.439	01Jan2000, 04:12	68.16
PostDev_Pervious	0.035	0.136	01Jan2000, 04:16	30.09
DetentionPond	0.100	0.367	01Jan2000, 04:57	52.98
Outlet_PostDev	0.100	0.367	01Jan2000, 04:57	52.98



Triangular - SCS, 24 hour:



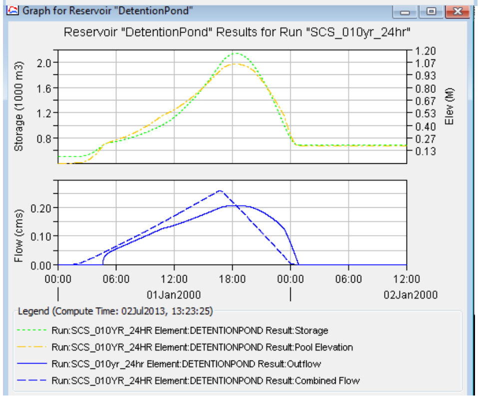

Global Summary Results for Run "SCS_010yr_24hr"

Project: Triangular_Storms   Simulation Run: SCS_010yr_24hr

Start of Run: 01Jan2000, 00:00   Basin Model: SCS_010yr_24hr
End of Run: 02Jan2000, 12:00   Meteorologic Model: 010yr_24hr
Compute Time: 02Jul2013, 13:23:25   Control Specifications: Control_24hr

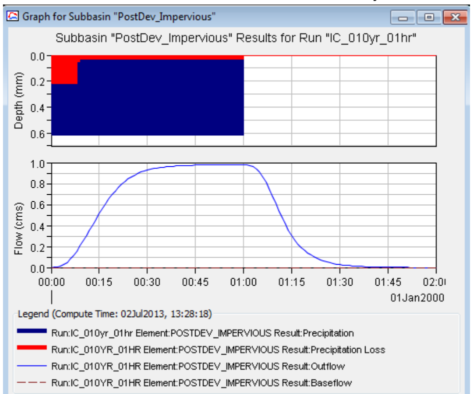
Show Elements: All Elements   Volume Units: MM 1000 M3   Sorting: Hydrologic

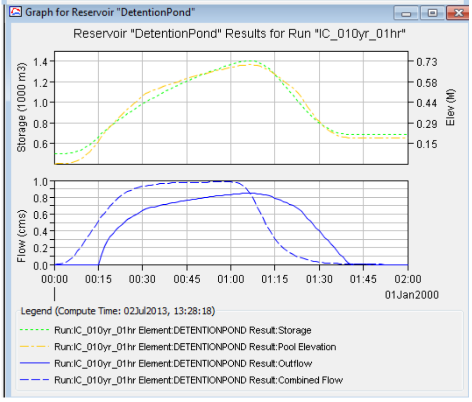
Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.209	01Jan2000, 16:59	69.64
PostDev_Impervious	0.065	0.188	01Jan2000, 16:44	120.02
PostDev_Pervious	0.035	0.074	01Jan2000, 16:46	69.64
DetentionPond	0.100	0.209	01Jan2000, 18:25	100.54
Outlet_PostDev	0.100	0.209	01Jan2000, 18:25	100.54



Constant Storm Results

Constant - Initial and Constant, 1 hour:





Global Summary Results for Run "IC_010yr_01hr"

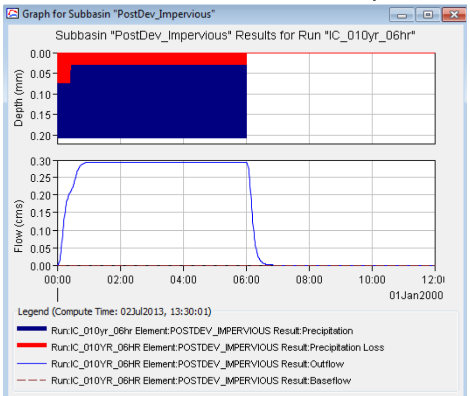
Project: Constant_Storms   Simulation Run: IC_010yr_01hr

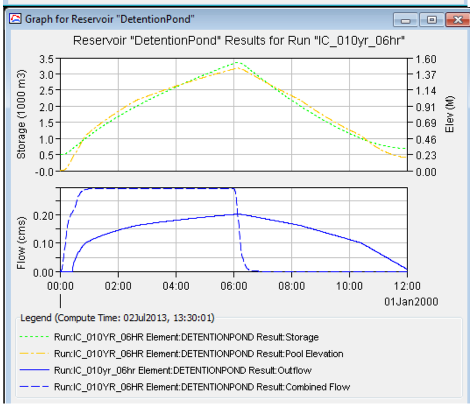
Start of Run: 01Jan2000, 00:00   Basin Model: IC_010yr_01hr
End of Run: 01Jan2000, 02:00   Meteorologic Model: 010yr_01hr
Compute Time: 02Jul2013, 13:28:18   Control Specifications: Control_01hr

Show Elements: All Elements   Volume Units: MM   1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	0.850	01Jan2000, 01:03	27.54
PostDev_Impervious	0.1	0.980	01Jan2000, 01:00	33.76
DetentionPond	0.1	0.849	01Jan2000, 01:06	31.91
Outlet_PostDev	0.1	0.849	01Jan2000, 01:06	31.91

Constant - Initial and Constant, 6 hour:





Global Summary Results for Run "IC_010yr_06hr"

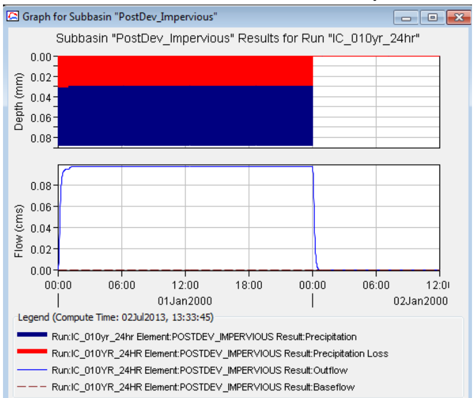
Project: Constant_Storms   Simulation Run: IC_010yr_06hr

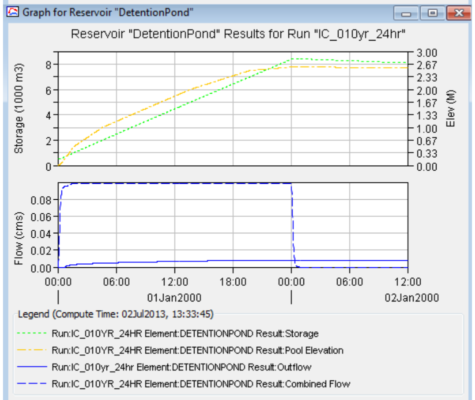
Start of Run: 01Jan2000, 00:00   Basin Model: IC_010yr_06hr
End of Run: 01Jan2000, 12:00   Meteorologic Model: 010yr_06hr
Compute Time: 02Jul2013, 13:30:01   Control Specifications: Control_06hr

Show Elements: All Elements   Volume Units: MM   1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	0.204	01Jan2000, 02:14	41.18
PostDev_Impervious	0.1	0.295	01Jan2000, 01:17	62.62
DetentionPond	0.1	0.204	01Jan2000, 06:09	60.75
Outlet_PostDev	0.1	0.204	01Jan2000, 06:09	60.75

Constant - Initial and Constant, 24 hour:





Global Summary Results for Run "IC_010yr_24hr"

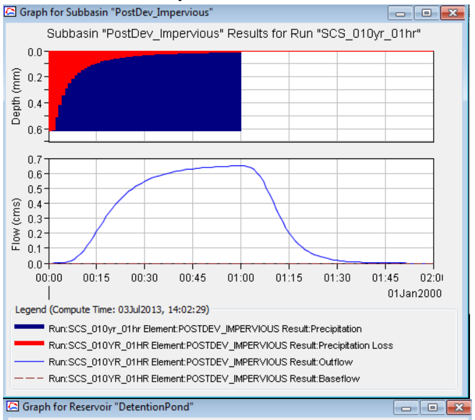
Project: Constant_Storms   Simulation Run: IC_010yr_24hr

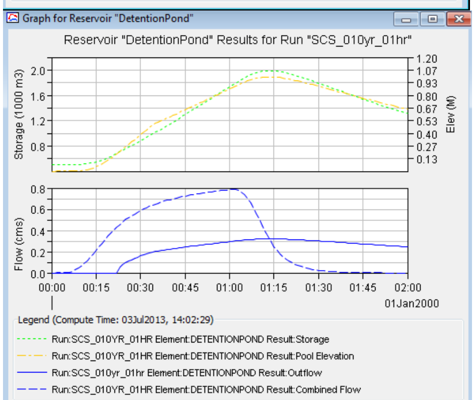
Start of Run: 01Jan2000, 00:00   Basin Model: IC_010yr_24hr
End of Run: 02Jan2000, 12:00   Meteorologic Model: 010yr_24hr
Compute Time: 02Jul2013, 13:33:45   Control Specifications: Control_24hr

Show Elements: All Elements   Volume Units: MM 1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.1	0.008	01Jan2000, 02:44	6.45
PostDev_Impervious	0.1	0.098	01Jan2000, 01:51	84.63
DetentionPond	0.1	0.008	02Jan2000, 00:23	8.77
Outlet_PostDev	0.1	0.008	02Jan2000, 00:23	8.77

Constant - SCS, 1 hour:





Global Summary Results for Run "SCS_010yr_01hr"

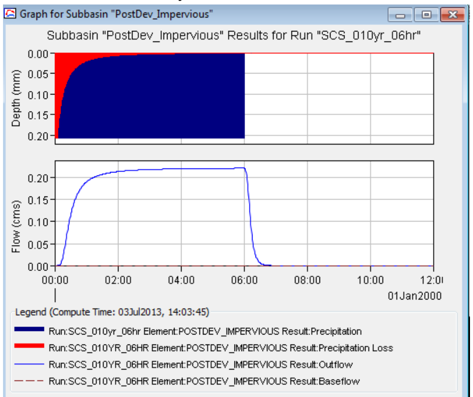
Project: Constant_Storms   Simulation Run: SCS_010yr_01hr

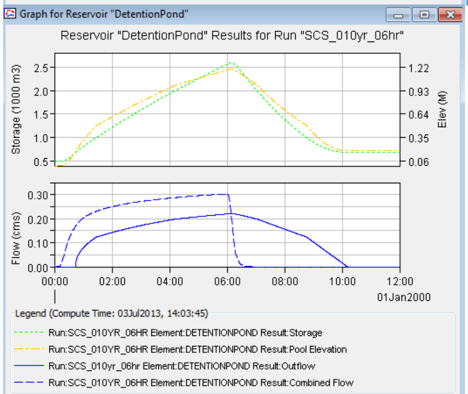
Start of Run: 01Jan2000, 00:00   Basin Model: SCS_010yr_01hr
End of Run: 01Jan2000, 02:00   Meteorologic Model: 010yr_01hr
Compute Time: 03Jul2013, 14:02:29   Control Specifications: Control_01hr

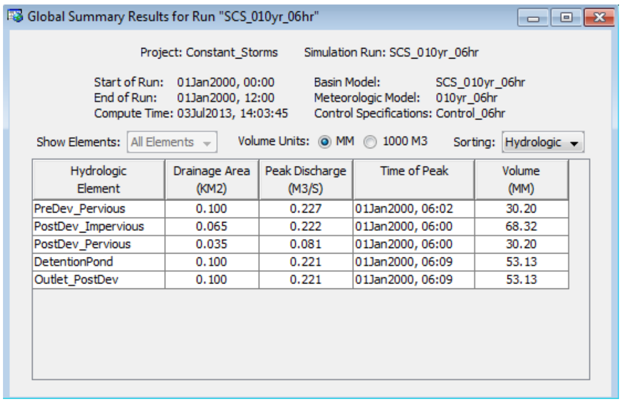
Show Elements: All Elements   Volume Units: MM 1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.326	01Jan2000, 01:09	8.38
PostDev_Impervious	0.065	0.651	01Jan2000, 01:00	31.49
PostDev_Pervious	0.035	0.139	01Jan2000, 01:03	8.45
DetentionPond	0.100	0.321	01Jan2000, 01:13	15.35
Outlet_PostDev	0.100	0.321	01Jan2000, 01:13	15.35

Constant - SCS, 6 hour:







Global Summary Results for Run "SCS_010yr_06hr"

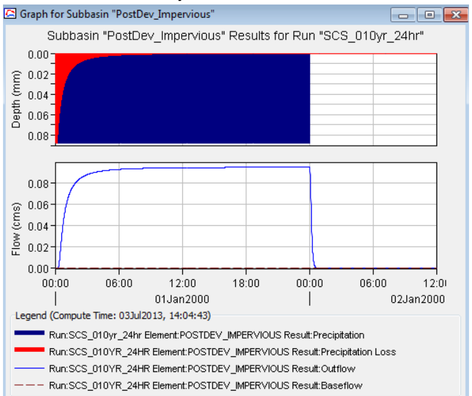
Project: Constant_Storms Simulation Run: SCS_010yr_06hr

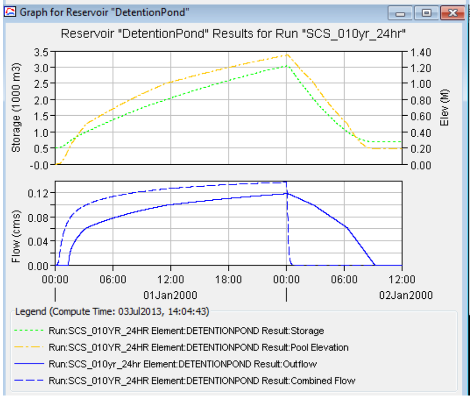
Start of Run: 01Jan2000, 00:00 Basin Model: SCS_010yr_06hr
End of Run: 01Jan2000, 12:00 Meteorologic Model: 010yr_06hr
Compute Time: 03Jul2013, 14:03:45 Control Specifications: Control_06hr

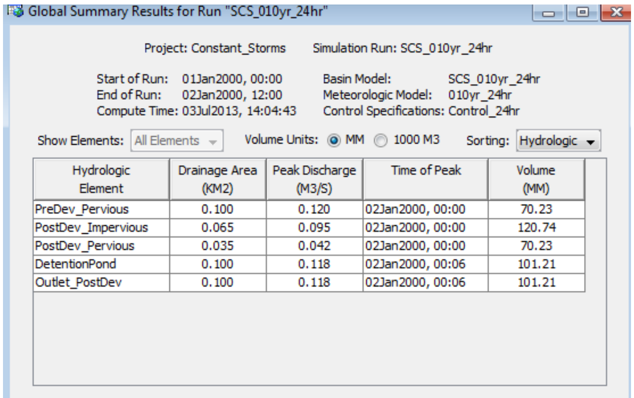
Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.227	01Jan2000, 06:02	30.20
PostDev_Impervious	0.065	0.222	01Jan2000, 06:00	68.32
PostDev_Pervious	0.035	0.081	01Jan2000, 06:00	30.20
DetentionPond	0.100	0.221	01Jan2000, 06:09	53.13
Outlet_PostDev	0.100	0.221	01Jan2000, 06:09	53.13

Constant - SCS, 24 hour:







Global Summary Results for Run "SCS_010yr_24hr"

Project: Constant_Storms Simulation Run: SCS_010yr_24hr

Start of Run: 01Jan2000, 00:00 Basin Model: SCS_010yr_24hr
End of Run: 02Jan2000, 12:00 Meteorologic Model: 010yr_24hr
Compute Time: 03Jul2013, 14:04:43 Control Specifications: Control_24hr

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
PreDev_Pervious	0.100	0.120	02Jan2000, 00:00	70.23
PostDev_Impervious	0.065	0.095	02Jan2000, 00:00	120.74
PostDev_Pervious	0.035	0.042	02Jan2000, 00:00	70.23
DetentionPond	0.100	0.118	02Jan2000, 00:06	101.21
Outlet_PostDev	0.100	0.118	02Jan2000, 00:06	101.21