Hydrologic Impacts Due to Development: The Need for Adequate Runoff Detention and Stream Protection

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Introduction

A watershed's hydrologic characteristics are altered as development occurs within its boundaries. Urbanization in a watershed tends to fill in low areas, which previously provided storage, and pave over pervious areas, which had provided infiltration. The addition of a storm sewer system, along with curb and gutters, collects more runoff and directs it to the stream, lake, or wetland more quickly. These actions produce greater runoff volumes with higher and more frequent flood peaks. Left unchecked, this will cause serious damage to the physical and biological integrity of the receiving stream. Many communities have adopted stormwater ordinances intended to control the increased flooding associated with urbanization. But few have addressed the water quality and stream impacts caused by smaller runoff events.

This report identifies some of the stream impacts caused by urbanization. These impacts are discussed and classified in three groups:

- water quality
- stream channel protection
- flood control

Best Management Practices (BMPs) that can control or mitigate some of the impacts, including detention/retention, are then identified.

Surface Runoff Effects

Stream Characteristics

Local officials, developers, and engineers need to understand the characteristics and capacities of receiving streams to make wise, land use decisions that protect the value of the water resources. It is necessary to evaluate a stream's characteristics and capacities to determine the BMPs needed to maintain the physical stability and ecological health of the stream. Stream characteristics fall into two categories and include:

- Biological
    - type of fisheries
    - aquatic habitat
    - temperature
    - designated use
    - dissolved oxygen

- Hydraulic
    - soil types
    - vegetation
    - floodplain extent
    - hydraulic capacity of any artificial structures
    - channel planform (sinuosity), cross-section dimensions, and profile
    - active erosion sites

Biological characteristics are affected by the runoff water quality and quantity. Runoff from urban sites is often associated with increased pollutants that degrade the ecological health of the stream. Urbanization can also increase the volume and intensity of runoff, affecting both biological and hydraulic characteristics of the stream. Interaction of the hydraulic characteristics determines how well a stream conveys runoff stormwater and how susceptible it is to changes in the watershed hydrology. The presence of certain soils, the lack of vegetation, or the loss of floodplain storage increases the likelihood of streambank erosion if flows are increased. Artificial structures, such as bridges or culverts, may restrict flows, locally increasing the water velocity and erosion potential at the restriction. They can also increase the water depth above the restriction. Other hardened structures, such as walls and riprap, transmit more energy downstream than vegetated streambanks, which increases erosive stresses on weaker areas of the streambank.

Water Quality

Unbalanced hydraulic characteristics may affect the biological characteristics of the stream. For example, accelerated erosion increases streambed sedimentation, impairing aquatic habitat for both fish and their flood source, and aquatic insects. Runoff from hard, land surfaces can increase the stream temperature, changing it from a cold water fisheries stream to a warm water fisheries stream. Runoff from all surfaces can carry pollutants that have a detrimental effect on the biological characteristics of the stream. These pollutants include sediment, oil, grease, nutrients, and metals, and are typically more concentrated in the initial runoff (Menerey, 1999 and Schueler, 2000). Capturing and treating this first portion, or first flush, from smaller sites is a priority for managing these nonpoint pollutants. The concept of first flush may not apply to sites larger than approximately 100 acres (Hager, 2001). Runoff from these larger sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet. Larger sites may need to be split into smaller units for treatment.

Channel-Forming Flows

The stream's morphology - its planform, cross-section dimensions, and profile - develops in response to stream flows. Extreme flood flows generally do not shape channel morphology because they are so rare. More frequently occurring flows, those with a 1.5 to 2 year recurrence interval, are generally the dominant channel-forming flows in stable, natural streams (Schueler, 1987 and Rosgen, 1996). Hydrologic changes that increase these channel-forming flows can cause the stream morphology to become unstable; leading to extensive erosion as the stream tries to adapt to the higher flows. The presence of multiple, active erosion sites can indicate that the stream morphology is already unstable and that further increases in flow will accelerate the erosion.

Development generally increases both peak flow and total runoff volume. Detention can control peak flows in developing areas but does not reduce the total runoff volume. Therefore, the duration of post-development peak flows controlled with detention will be longer than those from pre-development conditions. The longer duration may cause additional erosion of the streambanks. The results from a calibrated hydrologic model, Figure 1, illustrates this for a small stream tributary to the Grand River. Approximately 40 percent of the watershed transitioned from natural area to residential within a few years. The developer put in detention areas designed to control flooding, as required by the stormwater ordinance in effect at the time. The 2-year peak flow, which approximates the channel-forming flow, has nearly doubled, but would have been six times higher without the detention. The channel is also exposed to the undeveloped channel-forming flow longer. The added detention increases this duration more than if the detention had not been installed.

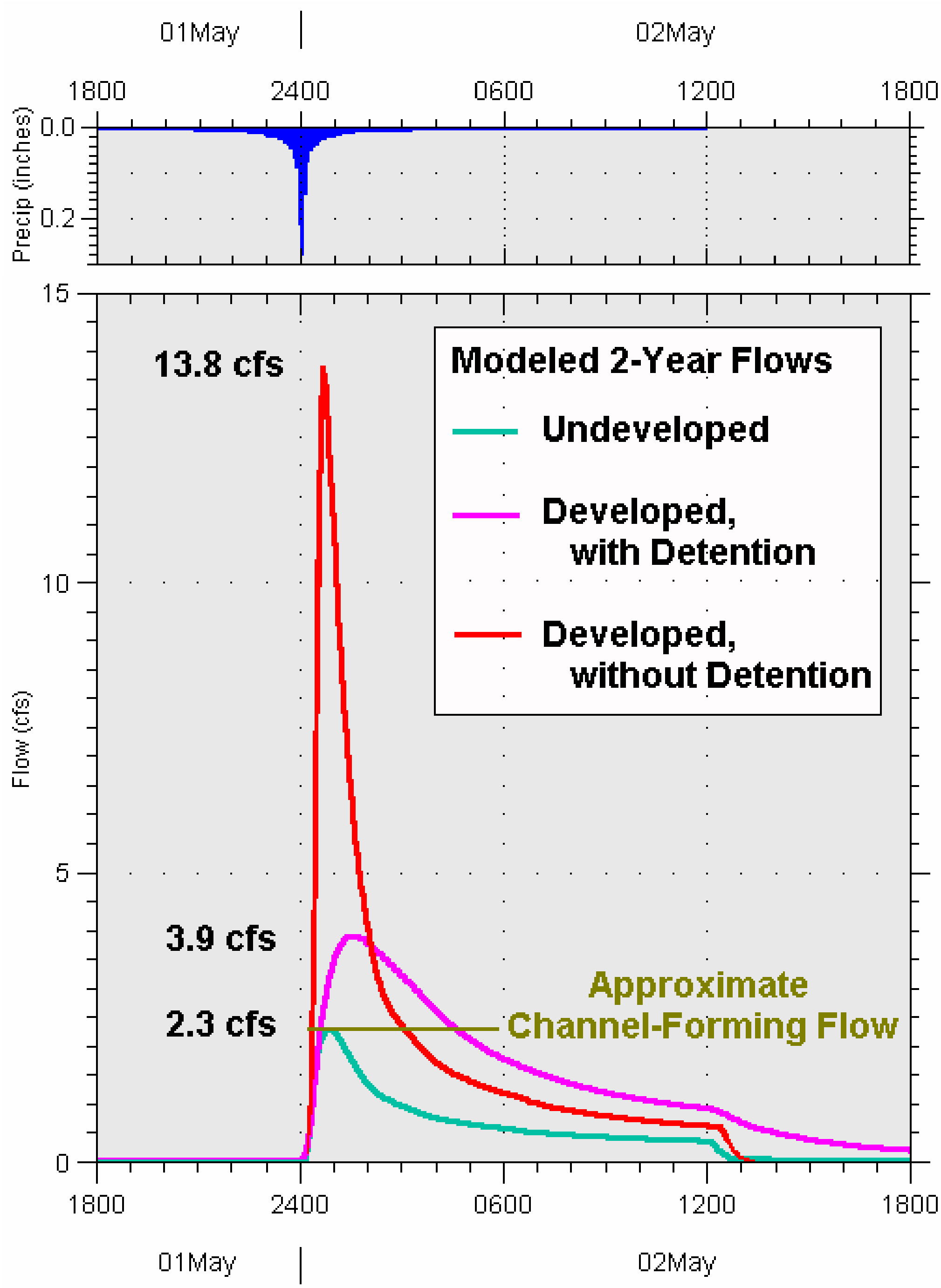

Figure 1 – Changes in Flow Due to Development

Flood Flows

A river, stream, lake, or drain may occasionally overflow its banks and inundate adjacent land. This land is the floodplain. The floodplain refers to the land inundated by the 1 percent chance flood, commonly called the 100-year flood. Typically, a stable stream will recover naturally from these infrequent events. Developments should always include stormwater controls that prevent flood flows from exceeding pre-development conditions. Many localities require new development to control the 4 percent chance flood, commonly called the 25-year flood, with some adding requirements to control the 1 percent chance flood.

Urbanization Impacts

List of Identified Impacts

Schueler (1987) identifies the following stream impacts caused by increased development:

- Peak flows are increased two to five times over pre-development flow rates.
- The frequency of bankfull flooding may increase from an average of once every two years to three or four times each year. A stream that was able to handle bankfull flooding will be reshaped due to increased flow volume and water velocity. The stream will show channel down-cutting and widening, streambank erosion, falling trees, and slumping banks.
- Runoff will reach the stream up to 50 percent faster.
- The channel will widen to adjust to increased storm flows. Streambanks are gradually undercut and slump into the channel. Trees that protected the streambanks are exposed at the roots and more likely to be wind thrown, triggering a second phase of bank erosion. Many streams widen two to four times their original size if post-development runoff is not controlled.
- Pools and riffles are eliminated due to sedimentation caused by increase soil erosion. This has a direct impact on the aquatic community and the number and types of organisms found there.
- Less infiltration reduces baseflow.
- Fish communities become less diverse with a reduction or elimination of sensitive fish species.
- The amounts of pollutants entering the stream system during and after development increase substantially. The amount of nitrogen and phosphorous from a developed watershed can be several times higher than an undeveloped watershed. Other pollutants, such as oils and trace metals, may exhibit even higher increases because there are generally no significant sources of these in an undeveloped watershed.
- The temperature of an urban stream may increase 0.14 degrees Fahrenheit for every 1 percent increase in imperviousness (Galli, 1990).
- The temperature of an urban stream may increase 1 to 3 degrees Fahrenheit per 100 feet when flowing through unshaded areas. Removal of all vegetation shading the stream can raise the summer water temperature by 11 to 20 degrees Fahrenheit and lower winter water temperatures by 5 to 7 degrees Fahrenheit (Galli, 1990).

Case Studies

The following examples document some of the impacts listed above.

- Urbanization significantly increased the frequency of channel-forming in the River Rouge near Detroit. Figure 2 indicates the number of times per decade a flow of 1,200 cubic feet per second (cfs) was exceeded at the River Rouge at Detroit gaging station #04166500. A flow of approximately 1,200 cfs would approximately correspond to the channel-forming flow.

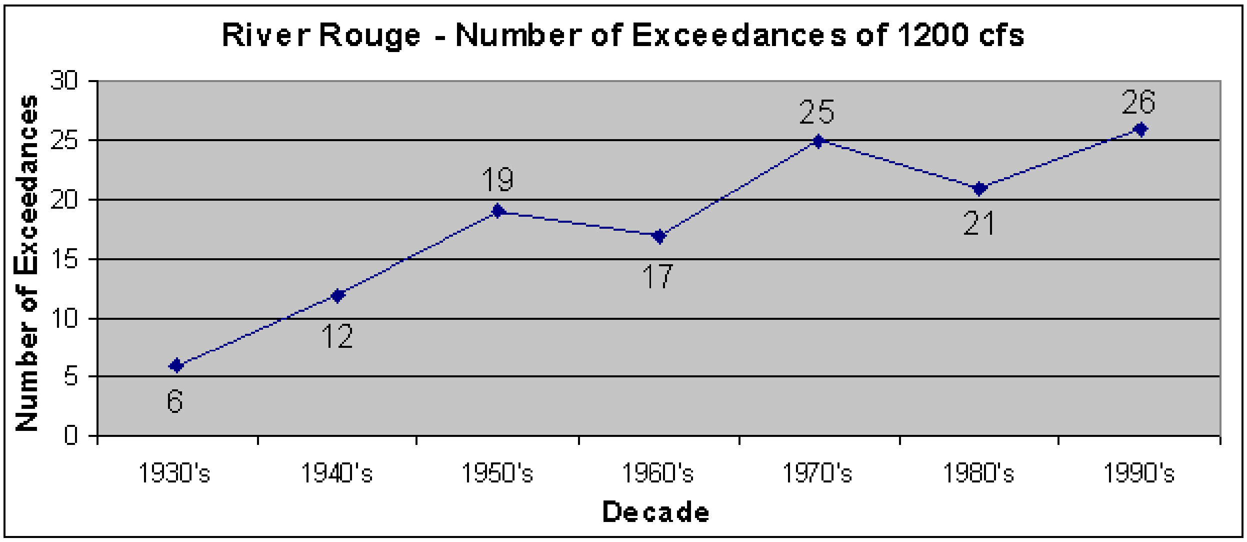

Figure 2

The hydrographs at this gaging station indicate the flow changes rapidly in response to runoff events (Hamilton, 1994). Many locations along the River Rouge system have experienced streambank erosion problems as the stream attempts to adjust to changes in flow.

- A study for the York Creek watershed in Kent County indicates a large suspended sediment load in this small urbanizing stream (Feldpausch, 1995). This creek is probably typical of many small streams in Michigan, which have been heavily urbanized without adequate safeguards to minimize the increase in flow. The fishery and biological communities in this stream are seriously impacted as a result of the increased sedimentation. The increased sedimentation is caused by many factors, including streambank erosion, unprotected soil from construction sites, and sediment picked up in the stormwater runoff from paved areas.

Minimizing Flow Impacts and Sedimentation

Best Management Practices

The following is a partial listing of some of the BMPs that can be used to minimize the adverse effects caused by sedimentation and increased flows.

- Provide a buffer or green belt along all streams, drains, wetlands, and lakes.

- Preserve as much green space as possible.
- Use effective soil erosion controls at construction sites.
- Avoid clear cutting and exposing bare soil for the entire development project. Stabilize an area before moving on.
- Use sediment basins at construction sites.
- Use sediment sumps in storm sewers and clean them out when 50 percent full.
- Restrict development in environmentally sensitive areas.
- Use grassed waterways and water quality swales for street drainage instead of curb and gutters.
- Disconnect down spouts from storm sewers.

A more detailed description of BMPs can be found in the Michigan Department of Environmental Quality's Guidebook of Best Management Practices for Michigan Watersheds, available at https://www.michigan.gov/egle/about/Organization/Water-Resources/nonpoint-source/BMP-manual-and-design-references. Additional information can be found in the National Pollutant Removal Performance Database, which summarizes and compares removal rates for six groups of stormwater management practices: ponds, wetlands, open channels, filters, infiltration, and on-site devices.

Detention/Retention

A detention/retention ordinance must be developed and enforced to control the increased flow rates caused by urbanization. Even in those communities that have one, the ordinance often only addresses control of the larger floods. A detention/retention ordinance can also regulate smaller flows, which would address water quality concerns and streambank erosion problems.

To Improve Water Quality

Small runoff events and the first portion of the runoff from larger events typically pick up and deliver the majority of the pollutants to a watercourse in an urban area (Menerey, 1999 and Schueler, 2000). Some of the pollutants can settle out before discharging to a stream if this first flush runoff is detained for a period of time. Nationally, the amount of runoff recommended for capture and treatment varies from 0.5 inch per impervious acre to the runoff from a 50 percent chance storm. Michigan BMP guidelines recommend capture and treatment of 0.5 inch of runoff from the entire site. The runoff is then released over 24 to 48 hours or is allowed to infiltrate into the ground within 72 hours. Dry detention ponds are less effective than retention or wet detention ponds because the accumulated sediment in a dry detention pond may be easily resuspended by the next storm (Schueler, 2000).

To Reduce Streambank Erosion and Control Flood Flows

Schueler (1987) and Rosgen (1996) indicate that the 67 percent to 50 percent chance flows shape most natural streams. These events are generally associated with bankfull conditions. Failure to control increases in these smaller flows can lead to increased streambank erosion, down-cutting, and widening as the stream attempts to adjust to the higher, more frequent channel-forming flows. The goal of any detention/retention ordinance should be to maintain existing natural flow rates based on undeveloped conditions for the 50 percent through 1 percent chance events. Release rates from a detention/retention pond should be based on the 50 percent chance event undeveloped flow rate or less. Allowing for higher release rates could lead to increase streambank erosion. Ordinances which address only the 10 percent to 1 percent chance flows often allow for release rates which are higher than the existing 50 percent chance flow.

Flows depend on the soils, land use, topography, and slope within the watershed. In evaluating the flows at 188 United States Geological Survey (USGS) gaging stations, the average yield associated with the 50 percent chance flood varied from 0.0023 cfs/acre to 0.094 cfs/acre (Fulcher, unpublished document, 1991). Normal development sites have drainage areas significantly less than the gaging stations and may have yield rates outside of this range. Each site should be evaluated individually.

Studies for Mitchell Creek in Grand Traverse County and Bear Creek in Kent County predicted 50 percent flow rates for existing conditions of 0.012 cfs/acre and 0.025 cfs/acre, respectively (Fulcher, Bear Creek and Mitchell Creek Watershed Studies, 1991). The Grand Traverse County Drain Commissioner's stormwater ordinance requires new development to provide detention to store the increase in runoff between the existing and proposed conditions for the 4 percent chance storm. It further states that the release rate shall not exceed the peak flow from a 50 percent, 24-hour storm based on grassed, undeveloped conditions or 0.2 cfs/acre, whichever is less. The grassed undeveloped condition will generally yield the lower rate under most circumstances.

Detention/retention is not essential for the control of peak flows from every drainage area. In some cases, modeling should be performed to insure that flood peaks are not increased due to the timing of the peak flows. Detention designed to prevent streambank erosion may not be needed for runoff routed through storm sewers to a large river, for example. As shown in Figure 3, peak flows in the Looking Glass River near the City of DeWitt lag rain events by 20 to 24 hours. The predominantly agricultural watershed encompasses 235 square miles to this point. Runoff routed through storm sewers from the City of DeWitt enters the Looking Glass much more quickly, well ahead of the peak flow. Detention of stormwater runoff from the city will not noticeably change the flow regime of the Looking Glass River. This city's management plan for stormwater routed through storm sewers should focus on treating the runoff to maintain water quality and providing sufficient drainage capacity to minimize flooding. Detention/retention might also be encouraged or required for other reasons, such as the water quality benefits of these BMPs, groundwater replenishment, or watershed planning that indicates continued growth of the city would significantly alter the flow regime of the river if these BMPs are not used.

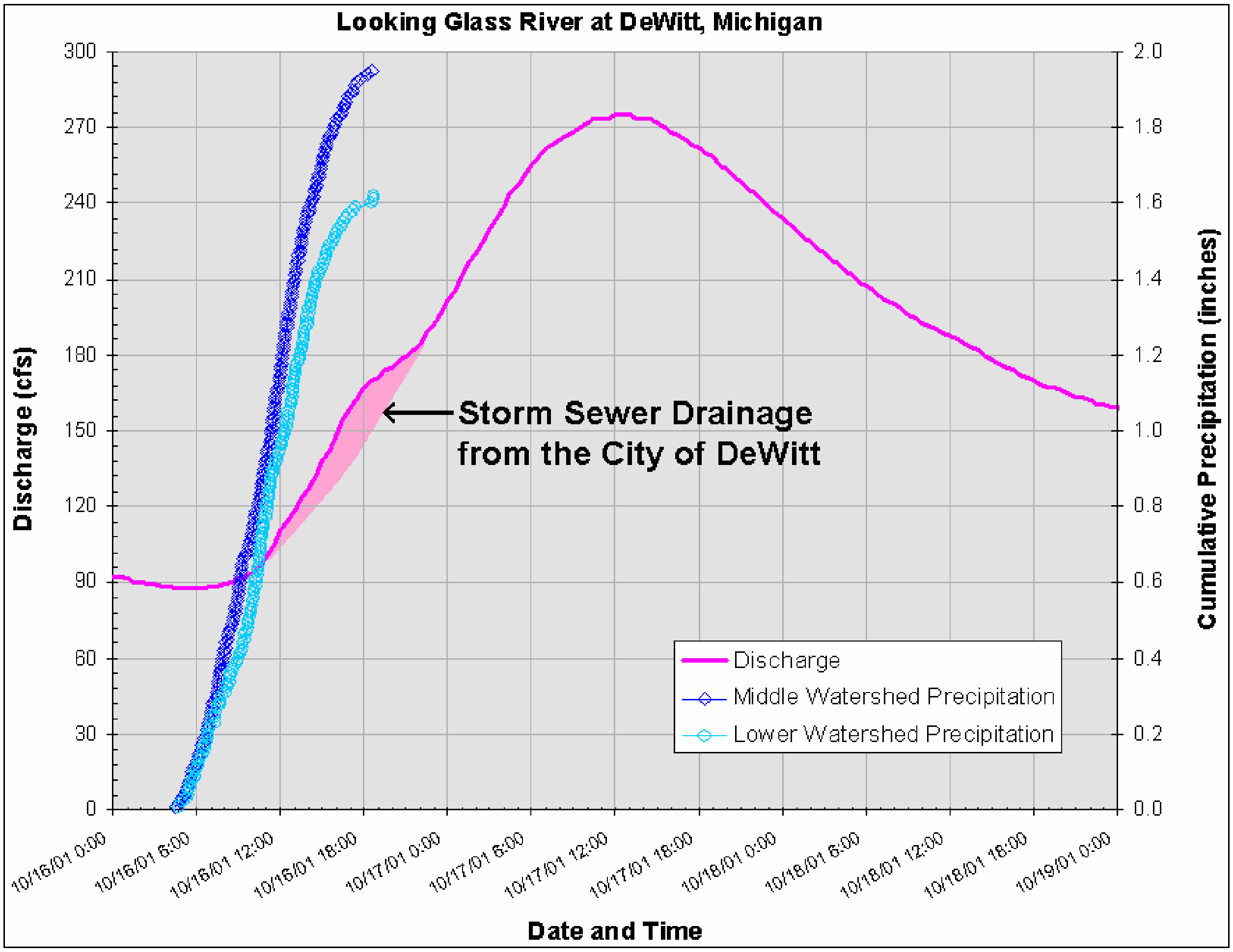

Figure 3 – Monitoring Results, Looking Glass River

Detention Pond Design Examples

The following examples are the type of analysis to conduct when evaluating the effects of a development project on existing flows. This analysis uses the Natural Resources Conservation Service (NRCS) curve number and time of concentration methodology (Sorrell, 2000).

Example 1

The criteria in this example are intended to reflect the requirements of the Grand Traverse County stormwater ordinance, which has been used as a model for other ordinances in other parts of the state.

Site Description:

- Development Location: south central Michigan (the rainfall used in the calculations is based on the location).
- Development Size: 50 acres.
- Existing Conditions: meadow, hydrologic group B soils, corresponding curve number is 58, calculated time of concentration is 1.5 hours.
- Proposed Development Conditions: commercial, hydrologic group B soils, corresponding curve number is 92, calculated time of concentration is 1.0 hour.

Detention Requirements:

- Must store the increase in runoff volume from existing to proposed conditions for a 4 percent chance, 24-hour storm. The release rate is not to exceed the 50 percent chance flow based on grassed conditions or 0.20 cfs/acre, whichever is less.

Release Rate for Required Detention:

- The required release rate is 1.6 cfs, which is calculated as follows:
  - 1.6 cfs or 0.03 cfs/acre (1.6 cfs/50 acres) based on grassed conditions with a curve number of 61, a time of concentration of 1.5 hours, and rainfall from a 50 percent chance, 24-hour storm of 2.42 inches
  - 10 cfs (0.20 cfs/acre * 50 acres) based on 0.20 cfs/acre, the maximum allowable by ordinance
  - The ordinance requires the lesser of these two values be used as the release rate. Therefore, for this example, the release rate of 1.6 cfs, based on the peak flow from grassed conditions, is used, as it is significantly less than the release rate of 10 cfs

Calculated Runoff Volume for Required Detention:

- The required detention volume is 10.1 acre-feet. This is based on the difference in calculated runoff volume from a 4 percent chance, 24-hour storm (4.09 inches of rain) between existing and developed conditions as follows:
  - Meadow (existing) Conditions: runoff volume is 3.6 acre-feet, based on the curve number of 58 and 4.09 inches of rain
  - Developed Conditions: runoff volume is 13.7 acre-feet, based on the curve number of 92 and 4.09 inches of rain
  - Detention Pond Design Volume: The volume required to be stored is 10.1 acre-feet (13.7 - 3.6)

Comparison of Flows:

Table 1 and Figures 4 through 7 are a comparison of peak flows for existing and proposed conditions, with and without detention, using the detention pond release rates as described above. The United States Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) program is used to model the flood flows. The storage-discharge relationships used in this model are shown in Table 2.

Table 1 - Example 1 Calculated Peak Flow Comparison

Storm Frequency (24-hour duration)	Rainfall (inches)	Peak Flow (cfs)			
		Existing Conditions	Proposed Development		
			Without Detention	Detention Release Rate 0.03 cfs/acre	Detention Release Rate 0.20 cfs/acre
50% (2-year)	2.42	0.9	36	0.9	4.4
20% (5-year)	2.98	2.8	48	1.2	5.9
10% (10-year)	3.43	5.0	57	1.5	7.0
4% (25-year)	4.09	9.3	70	4.2	8.8
1% (100-year)	5.20	19.0	93	23.0	29.0

Table 2 - Example 1 Hypothetical Storage-Discharge Relationships

Storage (acre-feet)	0	10.1	10.6	11.1	11.6	12.1
Discharge (cfs): 0.03 cfs/acre release rate criteria	0	1.6	3.2	6.4	12.8	25.6
Discharge (cfs): 0.20 cfs/acre release rate criteria	0	10	20	40	80	10.0

In comparing the existing and proposed flows, there would be significant increases in peak flows for this development without any detention. While the detention with a release rate of 0.20 cfs/acre comes close to matching the existing 10 percent, 4 percent, and 1 percent chance flow rates, the 50 percent and 20 percent chance rates are two to five times higher than the existing flow rates. The higher flow rates at the lower frequency storm events are likely to cause increased streambank erosion. By using a release rate based on the grassed conditions (0.03 cfs/acre), the proposed development's channel forming flow rates (50 percent chance flow) more closely match the existing flow rates than when a release rate of 0.20 cfs/acre is used.

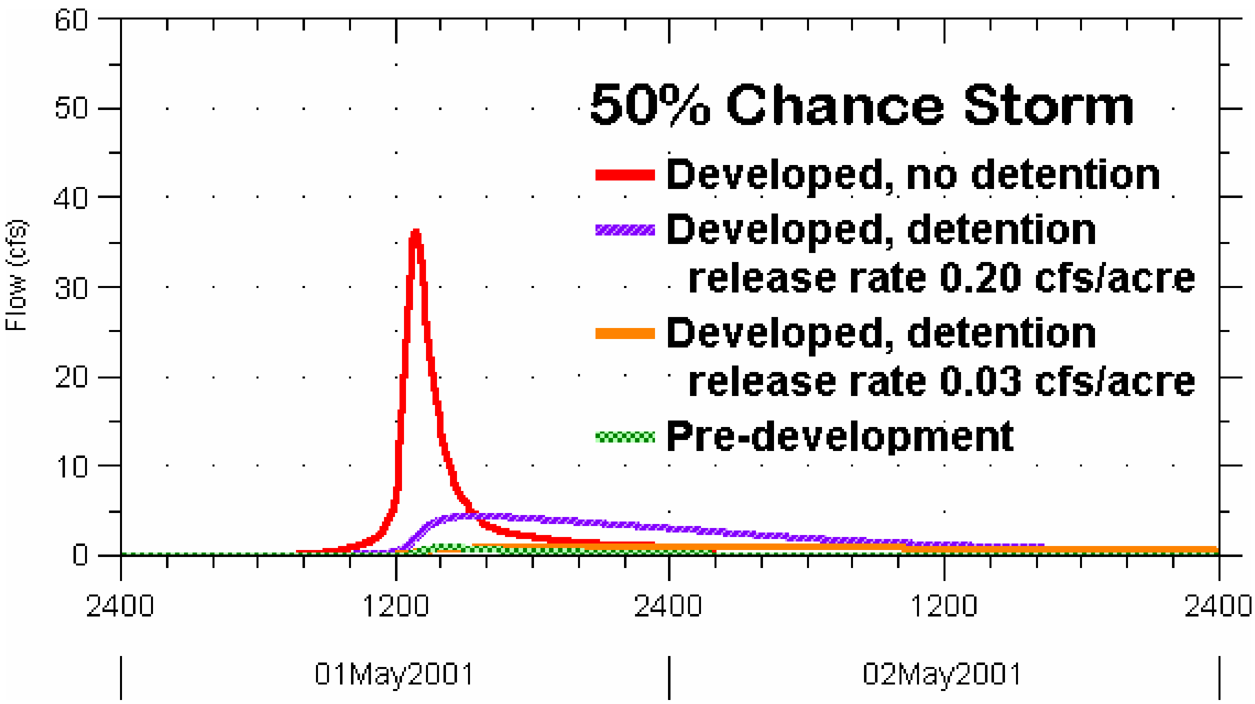

Figure 4 - Example 1 Flow Comparison

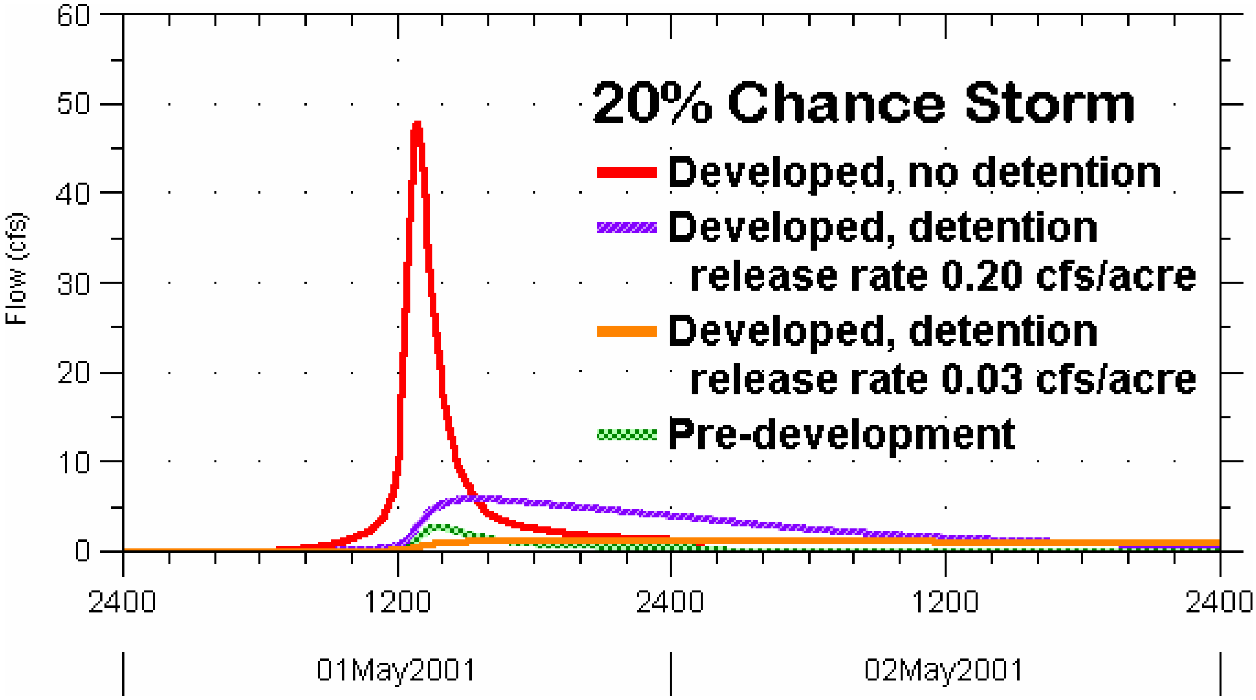

Figure 5 - Example 1 Flow Comparison

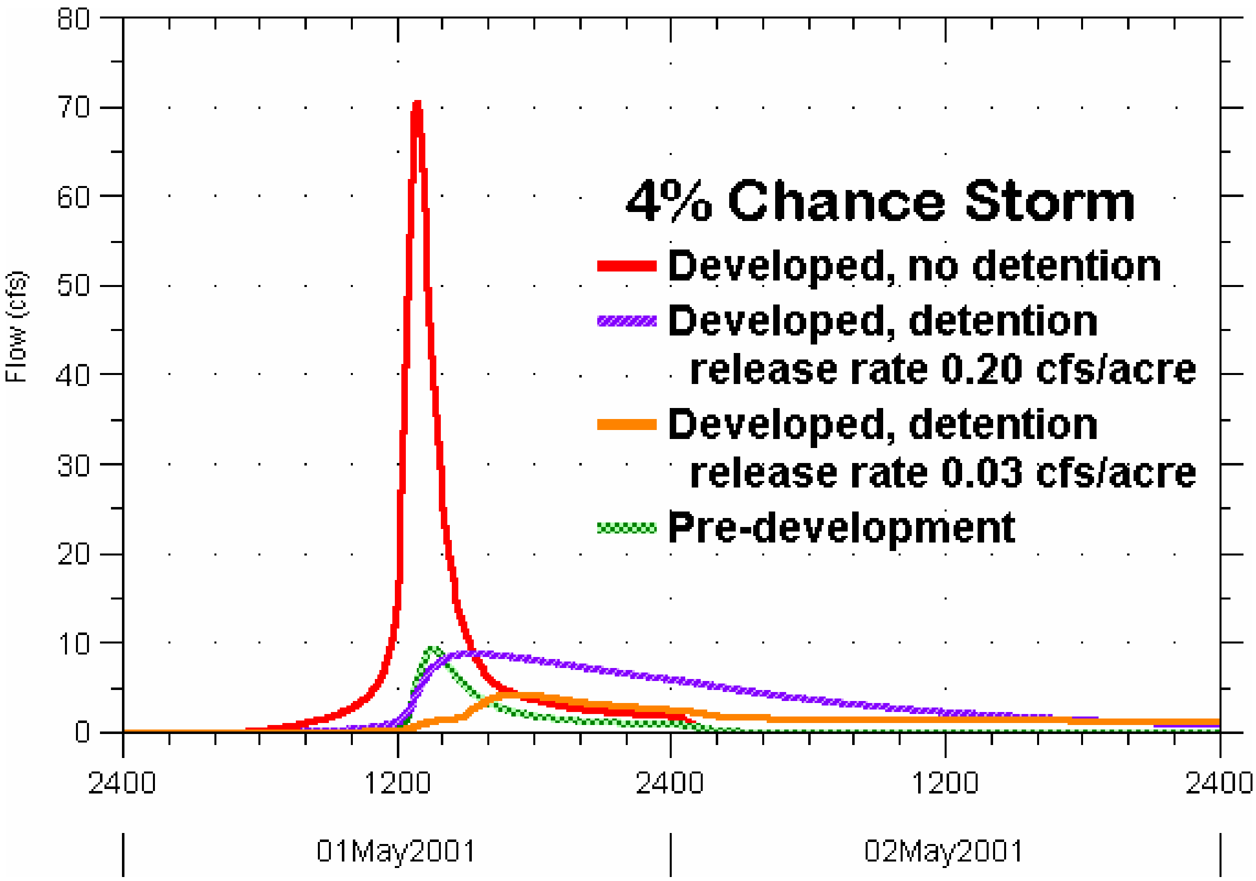

Figure 6 - Example 1 Flow Comparison

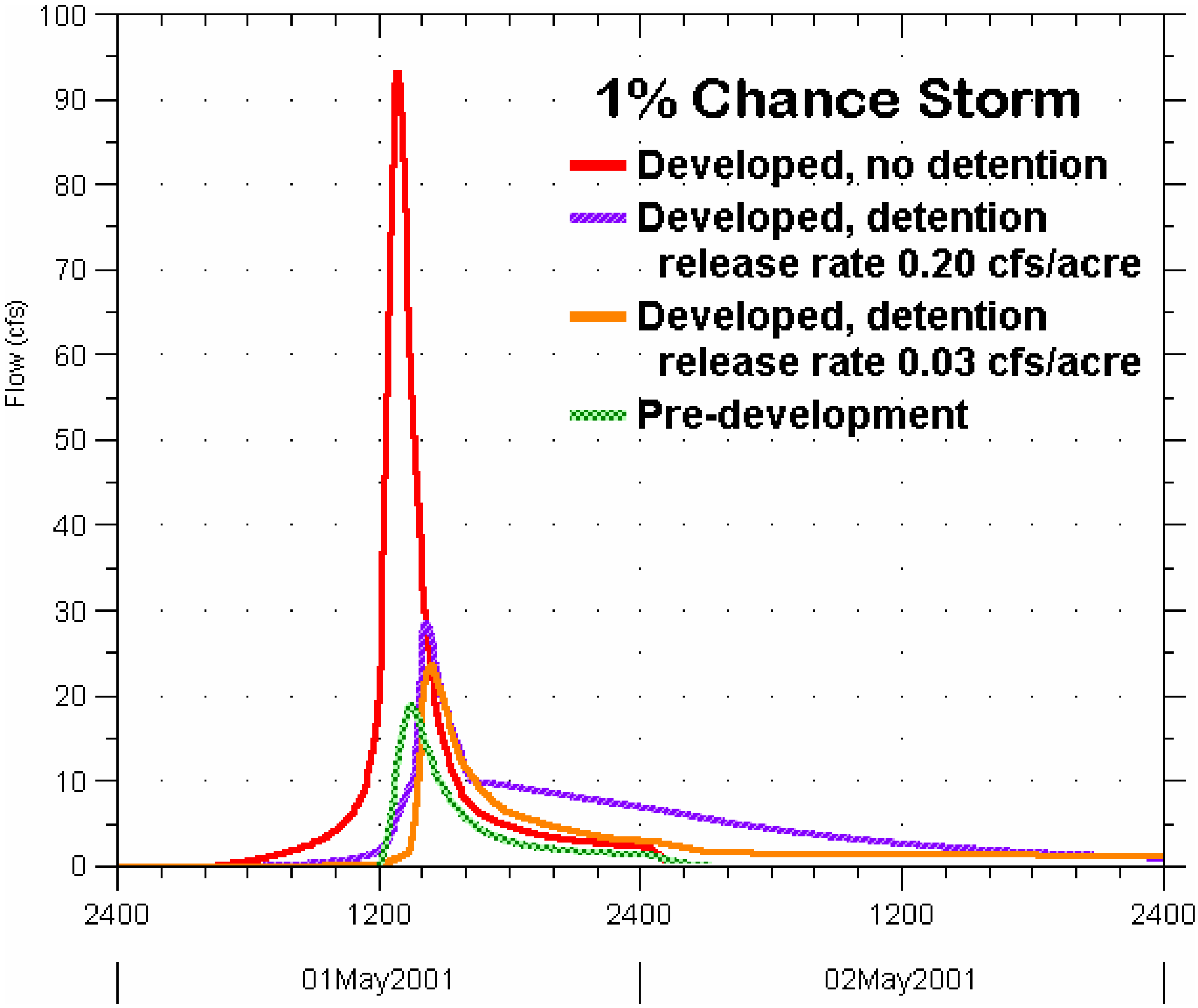

Figure 7 - Example 1 Flow Comparison

Example 2

The criteria in this example are intended to reflect the requirements of the Kent County model stormwater ordinance, which is used as a model for other ordinances in the county and throughout the state.

Site Description (identical to Example 1):

- Development Location: south central Michigan (the rainfall used in the calculations is based on the location).
- Development Size: 50 acres.
- Existing Conditions: meadow, hydrologic group B soils, corresponding curve number is 58, assumed time of concentration is 1.5 hours.
- Proposed Development Conditions: commercial, hydrologic group B soils, corresponding curve number is 92, assumed time of concentration is 1.0 hour.

Detention Requirements:

- Must store the runoff from proposed conditions from a 4 percent chance 24-hour storm. The release rate is 0.05 cfs/acre for detention volumes for runoff from a 50 percent chance 24-hour storm. The release rate is 0.13 cfs/acre for detention volumes for runoff from between the 50 percent chance storm to the 4 percent chance 24-hour storm.
- In some cases, the ordinance encourages increasing the detention volume to store the runoff from the 1 percent 24-hour runoff volume with the same maximum release rate of 0.13 cfs/acre.

Release Rates for Required Detention:

- The required release rate for runoff from a 50 percent chance, 24-hour storm (2.42 inches of rain) is 2.5 cfs which is calculated as follows:
  - Based on the ordinance requirement of 0.05 cfs/acre: 2.5 cfs (0.05 cfs/acre * 50 acres). For comparison, if existing conditions are considered, the release rate for the 50 percent storm is 0.9 cfs or 0.02 cfs/acre (0.9 cfs/50 cfs/acre) based on the curve number of 58, time of concentration of 1.5 hours and rainfall from a 50 percent chance, 24-hour storm of 2.42 inches.
- The required release rate for runoff from a 4 percent chance 24-hour storm (4.09 inches of rain) is 6.5 cfs which is calculated as follows:
  - Based on the ordinance requirement of 0.13 cfs/acre: 6.5 cfs (0.13 cfs/acre * 50 acres). For comparison, if existing conditions are considered, the release rate for the 4 percent chance storm is 9.3 cfs or 0.19 cfs/acre (9.3/50) based on the curve number of 58 and 4.09 inches of rain.

Calculated Runoff Volumes for Required Detention:

- Calculated runoff volume for the 50 percent chance 24-hour storm (2.42 inches of rain):
  - Developed Conditions: The calculated runoff volume is 6.7 acre-feet based on a curve number of 92 and 2.42 inches of rain. The volume of 6.7 acre-feet is to be released at a maximum rate of 2.5 cfs.
- Calculated runoff volume for the 4 percent chance 24-hour storm (4.09 inches of rain):
  - 13.7 acre-feet based on the developed conditions curve number of 92 and 4.09 inches of rain. The total required detention volume is 13.7 acre-feet. A portion of this,

6.7 acre-feet, is released at the rate of 2.5 cfs. The remaining 7.0 acre-feet can be released at 6.5 cfs.

- If storage of the 1 percent 24-hour storm (5.20 inches of rain), rather than the 4 percent, is needed for additional flood control, the calculated runoff volume is:
    - ♦ 17.6 acre-feet based on the developed conditions curve number of 92 and 5.20 inches of rain. Therefore, the total required detention volume is 17.6 acre-feet. A portion of this, 6.7 acre-feet, is released at the rate of 2.5 cfs. The remaining 10.9 acre-feet can be released at 6.5 cfs.

Comparison of Flows:

Table 3 and Figures 8 through 11 are a comparison of peak flows for existing and proposed conditions, with and without detention, using the detention pond release rates as described above. The HEC-HMS program is used to model the flood flows with the detention added. The storage-discharge relationships we used in this model are shown in Table 4.

Table 3 - Example 2 Calculated Peak Flow Comparison

Storm Frequency (24-hour duration)	Rainfall (inches)	Peak Flow (cfs)			
		Existing Conditions	Proposed Development		
			Without Detention	With Detention for 4% Storm	With Detention for 1% Storm
50%	2.42	0.9	36	1.9	1.9
20%	2.98	2.8	48	2.6	2.6
10%	3.43	5.0	57	3.4	3.1
4%	4.09	9.3	70	4.5	3.8
1%	5.20	19	93	6.4	5.1

Table 4 - Example 2 Hypothetical Storage-Discharge Relationships

Detention Sized for 4% Storm					
Storage (acre-feet)	0	6.7	13.7	14.4	15.1
Discharge (cfs)	0	2.5	6.5	13.0	26.0
Detention Sized for 1% Storm					
Storage (acre-feet)	0	6.7	17.6	18.5	19.4
Discharge (cfs)	0	2.5	6.5	13.0	26.0

Again, in comparing the existing and proposed flows, there are significant increases in peak flows for this development without any detention. Adding detention, using the techniques described in this example, reduces the proposed development's peak flows to rates similar to desired pre-development peak flows. However, in this example, the proposed 50 percent peak flows of 1.9 cfs are still twice the existing flow of 0.9 cfs. Accelerated streambank erosion problems could still occur. Controlling runoff from the 1 percent storm by providing detention sized for the 1 percent storm rather than the 4 percent storm, further reduces the 1 percent peak flow. Since some water discharges from the detention pond as additional runoff is entering, the entire volume of runoff from a given storm is never in the detention pond at one time. In this sense, the detention pond could be viewed as oversized. However, the protection of life and property from the hazards of flooding associated with infrequent storms could well justify the extra cost.

In both examples 1 and 2, the stream is less likely to experience erosion problems with the proposed detention than if no detention were in place. However, the total runoff volume, and therefore the duration of near-peak flows, will increase, unless retention BMPs is selected.

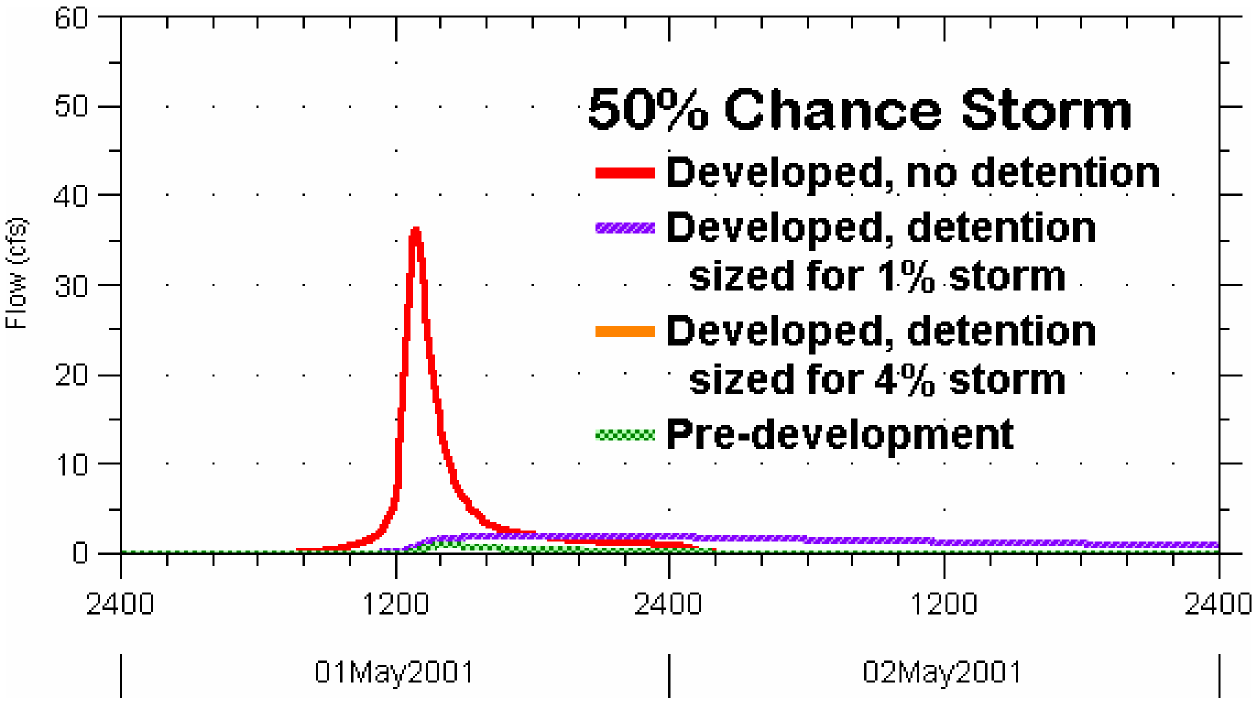

Figure 8 - Example 2 Flow Comparison

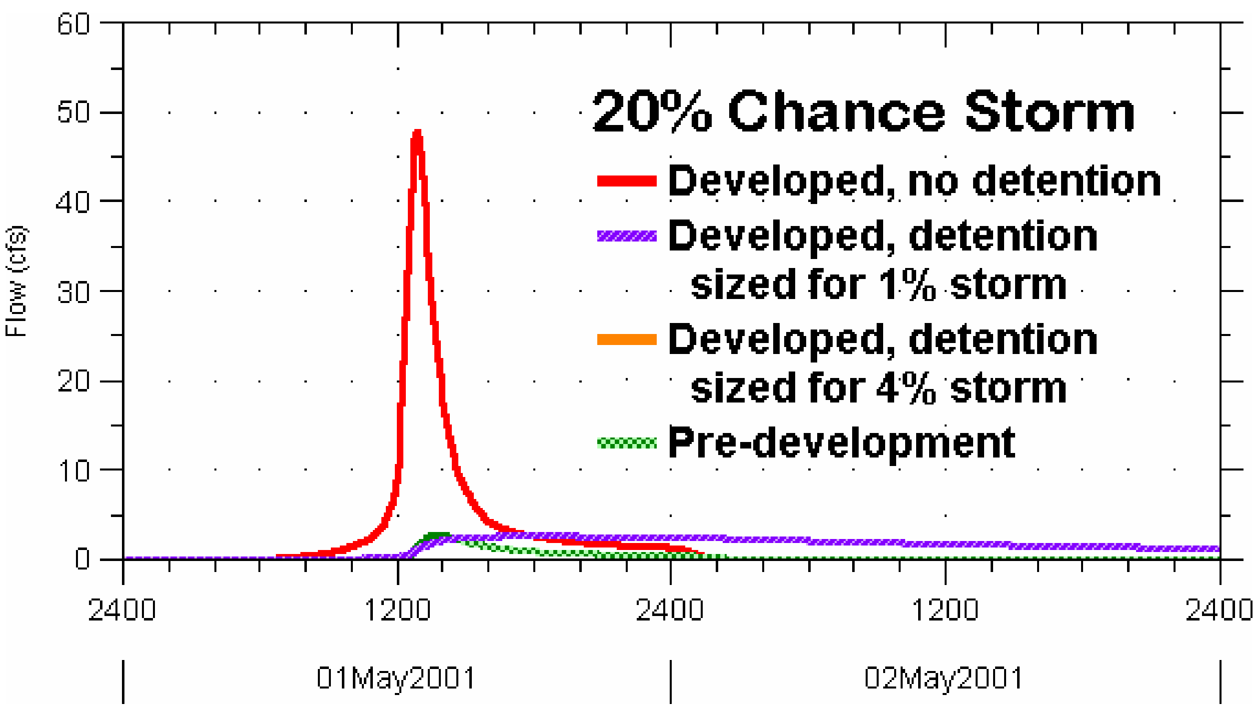

Figure 9 - Example 2 Flow Comparison

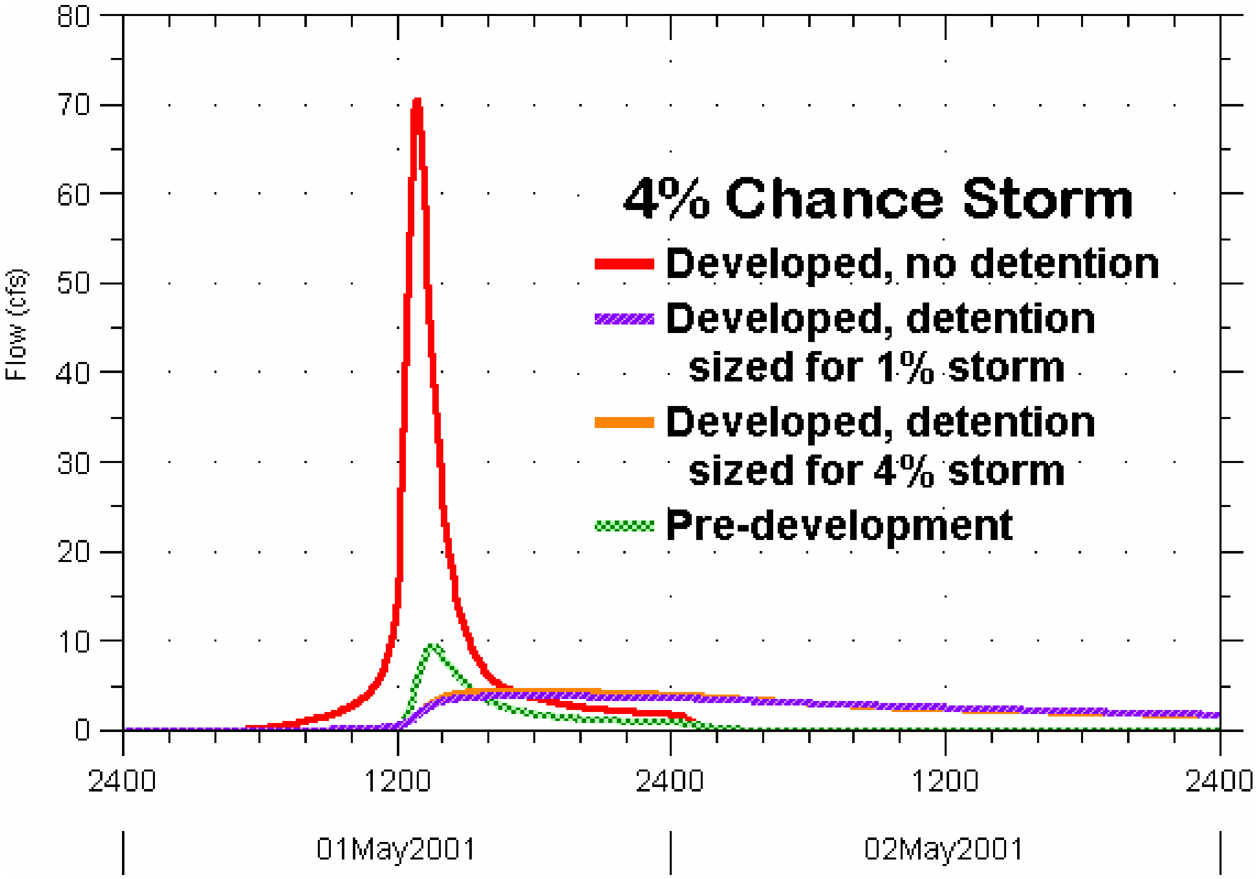

Figure 10 - Example 2 Flow Comparison

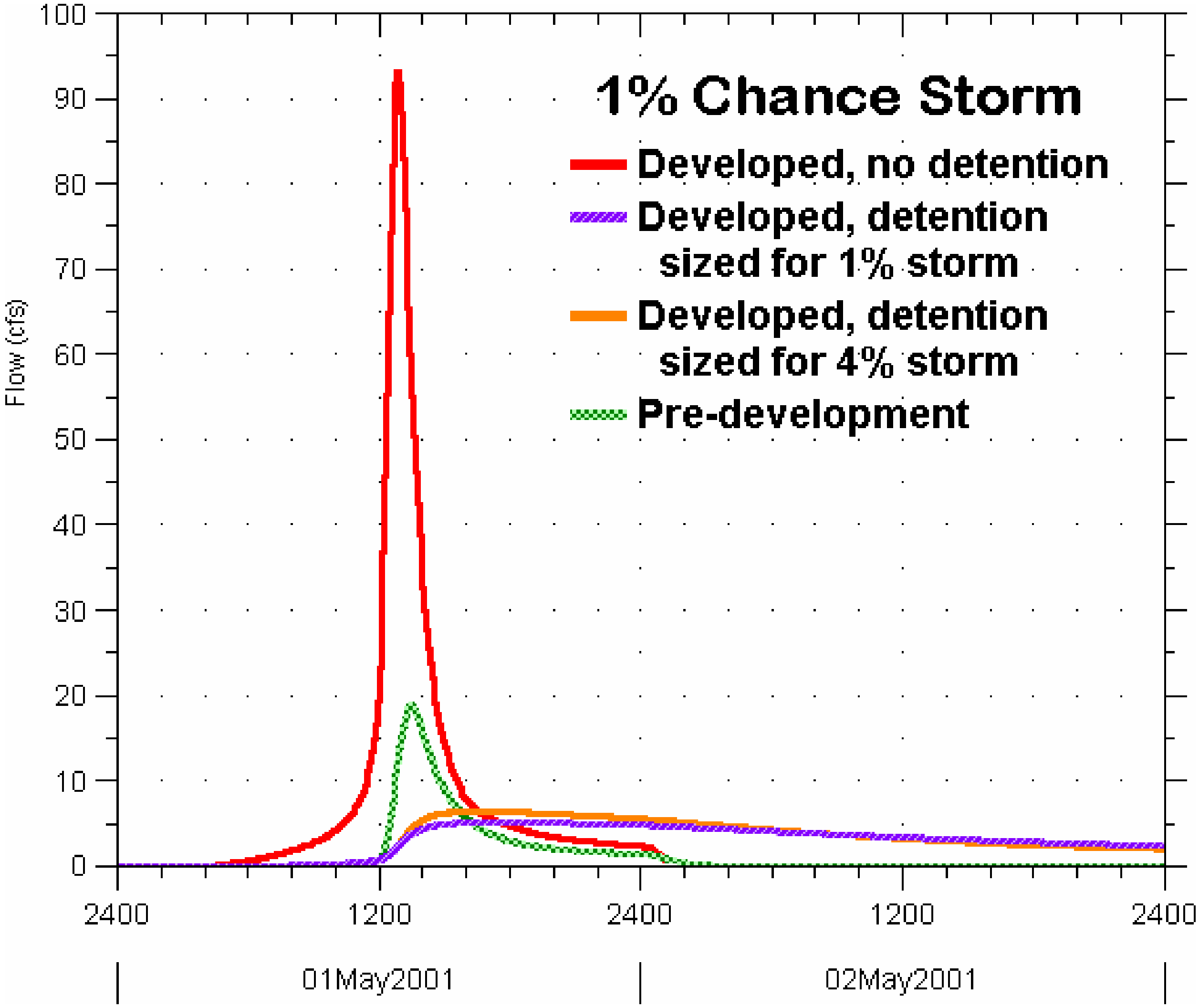

Figure 11 - Example 2 Flow Comparison

Glossary

Bankfull Flow - the flow that occurs when the water just begins to leave the channel and spreads onto the floodplain. In an undisturbed watershed, this corresponds to the channel-forming flow, which occurs, on average, every 1.5 to 2 years. Other definitions, with significantly different meanings, are commonly used in other documents.

Baseflow - the part of the stream flow that represents the long-term discharge of groundwater to the stream. It is that portion of the flow that is not due to direct runoff from precipitation.

Best Management Practices (BMPs)- structural, vegetative, or managerial practices used to protect and improve surface water and groundwater.

Buffer –a zone where plants capable of filtering stormwater are established or preserved, and where construction, paving, and chemical applications are prohibited.

Channel-Forming Flow - a theoretical, constant flow that would result in a channel morphology close to the existing channel.

Design Storm - a rainfall event of specified size and return frequency, (e.g., a storm that has a 50 percent chance of occurring or being exceeded in a given year, or, on average, once every 2 years); typically used to calculate runoff volume and peak flow rate.

Detention basin - practices which temporarily store stormwater for some period of time before releasing it to a surface waterbody.

Discharge - rate of flow or volume of water passing a point in a specified amount of time. It is usually expressed as cubic feet per second (cfs).

Dissolved Oxygen – the amount of gaseous oxygen dissolved in the water.

Dry Detention Basin - a basin that remains dry except for short periods following large rainstorms or snowmelt events. Dry detention basins are typically much less effective than wet detention basins for pollutant removal.

First flush – highly-concentrated pollutant loading during the early portion of stormwater runoff caused by the rapid runoff of accumulated pollutants.

Floodplain – the area in a river valley covered with soil deposited by floods; typically carries water during a flood.

Grassed Waterway - a natural or constructed vegetated watercourse designed to accommodate concentrated flows without causing erosion.

Hydraulic Capacity - the flow capacity of a channel based on channel slope, cross-sectional area, and bank roughness. This value may exceed the channel-forming flow.

Hydrograph - a graph showing the variation in stage (height of the water) or flow in a stream or channel, over time, at a specific point along a stream.

Hydrology - the occurrence, distribution, and movement of water both on and under the earth's surface.

Impervious - a surface through which little or no water will move, for example, paved parking lots and rooftops.

Infiltration - the penetration of water through the ground surface into the soil.

Morphology, River - the study of the form and structure of a river, generally considered from three perspectives:

- planform (sinuosity): the shape or pattern of the river as seen from above
- cross-section: the shape of the channel at a specific point
- profile: the slope of the channel, generally measured at the water surface or the bottom of the thalweg, the deepest part of the stream or the "channel within the channel" that carries water during low flow conditions

Nonpoint Source Pollution – pollution that is not identifiable to one particular source, and is occurring at locations scattered throughout the drainage basin. Typical sources include erosion, agricultural activities, and urban runoff. Point sources emanate from a single source, generally a pipe.

Peak Flow - the highest flow that occurs for a given set of hydrologic and climatic conditions. The peak flow for a given frequency may be based on measured data, calculated using statistical analysis of peak flow data, or calculated using hydrologic analysis techniques. Projected peak flows are used in the river rehabilitation analysis and design as well as the design of culverts, bridges, and dam spillways.

Retention Practices – infiltration basins, infiltration trenches, dutch drains, pervious pavement, and other structures or constructed areas which capture stormwater and slowly release it into the ground.

Riffle - a stretch of fast, choppy water caused by a shoal or sandbar just beneath the water surface.

Runoff – flow of water across the land surface or through the upper soil layers. The volume is equal to the total rainfall minus rainfall that evaporates, infiltrates into the ground, and is held in ponds, small surface depressions, leaves, etc.

Runoff Curve Number - parameter that indicates runoff potential, based on soil type and land use, in the NRCS method for calculating runoff.

Sediment - soil particles detached by erosion that are deposited elsewhere on the land or in lakes, streams, or wetlands.

Sediment Basin – management practice designed specifically to control off-site migration of sediment. Controlling peak flows from stormwater runoff can be a secondary benefit.

Soil Types - soils are classified into one of four hydrologic groups based on infiltration and transmission rates. The group designations are from A through D. Group A is chiefly well-drained sands or gravel and has the lowest runoff potential. Group D is chiefly clay soils and has the highest runoff potential.

Stability, Hydrologic – condition such that a drainage area maintains an identical response (runoff volume and peak flow) to an identical rainfall over a long time period. This is expected if the land uses, soils, and drainage characteristics within the watershed are not changing.

Stability, Morphologic – conditions such that the stream's sinuosity, cross-sectional dimensions, and profile are constant. Because the stream is a dynamic system, this does not mean that the river is not moving laterally over time, but only that it maintains its characteristics such as bankfull width and width/depth ratio.

Swale - an elongated depression in the land surface that is seasonally wet, usually heavily vegetated, and normally lacks flowing water. Swales direct stormwater flows into primary drainage channels and allow some of the stormwater to infiltrate into the ground surface.

Time of Concentration - the time it takes for surface runoff to travel from the hydraulically farthest portion of the watershed to the design point.

Water Quality Swale - an open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

Watershed - area of land that drains to a single outlet and is separated from other watersheds by the drainage divide.

Wet Detention Pond – a detention basin that contains a permanent pool of water that will effectively retain sediment and nutrients in addition to other pollutants.

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