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I. Introduction

Rutgers Cooperative Research & Extension's Water Resources Program has completed a hydrologic and a hydraulic evaluation of the Many Mind Watershed, located in Atlantic Highlands and Middletown, NJ (Figure 1). This study was funded by the Atlantic Highlands Environmental Commission through a five thousand dollar grant provided by the New Jersey Department of Environmental Protection (NJDEP) Office of Environmental Services and the New Jersey Agricultural Experiment Station. The study was performed to assist the Many Mind Regional Stormwater Management Planning Committee in their efforts to assess water quality issues that adversely affect the health and safety of local residents, as well as water quantity issues that impact the structure of stream banks and the quality of the water. This study intended to represent the existing characteristics of the hydrology and hydraulics within the watershed and to provide insight into potential improvement plans.

To identify critical areas of flooding and to represent the benefits of potential mitigation measures, hydrologic and hydraulic models were developed for the Many Mind system. An approach using two models, the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and the Hydrologic Engineering Center's River Analysis System (HEC-RAS), both developed by the United States Army Corps of Engineers, was used to model surface runoff coming from the subbasins, routing stream flow and producing water surface elevation profiles under a variety of hypothetical storm events. These models were produced over a period of time beginning in July 2004. Progress on the models was presented to the Many Mind Regional Stormwater Management Committee in order to solicit their input (see Attachment 1 for Power Point Presentations).

HEC-HMS is designed to simulate the precipitation-runoff processes of watershed systems such as the Many Mind Creek. This hydrologic model performs algorithms to simulate infiltration losses, precipitation to runoff transformation, and open channel routing and allows for the use of different methods to simulate these processes (U.S. Army Corps of Engineers, 2001). HEC-HMS employs two main model components: a basin model and a meteorological model. The basin model component contains the watershed properties such as delineated subbasins, junctions, stream reaches (sections containing similar properties), and the connections between them. The meteorological model component contains precipitation types and intensity. Final results of a simulated run in HEC-HMS will provide data that includes the hydrograph (i.e., flow vs. time plot) and peak flow for model elements such as junctions and reaches.

The hydraulic model HEC-RAS contains one-dimensional hydraulic analysis components for steady flow water profiles. HEC-RAS uses the geometry of the stream and floodplain, boundary conditions, and flows entering the river system according to different design storms (U.S. Army Corps of Engineers, 2002). Geometry and flow data are entered into different files much the same way as in HEC-HMS.

To simulate the water surface profile in the hydraulic model HEC-RAS, the peak flows that have been simulated by the hydrologic model HEC-HMS are used as inputs. HEC-HMS uses a

predetermined meteorological model and simulates the surface runoff which enters the stream system from different source areas. The site of the entrance of the runoff into the stream system is denoted by a peak flow value that is calculated within HEC-HMS. These simulated peak flows, together with the flood plain and stream geometry, are entered as inputs to the hydraulic model, HEC-RAS. HEC-RAS is then used to simulate the water surface elevation profiles that relate to the different storm events.

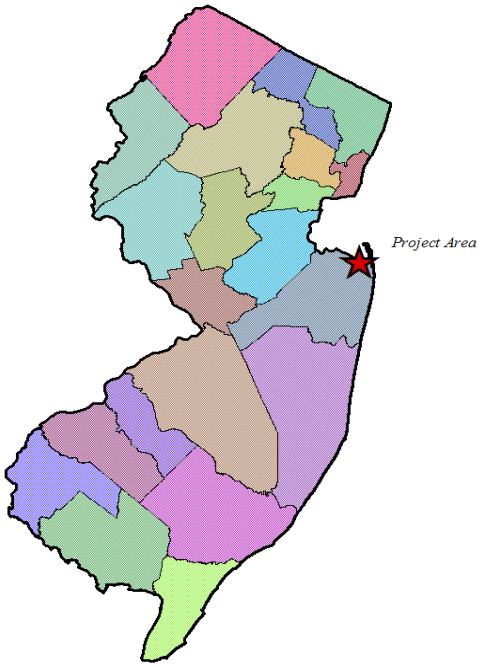

Figure 1: Location of the Many Mind Watershed in NJ

With the availability of extensive Geographic Information System (GIS) data coverages for the watershed, modeling set up and post processing was achieved using an ArcView GIS interface using ESRI's ArcView software. HEC-GeoHMS and HEC-GeoRAS are the ArcView extensions that were used to generate a good portion of the input data for HEC-HMS and HEC-RAS, respectively.

As a result of this study of the Many Mind Creek, a series of flood area delineations were developed based on different storm events and runoff scenarios. Among these scenarios, multiple design storms were used to produce water surface elevations in a variety of land use situations.

II. Study Area

The Many Mind Watershed is located in the northeast section of Monmouth County, NJ. The watershed is approximately five miles southwest of Sandy Hook and less than twenty miles from New York City. The watershed drains approximately 1.38 square miles of land in Atlantic Highlands and Middletown, NJ (Figure 2). There are no major impoundments within the watershed, however the detention facility at the Senior Housing Center on First Avenue and the topography of a detention area next to West Highland Avenue, have been considered in the peak flow calculations. The Many Mind Creek consists of a main branch running from Lenape Woods Nature Preserve in Middletown through to the mouth of Sandy Hook Bay located between Avenue A and First Avenue in Atlantic Highlands, NJ. A tributary coming from the southwest to the main-stem was found to contribute to the final output of the creek.

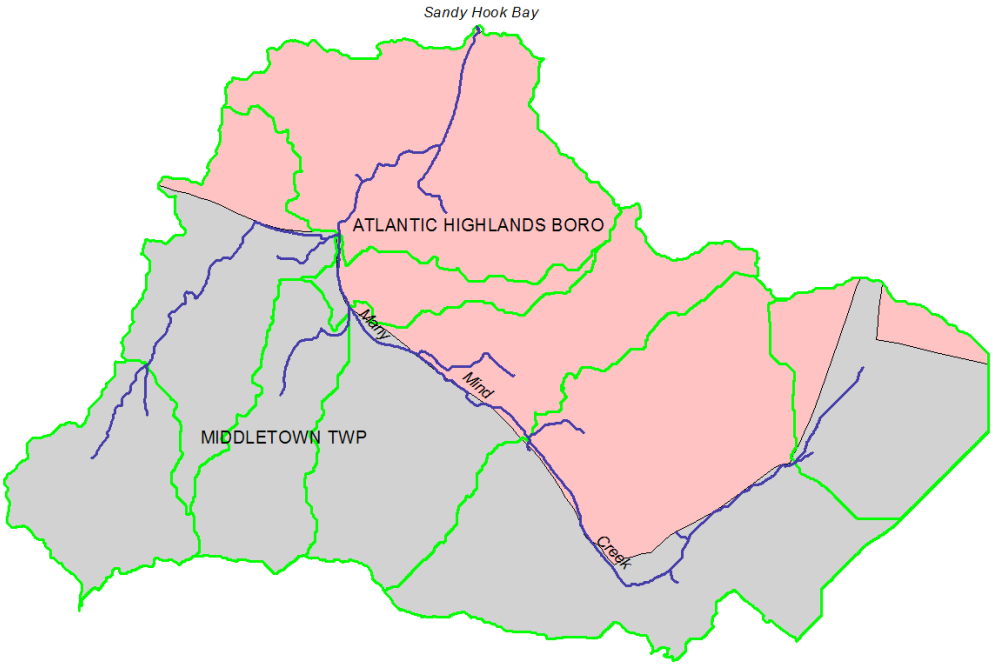

Figure 2: Many Mind Watershed

The land use of this drainage area, which contains sections of Atlantic Highlands and Middletown, is primarily residential. Up to 58% of the 884 acres are being used for this purpose. The headwaters emerge from Lenape Woods, a deciduous forest, which comprises the second largest land use of 11%. Nine percent of the land use is commercial with the placement of this

use surrounding the stream in the downstream reaches of the watershed. Much of this development took place before adequate stormwater management was a consideration, and therefore lacks sufficient infiltration and drainage. Table 1 gives the details of the land use within the Many Mind Creek Watershed.

Table 1: Land Use in the Many Mind Creek Watershed

LandUse	Acres of Watershed	Percentage of Land Use
Beaches	0.8	0.1
Brushland/shrubland	2.0	0.2
Commercial/services	81.0	9.2
Cropland and pastureland	4.7	0.5
Deciduous forest	102.2	11.6
Deciduous wooded wetlands	64.3	7.3
Herbaceous wetlands	14.4	1.6
Industrial	19.6	2.2
Other urban or built up land	17.0	1.9
Recreational land	61.8	7.0
Residential	513.2	58.1
Undifferentiated barren	2.8	0.3
Total	883.9	100.0

III. Precipitation-Runoff Processes and Flow Routing Simulation with HEC-HMS

A HEC-HMS hydrologic model was prepared for the Many Mind Watershed. The modeling of precipitation and runoff processes consists of determining the amount and rate of surface runoff reaching the Many Mind Creek and its tributaries and routing it through a channel network. The model set up was prepared using two primary files: the basin model file and the meteorological model file. The basin model identifies and analyzes properties of the watershed such as drainage and connectivity, or interconnectedness. The meteorological model is used to represent precipitation amount and intensity.

A. HEC-HMS Basin Model Setup

One of the components that the hydrologic model employs is a basin model. The basin model includes the watershed elements and their relationships. The initial defining parameter is the delineation of the subbasins within the watershed. Each of these subbasins will have properties that will influence the precipitation-runoff process. The HEC-GeoHMS extension of ArcView

GIS software was used to subdivide the Many Mind Watershed into eight subbasins. This method uses the Digital Elevation Model (DEM) and standard algorithms for watershed delineation. The accuracy of the watershed delineation is a function of the resolution of the DEM.

A DEM with a finer resolution is expected to create watershed delineations that are of higher quality. This modeling study for the Many Mind Creek Watershed was able to use a DEM derived from two foot contour data provided by the Monmouth County Office of Geographic Information Systems. This DEM provides a high resolution data set which appears to represent the topography and drainage of the watershed very well.

The subbasins are defined and then connected through a series of channels. A stream network is created which connects the subbasins and is defined by junctions and reaches. Each reach has an upstream and a downstream junction. Every junction can define either the beginning or end of multiple reaches and is connected to one or more subbasins. Figure 3 shows the Many Mind Creek Watershed subbasin delineation with the model elements and schematics as presented in the HEC-GeoHMS interface.

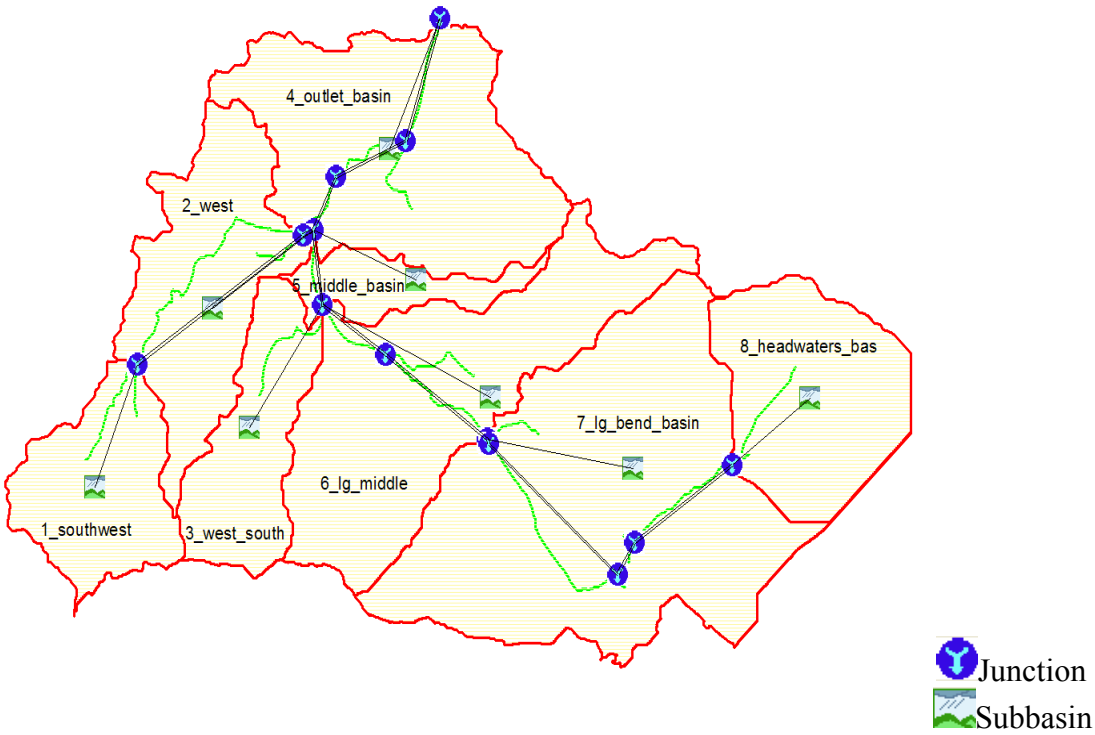

Figure 3: Eight Subbasins Used in the Hydrologic (HMS) Model

The basin model created by HEC-GeoHMS was then imported for use in the HEC-HMS hydrologic model. Parameters determined from the earlier program, such as curve numbers, were also entered into the hydrologic model.

1. HEC-HMS Basin Model Methods

HEC-HMS provides choices from a collection of methods to simulate infiltration losses, runoff transform and flow routing. For the purpose of the Many Mind Creek Watershed modeling, the Soil Conservation Service (SCS) curve number (CN) method was used to determine the volume of runoff from each watershed, the Snyder unit hydrograph was used as the runoff transform method, and the Muskingum-Cunge method was used to simulate stream flow routing. These methods have been widely applied and evaluated in the HEC-HMS manual (U.S. Army Corps of Engineers, 2001) and in standard hydrology text books.

The curve number is assigned to a parcel of land according to its properties of land use/land cover and soil type. This procedure was accomplished through the unionization of the land use/land cover GIS shapefile and the Soil Survey Geographic (SSURGO) soils GIS shapefile found on the NJDEP website. The process of unioning two GIS shapefiles provides areas of detail which represents characteristics of both of the different shapefiles. Once the features have been combined, each area contains attributes that can be defined by the accepted CN according to the Technical Release 55 (TR55) from the Natural Resource Conservation Service (NRCS). This CN is a number between zero and one hundred and is used to represent the properties of runoff that the land is expected to possess. Essentially, the higher the CN the more runoff that the land is expected to produce.

2. HEC-HMS Basin Model Parameterization

Each of the eight subwatersheds in the Many Mind Watershed was assigned various hydrologic properties that would define how the model computes the runoff. Runoff is that precipitation that does not infiltrate the land on which it falls, rather it becomes part of the drainage that will ultimately reach the stream. Parameters that were used in the hydrologic model were as follows: Loss rate: SCS curve number, initial loss; transform: Snyder lag (t_p) and Snyder peaking coefficient; baseflow method: assumed no baseflow. Descriptions and uses of these methods are well documented in general hydrology texts and have been assumed to represent the hydrologic characteristics of this watershed.

Table 2 provides the curve numbers employed for the specific land uses found within the Many Mind Creek Watershed. Soils have been classified by the Natural Resource Conservation Service into four Hydrologic Soil Groups based on the soil's runoff potential and are labeled A, B, C and D. The "A" soils are presumed to have the smallest likelihood of runoff, whereas the D soils are assumed to have the largest percentage of runoff. Specifics regarding the soil type

classifications can be found in the Technical Release-55 put out by the Natural Resource Conservation Service (1986).

Table 2: SCS Curve Numbers Employed for the Hydrologic Modeling of the Many Mind Watershed

LAND USE	Hydrologic Soil Group			
	A	B	C	D
BEACHES	NA*	NA	79	89
BRUSHLAND/SHRUBLAND	39	61	NA	NA
COMMERCIAL/SERVICES	89	92	NA	95
CROPLAND AND PASTURELAND	NA	69	NA	NA
DECIDUOUS FOREST	36	60	73	79
DECIDUOUS WOODED WETLANDS	100	100	100	100
HERBACEOUS WETLANDS	100	100	100	100
INDUSTRIAL	NA	NA	91	NA
OTHER URBAN OR BUILT-UP LAND	NA	88	NA	93
RECREATIONAL LAND	49	69	79	NA
RESIDENTIAL	61	75	87	75
UNDIFFERENTIATED BARREN LANDS	NA	NA	86	NA

*NA depicts combinations of land use and soil types not present in the watershed.

Each individual area was represented by a polygon with the properties of both the land use type and the soil type. These polygons were then assigned their corresponding curve number. The curve number generally represents the portion of the precipitation that will become runoff. The higher the curve number, the more precipitation will become runoff. A curve number of 100 would indicate no infiltration, or a direct input to the stream system. After the individual areas were defined, an area weighted curve number was calculated to represent the transformation (precipitation input to flow) for each of the subbasins. This was achieved using the following equation:

$$CNcomposite = \frac{\sum A_i CN_i}{\sum A_i} \qquad (1)$$

Where: CNcomposite is the composite curve number; A_i is the area of the polygon i within the watershed, and CN_i is the curve number of polygon i.

The SCS analyzed many small watersheds and determined an empirical relationship to represent the initial loss to the system known as the initial abstraction (I_a) and maximum retention (S).

These values are dependent on the curve number and were determined for the Many Mind subbasins by the following equations:

$$I_a = 0.2S \qquad (2)$$

$$S = \frac{1000 - 10CN}{CN} \qquad (3)$$

The Snyder unit hydrograph transform method uses the parameters of lag (t_p) time and the unit hydrograph peaking coefficient (C_p). The lag time is that length of time between the centroid of the excess rainfall hyetograph and the unit hydrograph peak. The unit hydrograph peaking coefficient establishes the shape of the curve and has been estimated based on typical values. The lag time was estimated according to the following equation:

$$t_p = CC_t(LL_c)^{0.3} \qquad (4)$$

Where: C_t is the basin coefficient; L is the length of the main stream from the outlet to the subwatershed divide in miles; L_c is the length along the main stream from the outlet to a point nearest the watershed centroid in miles; and C is a conversion constant (0.75 for S.I. and 1 for foot-pound system). Values of L and L_c are computed by HEC-GeoHMS and presented as the longest watershed flow path and centroidal flow path, respectively. Table 3 presents a summary of the subbasin parameters such as area, composite curve numbers, and Snyder lag time calculated for the Many Mind Watershed. The composite curve numbers that represent each of the subbasins show the runoff characteristics that are defined by the land use and the soil types within that subbasin. The higher the curve number, the more runoff and less infiltration that would be expected.

Table 3: Subbasin Parameters Used in the Many Mind HEC-HMS Model

	Subbasin	Area (mi^2)	Curve Number, composite	Initial Loss, I_a	Snyder Lag Time, t_p (hours)
1	1_southwest	0.102	63.3	1.16	1.18
2	2-west	0.149	75.6	0.65	1.30
3	3_west_south	0.094	76.1	0.63	1.32
4	4_outlet_basin	0.237	82.5	0.42	1.35
5	5_middle_basin	0.043	87.4	0.29	1.33
6	6_lg_middle	0.239	76.3	0.62	1.58
7	7_lg_bend_basin	0.375	77.2	0.59	1.87
8	8_headwaters basin	0.143	69.0	0.90	1.04

B. HEC-HMS Meteorological Model

HEC-HMS allows the user to choose from a variety of methods to represent the precipitation that the watershed will receive. This can be performed through the use of gage data, user hyetograph, or the SCS hypothetical storm methods, among others.

To acquire the information on the potential consequences of precipitation events, the SCS hypothetical storm precipitation method was selected. In this method, rainfall distributions are characterized according to the average frequency of events, statistically determined on a time span basis.

Model parameters use the specific storm depths corresponding to the 2, 10 and 100 year design storms, according to the revised New Jersey 24 Hour Rainfall guide by the NRCS (January 2005). A Type III storm distribution was selected due to its representation of the typical storm distribution within the Atlantic Coast region. Table 4 summarizes the 24-hour rainfall depths for Monmouth County that were used to represent the design storms within the Many Mind meteorological model. Attachment 2 contains complete data on the precipitation depths for New Jersey as revised by the NRCS in January of 2005.

Table 4: Monmouth County Rainfall Totals for Standard Design Storms

Type III Storm	24-Hour Rainfall (inches)
2-year design storm	3.4
10-year design storm	5.2
100-year design storm	8.9

C. HEC-HMS Simulation and Output

Simulations could be initiated once the basin model and meteorological model were set up, and model controls were defined. The model controls consist of defining the period of simulation and the frequency time step to be used. For the purpose of the Many Mind Watershed, a 24-hour period simulation was performed using one minute time steps.

Model results can be seen in a graphical or tabular format for all junctions, reaches and subbasins. For the purpose of this effort, the peak flows at the junctions was the primary area of focus. It is the values that are obtained at these junctions that provide the input flows to the HEC-RAS hydraulic model to obtain the water surface elevation profiles. Attachment 3 presents

the tables containing the values used to represent the peak flows at junctions for the design storms in question. The hydrographs for each basin for the 2, 10 and 100 year design storms are presented in Attachment 4: Basin Hydrographs.

IV. Stormwater Routing and Water Surface Elevation modeling with HEC-RAS

HEC-RAS is an integrated software package with hydraulic analysis components along with data management, graphics and reporting abilities that can be used to evaluate the channel dynamics of the stream. Two discrete modules are used within the HEC-RAS program: a geometry file and a flow file. The data relating to the geometry file contains the river system network, cross sectional information and the dimensions of the obstructions. The flow regimen was obtained from the design storms simulated in the HEC-HMS model and modeled as a steady state, gradually varied flow.

Each section of stream is further defined by its Manning's n, also known as the roughness coefficient. This coefficient is a parameter of the "drag" that the stream encounters from the stream channel banks due to sinuosity, vegetation and geological substrate.

The output from the hydraulic simulations can be accessed in a variety of ways. Profiles and plots of the simulated data can be viewed, or tables can be processed.

A. Geometry Data for HEC-RAS

The geometry data file contains the information on the stream connectivity, cross sectional data, and hydraulic structure data. The HEC-GeoRAS extension of ArcView was able to compile and process the data necessary for input to the HEC-RAS model. It was in this interface model that the stream network connectivity and cross sectional data was extrapolated based on spatial datasets. With the high resolution of the digital elevation model used, it was expected that the data was accurately representing the watershed.

Cross-section lines are an important element in the representation of a flood plain. Cross-section cut lines are used to identify the location at which data will be extracted for model computations. The positioning of the cross section cut lines requires a considerable amount of effort and technical judgment. Again, with the high resolution of the digital elevation that was made available for this effort, the cut lines are expected to correctly represent the elevations within the watershed. The cross-sections used as a part of the hydraulic model for the Many Mind Watershed can be seen in Figure 4.

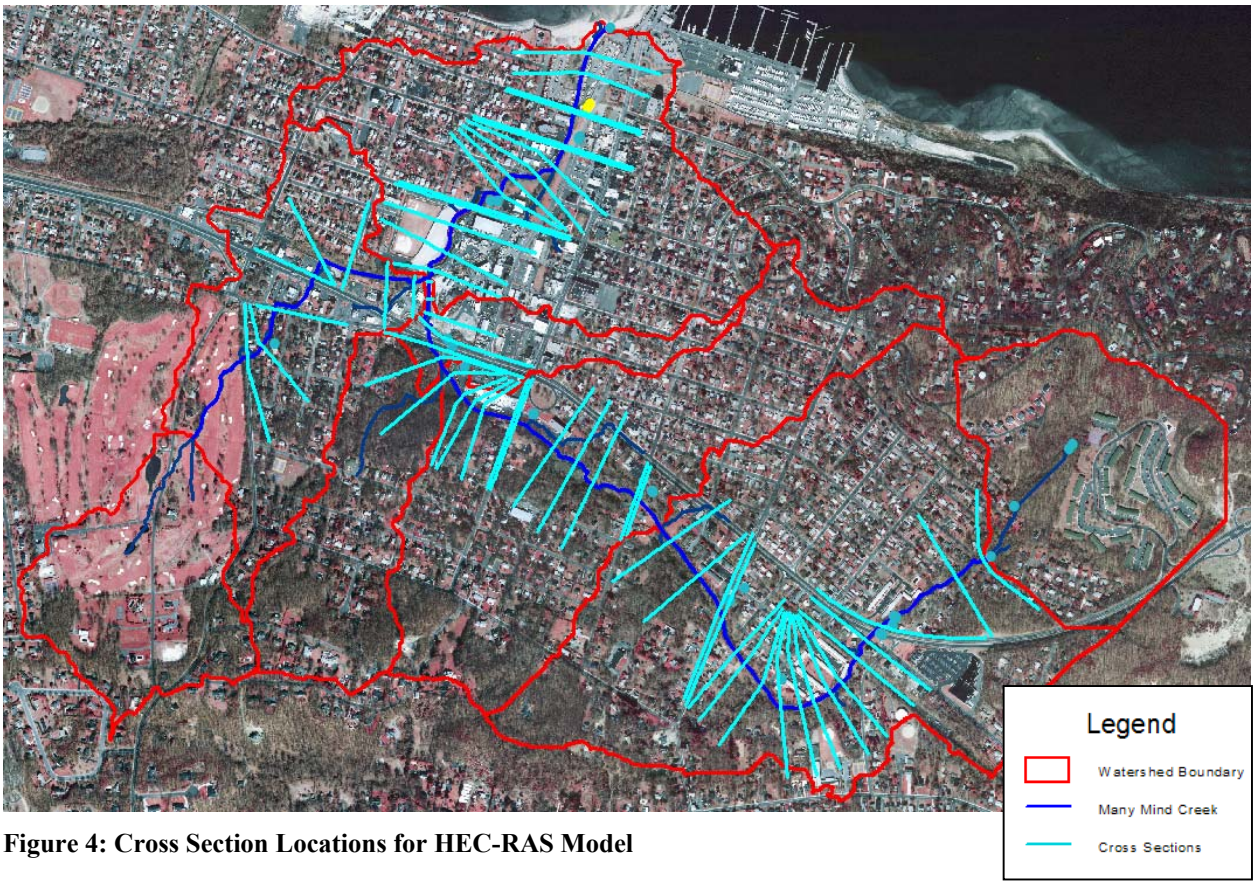

Figure 4: Cross Section Locations for HEC-RAS Model

After the necessary RAS themes are processed in HEC-GeoRAS, the geometry input files can be imported for further editing in HEC-RAS. The correction of station elevations within the stream channel was necessary, as the digital terrain model does not capture the elevations under water. This required field surveys of the stream channel. Ten cross sections were field verified, and the balance were defined through interpolation and known bank elevations. A total of 58 cross sections were entered into the HEC-RAS model. A sample cross section upstream of the Seventh Avenue Bridge south of Route 36 can be viewed in Figure 5.

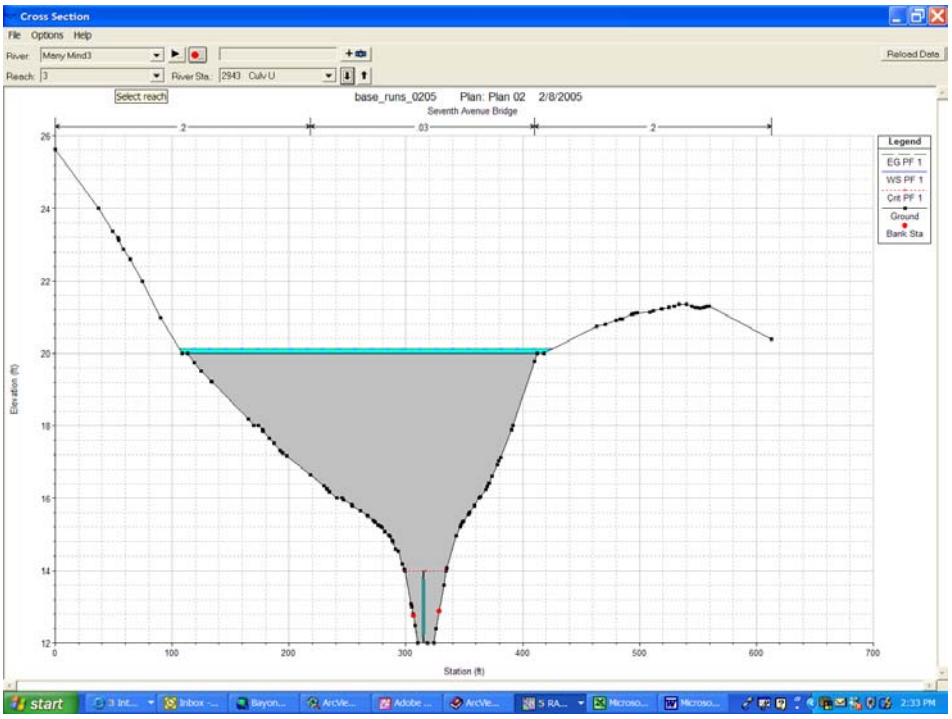

Figure 5: HEC-RAS Cross Section Upstream of the Seventh Avenue Bridge

In addition to flood plain elevation and channel geometry, channel obstructions are a key consideration of the data set necessary for the hydraulic calculations. It was necessary to field survey each bridge and culvert in the watershed and manually enter the dimensions into the HEC-RAS geometry file. Since obstructions can significantly influence water surface elevation profiles, the accurate representation of these obstructions was a critical element within the model. For each obstruction, the model included a cross section immediately upstream and immediately downstream of the obstruction to provide the information needed to calculate conveyance. Eight bridges and culverts were identified and included in the HEC-RAS model for the Many Mind Creek. Field surveillance and aerial photography indicated no obstruction to the creek at the end of Third Avenue. However, if an obstruction was determined to be present, the representation of those dimensions could further increase the accuracy of the hydraulic model. The culvert at the end of Washington Avenue was not modeled due to its location upstream of the first junction. Field data were collected to determine the geometry of these bridges so they could be accurately represented in the model.

Senior Center Detention Facility

Plans for the construction of a detention facility at the Senior Center on First Avenue were acquired from a representative of the Monmouth County Soil Conservation District. It is unclear whether these designs were implemented or if an alteration in stormwater management was put into place. Field surveillance indicates drainage from impervious areas passing to a stormwater

swale before entrance to the stream system. This appears slightly different than original plans, but does provide stormwater management.

The drainage facility as submitted to the Soil District was modeled separately in HydroCAD, a computer aided design system for the modeling of stormwater runoff. This model was performed to verify that the drainage system is adequate for the area. This model could also depict the degree to which the detention basin would delay the peak flow into the system. Although adequate to mitigate stormwater affects from the particular site, it was determined that the basin in its original design did not create a significant change to the overall river system.

Ultimately, the topography obtained from the DEM was used to represent the drainage and infiltration rate of the area without any expected decrease in accuracy.

B. Steady State Flow Data for HEC-RAS

Steady state flow data is necessary for all reaches to simulate water surface profiles for the Many Mind Creek. These flow entries are obtained from the HEC-HMS output. The output of HEC-HMS that is of greatest interest is the peak flow at junctions located at upstream boundaries and reach intersections. The different flow scenarios are dependent on the precipitation event scenarios simulated within the HEC-HMS model. These flow scenarios were used to establish the 2, 10 and 100 year flood plain perimeter in the HEC-RAS hydraulic model.

Boundary conditions necessary to the model included defining the flow regime. Subcritical and supercritical flow regimes are a function of the turbulence of the flow. For the Many Mind Creek Watershed, the flow regime was assumed as subcritical, as is the general assumption for low gradient streams in the coastal plain.

C. Many Mind Creek Steady State Simulations and Water Surface Elevations

Once the peak flows generated from HEC-HMS for the selected storm events were defined at the flow change locations for all stream reaches, the steady state hydraulic simulation was performed with HEC-RAS. The output from the simulation include the steady state water surface elevation, critical depths, energy gradient elevations, energy gradient slopes, flow area and velocities at the cross sections. These results can be displayed graphically as X-Y plots of the river system schematics, cross sections, rating curves, and hydrographs. Detailed output of the water surface and velocities at all the bridges, culverts and flow change locations can also be viewed in tabular formats.

The final step in the modeling process was to post process the results of the HEC-RAS simulations and create water surface elevation profiles for the various chosen storm events. The water surface elevation along with the river network was exported to a RAS GIS Export File. It is then possible to create a flood plain delineation based on the water surface elevations and the

cross sectional data. Attachment 5 contains maps illustrating the results with the extent of flooding indicated for each of the design storm simulations.

V. Scenarios, Analysis and Recommendations

The primary purpose of this modeling study was to evaluate the hydrologic and hydraulic benefits of several proposed land use changes along the Many Mind Creek. The precipitation and runoff determined by the hydrologic model was represented by specific design storms. Parameters of the geometric component within the hydraulic model were modified to represent the potential land use changes that have been proposed. Therefore, four different land use scenarios, including existing conditions, have been modeled. The three land use changes that have been proposed have had initial plans developed by Amy Greene Consultants for the design of Many Mind Creek Greenway and Trail (2002) and Amy Greene Habitat Restoration Plan for Many Mind Creek estuary and saltmarsh area (2004). In an effort to illustrate and quantify the benefits of the land use changes, the hydraulic model output has been analyzed for changes in water surface elevation and velocity. A pseudo steady state flow representing the effect of high tide on the tidal zone was simulated for the geometric model representing existing conditions only.

A) Existing Conditions

As previously explained, the geometric file for the HEC-RAS model was primarily based on the two foot contour digital elevation model, along with field verification of various cross sections. Initial runs of the hydraulic model were presented to the Many Mind Regional Stormwater Planning Committee at the January 2005 meeting, and areas of concern were identified. Also, areas of flooding potential found in the initial runs of the hydraulic model were confirmed in the case of Seventh Avenue and denied in the case of the upstream Rt. 36 crossing. This input was taken into consideration, and adjustments were made.

The steady state flow determined to occur from the design storms run in the hydrologic model were modified to analyze potential effects on flooding situations. Table 5 shows the varying flow input that was used to determine water surface elevations in the hydraulic model, HEC-RAS.

Table 5: HEC-RAS Flow Input Options

Basin	Cross section	2 yr (cfs)	2 yr low CN (cfs)	Option 9 (cfs)	Option 12 (cfs)
7	7361	20.7	16.4	10	10
7	5922	20.7	16.4	10	10
7	5542	20.7	16.4	10	10
7	4136	Grand Avenue Bridge			
6	2961	79.2	62.0	10	30
6	2943	Seventh Avenue Bridge			
6	1619	79.2	61.9	79.1	79.1
6	908	133.9	104.5	133.9	133.9

Analysis:

- Water surface elevations showed that the stream overran its banks during the two year design storm. Most notably, flooding was determined to occur in the area upstream of the Seventh Avenue Bridge and during mean or high tide in the area upstream of the Center Avenue Bridge.

- The water surface elevation appeared to exceed the Grand Avenue Bridge deck elevation of 20 feet during the two year design storm (See Table 6). A variety of flow schedules were implemented in the model to predict the volume of water that could pass without approaching flood conditions. (Options defined in Attachment 6).

Table 6: HEC-RAS Output Results

Grand Avenue Bridge		
	Q total (cfs)	Water Surface Elevation
2 yr	20.7	20.4
2 yr low CN	16.4	20.4
Option 9	10	15.8
Option 12	10	18.5
Seventh Avenue Bridge		
	Q total (cfs)	Water Surface Elevation
2 yr	79.2	20.1
2 yr low CN	62.0	20.1
Option 9	10	13.7
Option 12	30	16.9

- The culvert at the Seventh Avenue Bridge appeared inadequate to pass the volume of water required even in the two year design storm. However, if an increase in the culvert diameter was to allow more water to flow downstream, one could expect higher velocities creating increased downstream erosion.

- The culvert running under First Avenue, upstream of the reach behind the Foodtown, appears to handle only the two year design storm, with the heavier storms overtopping the banks. However, heavy debris including shopping carts and other litter observed in the field would contribute to the slowing of the stream's flow, thereby potentially causing flooding at that culvert in storms of the two year magnitude or lower.

- The floodplain delineation as defined by the hydraulic model runs correlated well with the digital Q3 Flood Data [Q3 data is a digital representation of certain features of the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps (FIRM)]. This Many Mind model was able to represent the hydraulic features such as bridges and culverts and therefore appears to represent the watershed more accurately in the region upstream of the Rt. 36 (Foodtown) bridge. However, the influence from the Sandy Hook Bay tidal influence appears to be better represented in the Q3 digital data.

Recommendations:

- To mitigate potential flooding in these areas upstream of tidal influence, temporary storage of excess stormwater runoff would need to be considered. One or more upstream detention/retention basins could be a solution that would reduce the volume of stormwater that is released into the creek at a critical point in time. Considerations for the design would include the volume of water that was attempting to be stored, the area of land available for storage, and the potential for infiltration through the use of best management practices (BMP's).

  A total of seventeen different flow regimens were introduced to the hydraulic model to determine the response of the water surface elevation. These flow regimen options that are detailed in Attachment 6 change the potential runoff into the stream system at a variety of points (represented by cross sections) along the stream. These varied reductions in input can be compared to the reduction in flow that would occur with the introduction of a detention/retention basin that would store runoff for a time period in a specific area and that would reduce the peak flow. These seventeen "options" in flow include the 10% reduction in curve number as well as existing conditions.

  Table 6 shows the water surface elevation modeled for existing conditions and for the reduction in the curve number. This table also shows the two potential peak flow regimens that were found to have a significant reduction on the downstream

water surface elevation. Reductions in the peak flow using the attenuating effects of a detention/retention basin were analyzed to see the flow reduction in the areas of the Grand Avenue and the Seventh Avenue Bridges. These two bridges were chosen due to the prevalence of flooding found in initial hydraulic runs.

As the table shows, the flow, in cubic feet per second (cfs) was reduced at two cross sections. The peak flow from subbasin 8 at the headwaters of the Many Mind Creek was decreased from 20.7 to 10 cfs. Additionally, the peak flow from subbasin 7 was decreased from 79 to 30 cfs. The decreases in peak flows result in the surface elevation decrease from 20.41 to 18.53 feet at the Grand Avenue Bridge (see Table 6). If further decreases in peak flows are made in subbasin 7 to 10 cfs, the water surface elevation would decrease to 15.79 at the Grand Avenue Bridge. The water surface elevation at the Seventh Avenue Bridge follows suit. The reduction of peak flow from both subbasins 7 and 8 to 10 cfs would eliminate flooding during the 2-yr design storm. One method to reduce the peak flows from subbasins 7 and 8 would be to install stormwater detention or retention.

A preliminary HydroCAD model was prepared to represent the potential reduction in flow over time. Peak flow was reduced from approximately 80 cfs to 50 cfs using a storage capacity of roughly 14 acre-feet in one detention basin. For optimal reduction in peak flow, more than one area of detention need to be considered to attenuate the effects of downstream flooding. Figure 6 shows the preliminary graph of the peak flow change expected if detention of this size were to be in place.

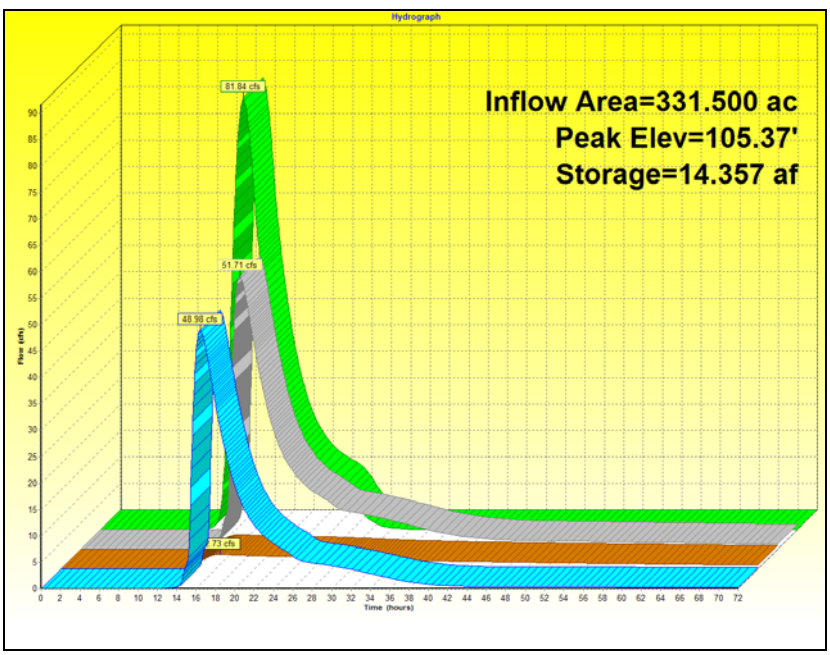

Figure 6: HydroCAD Hydrograph with Effects of Potential Detention

- Another method to reduce these peak flows would be to reduce the CN further than 10% by disconnecting impervious surfaces. The NJDEP Best Management Practices (BMP) manual discusses disconnection of impervious surfaces in Chapter 5. An example present in the BMP manual that shows by simply having a one acre parking lot sheet flow over a pervious lawn area, the runoff volume can be decreased from 3800 ft^3 to 581 ft^3. Disconnecting impervious surfaces can be a simple BMP to implement. A more detailed discussion of varying curve number is presented later in this report.

- Flooding in the tidally influenced zone of Center Avenue is better addressed by giving the stream better access to the floodplain. Downcutting in the area has resulted in steep slopes to the stream banks. Re-grading stream banks to a gentler slope and allowing an adequate flood zone would mitigate flashy streams and increased suspended solids from erosion associated with heavy rain falls.

- The bridges in the tidal zone (Rt. 36 to the Sandy Hook Bay) were designed and implemented well over fifty years ago. Redesigning these bridges with higher deck elevation would allow for increase flow and less flooding of the roadways.

- Debris removal is indicated in the portion of the stream that runs behind the Foodtown on Rt. 36. This would include removal of shopping carts and construction debris, but not naturally fallen vegetation. This should allow for the proper and expected flow through the area and also allow the potential for natural habitat accumulation.

B) Proposed Land Use Alterations

Three land use change scenarios suggested by the Greenway/Trail Concept plans for the Borough of Atlantic Highlands were modeled by altering the existing geometric model attributes. The three areas start most upstream with a proposed park on Borough-owned land that would join South Avenue Park with the West Highland Avenue detention basin ("Creek Bend Park"), as well as the proposed wetland creation between the Highland Avenue and Center Avenue Bridges. The second modification is the proposed wetland creation between the Center Avenue and the Bay Avenue Bridges. The last proposed alteration in land use is the increase in the area that the salt marsh dominates, located downstream of the Bay Avenue Bridge and ending at the mouth of the Sandy Hook Bay.

These modifications to the geometric model in HEC-RAS were required in only the most downstream reach of the Many Mind Creek. Therefore, analysis of the velocity and water surface elevation was performed for this last reach only.

1) "Creek Bend Park"

(South Avenue Park joined with Highland Avenue detention basin area)

The most upstream land use change scenario would take place just downstream of the Highland Avenue Bridge. A conceptual plan of the Many Mind Creek Greenway & Trail provided by Amy S. Greene Environmental Associates in August of 2002 was used to locate proposed land use changes between Highland Avenue and Center Avenue. The Greenway Concept Plan proposes to create wetlands and retrofit the existing detention basin. Additional details were obtained using plans created by Maser Consulting (May 2003).

Changes to the existing geometric data included expanding the floodplain to represent the change in grading proposed. An increase in the Manning's n coefficient was used to represent the increase in roughness due to the proposed vegetation that would occupy the banks.

Analysis:

- Although the increase in stream cross sectional area should be expected to decrease velocity, and therefore decrease erosion, the actual effect after the alteration is small. The output of the hydraulic model analyzed at the cross section just upstream of the Center Avenue Bridge shows a very slight decrease in the water surface elevation and no significant change in the velocity during the two year storm.
- The increase in roughness due to installation of wetland vegetation along the stream bank, again, shows a minimal effect on the water surface elevation and velocity in the HEC-RAS model. However, it is expected that the root system that would be created would serve to reduce the erosion of the stream banks leading to an increase in the water quality of the stream. The reduction in total suspended solids (TSS) at the mouth of the Many Mind Creek would serve to introduce a higher quality of water to the Sandy Hook Bay. The vegetation should also reduce nutrient loading from overland flow that enters the stream at this point.
- The existing detention basin appears to not be creating any significant storage due to design and would require retrofitting if this was considered an objective of the plan. In its existing condition, it appears to flow without obstruction between the basin and the stream. The effect of the tide in the area becomes an overriding factor making the present design of the detention basin ineffective. For the basin to have its intended effects, the flow out of the detention area would need to be controlled to store stormwater and release only when the stream is low and can handle the increase in flow.

Recommendations:

- The creation of wetlands would be an apparent benefit to the area considering wildlife habitat, water quality and reduction of stream bank erosion. Although this would not appear to mitigate flooding in the area to any significant degree, other benefits are clear.
- If the detention basin is simply revegetated and used as a water feature, there would be no changes in the hydraulics of the system. A more detailed analysis of the

mechanics of the basin would provide information on the possibility of creating a better functioning storage facility. One potential option for creating efficient storage during high tide could be the installation of a tidal gate that would serve to retain stormwater in the basin during high tide, and only allow release when the water surface elevation recedes.

2) Wetlands Creation between Center Avenue and Bay Avenue

The Amy Greene conceptual plan (August 2002) also sited the proposed wetland creation to be constructed between Center Avenue and Bay Avenue, on the east bank of the creek on borough owned property. Additional details were obtained using plans proposed by Maser Consulting (May 2003). Presently, this area has approximately 270 feet adjacent to the Many Mind Creek, with steep banks, heavy P*hragmites sp.*, and little access to the flood plain.

Modifications to the geometric file included grading the stream banks and adjusting the Manning's n to represent the extended floodplain according to the plans presented by Maser Consulting.

Analysis:

- No significant effect on water surface elevation or stream velocity was found in implementing this particular land use change in the hydraulic model.
- This area lies well within the effects of the tidal zone. The tidal influence will be a controlling factor in the water surface elevation of the stream.
- Re-grading the steep banks would allow better access to the floodplain. This would serve to moderate quick fluctuations in water surface elevations and reduce the potential for erosion.
- Re-vegetating stream banks would provide increased habitat and a more adequate root system to contribute to the retention of soil. Both the re-grading and the re-vegetating would increase soil retention of the banks. Decreasing the erosion of the stream banks would decrease TSS in the Many Mind Creek and reduce the TSS inputs to the Sandy Hook Bay.

Recommendations:

- Implementation of the addition of these wetlands and the elimination of steep banks is recommended to reduce stream bank erosion and the concurrent deposition of eroded soil into the Many Mind Creek and ultimately the Sandy Hook Bay.

3) Expanding the Salt Marsh

An additional Amy Greene plan (February 2004) was used to determine the site and extent of a proposed increase in existing salt marsh adjacent to Sandy Hook Bay. The proposed area lies

between the Bay Avenue Bridge and the Sandy Hook Bay. The salt marsh boundary on the west side of the Creek would be extended slightly westward.

Two changes to the hydraulic model were made to represent the alterations in parameters expected. First, flow to the stream was reduced due to the expectation that more infiltration would be presumed to occur with the addition of a salt marsh in place of the present land use. This was not performed using the curve number, as the area does not occupy a large enough portion of the subbasin to significantly affect the area weighted curve number. However, with the location of the area of increased infiltration being so close to the stream, it is assumed that overland flow would be significantly affected. Second, adjustments were made to the Manning's n, or roughness, coefficient, to represent the increase in drag expected to occur with a more heavily vegetated land use.

Analysis:

- The results of the model runs show that this project will have little effect on stream flow, water surface elevation or water velocity due to its proximity to the bay and the tidal influence of the bay.
- This proposed restoration will create a more diverse habitat, including a fishery habitat, within the watershed.
- Overland flow should experience filtration and an increase in water quality for the area.

Recommendations:

- This project provides a variety of benefits to the ecosystem, therefore this land use change is recommended.

C) High Tide

The tidal fluctuation is six feet in the Sandy Hook Bay. During the flood tide, the water surface elevation of the lower reach of the Many Mind Creek is affected due to the low gradient of the stream (i.e., very little change in stream bottom elevation in the watershed). This tidal influence appears to affect the water surface elevation in the stream upstream to the area past the Rt. 36 Bridge near the Foodtown.

Analysis:

- The detention basin on the west bank downstream of the Highland Avenue Bridge is ineffective in its present condition.

- The high tide serves as a wall of water that opposes the Many Mind Creek flow destined for the Sandy Hook Bay. When these conditions coincide with additional flow from stormwater, upstream flooding will dramatically increase.

Recommendations:

- Additional stormwater storage could be useful in mitigating flows during high tide that would overflow stream banks. However, tidal influence is not easily deterred, and measures to accept the floodplain delineation should be taken. This includes removal of constructed objects within the floodplain, grading stream banks and installation of native vegetation that would support the banks under high flow conditions.

D) Changes to the Curve Numbers

Each subbasin in the Many Mind Watershed was initially assigned a weighted curve number due to the land use/land cover and soil characteristics of the area within that subbasin. It is often useful to determine the effect of a change in the curve number on the flow and water surface elevation. A decrease in the curve number would occur when land use is changed to accept additional infiltration, and therefore would supply less runoff to the stream. An increase in the curve number would correlate with a land use that increased impervious area or changed to a land use that infiltrated a reduced amount of the rainfall.

The HEC-HMS model was used to acquire peak flows during the 2, 10, and 100 year storms with the assigned curve number reduced by 10% and increased by 10%. Those peak flows were set into the HEC-RAS hydraulic model at the corresponding cross sections. HEC-RAS was then able to produce information on what levels of flow and water surface elevation changes would occur. Table 7 shows the water surface elevation changes found during the model run of the 2 yr design storm. Table 8 depicts the change in flow that the model predicts.

Table 7: Water Surface Elevation (W.S. Elev): HEC-RAS Output for CN Comparison

Station	2yr-low W.S. Elev (ft)	2yr_exist W.S. Elev (ft)	2yr_high W.S. Elev (ft)	10% decrease CN diff(ft)	10% increase CN diff(ft)
Pour Point: 8-headwaters	49.14	49.2	49.26	-0.06	0.06
Grand Ave Br: upstream	20.17	20.21	20.25	-0.04	0.04
7th Ave: upstream br & pr pt 7	20.08	20.13	20.17	-0.05	0.04
First Ave: upstream of bridge	9.11	9.74	10.57	-0.63	0.83
Pour Point: 3_west south	5.61	5.89	6.22	-0.28	0.33
Rt 36 at Foodtown: upstream	5.56	5.83	6.14	-0.27	0.31
Pour Point: 1 southwest	20.5	20.53	20.55	-0.03	0.02
Area next to Fireman's Field	4.42	4.68	4.98	-0.26	0.3
Highlands Ave Brdg, upstream	3.76	4.12	4.57	-0.36	0.45
Center Ave Brdg, upstream	2.1	2.47	2.92	-0.37	0.45
Bay Ave Brdg, upstream	0.4	0.87	1.48	-0.47	0.61
outlet	-1.01	-0.68	-0.29	-0.33	0.39

Table 8: Flow (Q): HEC-RAS Output for CN comparison

Station	2yr_low Q Total (cfs)	2yr_existing Q Total (cfs)	2yr_high Q Total (cfs)	% change w/ decrease in CN	% change w/ increase in CN
Pour Point: 8-headwaters	16.39	20.7	26.37	-20.82	27.39
Grand Ave Br: upstream	16.38	20.69	26.36	-20.83	27.40
7th Ave: upstream br & pr pt 7	62.01	79.2	102.51	-21.70	29.43
First Ave: upstream of bridge	61.97	79.16	102.45	-21.72	29.42
Pour Point: 3_west south	104.55	133.93	173.9	-21.94	29.84
Rt 36 at Foodtown: upstream	104.55	133.93	173.9	-21.94	29.84
Pour Point: 1 southwest	6.71	8.35	10.43	-19.64	24.91
Area next to Fireman's Field	140.74	180.59	234.53	-22.07	29.87
Highlands Ave Brdg, upstream	140.64	180.46	234.34	-22.07	29.86
Center Ave Brdg, upstream	181.16	233.62	305.04	-22.46	30.57
Bay Ave Brdg, upstream	181.16	233.62	305.04	-22.46	30.57
outlet	166.57	216.62	285.27	-23.10	31.69

Analysis:

- A decrease in the area weighted curve number decreases the water surface elevation at all stations. This effect is seen most significantly at the First Avenue Bridge where the model predicts a 0.63 foot reduction in water surface elevation expected with a 10% decrease in the curve number associated with potential land use changes, but this alone is not sufficient to eliminate flooding, although it would serve as an important component of an overall plan.
- The reduction in the curve numbers shows an increase in effect the more downstream it is analyzed. This accounts for the relatively small effect on water surface elevation

at the Grand Avenue and Seventh Avenue Bridges. With flooding being an issue in these areas, other means of mitigation would need to be considered to address those concerns.

- Water surface elevations are more significantly affected in the lower reaches of the stream. The model predicts that the three bridges downstream of the Rt. 36 Bridge show the potential for a reduction in water surface elevation of almost one-half of a foot due to the 10% decrease in curve numbers throughout the watershed.

VI. Summary and Conclusions

The HEC-HMS and HEC-RAS models developed for the Many Mind Watershed provide a detailed understanding of the dynamic nature of the watershed's runoff and stream responses during a variety of storm events. Using these tools, the decision makers can evaluate the conditions that lead to flooding and erosion, and identify where changes can be made to make the most significant impact.

The two models employed in this study were able to replicate the changes in contours of the stream channel and characteristics of drag on flow to represent projected land use changes being planned in the most downstream sections of the creek. Three land use change projects that are in the planning process and have engineered designs for them, were replicated for analysis in the hydraulic model. These three projects, specified by Many Mind Regional Stormwater Management Planning Committee, were found to have benefits, but no significant effect on the hydrology or the hydraulics of the stream.

The hydrologic and hydraulic models were also able to conceptually represent the benefits of increased infiltration, or decreased runoff through the use of lower curve numbers within the model runs. This reduction showed benefits, but not enough to consider this curve number reduction by itself as a solution to eliminate flooding. An additional use of the models was to portray a potential reduction in flow that would be expected with the use of a detention or retention area.

Although a reduction in curve numbers for a subbasin is not unrealistic, it would require a change in the way homeowners and businesses deal with stormwater. Stormwater Best Management Practices (BMP's) can be incorporated into the existing landscape of the Many Mind Creek Watershed, but a strong public education program would be required to assure its success. The newly formed Many Mind Creek Regional Stormwater Management Planning Committee could lead this effort. The Rutgers Cooperative Research & Extension of Monmouth County Planning Department are two of the resources that could provide assistance in this effort.

Table 9 presents some preliminary recommendations that the Many Mind Regional Stormwater Planning Committee may choose to investigate further. Land ownership and other planned projects may need to be considered along with the priorities of the stakeholders.

Although these models can produce analysis at a fine scale, this project was intended to be a regional study. The accuracy of the final results is limited to the accuracy of the datasets used to set up the modeling analysis. Enhancements to the dataset were made in the field at a large scale, but if detailed localized calculations are required for future analyses, further refinement of the input data would be necessary.

Table 9: Preliminary Recommendations for Potential Mitigation

Area of Potential Mitigation	Problem	Possible solution/comments
Seventh Avenue Bridge	flooding in the 2yr design storm	1,3,5
Center Avenue Bridge	flooding in the 2yr design storm	1,3,4,5
Grand Avenue Bridge	flooding in the 2yr design storm	1,3,5
First Avenue Bridge	flooding in the 10yr design storm	1,2,3
Three bridges in tidal zone	flooding	6
"Creek Bend Park"	steep banks and inadequate vegetation	7,8
Existing detention basin at Highland Avenue	does not appear affective	9
Wetlands creation between Center and Bay Avenue Bridges	steep banks and inadequate vegetation	7,8
Expansion of Salt Marsh	Existing land use in area is of little ecological benefit	7,8,10
Tidal area flood zone protection	High tide flooding	11
First Avenue Bridge	Increased water surface elevation	3
Bay Avenue Bridge	Increased water surface elevation	3

1: Detention/retention upstream of flooding or other BMP used to delay peak flow and/or increase infiltration
2: Removal of artificial debris causing unnatural blockage.
3: Reduction of direct runoff by altering land use to accept greater infiltration (reduction in "curve number"). This includes disconnecting impervious surfaces through the use of pervious surfaces having runoff directed to them, rather that directly to storm sewers.
4: Allow reasonable access to the floodplain by regrading stream banks and
5: Redesign bridges to accept larger flows without overtopping
6: needs field verification of flooding and potential redesign of bridge
7: Model does not show significant hydraulic benefit of proposed land use change
8: Proposed land use change should have beneficial effect on water quality
9: Retrofit existing outlet structure and/or basin dimensions to provide more reliable storage
10: Proposed land use change is expected to have a positive effect on habitat and nursery zones.
11: Efforts should be made to accept the water surface elevation expected during high tide and high flows. This could mean limiting unnatural structures, regrading stream banks and installing native vegetation.

VII. References

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U.S.D.A. Natural Resource Conservation Service, New Jersey 24 Hour Rainfall Frequency Data, New Jersey State Office, Exhibit 2 NJ 2, September 2004, Somerset, NJ.

Attachments

Attachment 1: Power Point Presentations

Attachment 2: Precipitation Depths for New Jersey

Revised by NRCS, January of 2005

USDA-NRCS Rainfall Amounts
NJ 24 hour rainfall frequency data
Rainfall amount in inches per 24 hours

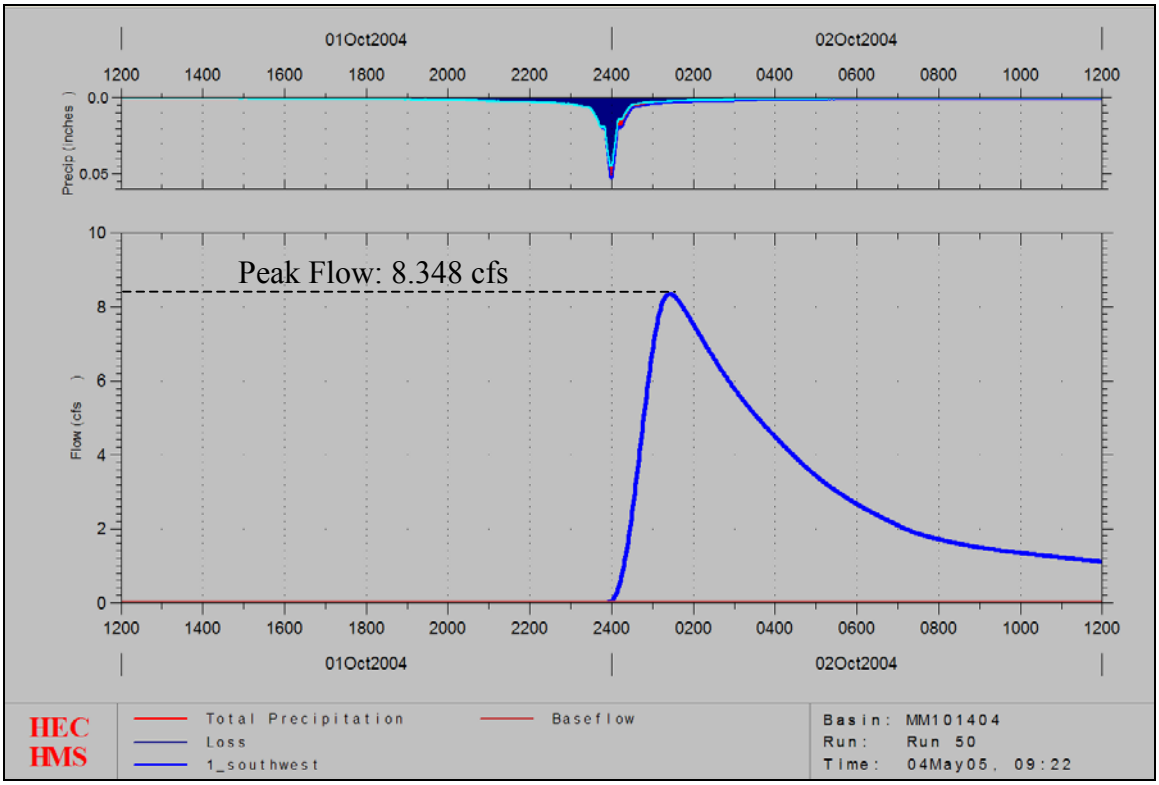
County	1 yr	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
Atlantic	2.8	3.3	4.3	5.2	6.5	7.6	8.9
Bergen	2.8	3.3	4.3	5.1	6.3	7.3	8.4
Burlington	2.8	3.4	4.3	5.2	6.4	7.6	8.8
Camden	2.8	3.3	4.3	5.1	6.3	7.3	8.5
Cape May	2.8	3.3	4.2	5.1	6.4	7.5	8.8
Cumberland	2.8	3.3	4.2	5.1	6.4	7.5	8.8
Essex	2.8	3.4	4.4	5.2	5.4	7.5	8.7
Glouster	2.8	3.3	4.2	5	6.2	7.3	8.5
Hudson	2.7	3.3	4.2	5	6.2	7.2	8.3
Hunterdon	2.9	3.4	4.3	5	6.1	7	8
Mercer	2.8	3.3	4.2	5	6.2	7.2	8.3
Middlesex	2.8	3.3	4.3	5.1	6.4	7.4	8.6
Monmouth	2.9	**3.4**	4.4	**5.2**	6.5	7.7	**8.9**
Morris	3	3.5	4.5	5.2	6.3	7.3	8.3
Ocean	3	3.4	4.5	5.4	6.7	7.9	9.2
Passaic	3	3.5	4.4	5.3	6.5	7.5	8.7
Salem	2.8	3.3	4.2	5	6.2	7.3	8.5
Somerset	2.8	3.3	4.3	5	6.2	7.2	8.2
Sussex	2.7	3.2	4	4.7	5.7	6.6	7.6
Union	2.8	3.4	4.4	5.2	6.4	7.5	8.7
Warren	2.8	3.3	4.2	4.9	5.9	6.8	7.8

Attachment 3: Peak Flows and Volumes from Hydrologic Model

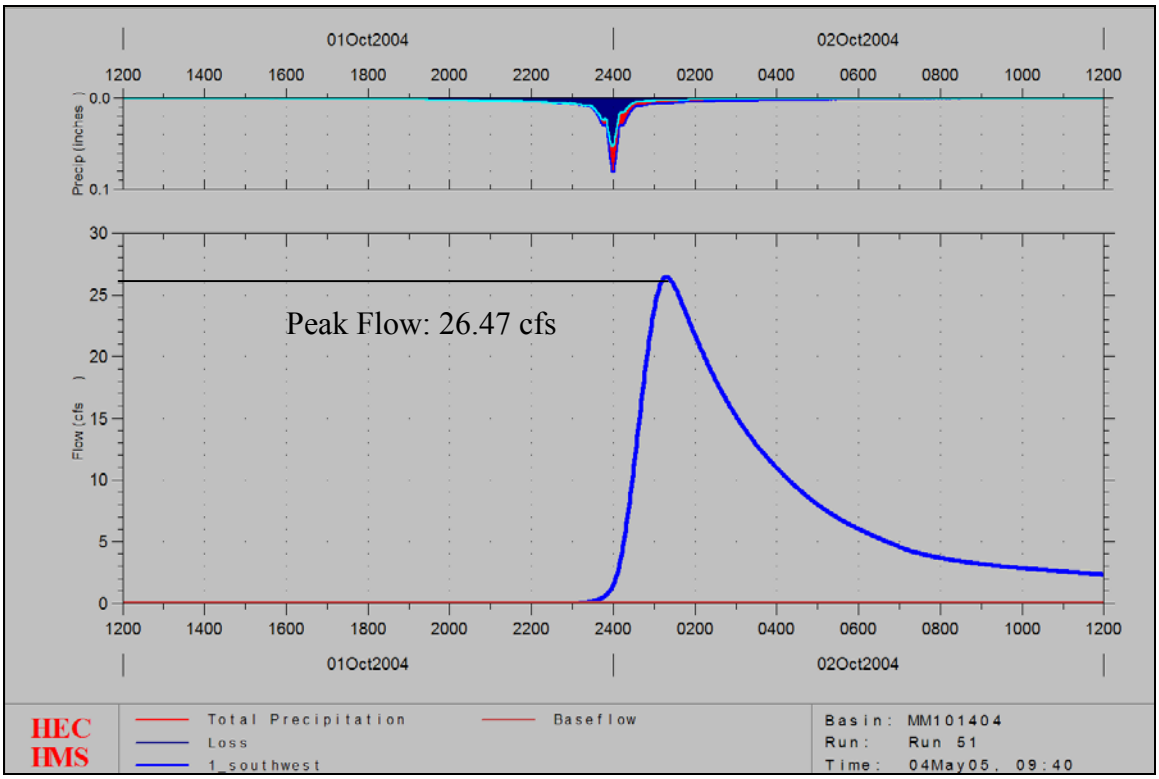
Many Mind Existing Conditions: Flow and Volume results during three design storms

Basin	Hydrologic Element	Drainage Area (sq mi)		2 year storm		10 year storm		100 year storm	
				Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)	Discharge Peak (cfs)	Total Volume (ac ft)
1	1_southwest	0.10		8.35	3.24	26.47	8.69	76.58	23.36
2	2-west	0.15		28.53	9.67	63.12	20.47	142.87	45.83
3	3_west_south	0.09		18.39	6.27	40.21	13.15	90.20	29.23
4	4_outlet_basin	0.24		63.98	21.28	123.55	40.62	251.68	83.51
5	5_middle_basin	0.04		14.52	4.72	25.91	8.47	49.52	16.50
6	6_lg_middle	0.24		41.63	15.94	90.57	33.38	202.86	74.08
7	7_lg_bend_basin	0.38		61.00	25.88	130.20	53.51	287.77	117.53
8	8_headwaters	0.14		20.70	6.58	54.08	15.59	137.47	38.16
Total	Outlet1	1.38		216.62	89.55	483.17	187.62	1108.90	418.04

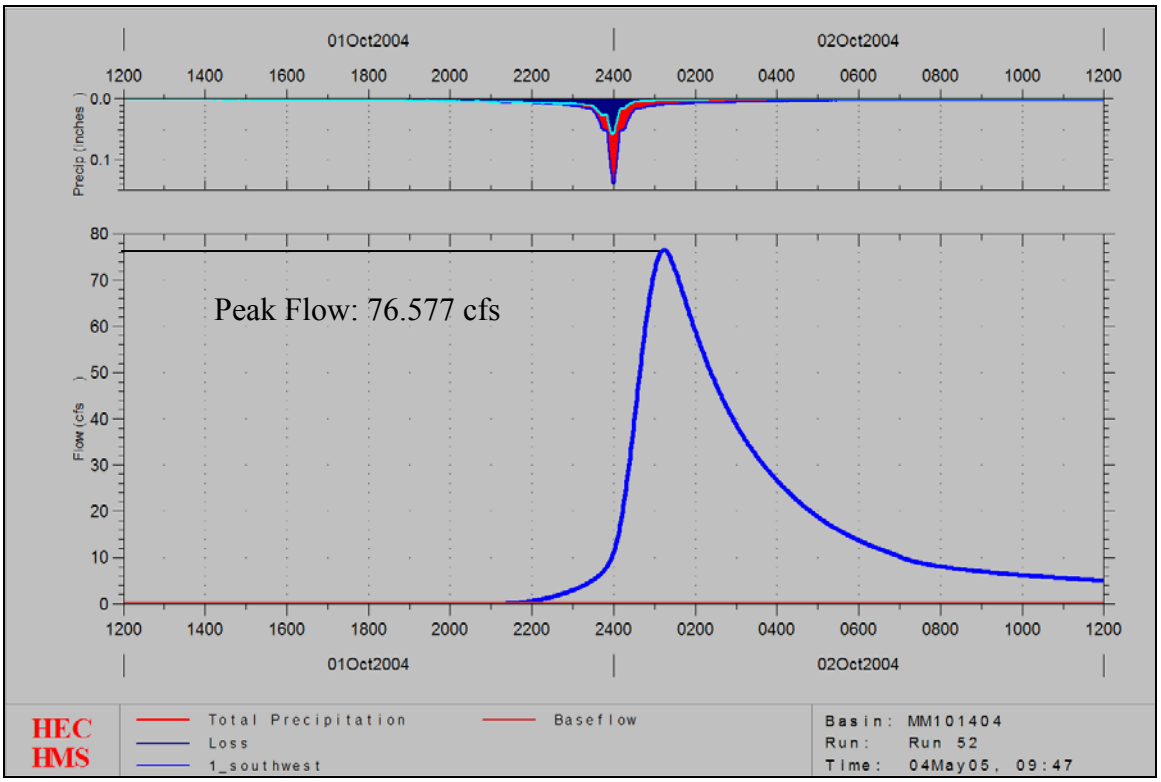
Attachment 4: Basin Hydrographs



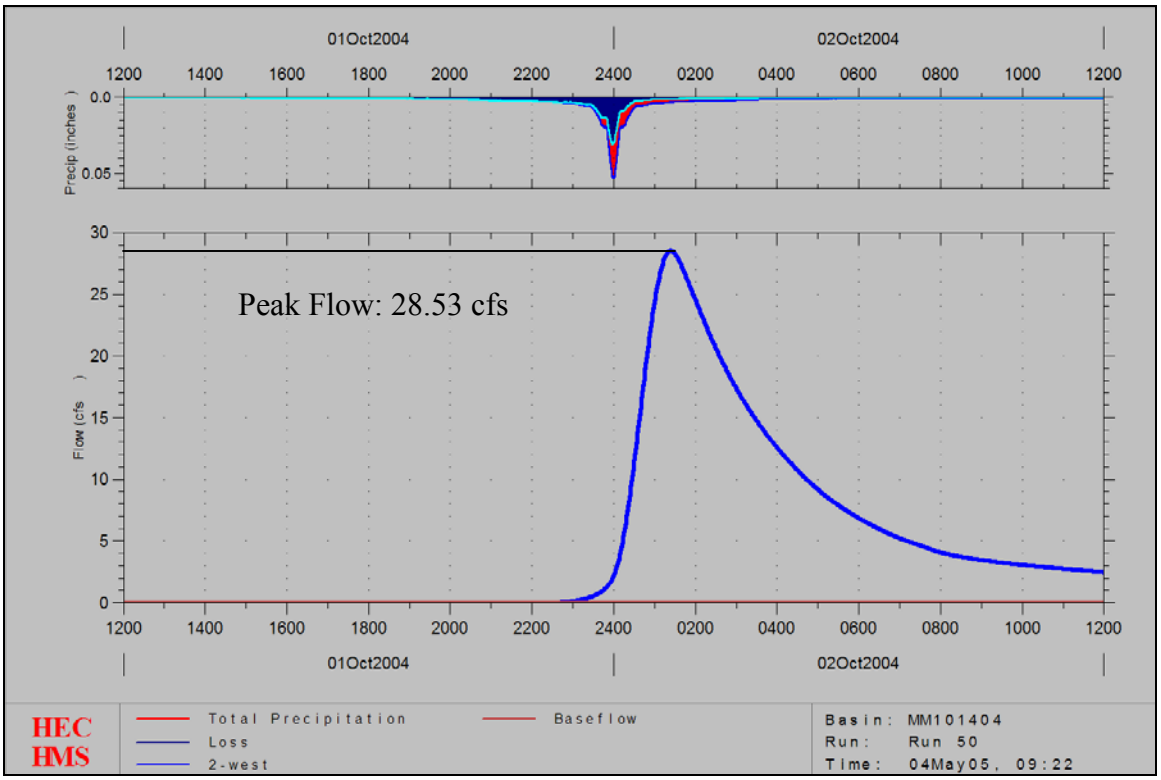
Basin 1, 2yr storm



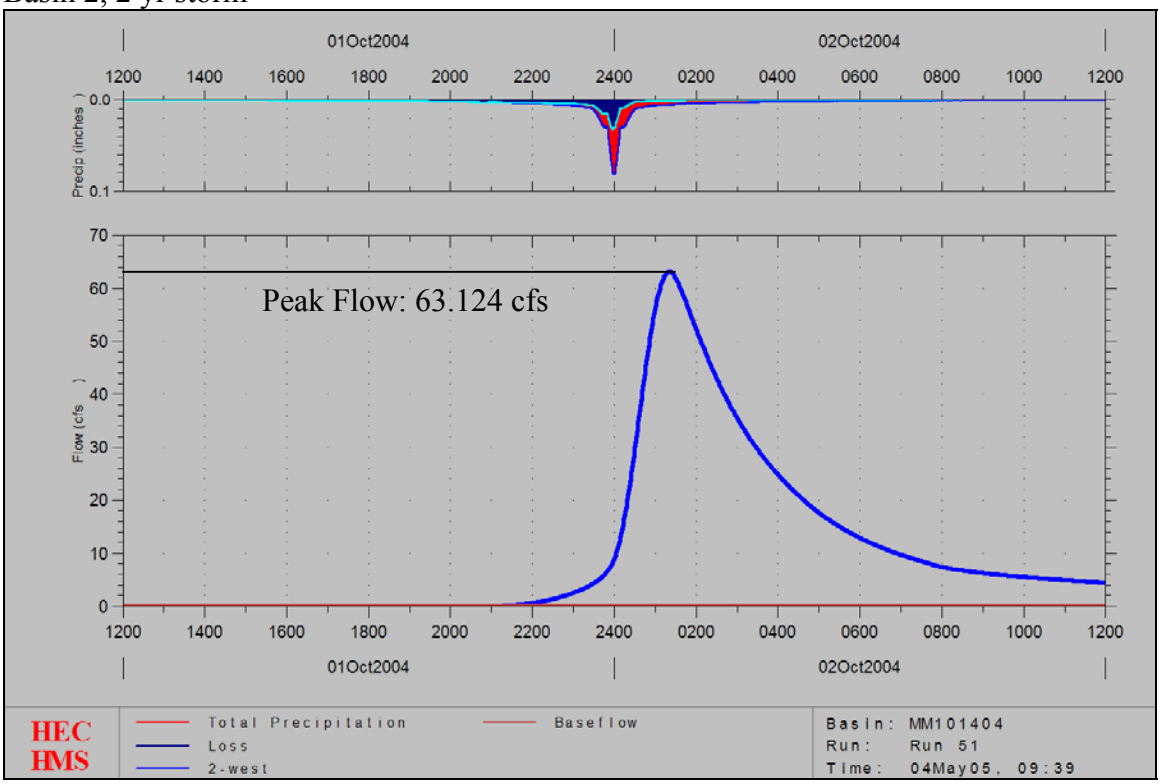
Basin 1, 10 yr storm



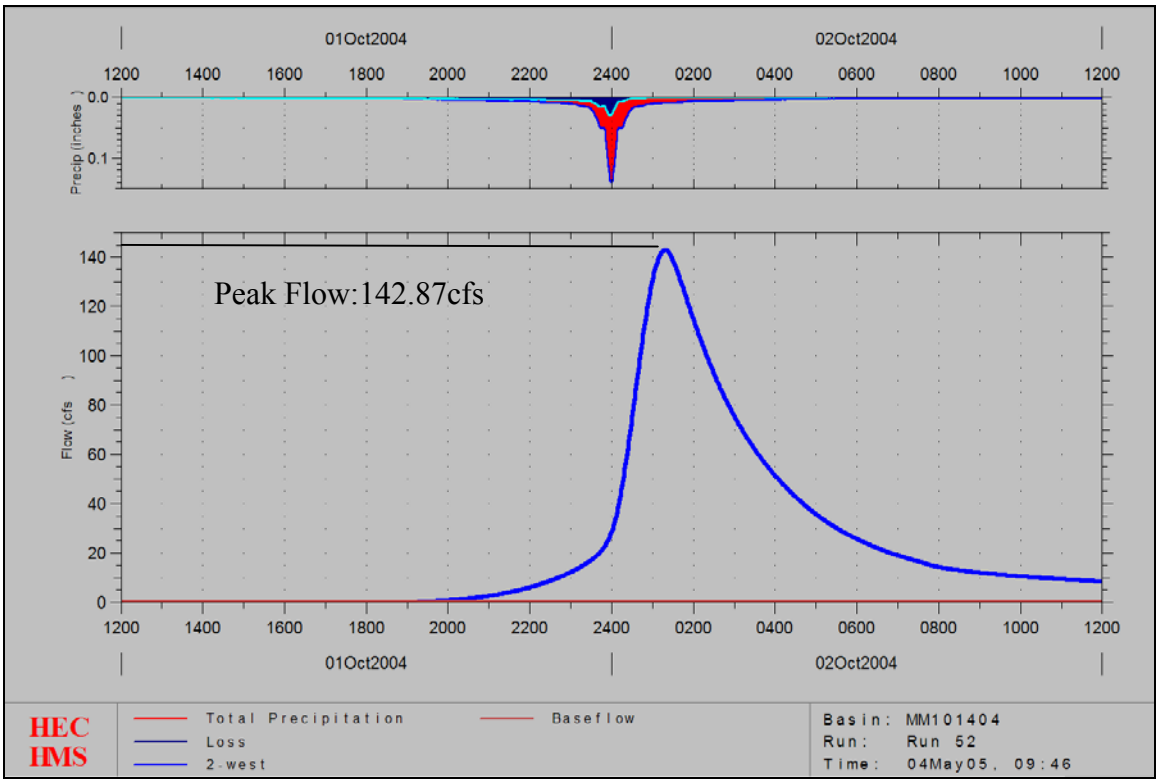
Basin 1, 100 yr storm



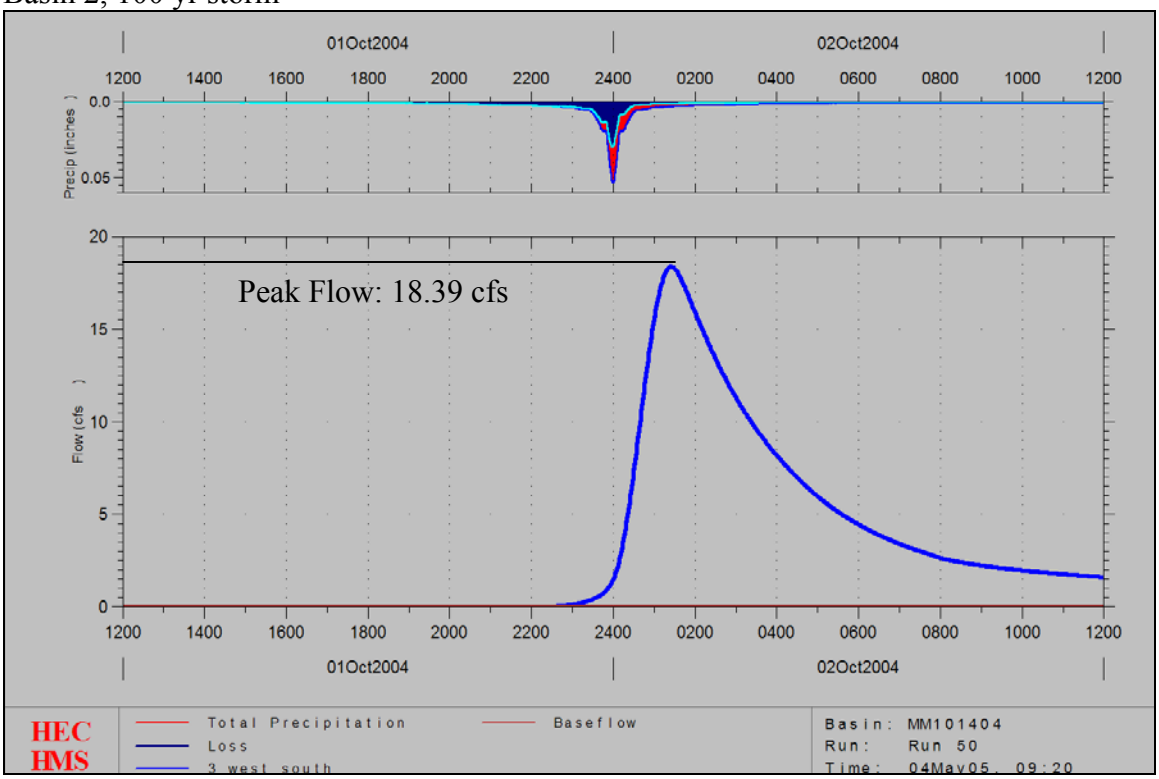
Basin 2, 2 yr storm



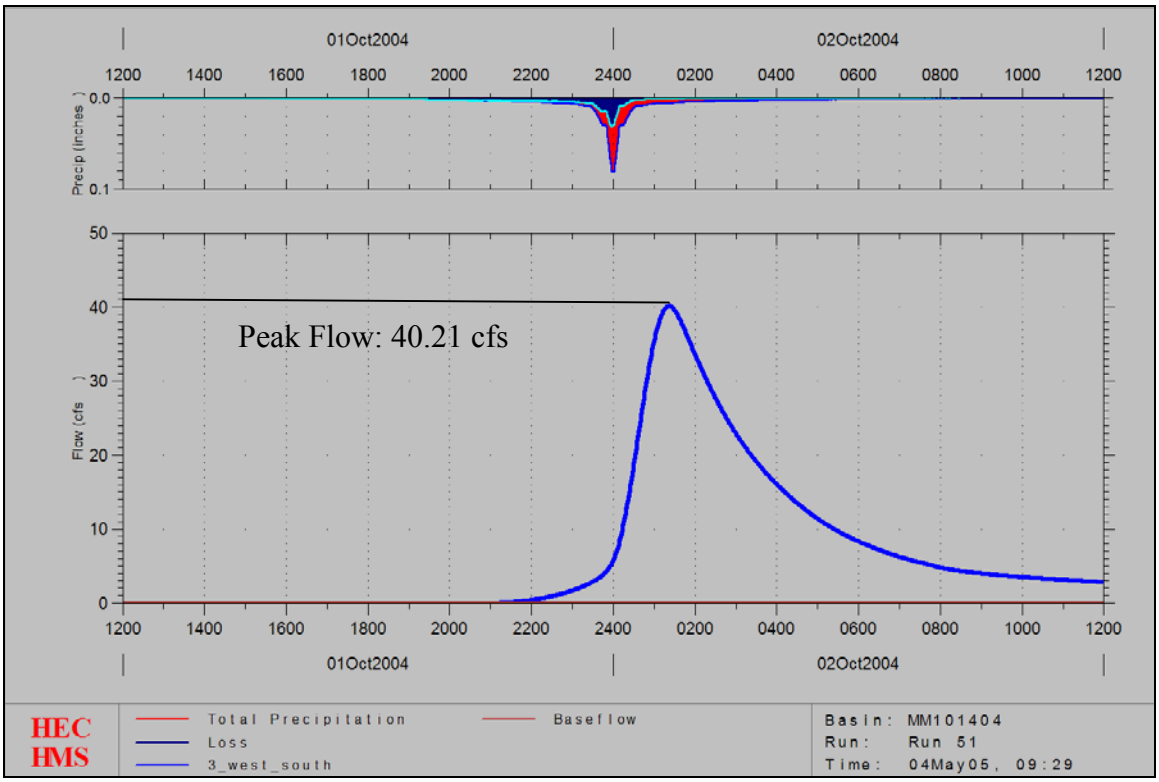
Basin 2, 10 yr storm



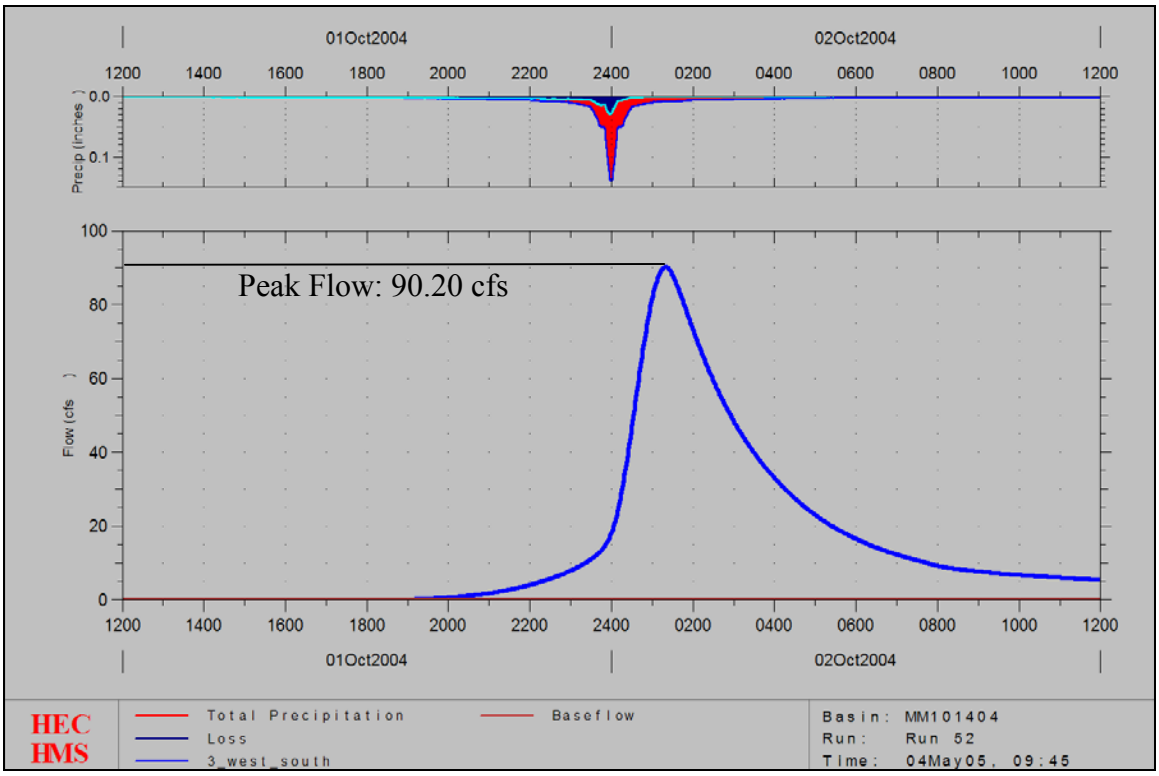
Basin 2, 100 yr storm



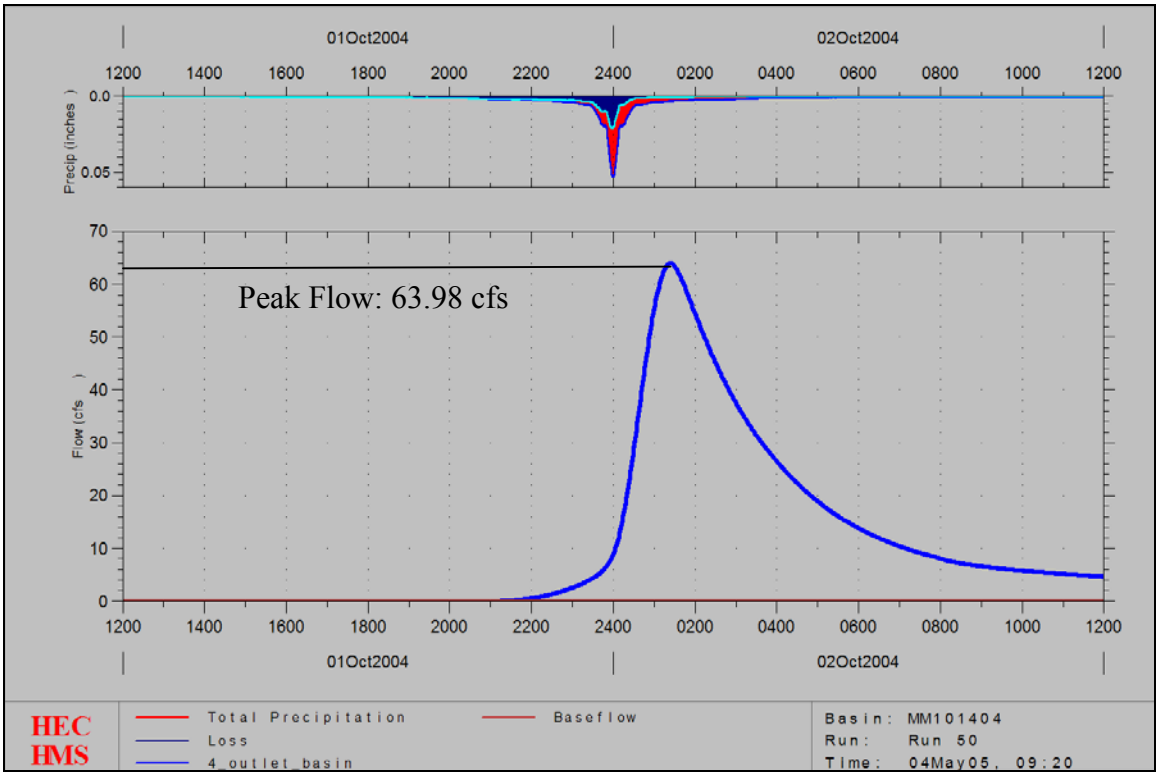
Basin 3, 2 yr storm



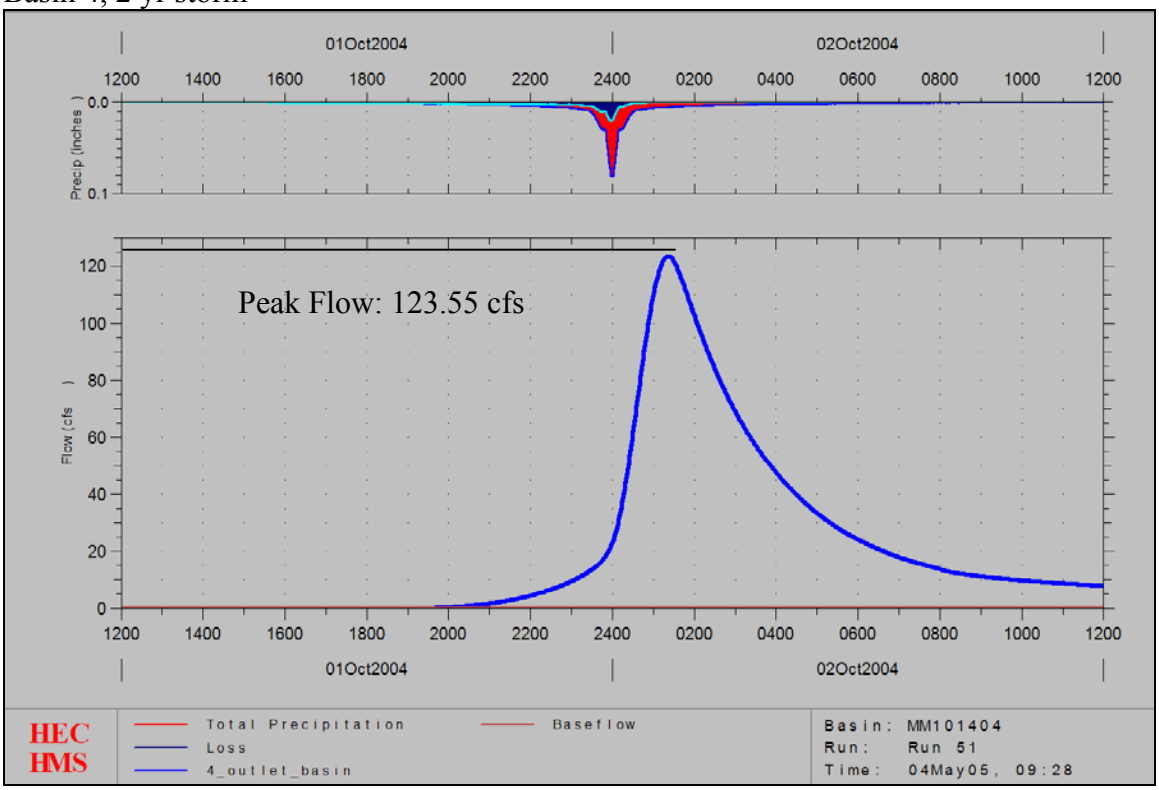
Basin 3, 10 yr storm



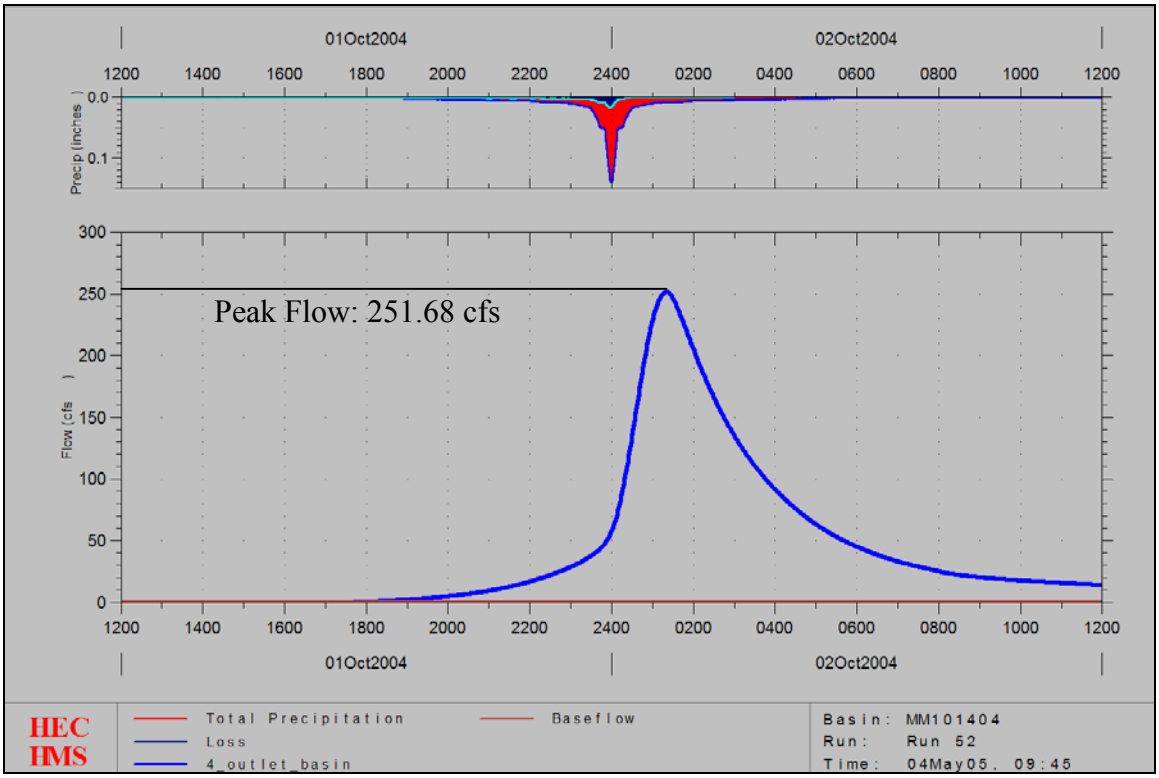
Basin 3, 100 yr storm



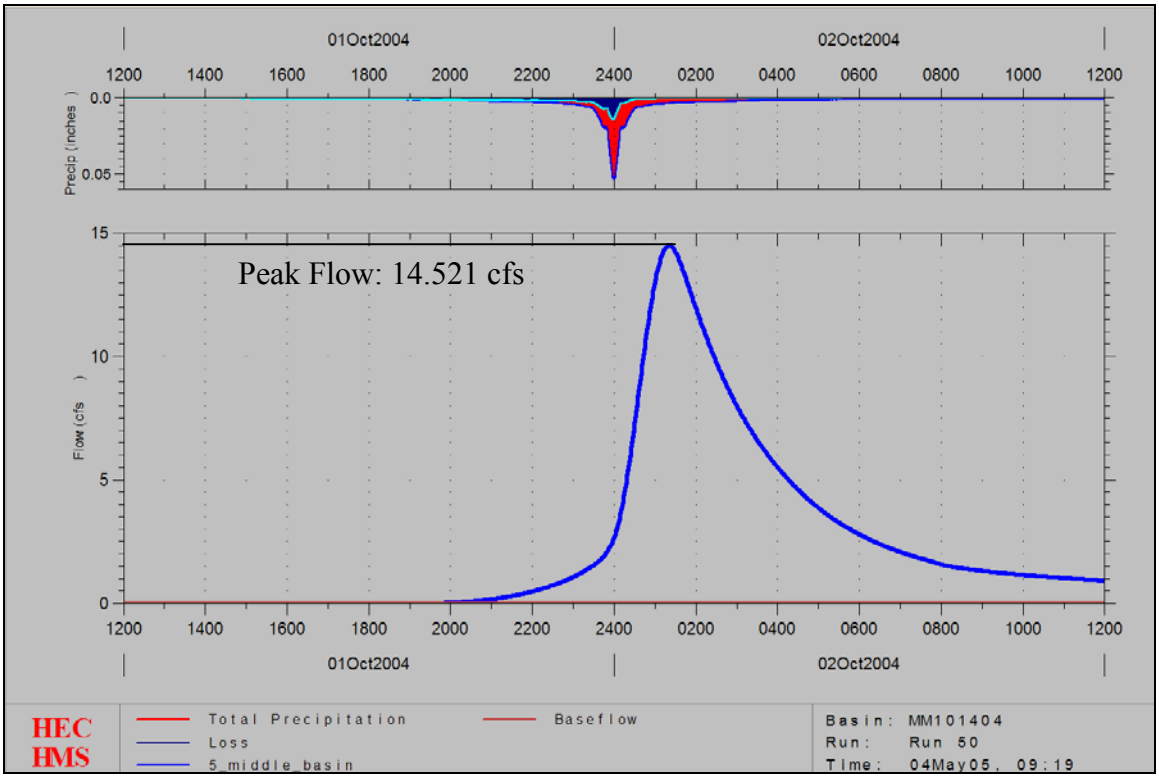
Basin 4, 2 yr storm



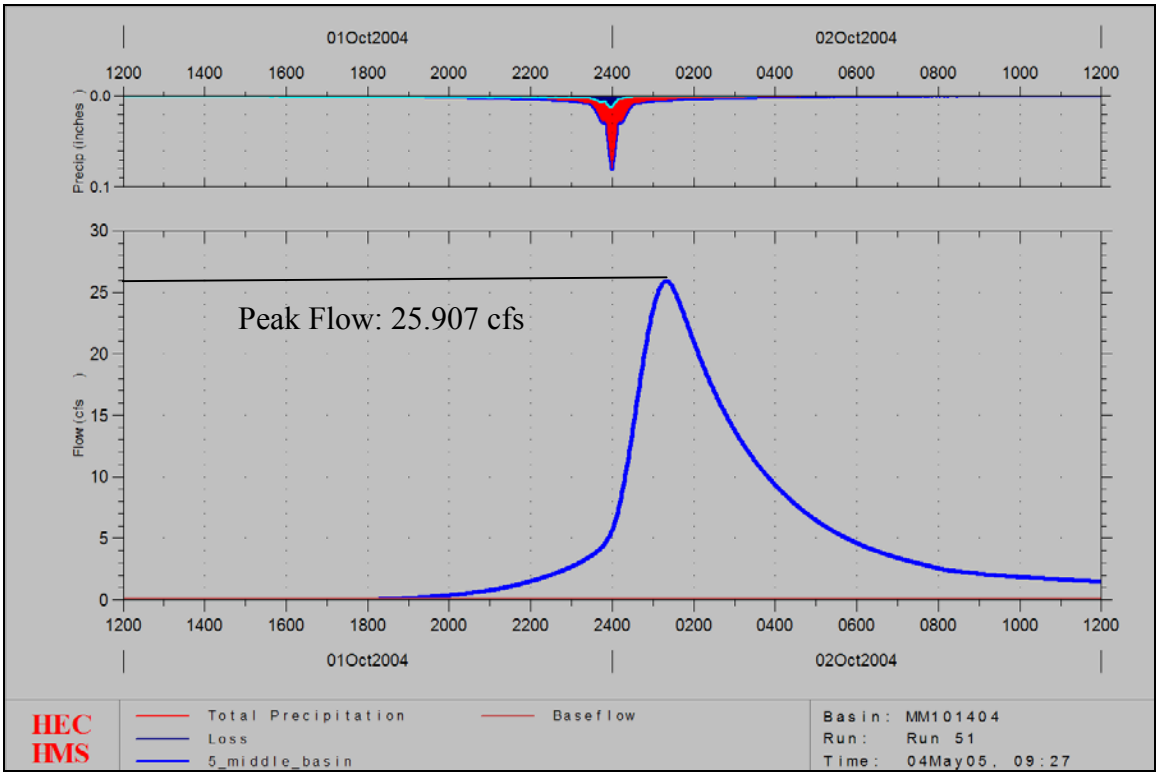
Basin 4, 10 yr storm



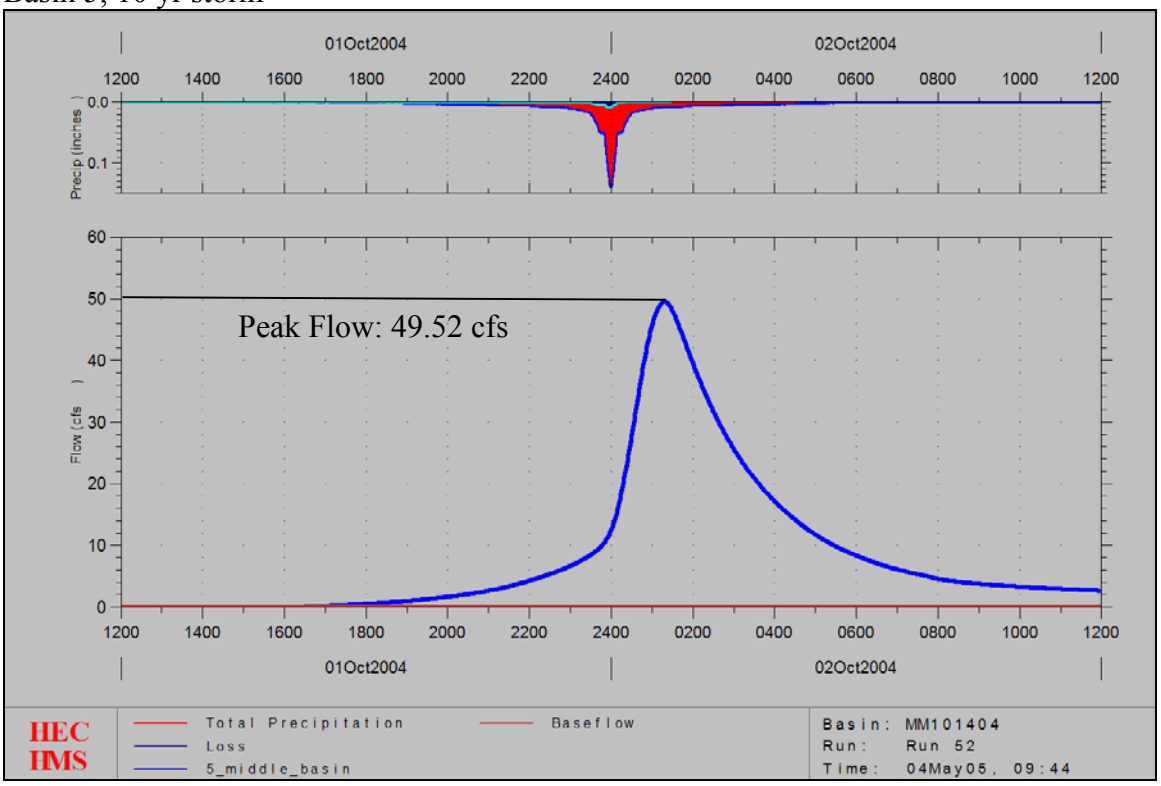
Basin 4, 100 yr storm



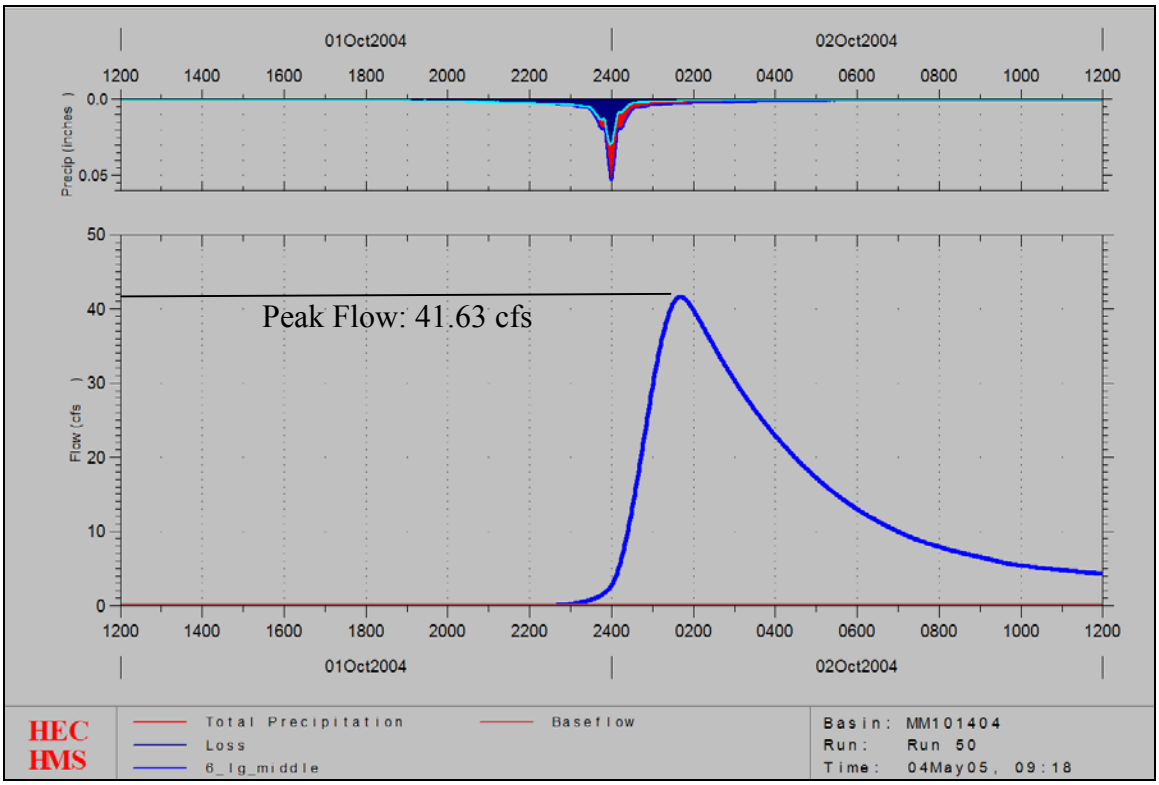
Basin 5, 2 yr storm



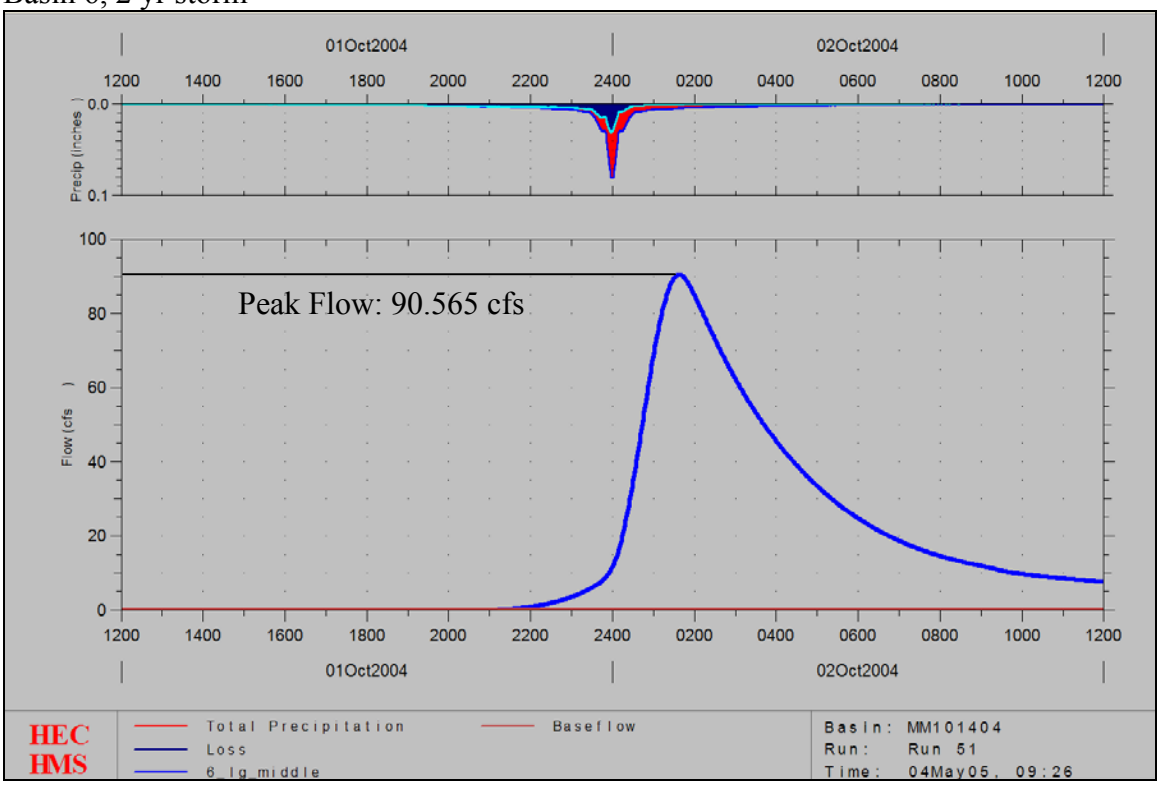
Basin 5, 10 yr storm



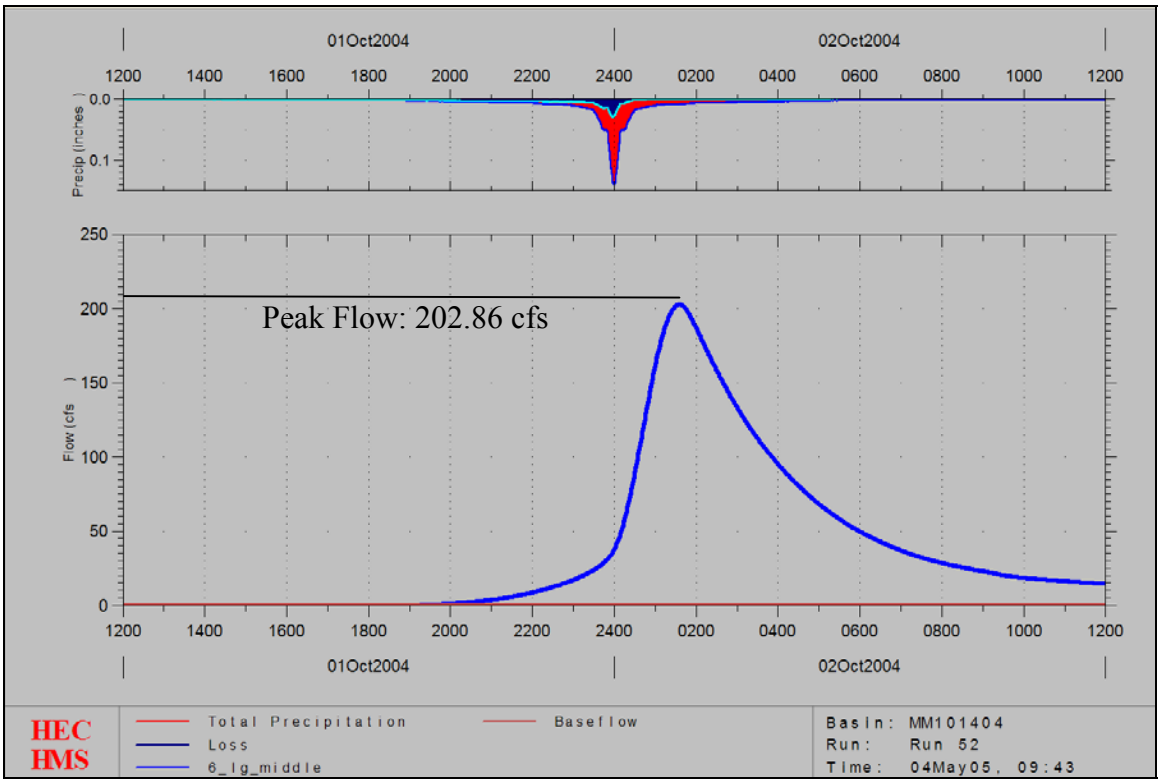
Basin 5, 100 yr storm



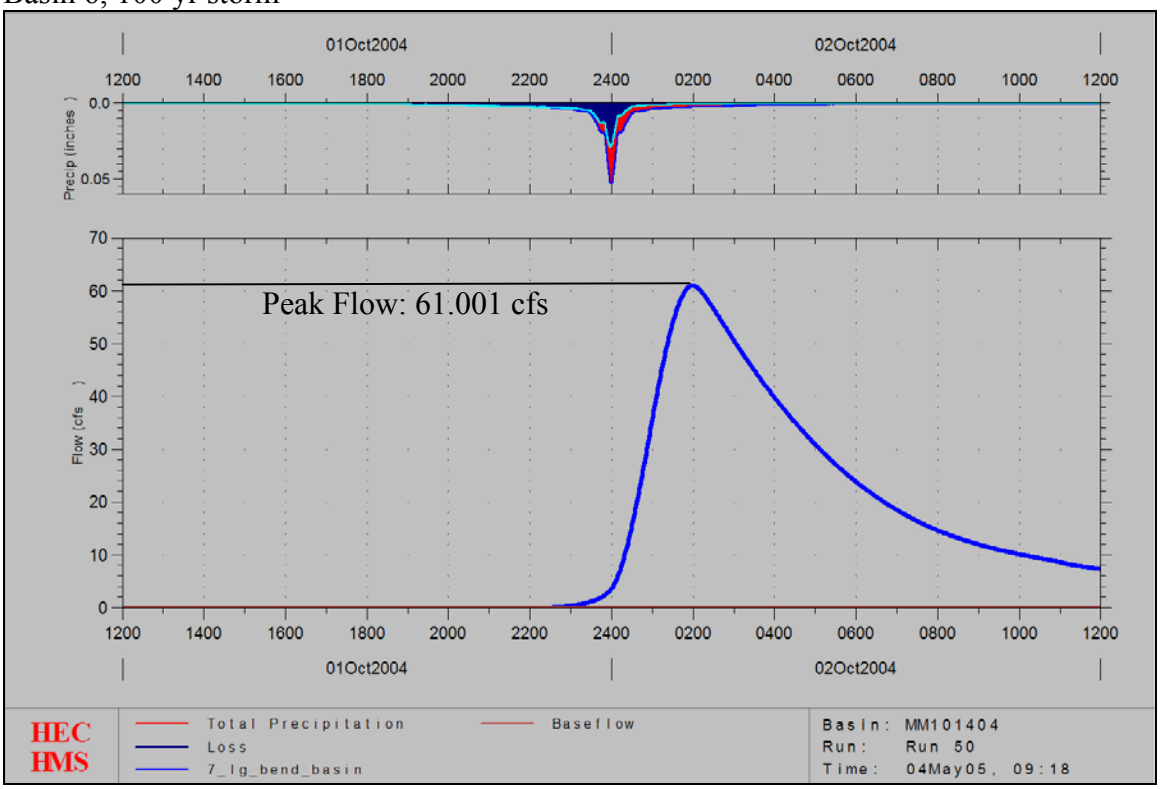
Basin 6, 2 yr storm



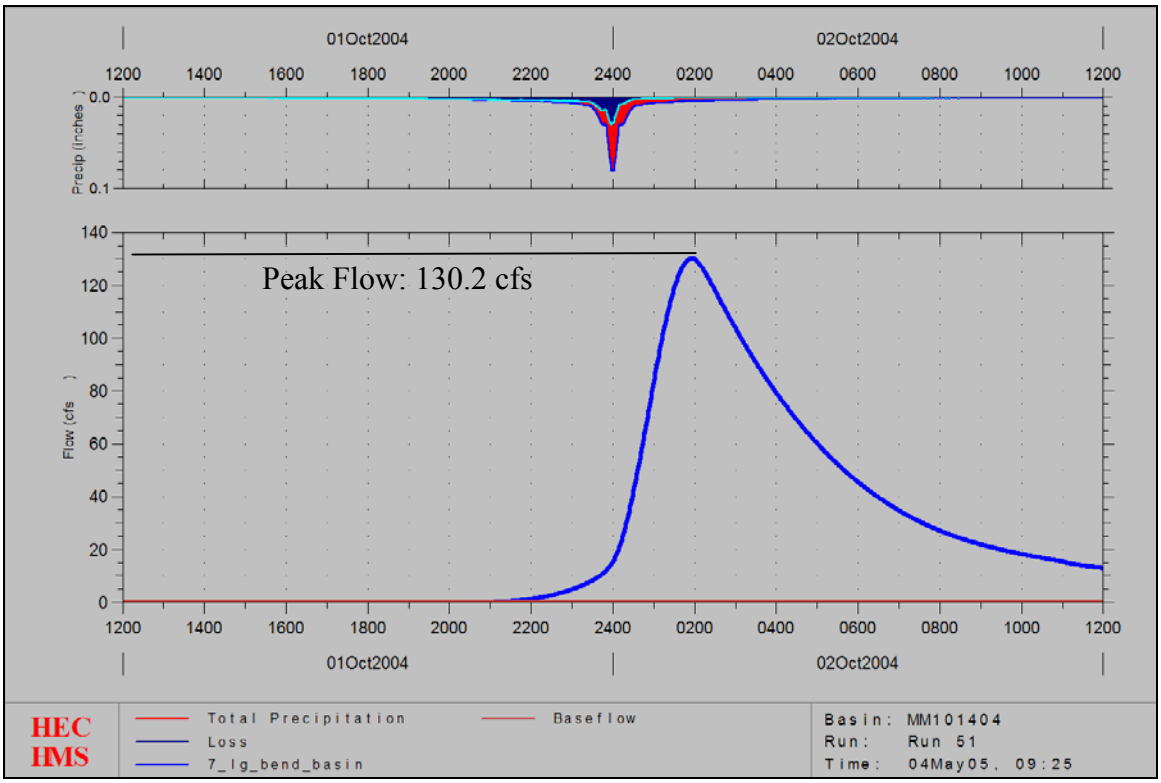
Basin 6, 10yr storm



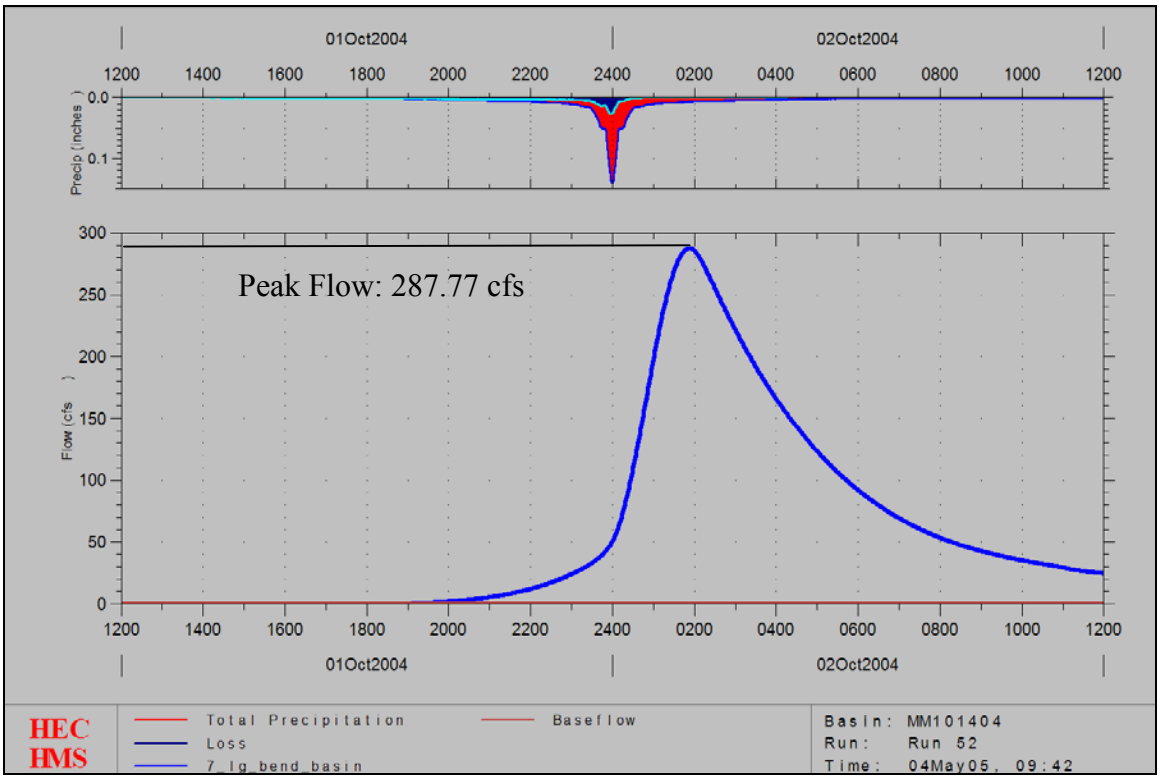
Basin 6, 100 yr storm



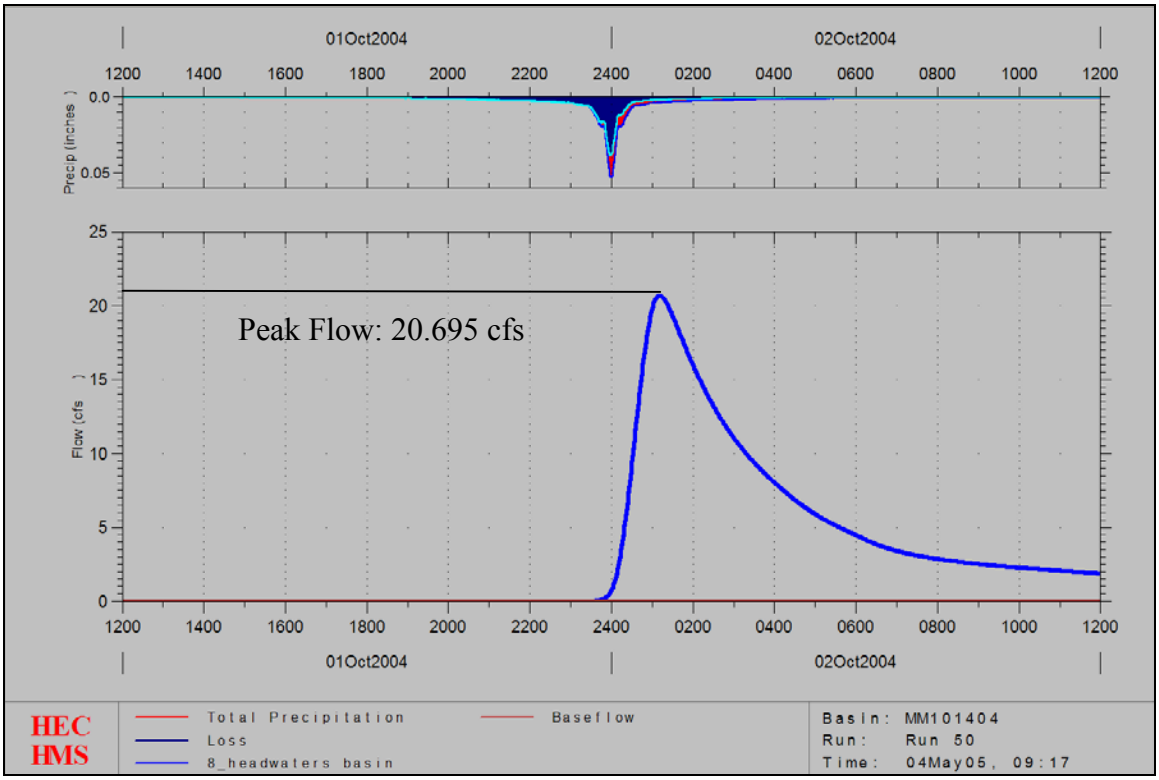
Basin 7, 2 yr storm



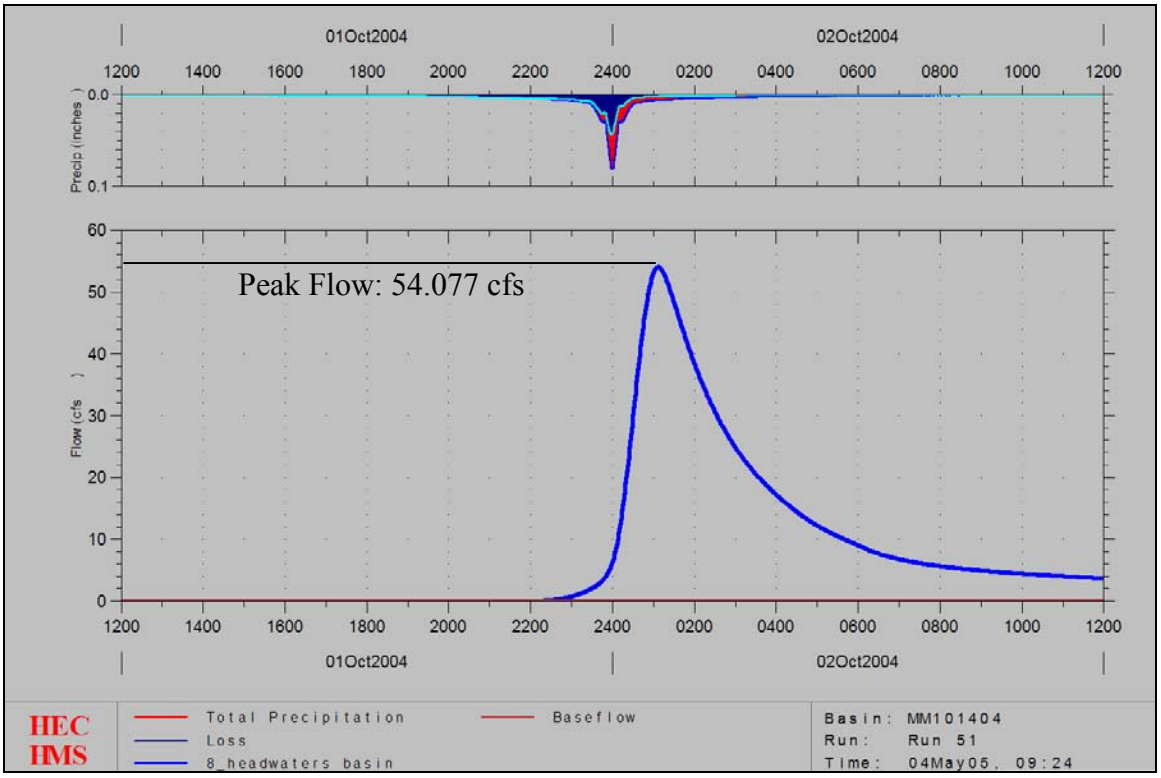
Basin 7, 10 yr storm



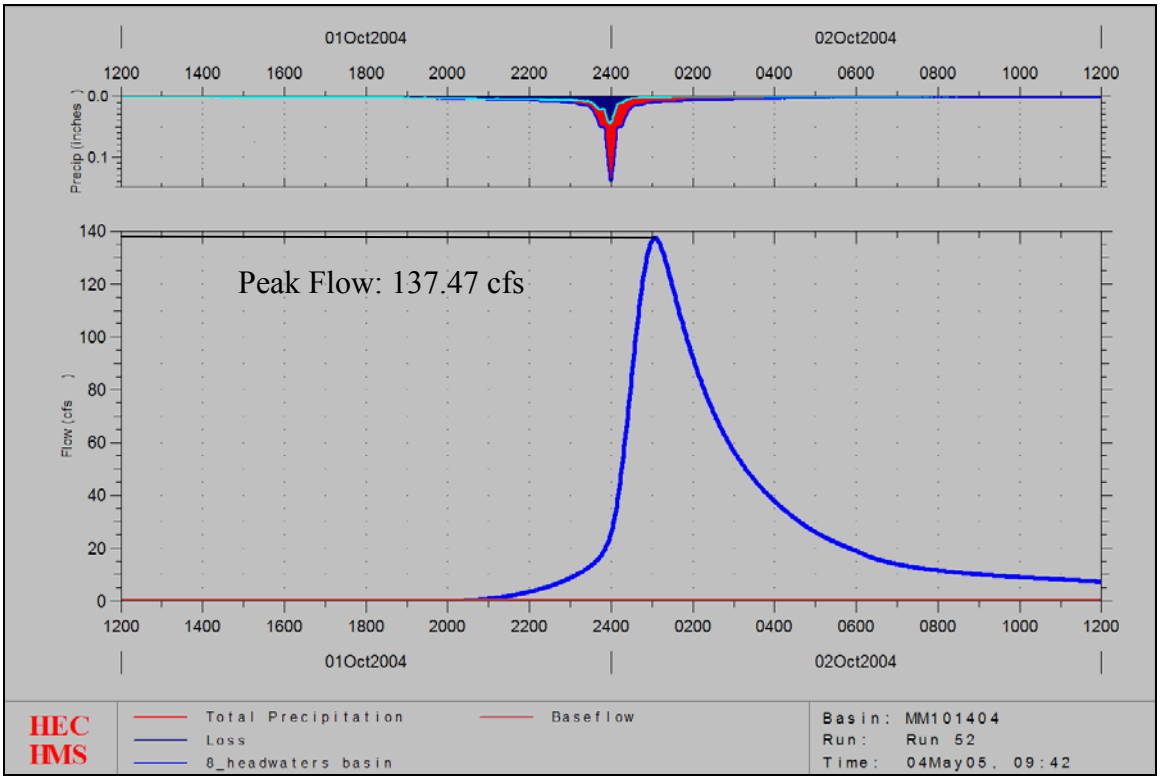
Basin 7, 100 yr storm



Basin 8, 2 yr storm



Basin 8, 10 yr storm



Basin 8, 100 yr storm

Attachment 5: Many Mind Creek Subbasin and Flood Delineation Maps

Attachment 6: Flow Regimen Options Used in Hydraulic Model

Flow Regimen Used in Comparing Response of Water Surface Elevation to Reduction in Flow

Reach	Cross Section	**FLOW in Cubic Feet per Second (CFS):** 2yr	2yr_lowCN	opt1	opt2	opt3	opt4	opt5	opt6	opt7
	(Upstream to Downstream)									
3	7361.626	20.695	16.388	1	20.695	8	20.695	1	20.695	20.695
3	5922.09	20.693	16.386	20.693	1	8	20.693	1	1	20.693
3	5542.364	20.689	16.383	20.689	20.689	8	4	1	1	4
3	2961.497	79.203	62.007	79.203	79.203	79.203	79.203	79.203	79.203	40
3	1619.356	79.161	61.973	79.161	79.161	79.161	79.161	79.161	79.161	79.161
3	908.378	133.93	104.55	133.93	133.93	133.93	133.93	133.93	133.93	133.93
4	2120.149	8.348	6.714	8.348	8.348	8.348	8.348	8.348	8.348	8.348
5	2865.557	180.59	140.74	180.59	180.59	180.59	180.59	180.59	180.59	180.59
5	2414.139	180.46	140.64	180.46	180.46	180.46	180.46	180.46	180.46	180.46
5	1284.001	233.62	181.16	233.62	233.62	233.62	233.62	233.62	233.62	233.62
5	288.65	216.62	166.57	216.62	216.62	216.62	216.62	216.62	216.62	216.62

Reach	Cross Section	opt8	opt9	opt10	opt11	opt12	opt13	opt14	opt15
3	7361.626	20.695	10	20.695	20.695	10	20.695	18	20.695
3	5922.09	20.693	10	20.693	20.693	10	20.693	18	20.693
3	5542.364	20.689	10	20.689	10	10	20.689	18	20.689
3	2961.497	30	10	50	50	30	20	50	20
3	1619.356	79.161	79.161	79.161	79.161	79.161	79.161	79.161	79.161
3	908.378	133.93	133.93	133.93	133.93	133.93	133.93	133.93	133.93
4	2120.149	8.348	8.348	8.348	8.348	8.348	8.348	8.348	8.348
5	2865.557	180.59	180.59	180.59	180.59	180.59	180.59	180.59	180.59
5	2414.139	180.46	180.46	180.46	180.46	180.46	180.46	180.46	180.46
5	1284.001	233.62	233.62	233.62	233.62	233.62	233.62	233.62	233.62
5	288.65	216.62	216.62	216.62	216.62	216.62	216.62	216.62	216.62