HEC-HMS AND XP-STORM SOFTWARE PROCEDURES EVALUATION

FCD 2011C002
Work Assignment #8

Prepared For:

Flood Control District of Maricopa County

Registered Professional Engineer (Civil)
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Date Signed 4/16/13
ARIZONA, U.S.A.
Expires 6/30/14

April 16, 2013

Prepared By:

JE FULLER
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TECHNICAL EVALUATION OF HEC-HMS SOFTWARE CAPABILITIES IN COMPARISON TO FCDMC HYDROLOGY PROCEDURES

Memorandum

Registered Professional Engineer (Civil)
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Date Signed 4/16/13
ARIZONA, U.S.A.
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DATE: April 16, 2013

TO: Bing Zhao, PhD, PE (FCDMC)
CC: Nathan Logan, PE, JEF
CC: Ted Lehman, PE, JEF

FROM: Hari Raghavan, PhD, PE, CFM

RE: HEC-HMS and XP-STORM Software Procedures Evaluation
(Contract Number 2011C002- Work Assignment #8)

HEC-HMS REVIEW

Purpose

JE Fuller/Hydrology & Geomorphology, Inc (JEF) has been contracted by the Flood Control District of Maricopa County (FCDMC) to evaluate HEC-HMS Version 3.5 and XP-Storm Software Version 12 to investigate compliance of the built-in procedures of each software against the methodologies and procedures in the FCDMC Drainage Design Manual-Hydrology (FCDMC, 2011) (Fourth Edition November 2009 with February, 2011 revisions). For sake of brevity, FCDMC Drainage Design Manual-Hydrology (FCDMC, 2011) is referred to as "FCDMC 2011 Manual" in the remainder of the text. This technical memo presents evaluation the overview and a list of deficiencies of HEC-HMS Software Version 3.5 (USACE 2010a).

1. Rainfall

a. Depth Area Reduction

The FCDMC 2011 manual specifies the Depth Area Reduction using Hydro-40. This is specified with HEC-1 (USACE, 1998) using the JD-PC or JD-PI records. HEC-HMS uses the curve presented in TP-40 document. In addition, HEC-HMS uses point values when storm area is less than 9.6 square miles and no adjustments are made for durations less than 30 minutes.

b. Temporal Pattern

The FCDMC 2011 manual defines rainfall hyetograph shape as a function for the contributing storm area. Specifically, the 6-hour storm is defined using 5 separate patterns. HEC-1 (USACE, 1998) allows the specification of the different shapes using the JD-PC or JD-PI combination.

c. Multi-storm Analysis

The Multi-Frequency storm analysis is available within HEC-HMS using only the Frequency Storm option. While this has some similarities, there are differences as well. The similarities include:

- Consideration of multiple frequencies
- Use of Depth Area Reduction

The differences are:

- Alternating block method is used to define the hydrograph shape. The peak time position can be specified as 25%, 50% and 75% of the total time duration.
- Depth area reduction curve is hardcoded from TP-40.
- The approach avoids doing multi-storm analysis as depth area reduction is performed individually for every concentration point using the total contributing area at that location. This process is somewhat computationally intensive compared to the interpolation process used in HEC-1.

2. Inflows

Both HEC-1 and HEC-HMS allow the specification of the hydrograph as source of inflows. HEC-1 allows the specification using the QI card as well as from DSS file. The same is true for HEC-HMS.

3. Rainfall Losses

FCDMC 2011 manuals presents computations of rainfall using Green and Ampt and Initial+Uniform Loss methods. Green and Ampt method is the preferred approach according to FCDMC.

a. **Green and Ampt** (G&A)

The FCDMC 2011 manual presents detailed procedures as to how to arrive at the G&A parameters. The DDMSW software (KVL Consultants Inc., 2010) is aimed at aiding the pre-processing of the inputs using the soil and land use coverages. Geo-HMS can be used develop the G&A inputs for HEC-HMS. However, the field names are different from the ones used by the District. The HEC-HMS Technical Reference Manual (USACE, 2010b) as well HEC-1 Users Manual (USACE, 1998) refers to EM 1110-2-1417 (USACE, 1994) for G&A procedure. The procedure uses Taylor-series expansion for the log-term in the G&A solution to the differential equation for the infiltration rate. A second-order approximation is used simplify the computations. Literature search specifies that the maximum error first-order approximation is 8% while the error is 0.003% for the second-order.

The HEC-HMS Version 3.5 Release Notes describes some changes made to the G&A procedure. Some of the changes are:

- Moisture deficit is replaced by Saturated content and Initial Content. Old models which specify only deficit will use 0.46 for Saturated Content and Initial Content will be 0.46 - deficit.
- Canopy method in the subbasin replaces the G&A initial loss rate method. Old models will have the initial loss rate moved to new canopy method. In HEC-HMS, Canopy method uses Initial Storage (%) and Maximum Storage (inches) as input.
- Changes may result in changed simulation results.

Tc and R can be specified in both HEC-1 and HEC-HMS. DDMSW Software (KVL Consultants Inc., 2010) has built in calculator. A similar calculator can be added to HEC-HMS.

b. **Initial Plus Uniform Loss**

Both HEC-1 and HEC-HMS have similar inputs: Initial loss, constant loss rate and % Imperviousness to handle this method.

4. Unit Hydrograph –

a. **Clark Unit Hydrograph**

The Clark-Unit Hydrograph procedure presented with HEC-1 and HEC-HMS area similar. The FCDMC 2011 manual employs two different Time-Area relations in addition to the HEC-1 Default: Urban and Natural. HEC-1 allows the specification of District customized Time Area Relations using UA card. HEC-HMS allows only the HEC-1 Default method.

b. **S-Graph**

It appears that the specification of the dimensionless S-graph and the time lag is similar in HEC-HMS

5. Channel Routing

FCDMC 2011 manual recommends use of Modified puls, Kinematic wave, Muskingum and Muskingum Cunge methods for channel routing. HEC-HMS incorporates the Kinematic Wave and Muskingum Cunge methods. The Modified puls channel routing method uses 8-point cross-section in HEC-1. Only the Muskingum Cunge method in HEC-HMS allows the use of 8-point cross-section. HEC-HMS supports Modified puls in reservoir routing. A stage-storage curve can be computed externally from 8 point cross-section and input as reservoir routing within HEC-HMS.

6. Diversions and Combines

Diversions and combines are handled similarly in HEC-HMS. However, the main issue is related to areal reduction. Since TP-40 builtin areal reduction is used, the areas are computed at each concentration location. The contributing area can be specified at the combines. If none is specified the areas are from individual combining hydrographs area added up.

7. Storage Routing

HEC-1 and HEC-HMS implement SV-SQ-SA-SE procedure similar to HEC-1. In HEC-1, only either area or volume specified. HEC-HMS requires specification of area as well as volume. This needs to be investigated further.

REFERENCES

FCDMC (2011), Drainage Design Manual for Maricopa County, Arizona – Hydrology, Fourth Edition with revisions made on February 2011.

USACE (2010a), Hydrologic Modeling System HEC-HMS User's Manual, Version 3.5, August 2010.

USACE (2010b), Hydrologic Modeling System HEC-HMS Technical Reference Manual, Version 3.5, August 2010.

USACE (2010c), HEC-GeoHMS Geospatial Hydrologic Modeling Extension, Version 5.0, October 2010.

KVL Consultants Inc. (2010), Drainage Design Management System – Users Manual, Version 4.6.0.

USACE (1998), HEC-1 Flood Hydrograph Package User's Manual, June 1998.

USACE (1994), Flood-Runoff Analysis, Engineer Manual, August 1994.

ACTION PLAN
FOR IMPLEMENTATION OF
FCDMC HYDROLOGY PROCEDURES IN
HEC-HMS SOFTWARE

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

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RE: HEC-HMS and XP-STORM Software Procedures Evaluation
(Contract Number 2011C002- Work Assignment #8)

HEC-HMS SOFTWARE MARICOPA COUNTY PROCEDURES IMPLEMENTATION PLAN

Purpose

JE Fuller/Hydrology & Geomorphology, Inc (JEF) has been contracted by the Flood Control District of Maricopa County (FCDMC) to evaluate HEC-HMS and XP-Storm software to investigate compliance of the built-in procedures of each software against the methodologies and procedures in the FCDMC Drainage Design Manual-Hydrology (FCDMC, 2011) (Fourth Edition November 2009 with February, 2011 revisions). For sake of brevity, FCDMC Drainage Design Manual-Hydrology (FCDMC, 2011) is referred to as "FCDMC 2011 Manual" in the remainder of the text. This technical memo presents a compilation of tasks identified as part of the implementation plan for incorporating the Maricopa County Hydrology procedures into the HEC-HMS software Version 3.5 (USACE, 2010).

Task 1 - Rainfall - Depth Area Reduction/Interpolated Multistorm Analysis

The procedure in FCDMC 2011 Manual uses NOAA14 rainfall depths, two sets of temporal rainfall distributions, and areal reduction factors to describe design rainfall events. Since the NOAA 14 rainfall statistics represent point probabilities, the FCDMC procedure uses a reduction factor to convert the point rainfall to an equivalent uniform depth of rainfall over the entire watershed, thus preserving the probability, or frequency, of the rainfall depth. As watershed area increases, the reduction factor decreases which has the effect of reducing the total rainfall and maintaining the same probability.

The FCDMC procedure presents the areal-reduction factor for 6-hour and 24-hour storm events as a function of drainage area (See Table 2.1 and Table 2.2 in FCDMC 2011 Manual). Within HEC-1, the storm area and reduced rainfall depth are specified using the JD record. Using the JD in combination with the PC or PI record, a temporal rainfall distribution or pattern can also be assigned to each storm area/reduced rainfall set. For the 6-hour storm event, five distinct rainfall patterns are identified as a function of drainage area. Table 2.4 in FCDMC 2011 Manual presents these five patterns. Figure 2.5 in FCDMC 2011 Manual presents the relationship between drainage area and pattern number.

Using these sets of areally reduced rainfall depth and storm pattern, HEC-1 performs a separate analysis for each storm, the so-called index storms. HEC-1 computes runoff hydrographs for each computation block for each index storm. HEC-1 then goes through each computation block within the model and computes the contributing drainage area using the drainage area information from all the upstream hydrological elements. This gives a specific computed contributing drainage area at each concentration point. Using these drainage area values, HEC-1 then interpolates the hydrograph results computed from the different index storms. In this manner, HEC-1 arrives at a distinct hydrograph for each concentration point. This entire procedure is done in a single run of HEC-1 and the results are presented in a single output.

In comparison, HEC-HMS incorporates depth-area relation only with the points selected for the simulation run and only when using the Frequency Storm and Depth Area Analysis options in HEC-HMS. In other words, HEC-1 incorporates areal-reduction for all the concentration points located in the model while HEC-HMS performs this only for the location selected for the simulation. In this process, HEC-HMS performs the exact areal reduction computations and eliminates the interpolation done within HEC-1. However, the computations performed are valid only for the selected concentration point as the areal reduction is performed with using contributing area to that concentration point.

HEC-HMS has the capability to automate the depth-area analysis to produce flow estimates at multiple concentration points when using the Frequency Storm and Depth Area Analysis option. However, for large Area Drainage Master Plan models, flow estimates with appropriate areal reduction are needed at all points within the model.

The purpose of this task will be to implement a procedure similar to that in HEC-1. The ability to input areal reduction factors as a function of drainage area with a specific rainfall distribution attached to each of data pairs (areal reduction factor and drainage area).

This capability could be conceptually based on the "Analysis" capability of the HEC-HMS but with interpolation of results instead of repeated runs for all concentration points. In addition, the option to use other Meteorological method types besides the Frequency Storm would need to be incorporated into HEC-HMS. Additional elements of the FCDMC rainfall procedures and their implementation in HEC-HMS are addressed in separate tasks below.

Task 2 - Rainfall - Hydro-40 Depth Area Reduction

The FCDMC 2011 Manual specifies the Depth Area Reduction using depth-area relations from Hydro-40. This is specified with HEC-1 using the JD-PC or JD-PI records. HEC-HMS uses the curve presented in TP-40 document. The purpose of this task will be to add Hydro-40 as an alternative to the TP-40. The data needed for this can be obtained from Table 2.1 and Table 2.2 of the FCDMC 2011 Manual for the 6-hour and 24 hour storms respectively.

Task 3 - Rainfall - Custom Temporal pattern

The FCDMC 2011 Manual defines the rainfall hyetograph shape for the 6-hour storm as a function for the storm area. Specifically, the 6-hour storm is defined using five separate patterns (See Table 2.4 in FCDMC 2011 Manual). The FCDMC procedures also use separate distinct 2-hour and 24-hour storm patterns (See Tables 2.3 and 2.5 in FCDMC 2011 Manual). HEC-1 allows the specification of the different shapes using the JD-PC or JD-PI combination. In HEC-HMS, the capability of inputting a custom hyetograph is available for single-storm analysis only. For a multi-storm analysis, the alternating block method in the Frequency Storm is used to define the hydrograph shape where the peak time position can be specified as 25%, 50% and 75% of the total time duration. The purpose of this task to incorporate the capability to use a custom storm specification within the multi-storm analyses as discussed in Task 1 presented above. The custom storm will be implemented in a similar way to the current capability where the "Specified Hyetograph" is assigned to a subbasin under "Meteorological Models" in combination with the Depth Area Analysis functionality.

Task 4 - Rainfall - Compute Watershed Average Rainfall

The FCDMC provides a GIS polygon shapefile of rainfall to be used in the development of hydrological models. This shapefile consists of polygons with a unique "RAINID" that is present in an integer attribute field. An accompanying table is also provided which relates the RAINID to the rainfall depths for the 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 200-year, 500-year and 1000-year storm frequencies and storm durations of 5, 10, 15, 30 minutes and 1, 2, 3, 6, 12 and 24 hour durations. The FCDMC procedure requires the hydrological modeler to develop a polygon shapefile coverage of subbasins. The purpose of this task is to develop a capability to compute watershed average rainfall using these three as inputs: rainfall shapefile, rainfall table and subbasin shapefile. The procedure will be based on the following steps:

a) Intersection of GIS layers of rainfall and subbasin
b) Compiling a list of RAINID's and corresponding areas from the intersection shapefile.
c) Computing the area-weighted average of the rainfall for various storm-events using the rainfall table.

Task 5 - Clark Unit Hydrograph - Custom Time Area Relation

The Clark-Unit Hydrograph procedure presented with HEC-1 and HEC-HMS are similar. The FCDMC 2011 Manual employs two different Time-Area relations in addition to the HEC-1 Default: Urban and

Natural. HEC-1 allows the specification of customized Time-Area Relations using UA card. HEC-HMS allows only the HEC-1 Default method.

The purpose of this task would be to incorporate the capability to use a custom Time-Area relation. The procedure adopted within HEC-HMS will be otherwise similar to the current procedure. The custom data can be entered into HEC-HMS as a paired data and used in the same manner as the other paired data. It may be noted that HEC-HMS improves upon the procedure in HEC-1 by scaling the unit hydrograph to achieve volume conservation (See HEC-HMS user's manual Appendix D for details). This improved procedure should be retained as is within HEC-HMS.

FCDMC procedure recommends the use of two specific custom time-area relations for the "Urban" and "Natural" watersheds. These are presented as paired data in Table 5.4 of the FCDMC Hydrology manual. These tables could be made available as built-in paired data for the users to select from.

Task 6 - Clark Unit Hydrograph - County Tc and R Calculation

FCDMC procedure requires the computation of time of concentration (Tc) and Storage Coefficient (R) using equations presented in Section 5.5 of the FCDMC Hydrology manual. The Tc equation requires the input of the following variables:

- L = Length of the hydraulically connected longest flow path in miles
- Kb = Watershed resistance coefficient
- S = Watershed Slope as ft/mile
- i = average rainfall excess intensity inches/hr

The values flow path length (L) and slope (S) are direct inputs from the user. Slopes (S) higher than 200 ft/mile are to be adjusted based on an equation presented in Section 5.5. The Kb value is computed using equations presented in Table 5.3 of the FCDMC 2011 Manual. This table identifies four simple equations for four different landuse types with three parameters: drainage area, m and b. The value of average rainfall excess intensity is to be computed by performing the subbasin Clark Unit Hydrograph run-off calculations with Tc=0 and R=0 with specified infiltration parameters using the same time step as the simulation run. The average of the highest ten rainfall excess values is then divided by the length of ten time intervals to arrive at the average rainfall excess intensity inch/hour.

The R equation is a simple equation (See Equation 5.8 in FCDMC 2011 Manual) requires the input of the following variables:

- Tc = Time of concentration in hours
- A = drainage area in square miles
- L = length of the flow path in miles

All the above parameters are user input parameters.

The purpose of this task is to incorporate the above procedure to compute the Tc and R values to be used in the Clark Unit Hydrograph computations. The procedure can be implemented within HEC-HMS under the "Transform" Tab.

Task 7 - Unit Hydrograph - County Specific S-Graph

FCDMC procedure requires the use of custom dimensionless S-Graphs. The procedure identifies 4 different S-Graphs (See Table 5.5 in FCDMC 2011 Manual) based on different landform type. In addition, the procedure requires the use of a specific Lag equation (See Equation 5.11 in FCDMC 2011 Manual) which requires the input of the following variables:

- L= length of the longest watercourse in miles
- Lca = length along the watercourse to a point opposite centroid in miles
- S = watercourse slope in ft/mile
- C = coefficient
- m and p = exponents

The parameters L, Lca and S are direct user inputs. C is computed as a simple function of another parameter Kn (24Kn or 26Kn). Table 5.6 in the FCDMC 2011 Manual identifies the relation between the landform type and Kn. The values of m and p are simply assigned depending on the source of Kn. The procedure to compute the Lag is briefly described as following:

- Determine landform type
- Compute Kn
- Assign m and p based on source Kn
- Compute C using either 24Kn or 26Kn depending on source of Kn
- Compute Lag using Eq 5.11 in FCDMC 2011 Manual.

The purpose of this task is to do the following:

- Incorporate the 4 different S-graphs as built-in S-graphs within HEC-HMS. These can be implemented as paired data within HEC-HMS.
- Add the ability to compute Lag using above procedure. This can be implemented in the "Transform" Tab within HEC-HMS.

Task 8 - Channel Routing - Modified Puls

FCDMC procedure requires one of these methods for channel routing: Modified Puls, Kinematic wave, Muskingum and Muskingum Cunge methods. HEC-HMS incorporates the Kinematic Wave, Muskingum, and Muskingum Cunge methods. The Modified Puls channel routing method uses an 8-

point cross-section in HEC-1. Only the Muskingum Cunge method in HEC-HMS allows the use of an 8-point cross-section. HEC-HMS supports Modified Puls in reservoir routing. A stage-storage curve can be computed from the 8 point cross-section and other normal depth parameters such as Manning's n, slope and reach length.

The purpose of this task is to implement the ability to accept an 8-point cross-section as input with HEC-HMS and compute channel routing using Modified Puls method. The channel reach may have to be split into sub-reaches to allow for stable computations.

Task 9 - Import Subbasin From Shapefiles

FCDMC procedure requires the creation of a polygon shapefile to represent the subbasins. The polygon shapefile has two attribute fields: "AREAID" and "BASINID". The "BASINID" field has the name of the major basin and "AREAID" field has the name of the subbasin.

The purpose of the task is to add the following capabilities:

- Read the shapefile and create subbasins that do not already exist.
- Assign areas to the subbasins using the polygon areas in the shapefile.

Task 10 - Import Parameters From Landuse and Soils Coverages

The FCDMC also provides landuse and soils coverages for the entire County with attribute fields identifying unique soil ids in "SOIL_LID" field and landuse id "LUCODE" fields. The soil and landuse coverages are accompanied by tables that relate the soil and landuse id's to the Green and Ampt parameters. The parameters in the soils table are:

- Soil ID, XKSAT, Rock Outcrop % and Erodibility factor K

The parameters in the landuse table are:

- Landuse code, Intial Loss (IA), % Impervious (RTIMP), Vegetation Cover, Moisture deficit type (DTHETA type) and Resistance Coefficient Type (Kb Type)

The ability to allow the modeler to add custom values to the Land Use and Soils data parameters to the tables should be included.

In addition, FCDMC also requires the development of subbasin shapefile as described in Task 9.

FCDMC requires the derivation of the following several input parameters from these shapefiles. A brief description of how the parameters are computed is presented below:

Green and Ampt parameters

The FCDMC 2011 Manual presents detailed procedures as to how to arrive at the Green and Ampt loss parameters. Section 4.5.1 in FCDMC 2011 Manual explains the procedure to compute the Green and Ampt parameters using the 3 shapefiles: soils, landuse and subbasins. In addition to the shapefiles, the procedure uses relationships between

a) Capillary suction (PSIF) and Hydraulic conductivity (XKSAT) (See Figure 4.3 in FCDMC 2011 Manual)
b) Moisture deficit (DTHETA) and Hydraulic conductivity (XKSAT) (See Figure 4.3 in FCDMC 2011 Manual)
c) Ratio of Hydraulic Conductivity to Bare Ground Hydraulic Conductivity and Vegetation Cover (See Figure 4.4 in FCDMC 2011 Manual). This is used in adjusting hydraulic conductivity for vegetation cover.

The procedure to compute these parameters are briefly described as:

- Perform GIS intersection of Subbasins and Soils layer and compute area-weighted (Some parameters log10-area weighted) estimation of soils-related parameters.
- Perform GIS intersection of Subbasins and landuse layer and compute area-weighted (Some parameters log10-area weighted) estimation of landuse-related parameters.
- Compute other parameters using equations or lookup tables (provided in Chapter 4 of FCDMC 2011 Manual).

Clark Unit Hydrograph Kb parameter

The landuse table includes the parameter identifying the Kb Type. This information along with the equations presented in Table 5.3 of FCDMC 2011 Manual is used to compute the Kb values. GIS intersection of the landuse and subbasin coverages are performed and the values assigned to the subbasins are computed using area-weighting method.

S-Graph Kn parameter

The landuse table includes the parameter "average Channel Mannings n" which can be used as the Kn value in S-Graph. . GIS intersection of the landuse and subbasin coverages are performed and the values assigned to the subbasins are computed using area-weighting method.

The purpose of this task is to develop capability to estimate and assign the above mentioned Green and Ampt, Clark Unit Hydrograph and S-Graph parameters using the subbasin shapefile, landuse shapefile, soils shapefile, landuse table, soils table and other equations/figures/tables presented in the FCDMC 2011 Manual.

Task 11 - Import Parameters From Flowpath and Lca Shapefiles

FCDMC requires the development of longest flowpath polyline and Lca polyline GIS shapefile by the hydrologic modeler. These shapefiles are attributed with ids "AREAID" and "BASINID" similar to the subbasin shapefile (described in Task 9). The flowpath shapefile has additional attributes "USGE" and "DSGE" containing the upstream and downstream elevations. The values from these attribute fields are to be used in the computation of slope parameter.

The purpose of this task is to import and estimate the length and slope parameters using the flowpath polyline and Lca polyline GIS shapefiles.

Task 12 - Development of Report Templates

FCDMC requires submittal of hydrology results in the form of tables. Most model outputs are submitted as a DDMSW model which is a pre- and post-processor to HEC-1. DDMSW is FCDMC developed software (KVL Consultants Inc., 2010) that has the capability to print hydrologic results in tabular form using the built-in report capability.

The purpose of this task is to develop capability to generate reports of hydrologic results similar to that generated by DDMSW software.

REFERENCES

FCDMC (2011), Drainage Design Manual for Maricopa County, Arizona – Hydrology, Fourth Edition with revisions made on February 2011.

KVL Consultants Inc. (2010), Drainage Design Management System – Users Manual, Version 4.6.0.

USACE (2010), Hydrologic Modeling System HEC-HMS User's Manual, Version 3.5, August 2010.

TECHNICAL EVALUATION OF XP-STORM SOFTWARE CAPABILITIES IN COMPARISON TO FCDMC HYDROLOGY PROCEDURES

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Memorandum

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Expires 06-30-2015

DATE: April 16, 2013

TO: Bing Zhao, PhD, PE (FCDMC)
CC: Hari Raghavan, PhD, PE, JEF
CC: Ted Lehman, PE, JEF

FROM: Nathan Logan, PE, CFM

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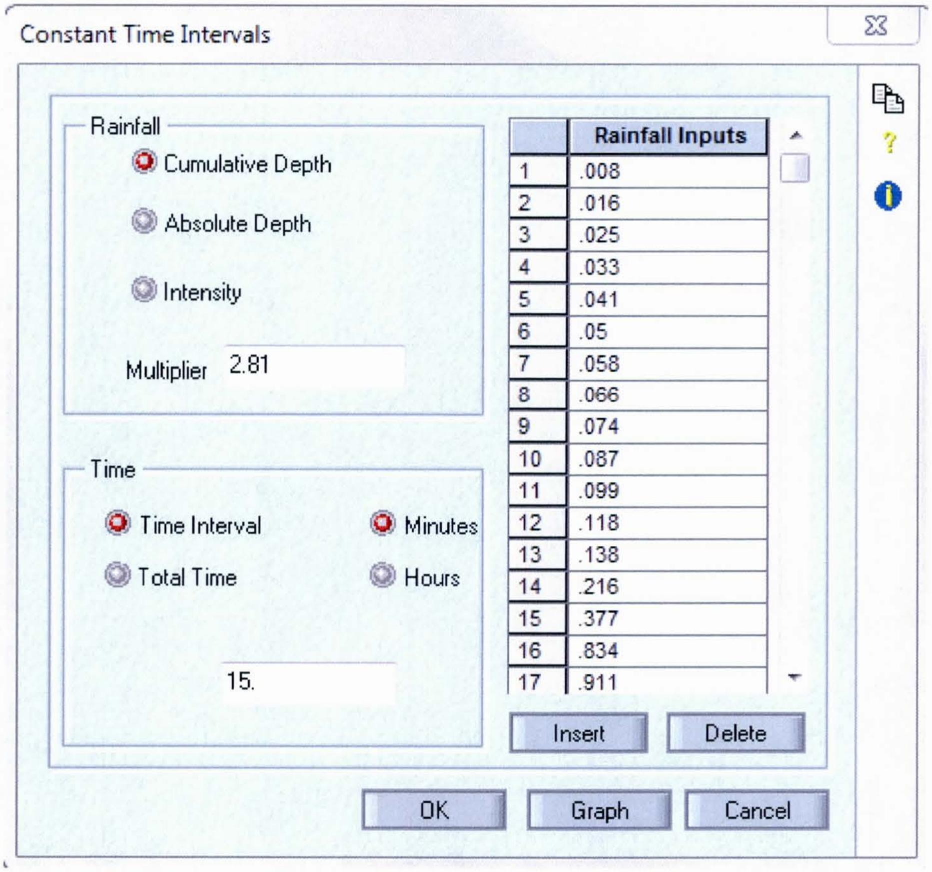
To Do List For XPStorm

One-Dimensional Module (xpswmm):

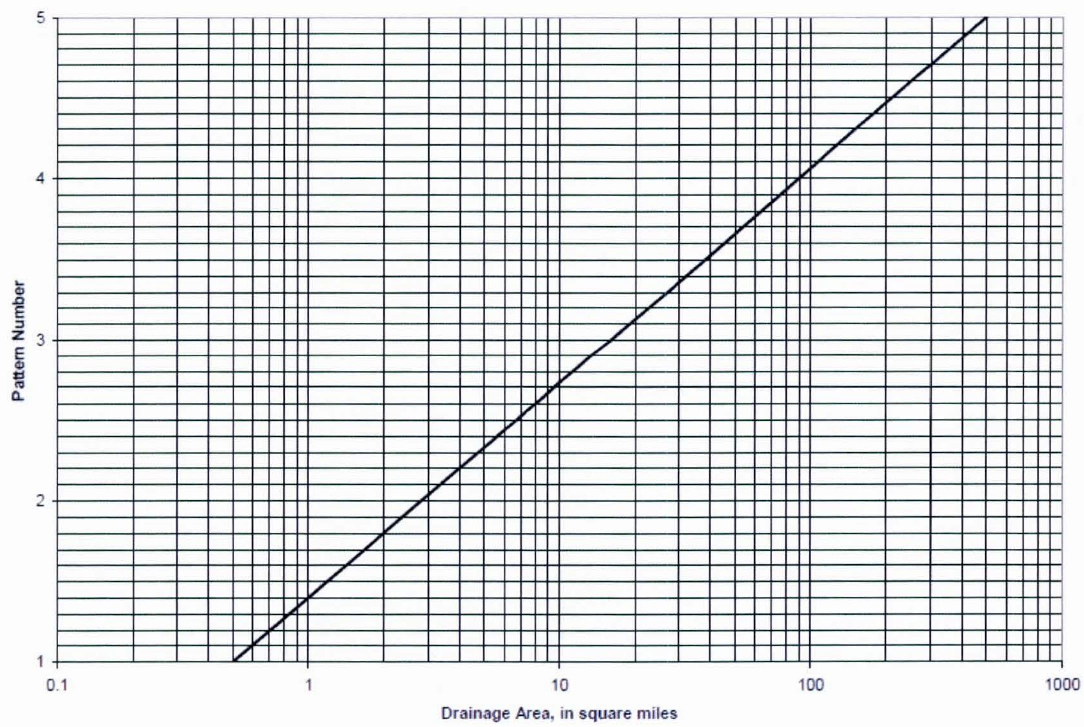
1. **Rainfall** – Each node is effectively a subbasin requiring a rainfall database associated with it. The database is a point rainfall depth and a temporal distribution that will be applied to the node. Multiple nodes can reference the same rainfall database if applicable but individual databases are required if there are variations in rainfall data, such as the point precipitation depth or temporal distribution, for each subbasin. A view of a typical rainfall database is shown below.



a. **Point-Precipitation Depth** - There is no GIS interface to compute the point rainfall over the watershed like there is with DDMSW, the point rainfall must be manually entered for each distribution/rainfall database.

b. **Temporal Distributions** - Temporal distributions can be manually added and exported/imported from xpswmm. A user can enter the FCDMC Temporal distributions per the Manual and export them for future import into future projects. The first entry into the Temporal Distribution is the first time interval entry and not 0hr, 0% depth. If the first input into the distribution is "0", the distribution will be offset by one time interval and will offset the Time to Peak. A function needs to be incorporated into xpswmm to allow the user to link the correct 6-hour temporal distributions to a node based on its drainage area using the following figure from the FCDMC 2011 Manual and the 6-hour patterns.

Area Versus Pattern Number for Maricopa County



6-Hour Distributions

Time, in hours	Percent of Rainfall Depth				
	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5
0.00	0.0	0.0	0.0	0.0	0.0
0.25	0.8	0.9	1.5	2.1	2.4
0.50	1.6	1.6	2.0	3.5	4.3
0.75	2.5	2.5	3.0	5.1	5.9
1.00	3.3	3.4	4.8	7.1	7.8
1.25	4.1	4.2	6.3	8.7	9.8
1.50	5.0	5.1	7.6	10.5	11.9
1.75	5.8	5.9	9.0	12.5	14.1
2.00	6.6	6.7	10.5	14.3	16.2
2.25	7.4	7.6	11.9	16.0	18.6
2.50	8.7	8.7	13.5	17.9	21.2
2.75	9.9	10.0	15.2	20.1	23.9
3.00	11.8	12.0	17.5	23.2	27.1
3.25	13.8	16.3	22.2	28.1	32.1
3.50	21.6	25.2	30.4	36.4	40.8
3.75	37.7	45.1	47.2	50.0	51.5
4.00	83.4	69.4	67.0	65.8	62.7
4.25	91.1	83.7	79.6	77.3	73.5
4.50	93.1	90.0	86.8	84.1	81.4
4.75	95.0	93.8	91.2	88.8	86.4
5.00	96.2	95.0	94.6	92.7	90.7
5.25	97.2	96.3	96.0	94.5	93.0
5.50	98.3	97.5	97.3	96.4	95.4
5.75	99.1	98.8	98.7	98.2	97.7
6.00	100.0	100.0	100.0	100.0	100.0

c. **Depth-Area Reduction Factors** – Depth-Area reductions factors are currently not present in xpswmm and to account for the areal reduction factor individual rainfall databases are required for each node with node specific point rainfall depths that have been adjusted based upon the subbasin area and subsequent reduction factor. Per the FCDMC 2011 Manual, the following depth-area reduction factors need to be incorporated into the xpswmm module.

DEPTH-AREA REDUCTION FACTORS FOR THE 24-HOUR DURATION RAINFALL

Area, sq. miles	Depth-Area Reduction Factor (ratio to point rainfall)
0	1.000
1	0.995
5	0.975
10	0.950
20	0.918
30	0.900
40	0.887
50	0.877
60	0.870
70	0.863
80	0.857
90	0.852
100	0.848
110	0.845
120	0.841
130	0.838
140	0.835
150	0.832
200	0.820
250	0.812
300	0.806
400	0.796
500	0.783

DEPTH-AREA REDUCTION FACTORS FOR THE 6-HOUR DURATION RAINFALL

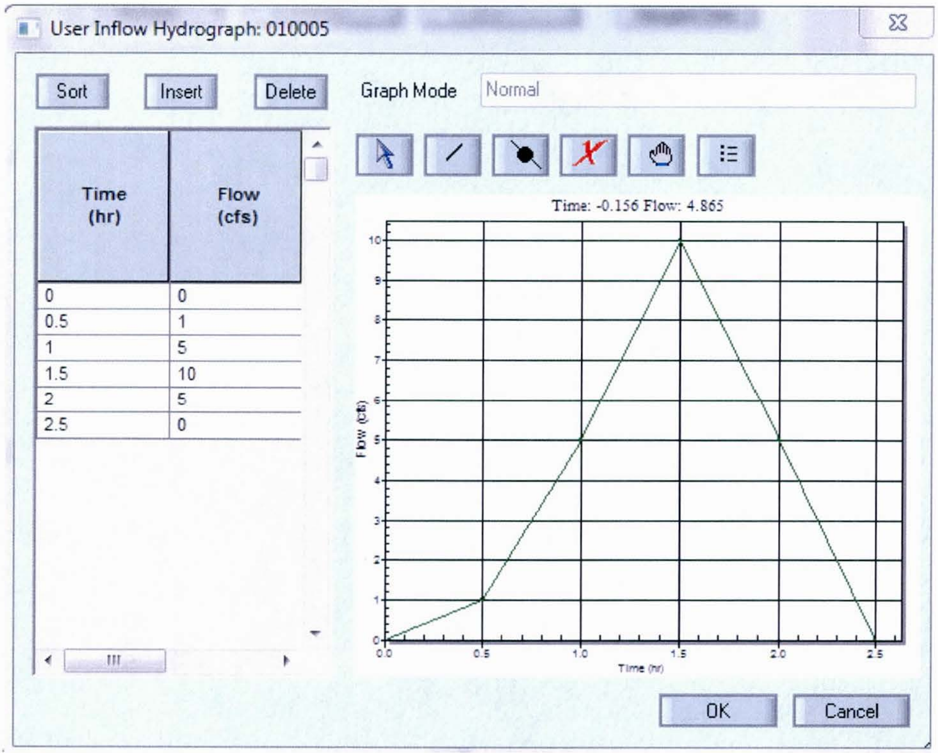
Area, sq. miles	Depth-Area Reduction Factor (ratio to point rainfall)
0.0	1.000
0.5	**0.994**
1.0	0.987
2.8	**0.975**
5.0	0.960
10.0	0.940
16.0	**0.922**
20.0	0.910
30.0	0.890
40.0	0.870
90.0	**0.810**
100.0	**0.800**

Note: Bold values correspond to the 6-hour design storm pattern numbers.

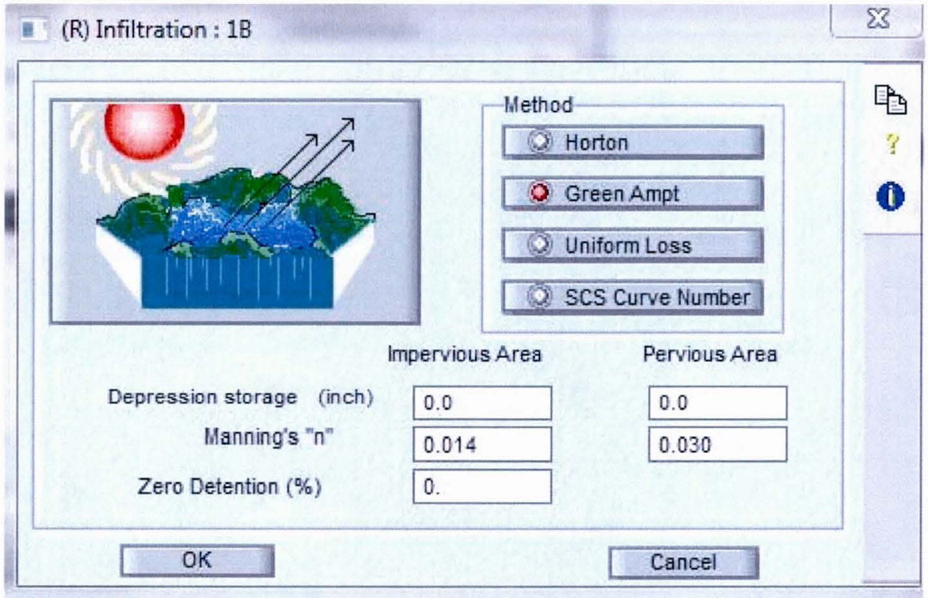
d. **Multiple Frequency Events** – Multiple frequencies can be modeled in the same model by creating "Child" scenarios. This would allow the user to update the model rainfall data only and run multiple scenarios under a single model run.

e. The xpswmm user can remain compliant with the FCDMC 2011 Manual with respect to rainfall data. The user would have to use different rainfall depths and temporal patterns for each subbasin depending on the subbasin area. This however, can be time consuming and opens the possibility of input error. The xpswmm program would be more useful if a function or external calculator could link the node with correct rainfall depths and distributions depending on the area rather than requiring the user to manually update individual rainfall databases.

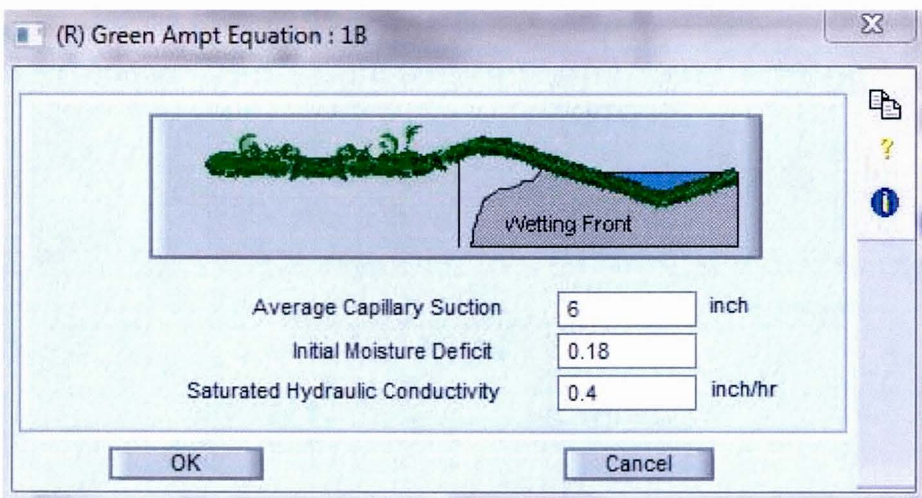
f. Inflows – Inflows can be entered as ser defined rating curves in the node data.



2. **Rainfall Losses** – The rainfall loss (Infiltration) methods available include Green and Ampt, and Initial and Uniform Loss. Each method is discussed in further detail in the following sections.
    a. **Green and Ampt** - Global data for the Green and Ampt infiltration is Depression Storage (Initial Abstraction), manning's n-values for overland flow, and Zero Detention percentage. The Zero Detention percentage is described in the user's manual as "Percentage of the subcatchment impervious area with zero detention (immediate runoff), 0.0 - 100.0 percent. This parameter assigns a percentage of the impervious area a zero depression storage in order to promote immediate runoff."



Under the Green Ampt toggle button the user can enter the remaining required parameters.



The xpswmm algorithm for Green and Ampt infiltration is shown in the following equations:

```
IF F < Fs THEN
        f = i
        IF i > Ks THEN
            Fs = (Su * IMD) / (i/Ks - 1)
        END
ELSE
        f = Fp
        Fp = Ks * (1 + Su * IMD / F)
END
```

Where:

f	= infiltration rate, ft/sec
Fp	= infiltration capacity, ft/sec
i	= rainfall intensity, ft/sec
F	= cumulative infiltration volume, this event, ft
Fs	= cumulative infiltration volume required to cause surface saturation, ft
* Su	= average capillary suction at the wetting front, ft water
* IMD	= initial moisture deficit for this event, ft/ft
* Ks	= saturated hydraulic conductivity of soil, ft/sec

To compare the total infiltration between xpswmm and HEC-1, a simplified HEC-1 model was constructed to compare subbasin infiltration values with those of xpswmm, see the total loss column in the table below.

Subbasin Basin A was modeled under three infiltration scenarios to see the effects of a large subbasin with high, middle, and low infiltration rates. With the exception of the modeling of Basin A under the low infiltration scenario xpswmm produced equal to higher peak flows with very similar total infiltration losses relative to HEC-1.

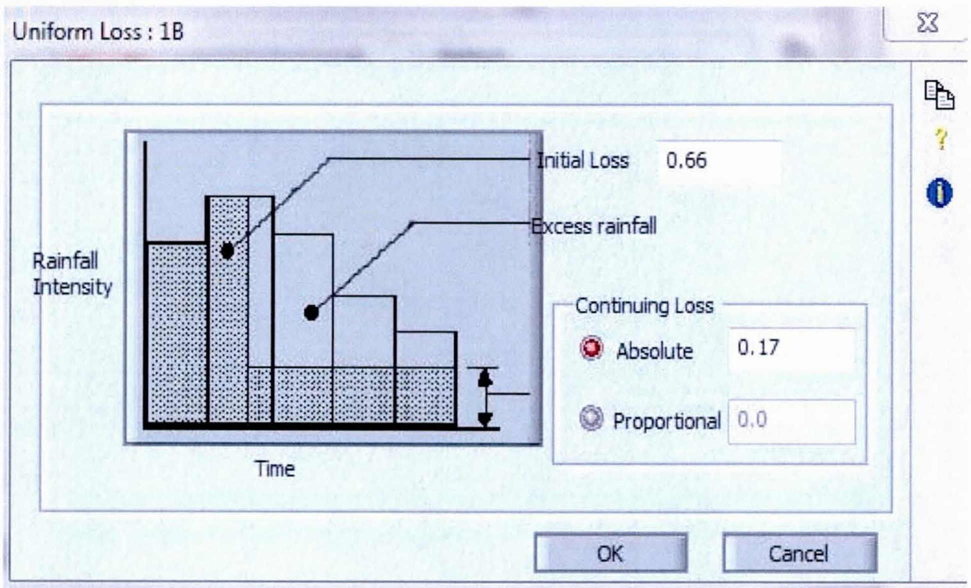
SUBBASIN ID	Area (sq mi)	HEC-1				xpswmm		
		Q Peak (cfs)	Tp (hrs)	Total Loss (in)		Q Peak (cfs)	Tp (hrs)	Total Loss (in)
010005	0.06	149	4.03	0.96		151	4.03	0.96
010010	0.14	208	4.15	1.26		210	4.15	1.26
010110	0.02	38	4.07	1.16		39	4.07	1.15
010105	0.02	48	4.03	1.48		50	4.03	1.46
010015	0.1	241	4.03	0.88		241	4.03	0.89
***Basin A_1**	5.7	8,275	4.47	0.22		8,227	4.47	0.29

SUBBASIN ID	Area (sq mi)	HEC-1				xpswmm		
		Q Peak (cfs)	Tp (hrs)	Total Loss (in)		Q Peak (cfs)	Tp (hrs)	Total Loss (in)
*Basin A_2	5.7	6,708	4.48	0.85		6,743	4.48	0.86
*Basin A_3	5.7	5,738	4.48	1.09		5,768	4.48	1.09

*Basin A was modeled under 3 conditions to see the effect of different infiltration parameters on the results:

1. Low Infiltration (XKSAT 0.01 in/hr, PSIF 12.4 in, DTHETA 0.05)
2. Mid Infiltration (XKSAT 0.40 in/hr, PSIF 4.3 in, DTHETA 0.25)
3. High Infiltration (XKSAT 1.20 in/hr, PSIF 2.4 in, DTHETA 0.30)

b. **Initial Plus Uniform Loss** – The Initial plus Uniform Loss method is under the same primary infiltration window previously shown for the Green and Ampt method. The initial and constant loss values are entered under the Uniform loss toggle.

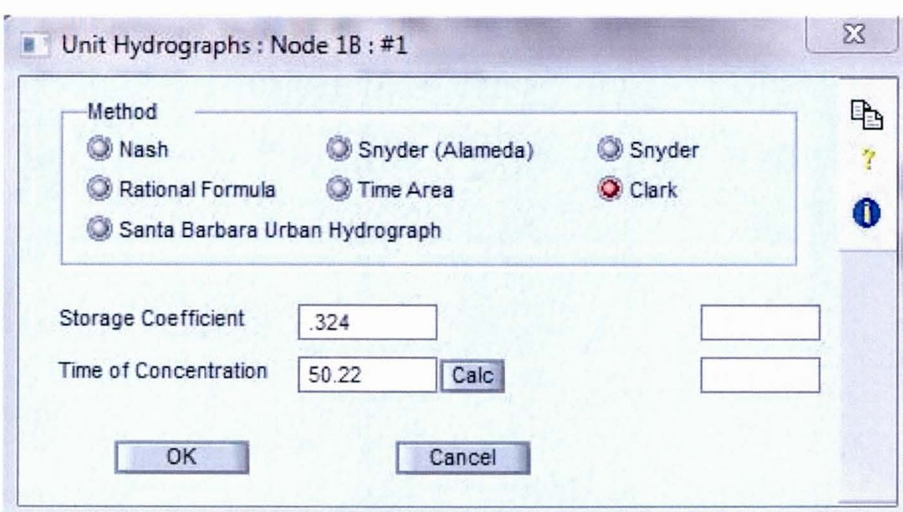


A simple HEC-1 model and xpswmm model is used to compare the results between the two models. The results between the two models are summarized in the following table.

SUBBASIN ID	Area (sq mi)	RTIMP %	HEC-1			xpswmm		
			Q Peak (cfs)	Tp (hrs)	Total Loss (in)	Q Peak (cfs)	Tp (hrs)	Total Loss (in)
1A	7.00	0	6,455	4.55	1.24	6,438	4.55	1.24
1B	5.70	25	5,461	4.48	0.85	5,452	4.48	0.84
1C	1.00	85	963	4.43	0.18	963	4.43	0.14
1D	1.00	50	913	4.45	0.61	912	4.45	0.58
1E	1.00	25	877	4.45	0.91	875	4.45	0.90
1F	1.00	0	842	4.45	1.22	839	4.45	1.21

The peak flows are very similar in the large area basins (1A and 1B) and nearly identical for the smaller 1 sq. mi. basin (1C through 1F) but the total loss due to infiltration changes with the change in the basin percent impervious. Subbasin 1C, 1D, 1E, and 1F area identical basins with the exception of the percent impervious, as the percent increases the so does the loss difference between HEC-1 and xpswmm. Although minor, there appears to be a difference in how the percent impervious is applied to the Initial and Uniform total loss between the two models.

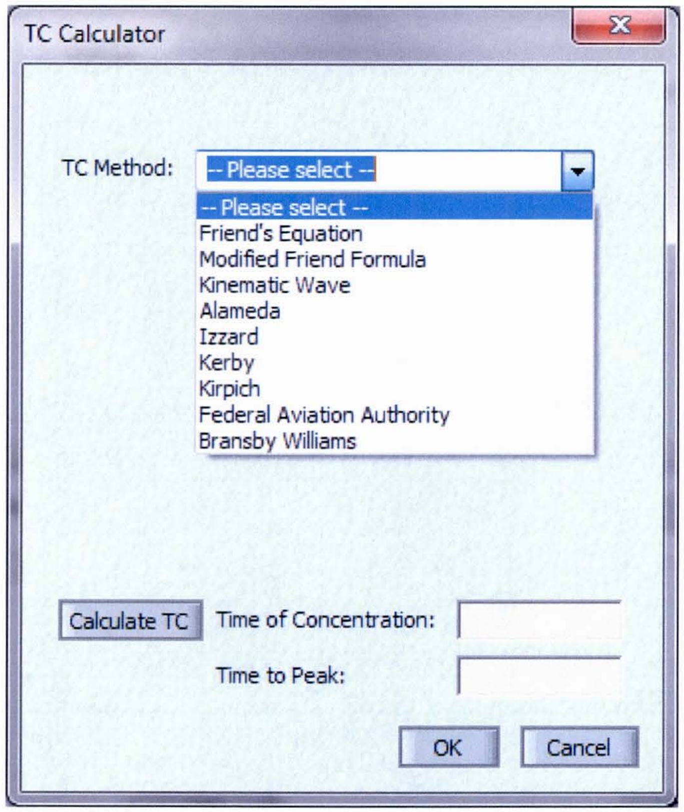
3. **Unit Hydrograph** – Per the FCDMC 2011 Manual there are two unit hydrographs available for use, Clark Unit Hydrograph and S-Graph.
   a. **Clark Unit Hydrograph** – The Clark Unit Hydrograph is an available method within xpswmm.



The input is Tc (min) and the storage coefficient (R) in hours. Per the FCDMC 2011 Manual, the method of calculating the Tc is the Papadakis and Kazan equation as shown below (Equation 3.2 in the Manual):

$$T_c = 11.4L^{0.5}K_b^{\ 0.52}S^{-0.31}i^{-0.38}$$

This method is not one of the methods available for calculating the Tc within xpswmm, the Tc can be manually entered but not automatically computed. The Papadakis and Kazan equation should be added to the Tc equations list.



Once the Papadakis and Kazan equation is added to the list of Tc methods, the Tc computation window should also include the FCDMC Kb equation with descriptions and include the adjustment factors for slope adjustments using the FCDMC adjustment factors.

Table 5.3
EQUATION FOR ESTIMATING K_b IN THE T_c EQUATION

$$K_b = m \log A + b$$

Where A is drainage area, in acres

Type	Description	Typical Applications	Equation Parameters m	Equation Parameters b
A	Minimal roughness: Relatively smooth and/or well graded and uniform land surfaces. Surfaces runoff is sheet flow.	Commercial/industrial areas Residential area Parks and golf courses	-0.00625	0.04
B	Moderately low roughness: Land surfaces have irregularly spaced roughness elements that protrude from the surface but the overall character of the surface is relatively uniform. Surface runoff is predominately sheet flow around the roughness elements.	Agricultural fields Pastures Desert rangelands Undeveloped urban lands	-0.01375	0.08
C	Moderately high roughness: Land surfaces that have significant large to medium-sized roughness elements and/or poorly graded land surfaces that cause the flow to be diverted around the roughness elements. Surface runoff is sheet flow for short distances draining into meandering drainage paths.	Hillslopes Brushy alluvial fans Hilly rangeland Disturbed land, mining, etc. Forests with underbrush	-0.025	0.15
D	Maximum roughness: Rough land surfaces with tortuous flow paths. Surface runoff is concentrated in numerous short flow paths that are often oblique to the main flow direction.	Mountains Some wetlands	-0.030	0.20

Note: A is the area of the entire subbasin, not the area of the surface type A, B, C or D within the subbasin.

Table 5.2
SLOPE ADJUSTMENT FOR STEEP WATERCOURSES

Natural Slope (S)	Adjusted Slope (S_{adj})	Natural Slope (S)	Adjusted Slope (S_{adj})
200	200	410	290
210	209	420	292
220	218	430	294
230	226	440	295
240	233	450	296
250	240	460	298
260	246	470	299
270	251	480	300
280	255	490	301
290	260	500	303
300	263	510	304
310	267	520	305
320	270	530	306
330	273	540	307
340	275	550	309
350	278	560	310
360	280	570	311
370	283	580	312
380	285	590	313
390	287	600	313
400	288		

The adjusted slope is based on the following:

1. For $0 < S <= 200$, $S_{adj} = S$
2. For $200 < S <= 600$, $S_{adj} = a_0+a_1S+a_2S^2+a_3S^3+a_4S^4+a_5S^5+a_6S^6+a_7S^7$

   where:

$a_0 =$ 6.725897827E+02
$a_1 =$ -1.634093666E+01
$a_2 =$ 1.739404649E-01
$a_3 =$ -8.902683621E-04
$a_4 =$ 2.552852266E-06
$a_5 =$ -4.203532411E-09
$a_6 =$ 3.721179614E-12
$a_7 =$ -1.374400319E-15

In the current input window for Tc and R, the storage coefficient must be manually entered. The input window should be modified to compute the coefficient using the equation specified in the FCDMC 2011 Manual.

$$R = 0.37 T_c^{1.11} A^{-0.57} L^{0.80}$$

where:

R = storage coefficient, in hours,

T_c = time of concentration, in hours,

A = drainage area, in square miles, and

L = length of flow path, in miles.

i. *Clark Unit Hydrograph Time-Area Methods* - The time-area relationships specified for Urban and Natural Watersheds as shown in the FCDMC 2011 Manual are not available to be used with xpswmm since there is not a location for entry of user defined Time-Area relationship available. The xpswmm program uses the HEC-1 Default and the relationship is defined below as noted in the xpswmm reference manual.

xswmm utilizes a dimensionless time area curve:

$AI =$	$1.414\ T$^1.5	for $0 <= T < 0.5$
$1 - AI =$	$1.414\ (1 - T)$^1.5	for $0.5 < T < 1$

where:

AI = cumulative area as a fraction of total subcatchment area and
T = fraction of time of concentration.

A location should be added in the primary Clark Unit Hydrograph input parameter window in xpswmm to either include a option for user defined time-area relationships or include the FCDMC relationships shown below.

VALUES OF THE SYNTHETIC DIMENSIONLESS TIME-AREA RELATIONS
FOR THE CLARK UNIT HYDROGRAPH

Time, as a percent of Time of Concentration (1)	Contributing Area, as a Percent of Total Area		
	Urban Watersheds (2)	Natural Watersheds (3)	HEC-1 Default (4)
0	0	0	0.0
10	5	3	4.5
20	16	5	12.6
30	30	8	23.2
40	65	12	35.8
50	77	20	50.0
60	84	43	64.2
70	90	75	76.8
80	94	90	87.4
90	97	96	95.5
100	100	100	100.0

b. **S-Graph** - S-Graph unit hydrograph is not currently an option in xpswmm and should be added as an option in the primary Unit Hydrograph window. The documentation of the FCDMC S-graph data is in the appendix of this memo.

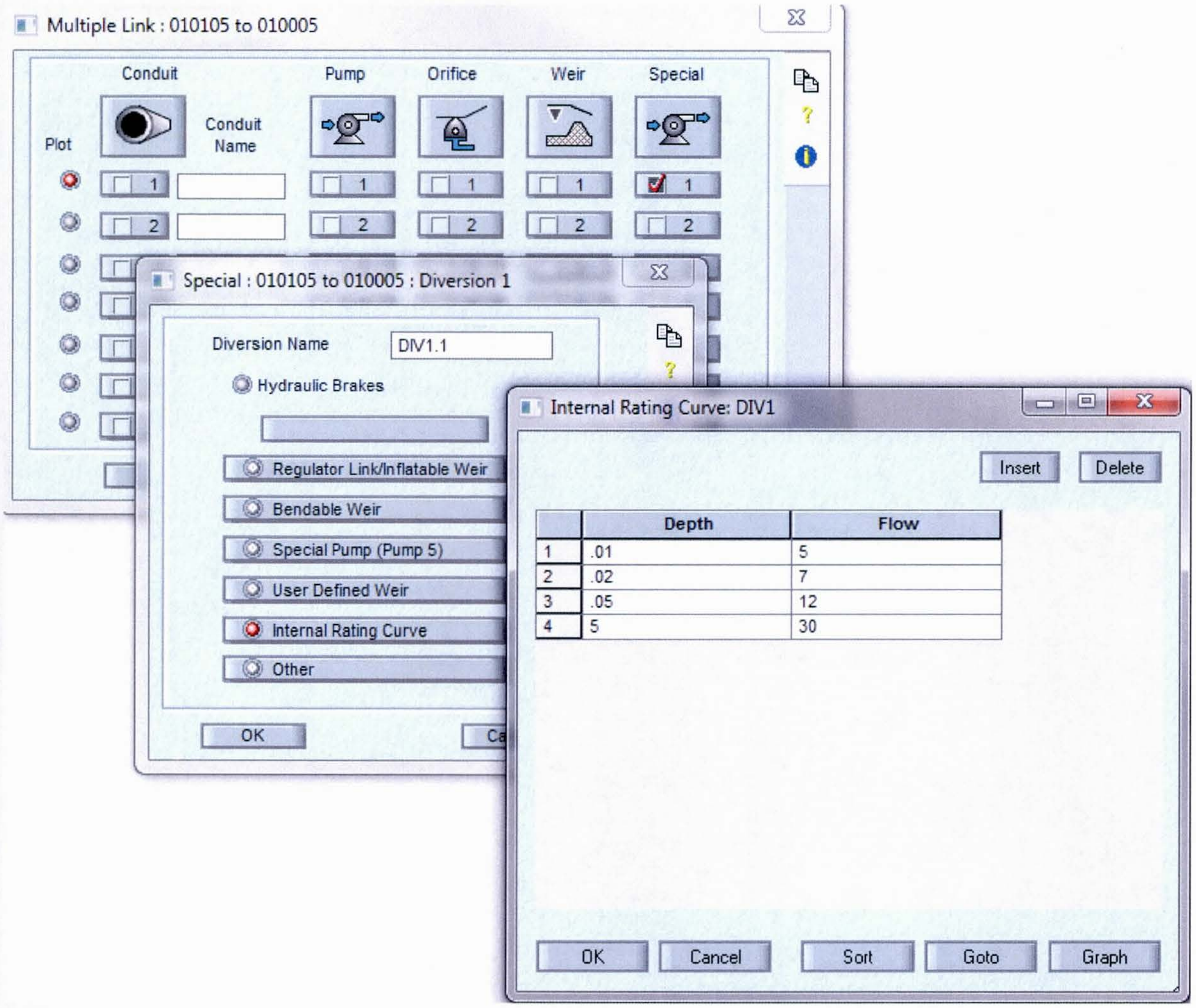
4. **Routing** – Hydrograph routing is accomplished in xpswmm though the use of links connected to nodes. The links can be closed conduits, open channels (engineered or naturally shaped), or a combination of both consisting of a variety of shapes, sizes, and materials. The routing numerical method is accomplished using the full St. Venant equations. There are advanced routing options to use the full Dynamic Wave routing, which is the default, and then options of always use non-linear acceleration terms, never use non-linear acceleration terms, and then Kinematic Wave. Per the xpswmm manual, the Dynamic Wave method is recommended where there is any chance of a backwater effect in the system.

   a. A simplified model was constructed using a single inflow hydrograph (from DDMSW KVL Example 1, HYD001 Qpeak = 7,765 cfs) and routed through a route. The routings consisted of an 8-point channel routing (Routing 010110 in DDMSW KVL Example 1), and then using the Kinematic Wave, and the Muskingum Cunge with a trapezoidal section to compare the results of xpswwm against HEC-1. The xpswmm routings were modeled using the same 8-point section as the HEC-1 model under each of the 4 advanced routing techniques available in xpswmm. Likewise, the same trapezoidal section modeled in HEC-1 for the Kinematic and Muskingum Cunge methods was used for xpswmm under the 4 advanced routing conditions. The results are summarized in the following table:

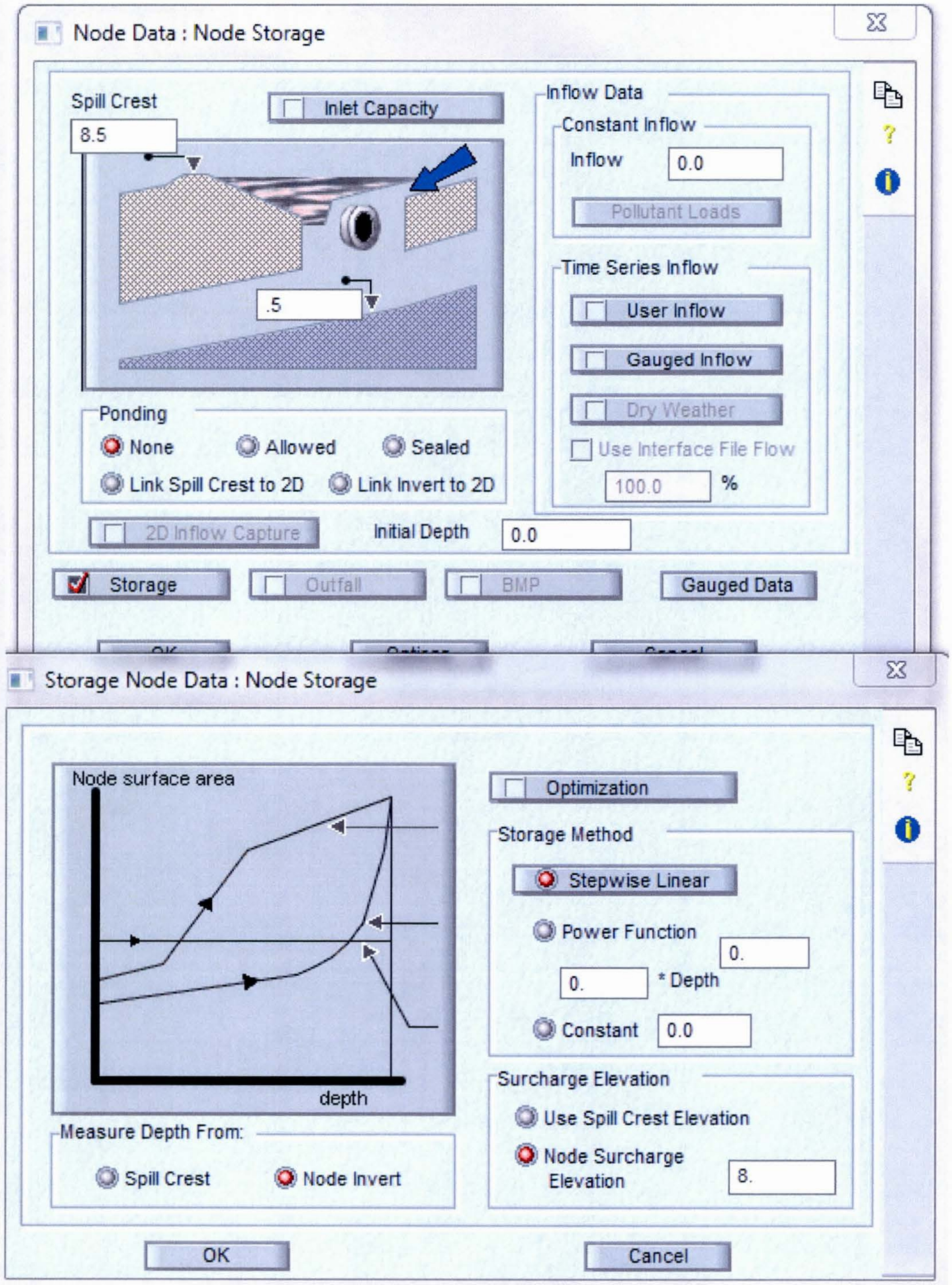
HEC-1 Routing		
Routing Type	Qpeak (cfs)	Tp (hrs)
Normal Depth (8-pt section)	6,447	2.17
Kinematic Wave (Trapezoidal Section)	7,690	1.92
Muskingum Cunge (Trapezoidal Section)	7,152	1.92
Xpswmm Routing		
Routing Type (8-pt section)	Qpeak (cfs)	Tp (hrs)
Standard-Dynamic Wave	6,358	2.017
Always use Non-Linear Terms	6,354	2.017
Never Use Non-linear Terms	6,383	2.017
Kinematic Wave	6,524	1.967
Xpswmm Routing		
Routing Type (Trapezoidal Section)	Qpeak (cfs)	Tp (hrs)
Standard-Dynamic Wave	7,229	1.917
Always use Non-Linear Terms	7,214	1.917
Never Use Non-linear Terms	7,265	1.917
Kinematic Wave	7,263	1.883

There is clearly a difference between the way that HEC-1 and xpswmm route flow. However, per xpswmm, using the full St. Venant equations for flow routing is a more accurate and precise method of flow routing over the more simplified equations in HEC-1.

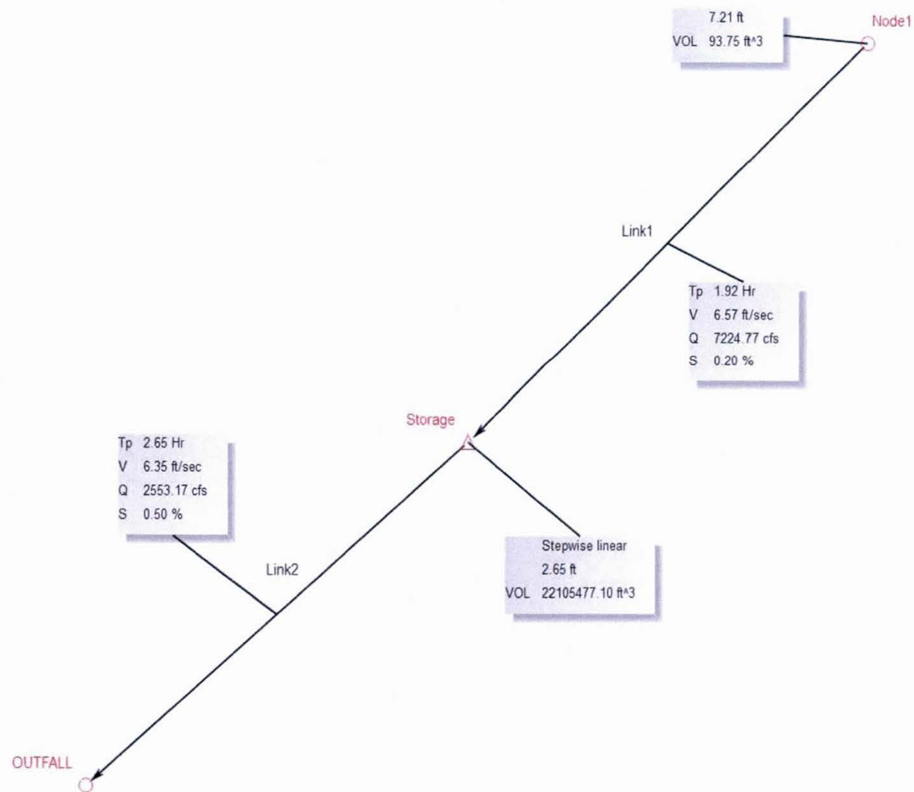
5. **Diversions** – Diversions are modeled as links and can be as simple as a direct rating curve of depth versus flow from one node to another. Multiple Links can divert flow from one node to another and can consist of conduits, pumps, orifices, weirs, or special user specified methods. Since the model is dynamic, there is no need for retrieval of hydrographs as is done with HEC-1. The dialog boxes for the diversion rating curves are shown below.



6. **Storage Routing** – The node storage option does not include a user defined stage-storage-discharge rating curve. This option should be added to the storage node data dialog box shown below.


Node Data : Node Storage
Spill Crest
8.5
Inlet Capacity
.5
Inflow Data
Constant Inflow
Inflow
0.0
Pollutant Loads
Time Series Inflow
User Inflow
Gauged Inflow
Dry Weather
Use Interface File Flow
100.0
%
Ponding
None
Allowed
Sealed
Link Spill Crest to 2D
Link Invert to 2D
2D Inflow Capture
Initial Depth
0.0
Storage
Outfall
BMP
Gauged Data
Storage Node Data : Node Storage
Node surface area
depth
Optimization
Storage Method
Stepwise Linear
Power Function
0.
0.
* Depth
Constant
0.0
Surcharge Elevation
Use Spill Crest Elevation
Node Surcharge Elevation
8.
Measure Depth From:
Spill Crest
Node Invert
OK
Cancel

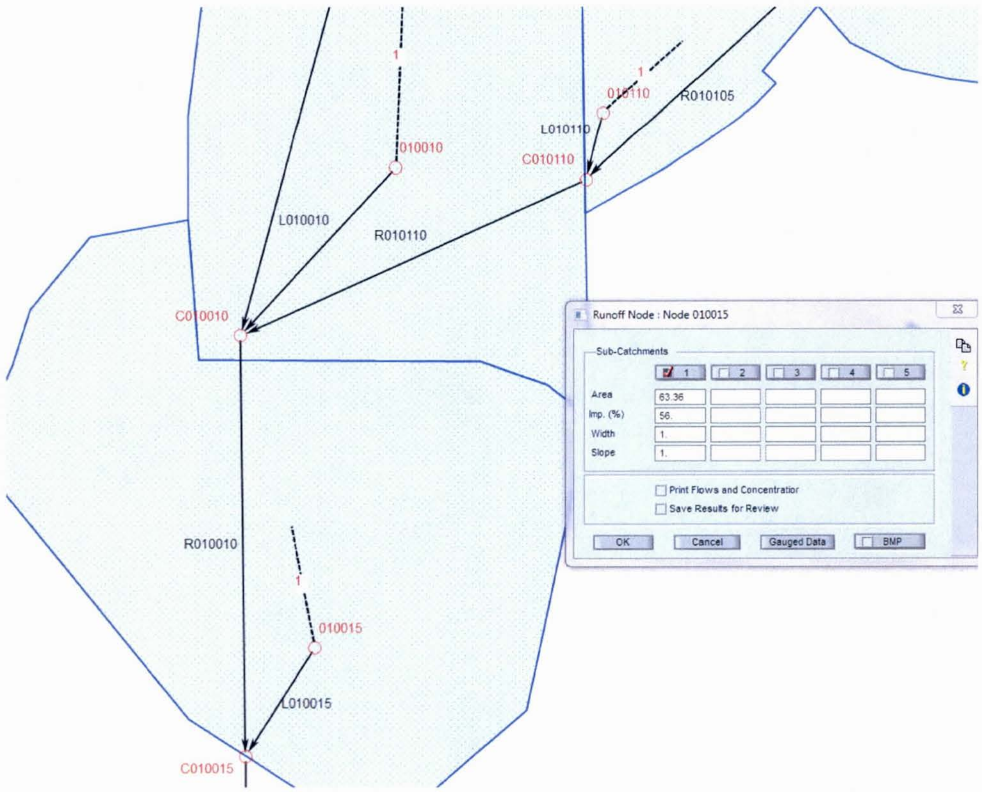
7. **Pre- Processing of inputs** –
    a. **Linking to an external Database** - Currently xpswmm can be linked to a database (GIS Shapefile DBF file or excel file) and certain specific values can be mapped from the GIS database to the xpswmm databse. This can include catchment data such as area, width, slope, unit hydrograph procedures etc. or hydraulic node data such as invert and ground elevations etc. Links can be mapped to a database with parameters such as elevations and lengths etc. There are certain variables however, that cannot be mapped and these include Tc and R values. The data entered into the xpswmm Global Databases can be linked to an external database but this method seems inefficient, it would be easier to import all subbasin data (rainfall depth, area, Tc, R, Infiltration parameters etc.) in one spot rather than having to link through series of different database mappings. A tool to "read in" the data could be developed to automatically link to a database if the attributing is correctly formatted rather than going through the process of mapping the data every time. This tool would only serve a purpose if the data is all processed outside of xpswmm.
    b. **GIS Shapefile Pre-Processing** - A function to process GIS Shapefile data of Subbasins, Soils, Land Use, and Tc lengths should be added to automatically process subbasin area and rainfall loss parameters from shapefile data. This tool could have the ability to automatically populate the necessary data in xpswmm or prepare an output file to format for "read in" through the external database link. Currently all of the parameters have to be pre-processed before inputting it into xpswmm.
8. **General Model Notes/Issues and Results** –
    a. It is a benefit to graphically see the network set up and the routing directions rather than stacking the model network similar to what is done in HEC-1/DDMSW. This also makes model updates/changes quicker and easier to accomplish. A variety of results can be spatially displayed in the xpswmm interface, shown in the image below, and the results are automatically updated after each model run.



b. A junction can be modeled where several links (routes) are combined but the junction is modeled in the Hydraulic mode since there are no runoff parameters associated; therefore, a hydrograph is not viewable when the results are viewed. The output hydrograph can be written to an external csv file where the data has to be manually extracted out and graphed. The Junction hydrograph should be written to the node and tabular output results.

c. There are two ways to simulate the subbasins, either through the use of subcatchments linked to a specific node or treating each node as a single subbasin.

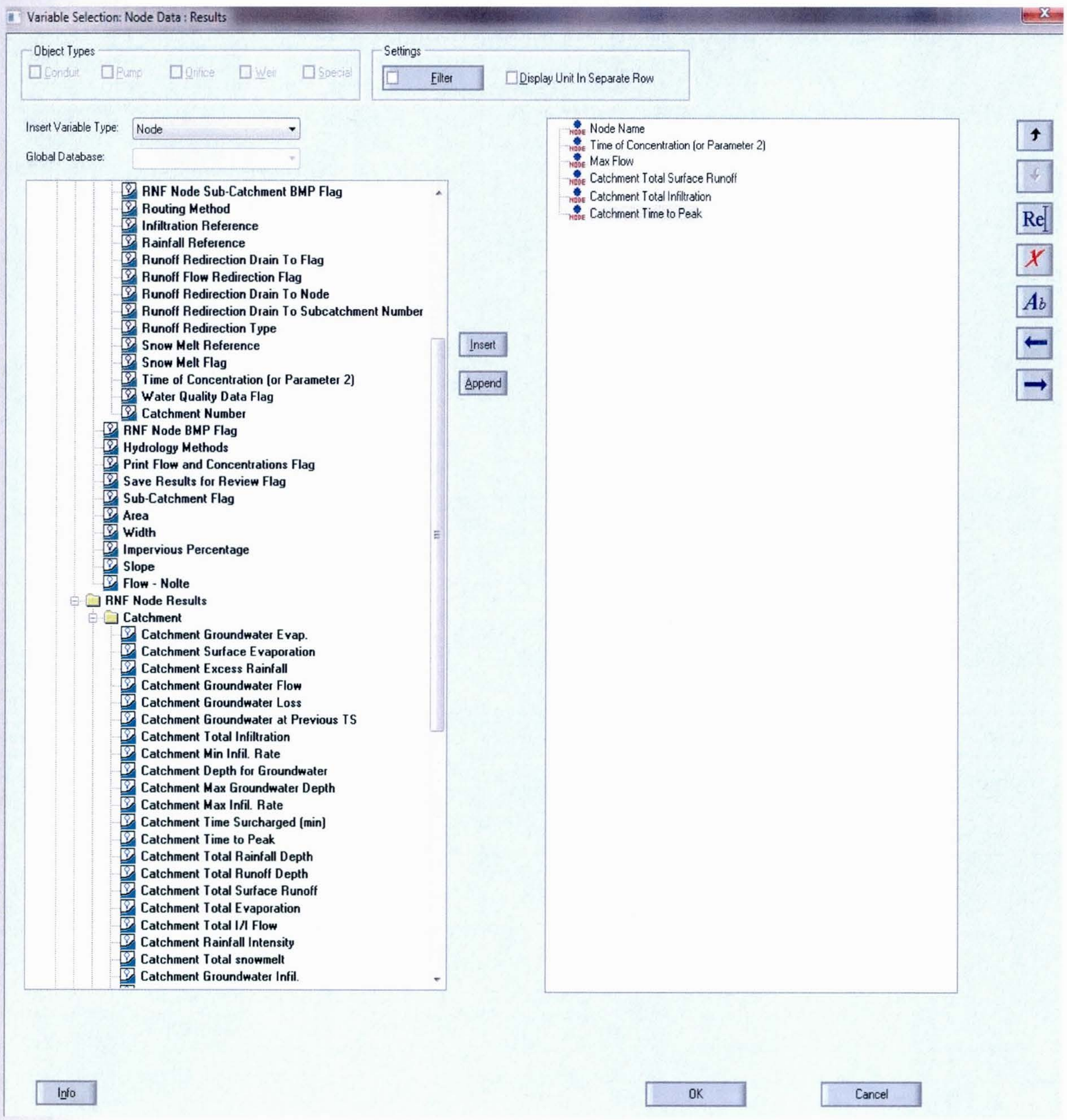
    i. Modeling subcatchments uses connections to link the subcatchments to a node; these connections (dashed lines in the image below) are not links and are not treated as routings for flow attenuation. A model can be set up using this method where the Node is viewed as a concentration point and the subcatchments are treated as individual subbasins contributing to the concentration point. There are two issues with this method. The first is that there is a maximum of five subcatchments allowed for each node, see the dialog box shown in the image below. The second is that the results are not printed for subcatchment data and the results are not listed in the tabular output. To make this more useful, a higher limit of subcatchments should be allowed to drain to a node and detailed output needs to be available for each subcatchment.



ii. Modeling each node as a single subbasin with a single subcatchment will provide detailed output including the hydrograph and tabular data for the subbasin. However, to combine the flow with another subbasin or routing at a hydraulic junction/concentration point a routing link needs to be used with full data entry of inverts, lengths, shape material, etc. The option to just use a connection, similar to the connection used to connect subcatchments to a node, that is not treated as a route and does not attenuate flow should be implemented.

d. The tabular results can be viewed through the xptables function where the user can specify the output variables to review, this includes maximum discharge, time to peak, basin area, max infiltration etc. The tables can be built per user specified data/results and can be done for nodes, links, or global databases.

There is a import template that allows for the import of a variety of predefined xptables. The template is located under the directory of the software and is created when the software is installed.



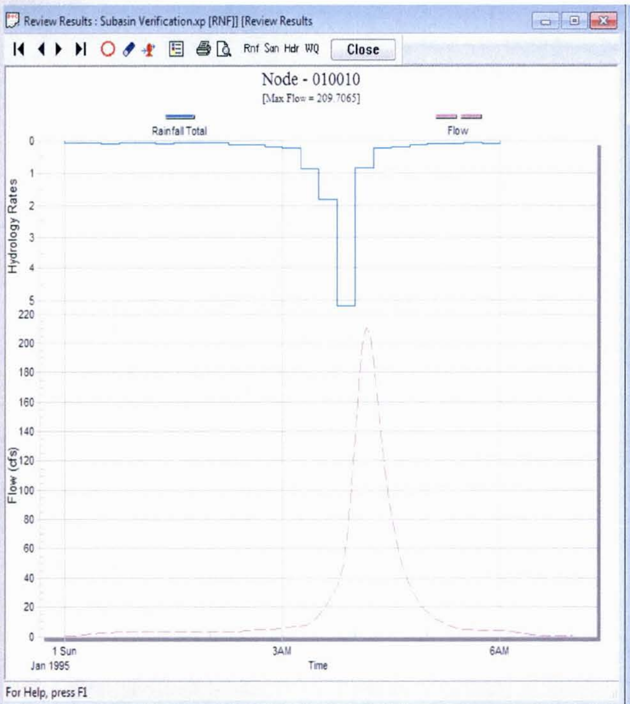
xpstorm 2012 - [Untitled] [XP Tables]

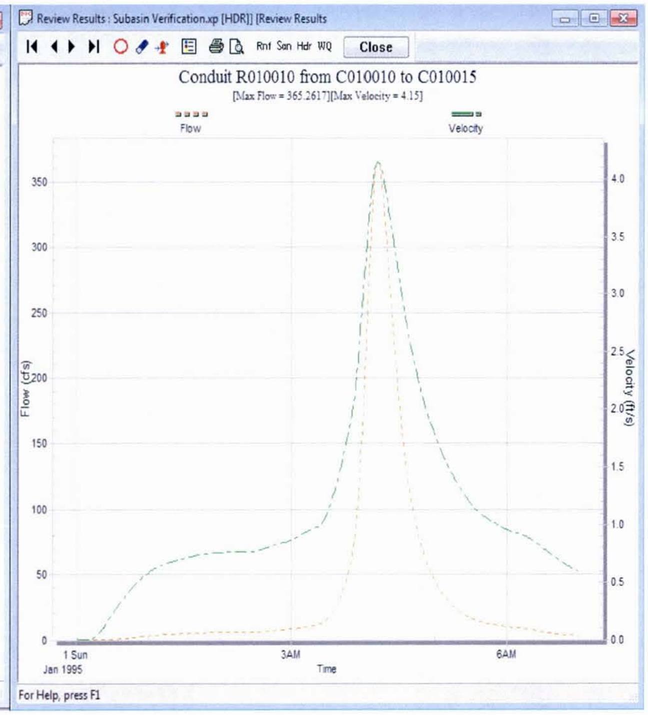
File Edit View Options Format Window Help

Base Sce

Name	Initial Moisture Deficit Input	Saturated Hydraulic Conductivity	Initial Abstraction in	Average Capillary Suction Input
010005	0.290	1.440	0.180	2.770
010105	0.290	1.340	0.250	2.760
010110	0.290	1.340	0.250	2.760
010010	0.280	1.130	0.230	3.030
010015	0.270	1.050	0.190	3.210
BA_MID_INFIL	0.250	0.400	0.170	4.300
BA_LOW_INFIL	0.050	0.010	0.170	12.400
BA_HIGH_INFIL	0.300	1.200	0.170	2.400

The element hydrographs can be plotted and exported for each node modeled in the Runoff mode (having hydrologic parameters associated with it) and each link/route modeled in the hydraulic mode.



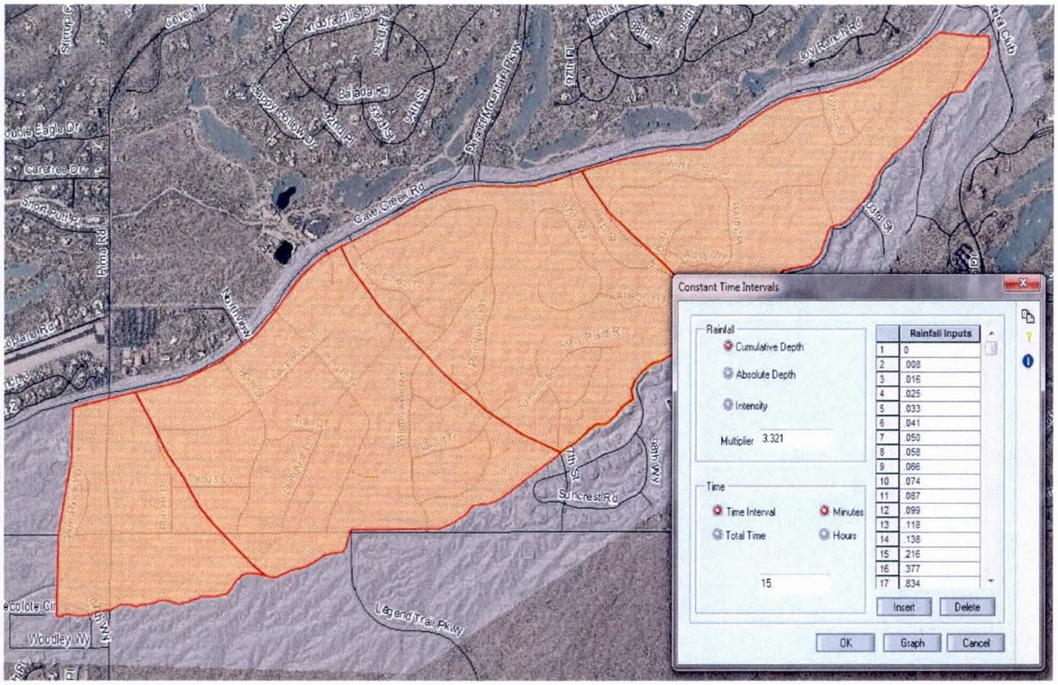


Two-Dimensional Module (xp2D):

Two-dimensional modeling uses a square grid to route a floodwave across the grid using the topographic and roughness (Land Use Manning n-value) data and can be linked to one-dimensional node and link elements. The model can simulate the hydrology from one-dimensional elements routed onto the two-dimensional grid and solve the hydrologic/hydraulic routing simultaneously solving the model in one run. The grid can be used for hydraulic routing only as well as hydrologic modeling. The 2D module makes good use of importing GIS Shapefile data for areal coverage of inputs such as land use, rainfall, fill/depression areas, etc. and linear features such as walls, ridges, boundary conditions etc.

1. **Rainfall** – Rainfall is optional on the grid and can be entered by importing a shapefile for rainfall areal coverage extents. The shapefile polygon is then assigned a rainfall database with a temporal distribution and rainfall depth. The database for the 2D module utilizes the same setup as the one-dimensional elements in xpswmm and has the same deficiencies as previously discussed.

a. **Spatial Variations** - If spatially varied rainfall depths are desired, a new polygon and associated database with an adjusted rainfall depth is required for each polygon area covered by a new rainfall depth/distribution, see the image below. There does not seem to be a limitation to the number of polygons used for varying rainfall depths/distributions.



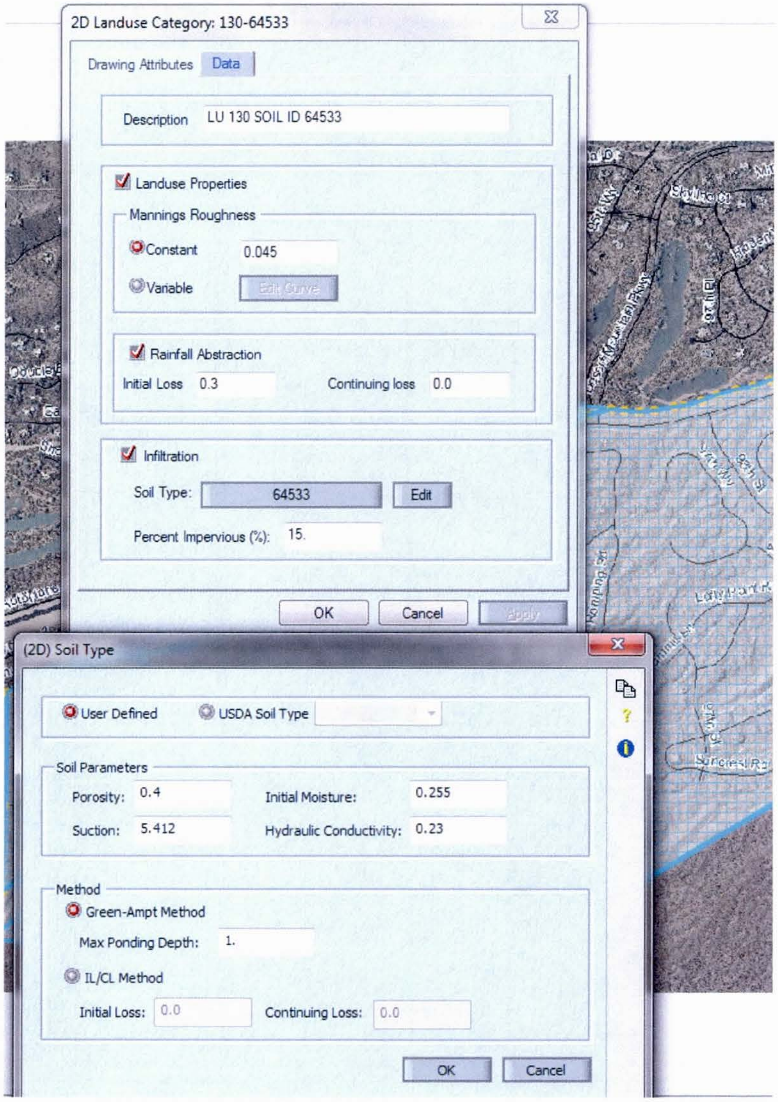
In theory, a two-dimensional grid can have a distinct rainfall depth and temporal distribution for each grid element by creating a polygon shapefile with a polygon for each grid element. Each polygon covering each grid can be assigned a distinct point rainfall depth and distribution. This, however, could be extremely time consuming since a rainfall database has to be created for each distinct rainfall and each polygon would have to be assigned to each associated database.

b. **Inactive areas** - Inactive areas on a grid can be used to model items such as building structures that block the available flood storage on a grid, this is discussed in more detail in the structures section, but rainfall does not fall on the inactive areas and can reduce the rainfall volume over the watershed. This can be a minor effect in non-urban watersheds but can have a large effect in extremely urbanized areas since the inactive areas decrease the flood volume.

2. **Rainfall Losses** – There are two methods for accounting for rainfall losses on the two-dimensional grid, Initial and Uniform Loss, and Green and Ampt losses. For the

examples modeled for this project, only the Green and Ampt losses were considered.

a. **Green and Ampt** - The Green and Ampt infiltration input consist of the typical parameters, DTHETA, PSIF, XKSAT, IA, and Percent Impervious. There are two additional parameters that are input into the infiltration dialog box for xp2D, see the following image of the infiltration dialog boxes, the soil porosity and the Maximum Ponding Depth. The maximum ponding depth is essentially a limit to stop infiltration into the soil even if the soil is not yet saturated. This is a useful function to calibrate models if over-infiltration is a modeling concern.
    i. The xp2D module will allow infiltration until the soil reaches saturation, once the soil is saturated the infiltration is shut off and no more infiltration occurs.
    ii. An infiltration database is required for each Land Use and Soils database to assign not only Manning's roughness to the Land Use, but also the Soil Green and Ampt parameters. Once the databases are created individual shapefile polygons have be imported for each Land Use/Soil database. An improvement would be to import a single shapefile that can be mapped through the file attributes to the specific Land Use/Soil Database, or have the Land Use/Soil Database generated from Shapefile attributes.



i. A sample model was built to compare the infiltration of xp2D with the infiltration of FLO2D. A small grid of 10' x 10' elements at a constant elevation of 10-feet was generated without an outflow. Basically, the rainfall on the grid either remained on the grid or infiltrated. The results and input are tabulated in the following table.

ii. The total volume of rainfall for both models is the same at 0.65 acre-feet. The xp2D *Volume In* is the rainfall minus the initial abstraction and as can be seen in the table above very little water was lost to infiltration in xp2D (0.07 ac-ft (0.65 total rainfall volume minus 0.58 end volume)) versus FLO2D (0.6 ac-ft lost to infiltration and interception). The maximum flow depth on the grid, although different, is similar to each model 0.2 ft for xp2D and 0.13 ft for FLO2D. The primary difference is that at the end of the simulation 0.199 ft is still on the grid with xp2D versus 0.02 ft for FLO2D. This is the result of the infiltration being shut off for xp2D once the ground becomes saturated whereas FLO2D will keep infiltrating until the simulation end.

Infiltration Comparison Model:					
Input Parameters					
Simulation time	7 Hrs				
Rain Depth	3.0 Inches				
Distribution	Maricopa County 6 Hr Pattern 1				
IA (in)	0.1				
DTHETA	0.25				
PSIF (in)	3.5				
XKSAT (in/hr)	0.35				
POROSITY	0.4				
Model Results					
XP2D	*m^3*	*ac-ft*		***FLO2D***	*ac-ft*
Total Rainfall Volume	804	0.65		*Total Rainfall Volume*	0.65
Total Volume at End	712	0.58		*Water Lost to Infiltration and Interception*	0.6
Total Volume In	721	0.58		*Floodplain Storage*	0.05
Total Volume Out	8	0.01		*Total Outflow from Grid System*	0
Max Flow Depth on Grid (ft)	0.2			*Max Flow Depth on Grid (ft)*	0.13
Flow depth at end of simulation (ft)	0.199			*Flow depth at end of simulation (ft)*	0.02

b. **Manning's n-values** - The manning n-value roughness is specified in the Land Use database and can consist of a constant n-value of a value varying with depth. The variation with depth is generated by a user-defined rating curve.

c. A precise description of the methodology and numerical analysis behind the 2D infiltration was not acquired for this investigation. It is recommended however, that the methodology and numerical analysis be requested from XP solutions to verify that the methods adhere to the FCDMC requirements.

3. **Structures** – A variety of structures can be modeled in xp2D and include building footprints, fill/depressed areas, ridgelines, walls, and one-dimensional hydraulic

structures like culverts and storm drain. The ability to model the one-dimensional elements in conjunction with the 2D grid is a large benefit to xp2D. A lot is discussion could go into the variety and types of structures and designs available in xp2D but the overview of each type is discussed in the following sections.

a. **Building structures** can be imported as a shapefile as inactive areas. The inactive areas are modeled like "glass walls" and make the encompassing area unavailable for flood storage. As previously mentioned however, the inactive areas do not allow rainfall to fall within the encompassing inactive area. This reduces the total volume of runoff from the rainfall event.
b. **Fill/depression areas** can be imported as shapefiles and can be used to model depressions such as a proposed detention/retention basin without having to edit the existing topographic data. Likewise, a depression in the existing ground, such as a retention basin, can be modeled as full using the fill area feature. This feature makes it easy to model multiple scenarios without having to edit the existing ground topographic data.
c. **Ridgelines** can be imported from a shapefile to model features such as roads or walls and can be given a specified elevation, sample elevations directly from an existing ground DTM, or raise/lower existing elevations by a specified amount. This feature is applicable on structures such as roads where the direct ground DTM elevation can be assigned to a grid element instead of an averaged elevation or walls where the existing ground can be raised by a user specified height.

d. **Topographic features** can be created as rigid elevation shapes that are permanent throughout the model simulation or they can be dynamic elevation features which can be failed based upon specific criteria. For example, a wall can be created as a dynamic feature and a trigger point can be set to fail the wall by a variety of measures including depth, time, and water surface or elevation differences.

e. **One-Dimensional Structure Linking to the Two-Dimensional Grid** - A large benefit to xp2D is the use of one-dimensional elements in conjunction with the two-dimensional grid. The use of one-dimensional nodes connected by a conduit link can be used to model the effects of culverts or even storm drain with the 2D grid. The links can be a variety of shapes and materials including natural shaped or user defined specialty shapes. The nodes can be simply culvert inlet/outlet or, if storm drain is being modeled, the nodes can be treated as inlets configured to a grate, curb, slotted, or combination grate and curb inlet. The link can have specified factors such multiple barrels, entrance/exit loss coefficients, design functions, sediment depth, and roughness changes. The user can specify the inlet type which uses the FHWA inlet control equations in the modeling of the culvert/pipe. This one-dimensional network can all be linked and tied to collectively interact with the 2D grid.

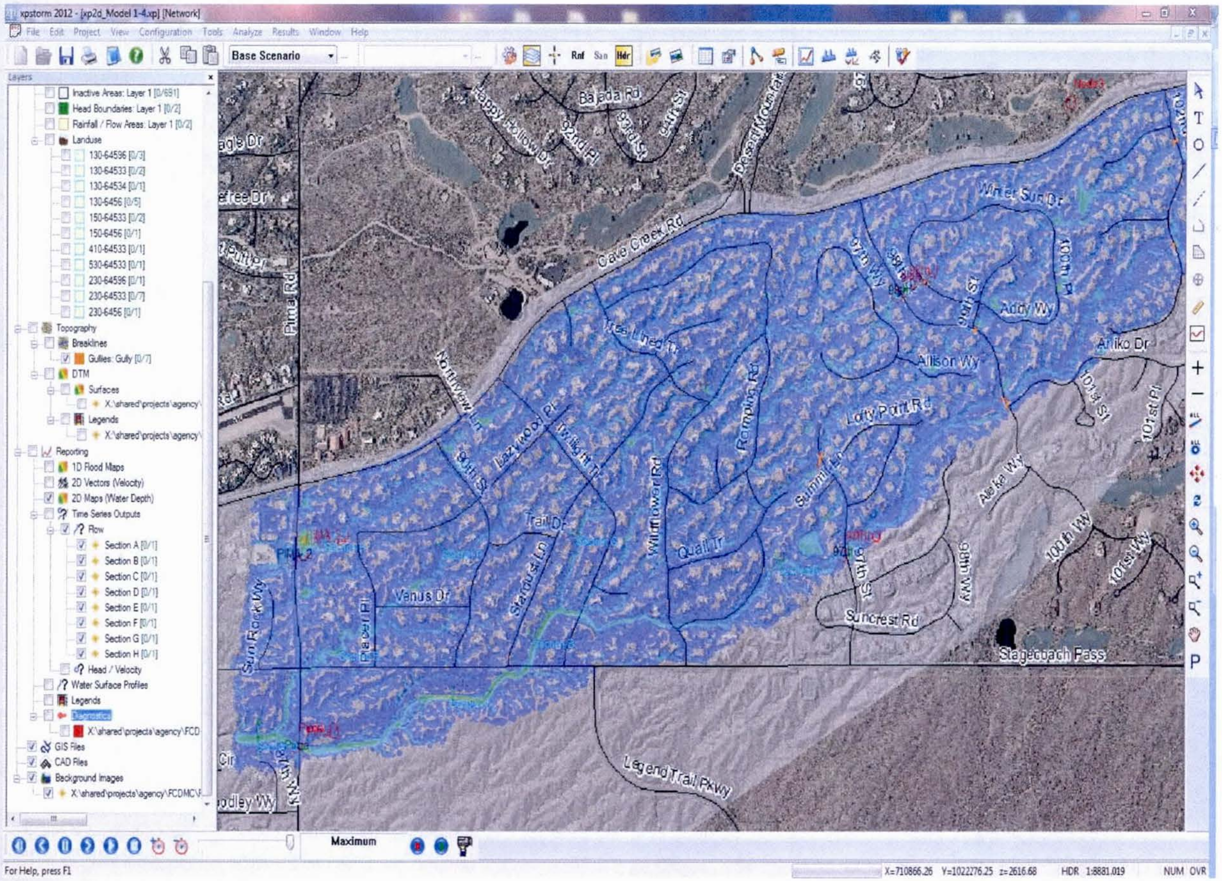
The use of nodes and links can also be used to simulate channels on the 2D grid for one-dimensional routing. Flow can be connected to the grid to allow shallow sheet flow from the grid to enter and drain into the channel and vice versa, when channel capacity is reached, flow from the channel can flow back on to the 2D grid.

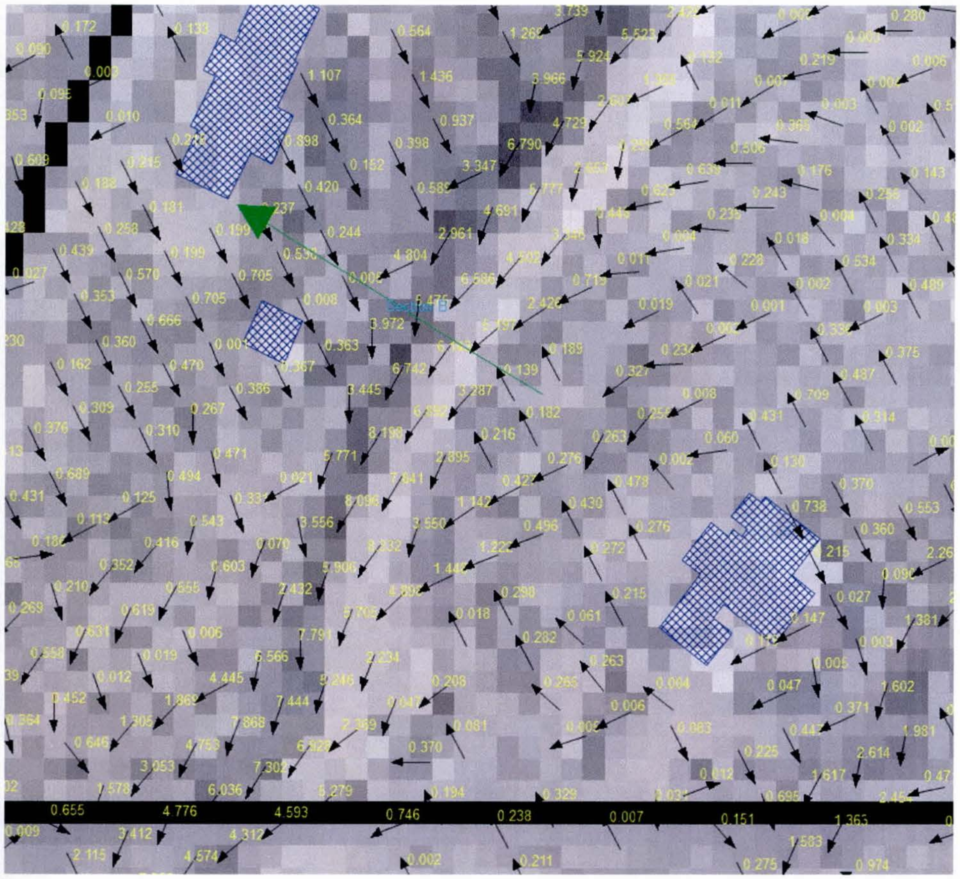
f. The xp2D grid can also be linked to the one-dimensional xpswmm hydrologic elements. As a hydrograph is generated from subbasins or routings, the hydrograph can be linked to the 2D grid and used as inflow directly onto the grid. This one-dimensional hydrograph generation and subsequent hydraulic routing on the grid is done simultaneously eliminating the need to model each item separately.

g. Although technically not a structure, Flow Sections can be drawn in xp2D to extract the full hydrograph from that location on the grid. The Flow Section generation is a simple line drawn perpendicular to the direction of flow.

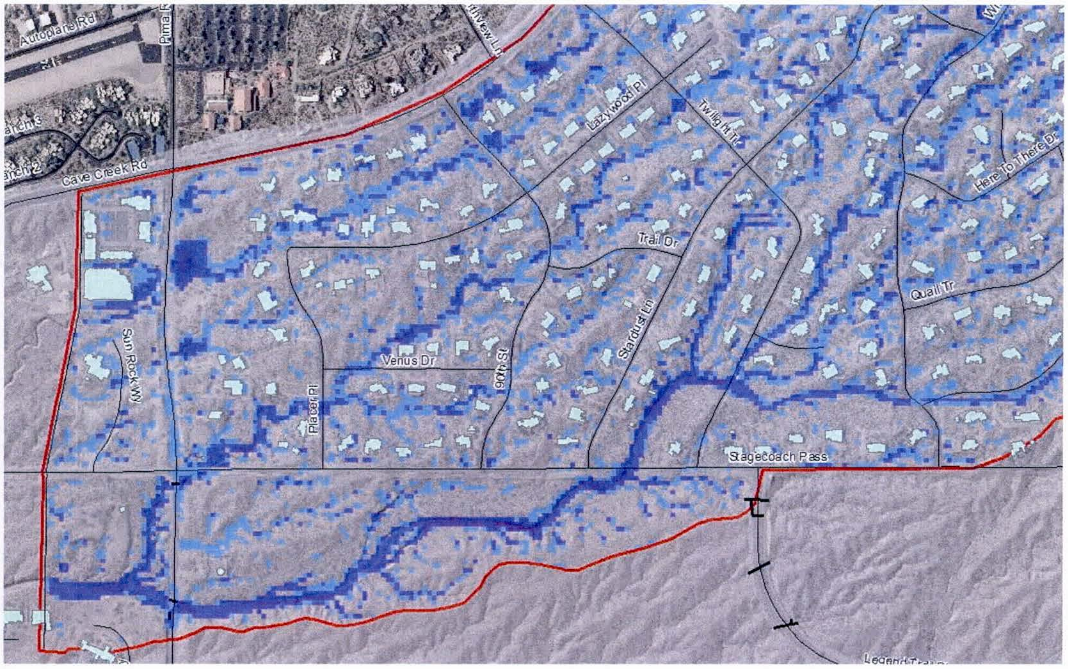
4. **GIS Features** – Each input to xp2D, grid area, land use/soil coverage, boundary conditions, inactive areas, elevations shapes etc. can be imported using GIS shapefiles. General shapefiles and images can also be imported as references. For example, a GIS shapefile showing the locations of desired Flow Sections can be imported as a shapefile and then drawn in xp2D over the shapefile feature(s). Many features, such as links, nodes, inactive areas, boundary conditions etc. can be exported to a GIS shapefile from xp2D and, as previously mentioned, have the attributes mapped to xpswmm data entry fields.

   a. The results of the 2D model can easily be viewed in the xp2D interface. The results include the gridded depth, velocity vectors, Hazard Maps, and flow vectors during the model simulation. The maximum flood depths and velocity vectors are shown in the following two images respectively. The results can also be viewed in a playback mode where the movement of the floodwave can be viewed, and recorded, for the entire simulation. This is very useful in trouble shooting a model since it is possible to see where issues may exist during any time of the simulation.


xpstorm 2012 - [xp2d_Model 1-4.xp] [Network]
File Edit Project View Configuration Tools Analyze Results Window Help
Base Scenario
Layers
Landuse
Topography
Breaklines
DTM
Surfaces
Legends
Reporting
1D Flood Maps
2D Vectors (Velocity)
2D Maps (Water Depth)
Time Series Outputs
Flow
Section A
Section B
Section C
Section D
Section E
Section F
Section G
Section H
Head / Velocity
Water Surface Profiles
GIS Files
CAD Files
Background Images
Bajada Rd
Cave Creek Rd
Winter Sun Dr
Addy Wy
Allison Wy
Lofty Point Rd
Trail Dr
Quail Tr
Venus Dr
Suncrest Rd
Stagecoach Pass
Legend Trail Pkwy
Pima Rd
Maximum
For Help, press F1



b. The maximum flood depth for each grid can be exported as a GIS shapefile or ESRI Grid file. Furthermore, contour data of the depth can also be exported as a shapefile. The maximum depth is the maximum for each grid at any time during the simulation and is GIS compatible, see the image below of the flow depths in GIS from a sample model run.

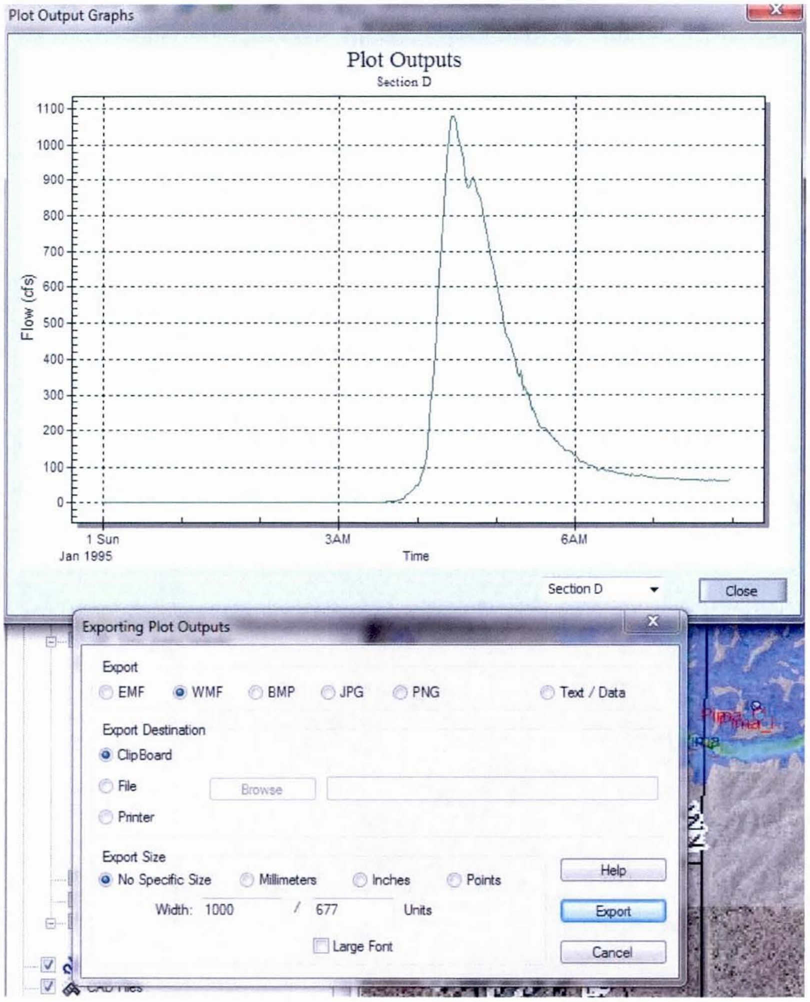


c. The velocity values for each grid can be exported as an ESRI Grid file or a .csv file containing the X- and Y- coordinates of the grid centroid and the associated x- and y- maximum velocity values. This data can be used to determine the maximum velocity of the grid but it is worth noting that the velocity that is exported is the maximum velocity at the time of maximum depth. It might not necessarily be the maximum during the entire simulation.

   An improvement to xp2D would be a GIS shapefile export of the maximum velocity during the entire simulation, much like the maximum depth.

   Similar to the velocity, the maximum flow value of a grid during the simulation is not a currently available export. The flow values may be exported at any time of the simulation but there is not a function to export out the maximum flow values regardless of time of occurrence. This function should be added to xp2D as an available export, like the maximum depth, as this is useful reporting data.

d. The plotted hydrograph from each one-dimensional element and two-dimensional flow section can be plotted and reviewed within the xp2D interface. The data can also be exported as an image file or a text file for editing/plotting within Excel.



REFERENCES

FCDMC (2011), Drainage Design Manual for Maricopa County, Arizona – Hydrology, Fourth Edition with revisions made on February 2011.

KVL Consultants Inc. (2010), Drainage Design Management System – Users Manual, Version 4.6.0.

XP Software Inc. (2012), XPSWMM/XPSTORM Reference Manual, XPSTORM/TUFLOW Engine Version 12, Interface Version 2012 Build: 2012-05-AA-iDP-w32.

ACTION PLAN
FOR IMPLEMENTATION OF
FCDMC HYDROLOGY PROCEDURES IN
XP-STORM SOFTWARE

JE FULLER
HYDROLOGY & GEOMORPHOLOGY, INC.

DEFINE | COMMUNICATE | SOLVE

Memorandum

Registered Professional Engineer (Civil) CERTIFICATE NO. 42522 HARI RAGHAVAN Date Signed 4/16/13 ARIZONA, U.S.A. Expires 6/30/14

DATE: April 16, 2013

TO: Bing Zhao, PhD, PE (FCDMC)
CC: Nathan Logan, PE, JEF
CC: Ted Lehman, PE, JEF

FROM: Hari Raghavan, PhD, PE, CFM

RE: HMS and XP-STORM Software Procedures Evaluation
(Contract Number 2011C002- Work Assignment #8)

XP-STORM SOFTWARE MARICOPA COUNTY PROCEDURES IMPLEMENTATION PLAN

Purpose

JE Fuller/Hydrology & Geomorphology, Inc (JEF) has been contracted by the Flood Control District of Maricopa County (FCDMC) to evaluate HEC-HMS and XP-Storm software to investigate compliance of the built-in procedures of each software against the methodologies and procedures in the FCDMC Drainage Design Manual- Hydrology (FCDMC, 2011) (Fourth Edition November 2009 with February, 2011 revisions). For sake of brevity, FCDMC Drainage Design Manual-Hydrology (FCDMC, 2011) is referred to as "FCDMC 2011 Manual" in the remainder of the text. This technical memo presents a compilation of tasks identified as part of the implementation plan for incorporating the Maricopa County Hydrology procedures into the XP-Storm software (XP Software Inc., 2012).

Task 1 - Rainfall - Depth Area Reduction/Interpolated Multistorm analysis

The procedure in FCDMC 2011 Manual uses NOAA14 rainfall depths, two sets of temporal rainfall distributions, and areal reduction factors to describe design rainfall events.. Since the NOAA 14 rainfall statistics represent point probabilities, the FCDMC procedure uses a reduction factor to convert the point rainfall to an equivalent uniform depth of rainfall over the entire watershed, thus preserving the probability, or frequency, of the rainfall depth. As watershed area increases, the reduction factor decreases which has the effect of reducing the total rainfall while maintaining the same probability.

The FCDMC procedure presents the areal-reduction factor for 6-hour and 24-hour storm events as a function of drainage area (See Table 2.1 and Table 2.2 in FCDMC 2011 Manual). Within HEC-1, the storm area and reduced rainfall depth are specified using the JD record. Using the JD and PC record in combination, a temporal rainfall distribution, or pattern, can also be assigned to each storm area/reduced rainfall set. For the 6-hour storm event, five distinct rainfall patterns are identified as a function of drainage area. Table 2.4 in FCDMC 2011 Manual presents these five patterns. Figure 2.5 in FCDMC 2011 Manual presents the relationship between drainage area and pattern number.

Using these sets of areally reduced rainfall depth and storm pattern, HEC-1 performs a separate analysis for each storm, the so-called index storms. HEC-1 computes runoff hydrographs for each computation block for each storm. HEC-1 then goes through each computation block within the model and computes the contributing drainage area using the drainage area information from all the upstream hydrological elements. This gives a specific computed contributing drainage area at each concentration point. Using these drainage area values, HEC-1 then interpolates the hydrograph results computed from the different index storms. In this manner, HEC-1 arrives at a distinct hydrological result for each concentration point t. This entire procedure is done in a single run of HEC-1 and the results are presented in a single output.

In comparison, XP-Storm does not perform any depth-area reduction. Each node in XP-Storm is effectively a subbasin requiring a rainfall database associated with it. The database is a point rainfall depth and a temporal distribution that will be applied to the node. While it is possible to reduce the rainfall depth and choose a custom distribution for each subbasin, the areal reduction applied in this manner is unable to use the appropriate drainage area at each concentration point to obtain correct areal reduction when subbasin hydrographs are combined.

The purpose of this task will be to implement the procedure similar to that in HEC-1. The ability to input areal reduction factors as a function of drainage area with a specific rainfall distribution attached to each of data pairs (areal reduction factor and drainage area).

The development of this capability can be somewhat based on Multi-Frequency storm analysis capability with XP-Storm. The FCDMC 2011 Manual specifies the Depth Area Reduction using depth-area relations from Hydro-40. The data needed for this can be obtained from Table 2.1 and Table 2.2 of the FCDMC 2011 Manual for the 6-hour and 24 hour storms respectively.

The FCDMC 2011 Manual defines rainfall hyetograph shape as a function for the contributing storm area. Specifically, the 6-hour storm is defined using five separate patterns (See Table 2.4 in FCDMC 2011 Manual). The FCDMC procedures also use different single 2-hour and 24-hour storm patterns (See Tables 2.3 and 2.5 in FCDMC 2011 Manual). HEC-1 allows the specification of the different shapes using the JD-PC or JD-PI combination. As part of this task, the capability to incorporate the appropriate temporal distribution based on drainage area must be also be implemented.

Task 2 - Rainfall - Compute Watershed Average Rainfall

The FCDMC provides a GIS polygon shapefile of rainfall to be used in the development of hydrological models. This shapefile consists of polygons with a unique "RAINID" that is present in an integer attribute field. An accompanying table is also provided which relates the RAINID to the rainfall depths for the 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 200-year, 500-year and

1000-year storm frequencies and storm durations of 5, 10, 15, 30 minutes and 1, 2, 3, 6, 12 and 24 hour durations. The FCDMC procedure requires the hydrological modeler to develop a polygon shapefile coverage of subbasins. The purpose of this task is to develop a capability to compute watershed average rainfall using these three as inputs: rainfall shapefile, rainfall table and subbasin shapefile. The procedure will be based on the following steps:

a) Intersection of GIS layers of rainfall and subbasin
b) Compiling a list of RAINID's and corresponding areas from the intersection shapefile.
c) Computing the area-weighted average of the rainfall for various storm-events using the rainfall table.

Task 3 - Clark Unit Hydrograph - Time Area Relation

The Clark-Unit Hydrograph procedure presented with HEC-1 and XP-Storm are similar. The FCDMC 2011 Manual employs two different Time-Area relations in addition to the HEC-1 Default: Urban and Natural. HEC-1 allows the specification of customized Time-Area Relations using UA card. XP-Storm allows only the HEC-1 Default method.

The purpose of this task would be to incorporate the capability to use a custom Time-Area relation. The procedure adopted within XP-Storm will be otherwise similar to the current procedure. It may be noted that HEC-HMS improves upon the procedure in HEC-1 by scaling the unit hydrograph to achieve volume conservation (See HEC-HMS user's manual Appendix D for details). This improved procedure should be implemented within XP-Storm.

FCDMC procedure recommends the use of two specific custom time-area relations for the "Urban" and "Natural" watersheds. These are presented as paired data in Table 5.4 of the FCDMC Hydrology manual. These tables could be made available as built-in paired data for the users to select from.

Task 4 - Clark Unit Hydrograph - County Tc and R Calculation

FCDMC procedure requires the computation of time of concentration (Tc) and Storage Coefficient (R) using equations presented in Section 5.5 of the FCDMC Hydrology manual. The Tc equation requires the input of the following variables:

- L = Length of the hydraulically connected longest flow path in miles
- Kb = Watershed resistance coefficient
- S = Watershed Slope as ft/mile
- i = average rainfall excess intensity inches/hr

The values flow path length (L) and slope (S) are direct inputs from the user. Slopes (S) higher than 200 ft/mile are to be adjusted based on an equation presented in Section 5.5. The Kb value is computed using equations presented in Table 5.3 of the FCDMC 2011 Manual. This table identifies four simple equations for four different landuse types with three parameters: drainage area, m and b. The value of average rainfall excess intensity is to be computed by performing the subbasin Clark Unit Hydrograph run-off calculations with Tc=0 and R=0 with specified infiltration parameters using the same time step as the simulation run. The average of the highest ten rainfall excess values is then divided by the length of ten time intervals to arrive at the average rainfall excess intensity inch/hour.

The R equation is a simple equation (See Equation 5.8 in FCDMC 2011 Manual) requires the input of the following variables:

- Tc = Time of concentration in hours
- A = drainage area in square miles
- L = length of the flow path in miles

All the above parameters are user input parameters.

The purpose of this task is to incorporate the above procedure to compute the Tc and R values to be used in the Clark Unit Hydrograph computations. The procedure can be implemented within XP-Storm in the dialog box where Tc and R are entered.

Task 5 - Unit Hydrograph - County Specific S-Graph

XP-Storm does not include the capability to model S-Graph method. For the S-Graph method, FCDMC procedure requires the use of custom dimensionless S-Graphs. The procedure identifies 4 different S-Graphs (See Table 5.5 in FCDMC 2011 Manual) based on different landform type. In addition, the procedure requires the use of a specific Lag equation (See Equation 5.11 in FCDMC 2011 Manual) which requires the input of the following variables:

- L= length of the longest watercourse in miles
- Lca = length along the watercourse to a point opposite centroid, in miles
- S = watercourse slope in ft/mile
- C = coefficient
- m and p = exponents

The parameters L, Lca and S are direct user inputs. C is computed as a simple function of another parameter Kn (24Kn or 26Kn). Table 5.6 in the FCDMC 2011 Manual identifies the relation between the landform type and Kn. The values of m and p are simply assigned depending on the source of Kn. The procedure to compute the Lag is briefly described as following:

- Determine landform type

- Compute Kn
- Assign m and p based on source Kn
- Compute C using either 24Kn or 26Kn depending on source of Kn
- Compute Lag using Eq 5.11 in FCDMC 2011 Manual.

The purpose of this task is to do the following:

- Develop the S-Graph method as an optional method for computing run-off. This can be implemented in the XP-Storm software similar to Santa Barbara Unit Hydrograph option.
- Incorporate the 4 different S-graphs as built-in S-graphs within XP-Storm.
- Add the ability to compute Lag using above procedure.

Task 6 - Channel Routing

FCDMC procedure requires one of these methods for channel routing: Modified Puls, Kinematic wave, Muskingum and Muskingum Cunge methods. XP-Storm incorporates the Kinematic Wave and full dynamic wave methods. Additionally, XP-Storm has the option include or exclude non-linear terms.

The purpose of this task is to implement the ability to compute channel routing using Modified Puls, Muskingum and Muskingum Cunge method. The HEC-1 and HEC-HMS manual may be used as a reference for implementation of these procedures.

Task 7 - Storage Routing

XP-Storm does not have the ability to model storage routing via specification of stage-storage-elevation-discharge relationship as can be done in HEC-1.

The purpose of this task is to implement storage routing with ability to specify outflows as well weir-type overtopping. The HEC-1 and HEC-HMS manual may be used as a reference for implementation of these procedures.

Task 8 - Junctions

XP-Storm does not have the ability to combine hydrographs from multiple subbasins without adding routing reaches.

The purpose of this task is to implement the ability to add junctions which will perform the function of combining hydrographs. The graphical interface should allow the user to view the hydrologic results in a manner similar to other hydrologic elements.

Task 9 - Import Subbasin From Shapefiles

FCDMC procedure requires the creation of a polygon shapefile to represent the subbasins. The polygon shapefile has two attribute fields: "AREAID" and "BASINID". The "BASINID" field has the name of the major basin and "AREAID" field has the name of the subbasin.

The purpose of the task is to add the following capabilities:

- Read the shapefile and create subbasins that do not already exist.
- Assign areas to the subbasins using the polygon areas in the shapefile.

Task 10 - Import Parameters From Landuse and Soils Coverages

The FCDMC also provides landuse and soils coverages for the entire County with attribute fields identifying unique soil ids in "SOIL_LID" field and landuse id "LUCODE" fields. The soil and landuse coverages are accompanied by tables that relate the soil and landuse id's to the Green and Ampt parameters. The parameters in the soils table are:

- Soil ID, XKSAT, Rock Outcrop % and Erodibility factor K

The parameters in the landuse table are:

- Landuse code, Initial Loss (IA), % Impervious (RTIMP), Vegetation Cover, Moisture deficit type (DTHETA type) and Resistance Coefficient Type (Kb Type)

The ability to allow the modeler to add custom values to the Land Use and Soils data parameters to the tables should be included.

In addition, FCDMC also requires the development of subbasin shapefile as described in Task 9.

FCDMC requires the derivation of the following several input parameters from these shapefiles. A brief description of how the parameters are computed is presented below:

Green and Ampt parameters

The FCDMC 2011 Manual presents detailed procedures as to how to arrive at the Green and Ampt loss parameters. Section 4.5.1 in FCDMC 2011 Manual explains the procedure to compute the Green and Ampt parameters using the 3 shapefiles: soils, landuse and subbasins. In addition to the shapefiles, the procedure uses relationships between

a) Capillary suction (PSIF) and Hydraulic conductivity (XKSAT) (See Figure 4.3 in FCDMC 2011 Manual)
b) Moisture deficit (DTHETA) and Hydraulic conductivity (XKSAT) (See Figure 4.3 in FCDMC 2011 Manual)

c) Ratio of Hydraulic Conductivity to Bare Ground Hydraulic Conductivity and Vegetation Cover (See Figure 4.4 in FCDMC 2011 Manual). This is used in adjusting hydraulic conductivity for vegetation cover.

The procedure to compute these parameters are briefly described as:

- Perform GIS intersection of Subbasins and Soils layer and compute area-weighted (Some parameters log10-area weighted) estimation of soils-related parameters.
- Perform GIS intersection of Subbasins and landuse layer and compute area-weighted (Some parameters log10-area weighted) estimation of landuse-related parameters.
- Compute other parameters using equations or lookup tables (provided in Chapter 4 of FCDMC 2011 Manual).

Clark Unit Hydrograph Kb parameter

The landuse table includes the parameter identifying the Kb Type. This information along with the equations presented in Table 5.3 of FCDMC 2011 Manual is used to compute the Kb values. GIS intersection of the landuse and subbasin coverages are performed and the values assigned to the subbasins are computed using area-weighting method.

S-Graph Kn parameter

The landuse table includes the parameter "average Channel Mannings n" which can used as the Kn value in S-Graph. . GIS intersection of the landuse and subbasin coverages are performed and the values assigned to the subbasins are computed using area-weighting method.

The purpose of this task is to develop capability to estimate and assign the above mentioned Green and Ampt, Clark Unit Hydrograph and S-Graph parameters using the subbasin shapefile, landuse shapefile, soils shapefile, landuse table, soils table and other equations/figures/tables presented in the FCDMC 2011 Manual.

Task 11 - Import Parameters From Flowpath and Lca Shapefiles

FCDMC requires the development of longest Flowpath polyline and Lca polyline GIS shapefile by the hydrologic modeler. These shapefiles are attributed with ids "AREAID" and "BASINID" similar to the subbasin shapefile (described in Task 9). The flowpath shapefile has additional attributes "USGE" and "DSGE" containing the upstream and downstream elevations. The values from these attribute fields are to be used in the computation of slope parameter.

The purpose of this task is to import and estimate the length and slope parameters using the Flowpath polyline and Lca polyline GIS shapefiles.

Task 12 - Development of Report Templates

FCDMC requires submittal of hydrology results in the form of tables. Most model outputs are submitted as a DDMSW model (KVL Consultants Inc., 2010) which is a pre- and post-processor to HEC-1. DDMSW is FCDMC developed software that has the capability to print hydrologic results in tabular form using the built-in report capability.

The purpose of this task is to develop capability to generate reports of hydrologic results similar to that generated by DDMSW software (KVL Consultants Inc., 2010).

REFERENCES

FCDMC (2011), Drainage Design Manual for Maricopa County, Arizona – Hydrology, Fourth Edition with revisions made on February 2011.

KVL Consultants Inc. (2010), Drainage Design Management System – Users Manual, Version 4.6.0.

XP Software Inc. (2012), XPSWMM/XPSTORM Reference Manual, XPSTORM/TUFLOW Engine Version 12, Interface Version 2012 Build: 2012-05-AA-iDP-w32.