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Development of a GIS-aided Watershed Scale Model to Predict Water Flow Patterns and Quantities via Surface Conduits

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Abstract. *The Marine Corps Air Station (MCAS) at Cherry* Point (Havelock, *North* Carolina), is a *military installation consisting of urban land ranging from residential areas to runways. Previous studies have documented potential hazardous sites and their impacts on surface and subsurface ground water flow within the air station. Nonetheless, documenting the effects of surface storm*

water runoff on the transport of pollutants from various points within a particular basin to an assigned outlet on the air station have been overlooked. Understanding the surface flow paths has prompted the creation of a Geographic Information Systems (GIS) database for the industrialized section.

A simulation model is needed to describe the hydrology of the Marine Corps Air Station at Cherry Point, North Carolina, for the purpose of predicting storm flow quantity and duration. Any pollutant accumulated on the surface is generally transported by storm flow, Travel time is the time elapsed from which the pollutant is initially lifted and carried to some point of outflow. Pollutant transport is dependent upon water velocity, travel path, and distance traversed. The travel path and total distance are measurable, but velocities can vary. Thus, the model must be capable of tracking surface water routes and recording flow rates. Results will be applied to predict water movements at specific points and how spilled substances are transported via drainage waters.

The purpose of this study is to apply an urban runoff model to estimate peak discharge at distinct points within a basin. Initial runs were confined to industrialized areas. The SWMM model is the primary model. The GIS database was useful in model parameterization. The resulting peak estimates at various locations in the drainage flow path and estimated travel times will assist in managing the water quality at Cherry Point.

Keywords. surface water runoff, SWMM, geographic information systems, Storm Water Management Model, hydraulics modeling, model interfacing, hydrology

Introduction

Groundwater and surface water contamination are national issues deserving localized reduction efforts. The Neuse River Basin of North Carolina has undergone water quality degradation due to upstream increases in urbanization and land use alterations. Thus, we intend to create a water quality model to assist officials in assessing water quantity issues.

The Marine Corps Air Station (MCAS) at Cherry Point (Havelock, North Carolina), is a military installation consisting of urban land ranging from residential areas to runways. Previous studies have documented potential hazardous sites and their impacts on surface and subsurface ground water flow. Nonetheless, the effects of surface water runoff pollutant transport have been overlooked. Understanding the surface flow paths has prompted the creation of a Geographic Information Systems (GIS) database for the industrialized section.

A simulation model is needed to describe the hydrology of the MCAS for the purpose of predicting storm flow quantity and duration; Surface bound pollutants are generally transported by storm flow. Travel time, water velocity, travel path, and distance traversed are relevant parameters effecting pallutant transport. The travel path and total distance are measurable, but velocities can vary. Thus, the model must be capable of tracking surface water routes and recording flow rates. Results will be applied to predict water movements at specific points and how spilled substances are'transported via drainage waters.

The purpose of this study is to apply an urban runoff model to estimate peak discharge at distinct points within a selected basin. Simulations were confined to industrialized areas using measured rainfall information to generate surface runoff. The storm-water management model (SWMM) (Huber et al. 1983) was the selected software package. The GIS database will be used during parameterization and eventually integrated into SWMM. Resulting peak estimates at various locations and estimated travel times will assist in managing the water quality at Cherry Point.

Safety Emphasis

This research is being developed to assist the officials at Cherry Point Marine Corps Air Station in making decisions regarding accidental pollutant spillage. By estimating pollutant travel times, we will calculate minimum response times needed to combat such a problem. Thus, we are improving environmental awareness and making efforts to reduce the impact of harmful substances entering this nation's waterways.

Literature Review

The Water Quality Act of 1987 mandated the U.S. Environmental Protection Agency (EPA) to create regulations regarding storm water discharges, which prompted the creation of the National Pollution Discharge Elimination System (NPDES) (Warwick, 1991). Municipalities totaling more than 100,000 residents now must apply for NPDES permits for all locations with storm water outflows. To achieve compliance, municipalities requested the research community to develop and implement software to estimate hydrologic trends due to land use changes.

Distributed watershed models are often used to quantify and solve water resources problems (Garbrecht, 2002). Unfortunately, surface water modeling requires an extensive dataset. Data collection is essential but the systematic compilation and quality control concerns are incredibly time consuming. Following collection, the data must be processed to meet system requirements.

As Geographic Information System (GIS) based tools have become more available to the public, hydrologists must select the most appropriate application. The increase in availability has also generated doubts regarding the source, accuracy, storage requirements, and applicability of spatial data, GIS tools and models (Garbracht, 2002). Commonly, spatial data in GIS is arranged in vector and raster data structures (Garbracht, 2002). Vector structuring encompasses geographic features being represented by points, lines and polygons, similar to traditional hard copy maps,- while raster formatting divides a space into a selectable-sized grid (Garbracht, 2002). In some cases a raster-to-vector converter is needed to allow data insertion into a lumped hydrologic model (Olivera, 2002).

According to Garbracht, square Digital Elevation Maps (DEM) are most widely used due to their simplicity, processing ease and computational efficiency (2002). DEMs have fairly high quality (accuracy of elevation data) and resolution (horizontal grid spacing and vertical elevation increment) (Garbracht, 2002). One main disadvantage is grid size dependency, meaning some features may be too small to be actually depicted by a larger sized grid, but a smaller-size grid is unnecessary. TIN, triangulated irregular network, maps solve the dependency issue, but are more complex and lack wide distribution.

Jensen and Dominque (1988) and Jensen (1991) utilized a grid scheme to collect watershed attributes and to determine the stream network. A DEM was used to assign flow directions from ceils into adjacent cells according to elevation changes. [Note: Since flow direction cannot be determined for cells that are lower than their surrounding area, a sink algorithm is applied to fill low areas to a value equal to its surroundings.] The cells contributing flow to one outlet point may then be counted and the representative area containing those cells determined. Cells not contributing flow outline the watershed boundary. Cells having accumulated flow exceeding a threshold are considered streams. Functions that delineate streams and watershed using the Jensen-Domingue procedure are available through Avenue requests in ArcView 3.0x Spatial Analyst 1.1, the Hydrologic Modeling ArcView extension (ESRI), or the Watershed Delineator ArcView extension (ESRI) (Olivera, 1998).

There are six major steps needed for watershed-surface water modeling automation, the first five being adapted from a study examining HEC-PrePro v2.0 (et. al. Olivera, 2002). The sixth step was originally included in the fifth step, but deserves separation for universality.

1. Analyze a raster-based terrain map and define the stream network
2. Vectorize the hydrologic elements
3. Compute the hydrologic element parameters (area, length, slope, etc.)

4. isolate a hydrologic sub basin
5. Analyze the topographic features of the sub basin (width, slope, etc.)
6. Prepare a model-readable input file (ASCII format)

The above steps only involve placing information into the model and running the simulations. To complete automation, model outputs would need to be converted back into the selected GIS package. MODLFOW received such automation when researchers rewrote the output data from the simulations into an ARC/INFO format (Orzol, 1994). Later, Orzol and McGrath used FORTRAN to create a modified MODLFOW, named MODFLOWARC that directly read and wrote ARC/INFO files.

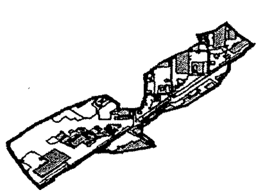
Computational Hydraulics, Incorporated (CHI), the authors of PCSWMM, have also created a stand-alone package of SWMM that is capable of GIS linkage. The GIS component of PCSWMM 2002 can interface directly with databases of almost any GIS/AM/FM/CAD system (CHI, 2002). ESRI, MapInfo and AutoCAD layers can be displayed. Node, conduit, and sub basin information can be selected from the associated attribute table, exported to a SWMM input file and simulated but PCSWMM GIS does not determine input parameters directly from shapefiles, The GIS component is used mainly for drawing/editing model elements and constructing connectivity networks within the SWMM program (CHI, 2002). The model portion of PCSWMM 2002 handles file management, input data file development, model simulations, output visualization and interpretation, sensitivity, calibration and error analysis, etc. (CHI, 2002).

One objective is to advance the linkage possibilities between an existing model, SWMM, and an available GIS package, ARCmap, to allow direct data input into the modeling software, for simulation and

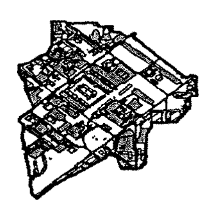
Study Area

The study site is located within the Marine Corps Air Station (MCAS), a military installation situated north of the City of Havelock in Craven County of eastern North Carolina. Five drainage basins (School House Branch,Sandy Branch, Luke Rowe's Gut, Turkey Creek and Mill Creek) drain approximately 2450 acres of wooded, industrial, and residential land types. A portion of the Sandy Branch area is examined in this study.

Figures 1 & 2: Created Sub basins, Areas K2 and K3, used for SWMM simulations

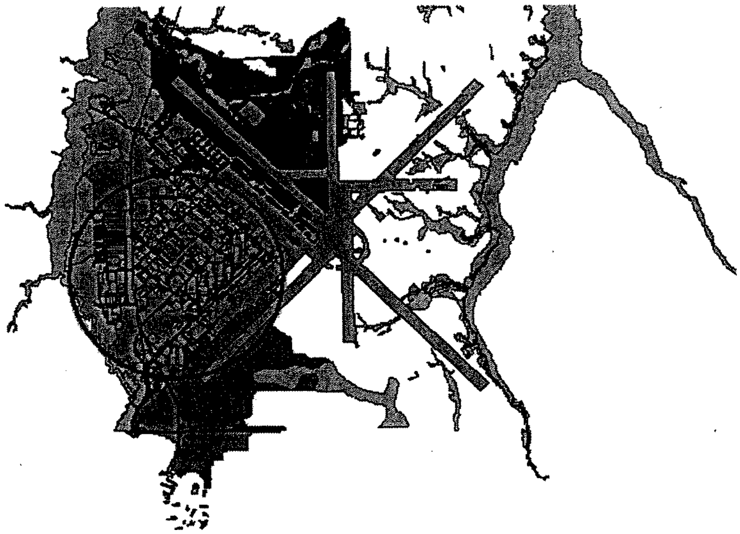


Area K2, 119 ac. (not to scale)



Area K3, 259 ac. (not to scale)

Figure 3: Sandy Branch hydrologic unit (MCAS), including sub basins K2 and K3 (not drawn to scale, CPEC, Inc. 2000)



This 500+ acre area was divided into two smaller hydrologic units (sub basins) using available GIS databases. The created units, K2 and K3 then served as the "watershed" for the SWMM applications (see Figures 1 & 2). Sandy branch is situated in the industrial portion of the air station (refer to Figure 3). The mapped soil textures for the A-horizon are mucky fine sandy loam, loamy fine sand, fine sandy loam, and urban. The B-horizon textures ranged between fine sandy loam to silt loam and sandy loam to sandy clay loam. K2 has an area of 115 acres, consisting mainly of industrial buildings and is approximately 59% impervious. K3 has an area of 259 acres and is 40% impervious. Both areas consist mainly of buildings, parking lots, roads, and other impervious structures, nonetheless, there are still open areas, including wetlands and forested land located in K2. Slopes for the units range from 0.1% to 2.0%.

Instrumentation, and Data Collection

Precipitation and runoff have been monitored at the study site since October 2000 using one HOBO self-recording, tipping bucket type automatic gauge and three manual gauges. Cumulative rainfall was recorded by the automatic rain gauge. Likewise, the manual gage cumulative amounts were recorded during visitations.

An official National Weather Service (NWS) weather station, located in the control tower, monitors air temperature, dew point temperature, wind speed, sky cover and precipitation (NCDC, 2000). Rainfall collected at the station is substituted whenever data was unavailable. Penman-Monteith based potential evapotranspiration (PET) values were adaptedfrom another research site located approximately 19 miles northeast of MCAS (Amatya, 2001).

Three instruments were installed at each watershed outlet. First, a sharp-crested V-notch weir was placed in each culvert barrel. Second, a stage recording apparatus equipped with a Blue Earth microprocessor was installed on the upstream side of each culvert. Third, one self-recording STARFLOW flow meter was installed downstream of the lowest weir. The v-notch weir captured low flow measurements, while the flow meter recorded data during weir submergence.

The STARFLOW ultra-Doppler flow meter (Unidata Corp.) continuously measures stage and average velocities in ten-minute intervals. The digital flow meter records time, date, water temperature, and water velocity by emitting ultrasonic Doppler waves in an upstream direction. A pressure transducer measures stream stage (Unidata, 2000). The recorded measurements are stored as text files and later converted to a spreadsheet form.

The Blue Earth assembly record stage readings and consists of two pulley systems. One pulley is fastened to a float that changes with water height fluctuations; the other pulley acts as the counterweight. A potentiometer converts the degree of rotation into electrical signals that are recorded by the Blue Earth microprocessor as elevation changes. Data is stored only if significant change has occurred. Similar to the STARFLOW, data is written in a text format, downloaded, and entered into a composite spreadsheet.

Methodology

The scope of this paper is limited to two sub-basins, K2 and K3. These two units were selected due to their dense industrial population and rankings as potential risks due to pollutant discharge into neighboring ecosystems. The initial steps of the project required selecting and installing flow-monitoring equipment capable of recording continuous flow data.

The main goal of the modeling section is to simulate peak flow rates at various locations to predict minimum travel times. The peak flow was selected since it represents the highest flow rate during a storm event, thus, being accompanied by the quickest travel (quickest travel time relates to the minimum response time required to combat an accidental spill at any point in the sub basin). Using the peak rate estimates from the calibrated model the shortest time of travel of water/pollutant movement will be determined.

Initial estimates for the peak runoff rates were determined for the overall sub-basins using a lumped parameter version of the Rational Equation (Bedient and Huber, 1988):

$$Q = k\,C\,I\,A \qquad (1)$$

Where, k=conversion factor, Q=peak flow rate (cfs or m^3/s), C=runoff coefficient, I=rainfall intensity(in/hr or mm/hr), and A= watershed area (ac. or ha). In most cases the coefficient, k=1.008, is ignored when using English units. The runoff coefficient, C, is usually available as a function of land use. When considering multiple land uses, a weighted C-value may be computed as applied to this study. From the GIS attribute table, land uses were identified. A C-value was selected for each land use type (i.e. parking lots, buildings, open area, and roads) and the weighted average for the area was completed. Intensity, I, may be obtained from an Intensity-Duration-Frequency (IDE) curve for a specified return period when assuming that rainfall duration equals time of concentration. Time of concentration, Tc, is the amount of time required for water to travel from the most remote point of the watershed to the watershed outlet. The Kirpich formula is a common equation employed to determine this parameter (Sheridan, 1994):

$$Tc=(k / 128) * (L^3 / H)^{0.385} \quad (2)$$

Where, Tc is computed in minutes, k=watercourse multiplier, d-channel length (ft), and H=height of most remote point (ft/ft).

The Blue Earth stage information served as the basis for the flow calculations. Using a v-notch weir equation, flow rates were calculated during low flow periods. The following equation was used only if the height above the crest of the weir did not exceed the threshold.

$$Q = 4.43 (H)^{2.48} \quad (3)$$

Where, 4.43 is the coefficient for a 120 degree weir, H=height above weir crest (ft) , and Q= flow rate (cfs). One weir maintained the lowest elevation and served as the benchmark for that location. The additional weirs were correlated to the lowest weir, and their H-values were adjusted accordingly. The flow rates of each barrel were summed, creating a total flow rate for the culvert (note, backwater conditions were not considered).

The Starflow self-recorder was installed to handle periods of intense flow. The Starflow "awakened" every ten minutes to record stage, water temperature, velocity, battery voltage and date/time. The archived data was converted to an ASCII format and appended bi-weekly. The velocity data was then converted to flow data using a FORTRAN program named Velflo. Using the created breakpoint output file, the Starflow flow data was combined with the Blue Earth data to complement weir submergence.

The most pivotal model input section is rainfall. The HOBO was downloaded onto a HOBO shuttle and then processed in the laboratory using the BOXCAR Pro program and later exported to Microsoft Excel. If discrepancies existed, the manual gage was used to correct errors.

For modeling, the rainfall needed to be in intensities or volumes. Using a filter, the hourly precipitation was tabulated for only the selected storm events and converted to hourly intensities.

Parameterization

As stated before, SWMM is the main model and the RUNOFF block was only explored. SWMM Beta 4.4 is the newest version of SWMM and was used for most simulations. PCSWMM 98 conducted several initial simulations before progressing to the newer version. The RUNOFF module is a hydrology/hydraulics module that may be run independently from the rest of the SWMM modules (James, 1999). Using a text file, the input files needed for simulations were created from several sources. First, the rainfall data was adapted from the HOBO information. Second, the catchment characteristics were generated from the GIS database and its associated spreadsheets. Last, routing features (channel and pipe sections) were attributed from the GIS database and created by manually assessing the surface/subsurface connectivity.

The catchment attributes were solely the result of the GIS work completed by CPEC, Inc. Building, parking lots, paved areas, roads, open areas, runways, and other features were entered using GPS (global positioning system) technology. We created land use coverages via the constructed GIS layers. Sub basins were created using the provided digital topography. Catchment measurements such as area, width, and watercourse length were measured in the GIS shapefiles/layers. Other parameters, such as slope, roughness, depressional storage, and infiltration rates required further calculations. Below is a sample input Runoff module dataset.

Figure 4: Sample SWMM Runoff Dataset for Storm Event 243 (2001) in area K3

```
                                                            k2_243.txt
SW 10 3
MM 4 1 2 3 4
*------------------------------------------------------------------------
*        SWMM 4.4 RUNOFF DATA FILE
*------------------------------------------------------------------------
$RUNOFF
*------------------------------------------------------------------------
*        Create title lines for the simulation.
*------------------------------------------------------------------------
A1  'CP-K2'
A1  'EVENT 243 '
*------------------------------------------------------------------------
*        The 'B' lines are for program control purposes.
*------------------------------------------------------------------------
*  METRIC ISNOW NRGAG INFILM KWALTY IVAP NHR NMN NDAY MONTH IYRSTR
B1   0      0     1     1      0     1   00  00   01    09    01
*   IPRN(1) IPRN(2) IPRN(3)  IRPNGW
B2     0       0       1
*   WET   WET/DRY  DRY  LUNIT LONG
B3  900.  3600.   7200.   3    2
*------------------------------------------------------------------------
*        Line D1 is the first rainfall control line.
*------------------------------------------------------------------------
*     ROPT
D1  0
*------------------------------------------------------------------------
*        Paste rainfall data (F lines) here.
*------------------------------------------------------------------------
*  KTYPE KINC KPRINT KTHIS KTIME KPREP NHISTO THISTO TZRAIN
E1   0    12    0      0     1     1     48     1.0    0
E3   0    0     0   0   0   0   0   0   0   0   0
E3   0   .01 " 0 2 0   0   0   0   0   0   0   0   0
E3   0    0     0   0   0   0   0  .04 .60 .01  0   0
E3   0    0     0   0   0   0   0   0   0   0   0   0
F1 0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
*------------------------------------------------------------------------
*     Enter gutter information on line G1. If weir is present also use G 2.
*     NAMEG NGTO NPG PG  GWIDTH GLEN   G3      GS1   GS2    G6    DFULL GDEPTH
G1     320   321   2      1.5    185   0.0054  0            0.014        0
G1     324   320   3      1.5    10    0.0011  0     8      0.014  8     0
G1     321   319   2             899   0.0011  0     0      0.014  0     0
G1     319   323   2      3::    952   0.0011  0     0      0.014  0     0
G1     323   317   3      1.5    196   0.0510  0.32  0.32   0.023  2.0   1.0
G1     317   309   1      1.5    196   0.0510  0.32  0.32   0.023  2.0   1.0
G1     309   315   1      3:o    345   0.0058  0.32  0.32   0.023  2:0   1.0
G1     316   309   1      2.5    165   0.0480  0.60  0.60   0.023  3.0   1.0
G1     315   310   1      20.0   1028  0.0001  0.01  0.01   0.023  1.0   0.02
G1     314   310   1      20.0   820   0.0001  0.01  0.01   0.023  1.0   0.02
G1     312   310   1      20.0   459   0.0001  0.01  0.01   0.023  1.0   0.02
G1     310   322   1      3.0    641   0.0001  0.32  0.32   0.023  3.0   1.0
G1     322   300   1      3.0    125   0.0001  0.32  0.32   0.023  3.0   1.0
G1     308   307   1      20     35    0.0001  0.01  0.01   0.023  1.0   0.01
G1     307   305   1      20     174   0.0057  0.01  0.01   0.023  1.0   0.01
G1     305   302   1      20     234   0.0001  0.01  0.01   0.023  1.0   0.02
G1     303   302   1      20     174   0.0001  0.01  0.01   0.023  1.0   0.02
G1     302   301   1      2.0    808   0.0062  0.50  0.50   0.023  0.5   0'1
G1     301   322   3      1.5    10    0.0001  0.32  0.32   0.023  2.0   1:0
*     Enter Subcatchment Data on line H1.
*  JK NAMEW NGTO WIDTH AREA  %IMP   SLP     IMPN   PERVN IDS  PDS  MAX  MIN  DECAY
H1  1   1   200   321  6.27  57.4  0.0207  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   2   201   259  6.66  52.1  0.0144  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   3   202   464  7.86  42.5  0.0189  0.014  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   4   203   270  3.03  20.0  0.0032  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   5   204   178  3.27  20.0  0.0038  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   6   205   467  9.72  40.7  0.0149  0.013  0.25 0.05 0.10 4:o  1.00 0.34
H1  1   7   206   12s  2.02  35.8  0.0194  0.013  0.2s 0.05 0.10 4.0  1.00 0.34
H1  1   8   207   170  2.68  51.1  0.0171  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   9   208   463  8.95  77.6  0.0100  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   10  209   499  4.33  59.4  0.0162  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   11  211   318  2.30  77.8  0.0386  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   12  210   528  7.66  61.4  0.0064  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   13  212   188  9.38  77.9  0.0018  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   14  213   264  8.19  54.8  0.0030  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   15  214   550  16.1  66.2  0.0054  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   16  217   283  6.23  59.3  0.0014  0.013  0.25 0.05 0.10 4.0  1.00 0.34
H1  1   17  215   128  3.25  72.7  0.0020  0.013  0.25 0.0s 0.10 4.0  1.00 0.34
H1  1   18  216   327  6.72  74.4  0.0022  0.013  0.25 0.05 0.10 4.0  1.00 0.34
*------------------------------------------------------------------------
*        Enter data for Channel/Inlet print control M lines.
*------------------------------------------------------------------------
* NO water quality simulations
*  NPRNT  INTERV
M1 1   1
*  NDET  STARTP(1) STOPPR(1)  IPRNT(1)
M2 1 0 0
M3 300
*------------------------------------------------------------------------
*        End your input data set with a $ENDPROGRAM.
*------------------------------------------------------------------------
$ENDPROGRAM
                                                            Page 1
```

Routing was the next step. The field crews measured the surface conduit features and created the GIS attribute tables. Unfortunately, only inlets or outlets of pipes were measured so pipes were assumed to remain uniform between points of known measure (i.e. headwalls). Side slope information was not directly measured, but determined from channel depth, bottom width, and top width values. Likewise, stream channel slope was acquired by dividing the change in elevation by the stream length. A Manning's roughness value of 0.023 was used for natural stream sections while 0.014 was reserved for piped areas. From the delineated catchments a stream/pipe network was created. Each catchment area had a numbered outlet point, which was connected to a pipe or stream section. Eventually, all water was routed to a main watershed outlet point that represented the culvert entrance.

Modeling Results

The actual simulations comprised approximately one-fourth of the research effort. After collecting measured data and preparing the data for model entry, the simulations followed. The last portion of the project is developing a GIS interface for SWMM simulations.

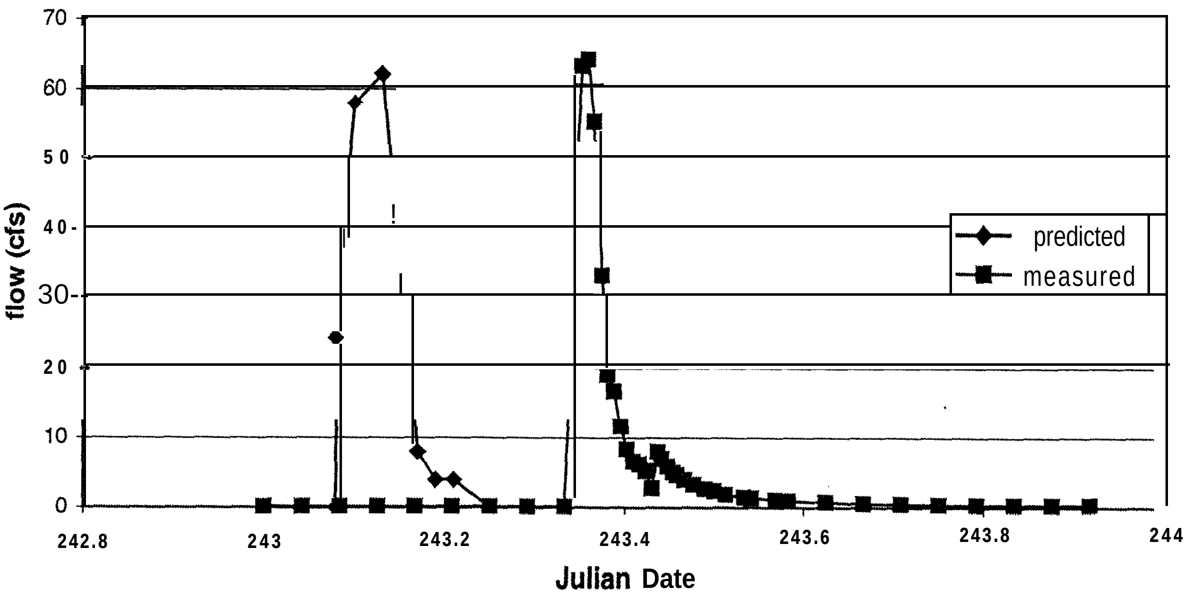
Several input datasets were created for the SWMM runoff module. Five storm were selected based upon their relative peak runoff rate and the their timing. Initially seven storms were selected, but five proved to be meaningful following the simulations. Table 1 provides precipitation data about each storm event.

Table 1: K3 sub basin 2001 storm eventsummaty

Peak date (Julian Date)	Duration (hr)	Time to Peak (hrs),	Measured Peak Flowrate (cfs)
20	19.8	3.8	12.6
59	32.2	2.0	11.4
143	31.0	1.8	15.4
167	38.2	0.1	75.8
185	10.0	2.0	17.2
243	10.1	1.0	63.0
352	25.0	1.9	16.3
358	13.9	1.9	1.9

For this report only two events will be discussed. Events 167 and 243 (year 2001) have been identified by the Julian date upon which the peak flow rate was noticed. Events 167 and 243 had rainfall amounts of 2.2 in. and 0.68in. respectively. Storm durations ranged from several hours to more than one day, achieving a maximum intensity of 0.60 in/hr on day 167 and 0.20 in/hr for day 243. The estimated surface runoff depths of each storm were 1.20in and 0.35in. for K2 and 0.80in. and 0.26in. for K3. Employing the rational method (Q=CIA) the simulated peak rates should be near 14 cfs (K2) and 2lcfs (K3) for the 167 event, respectively. Likewise, the 243 event yielded rational results of 41 cfs and 68 cfs for K2 and K3, respectively. The composite flow spreadsheet using measured data revealed flow rates for K2 near 20 and 27 cfs for the two dates. The K3 measured data reported values of 76 and 63 cfs for the same storm events. The following charts illustrate output generated from SWMM and the measured data prior to model calibration.

Figure 5: Single event hydrograph showing SWMM predicted vs. measured flow rates for Storm 243 at area K3 outlet



Rainfall, catchment characteristics, routing, and control options were all determined using the "Hydrology: a guide to the Rain, Temperature, and Runoff modules of the USEPA SWMM4." (James and James, 1999). Rainfall was collected from the cumulative rain spreadsheet. Catchment and routing information were entered from the GIS databases and other sources. The routing elements varied between natural stream channels, concrete pipes and dummy sections (inflow equals outflow). The evaporation value was set to 0.1in/day for each simulation. The Green-Ampt equation handled infiltration and its associated parameters were adapted from literature for a similar urban watershed. Several simulations were completed using a 5-day period in most cases. Water quality was not simulated. The model was not verified, rather the purpose of this step was to get a working model, realize its sensitivities, and to refine it as the study progressed.

The uncalibrated version of SWMM seemed to work fairly well with these first simulations. Remember, percent imperviousness for each area is 0.59 (K2) and 0.40 (K3) and K2's overall area is 119 acres, while K3 covers 259 total acres. For area K2, the 167 event simulated a maximum flow rate of 22 cfs, while the 243 event reached a height of 34 cfs. For area K3, the predicted peaks were 23 and 6lcfs. The model reported water balance errors ranging from -1.019% to .094 % where error was calculated by:

$$\frac{\text{(Precipitaion} - \text{Infiltration} - \text{Evaporation} - \text{Surface runoff} - \text{Stored water)}}{\text{Precipitation}} \quad (4)$$

A connectivity check for the channels and pipes was also conducted and yielded errors from 59% to 9.42%. Event 167 in area K2 was exceptional, yielding a 95% error.

Conclusion

The following table summarizes the results from the various techniques:

Table 1: Simulation and equation estimates for two storm events at Cherry Point, NC (2001)

Measured Data (cfs)	Rational Method (cfs)	SWMM output (cfs)	Event
20	14	22	K2-167
27	41	34	K2-243
63	21	23	K3-167
76	68	61	K3-243

There are varying degrees of differences between the measured, estimated, and predicted values. Overall it seems as though area K2 worked better in SWMM than does area K3. Both events modeled in area K2 produced reasonable estimates that were closer to the rational value and the measured maximum than its K3 counterpart. For K3, SWMM over predicted the measured event 167 maximum by nearly 10% and the rational value by 36%. Likewise for event 243 the measured data was surpassed by 26% and the SWMM output only represented 80% of the rational value. On the other hand, SWMM did not handle K3's event 167 very well. At first, the rainfall had been entered in a different manner that calculated values in the upper teens. After re-entering the rainfall in a fashion similar to that of the other input datasets, and adjusting the simulation period, a maximum value to 23 cfs was achieved although it was 40 cfs under the measured value and reflected only 91% of the rational value. Event 243 for area K3 seemed to run a bit smoother although the measured maximum flow rate is nearly 25% greater than the SWMM prediction and the rational estimate surpasses the SWMM value by about 10%. Both areas had numerous areas of surcharged pipes and channels that probably added to the inaccuracy of the some simulations.

Remember that SWMM was not calibrated for these simulations; rather the real importance was to be able to use the GIS database to create a SWMM input file. There were several bugs in the modeling simulations that have yet to be addressed. Although the K3 may seem almost twice the size of K2, rainfall runoff travels differently between the two catchments. K2 (59% impervious, 115 ac.) has a large wetland and forested areas upstream from the monitoring station that usually increases infiltration due to flow retardation. K3 (40% impervious, 259 ac.) is mostly open area, parking lots, buildings and roadways; mostly elements that generate accelerated runoff rates.

Watershed area and percent imperviousness are additional areas of concern. In discretizing the sub basins, watershed measurements such as length and width may greatly affect model outputs. In general, the modeler is attempting to represent a complex area using limited measurements. For this study, we measured area lengths, widths and slopes in accordance to SWMM documentation, and generated averages. During testing, we noticed a direct relationship between sub basin area and simulated runoff. Likewise, increasing percent impervious increased surface runoff, but the degree of difference was dependent upon rainfall amounts.

The SWMM generated output was also incorporated to determine travel times. Using the measured stream lengths and the SWMM estimated water velocities; we calculated travel times from sub basin outlets with the following equation:

$$\frac{\text{Measured stream length (ft)}}{\text{Predicted peak velocity (ft/s)}} \qquad (5)$$

The calculated travel times represent the shortest elapsed time for pollutant transport since peak flow rates were utilized. MCAS could now use the predicted travel times to manage pollutant movement between distinct points within the watershed.

As the research progresses the modeling difficulties will be addressed and fixed accordingly. After calibrating and verifying SWMM, for the specific location, the interface development begins. The main focus of the project is to create a user-friendly interface between SWMM and ARCGIS. Using the Visual Basic (VB) programming language, we plan to incorporate a system where an end-user will be able to "read" an ARCGIS attribute table directly into SWMM, run the needed SWMM simulations, and create output files within SWMM. As mentioned in the literature review section, other researchers have successfully used attributed GIS based information to run SWMM simulations and a GIS version of SWWM does exist, called PCSWMM-GIS. Nonetheless, the two aforementioned software packages are not able to parameterize the inputs needed for a SWMM dataset. For a specific application, we plan to have SWMM use the GIS database uniquely to write the input text file and graphically interpret the SWMM outputs using a GIS based visual display. This development would be our contribution of the hydrologic modeling community, and more importantly, the command officials at Cherry Point Marine Corps Air Station.

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