University of Southern Indiana
Pott College of Science, Engineering, and Education
Engineering Department

8600 University Boulevard
Evansville, Indiana 47712

Continuous Hydrologic Modeling to Evaluate a Stream Water Diversion

Lauren Melchior and Noah Wagner
ENGR 491 – Senior Design
Spring 2022

Approved by: ______________________________
Faculty Advisor: Jason Hill, Ph.D.
Date

Approved by: ______________________________
Department Chair: Paul Kuban, Ph.D. Date

ACKNOWLEDGEMENTS

We would like to thank our advisor and liaison, Dr. Jason Hill, for his guidance and knowledge throughout this project.

We would also like to thank, Dr. Kerry Hall, Dr. Adam Tennant, and the rest of the University of Southern Indiana’s Engineering staff for the passion and education throughout our years here at USI.

EXECUTIVE SUMMARY

A continuous hydrologic model (HEC-HMS) was developed and will be used to evaluate a water diversion for wetland creation in Evansville, IN. Continuous hydrologic models require continuous tracking of soil moisture changes. This requires vapor loss to the atmosphere via evapotranspiration (evaporation plus transpiration) to be modeled. Two methods were used to calculate evapotranspiration using 20 years of historic meteorological data. Field data was collected to aid in validation of the HEC-HMS model. This required installation of a staff gauge and a water level measurement station. The validated model will be used in future storage routing calculations to design a culvert to divert water towards the center of the site. A hydraulic model (HEC-RAS) developed by a previous capstone design team was also used to aid storage routing calculations with HEC-HMS. In addition to the developed model, water quality analysis was conducted to reinforce the objective of improving water quality at the site. The results from the model will provide estimates of water diversion quantities achievable over a wide range of meteorological conditions.

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1.0 BACKGROUND

1.1 Site Overview

The project site is located on the west side of Evansville, Indiana on University of Southern Indiana's campus. The land was gifted to the University of Southern Indiana by the Diocese of Evansville with the expectation that the land is used for academic purposes. The site originally had wetland like conditions then was leased for farming, however in recent years the agricultural field has been left untouched. Wetland conditions currently exist on approximately 1 acre of the site.   The area of interest (AOI) drains through a culvert that goes underneath Nurrenbern Rd., which flows through a ponded area and eventually discharges through an existing farm culvert on the site. The ponded water is the focus area for data collection as well as the flow traveling through the farm culvert. The motivation for this project is to re-establish wetland conditions on the abandoned agricultural field using a stream water diversion. The environmental impact from reestablishing a wetland will cause the abandoned agricultural field to become a nutrient sink and it will also benefit groundwater quality in the area.

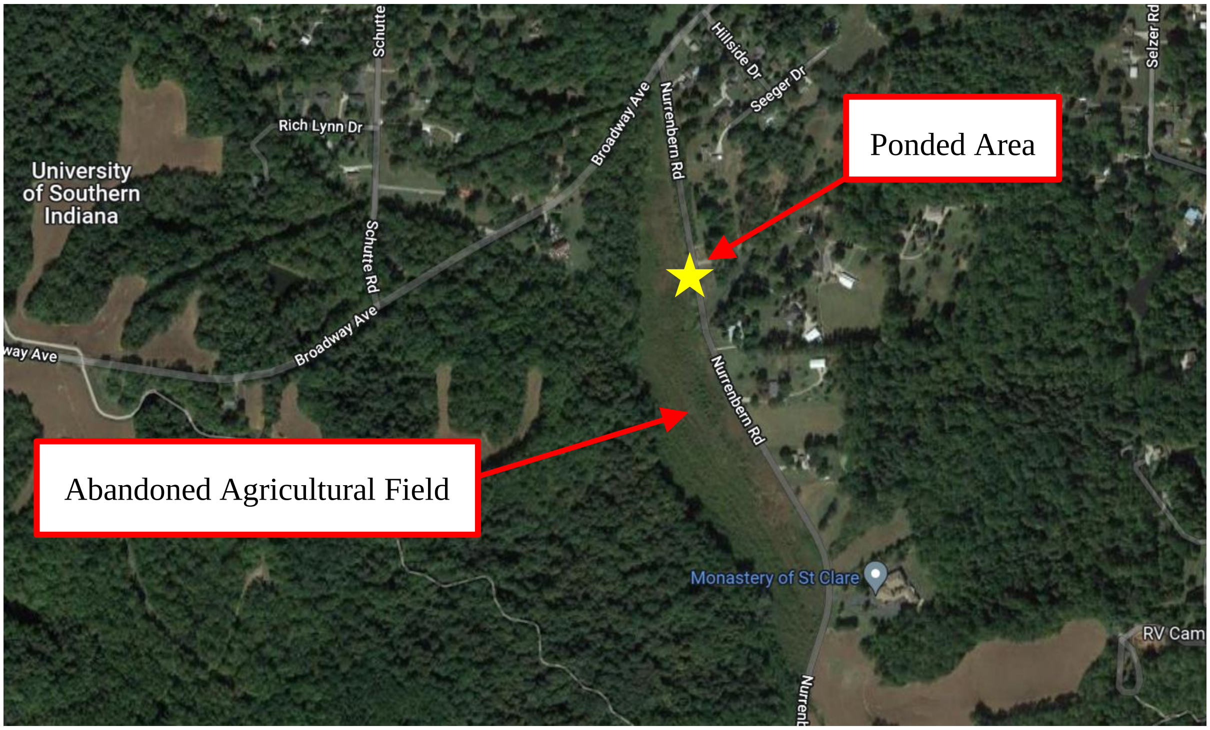


Figure 1. Project Location

1.2 Previous ENGR 491 Student Work

Two former cap stone design teams have completed work at this Nurrenbern project site. In 2013, Eric Bradshaw, Brandon Durchholz, and Juan Quiroz, a hydraulic model (HEC-RAS) was developed to model the flood discharges of the streams surrounding the site. The hydraulic model was able to simulate a flood event from October 5-6, 2013 (24-hour duration). Bradshaw, Durchholz, and Quiroz also developed a grading plan that promoted water storage and a water budget of the site.

In 2018, Corbin Sollman, Storm Kollak developed a proposed grading plan to also promote water storage and a proposed water diversion. The group proposed an inline, V-notched weir and a drainage culvert to divert additional water from the onsite stream into the designed wetland storage area.

1.3 Scope of Work

In addition to the previous projects conducted at the Nurrenbern restoration site, this project is a continuation of this overall project aimed at increasing site wetness and supporting academic activities on site, including research and field laboratories. The project builds upon the valuable work of previous student teams and USI faculty.

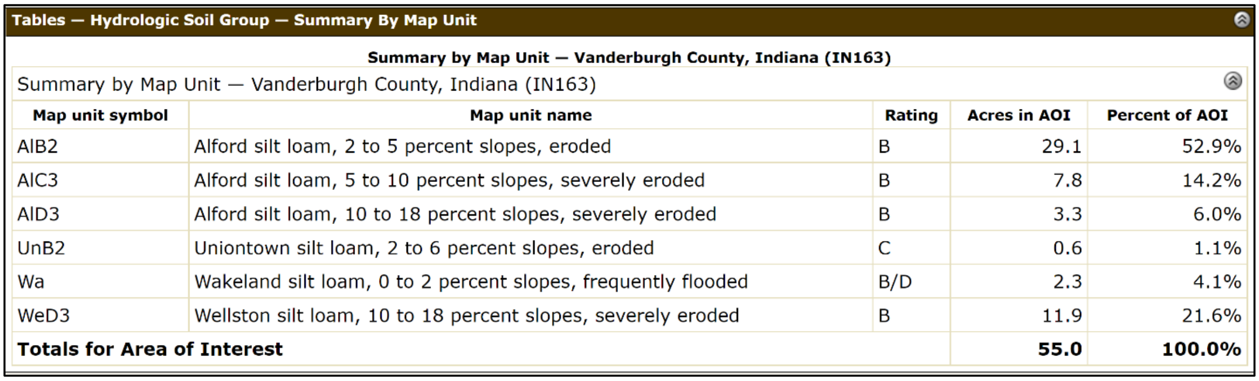
A continuous hydrologic model (HEC-HMS) was developed and will be used to evaluate a water diversion for the wetland restoration near Nurrenbern Rd. in Evansville, IN. Continuous hydrologic models require continuous tracking of soil moisture changes. This requires vapor loss to the atmosphere via evapotranspiration (evaporation plus transpiration) to be modeled. Two methods were used to calculate evapotranspiration using 20 years of historic meteorological data. Field data was collected to aid in validation of the HEC-HMS model. This required installation of a staff gauge and a water level measurement station. The validated model will be used in future storage routing calculations to design a culvert to divert water towards the center of the site. A hydraulic model (HEC-RAS) developed by a previous capstone design team was also used to aid storage routing calculations with HEC-HMS. In addition to the developed model, water quality analysis was conducted to reinforce the objective of improving water quality at the site. The results from the model will provide estimates of water diversion quantities achievable over a wide range of meteorological conditions.

2.0 PRELIMINARY SITE ANALYSIS

The watershed delineation process for this watershed began with a delineation using the StreamStats application by the United States Geological Survey (USGS). The outlet chosen to be delineated was the ponded area of the project site.

Figure 2. Delineated Watershed from StreamStats

Using the output from StreamStats, the shapefile was uploaded to USDA Web Soil Survey to determine the soil types of the watershed and other physical properties, such as hydrologic soil group.



Tables — Hydrologic Soil Group — Summary By Map Unit

Summary by Map Unit — Vanderburgh County, Indiana (IN163)

Summary by Map Unit — Vanderburgh County, Indiana (IN163)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
AlB2	Alford silt loam, 2 to 5 percent slopes, eroded	B	29.1	52.9%
AlC3	Alford silt loam, 5 to 10 percent slopes, severely eroded	B	7.8	14.2%
AlD3	Alford silt loam, 10 to 18 percent slopes, severely eroded	B	3.3	6.0%
UnB2	Uniontown silt loam, 2 to 6 percent slopes, eroded	C	0.6	1.1%
Wa	Wakeland silt loam, 0 to 2 percent slopes, frequently flooded	B/D	2.3	4.1%
WeD3	Wellston silt loam, 10 to 18 percent slopes, severely eroded	B	11.9	21.6%
Totals for Area of Interest			**55.0**	**100.0%**

Figure 3. Soil Type Percentage of AOI

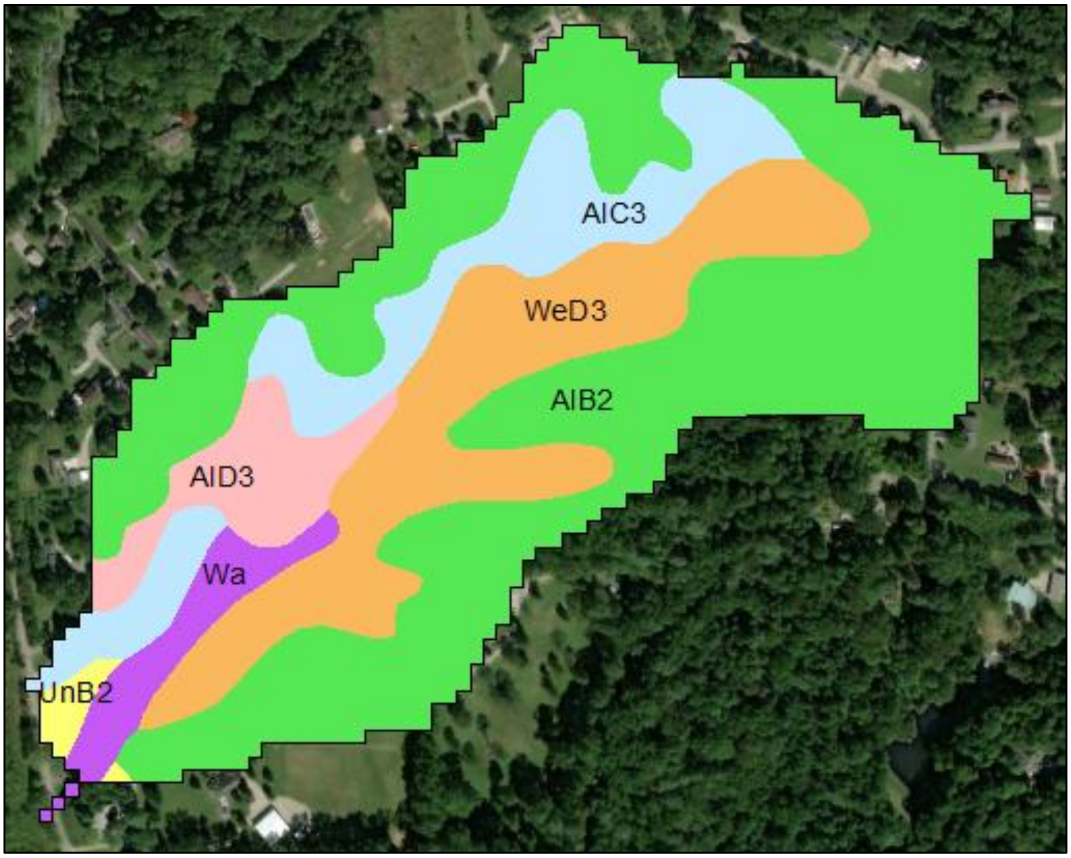


Figure 4. Web Soil Survey Soil Type Output

2.1 Water Quality

A brief water quality study was conducted on the ponded area. Previous studies have shown that there are high levels of E. coli in the stream and ponded area. This is most likely due to the failing septic systems in the watershed.

2.1.1 Chemical Oxygen Demand (COD)

A water sample was collected from the ponded area on March 1, 2022. The sample was collected near the widest point of the ponded area and was from about 3 inches below the water surface. Two samples were tested and the results are shown in Table 1. The equipment used for testing was a colorimeter, AQUAfast Orion4000. The procedure followed for testing of Chemical Oxygen Demand (COD) is listed in *Appendix A*. The results are shown below. The COD was found to have an average of 9.5 ppm.

Table 1. Results of COD in Ponded Area

COD (mg/L)(ppm)	
Sample 1	9.5
Sample 2	9.6

3.0 CONTINUOUS HYDROLOGIC MODEL DEVELOPMENT

There are two common forms of hydrologic modeling: event and continuous. Event modeling often models a single rain event and assumes an average soil moisture condition. Continuous modeling is a simulation over a period ranging from days to decades. Soil moisture conditions in continuous modeling need to account for the changes that occur within the soil over time. This is called the soil moisture accounting algorithm which is depicted below (Figure 5).

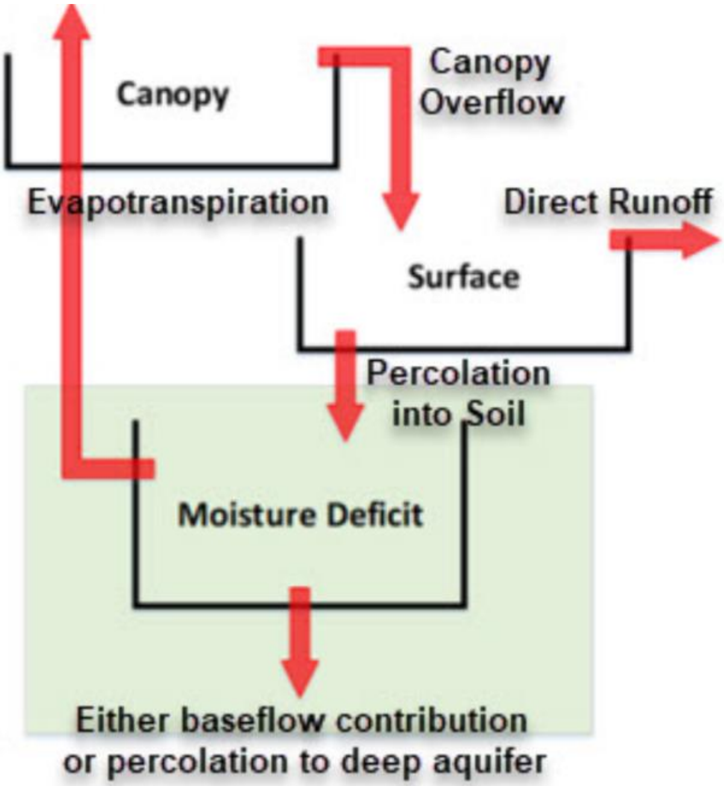


Figure 5. Soil Moisture Accounting Algorithm

The soil moisture accounting algorithm partitions rainfall into 1 of 3 storage areas. The model continuously tracks the storage in each zone. First, precipitation strikes the canopy and is intercepted based on present vegetation. The key parameter is the canopy storage capacity. At the soil surface, water is either stored as depression storage, infiltrated, or become surface runoff. Water is depleted from each storage zone through a process known as evapotranspiration. Evapotranspiration models water vapor losses to the atmosphere through evaporation and transpiration from the vegetation. The water that reaches and infiltrates the soil is modeled by quantifying the moisture deficits in the soil. The initial and maximum deficit of the soil depend on soil type. The estimation of the parameters that model the soil moisture accounting algorithm are described in *Section 3.1.* The soil moisture accounting algorithm is essential to the continuous hydrologic model to produce results that accurately models the changes in the soil through time.

3.1 Calibration of HEC-HMS Model

The loss model chosen for the development of the continuous model was the Deficit and Constant Method. The Deficit and Constant Method accounts for changes in soil moisture, evapotranspiration, canopy interception, and direct surface runoff. Most importantly, the inputs for the continuous hydrologic model reflect the changes in soil moisture through time.

3.1.1 Model Inputs

Wilting Point in the watershed was defined based on soil type in the watershed. A wilting point that represented the entirety of the watershed was calculated by taking a weighted average of the wilting point value corresponding to each soil type and the area *Figure 3*. The delineated watershed consists of varying classifications of silt loam. The wilting point input for the model was $0.13\ \frac{in^3}{in^3}$ (*Rawls, Brakensiek, and Miller (1983)).*

To estimate the initial parameter of saturation storage, effective porosity is based on soil type. According to *Rawls, Brakensiek, and Miller (1983),* effective porosity is $0.49\,\frac{in^3}{in^3}$.

The maximum deficit of the soil was estimated by taking the difference of the weighted porosity and the weighted wilting point and multiplied by the active soil layer depth (refer to *Equation 1*). According to Web Soil Survey (USGS), the active soil layer depth was estimated to be 2 meters.

$$Maximum\ Deficit = \left(0.49\frac{in^3}{in^3} - 0.13\frac{in^3}{in^3}\right) \times (2m)\left(\frac{100cm}{1m}\right)\left(\frac{1in}{2.54cm}\right) \qquad \text{(Eq. 1)}$$

The loss method chosen for this model was the SCS Curve Number Method. Using ArcGIS, landcover data from 2019 was mapped according to land usage (*Figure 6*). The hydraulic soil groups, given by Web Soil Survey, in addition with the land use type a curve number was assigned to each area/polygon. A weighted curve number was estimated using *Equation 2*. The estimated curve number for the watershed is 60.

$$CN = \frac{\sum(CN \times Area)}{Total\ Area\ of\ Watershed} \qquad \text{(Eq. 2)}$$

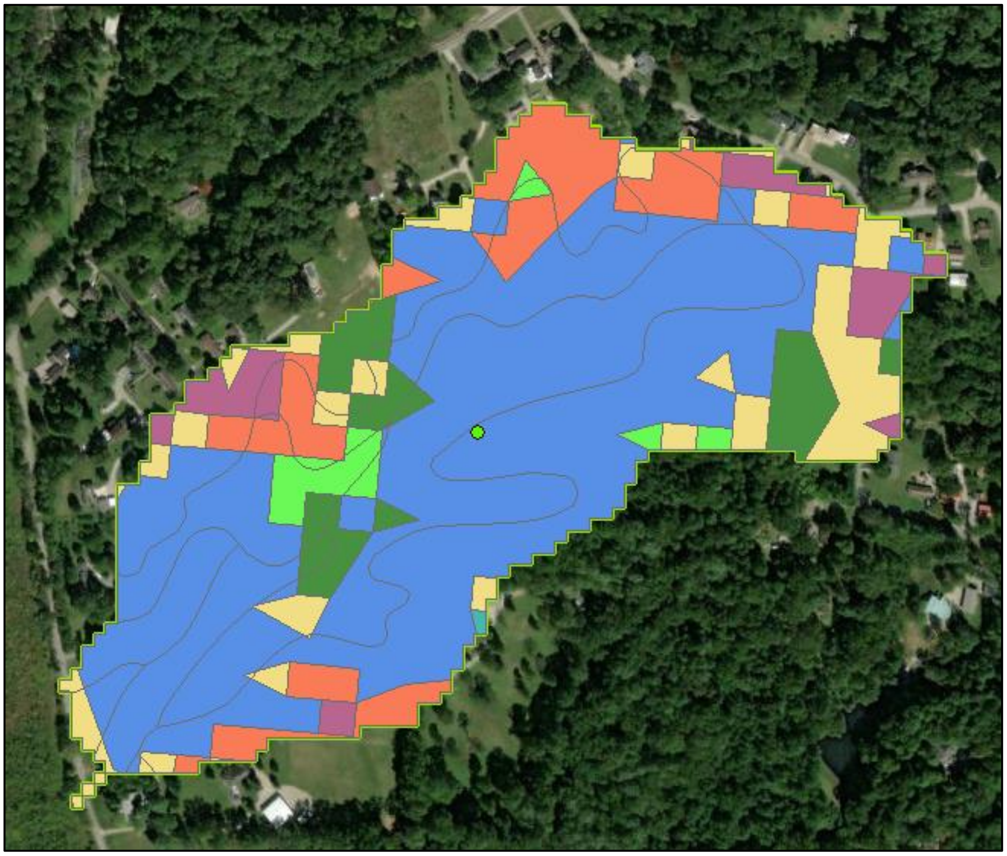
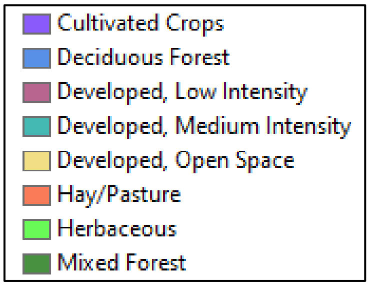


Figure 6. NLCD 2019 Landcover



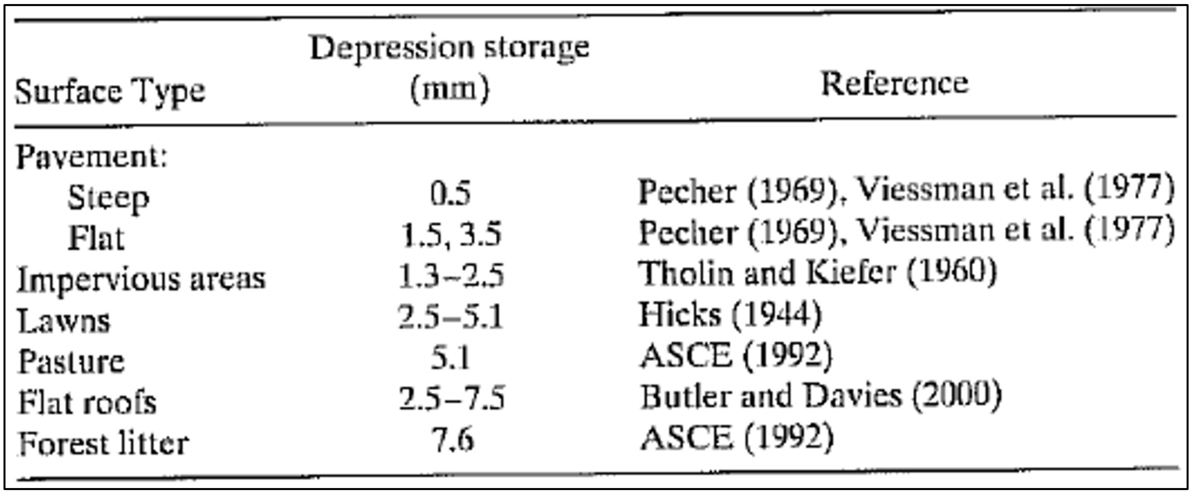
🟪 Cultivated Crops
🟦 Deciduous Forest
🟪 Developed, Low Intensity
🟦 Developed, Medium Intensity
🟨 Developed, Open Space
🟧 Hay/Pasture
🟩 Herbaceous
🟩 Mixed Forest

Figure 7. Landcover Key

Canopy interception is another key input when implementing the deficit and constant loss method. Using 2019 data from the National Landcover Database, 69% of the watershed is deciduous/mixed forest. The canopy storage parameter was estimated by computing a weighted average of land cover to area. The initial canopy storage is 0.089994 inches.

Surface storage was also estimated based on landcover. A weighted average of typical values, shown in *Table 2*, to area was estimated to be 0.1917 inches.

Table 2. Typical Values of Depression Storage



Surface Type	Depression storage (mm)	Reference
Pavement:		
Steep	0.5	Pecher (1969), Viessman et al. (1977)
Flat	1.5, 3.5	Pecher (1969), Viessman et al. (1977)
Impervious areas	1.3–2.5	Tholin and Kiefer (1960)
Lawns	2.5–5.1	Hicks (1944)
Pasture	5.1	ASCE (1992)
Flat roofs	2.5–7.5	Butler and Davies (2000)
Forest litter	7.6	ASCE (1992)

Time of concentration and the storage coefficient for the watershed was estimated using Tables presented in the *Journal of Hydrologic Engineering, Wilkerson and Merwade (2010). Equation 3 and Equation 4* listed below are specific for Southern Indiana watersheds.

$$t_c = -3.283 + 0.266(ULC) + 2.693(CN) + 1.696\left(R_f\right) - 0.568(H) \qquad \text{(Eq. 3)}$$

$$R = 2.012 + 1.450(L_{ca}) - 2.361(C) + 1.215(R_f) \qquad \text{(Eq. 4)}$$

The applicable ranges for the use of *Equation 3 and 4* are in *Appendix B*. Once the inputs for time of concentration and storage were found, time of concentration was calculated to be 0.065 hours, and the storage coefficient was estimated to be 22.4683hr.

A storage node was used in HEC-HMS to model storage and downstream flow in the ponded area (*Appendix C)*. Two functional inputs are required. They are the storage versus elevation curve and discharge versus elevation curve. Details on each function are discussed next.

Storage was found from a contour map of the site from Indiana Department of Transportation. At the ponded area, a storage vs elevation rating curve was calculated using AutoCAD. The change in storage at each contour was computed by taking the average area between contours and multiplying by the change in elevation. The calculated storage vs. elevation curve is shown below in *Figure 8.*

Table 3. Computed Storage and Elevation of Ponded Area

Storage (ft^3)	Elevation (ft)
0	377.5
30.54	378.0
94.01	378.5
194.20	379.0
334.11	379.5
534.36	380.0
784.49	380.5

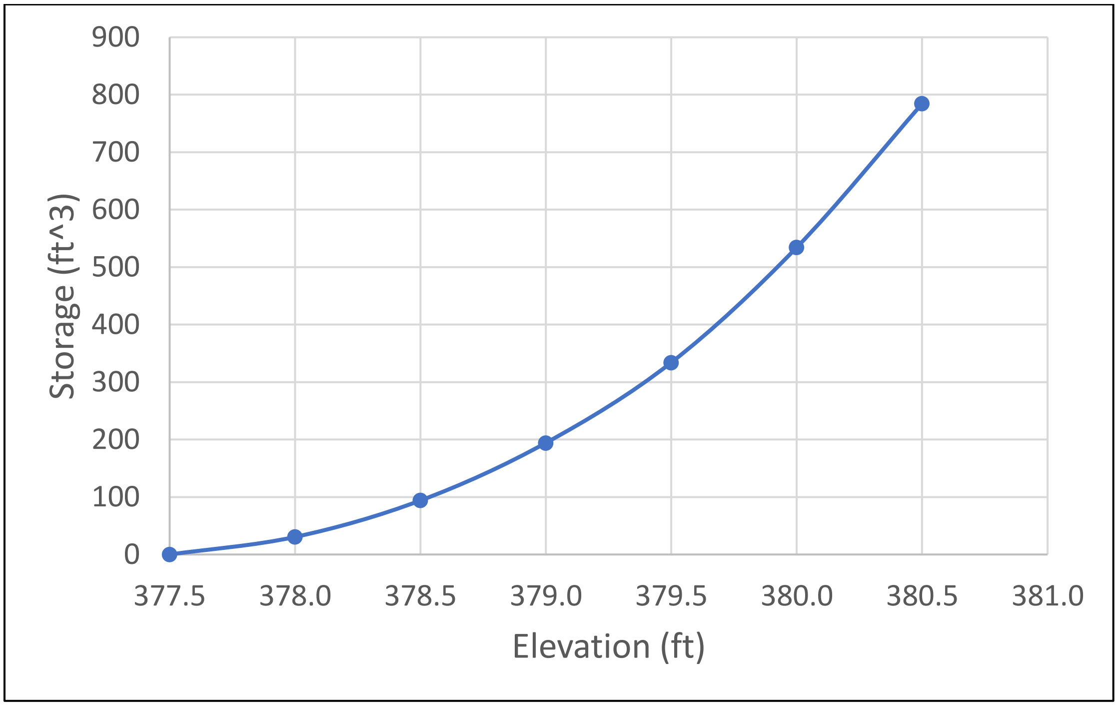


Figure 8. Storage vs Elevation Curve for Ponded Area

The discharge versus elevation curve was also developed using measured data described in *Section 4.2 Measured Data*. The limited field measurements of discharge shown in Table 4 were over a limited range of discharge values. Intermediate values between 30 cfs and the measured values were added to provide a complete curve. These values need further confirmation by field measurement. In *Table 4*, the measured flow values are highlighted in yellow.

Table 4. Discharge vs. Elevation

Elevation (ft)	Q (cfs)
377.500	1E-09
377.953	0.5276
378.000	0.902
378.500	10
379.000	15
379.500	23
380.00	30

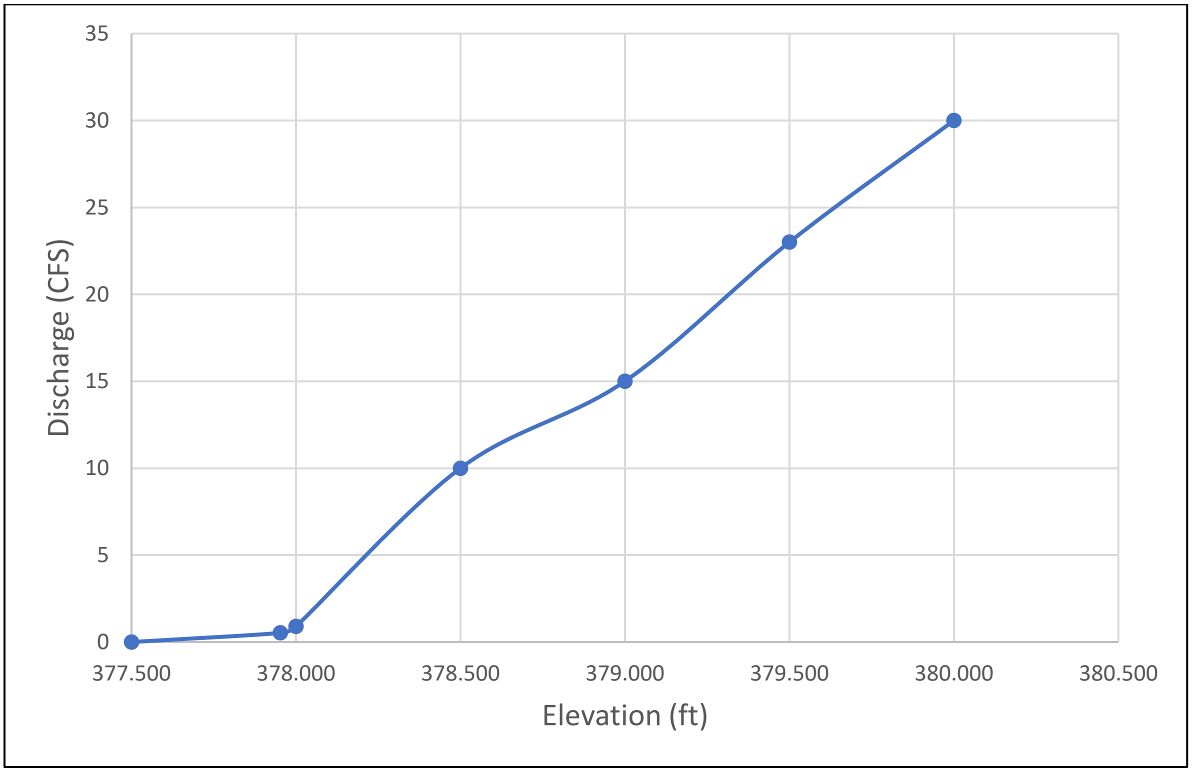


Figure 9. Discharge vs Elevation Curve for Ponded Area

Baseflow was modeled using the linear reservoir method. This is the only option in HEC-HMS that is compatible with continuous simulation. The other methods for baseflow simulation are more suited to event-based models.

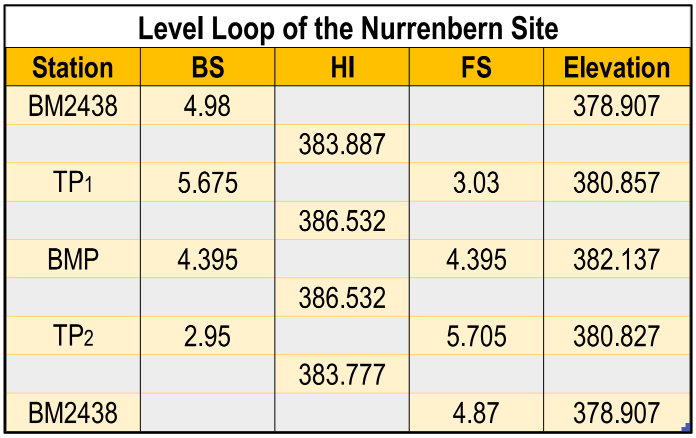
4.0 FIELD INSTALLATION AND MEASUREMENTS

4.1 Equipment Installation

4.1.1 Pre-Installation Survey

Prior to installing the field equipment, a survey of the site was performed to establish a new benchmark near the pond area with a level and rod. The level loop began on a previously established benchmark done by the Vanderburg County Surveyor Office. The results from the survey are seen in *Table 4*. From the new benchmark, elevation measurements were recorded for the installed equipment.

Table 5 5. Results from Survey



Level Loop of the Nurrenbern Site				
Station	**BS**	**HI**	**FS**	**Elevation**
BM2438	4.98			378.907
		383.887		
TP$_1$	5.675		3.03	380.857
		386.532		
BMP	4.395		4.395	382.137
		386.532		
TP$_2$	2.95		5.705	380.827
		383.777		
BM2438			4.87	378.907

4.1.2 Installation of Equipment

Two instruments were installed on site. The first of the instruments was a staff gauge. The staff gauge was used in the field to record the current water elevation when in the field gathering other data. The staff gauge was installed by driving a metal fence post into the soil under the ponded area and tightly securing the staff gauge to the post. The elevation of the base of the staff gauge was recorded to be 377.083ft.

The second instrument that was installed was a pressure sensor, a level TROLL 500 from In-Situ. The sensor was installed inside of a slotted PVC pipe and driven into the ground eight inches. Since the soil was loose and unstable, three pieces of rebar we also driven into the ground near the PVC pipe and tightly secured to the well to prevent the pipe from falling over. The sensor was then suspended by a cable wrapped around a screw through the top to prevent the desiccant from getting wet. A rubber stopper was also placed on top of the pipe to create a watertight seal.

4.2 Measured Data

One of the data measurements gathered from the field was the volumetric flowrate through the farm culvert. This data was recorded by using a Pygmy Current Meter attached to a USGS wading rod. The USGS wading rod guaranteed that the current meter would be 40% from the bottom of the channel to ensure that the current meter was measuring the average velocity. The number of revolutions in 60 seconds was recorded and converted to revolutions per second. This number was then used in *Equation 5* below.

$$V = 2.2048R + 0.0178 \qquad \text{(Eq. 5)}$$

This velocity was then multiplied by the cross-sectional area of the channel where the measurement was taken. The water surface elevation was also recorded from the staff gauge and paired with the flowrate to create *Table 6*.

Table 66. Measured W.S. Elevation and Discharge

Date	Time	W.S. Elevation	Q (cfs)
3/3/2022	12:20pm	377.962	0.7561
4/8/2022	11:09am	377.953	0.5276
4/14/2022	9:20am	377.993	0.9020
4/14/2022	11:32am	377.973	0.8370

Another component of field data collected was the water surface elevation from the pressure sensor. The sensor that was deployed in the field was a Level TROLL 500 by In-Situ and the software used to communicate with it was Win-Situ. The sensor was programmed to record the water depth every five minutes while being deployed. The sensor was deployed in the field from 3/21/22 to 4/15/22 and the data it recorded created the graph seen in *Figure 11*. One of the distinguishing features of the graph was an apparent diurnal fluctuation of 10 inches. This made the data from the sensor seem unreliable, so it was redeployed for a week and the water surface elevation was manually measured as well. The sensor indicated a fluctuation of 5.71

inches and during the same time period the manual measurements indicated a fluctuation of 1.82 inches. This not only proved that the sensor was not recording properly and needed to be troubleshooted, but also that there still was a significant diurnal fluctuation of the water surface elevation of the ponded area. The troubleshooting of the sensor included replacing the expired desiccant as well as an examination of the cable used to connect the sensor to the desiccant. It was discovered that the cable used in the field was an unvented cable and thus the sensor was reading absolute pressure and not just the water pressure. The unvented cable was replaced by a vented one and was redeployed for long term data collection.

Figure 10 10. Level TROLL 500 Pressure Sensor

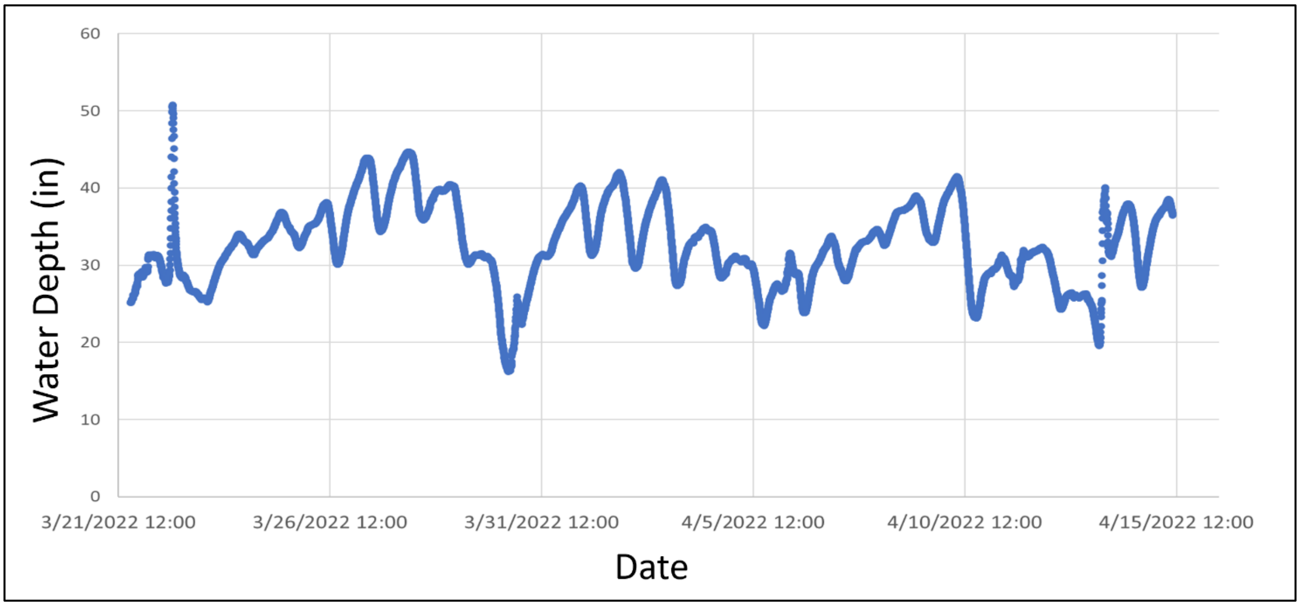


Figure 1111. Results from Pressure Sensor

4.3 Meteorological Data

In order to create a continuous hydrologic model, historic meteorological data is required. A study period of 20 years was chosen, and the historic data was gathered from the Evansville Regional Airport (EVV). This data was collected from the National Ocean and Atmospheric Association (NOAA) online database. EVV was chosen as the source of the historical data because it was the closest weather station that had data for the 20-year period.

To collect meteorological data to compare with the water surface elevation, a local weather station on Seger Dr. Was used. This weather station's data was accessed by Weather Underground. This station was chosen because of its proximity to the project site and thus would have more relevant data than the Evansville Regional Airport. Data from the Seger Drive station was retrieved for the period that the pressure sensor was deployed to compare how the water surface elevation varied with the precipitation. The meteorological data was useful not only for the precipitation but also the daily temperature to calculate evapotranspiration.

4.3 Evapotranspiration

The data used to calculate evapotranspiration for the initial input was the data gathered from NOAA. The model of evapotranspiration used in the continuous model was the McGuinness-Bordne model. This model of evapotranspiration was chosen based on a study comparing 27 different models of potential evapotranspiration in the *Journal of Hydrology.* This study found that the McGuinness-Bordne outperformed other models consistently. The original equation used in the study was *Equation 6.*

$$PE = \frac{R_e}{\lambda\rho}\frac{T_a+5}{68}. \qquad \text{(Eq. 6)}$$

Where: PE potential evapotranspiration [mm day^{-1}],

R_e extraterrestrial radiation (Equation 7) [MJ m^{-2} day^{-1}],

T_a air temperature [C^0].

λ latent heat of vaporization [MJ kg^{-1}]

ρ water density= 1000 [kg m^{-3}]

$$R_e = \frac{24\,(60)}{\pi} \cdot G_{se} \cdot d_r \cdot \{\omega_s \cdot \sin(\varphi) \cdot \sin(\delta) + \cos(\varphi) \cdot \cos(\delta) \cdot \sin(\omega_s)\} \qquad \text{(Eq. 7)}$$

Where: R_e extraterrestrial radiation [MJ m^{-2} day^{-1}]

	G_{sc}	solar constant = 0.082 [MJ m^{-2} min^{-1}]
	d_r	inverse relative distance Earth-Sun (Equation 8)
	ω_s	sunset hour angle (Equation 10) [rad]
	φ	latitude [rad]
	δ	solar declination (Equation 9) [rad]

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \tag{Eq. 8}$$

Where:	d_r	inverse relative distance Earth-Sun
	J	Julian day

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right) \tag{Eq. 9}$$

Where:	δ	solar declination [rad]
	J	Julian day

$$\omega_s = \arccos\big(-\tan(\varphi)\,Tan(\delta)\big) \tag{Eq. 10}$$

Where:	ω_s	sunset hour angle [rad]
	φ	latitude [rad]
	δ	solar declination [rad]

However, the study suggested a modification to the equation that produces *Equation 11*, and this was the equation of potential evapotranspiration used in the model (Oudin, 2005).

$$PE = \frac{R_e}{\lambda\rho}\frac{T_a+5}{100} \tag{Eq. 11}$$

In order to ensure that the McGuinness-Bordne was implemented properly, the Thornwaite model was calculated and compared to the monthly average potential evapotranspiration that the McGuinness-Bordne model predicted. This was done because the study found that the Thornwaite model under-preformed compared to the McGuinness-Bordne model. To ensure that the equation used in the study for the Thornwaite model was dependable, another equation for the Thornwaite model was used from *Engineering Hydrology: Principles and Practices* by Ponce. As seen in *Figure 12*, both models of potential evapotranspiration followed similar trends through the year and all three equations had little variance during the months of November to February.

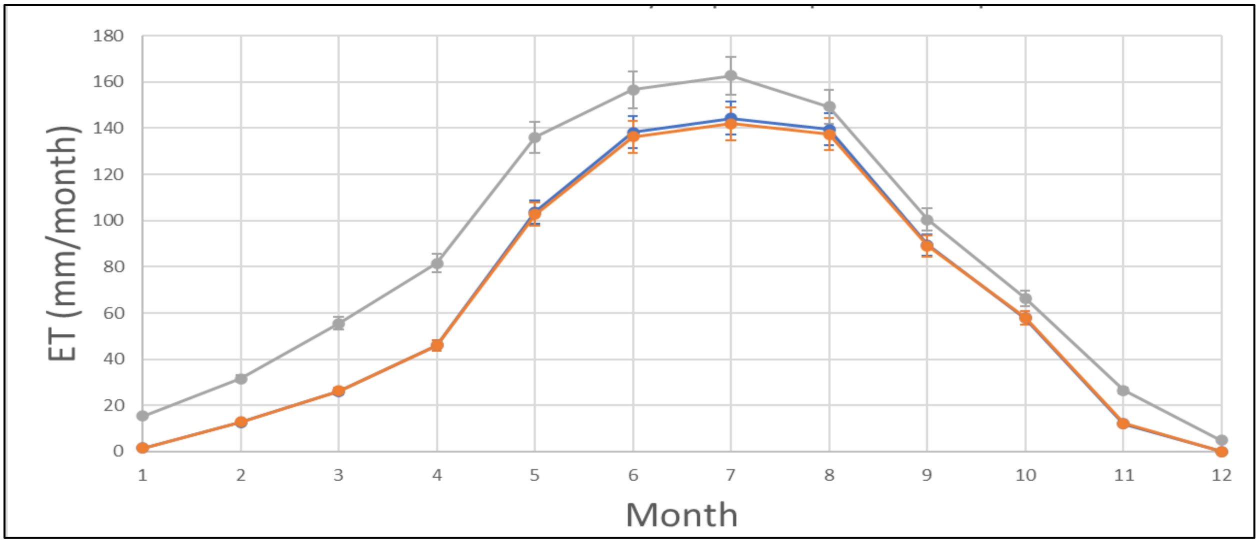


Figure 12. Monthly Evapotranspiration Comparison

5.0 MODEL ASSESSMENT AND RESULTS

To begin assessing the continuous model, the model parameters were to be checked to determine if the initial calculated and estimated parameters, shown in *Table 7*, were within range using a known event.

Table 77. Initial Model Parameters

	Parameter	Units	Initial Value
Canopy	Initial Storage	%	0.0
	Max Storage	in	0.089994
Surface	Initial Storage	%	0
	Max Storage	in	0.1917
Loss	Initial Deficit	in	0.1
	Maximum Deficit	in	28.34
	Constant Rate	in/hr	0.1
	Impervious	%	0.0
Transform	Time of Concentration	hr	0.06532
	Storage Coefficient	hr	1
Baseflow	Initial	cfs	0.5276
	R	hr	22.4683

For this calibration, the event hydraulic model (HEC-RAS) developed in 2018 was used. The measured precipitation data from October 5, 2013, to October 6, 2013, was downloaded from Weather Underground, Seeger Drive Weather Station. The flood event that occurred in 2013 overtopped the existing farm culvert at the site. Flowing full, the 36” culvert is expected to have 30cfs flowing through it. The objective is to reciprocate this flood event with a peak discharge greater than 30cfs, so we can validate the culvert was overtopped during the event.

After running the model with the initial model parameters, the peak discharge from the farm culvert was 32.0cfs. This proved that the farm culvert was overtopped during this 2013 flood.

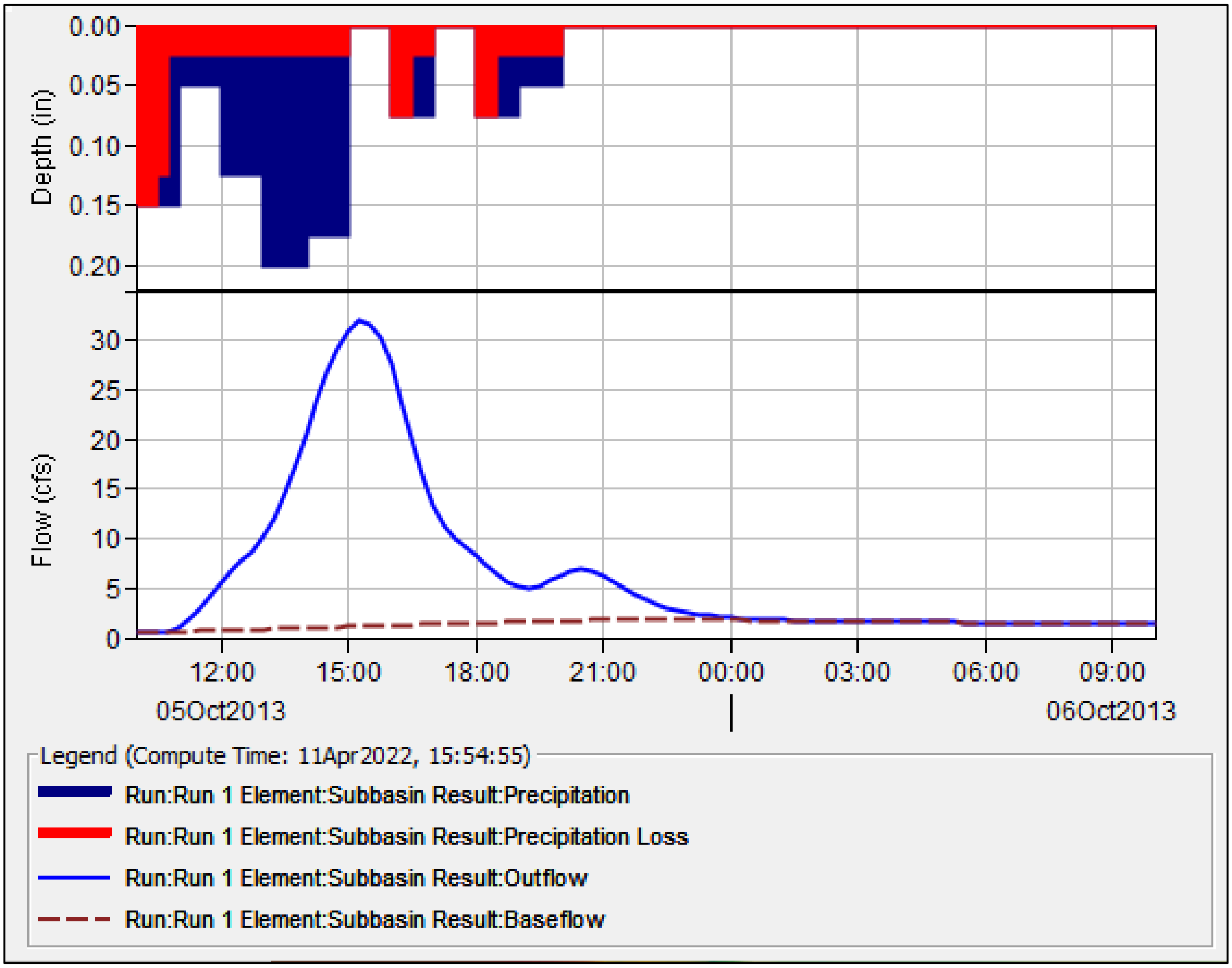
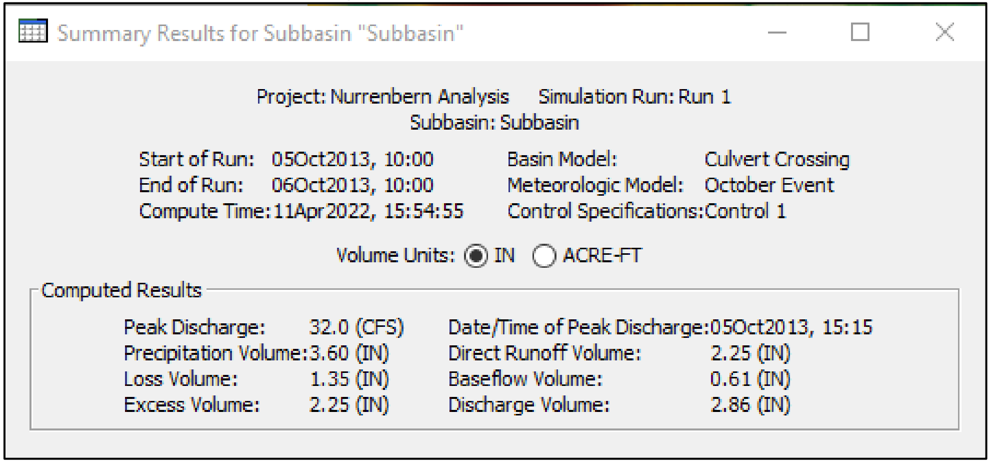


Figure 12. Discharge and Losses Results from October Event

Table 88. Summary HEC-HMS Table from October 5-6, 2013



Project: Nurrenbern Analysis   Simulation Run: Run 1
Subbasin: Subbasin

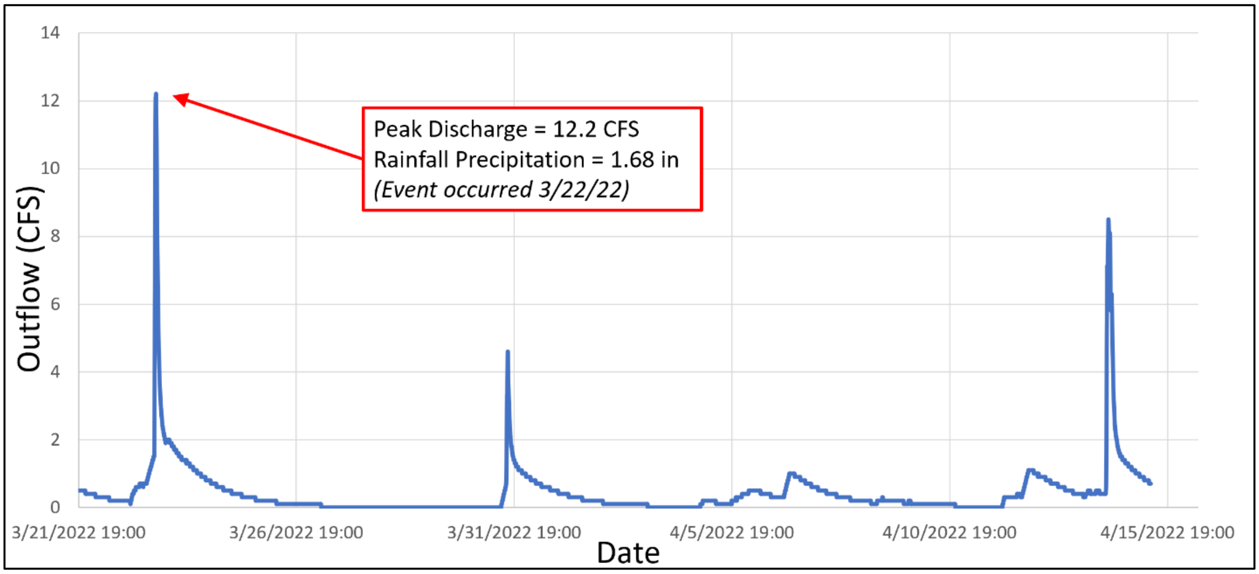
Start of Run: 05Oct2013, 10:00
End of Run: 06Oct2013, 10:00
Compute Time: 11Apr2022, 15:54:55
Basin Model: Culvert Crossing
Meteorologic Model: October Event
Control Specifications: Control 1

Volume Units: ● IN ○ ACRE-FT

Computed Results

Peak Discharge: 32.0 (CFS)
Precipitation Volume: 3.60 (IN)
Loss Volume: 1.35 (IN)
Excess Volume: 2.25 (IN)
Date/Time of Peak Discharge: 05Oct2013, 15:15
Direct Runoff Volume: 2.25 (IN)
Baseflow Volume: 0.61 (IN)
Discharge Volume: 2.86 (IN)

Since the event modeling showed that the parameters are within reason, by comparing the results from the model to the former capstone hydraulic model, the continuous model can be assessed. Measured data from the pressure sensor from March 21 to April 15, 2022 was used as an input of stage vs. time for the ponded area. Measured discharge and storage were also used as inputs to form rating curves to represent the discharge of the ponded area. The continuous simulation accounted for the changes in soil moisture and evapotranspiration for the given period of a month (3/21/22-4/15/22). The results shown in *Figure 14*, during the time of simulation, the model accurately computed the discharge of the farm culvert. The peak discharge reached 12.2cfs on March 22, 2022. The rain event that contributed to the peak discharge was 1.68 in.



Peak Discharge = 12.2 CFS
Rainfall Precipitation = 1.68 in
(Event occurred 3/22/22)

Figure 13. Output of Continuous Hydrologic Model (3/21/22-4/15/22)

6.0 SKILLS LEARNED

This project demanded a higher level of understanding of academic lessons as well as skills required in the field. One of the skills that was learned for this project was the ability to create a continuous hydrologic model for a study period of 20 years. This also includes learning how to calculate and estimate the input parameters like wilting point and evapotranspiration. In the field, more skills had to be learned to properly install equipment and collect data. These skills included use of a pygmy current meter in conjunction with a USGS wading rod. Another skill was how to program and install a pressure sensor in a water surface elevation well.

7.0 CONCLUSION AND FUTURE WORK

A continuous hydrologic model was successfully developed and executed for a selected period of twenty years. A model calibration was conducted using a flood occurring in October of 2013. A previous capstone design group documented a flood discharge of approximately 30cfs to overtop the farm culvert. Two model parameters (t_c and R) were used as calibration parameters. After calibration, the model successfully simulated observed field conditions for the 2013 flood event.

Field instrumentation was installed in the field and data recorded provided initial results. From March 21 to April 15, 2022, data was collected from the sensor and erroneous data was suspected. Additional manual field measurements verified a faulty sensor installation. A corrective action plan was designed and implemented, and the sensor has been redeployed. Through these corrective actions, a diurnal fluctuation of the water surface was detected. The sensor is currently operational and will be routinely visited for maintenance.

Through the project, teamwork was vital for the success. Lauren oversaw the continuous hydrologic model development whereas Noah focused on the installation of equipment in the field as well as data collection in the field, and meteorological data collection and calculations. This separation of the two components allowed for each member to dedicate their whole attention to the task at hand. This separation of work also facilitated quick and effective communication in the team for field data to be implemented properly into the model as well as what data was necessary from the field.

The vision of converting this donated property to a watershed laboratory and wetland environment remains elusive. There are several remaining tasks that must be completed to accomplish this goal. This study provided a critical step forward by moving from event based to continuous hydrologic modeling. Once validated, this model will be a valuable tool for water resource planning purposes. This relies on a lengthy record of measured field data. This study ends with that process initiated. The equipment installed in the field was prepared for long term data collection. The long-term viability of implementing a water diversion will require additional consideration. Long-term water budgets must also be developed. The success of this long-term project will ultimately result in stream water quality and a wetland environment that supports a diverse ecosystem on USI’s campus.

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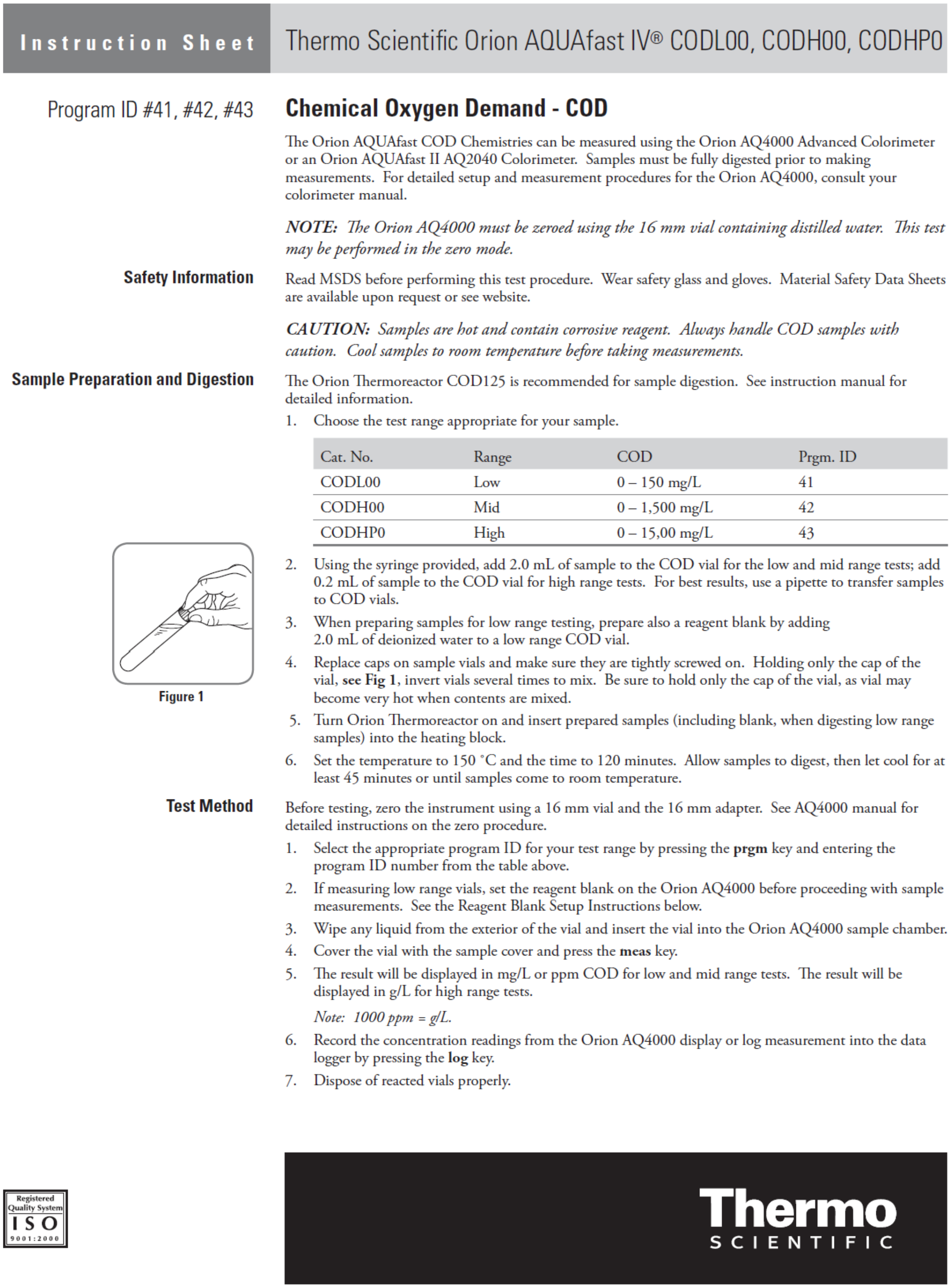
APPENDIX

Appendix A- Chemical Oxygen Demand (COD) Procedure



Instruction Sheet Thermo Scientific Orion AQUAfast IV® CODL00, CODH00, CODHP0

Program ID #41, #42, #43

Chemical Oxygen Demand - COD

The Orion AQUAfast COD Chemistries can be measured using the Orion AQ4000 Advanced Colorimeter or an Orion AQUAfast II AQ2040 Colorimeter. Samples must be fully digested prior to making measurements. For detailed setup and measurement procedures for the Orion AQ4000, consult your colorimeter manual.

NOTE: *The Orion AQ4000 must be zeroed using the 16 mm vial containing distilled water. This test may be performed in the zero mode.*

Safety Information

Read MSDS before performing this test procedure. Wear safety glass and gloves. Material Safety Data Sheets are available upon request or see website.

CAUTION: *Samples are hot and contain corrosive reagent. Always handle COD samples with caution. Cool samples to room temperature before taking measurements.*

Sample Preparation and Digestion

The Orion Thermoreactor COD125 is recommended for sample digestion. See instruction manual for detailed information.

1. Choose the test range appropriate for your sample.

Cat. No.	Range	COD	Prgm. ID
CODL00	Low	0 – 150 mg/L	41
CODH00	Mid	0 – 1,500 mg/L	42
CODHP0	High	0 – 15,00 mg/L	43

2. Using the syringe provided, add 2.0 mL of sample to the COD vial for the low and mid range tests; add 0.2 mL of sample to the COD vial for high range tests. For best results, use a pipette to transfer samples to COD vials.
3. When preparing samples for low range testing, prepare also a reagent blank by adding 2.0 mL of deionized water to a low range COD vial.
4. Replace caps on sample vials and make sure they are tightly screwed on. Holding only the cap of the vial, **see Fig 1**, invert vials several times to mix. Be sure to hold only the cap of the vial, as vial may become very hot when contents are mixed.
5. Turn Orion Thermoreactor on and insert prepared samples (including blank, when digesting low range samples) into the heating block.
6. Set the temperature to 150 °C and the time to 120 minutes. Allow samples to digest, then let cool for at least 45 minutes or until samples come to room temperature.

Figure 1

Test Method

Before testing, zero the instrument using a 16 mm vial and the 16 mm adapter. See AQ4000 manual for detailed instructions on the zero procedure.

1. Select the appropriate program ID for your test range by pressing the **prgm** key and entering the program ID number from the table above.
2. If measuring low range vials, set the reagent blank on the Orion AQ4000 before proceeding with sample measurements. See the Reagent Blank Setup Instructions below.
3. Wipe any liquid from the exterior of the vial and insert the vial into the Orion AQ4000 sample chamber.
4. Cover the vial with the sample cover and press the **meas** key.
5. The result will be displayed in mg/L or ppm COD for low and mid range tests. The result will be displayed in g/L for high range tests.

   Note: 1000 ppm = g/L.
6. Record the concentration readings from the Orion AQ4000 display or log measurement into the data logger by pressing the **log** key.
7. Dispose of reacted vials properly.

Registered Quality System ISO 9001:2000

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Reagent Blank Setup Instruction

When using low range test vials, set the meter blank using the digested reagent blank vial before processing with sample measurements. Ensure that the meter is in program 41 before processing.

1. Press **setup** key.
2. Press ▲ or ▼ keys until “BLANK” is displayed.
3. Press **yes** key, “SET BLNK?” is displayed.
4. Press **yes** key, “SAMPLE?” is displayed.
5. Insert vial containing digested deionized water sample and reagent into sample chamber. Cover sample with sample cover.
6. Press **yes** key and allow instrument to read the blank.
7. Blank value is displayed and unit will proceed to the next setup function.
8. Press **meas** key to proceed to the measure mode for sample measurement.

Calibration Standards

To check operation, use Orion COD calibration standards, Orion CODS01 (1,000 ppm) and CODS10 (10,000 ppm).

Helpful Notes

1. Always select COD chemistry range which best suits measurement range.
2. For low range (0 - 150 mg/L), a reagent blank vial is required. Use deionized water as the sample.
3. Suspended solids in the vials lead to incorrect measurements. For this reason, it is important to place the vials carefully in the colorimeter. The precipitate at the bottom of the sample should not be suspended. Do not mix vials after they have cooled.
4. DO NOT place hot vials in the colorimeter. Always cool the vials to room temperature for final measurement. A large temperature difference between the colorimeter and ambient conditions can lead to incorrect measurement, or build-up of condensation around the optics of the sample chamber.
5. Run samples and blanks using the same lot code of vials. The blank is stable when stored in the dark and can be used for further measurements with vials of the same lot code.
6. Solutions must be disposed of properly.

Chemical Methods

Method– The organic material present in the sample is oxidized by a standard amount of potassium dichromate oxidizing mixture. The excess of this reagent, after oxidation is complete, is measured photometrically. Ensure proper disposal of reagents.

Application– Samples can be measured where the chloride content does not exceed 1,000 mg/L (LR/MR) or 10,000 mg/L (HR). In exceptional cases, compounds contained in the water cannot be oxidized adequately, which results in minimum findings, compared with the reference method. Different methods of sampling, the preparation of the sample itself and the time elapsed between taking the sample and analysis, can all affect the results obtained.

Ordering Information

Orion	Description
COD125	Orion Thermoreactor for COD, 25 places, 110V/220V
CODL00	Orion COD Test Kit, 0 - 150 mg/L, 25 Tests
CODH00	Orion COD Test Kit, 0 - 1,500 mg/L, 25 Tests
CODHP0	Orion COD Test Kit, 0 - 15,000 mg/L, 25 Tests
CODS01	Orion COD Standard, 1,000 mg/L, 475 mL
CODS10	Orion COD Standard, 10,000 mg/L, 475 mL
AQ4CBL	Orion AQUAfast IV RS232 Cable
AC2V16	Orion Replacement Vials, 16 mm, pack of 10
AQ4000	Orion AQUAfast IV Advanced Colorimeter
AQ2040	Orion AQUAfast II COD Colorimeter

Environmental Instruments
Water Analysis Instruments

166 Cummings Center
Beverly, MA 01915 USA

256466-001 Rev.A 0108

Toll Free: 1-800-225-1480
Tel: 1-978-232-6000
Dom. Fax: 1-978-232-6015
Int’l Fax: 978-232-6031
www.thermo.com/water

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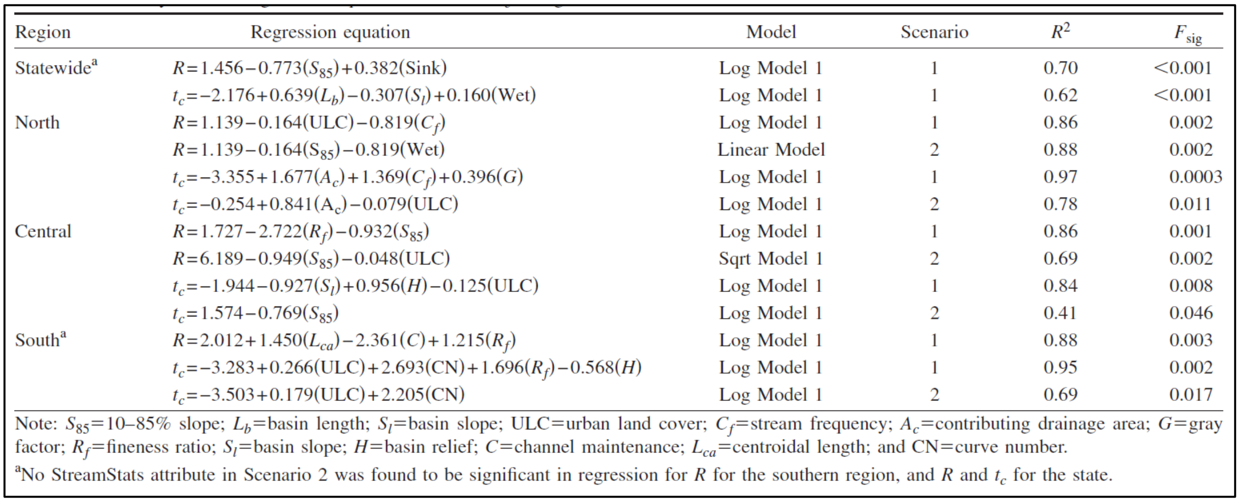
Appendix B- Time of Concentration and *R* Calculations

Table 99. Time of Concentration and R Equations Based on Region of Indiana

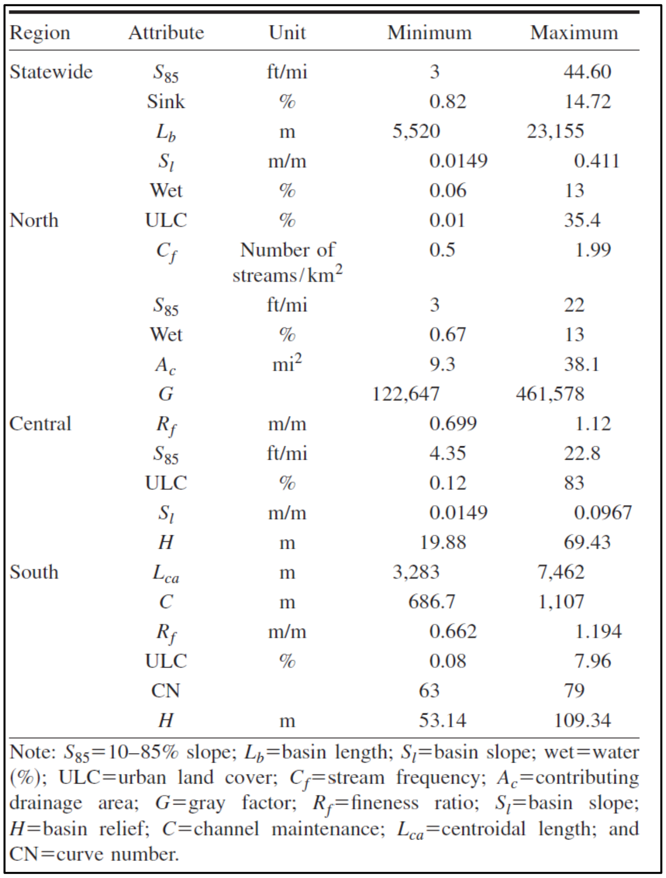


Region	Regression equation	Model	Scenario	R^2	F_{sig}
Statewide[a]	$R=1.456-0.773(S_{85})+0.382(\text{Sink})$	Log Model 1	1	0.70	<0.001
	$t_c=-2.176+0.639(L_b)-0.307(S_l)+0.160(\text{Wet})$	Log Model 1	1	0.62	<0.001
North	$R=1.139-0.164(\text{ULC})-0.819(C_f)$	Log Model 1	1	0.86	0.002
	$R=1.139-0.164(\text{S}_{85})-0.819(\text{Wet})$	Linear Model	2	0.88	0.002
	$t_c=-3.355+1.677(A_c)+1.369(C_f)+0.396(G)$	Log Model 1	1	0.97	0.0003
	$t_c=-0.254+0.841(\text{A}_c)-0.079(\text{ULC})$	Log Model 1	2	0.78	0.011
Central	$R=1.727-2.722(R_f)-0.932(S_{85})$	Log Model 1	1	0.86	0.001
	$R=6.189-0.949(S_{85})-0.048(\text{ULC})$	Sqrt Model 1	2	0.69	0.002
	$t_c=-1.944-0.927(S_l)+0.956(H)-0.125(\text{ULC})$	Log Model 1	1	0.84	0.008
	$t_c=1.574-0.769(S_{85})$	Log Model 1	2	0.41	0.046
South[a]	$R=2.012+1.450(L_{ca})-2.361(C)+1.215(R_f)$	Log Model 1	1	0.88	0.003
	$t_c=-3.283+0.266(\text{ULC})+2.693(\text{CN})+1.696(R_f)-0.568(H)$	Log Model 1	1	0.95	0.002
	$t_c=-3.503+0.179(\text{ULC})+2.205(\text{CN})$	Log Model 1	2	0.69	0.017

Note: S_{85}=10–85% slope; L_b=basin length; S_l=basin slope; ULC=urban land cover; C_f=stream frequency; A_c=contributing drainage area; G=gray factor; R_f=fineness ratio; S_l=basin slope; H=basin relief; C=channel maintenance; L_{ca}=centroidal length; and CN=curve number.

[a] No StreamStats attribute in Scenario 2 was found to be significant in regression for R for the southern region, and R and t_c for the state.

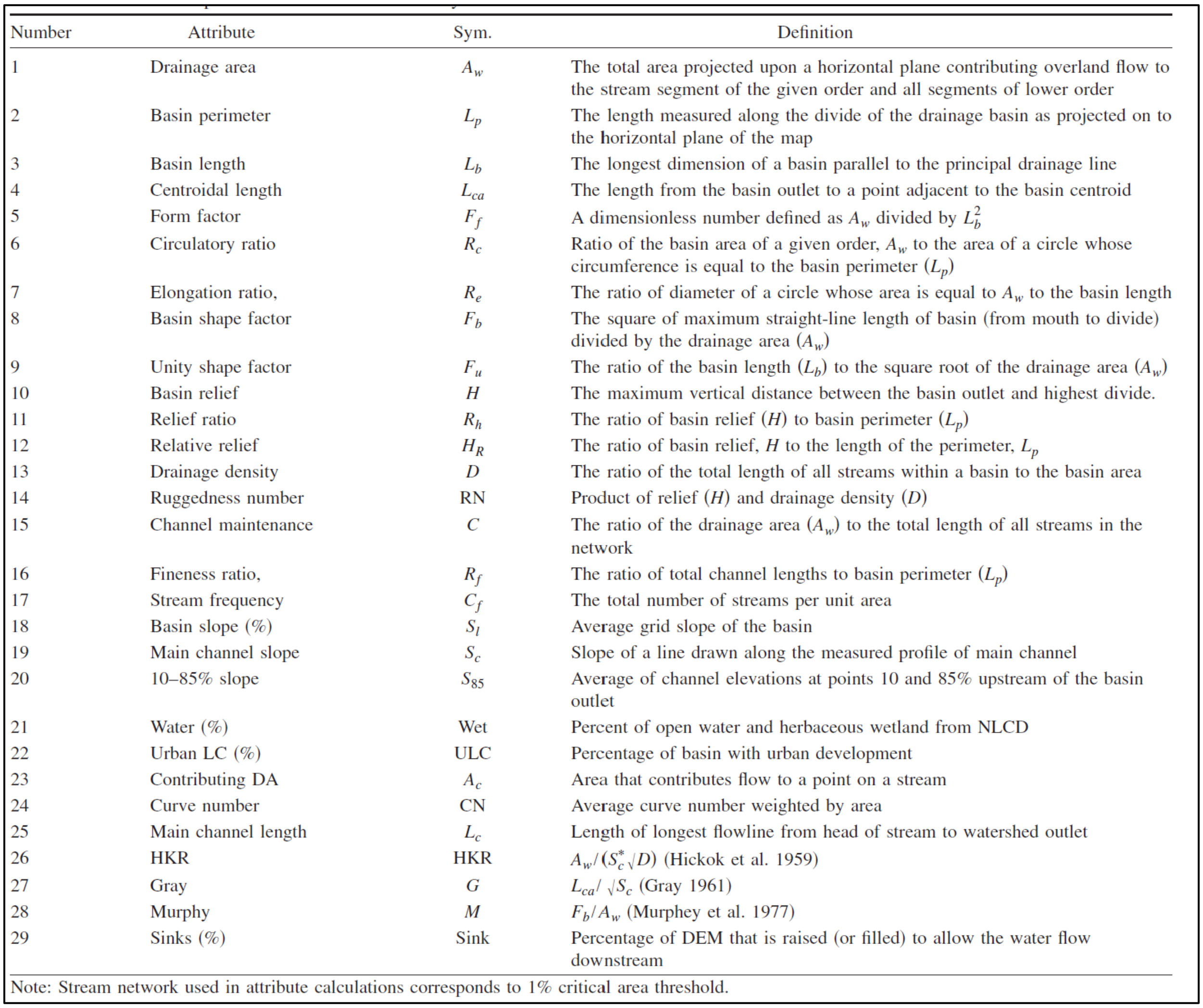
Table 1010. Applicable Ranges for Each Region of Indiana



Region	Attribute	Unit	Minimum	Maximum
Statewide	S_{85}	ft/mi	3	44.60
	Sink	%	0.82	14.72
	L_b	m	5,520	23,155
	S_l	m/m	0.0149	0.411
	Wet	%	0.06	13
North	ULC	%	0.01	35.4
	C_f	Number of streams/km^2	0.5	1.99
	S_{85}	ft/mi	3	22
	Wet	%	0.67	13
	A_c	mi^2	9.3	38.1
	G		122,647	461,578
Central	R_f	m/m	0.699	1.12
	S_{85}	ft/mi	4.35	22.8
	ULC	%	0.12	83
	S_l	m/m	0.0149	0.0967
	H	m	19.88	69.43
South	L_{ca}	m	3,283	7,462
	C	m	686.7	1,107
	R_f	m/m	0.662	1.194
	ULC	%	0.08	7.96
	CN		63	79
	H	m	53.14	109.34

Note: S_{85}=10–85% slope; L_b=basin length; S_l=basin slope; wet=water (%); ULC=urban land cover; C_f=stream frequency; A_c=contributing drainage area; G=gray factor; R_f=fineness ratio; S_l=basin slope; H=basin relief; C=channel maintenance; L_{ca}=centroidal length; and CN=curve number.

Table 1111. List of Geomorphic Attributes from Wilkerson and Merwade Study



Number	Attribute	Sym.	Definition
1	Drainage area	A_w	The total area projected upon a horizontal plane contributing overland flow to the stream segment of the given order and all segments of lower order
2	Basin perimeter	L_p	The length measured along the divide of the drainage basin as projected on to the horizontal plane of the map
3	Basin length	L_b	The longest dimension of a basin parallel to the principal drainage line
4	Centroidal length	L_{ca}	The length from the basin outlet to a point adjacent to the basin centroid
5	Form factor	F_f	A dimensionless number defined as A_w divided by L_b^2
6	Circulatory ratio	R_c	Ratio of the basin area of a given order, A_w to the area of a circle whose circumference is equal to the basin perimeter (L_p)
7	Elongation ratio,	R_e	The ratio of diameter of a circle whose area is equal to A_w to the basin length
8	Basin shape factor	F_b	The square of maximum straight-line length of basin (from mouth to divide) divided by the drainage area (A_w)
9	Unity shape factor	F_u	The ratio of the basin length (L_b) to the square root of the drainage area (A_w)
10	Basin relief	H	The maximum vertical distance between the basin outlet and highest divide.
11	Relief ratio	R_h	The ratio of basin relief (H) to basin perimeter (L_p)
12	Relative relief	H_R	The ratio of basin relief, H to the length of the perimeter, L_p
13	Drainage density	D	The ratio of the total length of all streams within a basin to the basin area
14	Ruggedness number	RN	Product of relief (H) and drainage density (D)
15	Channel maintenance	C	The ratio of the drainage area (A_w) to the total length of all streams in the network
16	Fineness ratio,	R_f	The ratio of total channel lengths to basin perimeter (L_p)
17	Stream frequency	C_f	The total number of streams per unit area
18	Basin slope (%)	S_l	Average grid slope of the basin
19	Main channel slope	S_c	Slope of a line drawn along the measured profile of main channel
20	10–85% slope	S_{85}	Average of channel elevations at points 10 and 85% upstream of the basin outlet
21	Water (%)	Wet	Percent of open water and herbaceous wetland from NLCD
22	Urban LC (%)	ULC	Percentage of basin with urban development
23	Contributing DA	A_c	Area that contributes flow to a point on a stream
24	Curve number	CN	Average curve number weighted by area
25	Main channel length	L_c	Length of longest flowline from head of stream to watershed outlet
26	HKR	HKR	$A_w/(S_c^*\sqrt{D})$ (Hickok et al. 1959)
27	Gray	G	$L_{ca}/\sqrt{S_c}$ (Gray 1961)
28	Murphy	M	F_b/A_w (Murphey et al. 1977)
29	Sinks (%)	Sink	Percentage of DEM that is raised (or filled) to allow the water flow downstream

Note: Stream network used in attribute calculations corresponds to 1% critical area threshold.

Appendix C- Images

Figure 1514. Ponded Area from Nurrenbern Rd POV

Figure 1615. Ponded Area

Figure 1716. Downstream of Farm Culvert