The following student exercise considers a hypothetical stormwater system design and input parameters, although the project on which it is based is real and on-going. The design aspects specified in this project are for educational purposes only and do necessarily reflect real-world conditions.

SUMMARY

You are hired to analyze (and improve upon) a preliminary design for a stormwater management system for the proposed Tech Smith headquarters to be located on the Michigan State University campus in East Lansing, Michigan (Figure 1). Stormwater captured by buildings, sidewalks and other paved areas is to be conveyed to an on-site holding pond through a proposed system of junctions (manholes) and conduits (pipes). Using both spreadsheet approaches and a sophisticated simulation software – MAGNET StormNET - you will design (and then refine) the pipes (including their sizes, slopes, and roughness) and a holding pond (total volume, dimensions, and outflow control structures). You will also assess potential impact of Low Impact Development (LID) controls or other green infrastructure integrated into the system.

Figure 1 – Proposed development and site location on the campus of Michigan State University.

BACKGROUND

Michigan State University continues to implement its vision of redeveloping Spartan Village – a 140-acre residential area - into a technology and innovation campus. Recently Michigan's governor and the MSU president were among others who announced the construction of a new headquarters for Tech-Smith, a software development company previously located nearby. The new headquarters is being developed on approximately 10 acres of land and will consist of buildings, outdoor patios, sidewalks, small green spaces, and parking areas.

Under natural conditions, storm water slowly drains from west to east, following the gentle slope of the land within the proposed parcel area. A preliminary design subdivides the property 6 lots (or subcatchments): 2 "building" lots in the north (consisting of headquarter buildings, sidewalks, and outdoor patios); 3 parking areas; and one building lot in the southeast corner (see Figure 2). It is proposed that storm water collected in the various subcatchments be routed to an on-site holding pond through an underground storm-sewer system consisting of 6 conduits (pipes) and 6 junctions (manholes). The alternative option for using pond outflow control structure to connect the existing MSU storm-sewer system is afforded by the proximity of the proposed pond to nearby sewer lines.

(*Again, the layout and design parameters presented here do not necessarily reflect real world conditions.*)
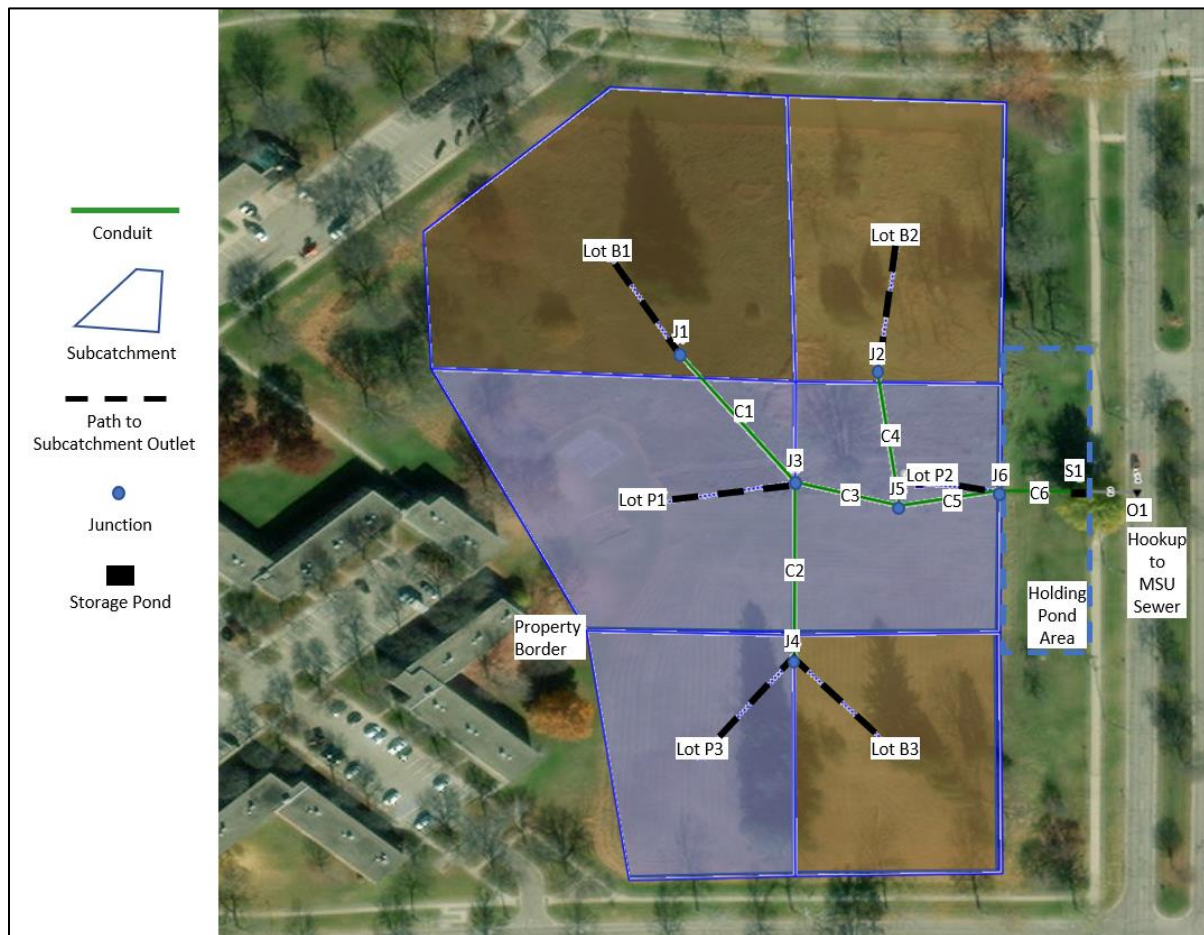

Figure 2 – Preliminary design of the storm-sewer system.

OBJECTIVE

Your objective is to determine the feasibility of the proposed storm-sewer system design. The major steps of the project involved include:

1. Initial storm sewer design – size each pipe for its peak flow using the Rational Method and Manning's equations for a design storm with a 10-year return period and a duration equal to the time of concentration.
2. Initial holding pond design – size the holding pond to store all surface runoff to the pond during a 24 hour, 100-year design storm event.
3. Storm sewer design refinement - perform simulation-based iterative design activities to optimize design parameters (pipe sizes and slopes) to ensure compliance to code (velocities are 1-3 m/s during the design storm).
4. Holding pond design refinement – perform simulation-based iterative design to optimize pond size and outflow structure so that outflow is less and or equal to that under natural conditions for a 24 hr., 100yr storm.
5. Green infrastructure design – assess potential impact of Low Impact Development (LID) controls or other green infrastructure integrated into the storm-sewer system.

Further instructions and retails regarding each major step are provided in the sections below. Detailed tables and figures needed for your analysis are included.

DELIVERABLE

Please assemble a professional-level technical report. Major components include:

- Title page
- Executive Summary
- Table of Contents
- Introduction
- Methods
- Results and Discussion
- Conclusions
- Appendix (Additional Supporting Information)

Make sure to document your entire procedure and list all assumptions. Answer all questions and include all items mentioned in the sections. Make sure your report is professional and well written. It must be typed using a word processor. All illustrations, graphs, figures, and equations must be computer generated. Grammar, spelling, sentence structure, and completeness will all factor into your grade in addition to your ability to solve the problem.

Keep in Mind:

The problem has been formulated such that all the data you need is contained in this report. When looking at your results, keep in mind if they seem reasonable. This will help tell you if you are on the right track. Make sure to list ALL assumptions and to show and explain how you solved the problem. There is no need to show every calculation but a step-by-step summary, including equations, variables, and definitions, should be a part of your report.

DETAILED INSTRUCTIONS

1. Initial System Design

A. <u>Storm-sewer Design with the Rational method</u>

Size each pipe for its peak flow using the Rational Method ($Q_{max}=CiA$). Data for each subcatchment, the storm-sewer pipes, and the junctions are presented in Tables 1, 2 and 3, respectively.

- Use the 10-yr-frequency return for this analysis.
- Time to inlet can be calculated using the Brasby-Williams equation and the given subcatchment data.
- Travel-time in the sewers can be estimated assuming a water velocity of 5ft/s.
- Determine the time of concentration to reach each junction. Then use Table 4 to determine the intensity in each pipe.
  - Time of concentration is the "duration" for identifying rainfall depth in the MDOT table.
  - You may need to interpolate between values in the table
  - Note: the values in a particular (row,column) represents the depth of rainfall for that duration. You must convert to intensity (in./hr.) before using the Rational method to compute Q_{max}
- Calculate Q_{max}, or the peak flow to each junction (or, the flow into each pipe)
- Determine the pipe diameter by using Mannings equation for a pipe flowing completely full. This requires an estimate of pipe slope.
  - Use the provided junction data to determine the invert elevation of each junction.
  - Hint: Invert Elevation = (Land elevation)-(Max Depth); assume a maximum depth; ensure at least 3 feet of burial.
  - Calculate the slope of the pipe based on invert elevations and pipe length.
- Make sure you recalculate the velocity when the pipe is sized. The velocity should be between the design parameters of 1-3 m/s.
  - If all velocities are not in this range, suggest possible changes to the design that could correct velocities to an acceptable range (you will test your suggestions later in the project using the StormNET software!)

It is recommended that you do the calculations using a spreadsheet. Present your results with a table of the pipes that shows their design size, flow capacity, and slope. Comment on the design parameters: do they seem reasonable? Explain.

Table 1 – Subcatchment Data.

Subcatchment	Type of Surface	Area Drained (Acres)	Length to Outlet (ft)	Ave. Ground Slope	C
Lot B1	Large Building with Sidewalks	1.92	350	0.004	0.8
Lot B2	Building with outdoor patios	1.27	275	0.0033	0.75
Lot P1	Paved parking lot	1.54	175	0.0016	0.9

Lot P2	Paved parking lot	1.09	150	0.0015	0.9
Lot P3	Paved parking lot	0.97	200	0.0018	0.9
Lot B3	Building with Sidewalk	1.05	225	0.0039	0.8

Table 2 – Storm-sewer data for initial design (pipe sizing). The initial design assumes all pipes are made of concrete (n=0.01) and are circular in shape.

Pipe	Upper Junction	Lower Junction	Length (ft)
C1	J1	J3	172.8
C2	J4	J3	196.1
C3	J3	J5	89.9
C4	J2	J5	149.0
C5	J5	J6	82.7
C6	J6	S1	66.9

Table 3 – Land surface elevations at each of the system node locations. Note that S1 is the holding pond and O1 is the hookup to the MSU sewer-system (their elevations are needed later, in your StormNET analysis).

Node	Land Surface Elevation (ft)
J1	856.5
J2	855
J3	853.5
J4	856
J5	853
J6	852.75
S1	852.5
O1	852.1

Table 4 – Intensity-duration-frequency estimates for mid-Michigan climatic zone. Note that the values inside the table are the depth of rainfall (e.g., for 10-yr, 15-min duration storm, a depth of 0.89 inches of rain is added to the landscape).

Zone 9						
Duration (min)	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
5	0.34	0.42	0.48	0.55	0.60	0.66
10	0.53	0.65	0.73	0.84	0.92	1.00
15	0.63	0.78	0.89	1.03	1.13	1.23
30	0.84	1.07	1.23	1.44	1.60	1.75
60 (1-hr)	1.16	1.48	1.74	2.08	2.35	2.62
120 (2-hr)	1.36	1.74	2.05	2.49	2.84	3.20
180 (3-hr)	1.49	1.91	2.26	2.55	2.92	3.30
360 (6-hr)	1.72	2.19	2.58	3.14	3.61	4.10
720 (12-hr)	1.97	2.48	2.92	3.53	4.04	4.57
1080 (18-hr)	2.14	2.68	3.14	3.81	4.35	4.91
1440 (24-hr)	2.56	3.20	3.73	4.50	5.15	5.85

B. Retention Pond Design (No Outflow Structures)

You will need to redirect the development runoff to a holding pond. Initially, you will size the pond so that it can store all flow to the pond during a 24 hour, 100-year (return period) storm event. Later, using the StormNET software (see below), you will resize the pond, taking into account outflows (to be directed to the existing MSU sewer-system).

Use the MDOT rainfall intensity-duration curves (Table 3) to determine the total rainfall depth for the design event. Then compute the total storm volume using the subcatchment data. You can assume that the pond has no water in it at the start of the storm.

Assume a trapezoidal shape and calculate the dimensions of the pond based on the total volume needed (see Figure 4). Later, you will use StormNET to optimize the dimensions of the trapezoidal-shaped pond with outflow structures.

Comment on the overall size and dimensions of the initial holding pond design: do they seem reasonable, given the space available at the site?
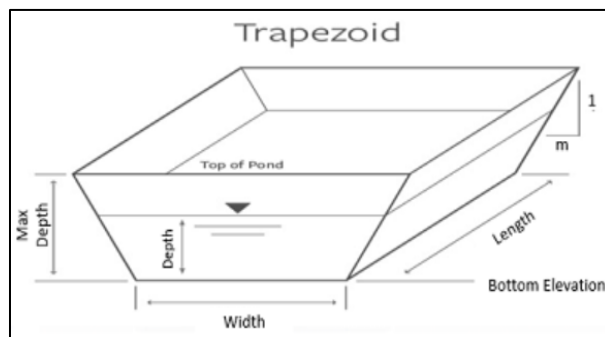
Figure 4 – Trapezoidal holding pond.

2. Setup an Initial StormNET Model

You will use a sophisticated modeling software called MAGNET Stormwater Network Analysis (or StormNET) to evaluate your calculations from Part 1 (using the Rational Method) and, later, improve the design to ensure that all design is code compliant. StormNET makes use of open source code developed by the US Environmental Protection Agency (EPA) for the program SWMM (Stormwater Management Model) to simulate water quantity dynamics in sewer systems and catchments.

A. Getting Started with StormNET

The first step towards using StormNET for site design and analysis is to create a free StormNET user account.

- Open a browser an navigate to: https://www.magnet4water.net/StormNET/
- Along the top header menus of the StormNET modeling environment, click: SIGN UP

Then, through and produce the Quick Tutorial:

- Along the top header menus of the StormNET modeling environment, click: HELP.
- Click: Quick Tutorial 2 – Georeferenced Model. This opens a PDF explaining, step-by-step, how to zoom into any location and create a georeferenced stormwater model with StormNET.
- Click: Quick Tutorial 3 – Georeferenced Model. This opens a PDF which provides graphics for a specific example of a hypothetical site in Haslett, Michigan, United States.
- NOTE: Quick Tutorial 2 and 3 are meant to be used together. (Tutorial 2 provides step-by-step instructions/notes; 3 provides graphics for a specific site).

B. Creating the Baseline StormNET Model

Use what you learned from going through the Quick Tutorials to draw the network and assign object attributes.

Draw the subcatchments and assign attributes (in Subcatchment Editor interface):

- Use Figure 2 as a guide for subcatchment positioning / size / extent.
- The area of the subcatchment is automatically assigned based on the map (you can overwrite the computed value, if needed)
- Compute and assign a characteristic width based on: Characteristic width = (Subcatchment area)/(Characteristic length). The Length to Outlet in Table 1 can be used as a guide of characteristic length.
- Assign a subcatchment slope based on provided subcatchment data.
- For subcatchments with building/sidewalks/etc., assume 80% coverage of impervious material
- For subcatchments with parking lots, assume 90% coverage of impervious material
- Mannings roughness for impervious Building lots can be assigned as 0.015; for impervious areas within Parking lots, use 0.01 (default value in StormNET). Mannings roughness for pervious areas can be assigned as 0.1 (default value in StormNET).

- Under Subcatchment Editor, N-Imper and N-Perv is Mannings roughness for impervious and pervious areas, respectively;
- All other default StormNET subcatchment parameters can be used in all subcatchments.
- Click the '?' button for explanations of all Subcatchment parameters.

Draw the Junctions and assign attributes:

- Draw the six junctions at the approximate locations indicated in Figure 2.
- Assign invert elevations and max depth based on what was used in Part 1 to compute pipe slopes.
- All other defaults for StormNET junction parameters can be used.

Link the Subcatchments to the Junctions:

- This is done one-by-one for each subcatchment.
- See the referenced Quick Tutorials for examples / details of linking subcatchments to junctions (or other network objects).

Draw the holding pond and assign attributes:

- Assign invert Elevation and Max Depth based on average land elevation at the pond and the assumed depth of the pond (from Part 2).
  - NOTE: The top of the pond should not be higher than the land elevation!
- For Storage Curves, select the Tabular Option, then select Trapezoid.
- Open the Curve Editor, Edit existing > Storage > Trapezoid. This interface takes defined input parameters and intelligently creates a range of depths (given a Max Depth and NH, the number of discrete depth values) and automatically calculates the surface area and volume of the pond at different depths. Calculation of routing and storage in the pond uses the generated relationship (or curve) between depth, area, and volume during simulation.
  - Change the Trapezoid Parameters to match those calculated in Part 2, and click apply.
  - Save the changes and close the Curve Editor.
- Later, you will link outflow structures

Draw Conduits and assign attributes:

- When drawing, always remember: conduits should start at the upstream node and end at the downstream node.
- The length of the conduit is automatically assigned based on the map (you can overwrite the computed value, if needed).
- Assign Max Depth (diameter) of each pipe based on your calculations from Part 1.
- You can use the default values for all other parameters in the Conduit editor. Later, you may want to apply non-zero Inlet and/or Outlet Offsets (or height of the conduit invert above the upstream or downstream node invert elevation). By default, conduits connect to the bottom of junctions.
- Remember to click the '?' button for explanations of all conduit parameters.

Add A Rain Gage and define the design storm event:

- Determine the average time of concentration from the Rational Method analysis
- Use the average time of concentration and Table 4 to determine the equivalent intensity (in./hr.) – just like you did in Part 1 for computing intensity for each junction.

- In the Time Series editor, create a new event that applies the calculated intensity for a total of 1 hours (consider using 5-minute intervals for data entry).
- Link the Rain Gage to the new time series (make sure you use the right Time Interval – it should match whatever you used in the Time Series editor).
- Link all Subcatchments to your Rain Gage (see Quick Tutorials for examples/details).
- You can use the default values for all other parameters in the Rain Gage editor.

Add an Outfall (but do not connect it, yet…)

- StormNET requires that all models have a system outlet (Outfall) to perform simulation. Add one to the map in the location depicted in Figure 2.
- But you do not have to connect it to the pond; for now, the pond represents the "end-point" in the system (you will add pond outflow structures in the next Part of the project).

Set up Simulation Options:

- Assign a 1-hour simulation time (Options > Dates) with a 5-minute (or shorter) reporting time (Options > Time Steps).
- Make sure you are using the Dynamic Wave Routing Model (Options > General).

Run the Simulation and view/analyze the Results

- Pay particular attention to:
  - Velocity in the Conduits at different time-steps.
  - Potential flooding at the nodes at different time-steps.
  - Storage in the Holding Pond at different time steps.
- The referenced Quick Tutorials includes examples of viewing plan view (map-based) results, time-series results, results along a profile, and a 3D depiction of the system with annotated/hover-based results.

3. Iterative Design Improvements and Performance Evaluation

The next step (or fun part!) is: iterative design and optimization.

In particular, you will optimize your design with respect to pipe sizes and pipe slopes to ensure compliance with the code using MAGNET StormNET. You will also optimize your pond design to ensure that your design is cost effective and complies with the code (the outflow must be less than or equal to that under natural condition; the outlet elevation is located such that a permanent storage is created for the first flush) using MAGNET StormNET. Local ordinance states that natural peak flows can be computed as: (0.15 cfs/acre)*(total acres)

A. Performance Evaluation Criteria

Consider following questions to iteratively optimize your design:

- Does your model behave as expected in response to the design events?

- In particular, does your storm water system behave as expected during the 10 year design storm (a rain event that lasts one hour with a constant 10 year 5 min intensity?)

- Are there any pipes overloaded during the 10-year design storm causing on site surface flooding?

- Are the storm sewers self-cleansing during the 10-year design storm when the rain intensity is at design intensity? Are velocities within 3 to 10 ft/s (in all pipes, for all times)?

- Does your storm water system behave as expected during the 100-year, 24 hour design storm (SCS Type II distribution)?

- What is the flow rate in the pipe upstream of the detention pond in response to a 100-year storm event?

- What is the flow rate in the pipe downstream of the detention pond in response to a 100-year storm event?

- How does the water depth in the pond vary over time in response to a 100-year storm event?

- Is pond drained in 48 to 72 hours as required by the code in response to a bankful storm event (2-year 24 hour storm)?

- Does your pond have a permanent storage to hold the "dirtiest", "first flush" (first 0.5 inches of rain)?

Take advantage of the powerful graphical capabilities to analyze / visualize your stormwater system:

- MAP (plan) view at different times;

- Profile view at different times,

- Time Series at different nodes/links;

- 3D plot

Remember to use an *iterative* approach: design, simulate, visualize/analyze, make changes to your design, simulate, visualize/analyze, and so on.

B. Storm-sewer Design Refinement

You may need to change aspects of your model to ensure that velocities in all conduits are within 1-3 m/s throughout the storm event. Consider the following modifications.

i) Changing the slope for one or more pipe(s):
- In StormNET, this is accomplished by adjusting the Invert Elevations of nodes connected by a conduit
- If you alter Invert Elevations, make sure Max Depth is adjusted accordingly (so that Invert Elevation + Max Depth always equals the land elevation).
- You can also adjust the slope by using non-zero Inlet and/or Outlet Offsets.

ii) Changing diameter for one or more pipe(s):

- This is accomplished by changing the Max Depth in the Conduit Editor

iii) if corrections to velocity are still needed, try changing roughness for one or more pipe(s):

- Consult Manning Roughness tables for typical range of values depending on pipe material

Also, **refer to the slide from your class lecture regarding iterative sewer design (see attachment in Appendix**).

C. Holding Pond Design Refinement

Evaluate the feasibility of connecting the holding pond to the existing MSU storm sewer line by modifying your StormNET model. More specifically, design the optimal pond size and outlet structure to ensure code compliance (see Part 3A); for example, ensure that the outflow is less than is equal to that under natural conditions, and the depth is reasonable not a hazard.

The outlet structure will consist of an orifice at the bottom of the holding pond, and emergency spillway through a weir so that pond depth does not exceed certain threshold depth. Also, a free board of at least 1 ft is required.

The ability to route water out of the holding pond should allow you to decrease its footprint.

Remember, to use an *iterative* approach: design, simulate, visualize/analyze, make changes to your design, simulate, visualize/analyze, and so on.

Add an Outfall to represent existing MSU storm-sewer line:

- Use a FREE condition for the outfall.
- The Invert Elevation of the outfall should not be higher than that of the holding pond
  - Recall that the land elevation at the outfall is 852.1ft (see Table 3).

Add a Junction near the east edge of the pond and assign attributes:

- Assume the land surface has an elevation of 852.3ft at the location of this junction.
- Remember, Invert Elevation = (Land Surface Elevation) – (Max Depth)

Link the Outfall and Junction with a Conduit:

- The conduit should start at the junction and end at the outfall.

Add an Orifice and assign attributes:

- The orifice should be placed at the bottom of the holding pond.
- The orifice should start at the holding pond and end at the newly added junction.
- Experiment with different sizes of the orifice (heigh and width) such that outflow does not exceed peak natural flows
- Also consider experimenting with the Discharge Coefficient. This parameter is a dimensionless number used to characterize the flow and pressure loss behavior of and orifice. A lower coefficient means more loss (e.g., because of a sharp edge opening and/or the use of gratings) and vice versa.

Add a Weir and assign attributes:

- The weir should be placed near the top of the holding pond, to be used in case of emergency overfilling of the holding pond. This is accomplished by using a non-zero Inlet Offset (height of weir opening from invert elevation of upstream node).
- The weir should start at the holding pond and end at the newly added junction.
- Remember, a freeboard of at least 1 ft is required. In other words, the top of the holding pond should be at least 1ft above maximum water level in weir as water moves through it? Freeboard is a guard (or safety factor against overtopping by waves or unexpected rises in the water level.
- You can start by using the default weir type: TRANSVERSE; but consider experimenting with different types/shapes for your design purposes.
- Also consider experimenting with the Discharge Coefficient.
- Remember to click the '?' button for more information on all Weir parameters.

Assign a 24-hr, 100-yr storm event to your rain gage:

- The SCS Type II curve is available as an existing Time Series in StormNET
- The Quick Tutorials referenced above describe how to use/assign the Type II-Intensity curve (1inch depth storm)
- Don't forget to apply a multiplier to create a rain event with a total depth equal to the design depth see Table 4).

Change the Simulation period to 24-hr:

- Options > Dates

Resizing your holding pond:

- Open the Curve Editor, Edit existing > Storage > Trapezoid
  - Change the Trapezoid Parameters to resize the volume
  - Save the changes and close the Curve Editor.

4. Green Infrastructure Design

The term "green infrastructure" refers to a variety of practices that restore or mimic natural hydrological processes. While "gray" stormwater infrastructure moves stormwater away from the built environment, green infrastructure uses soils, vegetation, and other media to manage rainwater where it falls — through capture and evapotranspiration.

Use your modified StormNET model (modified holding pond with outflow structures, hookup to MSU sewer system, 24-hr,100-yr storm, etc.) to experiment with implementation of Low Impact Development (LID) controls and quantity their impact on the water quantity dynamics.

Example LIDs that can be used in StormNET include:

- Green roofs
- Permeable pavement
- Rain gardens
- Bio-retention cells
- Vegetative swales
- Infiltration trenches

A. How to Add LID Controls

StormNET includes a default LID and set of input parameters for each type. You can view the default LIDs under Hydrology in the Network Objects menu. Then select 'Edit' mode and choose a LID from the drop-down list next to Control Name. Once a LID is selected, a small graphic and brief description of how the LID is modeled mathematically is provided, along with input parameter tables populated with default values. You can begin by using the default LID parameters, simulating, and analyzing the results, and then potentially experiment with different input values (within reasonable/plausible ranges) in an effort to maximize the impact of LID implementation. Make sure to click the '?' button for explanations of all LID input parameters.

A LID control must be tied to one or more subcatchments to be used in your model. Open the Subcatchment editor for the subcatchment(s) of choice and go to the Low Impact Design tab. Then click Add Lid Control and select from the list of default lids. You can check the box next to 'LID Occupies Full Subcatchment' to apply the LID to 100% of the subcatchment area, or you can enter the Area of each unit and Number of units to have the LID occupy only a portion of the Subcatchment. (You can adjust area of each unit and/or number of units to attain a desired percentage of the subcatchment.)

NOTE: An example of adding a LID control is provided in the referenced Quick Tutorials.

B. How to evaluate the impact of LID controls

Impact from LIDS can examined through the flows in certain appropriate conduits or depths at certain nodes (e.g. your pond) with and without the LIDs. Use time-series, map-based or tabular depictions of model outputs for representative times in your 24-hr simulation.

Remember to use an *iterative* approach: design, simulate, visualize/analyze, make changes to your design, simulate, visualize/analyze, and so on.

APPENDIX

Iterative Sewer Design
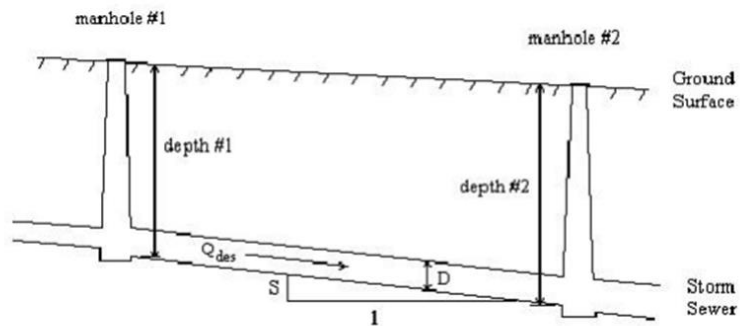
$$Q = \frac{1.49}{n} AR^{2/3}S^{1/2} \qquad D = \left(\frac{2.16Qn}{\sqrt{S}} \right)^{3/8} \qquad (1)$$

1. Assume a reasonable slope S, e.g., average land surface/street slope
2. Compute pipe diameter, D, from the Manning's equation, given S in step 1
3. Select the commercially available pipe size that is equal or larger than D computed in step 2
4. Compute velocity, v in the sewer, based on D in step 3 and the design peak flow, Q
$$v = Q/A ..... \qquad (2)$$

5. Verify if v from step 4 is in the appropriate range. v must be within 3 to 10 ft/s to be self cleansing and nonerosive

6. If v from step 4 is too small, increase the assumed pipe slope S in step 1 such that required D is reduced and the velocity in the pipe is increased to v_{min} or 3 ft/s.

7. The reduced D to achieve a velocity of 3ft/s can be computed from equation (2) , or
$$A = ¼ \text{ pi } D^2 = Q / v_{min} .... \qquad (3)$$

8. The corresponding increased slope S required to achieve the increased minimum velocity (in a pipe of reduced D obtained in step 7) can be computed from (1)