Main Projects, ESPM4295

Introduction

We have a semester-long project that will help structure our learning. We seek to analyze rainfall-runoff on the St. Paul Campus. A surprising amount of money and effort is spent by organizations to manage water from storms. Flooding is among the top one or two causes of property damage nationwide in most years, and therefor is the subject of much spatial analysis. It is also a good vehicle to learn new skills and practice old ones.

This project has two parts. The first is to develop skills for data creation, the second in analysis. We will build data, then an analysis workflow, and will use the workflow to estimate stormwater delivered to storm sewers, catch basins, and infiltration areas like rain gardens, under various storm rainfall amounts. We will then modify the landscape to catch all excess stormwater for specified storm levels.

An inexpensive and relatively effective way to mitigate stormwater flow is to increase tree canopy cover. Dense tree canopy typically intercepts between the first 0.1 and 0.4 inches of rainfall in a storm, with the amounts varying due to leaf type, rainfall duration, and intensity. When added canopy interception is not enough, then you may add surface storage (e.g., ponds, rain gardens, impervious pavement), underground storage, or green roofs.

Data Development

You will each sign up for a sub-area on which you will develop data. We limit the size for the data development area to manage the time requirements; it would take too long to develop some data sets for the entire campus. However, some of the exercises during data development and most of the analysis will involve most of the campus. Be careful to know the scope for each week's work.

You need to do several things, among them:

- You will develop a storm sewer grate layer, primarily from aerial photographs and a mostly-true but incomplete previous inventory. This incomplete inventory of storm sewers comes from UMN Landcare and Physical Plant, the entity responsible for the University physical infrastructure. The UMN layer includes many sewer features in addition to grates, so this layer must be subset, and verified, to identify flow entry points. We will use the open storm sewer grates as our "pour points" in a flow analysis, identifying flow direction, flow accumulation, and watersheds for each storm sewer and infiltrations area (catch basin, pond, raingarden). We will then estimate the amount of surface flow that reaches each one. We can identify high-contributing areas from the net amount at each grate.
- Collect ground surface cover, tree/large shrub canopy extent, building location, and other data for your project area, using aerial photographs, and verify your photo interpretation in the field.

- You'll need to organize the soils data, and come up with estimates of absorption percentage.
- You'll need to create flow-direction and flow accumulation rasters from available DEMs, modify them so that the stormwater grates effectively capture the water flowing to them, identify the "watersheds" for each grate, and calculate the amount of water that enters each grate.
- You'll need to identify areas that aren't captured by sewer grates and collects to basins and infiltration areas within your study area, and that drain outward from your project area, and calculate the total that flows off your project area from these.

Estimating Runoff
After data are complete, you will each independently conduct your rainfall analysis over a specified campus area. This area may/will likely be different than your data development area. We will give you a nearly complete set of data in the second half of the semester for this analysis, <u>you won't use your own data</u>. This starts everyone off on at the same level, irrespective if you've botched or completed your data development for your study area. Each person will develop a flowchart of their analysis and implement it, based on a skeleton provided later in the semester. You'll have to resolve the major steps, check to make sure these can be completed, and string them together in a graph. You'll then apply these steps, develop your recommendations, and write a short report describing your recommendations.

Note that we will also identify the points/storm sewer grates from which you have to mitigate runoff. You do not have to mitigate runoff for all grates. We will give you a data set with numbered points. You must maintain the numbering for those points in your estimates, so that we can compare your results to true values.

Runoff Calculations
Calculating runoff is not a simple spatial problem, particularly in an urban environment. Here we'll assume two levels of interception/absorption, first, the forest canopy, and then second, the ground surface. Once water reaches the surface, some infiltrates into the ground, and some flows over the surface. It flows over the surface according to gravity-defined flowpaths, and we can use high resolution, recently collected DEMs to estimate surface flow direction. Unfortunately, humans have altered these flowpaths via development. We've constructed sub-surface drainage networks, so once water enters these, it flows underground. A few buildings are connected to these drainage networks directly, e.g., when a downspout from a roof connects directly to a stormsewer grate or entry point. This only happens some of the time, so a building may contribute to overland flow. For this work, we will assume all buildings contribute all their water to overland flow. It is probably wrong for a few of the larger buildings, but since connection data are unavailable within the scope of this project, and direct connections are quite rare on the St. Paul campus, it is an acceptable assumption. We will assume the buildings contribute their runoff as indicated by flow direction from the building.

There may be sinks within building footprints that are artifacts of LiDAR processing. This may require some slight modification of the DEM within the footprint of the building to enforce proper flow direction to the exterior.

Our specific goals are to estimate the amount of rainwater delivered to each storm sewer and infiltration area in the study area, and the volumes of rainwater leaving the study area as overland flow, and how much it would cost to capture the water. To do this you need to estimate the amount of water delivered to each stormwater grate in your study area from a 1 inch and a 2 inch storm. Note that you do not need to worry what “runs on” onto the Campus from adjacent areas – much of the St. Paul Campus is generally higher or at the same level as the surrounding parcels. This is less true at the southern end of the Campus then the northern end, but for the sake of brevity we’ll restrict our work to a portion of the Campus.

Also note that you don’t have to worry about excess water in one location being absorbed into the surface by a particularly absorptive area downstream. A thorough analysis would consider these horizontal transfers, but almost no areas have good enough data, and these flow dynamics systems are quite complicated and specialized, so we’ll assume that a surplus at any one location makes its way to the nearest downhill stormsewer drain. This is admittedly a very simple model, but is valuable as a first approximation.

By not explicitly modeling runoff across every piece of ground, we must be careful if we sum the “surplus” water across our watersheds. We must be careful to not allow any negative surplus at any location in our analysis. If the rainfall is less than the interception plus absorption capacity at any point location, the runoff is zero, not negative. If the rainfall exceeds the interception plus absorption at that point, the runoff is positive, and is the surplus. Because most paths to an answer include steps to subtract maximum absorption from rainfall, and then sum values for each pourpoint/watershed, negative runoffs would affect the estimate. We must set a zero floor for surplus calculations at each step.

We will assume that the forest canopy and vegetation intercepts up to the first 1/3 inch of rainfall depending on height and canopy type, that grass, flower beds, and other unpaved/un-compacted areas absorb a percentage of the rainfall based on their soil type, and that impervious surfaces (buildings, streets, sidewalks, etc.) absorb none of the rainfall that falls on them – it all is runoff.

We will assume the two absorption effects are additive, for example tall conifer trees over asphalt will absorb the first 1/3 inch of rain, and the asphalt will absorb zero. Tall conifer trees over grass will absorb a 1/3 inch for the canopy, and then the grass below will absorb as much as the limits set by the soil type.

The amount of canopy absorption depends on the type, height, and density of the canopy. Conifers absorb more than broadleaves, taller canopies absorb more than shorter ones. We will assume that the canopy height generally integrates canopy density.

We'll use two simple rules for tree and shrub vegetation. We assume maximum absorption for trees taller than 9 meters (approx. 30 feet). Conifers taller than that absorb the first 1/3 of an inch of any storm, broadleaved species the first ¼ inch. Canopies from 1.5 to 9 meters absorb less, 1/6 inch for conifers, 1/8 inch for broadleaved. Shrubs/vegetation shorter than 1.5 meters absorbs at the rate of the underlying soil.

Note that rainfall and absorption rates are given in inches, but runoff volumes should be reported in cubic meters. Since our areas are in square meters, if you multiply water depth in meters by area in square meters, the output will be cubic meters, so we should convert rainfall and absorption to meters before the calculations, using 0.0254 m/inch as our conversion factor.

When reporting your final calculations, you should organize your output in a table so that each storm sewer grate has a unique ID, corresponding to its watershed ID, with this ID listed first in the runoff volume table. We will provide a set of final grates and IDs for which you must calculate and mitigate runoff. The table will thus have a row for each grate or infiltration area, and the volume runoff at that grate corresponding to the summed runoff for the corresponding watershed.

Landscape Modification and Recalculation

After you calculate the amount of runoff to the sewer grates and infiltration areas with the landscape "as is," you will also add storage to the extent needed to reduce storm sewer exports from i) a 1" storm, and ii) a 2" storm to zero. These are realistic limits, for example, new design is typically required to store at least the first 1" of rainfall, and some watershed districts in Metro Minnesota requiring storage of the first 2". The recommendation will take the form of a map of additional areas to provide forest canopy, and of areas to build additional infiltration – rain gardens or underground infiltration tanks, and enough supporting narrative and documented calculation to support your chosen alternative.

You will modify the landcover, canopy, buildings, and surface layers to try to eliminate the target storm runoff for the three levels. You will create new layers for canopy, landcover, and buildings corresponding to each mitigation level, and turn these in.

You can add new tree canopy by digitizing additional canopy polygons; you may also change canopy to conifers, subject to the smaller canopy diameter for conifers. You may only "plant" trees in locations where it is possible, i.e., you can't plant trees in the middle of the road. You can plant in/adjacent to sidewalks, and assume when mature they overhang the road, but the crown radius of broadleaved trees is limited to 13 meters (40 feet), and conifers to 7.5 meters (25 feet). The process should involve digitizing new tree stem locations as points, and then buffering to an appropriate size limit, and then adding these to your canopy layer.

You can't add tree canopy in impossible places, i.e., on top of buildings, or in the middle of lanes. You can be creative, adding tree canopy in center planters, if the road is wide enough, in planters in the middle of parking lots, or in grass strips between the sidewalk and roads. Trees planted on both sides of a two-lane road can completely cover the road.

You can modify surface permeability by converting sidewalks, paved plazas, parking lots and roads to permeable pavement, which raises surface absorption to the level of urban soils.

You can create new surface sink areas (e.g., rain gardens) by modifying the landcover, converting a paved area the infiltration rate of the soil. You can only put surface catch basins in areas that are currently not roads, sidewalks, or buildings. Surface sinks cannot takes up more than 15% of existing lawn or other greenspace. Parking lots and plazas are targets for conversion, but you must not reduce any one parking area by more than ½ the original size.

Note that you must not overestimate the amount of water a surface sink can absorb. Assume they can be no deeper than 1 meter, and the total volume they absorb will then be their area in meters, multiplied by 1, for an equal amount of cubic meters. If you put in a sink, you will have to compare the input to the capacity, and manually adjust outflow below the sink for your remaining calculations if the sink capacity is less than the inflow.

You can also reduce the amount of water by converting buildings to green roofs. This will absorb the first 2" rainfall. Green roofs can only be installed on flat-topped buildings.

You may specify underground storage, placing a new "grate" in a flowpath to absorb the flow volume, but it is after exhausting tree canopy and infiltration basin opportunities, as underground storage is dreadfully expensive. Underground storage can only go under existing parking lots, or tree-free areas, and not under existing buildings, as it assumes you excavate an area, create a water storage chamber, and then replace the surface. This has the effect of assuming all water draining to that area infiltrates, because we the underground storage is deep enough to catch all water, and then eventually soaks down into the ground below.

You will re-do the runoff analysis for your modified landscapes, first modifications needed to absorb a 1 rainfall, and then additional modifications to capture the first 1" rainfall, and another set to capture the first 2” of rainfall. You should create additional runoff tables, as above, for the three levels of storms. Keep the same numbering for existing grates, so we can compare tables.

Cost Estimates
Use the following estimated costs for each of your modifications, and report the total cost for the realized reductions for each scenario, based on these modification costs:

$0.40 per square meter new tree canopy
$30 per square meter to add surface sinks – but note that these may be no more than 1.5 meters deep, for safety reasons, so you need to calculate volume capacity, and note that you cant convert more than half of any one parking lot and 15% total reduction in parking space limits described earlier in this document.
$100 per square meter converting parking lots and streets to permeable pavement
$500 per square meter for a green roof
$2600 per cubic meter of water for underground storage

You can calculate total costs by the surface areas of each of these modifications, e.g., costs for trees as the added canopy area x $0.40.

Tables for Report
You’ll turn in a brief report at the end of the semester which includes a brief description of your study area, the problem, your analysis, and fuller discussion of your results. The report will include maps of your original data, your modified landscape, the watersheds and target grates you analyzed, and any other graphics you deem needed. You should turn in your final summary results as an MSWord file or PDF, and the tables included in the report AND turned in separately as Excel spreadsheet tables, structured as in the samples below.

Your first table/spreadsheet should record the sewer grate ID (integer), the sewer grate type, and the runoffs and costs for the various levels of rainfall and conditions. Grate types should be G for an actual sewer grate, NS for the new sinks, and US for underground storage you create as part of your modified conditions. There will be only zero values for the NS and US rows in the two “as-is” columns, (they aren’t there in those analyses), and the values for all the G grates should be near zero (< 0.5 m^3) for the modified surface calculations. Runoff volumes can be recorded to the nearest 0.1 m^3.

Sewer Grate ID	Sewer Grate Type	Runoff, as is, 1” storm (m^3)	Runoff, as is, 2” storm (m^3)	Runoff, mods to catch 1” (m^3)	Runoff, mods to catch 2” (m^3)
1	G				
2	G				
3	G				
.	.				
25	NS				
26	US				
Etc.					

Your second table/spreadsheet should include the costs for your modifications, for each category, and summed over your area:

Type	Cost, mods to catch 1” ($)	Cost, mods to catch 2” ($)
Added Canopy		
Change to permeable pavement		
New Surface Sinks		
Green Roof		
Underground storage		

ESPM4295 students will have to produce a report describing your results, with specific instructions on format provided elsewere. You should include maps of your original data, showing watersheds, labeled pourpoints, and flowpaths with a reasonable limit (that appear as surface flow lines, but without more than 1st level branching from the main flowpath), and the campus boundary, along with other usual map elements.

You should also produce a map for each level of mitigation, also depicting the NEW features to decrease runoff, i.e., the added/changed canopy, areas of changed surface permeability, surface sinks, green roofs, and underground storage. You should also include an image background, the watersheds, and pourpoints, as well as the campus boundary and typical map elements.