Lecture 28—Urban Hydrology

Hydrology is one of those disciplines that exists at the interface between geology and engineering. We're going to talk today about why that is. First, we need a little explanation about what engineering is (in theory) and what geology is (in theory). Supposedly, geologists are the information gatherers. We're the ones (along with meteorologists and other natural scientists) who provide engineers with the basic descriptors of the area they hope to modify. Engineers, on the other hand, are concerned with altering the natural world to make it more habitable for people (that's the idea, anyway). Want to design a bridge across the Hudson River? Call an engineer. Want to describe the material strength of the sediments and rocks underlying the proposed bridge piers? Call a geologist.

What creates a peculiar border zone in hydrology is what happens when people decide to live near water. Turns out, people like to do that. Then they get all pissy when every so often the water comes by for a visit. Then we need to *control* the water, and make it go where we tell it to. We take a natural drainage (geology) and modify it to become a more hydraulically efficient structure (engineering). This becomes especially plain in urban settings. Let's have a look.

In a city, we have two problems in terms of water. We *want* water on demand, and we want to be rid of that water when we want it gone. However, water falling from the sky is generally considered to be a bad thing, and is to be removed from the city quickly. It's considered a bad thing because *in general* we build cities with more regard to convenience or value than to natural drainage patterns. As a result, the existing drainage may be heavily modified (e.g. fill placed into an old drainage), and new, highly efficient drainages (e.g. roads) placed over the natural drainage. If water isn't removed from the city quickly, it tends to flow down the areas it likes best, generally some combination of the original drainages (leading to building flooding) and city streets.

What's typically done to combat this is to make drainages more *hydraulically efficient*, meaning that they're capable of moving more water more quickly. Part of this is natural—cities by their very nature make land more impervious to rainwater, so more is transmitted away quickly. However, part of this is also by design. We build a system of gutters and sewers to route water off streets and buildings. Sewers are generally unpressurized conduits, and (most often) route water back to the main drainage. This results in storm hydrographs that are significantly “peakier” than before urbanization. {figure}.

Cities also generally have a system for moving water around. Water is brought into the city in pressurized water supply mains, and distributed to individual homes and businesses through a basically dendritic flow network. Water is *returned* to the natural drainage via an unpressurized sewer system that routes all flow into a central wastewater treatment plant, where it’s (hopefully) cleaned.

Now for one problem. Back when many cities were first getting started (specifically eastern U.S. cities), it made a *lot* of sense to combine the stormwater sewer system with the wastewater sewer system. Why not? Why build a second system that we only use once in a while? As a result, a typical sewer system in the U.S. looks something like this {figure}. During dry periods, wastewater flows from industry and homes through an unpressurized pipe to a treatment plant, and out. *However*, when it rains the stormwater is added to this sewage. If the city’s wastewater treatment plant wasn’t designed to handle that amount of incoming wastewater, what can they do? As a result, most municipalities have *regulator* at the head of the treatment plant, and flow in excess of the amount the plant can handle is shunted directly to the outflow (a lake or river). This means that a combination of stormwater and sewer water goes untreated into the river. Yep. One of the big things happening these days is an attempt to stop this from happening, and the easiest way to do this is to have separate stormwater and wastewater sewer lines. This is easier said than done, however.

There’s another problem with all this. What happens when the pipe itself isn’t big enough to handle the load? We’ve talked about these pipes as being unpressurized, and what that really means is that they’re not flowing full. Once the pipe flows full, it obeys a different set of rules, and specifically, it becomes a kind of Bernoulli problem—there’s a head that may well extend above the water surface because of pressure in the pipe (we geologists might think of geysers). When this situation happens, the pressurized flow seeks ways to release that pressure. One place is to flow back out through storm drains or manholes; another is to flow back up basement drains and into houses. This problem results in some of the more fascinating “tales of the city”; manhole covers being blown off by geysers of wastewater, but the more likely problem is basements flooding or below-grade toilets overflowing. This is a special problem in rapidly developing residential areas where the pace of development has overmatched the infrastructure designed for it (which is one *big* reason for zoning laws).

What this all means is that engineers need to design structures capable of handling the water we’re going to throw at them. We’ll say nothing at this point about handling in an environmentally conscious way—just keeping raw sewage out of our lives. The basic problem the engineer faces is that his or her discipline is basically a *predictive* one, whereas ours is a *reactive* one. We can look at a drainage and think “huh, I wonder what will happen when it rains really hard?” and figure we’ll wait and find out. For the engineer, the drainage hasn’t been built yet—the engineer is *designing* the drainage to do something in response to really hard rain. Therefore, he or she needs to know something about how hard and what will happen before the structure is even built. In the case of sewer systems, engineers are told things like “ensure that this structure can handle the 25 year rainfall.” So what *is* a design rainfall?

One of the basic tools of urban rainfall analysis is something called an “intensity-duration-frequency” (IDF) curve. {figure}. Note that this is a *planning* tool that attempts to say things about the likelihood of rain of a given intensity and duration occurring. For example, there’s a 20% chance in any year (meaning the 5-year event) of a 24-hour rainfall exceeding 0.305 in/hr in average intensity in Tallahassee, Florida. This can be used to produce a synthetic *hyetograph* using hyetograph distributions produced by SCS {example}. These are based on previous experience about weather patterns (for example, cyclonic storms generally have the highest intensity near the middle of the storm, whereas convective storms are highest near the beginning). These synthetic design rainfall events are *the* way sewer structures in particular are tested.