# Lecture 4—The water cycle and watersheds

So, this is where we talk about the water cycle. I know, it's heady stuff, and it's really the *framework* for the *whole class*, so you'll probably be a little surprised to see how fast I go through it.

That's not too surprising in the end. First, you've seen versions of the water cycle like a *hojillion* times, and second, there's not that much to say, really. You know that water evaporates from the ocean, falls as precipitation onto the land, either evaporates again, soaks into the ground, or runs off, and then returns to the ocean. Yep, pretty much how it goes.

And yep, I could try to make this all fancier by saying "well, yes, but you have to understand the different fates of water hitting the ground, and that precipitation can happen over the ocean, too, and what about *lakes*?", but at the end of the day, there's really only one fancy part of this whole deal—how much of this is going to run off in rivers, and how time-dependent is that.

That's what we're going to spend the bulk of the course on. How rivers flow and why. So, forgive me for the water cycle getting short shrift. I figure you know it.

That's not to say this is *easy*. It's just easy when it's nothing but a concept. As a conceptual diagram, we can all say "yeah, sure, all these processes are happening, and all at the same time, and there's gradations between every one of them." And that's great right up until someone asks us to build a bridge that will stand up for 100 years, or to determine how much water can be removed from a river without detrimental effects to the wily snail darter (that's *Percina tanasi* for you biologists out there). Then life gets more complicated. First, we need some way of *quantifying* where water is going, and to do that we need some way of discretizing the conceptual diagram we made.

Commonly, then, hydrologic study is divided up into little chunks, sometimes called *operators*, that act on water. The diagram shows one such division. The idea is that, for example, the overland flow operator takes water from precipitation and sends some of it to infiltration, and some of it to surface runoff. The amount that goes to each place is both time and space dependent. Ick.

To make matters worse, our conceptual diagram doesn't have any place data. At the moment it's sort of a global model. What if we wanted to deal with just the Cuyahoga River? Does what happens in Pittsburgh affect flow in the Cuyahoga? How do we know? To answer this, hydrologists employ the concept of the *watershed*. A watershed is the area around a stream that actually sends water into the stream. SEEMS easy. Perhaps the most easily recognized watershed in the US is the Continental Divide. On one side, water eventually ends up in the Pacific, and on the other, the Atlantic. Yup. So things that are happening on one side of the divide don't affect things on the other, so you can safely ignore this. This is good. Let's take a look at a small drainage and talk about the watershed [haul out the Nemo map].

Watersheds can be defined at a number of different scales. Take, for example, French Creek in Pennsylvania. French Creek has a watershed of its own, and one could consider the French Creek Watershed to encompass the entire drainage around French Creek, and to end where it flows into the Allegheny River. Well and good. This is one watershed. HOWEVER, the Allegheny *also* has a watershed. It encompasses the entire French Creek watershed, and also the watersheds of all the other tributaries, ending only where the Allegheny joins the Monongahela to form the Ohio River. Yes, the Ohio has a watershed, too, as does the Mississippi, the river the Ohio drains to. In the end, the Mississippi is the largest watershed we can make because it flows directly into the ocean. Try this with Breakneck Creek, the little creek that flows just north of campus. [Breakneck—Cuyahoga—Lake Erie—St. Lawrence—Atlantic].

The watershed concept allows us to spatially discretize the world. Our conceptual water cycle now only takes place inside the watershed of interest. This is good. Well, almost good. Turns out there's sort of two different watersheds. There's the *surface water* watershed (you know, the one where water runs downhill), and there's the *groundwater* watershed (where water runs down the water table). Since these two don't *have* to coincide, it's not uncommon to have to consider both. It's also nice when you don't—on the Pacific Coast, there's vanishingly little groundwater, so most hydrology is just surface water. We'll probably live in this lie for much of the class, but bear in mind that it is a lie.

So, a simple model. Consider a watershed. We'd like to know, over the course of one month, how much water got added to the watershed (basically, how much water got stored in it. We might care because we're using that surface water for a water supply, or we might be worried that all that excess water will cause a flood). One way of describing this in math would just be to add up all the things we can think of that add water to the system, and then subtract all the things that we can think of that remove water from the system. Like this:

Inputs:

*P* = precipitation
*I* = inflow (if you're dealing with something other than a watershed, like a lake)
*G* = groundwater flow (could be an input, could be an output)

Outputs:

*E* = evaporation
*T* = transpiration (these are commonly combined to make *ET*)
*R* = surface runoff

So, a simple problem. For a given month, a 300-acre lake has 15 cfs of inflow, 13 cfs of outflow, and a total storage increase of 16 ac-ft. A USGS gauge next to the lake recorded a total of 1.3 in of precipitation for the lake for the month. Assuming that infiltration loss (that's *G*) is insignificant for this lake, determine the evaporation loss, in inches, over the lake for the month.

Ok, now. Let's talk. One of the nice things about this equation we made is that it's relatively easy to use, and there's nothing scary in it. It is not, however, without its problems. First, you can only use it in one month chunks (or, maybe in smaller chunks if you had data that was of good enough resolution). The point is, it's not continuous. By definition, you have to time-average over some time. What if we didn't want to do that? We *could* say the exact same thing we just did, but using *functions* instead of constants.

$$I(t) = O(t) + \frac{dS}{dt}$$

All this says is that if you add up all the inputs (I), and subtract the outputs (O), the result is the change in storage (S) with time.

Heck, we can make this even more exciting and say that any flux of water over an undefined boundary adds to the storage:

$$0 = \frac{d}{dt}\iiint \rho d\forall + \iint \rho \forall \cdot \mathbf{dA}$$

The *point* is that these are *all the same thing*. By and large, geologists are used to "plug and chug" like equations such as the first one I gave you. *However*, math is as much a language as it is anything else, and the last formula says the exact same thing—if you add something to the system, and it doesn't leave, then it's still there. One of my main goals for you in this class is to start "reading" equations instead of ignoring them.

Last thing! Many times, common equations are given names to make it easier for those working with them to follow along. It's a lot easier to say "we based our computer simulation on the Reynolds Transport Theorem" than it is to say "we based our computer simulation on the fundamental equation $0 = \frac{d}{dt}\iiint \rho d\forall + \iint \rho \forall \cdot \mathbf{dA}$, where *t* is time, ρ is fluid density, $\forall$ is a control volume, and A is the surface area of the control volume." The *problem* with this is that this requires us to have a *huge* vocabulary in our heads, and *worse* there are often multiple formulations for the same equation! I'll try to point out some of these terms, and what they really mean as we come across them. Here's the first one:

What you'll hear: Reynolds Transport Theorem
What it means: If some fluid quantity (typically mass or momentum) enters an area, and doesn't leave, then it's still there.
Where you'll see it: It's a common governing equation for models of fluid flow.

Ok, that's it. Next time we'll talk about some of the parts of the basic hydrologic equation, and talk about how they're estimated.