HYBRID MODELS: LAKE ST. LUCIA - PART 1

TONY STARFIELD: This is another story about a real-world problem. And it’s a real-world problem that led to two interesting new modeling paradigms, and that’s the reason for telling it. The background to the problem is in South Africa again. And it’s a story about an estuarine lake on the east coast of South Africa. It’s close to the Mozambique border, and the lake itself is known as Lake St. Lucia. And if you look at a map, you will see that Lake St. Lucia is very close to the coast; it’s separated from the Indian Ocean by ancient sand dunes.

The lake itself is about 40 miles long and two to three miles wide, and it empties into the Indian Ocean via an estuary that is about 12 miles long. A fairly thin estuary that’s about 12 miles long. Fresh water comes into the lake through rivers that empty into the northern part of the lake. And for the most part, they filter into the northern part of the lake through marshes. And the way the water flows in the lake is that the fresh water kind of flushes the lake down through the estuary into the Indian Ocean. So if you were to look at a salinity gradient, if you were up in the northern part of the lake, you would have a salinity that’s close to the salinity or equal to the salinity of fresh water, and then by the time you get to the mouth of the estuary, you have a salinity that is close to the salinity of seawater. And that, if you like, is kind of the natural state of the lake.

What happens, however, if there is a drought in the escarpment that provides water for the lake, is that you get very little or no fresh water coming into the lake. And the lake itself is very shallow. It's about three feet deep, on average. And so under drought conditions, you're going to have a lot of evaporation, and the water through the estuary is going to be reversed. So you're now going to have water evaporating in the northern part of the lake and you're going to have seawater migrating into the northern part of the lake and evaporating there too. And so the salinity gradient is going to be completely reversed. And in fact, the least saline water will be at the mouth of the estuary, and you might have salinities of two to three times the salinity of seawater up in the lake itself. So that's kind of the background to the hydrology of the lake.

Now, initially, before the Second World War, and in the ten or so years after the Second World War, Lake St. Lucia was a well-kept secret. Birders knew about it, because there's something like 350 bird species that you can find there, but for the most part, it was thought of as a recreation area for fishermen. And fishermen used to flock to the lake on holiday. After the Second World War, there was quite a bit of development in the northern reaches of the rivers leading into the lake. People started diverting water from the rivers for sugar cane production, and for forestry, and less and less fresh water was working its way into the lake itself. And then sometime in the late 1950s, there was a severe drought and, for the first time, people observed this massive change in salinity in the lake. And I remember as a teenager, seeing headlines in the newspaper saying, “Lake St. Lucia is dying.” And they were saying Lake St. Lucia is dying because, as a result of the high salinity, there were no fish to be caught. So it was thought of not so much as a conservation problem, but as a recreational fishing problem.

And what emerged from that crisis was a hydrological study of the lake. And, basically, people said, “We have a problem. We lose fish in the system if the salinity is too high.” The only biological input into the discussion was “high salinity is bad,” and given that information, the problem was handed over to hydrologists, and in some really interesting early computational hydrology models, they looked at various scenarios to try and mitigate the effect of high salinity in the lake. And as a result of that study, a freshwater canal was dug between a large river that empties itself into the Indian Ocean to the south of the lake. And it’s a river with a different catchment area, and a river that usually has lots of water in it. And so there was an ability to divert fresh water from the river into the lake itself. So that’s one control to try and reduce salinity.

The second control is dredging operations at the mouth of the estuary, right on the Indian Ocean. And dredging can work two ways. One possibility is dredge the estuary closed, and that means seawater can’t get into the lake, and the other is, of course, to open it, in which case you can either, depending on the level of the lake, have seawater coming into the lake, or you can have freshwater flowing out into the Indian Ocean. And by the 1980s, that was kind of the state of play. There hadn’t been a need to really use the canal yet, but the thought was that if salinity is increased, one could bring fresh water in via the canal, and one could dredge the estuary open or closed.

In the 1980s, for the first time, a biologist was stationed on the lake, with the idea of really studying what was going on biologically inside the lake. And the biologist worked for the local state conservation organization, and the conservation importance of the lake was beginning to be realized.

His name was Dr. Ricky Taylor, and he came up with the hypothesis that maybe salinity itself was not a problem. And from his studies of the lake he came up with almost three trophic pathways. The first was when salinity in the lake was low. And the idea then was that Potamogeton was going to be the basic underwater plant growing in the lake. That you would have some freshwater fish in the very north, probably good freshwater fish, and you would have a lot of ducks on the lake.

If the salinity increased, a little bit, not a lot, you would start seeing benthic fish coming into the lake and you would start noticing a lot of pelicans on the lake. There'd be flocks of pelicans feeding on the lake. And under the really high salinity conditions, you would lose the benthic component all together, and you would have mainly zooplankton, and you could get very large flocks of flamingos on the lake. And I think at one stage in the history they recorded something like 60,000 flamingos on the lake.

And Dr. Taylor came up with the idea that from a conservation point of view, these were all potentially interesting outcomes. And so the question now arose of, "Does one still need to use the controls? Do you still need to bring fresh water in from the river? And do you still need to think about conditions under which you would dredge the mouth of the estuary open or closed?"

And thinking about that, Dr. Taylor came up with the idea that what we really need here is a biological model.

The only modeling, let me stress, that had been done of the lake up to then, had been the hydrological model. And he reckoned if you were really going to match conservation goals to the two controls of the hydrology, you needed to have a biological model that would forecast what would happen if you use those controls in different ways. And having recognized that he needed a model, I got invited on one of my visits from the States to South Africa, to go and visit him and to spend a few days on the lake and to learn about what was going on there and to teach him something about modeling.

And Andrew Bleloch, who you might know as co-author of the two books I've done on modeling, was a graduate student at the time and he came along mainly for the fun of it, but also to contribute. And we had a wonderful time looking at the lake, and we explained to Dr. Taylor what modeling was all about. And this is kind of "Spreadsheet Modeling 101." What you need to do is decide what your input variables are, decide what your output variables are, and then develop an equation for each of your output variables.

And so, for example, if you're going to be looking at an equation for the reed biomass in the lake, you'll introduce a variable, say capital "R," subscript "t," which would represent the reed biomass at timestep "t," and you'd need to write down an equation, in words first, of how the reed biomass changes. And it will be an equation--a word equation that says, "the reed biomass at the next timestep is going to be the reed biomass at the current timestep plus the increase in the biomass," and you'd spell out what causes an increase in the biomass, "minus any decrease in the biomass," and you'd spell out what causes the decrease in the biomass. And from that word equation, you would then write down the typical kind of equation that we've been using on spreadsheets all along. And you would do that for all the variables of your model.

And Dr. Taylor, who hadn't done any modeling before, said, "That makes a lot of sense, I'm going to work on this." And I was heading back to the States, and he said, "Can I send you my equations so you can look at them and comment on them, and tell me if I'm on the right track?" And I said, "Yes, of course." I never got any equations from him. But nearly a year later, I got an email from him saying, "Are you coming to South Africa again this year?" And I said, "Yes." He said, "Would you and Andrew Bleloch like to come and visit me again? I'm having trouble with the model." And off we went to visit him again. And he said, "Look, I understand what I'm trying to do," he said. "I understand that I'm trying to develop these equations. But," he says, "I've got a problem. I just don't know what is causing the changes. I don't know how to actually write the equations. It isn't a lack of understanding of what you want me to do; it's a lack of understanding of what is actually driving the dynamics of this system."

And we went back and forth and back and forth, and, eventually, at some point, I said to him, "Why don't you just tell me everything you know; for example, about the reeds." And he thought for a little bit, and he said, "Well, the reed biomass will only increase during spring and summer. If the salinity is very low, it'll increase quite dramatically during spring and summer provided there aren't high winds on the lake. If there's a lot of wind, the increase in the reed biomass will be much lower. As salinity starts going up, the increase is going to decrease. And if salinity gets above a certain threshold, there won't be any growth in the reeds at all. If it gets above another threshold, the reeds will actually die back. In other words, we will lose most of the reed biomass. And if it gets even higher than that, not only will we lose the reed biomass, but if the water level in the lake is high, the rootstock of the reeds is going to get poisoned. And that would mean that if the salinity were to drop in the future, the reeds themselves could not recover for at least a year."

And he kept on talking about things like that. And Andrew and I reacted by saying, "Gee. You know a lot about reeds." He says, "Yes. But how do I put that into the equations?" And we stopped and thought about it for a little bit, and we realized that we didn't know how to put it into the equations. And then something clicked. Back when we'd been working on expert systems--if you haven't yet looked at the section on expert systems, or if you have, you'll remember that expert systems are driven by "if, then" rules. And Andrew and I had actually suggested that it might be possible to develop a qualitative model that was based on "if, then" rules. We'd thrown that out as a suggestion in our chapter on expert systems. And we never thought about it any further.

And suddenly what we'd realized was that Ricky Taylor had been telling us a whole lot of "if, then" rules. Everything he said about the reed biomass was an "if, then" rule. And suddenly we both clicked to the idea of, "Gee, maybe this is a situation where you could actually try and develop a qualitative model, not a numerical model, a qualitative model.

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