HYBRID MODELS: LAKE ST. LUCIA - PART 2

TONY STARFIELD: So what is a qualitative model? Or to ask the question in a different way, what are the differences between conventional numerical models and qualitative models? If you think about it, there are two essential components to a model. The first component is that you have to describe variables. Those could be input variables that drive the model, or output variables that respond to the input variables. And then the second part is the way in which you describe that response. So that is what I would call the "dynamics" of the model.

Now, in a conventional numerical model, if you look at this table, you will see that the variables are represented by numbers. "There are 376 elephants," or whatever. And the dynamics is represented by an equation, the kind of equations that you have been putting into spreadsheets throughout this course, for example. In a qualitative model, the variables are represented by states. So an input variable could be "low, medium, high," "states one, two, three." An output variable could be "very low, low, medium, medium-high, very high," "states one, two, three, four, five." And what drives the changes in states, the dynamics of the model, is developed through a set of "if, then" rules. So numerical models, numbers and equations; qualitative models, states and rules.

And once we'd realized that qualitative models really fit well with what Dr. Taylor knew about the lake, he moved very, very quickly to develop a qualitative model. It was a qualitative model that ran on a timestep of seasons. So you had spring, summer, fall, winter. The driving variables, the input variables, were water level: low, medium, high. And you can very quickly calibrate what you mean by low, medium, and high. A low water level means that if the estuary mouth is open, salt water from the sea is going to flow into the lake. A medium water level means there's not much flow either way. And a high water level means that fresh water, or whatever water you have in the lake, is going to be flowing out of the estuary into the sea. Then he introduced a wind variable. Wind could be low or high, in any season.

And then the key variable was the salinity variable. And here he introduced six states, going from the lowest salinity you would find in the water, which is probably the salinity of fresh water, up to the highest salinity you would ever find in the lake, which is probably something like three times the salinity of seawater. And in defining these states, there's no reason at all in a qualitative model that you have to have the states separated by equal intervals. So the thresholds between the states of salinity were determined by thresholds that were important in things that happened in the model. Thresholds that caused switches, for example, in the growth rate of different plants.

Okay. So he had these three input variables, and then he had a whole suite of output variables, and for each of the output variables he'd have four or five states. So, for example, the reed biomass could go from state one, which basically means the reeds are dead, or have died down to their lowest level, through to state five, and you could find a picture somewhere which shows a huge abundance of reeds in the lake, and you could say, "That is what we mean by state five. That's the highest level," and he very quickly developed the rules for his model. And with the help of a computer science graduate, who was switching from computer science to ecology, he managed to get the model running on a computer.

So you've got this model now, it's running on the computer, how are you going to test it? What kind of experiments are you going to do? Well, before we do that, let's just look at some of the rules that you might put into a model, just to get a better feel for what they are. For example, if you were to look at a rule for reed growth, you might have something that says, "If the season is spring or summer and if the wind level is low, then the reed biomass will increase by two states.” Now, of course, if you’re already in the maximum state of reed biomass, it’s not going to increase by two states because it’s as high as it’s going to get. But if you’re in state three, you could go to state five. So this would be a rule for very rapid growth in the reeds.

On the other hand, you might have a rule that says, “If the salinity level is state six, which is the highest salinity level, and if the water level is high, then the reed biomass will drop to state one and it will stay there for at least a year.” So this is the effect of the poisoning of the rootstock of the reeds. And so you might have five, six, seven rules for reed biomass, and, basically, the way the model would work at each timestep is to check through each of the rules, and if the “if” part of a rule, the conditions in the “if” part were met, then it would change the reed biomass according to the “then” part.

So as I said, you’ve got a model that has this whole suite of rules for all the variables, and now you want to test it. And since salinity is really driving the system, an interesting experiment to do would be to perhaps start with low salinity and then slowly increase it up to high salinity and then drop it back to low salinity again. And so one of the experiments we did with the model was to change the salinity in that kind of way, from low to high and back again, over a period of about 16 years.

And we looked at what would happen to three underwater plants that we modeled. And what distinguished these three underwater plants was that each of them had different salinity tolerances. And if you look at the output for these three plants, you will see exactly how a qualitative model works. Because what you see in the beginning, when salinity is low, is an exponential growth in the first underwater plant. And then somewhere along the way, you hit a salinity threshold where that plant dies back. And then you see a very rapid decrease in its biomass.

Meantime, a second underwater plant, which is more tolerant of salinity, is starting to grow. And it, too, gets up to a high level, but at a certain point, the salinity gets too high even for it, and it drops back. And meantime, again, a third plant, that enjoys high salinity, starts to grow and drops back. And then on the downward phase where you’re reducing salinity, you see, one by one, the three plants coming back.

Now there’s nothing very surprising in this result. I mean, the diagram shows you how a qualitative model produces output that you can graph. It also shows you--it builds confidence in the model because it shows you that your rules are behaving in the right kind of way. But apart from that, you haven't learned very much about the underwater plants. But an interesting experiment to do, whenever you change something so that it goes up and down over time, is to ask the question, "What happens if you change the frequency of that change? What happens if you make things go up and down more quickly, or if you make things go up and down more slowly?"

And so the next experiment we ran was again with the three underwater plants, but this time, instead of taking 16 years to go up and down in salinity, we did the whole thing in 8 years. And if you look at the results now, you see that, again, the three plants respond to salinity regimes in the appropriate way, but because the salinity changes are so fast, none of the plants manages to grow exponentially and reach the high levels of biomass. So, basically, you have salinity conditions that are good for the freshwater species, and it starts growing. But before it can get very far, the salinity's changed and it dies down. And then the second plant species comes in. And it starts, but it can't grow very fast.

And if you put these two results side by side, you can draw a qualitative conclusion from your qualitative model. And that qualitative conclusion is that rapid changes in salinity lead to an impoverished biomass in the lake. And it turns out that this qualitative result runs through all the trophic levels of the system. And so the ultimate result one gets from developing this whole qualitative model is that it isn't the level of salinity that matters. Remember when we came right in at the beginning of the story, the simple biological explanation was, "High salinity is bad." And what the model teaches us is that it isn't a question of the level of salinity, it is the rate of change in salinity. And rapid changes in salinity are bad because they lead to impoverished ecosystems.

And now you have a much more sophisticated rule to send to the hydrological modelers, so that they can decide if and when to dredge the mouth of the estuary open or closed and if and when to use the freshwater canal. And the purpose of both of these controls is to slow down rapid changes, up or down, in salinity. And this particular model, then, meets its purpose.

Well, this was really exciting. Hydrologists got excited about it and people started looking at the results of the model, and we wrote a paper on it, and people got very excited about the paper. I was approached by a civil engineering journal that said, "You know, civil engineers work a lot with biologists, but they don't quite know how to communicate with biologists modeling-wise. And it looks to us as though rule-based models could be a really exciting way of doing things. So there was a lot of interest from engineers at the interface between engineering and ecology and biology. The journal *Bioscience* asked me to write a popular article on qualitative modeling. I met an anthropologist at a meeting and he said, "Oh, I'm using the idea of qualitative modeling because it fits so well with the way in which indigenous people, hunters or fishing people, think about the way in which their ecosystem works."

So what are the advantages of qualitative models? Well, the first, obvious, advantage is that a qualitative model provides a mechanism for taking qualitative information and turning it into a dynamic model. And as you've seen over and over again, a dynamic model, something where you can change inputs and see what happens to the outputs, is the key to good modeling. So it enables you to take ideas that people just don't know how to fit into a conventional model, and to develop a qualitative model.

More than that, it draws on information that nonscientists might have. So, for example, in the case of Lake St. Lucia, there was a very thoughtful person who had spent 30 years working at a fishing village on the edge of the lake. Now, if you went up to that person and you said, “I’m trying to develop an equation for pelicans. You see here, it’s (P_t + 1) = (P_t ±)... get the idea of what models are about? Can you tell me what that equation should look like under these conditions?” You probably wouldn’t get any response at all. But on the other hand, if you go along and say, “I’m looking for some rules to tell me. Can you tell me what happens to the pelican population under these conditions?” you might well get a response that said, “Oh, yeah. Twenty years ago I remember there were conditions like that, and the lake was full of pelicans.” And, of course, as with all information, especially all expert opinion, you’ve got to try and verify it, but, there, you’re drawing on an information source you wouldn’t have had before.

The third great advantage is it makes communication with stakeholders and managers much easier because you can now actually go through the logic of why you reach a particular result with your model. When I say “go through the logic,” you can see which rules produce the results that you got. So you might well have a manager who knows a lot about Lake St. Lucia. Maybe the manager worked there when he or she was young. And you go to them and say, “We think we should manage the lake in this way,” and the manager says, “Why?” And you say, “Well, we got these results from a model.” And the manager might well say, “Well, I don’t know about models, but I know what my experiences were. And if I were at Lake St. Lucia, I would do something completely different.

Now, if the model’s a numerical model, it might be quite hard to convince the manager of the rationale of the model. But if the model is a qualitative model, you can say “Okay, look, here’s our model. These are the rules that led to this conclusion. If you’ve reached a different conclusion, please tell me which of these rules you think is wrong.” And what you have there is a win-win situation, because it could well be that the manager has had experiences which get you to correct your model, or it could be that the manager is going to have to switch off the sort of informal model running in his or her brain and say, “Yeah, I agree with you; I can see why you’re making this recommendation.” And that’s powerful.

And then perhaps the last advantage is that you can test ideas in a qualitative model very, very quickly. So you can do rapid prototyping with qualitative models in exactly the same way that you can do rapid prototyping with numerical spreadsheet models. So this all looks very exciting. One has a new modeling paradigm. Qualitative modeling. It’s something very easy to teach, it’s something very intuitive to use. But there’s some situations where it fits very well. But there are a lot of situations where, when you try to do qualitative modeling, the models fall flat on their faces. So after building up the hype, just as we went from the low salinity to high salinity, we’ve gone up to the hype of qualitative models to where we get really excited about them. I’m going to, in the next segment, deflate that to a certain extent, but then come up with a hybrid model between qualitative and numerical modeling that is even more powerful than qualitative models.

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