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Paul Thies: Each year, flooding disasters have the potential to cause billions and negative financial impact, and more importantly, can imperil the lives of many, many people caught up in their path. However, thanks to data science and advanced tools and technologies, scientists are now more able than ever to assess and contend with dangerous floodwaters. Hello, I'm your host, Paul Thies, and on this episode of If/When, I spoke with two experts in flood risk management and mitigation.

Joining me for this episode are Roger Falconer, Emeritus Professor of Water & Environmental Engineering in the School of Engineering at Cardiff University, and Dr. Richard Crowder, Jacobs' Director, Water & Environment. We discussed what they're seeing in terms of flooding frequency and severity, especially with a view towards the impact of climate change. We also discussed how emerging technologies can help with flood risk management and the latest advancements in flood model accuracy and response.

Roger and Richard, thank you both so much for joining me today. We're going to be talking about a number of topics related to flooding, flooding frequency, and severity, and then mitigation steps, and also flood modeling. Thank you both for joining me and sharing your expertise with our audience. I'd like to start with you, Roger, and my first question in to set the table in terms of the challenges before us that flooding presents, can you speak to the changes that we're seeing in flood frequency and severity, and how does climate change play a part in that?

Roger Falconer: I think over the last 20 years, people have the general public have taken climate change seriously now. Up to about the turn of the last century, I think there were a lot of cynics around, but today, I think most people on most continents in the world, regard climate change is probably the biggest challenge humanity faces towards the end of this century and it well into the future. It's really going to have two significant impacts on river basin systems. One, we are going to expect sea level rise depending upon which country you are in and so forth, and which part of the world, but we generally seem to be expecting sea level rise to rise by typically 1 meter by the end of the century.

That's going to happen in most parts of the world, and in some cases a lot more. We are going to expect to see rainfall intensity to change as well. Just in the UK for example, in the summer months, we used to historically have rainfall events. When I was a child of typical drizzled, I know it's always perceived that it always rains in the UK, but in the summer months, it tended to be just drizzle. When I was a child, there was no such thing as major storms in the summer. Now we have major convective storms in the summer, and I think this is making people much more aware of climate change.

In 2021, for example, there were two major storms in the city of London in the UK. These were convective storms, which are typical in the far east like Singapore, Malaysia, Indonesia, and so forth. We are not used to them here, yet the Boscastle flood storm in 2004, which I think was a bit of a turning point, it was a 1 in 400-year flood in July, which is the time of the year when people do not expect such rainfall events. I think most people in this country and across the world now expect significant change in sea level over up to typically a 1 meter, maybe more over the next 30, 40 years. Then perhaps leveling off a bit after that, but still continuing to rise.

Typically 30% to 40% increase in rainfall intensity, and in this part of the world anyway, mainly in the summer months. That's going to have significant impact on the effects of flooding in many ways actually, not just river flooding. It'll affect tidal locking. It'll affect surge levels as well. When you look at a city like London on the Thames, for example, then increasing tidal levels will have increased tidal locking. That means the sewers are locked by the water pressure being higher in the estuary than inside so the stormwater overflows in the sewers can't get out. That's another example of the impacts of climate change. We're going to have surges coming up much further into the estuary.

Alongside that, of course, we're going to have increased salinity levels and you could go on and on and on. What is the impact for flooding? You asked, where we're going to need more sophisticated models in the future that can run a lot faster, can integrate groundwater with surface water, and these models are going to help countries become more resilient to sea level rise and increased rainfall intensity. We have to look at both ends of the system, both at the seaward end and at the catchment or the upper catchments as we would call them in the UK.

We need more integrated models to address these challenges. Some of these are already being done, of course, with Jacobs' modeling and comparable in some of the other consultants, but we're going to need to use even more and better integrated models in the future, more dynamically linked so that it passes from one end to the system to the other.

Therefore we're going to have to link surface models, basically river models to subsurface models, that's groundwater models, and also the sewerage system as well.

Finally, on this point, we need to keep more intense rainfall events in the future out of the sewers. The sewers are typically designed for 1 in 25, 1 in 30, depends which country you're in, and so forth. The embankments protecting properties prone to flooding are typically designed to 1 in 100. The surface water regulatory authorities, like the environment agency, have a vested interest in making sure that the sewage drains, for example, surface runoff drains are clear, but that of course sends more water down to the sewer system, which can't cope with flows of one floods of 1 in 100. We're going to have to look at how we manage the system, how our drains are designed, and so forth.

Here, models like flood modeler are going to be even increasingly beneficial for the future for a much wider range of problems than simply working out flood inundation extent.

Paul: It's amazing when you think about the amount of rainfall and the impact that it can have on a water table and a local water table. I'm here in Texas, so while I tend to think of flooding as something that happens on the coast, we actually have flooding here as well when we have a lot of heavy rains and our water systems can't handle it. Listening to you, I was reflecting on, I have some family that live in Florida had weathered the hurricane event last year, and then helped with the cleanup efforts. What they were telling me is, when you have these huge hurricanes, it's not like suddenly the streets are just filled with this pristine ocean water.

It's the sewers are overrun and it's actually a really nasty business, and so it tends to be something that the water systems are not necessarily outfitted to handle, so anything we can do, I guess on the up, on the forefront to offset those, it sounds like that's what we should be doing. Now, Richard, Roger talked about modeling, he introduced the concept of modeling. Can you describe for us what role flood modeling plays in contributing to our understanding of flooding today, and the potential future impacts of climate change?

Richard Crowder: I think the understanding of flooding, it depends which lens or which perspective you are looking at it from. For example, as a member of the public, I live in the middle of England probably as far as where you can get from the coast, 2 meters above sea level. I might think I'm not vulnerable to flooding at all. Why should I be bothered about it? I've not been hit by flooding at all, but you only realize that you are at risk of flooding usually if it's happened to you before, or you've seen a neighbor or a local community or an area that you visited being impacted by it.

With flood modeling, you can look at scenarios, and understand general risks. For example, where I live, there's a reservoir just about a mile away from I live further up the valley. That could fail, you could say at any time, potentially, hopefully, it won't. By using flood modeling, you can model scenarios of whatever reservoir is to fail. What would be impacted similarly if an embankment or a levee was to fail along a river that was protecting communities, you can use flood modeling to help you understand what's going to be impacted upon if something was to fail. You can use modeling to try and provide those insights as to what is at risk.

It might be not just from where I live today, it could be where I actually want to buy a house because when people are buying a property, you'll often want to know how many area of flood risk your insurance could be impacted by it. Your ability to get a loan for a property or mortgage could be impacted upon it as well. There's many ways that flood modeling can contribute to society in terms of warning of a flood event coming along. If you look at the national flood forecasting systems, that some countries have in place, it could be from being awareness of buying a property or even on your holiday.

There's been plenty of examples where people have been on a campsite with a tent or a caravan next to a nice river and not realized that they're at risk of flooding. If they just looked at the flood maps for a particular area that are produced and are widely available on the internet, they'll realize that they could be in a zone at high risk of flooding. Flood modeling has a huge way of contributing to just the general public.

When it comes to engineers and scientists, it's the fundamental building block of understanding risk and then coming up with ways to mitigate that risk, whether it be coming up with flood forecasting and warning system to evacuate people or actually come up with engineered solutions to protect properties, the environment or land. It's a fundamental tool that we use for today. The future, who knows what the future's going to be looking like?

Roger mentioned that sea level rise could be up to a **[unintelligible 00:10:59]** in some cases. We could have the intensity of rainfall changing significantly, the actual makeup of the land and how buildings are located, and so forth could have a huge impact on the environment going forward. We can use computer models to do what-if scenarios, to do testing to understand what the future might look like so we can adapt our future plans on investment strategies and invest widely. Flood modeling plays a huge part on everyone, whether you're a member of the public or an engineer or scientist.

Paul: Well said. I seem to recall, and the data point escapes me, but I recall seeing, I think it was the United Nations and some studies they had done, but the migratory patterns of the global population right now and in the years to come 2030, 2050 whatnot, tend to be that people are congregating more and more in mass in urban areas. You're having more people living in urban areas and they're tending to, I think, migrate more and more to coastal areas. We're seeing humanity moving, if I'm correct here, more toward the coastal areas and more people are living in coastal areas.

It sounds like flooding, flood modeling, coastal squeeze, those kinds of phenomenon are going to be more and more important to mitigate and manage in the decades to come. Now, Roger, you had mentioned catchment, can you tell us what is integrated catchment modeling and can you explain what that is, how it works, and how it helps with flooding management response?

Roger: Well, if I may, what I see is got integrated catchment modeling, which is not necessarily always what everyone might argue is the case. Historically, in my view, if we go back to when I first started my career in the late '70s, early '80s, and so forth because you didn't have the computing resources then to do intensive modeling, you would model just one small catchment. When the several farm fields, for example, in the brook and the small stream entered the river, that was the end of the catchment.

Using today's arguments, for example, you might build some woody debris dams, for example, and put them in that catchment to try and hold the water back in that catchment, which is a great thing to do. Then there'd be another catchment, the other side of the river, you do the same there and you're not actually solving the problem in an integrated way because you could find that both of those woody debris dams fill at the same rate. Then when they're full to capacity, they release more water back into the river at the same time. I tend to think of the catchment as being much more like what you were defined in the states as the watershed or the river basin.

To me, what we have now is the capabilities modeling right from the upper end of the catchment of the basin by UK standards all the way down through the river basin system, right down to where the big river or the relatively large river joins the sea or joins a major river which then takes it to the sea, for example. In the UK, we have the Wye flowing into the sand, for example. You might consider the Wye as a whole catchment. To me, integrated catchment modeling means modeling the system from right at the top of where the rain first falls on the land to when it ends up either in the sea or a major river, then taking it onto the sea.

This avoids the problems we have now in terms of flooding from what we would call a Victorian age when people would build a wheel across the river to stop a particular town flooding only then to have moved the problem further downstream. By adopting an approach where you model a whole of the system from the top to the bottom, you can optimize your flood risks so that you reduce it for the whole river basin or the integrated catchment if you like. Also when it comes to things like the adoption of nature-based solutions, which people are very enthusiastic about in the UK for example, as they are in many other parts of the world.

You can hold more water back in one catchment vis-a-vis another so that they're not all releasing the water from the smaller catchments into the main river at the same time. You can play tunes if you like, on your integrated catchment model from the top to the bottom so that you can get the best solution for everyone. Also, as we progress to integrate the catchment models, we can link in more sophisticated and powerful tools, we can integrate the model with the subsurface models too. For example, Richard mentioned where he lives, I can mention where I live. I live on the side of Ilkley Moor, halfway up the river.

There's a river from my house. You can see it further downstream called the Wharfe. We are about best part of 100 meters above that river. When I bought this house, I didn't think for one minute, there would be any chance of flood risk here. We don't flood from the river. When I started looking into details in the house, I had a cellar here, which I keep some wine in and that cellar flooded five years ago and that cellar flooded from the groundwater level. I lived in a house before, which was right by a major river in Cardiff called the Taff. It was at the 1 in 100-year flood level.

I found a big difference. Every time there was a flood, I used to get my friends in the Environment Agency Wales as it was then called to give me the flood levels. I would find there was a big difference between the summer, a big flood in perhaps say September, October, vis-a-vis the same level flood two months later when the ground was saturated. Integrated modeling, we can build these tools up and expand them to include groundwater for the future. Then, of course, once we've got our model system put in place from the top of the catchment right down to where the river joins the sea and so forth, we can extend these models beyond flooding in the future.

Because flooding has important impacts on bacteria levels in the river, for example. The cow goes on the land, the cow does its business on the land. It stays there until the flood comes. When the flood comes that dilutes that cow patch takes it into the stream, then from the stream to the river polluting the river downstream. We have the stormwater overflows, which can't cope with big floods, but a lot of the water goes into stormwater overflows. We can extend our models in the future to include bacteria levels, nutrient levels to look at phosphorate levels. Algal blooms, for example.

The developments that have been made now through flood modeler offer tremendous opportunities for the future to have much better management of our system for the whole catchment from the top to the bottom and to reduce health risks and improve ecological status. I had one other point, if I may. When it comes to modeling the upland catchments, one of the things that rather worries me, some of these upland catchments are very steep.

The flow is very complex and if you take an undergraduate civil engineering course, for example, and you look at flow on a flat plane, that's taught at undergraduate level and a competent undergraduate civil engineering student could answer tutorial questions in an idealized or exam questions in an idealized catchment and they could predict the water levels. When it comes to a steep catchment, that's beyond an undergraduate level. If you put this into a medical context, for example, the first example of flat terrain is a bit like an appendix operation and you can do a medical degree and you can go out and do a bit of appendix operations and it's pretty routine.

What we are talking about down steep catchments is neurological brain surgery, which you have to be a very highly specialized consultant surgeon to do that work. That's the same here, because now when we are looking at the catchment, we have what we call transcritical flow, supercritical flow, similar to a plane flying at supersonic speeds, which typical Boeing commercial jets can't do, for example, not to criticize all jets. You need a different level of highly sophisticated expertise.

In the flood modeler suite, for example, you have the TVD, which is a shock-capturing algorithm, which allows you to model these very accurately. You might think this is a technical point, which is rather for the academics, but quite a lot of flood modeling had been done in a site on West Wales many years ago. There was a caravan site which flooded badly under a particular event. I think it was 1 in 200-year flood and the caravans were all floating all over the place and a lot of people lived in these caravans. Yet the model predicted for this flow that this wouldn't happen.

It was only when we added this TVD algorithm that we were able to predict **[unintelligible 00:19:58]**, it's not supposing these caravans moved, they would have moved simply because they weren't including shock capturing before. This worries me a bit because what it means to me that as these models become more sophisticated, you need that technical expertise and understanding. It's a bit like the neurosurgery, it's not the sort of thing that any surgeon can easily undertake, you need sophisticated level of expertise in hydrology and hydraulics and so forth. I think you have that with big companies like Jacobs, but not only Jacobs, other companies as well.

Paul: Now, Richard, picking up on that point, let's talk about the Flood Modeller solution that Jacobs offers. Can you describe how it works and how the software delivers accurate modeling of rivers, surface water, and urban drainage systems?

Richard: I think probably, in very simple terms, it's a digital twin. Just look at, if you're familiar with Minecraft, where you've got a computer game and you've got different things that you're building a virtual world, that's exactly what we're doing with Flood Modeller. It's a little bit more sophisticated. It's built on a GIS interface, which people are very familiar with. You're taking real-world pieces of data, whether it be the dimensions of the river channel, whether it's the digital terrain for footprints of buildings, whether you've got structures in there, whether it be a culvert, a bridge, an embankment of a levee, whether you've got pumping stations.

You're taking all of these features and you're building into your model. One of the rich things about flood modeling and some modeling packages is that you can include a lot of detail. It's important to include that detail if it's going to have an impact on the flow. If you're just taking kind of a broad brush approach, there are a lot of features that could impact on flow rates and flow paths but if you don't pick up, it will give you the wrong answers. In simple terms, Flood Modeller, it is just a digital twin, but it's underpinned by proven science and technology.

As Roger was mentioning before on the TVD solver, you've got to use the right mathematical techniques or the right solvers, depending upon the hydraulic problems you have and you're trying to solve. Within a Flood Modeller, we've broken it down into, say, three core components. One is the hydraulics and the river. We have a solver that models the flow and the river and all the structures that you get there. It's got more than two dozen different types of structures that you can easily model.

Then you've got the, when it comes down to a bank and it starts flooding above ground. We've got the 2D solvers, so you can model in high resolution. It could be to a 1-meter grid cell or 20-meter, if you wish, the flow going over the ground and you can link that to your 1D river. Then of course, if it goes into the urban drainage system, you need to be able to model the interaction with it. That's a different type of hydraulics again and we have a different solver for that.

You've got three different components that you're trying to link together in a mathematical way. What Flood Modeller does, it enables you to build all those components from a visual perspective and then close all the maths together in a very sophisticated way. It makes it fairly straightforward for the user to run scenarios of, what if I dredged my channel? What if I raised my embankment by so much? What if we had a future climate scenario of additional rainfall or additional flows? You can put that into your model and then you can basically look at the results.

Whether you're looking at just the water level, a flood extent or a flood map, or the velocities as how fast the water's going in a particular area. Flood Modeller is a pretty sophisticated tool of bringing the science and technology that many academics have produced and we've worked on for many years since the late '70s and put it in a user interface that makes it practical, and I'll say easy to use. It's making it consistent to use, so it's robust and people can do it in a consistent way and from one project to the next applying as many scenarios as possible.

Paul: Let's take a look here in my next couple of questions for both of you talk about next steps and where we see the technology is going. I'll start with you, Roger, and I'd like to ask, what role do you see technologies such as artificial intelligence, machine learning, internet of things, and real-time remote sensing, things like that, how do you see that impacting flood modeling?

Roger: I see it as having a significant impact in the future. Artificial intelligence, I see this as been broken down in machine learning, artificial neural networks, GAs. I see these as all part of artificial intelligence or informatics. I think firstly, it will reduce the dependency of individuals' experience of parameters, for example, roughness coefficient, and so forth. This can all be automated through the artificial intelligence schemes picking the best parameters. If you ask two different-- I can remember when I was a young chap, I did one of the first modeling studies I worked on.

The engineer put in a Manning's roughness coefficient or whatever, I can't remember what it was and I asked him, "How do you know it's 0.15, let's say, why not 0.2 or 0.25?" He said, "Oh, young man, when you get to my age, you'll know what parameter you'll use, you need years of experience, young man, years of experience." He stopped by disfiguring, he didn't change at all, so he didn't look at variability and so forth. I see that being able to run a large range of an artificial intelligence tool could pick up just taking this very simple example, all the literature in the field and picking the best value, for example, as your baseline, and then you can perhaps vary that as well.

I see it in that context. You can optimize hundreds of simulations to give you the ideal solution for optimizing the order of the river basin to work out what should be the embankment right here, there, or wherever to reduce flood risk. Of course, you can take account of the local population density and so on. It can include the costs as well. How are you going to invest most effectively to solve your flood risk problems in a river which often causes flooding at many sites down the river? There's only so much you can spend at any one time, and where is it best to spend that?

Historically, we've often perhaps, spent the money where the people shout the loudest and have the impact to get on television and write the right letters to politicians and so forth, rather than perhaps to the best for the poorer end of the society who can't write those letters, can't have the same level of impact on television, and so forth. We want to optimize for a wide variety of variables, flood impact, cost, and so on.

Then coming on to drones and sensing technology, you can improve the modeling accuracy for the future by using state-of-the-art technology through remote sensing and drones, and so forth, so we can get better and better resolution so we can get more and more confidence. One example, if I may, of this point, I'm heavily involved, it's a different area, but the principle is the same, in designing lagoons for tidal energy. Here we've used genetic algorithms and artificial neural networks to optimize A, the number of turbines to give you the maximum hydropower. B, we then looked at a wide range of operations when you start opening the turbines and so forth.

You could say exactly the same for a flood defense system. We've come up with increasing the capacity and the power that could be produced by typically 20% by using artificial neural networks, and in this case, genetic algorithms. I think we could optimize our solution and get better value for money, so to speak, or best investment for your buck through the use of artificial intelligence to take the core results from something like Flood Modeller and then run thousands of runs in a very, very short period of time.

Also, it could be used to give you real-time predictions of flooding down a river catchment where things can be very rapid. I see great opportunities to integrate what I would call informatics tools, which are very data-dependent with deterministic models such as how Flood Modeller has been based historically.

Paul: That's interesting. I can imagine the way that we reacted to flooding in the past, like you alluded to, it was driven maybe somewhat by people who had the money and complain or whatever, but it may not have been modeling the entirety of the system. It's like, if we just listen to the squeaky wheel and we take care of them over here, but we're not thinking about this systemically, it's actually going to create more problems. We have to be able to take a larger view and do what's best for everybody, as opposed to just focusing on it on a single area.

Richard, let me ask you about hydrological methods. What are some of the latest advances we're seeing in hydrological methods? What exciting developments are occurring there that can assist in flood model accuracy and response?

Richard: It partly links back to what Roger was talking about, but it's not just hydrological methods, I think it's hydrological methods and hydrological techniques. For example, data underpins so much in our lives these days. As we get to store and acquire more hydrological data, whether it be from levels or flows in rivers, whether it be rainfall from radar, it's adding to that rich databank of information that we can build upon. For years, we've been able to get good weather forecasts.

If you look at what it was 20 or 15 years ago to what they are compared today, they're significantly more accurate, several days out. It's because they've used data. We can see some rapid changes happening in the collection of hydrological data using real-time information. We're seeing satellites going into space later this year, which will give greater resolution and coverage globally of rainfall. Bringing all that together and looking after the data will unlock new analysis methods, new ways of predictive analytics, bringing in the remote sensing again.

When you combine that with hydraulic calculations and switching to high-performance computing as we've done recently, we switched from using the CPU on our computer to using a GPU, and we've had significant speed-up times that unlocks different techniques of analysis that just weren't practical before. Because of that, you can run so many, not just hundreds, but thousands of what-if scenarios or sensitivity analysis, which enables us to understand the uncertainties in the models that we use, to understand the uncertainties and the data that we're using, which all leads to higher accuracy of the models and higher accuracy in our response.

I'll give you an example, only recently for the environment agency here in England, they adopted our technology to be able to do real-time 2D flood forecasting. They've only been able to do that because typically, they will want to model a catchment and get an answer within five minutes. To do a highly detailed 2D model, you might be taking five, six, seven, eight hours to get the answer, but by switching the technology, bringing in real-time river-level data from existing systems, you can do that in a matter of minutes, which previously wasn't possible.

When you bring all this together, it's pretty exciting what we're starting to be able to do now. I think we're just at a tipping point as to what really will be happening in the future. Five years time from now, I think our methods will advance quite rapidly. I think the challenge will be the appetite of people to be able to willing to take it on because there is a fairly slow pace of change in our industry. If you look at other industries, they've adopted technology far quicker than we have. I think this is a real opportunity for us as industry to make real strides forward.

Paul: Yes. I can see that the trajectory is more and more data gets generated, so the computing power is accelerating, but the ability to make sense of that is accelerating.

I know there's other technologies where you can take, like you alluded to, data that would take hours or maybe even days can be done in minutes now. Then as the interface becomes more and more simple, because I think that's what it comes down to-- maybe what you're saying Richard is, the professionals in the industry have to feel comfortable using the new technology.

It's not just enough to say, "Hey, here's the shiny new thing." It's like, "Okay, well how do I fold that into my workflow and I'm comfortable with it." As people get acclimated to new technology and are able to bring that into how they do their jobs. I just feel like it's a perfect storm, no pun intended, but it all comes together, right? So the adoption will raise because people are more comfortable using these incredible tools that are being provided to them.

Richard: I agree with you completely. I think the underlying technology and methods is pretty well proven. Roger gave some good examples of, for example, the TVD scheme. It's been around for years, you know when to apply it and you can quite easily switch between different types of solvers to do things. The trick is now is to be able to simplify the use of that for users, being able to use the data that we're being able to create to enable people to make decisions as quickly as possible with as high confidence as possible.

Paul: Well, Roger and Richard, I want to thank you both so much for talking with me today about flood modeling and flood mitigation efforts. Very fascinating stuff. It'd be very interesting to see where this goes and where we can deploy cutting-edge technology in these efforts. I want to thank you both so much for your time today.

Roger: Pleasure.

Richard: Thank you.

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