DORIAN: Thanks Thom. So when you introduced this next speaking group, you mentioned that there's a lot of grey in their beards. I went to the bathroom at break and I looked in my beard, and sure enough, three grey hairs. And I think they just sprouted in the last three days. So how do I get this thing started? Anyways they're going to get shaved off as soon as I get out of here.

[Slide 1] So, thanks everyone. My name is Dorian Turner, and again, I currently work for BC Hydro. First of all I'd like to thank the In-stream Flow Council for having me here today and speaking amongst this lineup of absolute rock stars in the in-stream flow world. I've honestly referenced close to half of you guys when I did my thesis. So, really excited to be here. It's quite an honor.

The title of my talk has changed slightly from what's in the program but more or less going over the same material. Title of my talk is Evaluating Uncertainty in Physical Habitat Modeling in a High-Gradient Mountain-stream. Now, the reason I changed my talk is because this is the title of a paper that we recently got accepted to River Research and Applications, so if you guys need to get into some more details or look into methodologies, it should be published sometime this year.

So, I guess what I want to talk about in this research -- well, I want to touch on a few topics that we've been talking about all weekend. Some of those are uncertainty in the science behind in-stream flow, the value of data, and also how to manage some of that uncertainty. So I guess I'll start with talking about how I got into this research and touch on some of the background. [Slide 2] So as you guys all know, there's a growing demand for water resources here I say in BC, but it's obviously across North America and across the world. Whether that's for agricultural demand, domestic industry, or hydroelectric power, it doesn't really matter.

Of particular concern to water resource managers is meeting these increasing demands during periods of natural low-flow periods, when the stream is naturally low. And that's because this is often assumed to be a product of activity limiting period, especially for some fish species. That's because of reduced habitat availability, reduced food production, reduced water quality, and the like.

[Slide 3] Now, in British Columbia, we have fairly strong legislation protecting fish and fisheries and aquatic habitat, and we've talked a little bit about that this weekend, including the Federal Fisheries Act. Then provincially we have the Water Act or Water Sustainability Act now and the Fish Protection Act. So, resource managers really have to make decisions regarding the in-stream flow requirements during these low-flow periods that avoid causing harm to fish or fisheries under the Federal Act or causing harm to aquatic habitat.

[Slide 4] Now, in British Columbia, in-stream flow issues really came to the forefront with the emergence of run of the river hydroelectric facilities as a major component of BC's clean energy policy, which was introduced by the government in the early 2000s. In the early 2000s, there is what some people refer to as a gold rush by independent power producers to acquire waterpower licenses across BC.

[Slide 5] So here's an image. It's a little outdated now, but it shows where applications had been or were submitted for hydroelectric purposes in BC. So as you can see, it's quite a scatter along the coastal mountains, and I guess it became clear that with all these applications, there had to be some improvements and standardization in assessment techniques for these small-scale hydroelectric projects.

[Slide 6] So I guess for those of you who aren't really familiar with run-of-the-river hydroelectric facilities, here's a little cartoon showing a typical run-over of a hydroelectric facility. So from an intake structure, usually on a very high-gradient mountain-stream, a portion of the water is diverted out of channel into a pen stock, diverted downslope to a powerhouse, obviously turning turbines, creating electricity, and then as we turn the channel down below the powerhouse.

Then you're left with a reach that has reduced flow. This is referred to as the diversion reach. During higher flows or flood periods, the water obviously spills over the weir, and flows down the channel. But during lower flows, the channel experiences reduced flows. This is where managers have to make decisions regarding protective flows during those periods. [Slide 7] So obviously, here, the golden question is what are the in-stream flow requirements for that stream?

[Slide 8] Now, we've talked about it already this weekend, but there are dozens of methods that can be used to determine in-stream flow requirements. They range from very simplistic methods like -- you can cross 7Q10 off that list, but tenants method, and then physical habitat simulation model, which has been used very widely across Canada, United States, and across the world, to more complicated models such as River 2D and ones that I was only introduced to recently, ELOHA, which is more of a holistic framework, I guess.

[Slide 9] So in British Columbia, the BC in-stream flow methodology [BCIFM] was developed as part of the British Columbia in-stream flow guidelines by Lewis et al in 2004. It's an empirical habitat-based in-stream flow assessment method used to determine the amount of habitat availability for a certain species or different species as a function of discharge. So very similar to PHABSIM except that it's an empirical version and it doesn't use hydraulic models. It combines measurements of physical habitat data at those different discharge levels with habitat suitability curves—again, similar to PHABSIM, of different organisms that you want to look at.

[Slide 10] So here's a little cartoon if people aren't familiar with BCIFM. As you can see, in that reach of interest, you go out and sample physical habitat and a number of different transects, and you go and you sample a number of different discharge levels as well, and you collect data such as depth and velocity and substrate at different cells along those transects. Then you weight that data by habitat suitability models for, again, the species in life history stages of interest.

[Slide 11] You wind up with a scatter plot here of weighted usable width at those transects at the different discharge levels. In the BCIFM, you can fit, as they suggest, a curve to get a reach average weighted usable width as a function of discharge. In this case we fit the data with a log-normal function. You can scale [weighted usable width] up to weighted usable area. Then you can obviously use that data with the hydrology time series and look at habitat duration curves.

[Slide 12] But also, this habitat flow relation can be used to make inferences about where protective flows might be. So, the optimal discharge, which obviously occurs at the maximum weighted usable width here. So in-stream flow, regulators can look at this or practitioners to make inferences about protected flows. So I think we're all – everyone that's ever used PHABSIM or has got into physical habitat modeling understands that there's a lot of uncertainties within the modeling. These uncertainties can be caused from observation error, obviously sampling error, natural variability, model error, these can add up. We all know [uncertainty] is there and we tend to ignore it. [Slide 14] So this is really the question of our research – how can we quantify uncertainties in this methodology? The two obvious first sources of uncertainty, digging through the literature, were in the habitat suitability models, and how could we include that into the methodology. Then also, variability in physical habitat among transects within the sample reach.

So we use a case study here. [Slide 15] We went up to a small stream, high-gradient stream that will be typical of run-of-the-hydroelectric facilities, near Vancouver, British Columbia. [Slide 16] We collected our physical habitat data, depth, velocity, substrate, at 20 different cross-team stream transects. There's a debate about how to lay out those transects, obviously, and whether or not you should stratify by meso-habitat type. In our stream, there wasn't a lot of variability in meso-habitat type. It was fairly uniform. It was a riffle cascade type stream. So we used a systematic design. We went out and resampled at five different discharge levels where we thought habitat might start to become limiting.

[Slide 17] Next step was I called Mr. Ron Ptolemy from Ministry of Environment and asked him if he could provide me with habitat suitability curves. This is what a lot of in-stream flow practitioners across BC do, because either they're time- or budget-limited, to collect these habitat suitability curves. Obviously there are some advantages in collecting stream-specific habitat suitability curves, but it's not always possible. [Slide 18] So I wasn't quite satisfied with just having one curve, so I started digging through the literature in Western North America and compiled as many curves as I could for depth and velocity for rainbow trout fry. I'm using rainbow trout fry just as an example here, or rainbow trout/steelhead fry. So I compiled as many curves as possible and ran them through the British Columbia in-stream flow methodology to look at how they affected the weighted usable width of flow relationship, or the habitat flow relationship. [Slide 19] It became immediately clear that those curves that were collected across North America, whether or not those curves were from expert opinion or a Delphi method, or if they're stream specific, they resulted in large differences in the shape of that habitat flow relation. So the variability among those curves can result from a number of different factors, for example, different seasons when they're sampled, different temperatures in the water, different habitat availability, different discharges. [Slide 20] So I wanted to incorporate this uncertainty into the analysis. So what we did is we assumed each curve was equally likely. Now, you don't have to assume each curve is equally likely. If you have some reason to believe that one curve is more likely, you can weight it that way. We bootstrapped the data to come up with a 95 percent confidence intervals and a median. [Slide 21] So there we have our confidence intervals around depth and velocity habitat suitability curves.

[Slide 22] And again, here's the deterministic habitat flow relation, and then, [Slide 23] adding the 95 percent confidence intervals in the HSI curves produces the 95 percent confidence intervals around the habitat flow relation. As you can see, it creates quite a bit of uncertainty around the shape of that relation. Optimal discharge ranges from -- here, this is in cubic meters a second from .5 to 1, so it doubles. So that was great. We were able to do that. [Slide 24] The next step was introducing variation in physical habitat among transects. This has been done before. [Slide 25] Williams has done this, and others have done this as well, whereby you assume each transect's equally likely and bootstrap your data and [Slide 26] show your 95 percent confidence intervals around your average habitat flow relation. Now, the next step we did, [Slide 27] we decided to cut the number of transects to look at I guess the value of going out and collecting the number of transects that we did. So as you can see, we cut the number of transects from 20 to 15 to 10 to 5 and 3 and looked at where we started to get a lot more uncertainty. Below 15 transects, in the reach we were looking at, we started to get a lot more uncertainty in the data.

So again, our reach was fairly uniform in **meso-**habitat type. So a stream that had more variability in **meso-**habitat type, you might want to either stratify by that habitat or collect more transects. But again, that's a totally different discussion. So, the next step was putting both those types of uncertainty together in the model to come up with the total uncertainty in the habitat flow relation.

[Slide 28] Uncertainty compounded in an additive type manner, which wasn't really unexpected. But at this point we weren't really satisfied with producing confidence intervals around the habitat flow relation because it isn't really that useful. [Slide 29] So this is kind of the gee-whiz part for Tom (Annear), wherever he is. How is a practitioner/resource manager going to set a protective flow with all that uncertainty in the habitat flow relation?

[Slide 30] So the next question or the so what, Tom, was how do you interpret and manage this uncertainty? So what we did, [Slide 31] we showed the probability of different magnitudes of habitat loss as a function of discharge in these probability loss curves. So these are more or less one minus the cumulative probability distribution of habitat loss of different magnitudes of habitat loss.

So you can read this, for example, at a discharge a .25 CMS here, there's a 90 percent probability of 5 percent habitat loss, 50 percent probability of 10 percent habitat loss, and a very small, 1 percent probability of 25 percent habitat loss. Now, this can be useful to a resource manager because it allows him to make decisions based on his individual risk tolerances and explicitly state those tolerances. So for example, one resource manager might take the deterministic median optimal flow, which in this case, there is very little probability of any sort of habitat loss at that deterministic maximum habitat or optimal discharge. [Slide 32] But another resource manager might have a slightly higher tolerance for habitat loss, and I'm not suggesting this should be the case, but he may, and may say well, I'm willing to take a 10 percent chance of 10 percent habitat loss as long as there's not any chance of 25 percent habitat loss.

So that's one way to look at it. Another way is [Slide 33] -- now, in this next example, these curves are a little more uncertain, so this cumulative probability distribution just got a little more flat. This might result from less sampling, transects sampling, for example. Now, in this case, the same resource manager might take that median optimal discharge but he would then realize that there was a 10 percent chance of 10 percent habitat loss at that same optimal discharge, and he might introduce what we describe as a risk premium or insurance [Slide 34] against habitat loss and actually penalize the water user for having uncertain data and choose a higher flow, something like 0.95, that has no probability of 10 percent habitat loss. So it becomes useful in this way to create this insurance against habitat loss. [Slide 35] So I guess in conclusion, I guess the main point here is it's important to incorporate this uncertainty in physical habitat modeling. I know PHABSIM has been around for longer than I have, and I know that it's possible to introduce this uncertainty but I have yet to figure out why we're not looking at this in a similar manner and developing tools to actually deal with that uncertainty.

So presentation of the uncertainty in terms of this probability of different magnitudes of habitat loss or the probability loss curves allows resource managers to choose protective flows based on individual risk tolerances and explicitly state what those tolerances are so everyone can see that. I would argue using this approach is a precautionary approach to water management, because it allows managers to put a risk premium or insurances against habitat loss and penalize water users for providing uncertain data to make those decisions.

This allows them to hedge away from those large magnitude uncertain events. I am hoping that this sort of data eventually could go into some sort of decision making or risk analysis framework because all the data is there. [Slide 36] With that, I'd like to thank a number of folks helped me in my masters, Adam Lewis at EcoFish Research, and Ron Ptolemy. So anyways, that's it. Thank you.