Webinar Transcript

Historical Trends in Summer Precipitation, Baseflows, and Stormflows in New England and Projections of Seasonal Streamflows for Coastal Streams in Maine

Speakers:
Robert Dudley and Glenn Hodgkins
USGS Maine Office, New England Water Science Center

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Ashley Isham: Good afternoon from the U.S. Fish and Wildlife Service's National Conservation Training Center in Shepherdstown, West Virginia. My name is Ashley Isham, and I would like to welcome you to today's broadcast of the NCCWSC's Climate Change Science and Management Webinar series. This series is held in partnership with the U.S. Geological Survey's National Climate Change and Wildlife Science Center in Reston, Virginia.

Today's speakers, Robert Dudley and Glenn Hodgkins, will be presenting "Historical trends in summer precipitation, baseflows and stormflows in New England and projections of seasonal streamflows for coastal streams in Maine".

I'm joined by Emily Fort, Data and Information Coordinator for the National Climate Change and Wildlife Science Center in Reston. Emily, would you please introduce our speakers, and welcome.

Emily Fort: Thanks Ashley, I'd be happy to. Welcome everyone. We're so glad to have you joining us today. I'm going to run through the introductions and then we'll get started.

Rob Dudley is a hydrologist at the USGS New England Water Science Center, Maine Office. Rob has been with the USGS since 1992, where he's been involved in a variety of hydrologic, hydraulic and statistical modeling studies.

His ongoing and recent work involves investigation of long-term groundwater trends in Northern New England and the National Glacial Aquifer System and the development of a national streamflow climate change indicator in cooperation with the U.S. EPA.

Glenn Hodgkins is also a hydrologist with the USGS New England Water Science Center, Maine Office. Glenn has been working as a hydrologist with the USGS since 1990. Much of his recent research has focused on historical trends and water-related variables such as river flows, river ice, lake ice and snowpack and on their relation with climatic variables.

He is the lead author or co-author on 37 journal articles and USGS publications in this area since 2002, focusing on changes at the regional to the international scale. Other areas of research include river flooding and bridge scour.

Rob and Glenn, we really appreciate you being with us today. We look forward to hearing your presentation. Thanks.

Rob Dudley: Thanks Emily. This is Rob speaking. Glenn and I will be sharing the presentation, but I'll be starting things off. Our talk this afternoon comprises three parts, and we'll begin with a quick background of documented historical climate-related trends in New England.

It's these observed trends that have provided the impetus for us to pursue the NCCWSC funded work, where we investigated historical trends in baseflows and stormflows in New England. And we pursued watershed modeling to estimate future hydrologic conditions for coastal streams in Maine under a range of climate change scenarios.

First, we'll look at a very brief summary of hydrologic trends that have been documented in New England. Investigations I'm going to mention here in this introductory part, it's necessarily going to be brief and it's not going to be complete.

I want to urge you to, all the publications that will be mentioned in this talk are located, links at this web page the me.water.usgs.gov/publications/climate. I'd urge you to look into that for more details of everything that we're talking about today.

Among the consistent changes that we documented the most notable have occurred during the winter and spring. And include decreases in duration and thickness of ice, denser and thinner snow pack and earlier snow melt runoff.

First an example of observed decreases in duration of lake ice, specifically lake ice-out dates measured the last day of the presence of ice on a lake. And what makes this an interesting dataset to look at is that the lake ice-out dates have been recorded for a relatively long period of time. Largely for recreational or economical purposes, like navigation. So lake ice-out is typically a notable event and fairly easily agreed upon when it happens.

The map at the left shows the locations of 28 lakes for which we have examined these data. Five of them have more than 160 years of data and 19 of them have more than 100 years of data. So let's look at ice out dates for Damariscotta and Moosehead Lakes. Both have well over 150 years of record and what's immediately apparent is the amount of variability in the lake ice out dates.

We have Julian date on the Y-axis as a measure of that lake ice-out date, years across the bottom. The spreads around 20 days there in the variability and drawing a stiff moving average LOESS curve through these data, illustrates a longterm variation in the central tendency of the date. You can see ice-out dates are earlier than in the 1800s and the trends are non-linear with multi-decadal components.

If we examine them in groups from north to south with red in the north and gray in the south, the lake ice-out trends through 2008 on this plot show a fair amount of coherence.

Of note is the cold period in the 1960s, during which we had a lot of snow records set in the region. Note also that the trends toward earlier ice-out dates in the most recent 50 years have a median of almost two days per decade, and it's not representative of changes during the most recent 75 to 125 years, which averages closer to about half a day per decade for a trend. We've had a mix of later and earlier dates in the last 25 years.

As a part of working up streamflow records, USGS hydrologists routinely document days during which the gauging of streamflow is affected by ice. Looking at trends in the presence of ice in rivers shows consistent evidence of warmer winters in New England.

Again, this is a plot of LOESS curves for the nine longest record rivers in New England for which we are able to pull together these ice affected flow data. The left axis indicating the number of days of ice affected flows. Again, years along the bottom. The heavy green curve and the data points are the nine river average.

The figure consistently and clearly illustrates fewer days of ice affected flows over time, with an average decrease of 20 days or about 18 percent from 1936 to 2000. The last days of affected ice in the spring being about 11 days earlier.

This is consistent with findings of trends in the characteristics of snow pack, in which we've seen a decrease in snow depth or increase in snow density at 18 of 23 snow core sites in Maine. The plot on the right is a time series of a 4-site average of snow density measured at the longest record snow sites in western Maine, northern New Hampshire on or near March 1st.

Another LOESS curve drawn through the data illustrate a trend toward denser snow pack, that is a snowpack that is riper, closer to melt conditions for the same time of year.

The photo at the left was taken in Maine in 1963, which was a record year for snow pack.

This is a satellite image of New England after an early winter snow storm. The role of snow and the hydrology of New England is an important one. The water delivered in the form of snow and stored as snowpack over the winter can make a substantial portion of the total streamflow that flows through New England streams every year.

The timing and quantity of water delivered by melting winter snowpack is not only ecologically important, but it's important from hazards and water availability standpoints.

Most of the flooding that occurs in New England has a significant snowmelt component. The timing and amount of snowmelt is also critical for proper reservoir operation, power generation, and agriculture.

In an effort to measure how timing of snow pack accumulates and melts in New England streams, we've used a metric we refer to as the winter-spring center of volume date. That is the date by which half of the total volume of streamflow from January 1st to May 31st has flowed past a river gauging station.

Let me illustrate what I'm talking about by looking at a spring hydrograph of the St. John River in northern Maine. St. John's been gauged at this location since 1926. The river at this spot delineates the Maine-Canadian border. This particular river basin gets over a third of its precipitation in the form of snow.

Here's an example of an average hydrograph for the St. John River from January 1st to May 31st along the bottom axis. Log scale for streamflow is on the left. The red line represents average streamflow for 84 years of record.

Though precipitation is relatively evenly distributed throughout the season, early in the season it falls as snow and is stored as snowpack. So that later in the season, when the snow melts, the hydrograph rises. That's what you see here in this graph.

The blue lines indicate the range of historical flows, with the interquartile range and the minimums and maximums observed for every day during that time period. The average historical center of volume date where half the runoff occurs on each side of the state was April 28.

In 2010 it was an early snowmelt year, which relative to the 84-year average was over two weeks early. That in turn resulted in record high flows for early April and record low flows for the end of May that year.

This demonstrates it's not only important to measure the quantity of streamflow but the timing as well. It's important to note that the total amount of runoff in the 2010 season wasn't anything abnormal. It was just simply the timing in which it ran off.

Here's an example of the LOESS curve drawn through center of volume dates for this Piscataquis River in Maine. Again, dates on the left axis and years along the bottom, clearly illustrating spring runoff advance over time.

Here, a set of LOESS curves for the 13 longest record rivers in New England with minimal human disturbance illustrate coherent trends in snowmelt runoff timing from Northern to Southern New England. Overall timing has changed from one to two weeks earlier.

This is a consistent observation across Eastern North America, there's a large annual snowpack. That is, approximately, where about one-third of annual participation falls in the accumulation of snow.

We can see a shift in the spring hydrograph if we look at this generalized spring hydrograph with the months across the bottom, streamflow along the left axis.

The earlier hydrograph results in increasing flows in winter months, lower flows for spring months, which is indeed what's been documented when we examined trends in monthly flows. Much of these winter-spring changes have correlated strongly with winter-spring air temperatures.

Given the clear changes in winter-spring hydrology in New England, we hypothesized that earlier snowfall runoff might in turn affect summer flows, specifically because groundwater is recharged in spring, largely by snowmelt. We wondered how historical winter-spring changes might be affecting summer low flows when discharging groundwater makes up a substantial component of total streamflow.

Glenn Hodgkins: This is Glenn. I'm going to take over this part of the presentation talking about the historical summer baseflow and stormflow trends in New England. Just to give you a quick visual and intuitive definition of baseflow being the sustained base level of flow in a stream.

If we talk about components of total streamflow people often will put them into bins, what makes up the total streamflow. This slide will go through hydrology 101, a slide of that.

When you get rainfall, obviously it hits the land surface. If the land surface is saturated or frozen, normally happening with intense precipitation, you can get direct runoff quickly into a stream. That's what can make up a large part of the runoff just after a large rainfall event.

The rain can also make it into the subsurface zone, the root zone, and that creates a delay in runoff coming into the streams. The rainfall can also make it into the groundwater into the aquifer and that can create a substantial delay in runoff coming to the streams.

Looking at this a different way, looking at the components of just a typical streamflow hydrograph, the surface runoff, the quick runoff, would make up the part of the hydrograph shaded in black that you can see.

The delayed runoff from subsurface runoff, called interflow by many people, would make up a more delayed contribution to the total streamflow. Then the groundwater discharging into the stream would also make up part of the streamflow hydrograph, but a different part as you can see.

The method that we're using for this study to look at baseflow and look at baseflow changes over time, it's not possible to differentiate between the subsurface runoff, the delayed surface runoff, which might come from lakes and wetlands from the groundwater runoff.

To go through what happens in a typical year in Northern New England, in your winter months and in your spring months, you typically have a snowmelt runoff. That runoff often combined with rainfall recharges groundwater and surface storage.

Again, typically in the summer, when flows are lower and you don't have as much recharge, you're getting discharge from those sources of storage such as groundwater and surface water such as the lakes and wetlands and such.

As Rob mentioned, because of the changes that we've seen over time, in the timing of spring snowmelt runoff, we thought that could potentially impact the magnitude of summer baseflows. The reason that could happen is if you have a longer time of recession in the summer, it's possible that you could have lower baseflows due to the amount of time when you have that recession. It could potentially lead to lower summer baseflows.

I would presume that many of the people listening today would be interested in this because of the ecological importance of baseflows and streamflows and what any changes that we've seen might mean. We're not biologists, but based on our review of the literature we can say that relatively cool baseflow helps to stabilize summer stream temperatures.

It can reduce the influence of high air temperatures, especially over short periods of time. Baseflow can also provide cold water refuge in summer. The cooler water seems to be important for pretty much everything that would be important for fish survival and reproduction, et cetera.

On the other end of things, in terms of the other component of streamflow, that being stormflow, if you could increase stormflow that could decrease water quality because of combined sewer overflows which are common in cities in the northeastern U.S. and also from non-point source runoff from agricultural fields and things like that.

The objective of this particular study was to see how big historical changes in summer baseflows and stormflows have been over time in New England as far back as we could go based on our historical streamflow data and then to have a first look at what's behind these changes.

We did that by correlating the interannual variability of baseflows and stormflows to potential causal mechanisms such as precipitation and air temperature, and we also looked into a few other things we won't get into today. We also looked at snowmelt, runoff timing, whether that could be behind...whether that's correlated to the variability of baseflows and stormflows.

Looking at what we used for data, as we've already mentioned, we used streamflow data, and I'll explain a little bit how we got baseflow and stormflow from that streamflow data, but we get streamflow data from 25 streams that had data from 1950 to 2006. 10 of those streams also had data from 1930 to 2006, and we analyzed trends in that time period as well.

It's very important when you're looking for climatic influences on streamflow to use relatively natural basins. There are very few basins in the US that could be considered pristine, but you can eliminate obvious things such as streamflow regulation, basins that have undergone substantial land use change, things like that.

We took a lot of time and effort to narrow down our streamflow gauges to ones most appropriate to looking at low streamflows, and we also had criteria for low amounts of missing data.

In terms of the meteorological data that we looked at it's also important to use good data, obviously, but data from the USHCN network has chosen the best long-term sites in terms of quality of data from those sites and in terms of minimizing changes over time that you can find such as changes in the location of weather stations and instrument changes and such. All this is described a lot more in our paper if people are interested in the details.

What we used to separate baseflow and streamflow was an automated method called HYSEP, short for Hydrograph Separation. It's one of several automated methods that you can use.

The most important thing is to use an automated method so that your comparison over time and between stations are at least consistent, and we discuss in the paper some of the limitations on using this type of method.

Here's an example from one streamflow gauge in Swift River in the western mountains of Maine and how HYSEP divided stormflow from baseflow for one summer in 1930.

In terms of looking at changes over time we tested several statistics. One was monthly in summer. Mean baseflows, we looked at mean August base flow, seven-day low baseflows, summer stormflow, which we mentioned was streamflow minus base flow. We also looked at baseflow ratio, which we don't discuss today. That's in the paper.

I won't bore people with a lot of statistical methods, but just wanted to say it's more complicated than you may think it is. Typically people, when they look for the significance of tests over time have used the Mann-Kendall Test, but it's now known you can't simplify things that much.

The Mann-Kendall test assumes independent data over time, and data can have short-term persistence and it can have long-term persistence, and those things need to be considered, and we did consider them in this article.

The magnitude of changes, looking at the magnitude of changes, estimates of the magnitude are not affected by things like long-term persistence, and we'll give estimates of the magnitude in later slides here.

We've used LOESS smooths to look at...you've already seen some of them, and you'll see some more. That is actually slightly different than the LOESS you see that has the W in it, but I'm not going to get into that. The trends you'll see were based on the Sen slope, which is a very robust measure of changes over time.

Here's an example of the data. This is summer seven-day low baseflow so for each year we took the lowest, the seven days that had the lowest average baseflow, and we calculated that for every year, and this is a plot of those over time. The vertical axis is the magnitude of the baseflow, and the horizontal axis is the year.

You can see in this case that there's a lot of variability from year to year. That's the case with most of the things that we work with, and the black line that you see there is the Sen slope estimate of changes over time, which you can compute as a percent change, and that's what we're going to present results as here.

One thing that's interesting on this plot is you can see in the 1960s, a period known for drought in New England, you can see that there were several years that had very low seven-day low baseflows for this river in Vermont.

Here's another example of another statistic, August mean baseflows on a different river, the Saco River, and it comes out of the mountains in northern New Hampshire, and again, lots of variability from year to year, and overall you see increases over time based on the Sen slope. You can see that visually, too, with the points even given the larger amount of variability.

Here's a map of results of changes over time in August mean baseflows from 1950 to 2006. The blue triangles represent increases over time. The red triangles represent decreases over time. The largest triangles are changes greater than 50 percent, the medium-sized triangles are 20 to 50 percent changes, and the small triangles are 5 to 20 percent changes.

You can see in western New England, particularly in Vermont and New Hampshire, you have large changes over time, large increases in August mean baseflows, and many of them 20 to 50, and greater than 50 percent. Interestingly, in eastern and northern Maine you have multiple sites with decreasing baseflows in August.

Using the same symbols, but looking at seven-day low baseflows, changes over time from 1950 to 2006, again you see increases over time in the lowest baseflows in New Hampshire and Vermont, and you see decreases over time in parts of Maine.

Looking at the other pilot hydrograph, the storm flows, summer storm flows, some are, if I didn't mention it before, was to find for our purposes from June through September. You can see really large increases over time in the summer stormflows in western New England, not so much in northern Maine. Those large triangles are greater than 50 percent changes in many different streams in western New England.

Getting into what may be behind this, this is summer precipitation for that same time period, and you can see throughout New England increases over time and summer rainfall more so...excuse me, more so in western New England. You can see they're a little bigger in Maine. You can see in places where the slight decreases or not a significant change indicated by the black circle.

In terms of reasons for the baseflow changes over time, it seems to be driven by precipitation increases over time in New Hampshire and Vermont, and the decreases they see in parts of Maine, what's behind that?

Well, it might be due to increased evapotranspiration, and it turns out that air temperatures have increased by about a degree C in New England during the same time period so increased air temperature would lead to increased evapotranspiration and could be behind some of the decreases in baseflows.

Interestingly, one of our original hypotheses, "Were summer baseflows related to snow and runoff timing?" and the answer seems to be a pretty clear, "No, they're not." There was very little correlation between summer baseflows and the timing of snowmelt runoff.

I'm going turn the presentation back over to Rob now to continue on with watershed modeling.

Rob: All right. Thanks. We received a couple questions, and I think what we'll do is just hold off until the end here in the off chance that maybe your question will be answered by what we present, and if not, we'll be very happy to talk about it at the end.

To take a look at, to estimate climate-related changes in the future for hydrology for coastal basins in Maine we built four watershed models and calibrated them, and these watersheds are home to various anadromous fish species, including Atlantic salmon in Pleasant, Narraguagus, and Sheepscot, and Royal rivers.

We built these models using USGS's precipitation runoff modeling system, PRMS, and it's a distributed parameter model that simulates rainfall runoff processes as affected by various characteristics of the basin.

Explicit modeling of streamflow and the other components of the rainfall runoff processes in a model like this is useful to support water quality calculations, fish populations, survival migration modeling, and scenario testing, like changes in land use, water use, flow management, and climate change.

Very briefly, what I mean by distributed parameter model can be illustrated here.

While the effects of basin characteristics on rainfall runoff processes can sometimes be lumped very simply, especially where hand calculations are being done, a distributed parameter model defines basin characteristics in a more spatially explicit way. So it breaks down the basin into more homogeneous sub-basins and characterizing the total basin responses with some of those distributed components.

The sub-basin characteristics are derived from data describing things like elevation, slope, aspect, soil types, and land cover. The characteristics are then translated into model parameters and the equations governing the various rainfall runoff processes.

That's what the four basins look like broken down into their component computational subbasins called model response units or MRUs. The MRUs each represent a largely homogeneous spatial unit with similar basin characteristics.

These are the rainfall runoff processes that the PRMS model aims to simulate computationally, essentially, the water-cycle components, including precipitation and evaporation, along with the various runoff processes, including overland and groundwater flow and storage.

Here's what the process looks like. It's represented as a computational schematic for PRMS. Precipitation and air temperatures are inputs to the system, as well as for the model itself.

Solar radiation is also an input to the system. That's data that we don't have, but that can be estimated as a function of your input: air temperatures and precipitation, time of year, latitude and slope and aspect of your topography of your different model response units.

Various components of water moving out of the system compose the total streamflow and include surface runoff, interflow and groundwater. Evaporation, transpiration and sublimation are other avenues for water to leave the system as well as groundwater sink for groundwater that might leave the basin through other ways other than streamflow.

These outflow components contribute to the total streamflow at different time scales, which Glenn illustrated a little bit earlier. Along those lines, those components making up the total streamflow measured by the hydrograph, and the time and quantities of the runoff described by each of these components, affects the final shape of the hydrograph.

That's basically how calibration is done. The calibration involves iteratively adjusting governing parameters to most closely match the shapes of the observed hydrograph given your input meteorological information, so input data describe daily precipitation and daily minimum and maximum air temperatures. In the end you've got a calibrated model which provides quantitative time series of the flow components.

Here it's showing storm runoff, interflow and groundwater broken apart. PRMS outputs dozens of various parameters, parts of the rainfall runoff system.

As an example, you can extract spatially distributed quantities for things like this graphic showing snowpack water equivalent distributed by model response unit. For example, north or south-facing slopes would have greater or lesser amounts of snowpack at a certain time in the spring, and that's explicitly modeled.

With the calibrated models in-hand, we proceeded to model a range of climate change scenarios using output from several general circulation models or GCMs, to simulate the response of the earth's climate to major drying forces like greenhouse gases. The GCMs are run by members of the Intergovernmental Panel on Climate Change, the IPCC.

Due to the uncertainties associated with these different GCMs, for example, differences in feedback mechanisms or spatial resolution or time schedule which they're run. We're using the output from several GCMs to have an ensemble of GCMs that we use as input to our watershed models.

Briefly, I want to acknowledge the help of the USGS Modeling of Watershed Systems research group in Denver for assistance with this climate modeling. It's the same modeling approach that they used in a climate change study for 14 watersheds across the US. Reference for that is at the bottom of this slide. You should also find it on that climate page that we pointed you to in the beginning of the talk, as well.

For each GCM, a range of future emission scenarios were run to describe how greenhouse gas emissions might evolve over the next century on the basis of assumptions, including things like population growth, technological changes and economic development and so on for the world.

We selected four scenarios from each of the five GCMs that were used to basically cover a representative range of scenarios where relatively low greenhouse gas emission scenario, B1, high emissions, A2, and a middle-of-the-road being A1B scenario.

The GCM and scenarios were applied to the watershed models using a downscaling scheme, the GCMs running on spatial scales of more than a degree latitude-longitude sized grids. Then we're scaling down to watersheds, down to those model response units which could be on the order of a square-mile or so.

We used a simple change field downscaling method in which the change in the future meteorological conditions were computed on a monthly basis between the current conditions scenario on the previous slide and the other three future condition scenarios. Those changes in meteorological input were applied to a 12-year historical input data set and applied in a moving window fashion over time.

Each day in the future ends up having 180 different realizations of daily meteorological input to the model representing an ensemble of climate conditions in GCM. Again, this is explained in detail in that pub that I pointed to.

See the time series plot showing overall changes in precipitation over time. This is, again, precipitation and air temperatures are inputs to the watershed models. This mean daily precipitation includes many days of no precipitation. The calculation for it will hence be relatively small numbers on that y-axis.

If you look at the change against the vertical axis, we're talking about perhaps an overall 10 percent increase in precipitation. Not much change at all really projected for all three scenarios.

If we look at only days for which there's non-zero precipitation, the maximum daily precipitation provides an indication of the amount of variability that we're inputting into the model over time. Again, if you look at the central tendencies of those plots, you see a 10 percent increase, if that.

For air temperature, here we're looking at maximum daily air temperature. The minimum plot looks essentially the same. I'm just showing you this. Overall the variability for temperature input is a lot lower than the precipitation. The overall change varies from about one degree Fahrenheit in the lowest emission scenario to about three degrees for the highest.

Your output daily streamflows, which we've been by month for the early part of the century, in this case the year 2020, for the Narraguagus River watershed model. Each box plot represents over 1,600 daily values and a central tendency of the data represented by the box with the median at that line in the middle of the box.

The highest flows, in general, are in April but can occur in March, much like they do presently. Lowest flows are in August and September. Mid-century, 2050, indicates higher flows during February and March, lower in the following months from April to July. Later century, 2080, further increases in streamflow are indicated during January through March and decreased flows for spring months, April, May and June.

You'll note the lowest flows in August and September don't really change much over the century with low flows affected largely by summer precipitation, as Glenn presented with the baseflow work, with precipitation being the primary driver of low flows. That's projected to be sustained or slightly increased, offsetting any increases in evapotranspiration during the low flow period.

The most substantial projected changes are expected to occur during winter, consistent with what's been historically observed to date. If we look at monthly mean base and snowpack water equivalent we can see the progression from early, mid to late century of decreased storage of water in the snowpack. We have arranged the months on the x-axis so that the winter season is in the middle of the plot.

It appears the greatest changes can be expected to occur in the early part of the century. Dramatic melting of snowpack typically occurs from March to April. If we focus on these months we can compare the different scenarios, how they impact monthly mean snowpack water equivalent, the B1 scenario being the lowest emission scenario with the least changes in snowpack and A2 being the highest, and having the greatest with A1B, the middle-of-the-road scenario.

Overall, late winter, early spring conditions are expected to, according to these projections, continue to look less like this and more like this over time for the same period of time in the spring.

It's the snowmelt process that most commonly contributes to our highest flows, which are our flood flows, which is of great interest to the transportation departments responsible for designing hydraulic structures capable of handling those flows.

To address those concerns of the main DOT we were able to leverage this modeling work to help address their concerns. We thought that a really brief synopsis of this project would be of interest to the audience, because it demonstrates an alternative method for presenting climate-related changes in the future. I'm handing that over to Glenn.

Glenn: It was very interesting to do this work because it took the calibrated models that Rob had used and used them for another purpose. In this case, our State Department of Transportation was interested in how flood flows in the future may change, because bridges are designed for 50- to 100-year life spans. They were interested in knowing how potentially climatic changes could affect future design.

What we did with those four rainfall runoff models and those four coastal main basins was to generate historical annual daily peak flows. Then with those annual daily peak flows we compute statistically the 100-year peak flow, also known as the one percent chance peak flow, and we compare those to actual historical flows, peak flows, flood flows. We also generate potential future design flood flows based on expected climatic changes.

First of all, it's obviously important to know whether your model is any good at predicting what you're interested in. In this case it seemed to be pretty good.

We had thought we were going to have to calibrate the models specifically to high flows, but when Rob went through that, it turned out we were able to use the calibration that he had done, which calibrated the outflows, low flows, medium flows and high flows. We did no special calibration for this study in terms of calibrating to the peak flows.

What we found was that it did a pretty good job estimating or modeling the two-year peak flow and the 100-year peak flow, based on actual historical estimates. We compared the modeled estimates to the 100-year estimates and the 2-year estimates that we would get from using historical flow.

What I'm going to do is show you some example output from one of the four basins. All four basins had similar patterns of what happened if you changed the precipitation or changed the temperature. In this case, this is the Narraguagus River in eastern Maine. What you see here on this table are changes in the 100-year peak flow if you change temperature or precipitation by a set amount.

In this red box you can see, in this row, what we're doing is we're holding precipitation constant, and we're changing temperature in the models. By increasing temperature by two degrees Celsius, you can see that, for example, a -12 percent decrease in the 100-year peak flow. By lowering temperatures you get an increase of 10 percent in 100-year peak flow.

You can look at this the other way. If you hold temperature constant but change the precipitation going into your models here by -15 percent or 15 percent, as you might expect, if you decrease precipitation you get decreased 100-year flood flows, and if you increase precipitation you increase the flood flows.

What we've essentially done here is a sensitivity analysis. Rather than directly taking model scenarios from GCMs and downscaling them and plugging them into rainfall route flows. What we're doing is we're just changing the historical temperature and precipitation by set amounts and seeing what that does to flood flows.

Based on published studies and work that Rob has done, the GCMs predict temperatures increasing and precipitation increasing in New England. We wanted to make sure we included changes in temperature and precipitation that I bracketed those potential changes.

Again, this is just one river. This is the Narraguagus River. You can see if we hold precipitation constant and we increase temperature you get lower 100-year peak flows. If you hold temperature constant and increase precipitation you get increased 100-year peak flows.

What's interesting is if you look at what might be considered likely changes, by mid-century temperature increases of two degrees or so and precipitation changes somewhere between 0 and 15 percent, the two seem to balance each other such that you generally get changes plus or minus less than 25 percent peak flows to flood flows.

Why might this be happening, and in particular why would you get decreased flood flows with increasing air temperature? The reason for it is probably because of changes in snowpack. This table represents modeled snowpack. It was explicitly modeled.

You can see that if you increase your air temperatures you start getting a substantial decrease in the maximum annual snowpack water flow. That's the amount of water within the snowpack if you were to melt it.

In summary, how might future floods be affected? If we have increases in precipitation, you're likely to get increases in large flood flows and small flood flows, but it didn't seem to be a 1:1 ratio. The increases in flood flows were two to three times greater than precipitation increases.

In terms of increases in the air temperature we got decreased design flood flows, probably due to less snow runoff in late winter and spring. Precipitation increases combined with temperature increases can result in little change in design flood flows.

Rob: That wraps up our presentation. I'm not sure if we answered a couple of questions I have been asked so far. If not maybe we can reiterate those questions.

Ashley: Yeah, that sounds great Rob and Glenn. If you just want to start, I'm going to go ahead and read the questions so we can get them into the audio record, and then if we can just have some clarifying remarks from you both that would be great.

Rob: Sure.

Ashley: The first one is from Shabnam Rouhani. I hope I pronounced your name right. They are saying, "I am wondering if they use daily or monthly streamflows for calculation center of volume date of streamflows?"

Glenn: The answer to that is they were calculated with daily streamflows.

Ashley: OK, and a follow-up question, "If you used daily streamflow have you considered auto-correlation, how about if they used monthly mean streamflows?"

Glenn: I know that correlation is important. The way we did it, we created one statistic for each year. There's only one value within each year. We sum up all the daily flows. We look for the date in which half of those flows went by a streamflow gauging station. You have one date for each year.

Where autocorrelation comes in is if you look in between the years, is it possible that the correlation between years, the autocorrelation between years could affect statistical tests. The answer to that is "Yes."

That's why it's important to do tests that take into account short-term persistence, and I also wanted to take into account long-term persistence, which we did, which you can view in probably more detail than you ever wanted to see in our paper, if you care to look.

Ashley: Is that the website underneath your contact information?

Rob: Yes.

Glenn: Yeah, and specifically I was referring to the trends in baseflow and stormflow in New England paper.

Rob: I did want to mention, encourage people to email or call us to. I'd be very happy to talk with you, with anybody about any of this.

Glenn: We put the link to all our journal articles and reports up there again, if anybody is interested. All of the USGS reports that that refers to are available online. If you don't have access to the journal articles that that refers to, just let us know.

Ashley: Excellent, thank you. We have another text question and it says, "What may cause larger variability of summer streamflow over time?"

Rob: I saw this question pop up during the discussion about baseflows. I wasn't sure if they're referring to the maps where we showed increases in baseflows or low flows over time. If that's what's being referred to, I'm not sure what's meant by the variability in the summer.

Glenn: I think that may refer to trends in the magnitude of summer streamflows.

Ashley: They say, "Yes." She also, or he also, I'm sorry, "In summary no climate change impact on flood design in Maine based on four watersheds in Maine. Not sure if this is the conclusion from the last page."

Glenn: Could you go up one slide around there?

Is this the page that Umi refers to here?

Ashley: If you'd like to press star six, they say "yes."

Glenn: What we're seeing there, if you look at the changes in precipitation and temperature that are currently projected to be happening as we move forward in New England, it would be an increase in air temperature and an increase in precipitation.

What we're seeing there is for many combinations where you both increase precipitation and you increase temperature, the two work against each other in terms of the magnitude of large flood flows.

We actually see, in general we see decreases if you increase the air temperature, probably due to the lower snow pack. We see, if you increase precipitation, you see increases, so the two often cancel each other out, depending on the particular amount that you change precipitation or air temperature. Not in all cases, of course.

It depends which ones actually occur in the future. If precipitation increases by more than is currently projected and air temperature increases less, just as an example, you would look on those tables and see, for that combination what happens? They may not cancel each other out. They may lean in one direction or another.

What we look about doing the sensitivity type of analyses as new projections come out, you can see what is expected for changes in air temperature and precipitation. Look in the tables and see, at least for these four coastal Maine sites what that might mean for changes in flood flow.

Ashley: Umi says thank you.

All right. We have another text chat question from Rachel Muir. She says, "Any effort under way to look at nutrient fluxes for these systems? For example, dissolved carbon, and how they might match up with trends regarding flow?"

Glenn: Tom Huntington is actually working on trends into the gulf of Maine from nutrients and some other things, so yes, there is. That hasn't been published yet. It's in the review process.

Ashley: Another question from Daryl Van Dyke. He says, "The particulars about your synthetic climate years are in the paper, but in general your procedure was to perturb prior records by factors statistically derived from GCM scenarios. Do you feel like this accurately captures changing temporal patterns in precipitation distributions?"

Rob: Yeah, that's a great point. He is exactly right. That is one limitation of the approach that was used was that we're not changing the spacing between storms, the frequency of storms. Whatever happened in the historical record happens again for those future years only with, that's right, perturbation supplied to the air temperature and precipitation.

Glenn: Just to point out that while that's a rather simplistic approach, to do any other approach you'd have to make quite a few more assumptions as to what will actually occur in the future in terms of spacing of storms and such.

Ashley: OK, thank you. I just want to remind everybody, if they have a question they can use the raise hand icon that's located between the participant list and the chat box. Or, of course you can use the chat box as you all have been doing. And Daryl wrote, "Thank you." Do we have any more questions? All right, Umi has a couple more questions, but she's just going to email you Glenn and Rob.

Rob: Sounds good.

Ashley: Or, they say thank you again. Richard Palmer, you can ask your question. Just press *6 to take off the global mute, and make sure your own phone is unmuted as well.

Richard Palmer: Thank you very much. First, thank you for that great presentation. That was really, really interesting. My question revolves around a slide. I don't really remember precisely what it said. But I believe that when you tried to look at the degree to which your model was calibrated for the 100-year floods, at least in one case it was off by something like 30 percent.

Maybe I misread that. I was just wondering if you would comment on the cascading uncertainty that occurs between the precipitation and the streamflow and then the estimations. And whether or not that you feel like the numbers that you arrive at at the end are pretty firm. Thank you.

Glenn: Let me try and answer here. If I don't answer your question please ask again. Yes, you're correct. On one of those sheets you can basically see that the 100-year peak flow was off by 36 percent, which is not ideal.

But one thing to point out is that even though it's off by that amount, what we're doing is we're comparing the historical modeled 100-year flow or 2-year flow to the historical modeled flows when we perturbate the air temperature and precipitation.

They did not calibrate perfectly. Whatever bias is built in there is being carried forward. Certainly, when you're trying to model something as complicated as flood flows, you introduce uncertainties.

When you have GCMs you're introducing certain uncertainties. There's a lot of cascading uncertainties when you do modeling work. Where we're doing a more sensitivity type of analysis, we're not completely dependent on what current GCMs are saying or projecting for the future for changes.

Did we cover the question or is there more or a different angle you would like us to try and answer?

Richard: I may have misunderstood the slide. I just want to make sure that the 36 percent is the difference in peak flows between what was recorded and what was estimated with historical data. Is that correct?

Glenn: The difference between what was modeled and the models are based on essentially historical temperatures and precipitation data, not on streamflows, but they're then compared to historical streamflows.

They're not only compared to historical streamflows, but compared to historical daily maximum streamflows, the highest daily average streamflow in any particular year, and then those are put into bulletin 17B statistical model to compute the 100-year flow and the 2-year flow and such.

One thing that could be happening, you can see there where the two-year peak flows are modeled quite well. Perhaps what's happening is that the model isn't capturing the skew of the population all that well for that one site over time.

Richard: Thanks for sparing the time on that. Thank you.

Ashley: Are there any last questions? Glenn, Rob, did you have any closing remarks?

Rob: Just that we appreciate the opportunity to present this to everyone that attended. Again, if you have more questions or you would like to talk with us more about it, our contact information, our email, or call us.

Glenn: Perhaps some details might be in the reports and articles that we didn't state today as well.

Ashley: Excellent. Holly or Emily, did you have any closing remarks?

Emily: No, just to say thank you to both Rob and Glenn. That was a great presentation and we really appreciate your time.

Rob: Thank you.

Emily: Thanks to everyone else for attending as well.

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