MANITOBA CLEAN ENVIRONMENT COMMISSION

LAKE WINNIPEG REGULATION REVIEW

UNDER THE WATER POWER ACT

VOLUME 4

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Transcript of Proceedings
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MONDAY, MARCH 16, 2015

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APPEARANCES

CLEAN ENVIRONMENT COMMISSION
Terry Sargeant - Chairman
Edwin Yee - Commissioner
Neil Harden - Commissioner
Beverly Suek - Commissioner
Bill Bowles - Counsel to Commission
Cathy Johnson - Commission Secretary
Joyce Mueller - Administrative Assistant
Amy Kagaoan - Administrative Assistant
Phil Shantz - Advisor
George McMahon - Advisor
Bob Armstrong - Report writer

MANITOBA CONSERVATION AND WATER STEWARDSHIP
Rob Matthews
Puru Singh

MANITOBA HYDRO
Doug Bedford - Counsel
Janet Mayor - Counsel

CONSUMERS ASSOCIATION OF CANADA (Manitoba chapter)
Byron Williams - Counsel
Aimee Craft - Counsel
Gloria Desorcy

MANITOBA METIS FEDERATION
Marci Riel
Jasmine Langhan

MANITOBA WILDLANDS
Gaile Whelan Enns

PEGUIS FIRST NATION
Lloyd Stevenson

PIMICIKAMAK OKIMAWIN
Annette Luttermann
Darwin Paupanakis
Jeremiah Raining Bird
William Osborne

KEWATINOOK FISHERS
Meryl Ballard

NORWAY HOUSE FISHERMAN'S CO-OP
Keith Lenton

APPEARANCES

TATASKWEYAK CREE NATION
Sean Keating

INTERLAKE RESERVES TRIBAL COUNCIL
Cory Shefman

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MONDAY, MARCH 16, 2015

UPON COMMENCING AT 9:30 A.M.

THE CHAIRMAN: Good morning. Welcome back. Welcome to our second week in Winnipeg. We'll be here at the Fort Garry all of this week.

Today and tomorrow we will be presenting the experts engaged by the Clean Environment Commission. They will present their papers and then be available for cross-examination.

This morning we're very happy to have Dr. Harvey Thorleifson, a Manitoban who now plies his trade just a few miles to the south of us in Minneapolis. He will be presenting on isostatic rebound and the influence that it has on Lake Winnipeg.

Are there any other preliminary matters we need to deal with other than swearing Dr. Thorleifson in? Could you do that, please?

Dr. Harvey Thorleifson: Sworn.

THE CHAIRMAN: You may proceed.

DR. THORLEIFSON: Well thank you, Mr. Chairman. I'm pleased to be here this morning and I welcome any suggestions on my microphone or my manner of presentation. I'm happy to have this opportunity to talk about the influence of isostatic rebound on Lake Winnipeg. And if we're all ready to proceed, I'll begin by providing some additional information on my background, my education, my experience with Lake Winnipeg.

So starting with a very brief summary of my CV, which is included in my report. I'm presently the state geologist of Minnesota. That means that I'm the director of the Minnesota Geological Survey. The Minnesota Geological Survey happens to be a portion of the University of Minnesota. So while being the director of the geological survey and the state geologist of Minnesota, I'm a University of Minnesota professor. I was enticed to move to Minnesota, despite my desire to stay in Canada and stay in Ottawa. I had been working very happily at the Geological Survey of Canada in Ottawa from 1986 until 2003. Before that, I completed a Ph.D. at the University of Colorado, in Boulder. At the time, this was one of the principal centres of research in quarternary geology, which is the study of the ice age and effects such as the isostatic rebound that we'll be discussing on Lake Winnipeg. So I certainly was pleased to have had the opportunity to do my Ph.D. at one of the principal centres for research in this field in the world.

Prior to my time at the University of Colorado, I did a Masters Degree in Science at the University of Manitoba. Again, I was very pleased to have had that opportunity to spend time at the University of Manitoba. And prior to that, I was a student at the University of Winnipeg in the late 1970s, at which time I spent time in the geography department, the biology department, and much time in the field of student politics at the time. Before that, I completed high school in my home town of Baldur, Manitoba, where I picked up the love of the science that I'll be speaking on today.

So to expand on what I have mentioned in terms of my interest and expertise in Lake Winnipeg and related topics across the region, to summarize my perspective on Lake Winnipeg, I mentioned that I was at the University of Manitoba to do my masters degree. My masters program included a thesis on Lake Agassiz, which is the lake that filled the entire Red River Valley during the retreat of the ice age. And my work on

Lake Agassiz required me to understand how Lake Winnipeg was evolving. The way that Lake Winnipeg evolved in post Lake Agassiz time told us something about what would have happened during the time of Lake Agassiz. So while at the University of Manitoba, I needed to understand everything that could readily be understood about Lake Winnipeg because that related directly to my thesis research under the supervision of Dr. Jim Teller at the University of Manitoba.

During the time of my undergrad and masters, I also gained experience in the field of lakes by working as a student for the Freshwater Institute in the group coordinated by Dave Schindler. I worked at the experimental lakes area, which is a facility that I believe many of you will be familiar with due to the discussions on its future in recent years. So these are examples of the experience I gained on the lakes related research during the time that I lived in Winnipeg, between my time in my home town and my Ph.D. studies in Colorado.

So I needed to understand what could be understood at the time. And as I made progress in my Lake Agassiz investigations, in cooperation with Jim Teller, I did pursue the topic of how Lake Winnipeg was evolving at the time. And the customary thing for a person like me to do is to present this work at a scientific meeting, and I sought to present what could be said at the time about how Lake Winnipeg was evolving. And I did so at the national convention of the Geological Society of America. That happened to be taking place in Nevada while I was at the University of Colorado.

So what I'll summarize today is the further development of the research that I attempted to summarize in a somewhat comparable, but considerably briefer and less well-developed presentation, in the 1980s. But it is comforting, I would suggest, that the overall picture of what we understand Lake Winnipeg to be doing now is, in terms of the broader aspects of the story, is unchanged since the thinking that developed in the 1980s. In contrast, in the '60s, there was much greater uncertainty. But through the 1970s, as the picture of isostatic rebound came into focus from, for example, tide gauges on Hudson Bay, lake gauges on the Great Lakes, and global compilations, things started to come into focus in the '70s and '80s.

And so the broad story that I presented at the Geological Society of America in 1985 is unchanged in terms of the broader picture. Certainly, the details we have made tremendous progress since that time, and I will seek to summarize that progress today.

So after those phases of work in the 1980s, I was very pleased to have had the opportunity to act as a member of a team that coordinated comprehensive geological research on Lake Winnipeg with some support from Manitoba Hydro in the 1990s. I had been working for the Geological Survey of Canada in Ontario in the late 1980s, and in the early '90s, Government of Canada decided to send me home to take advantage of my familiarity and my connections in the prairie region.

And so through the '90s, I was involved in a broad array of soil and water related research across the prairie provinces, and still extending into Ontario and offshore Hudson Bay. Initially we are focusing on groundwater, for example, in southeastern Manitoba. But by being here, I became more involved in cooperative research with the Manitoba Government. And of course, I had worked as a student with the Manitoba Government a decade earlier, so our interest in going beyond the sort of broad synthesis that I had presented in the '80s, our desire to do additional work on Lake Winnipeg was motivated by our scientific interests, our desire to discover. In particular, the discussions started between myself and Erik Nielsen, who was then with the Manitoba Geological Survey. And Erik and I had a great desire to work on Lake Winnipeg, simply because that's the science that we had a grade passion for and we still have a great passion for. And so we decided to pursue discussions in 1993 to see if we could possibly do some broad geological research on Lake Winnipeg.

And the way this developed, some of you are vividly familiar and some of you will more vaguely recall that 1993 was a year of high water levels across the region. For example, in the U.S., the Mississippi famously flooded in the summer of 1993, and similarly there were high water levels in this region. And so as Erik Nielsen and I somewhat innocently brainstormed about whether we could possibly do some work on

Lake Winnipeg, we said, well, how might we arrange this support? It's not easy to get support for research in Ottawa. But we thought perhaps a discussion with Manitoba Hydro would be, could be beneficial. And we quite innocently stumbled into a situation in which there was great concern about what was happening on Lake Winnipeg, great concern about shoreline erosion.

And our discussions with Manitoba Hydro in 1993 lead to realization that Manitoba Hydro had a desire to support work. And at the same time, we recognized that the work would be of greatest use if it was funded on a broad basis. So we entered into an arrangement in 1993 and 1994 in which a small portion of the funds for the research were contributed by Manitoba Hydro. And I was very pleased to not only be working with Erik Nielsen and Gaywood Matile of the Manitoba Government, but I also worked hard to make cooperative arrangements with the people, for example, at the Bedford Institute of Oceanography in Halifax, Nova Scotia. To work on Lake Winnipeg, we really needed oceanographic equipment, and it ended up taking an entire semi-trailer full of oceanographic equipment to do the work we needed to do on Lake Winnipeg. And so this is something that had to be arranged for. And so my job was largely to be the facilitator of these cooperative arrangements, to set up the funding arrangements. And I'm pleased that things came together very nicely.

And there we were on the Coast Guard ship, the Mayo, in 1994, with a truckload of oceanographic equipment, taking an approach that was very broad in scope. Manitoba Hydro put in a small amount of support relative to the total cost, that really helped make things happen, that once we were there, we took a very, very broad approach, as broad as we possibly could. Because our desire was to ensure that the full scope of scientific activities, ranging from the rocks, to the sediments, to the water, to the biological systems on the lake would be looked at. So that was something that we pursued through the 1990s.

The results of that work are published in the peer-reviewed literature, and as I'll describe later in my presentation, work that was started back in the 1990s continues to be worked on and papers are still appearing in the peer-reviewed literature and elsewhere, and I'll summarize that progress.

And something that's relevant to my presentation today is that in 1998, I was asked to write a plain language summary of the influence of isostatic rebound on Lake Winnipeg. And when I was asked to prepare something for these deliberations, I decided it would be most helpful for me to simply repeat what I wrote in 1998, to save trouble amongst people who had recently read what I wrote back then, if they know that I'm repeating verbatim what I said then, that helps them know how carefully to read what I have written now. And also I wanted to draw attention to the fact that, aside from tremendous progress on certain details, the broader aspects of our interpretations have not particularly changed since the late 1990s. So much of what I will present in my powerpoint presentation this morning comes directly from that document that I initially prepared in 1998, and that I repeated in my submission to the Commission.

So in this bullet, I reiterate that point, that my presentation today is largely based on my 1998 summary.

And in addition to the past activity

that I have summarized so far in my presentation, I want to emphasize that I continue to have a role in related research across the region. Minnesota, of course, is not far away, and things that are going on in Minnesota relate to things that are happening in Manitoba from a geological point of view. I'm still working in cooperation, for example, with Manitoba Geological Survey people, both active and retired. So I'm still very much in touch and involved with related research across the region.

So to broadly summarize what I'll seek to present over the next hour or so, during the ice age, Canada was covered by a continental ice sheet. And perhaps the best way to visualize this is that Canada was covered by an ice sheet similar to those that presently cover Greenland and Antarctica. So a sheet of ice shaped a bit like a pancake. If you picture a frying pan on your stove and you picture yourself pouring pancake batter into that frying pan, as you pour the batter, the pancake grows out in all directions. So if you now picture the continent of North America, you picture Hudson Bay, if you picture yourself looming above North America with a picture of pancake batter, and you picture yourself pouring that pancake batter into Hudson Bay, and then picture a pancake growing out in all directions, you have a helpful visualization, I would suggest, of the growth of the continental ice sheet. If you picture that pancake growing north from Hudson Bay into the Arctic Islands, if you picture it growing out towards Baffin Island, out towards Labrador, south to the Great Lakes, southwest across the Prairie Provinces, you picture that pancake growing out from Hudson Bay, that's more or less what the continental ice sheet looked like. We call it the Laurentide ice sheet. The geometry was governed by where snowfall was concentrated, where the melting was occurring, where icebergs were forming. But if you have paused to visualize that pancake growing out from Hudson Bay, that's a good picture of what the Laurentide ice sheet looked like.

And the ice sheet was about three or four kilometres thick. And when you consider the thousands of kilometres wide it was, that's really very thin, but it was a very significant load on the continent. And as I say in this next bullet, removal of the ice sheet resulted in what we called isostatic rebound of the land.

Isostatic is a word that we use for processes comparable to buoyancy. The surface of the earth floats on the interior of the earth. So, for example, when we are talking about trends in sea level, we tend to talk about isostatic components and eustatic components. That's our internal jargon. And I will apologize when jargon gets to be mystifying. But eustatic, for example, refers to global sea level. Isostatic relates to those buoyancy effects in which land is rising and falling in relation to the changes in the load. So isostatic rebound simply refers to the land rising as a result of removal of that weight. So this uplift, which is ongoing, is greatest in and around Hudson Bay. And the reason for that is because the ice was thickest in Hudson Bay.

I have offered for you this visualization of a pancake growing in all directions from Hudson Bay. And if you think back to your stove and that pancake that you made by pouring batter, when you pour batter in the centre of your frying pan, your pancake, of course, is thickest in the middle. So the Laurentide ice sheet that covered Canada and the Northern U.S.

was centred on Hudson Bay. It was thickest over Hudson Bay. So that means the load was greatest over Hudson Bay. So if the load was greatest over Hudson Bay, that means that the depression was greatest over Hudson Bay, that means that after the continental ice sheet was removed, the uplift is proceeding at the greatest rate in Hudson Bay.

But because the ice sheet was thinner in all directions out from Hudson Bay, because the load was less, because the depression was less, that means that the rate of uplift diminishes in all directions from Hudson Bay. So while the land surrounding Hudson Bay is rising at about a metre per century at present, the rate diminishes inland.

So this means that Lake Winnipeg, which has its outlet in the north, has a north end that is rising more rapidly than the rest of the basin. The north end of Lake Winnipeg is rising more rapidly because it's closer to Hudson Bay, it's closer to the centre of the depression, therefore, closer to the centre of the uplift.

So because the outlet of Lake Winnipeg is at the north end, and because that outlet is rising more rapidly than the rest of the basin, that means the entire Lake Winnipeg basin is being tilted. And as water continues to overflow into the Nelson River, as that tilting action applies to Lake Winnipeg, that means that Lake Winnipeg is expanding. The lake is gradually growing larger as the basin is tilted by that differential isostatic rebound.

So because the natural state of Lake Winnipeg is to steadily expand, because those rising water levels on a geological time scale are being imposed often to the landscape surrounding, this means that Lake Winnipeg's natural state is to expand through the mechanism of shoreline erosion. And based on our inferences of the ongoing tilting of the lake basin, based on the research that I'll describe on expansion of the lake, based on observations of the rate of shoreline recession prior to, for example, Lake Winnipeg Regulation, we see that the ongoing expansion of Lake Winnipeg through shoreline erosion is primarily natural, the natural behaviour of Lake Winnipeg, in particular in the south basin is to pervasively and persistently expand.

So I will now set out to illustrate

those points in greater detail, and I'll do so in a way that seeks to thoroughly review the fundamental aspects of this story. And so to begin with the fundamentals and to put things into context, let's start by looking at interpretation of the underlying rocks. Lake Winnipeg lies at the interface between granites and related rocks to the east and sedimentary rocks such as limestones to the west. The granites formed 2 to 3 billion years ago. And I'll pause and stress that's billions with a B. So that's a long time from any perspective. The limestones are much younger, only a half billion years old, 500 million years old in round figures. And the limestones formed when central North America was covered by a shallow tropical sea in which debris such as shells and corals accumulated, including the fossils that we see in tyndall stone. And I'm scanning the room to see if we have any tyndall stone present. We probably do elsewhere in the building. You all know throughout Winnipeg we see magnificent fossils best known, for example, at the Legislative Buildings, the Art Gallery, buildings throughout Winnipeg are made from tyndall stone from the Garson quarry, and we see distinctive fossils in those stones.

I am pausing on this point because we all struggle to visualize geological time and how these things all fit together. Tyndall stone formed in an ancient sea a half billion years ago, whereas Lake Agassiz is much, much younger, only 10,000 years in round figures. So tyndall stone is a half billion years old, Lake Agassiz is only 10,000 years old, vastly younger.

So to summarize this brief discussion of the rocks, including the rocks that we get tyndall stone from, the processes that formed these rocks no longer play a role in the evolution of Lake Winnipeg. The processes that gave us granites, the processes that gave us limestones are no longer active. That's an earlier phase.

In contrast, we really are living in the ice age. The ice age is today. The effects of the ice age are all around us. Tyndall stone, that's way back. Lake Agassiz, we're still living with the effects of the ice age. And in a way that's the theme of everything I will be saying this morning.

Shoreline erosion on Lake Winnipeg is directly linked to a very large degree to the after effects of the ice age, and in a way now that I've said after effects, it's almost better to recognize that we presently live in the ice age. Greenland is still glaciated. Antarctica is still glaciated. We live in a time of great continental ice sheets. We live in a time in which these ice sheets have been advancing or retreating readily. And so what's happening all around us is really the sort of thing that is part of the ice age as a whole.

So it's geologically very recent in terms of the time since the glaciation of Canada, and as I have just emphasized, it's something that we still live with today. The ice age is also known as the pleistocene. I mentioned, I'll apologize if I use too much jargon, but if you hear me or someone say the pleistocene, that's the ice age.

So during the peak of the most recent glacial cycle between 10,000 and 20,000 years ago, Canada was covered by a glacier similar to the continental ice sheets that presently cover Greenland and Antarctica. I have already stressed this point, so I am making it again. Ice flow radiated from Hudson Bay, you have heard this from me already multiple times, I'm trying to place emphasis on this so we all visualize it similarly. And this ice flow scoured the Lake Winnipeg basin as we know it.

So with the retreat of the continental ice sheet during the end of the last glacial cycle, during what I'll now call the current ice age, Lake Agassiz formed. As the continental ice sheet was reduced in size by climatic change at the end of ice age, the most recent cycle of the ice age, the land that slopes toward Hudson Bay in the Red River Valley filled with water due to the presence of the ice barrier to the north. The continental ice sheet extended south of here all the way to Iowa. So when the continental ice sheet margin was in southern Minnesota, melt water from the glacier was happily draining to the Mississippi River. But as soon as the margin of the ice sheet retreated north from the continental drainage divide located near where North Dakota, South Dakota and Minnesota meet, the land from there northward slopes to the north. We know that the land slopes to the north because the Red River flows from Fargo to Winnipeg and onto Lake Winnipeg. And so that land that slopes northward, therefore, driving the flow of the Red River, filled with water because the continental ice sheet was there in a gradually diminishing form to the north. So Lake Agassiz simply represented the filling of the Red River Valley up to a level determined by the drainage divide, which allowed Lake Agassiz to spill to the Mississippi River to the south. So Lake Agassiz filled the Red River Valley, and this was -- the lake was in existence in an ever-evolving form between about 11,000 radiocarbon years ago and about 8,000 radiocarbon years ago.

It was in Lake Agassiz that the clay soils of the Winnipeg region were deposited. When the glacier finally was split into two remnants that both soon melted by the formation of icebergs in Hudson Bay, that means the splitting of the ice sheet happened in Hudson Bay by the formation of icebergs Lake Agassiz drained. So with the drainage of Lake Agassiz, that lead to the initial inception of Lake Winnipeg and the remaining aspects of the landscape.

So now to focus on isostatic rebound, and I have emphasized that the word isostatic essentially refers to buoyancy. Rebound is the uplift of the land related to that buoyancy related action. And I have touched on this already but I'll reiterate it. The continental ice sheet was about four kilometres thick over Hudson Bay, the earth's surface of the earth basically floats on the interior of the earth, so accumulation of this ice mass depressed the surface of the earth by about a kilometre. Why a kilometre? That's a function of the ratio of the density of ice to the density of the interior of the earth.

As the glacier began to wane due to a shift from a positive to a negative balance between snow accumulation and loss due to melting, and formation of icebergs, its mass was reduced and eventually removed. The continental ice sheet melted and floated away into the north Atlantic as icebergs. Removal of this much weight is like taking a load out of a boat, and the surface of the earth rose. Much of the uplift took place under the glacier. In other words, as soon as the ice sheets started to thin, the mass was being reduced. And as soon as the mass was being reduced, the land began to rise. So uplift was taking place long before the glacier disappeared, simply because the load was being reduced as soon as the ice sheet began to thin. And as the thinning of the ice sheet accelerated, the uplift would have accelerated. And shortly after the withdrawal of the ice sheet, the uplift rates were quite rapid. And then when the ice sheet was gone, the rates began to diminish.

So the fact that Hudson Bay and the surrounding region rose after disappearance of the ice sheet was first recognized in the late 1800s. This was first recognized, for example, because there are seashells, marine shells well inland from Hudson Bay, so we can see that the sea water previously extended far inland. Also Lake Agassiz shorelines would have been horizontal when they formed, but as soon as people began to map those shorelines in the 1880s and 1890s, we saw that their elevation rises toward the northeast. So we recognized early in studies of the ice age in the late 1800s that the land had risen. But initially we had little idea whether that uplift was continuing, and that remained uncertain, as I mentioned, really into the 1960s and 1970s.

So I summarize with this bullet point, that several observations indicate that the 8,000 year period since deglaciation, in other words the retreat of the ice sheet, has not been enough time for the earth to adjust to removal of the glacier.

So gradually we began to recognize that not only had uplift occurred after the end of the ice sheet, we came to realize it was still ongoing at a very significance pace. So around Hudson Bay, there are many marine shorelines that have been left behind by retreat of the bay due to uplift. I have already mentioned this. But in the early investigations, there was no obvious way to determine how old the shorelines were, but this dramatically changed with the invention of radiocarbon dating, carbon 14 dating, which allowed us, starting in the 1950s, to analyze for example these shells from shorelines around Hudson Bay and we were able to see the age of successive shorelines.

So here I summarize by saying the age of these shorelines can be determined by radiocarbon dating of shells found in the gravels of these fossil beaches and in other deposits.

The highest shoreline around Hudson Bay dates to about 8,000 years. That was the basis for what I said earlier, that the breakup of the ice sheet, we clarified to be 8,000 years. And that had already been known to some degree from other inferences such as the retreat of the waterfall in Minneapolis. This was one of the basis with which some indication of the duration of post glacial time was determined in the late 1800s.

So we recognize that the highest shoreline around Hudson Bay was about 8,000 years old, but we recognize that shorelines closer to the bay are as young as only about a thousand years or so. So with the availability of radiocarbon dating in the 1950s, we recognized that the uplift to Hudson Bay is ongoing at least close to the present, and that the uplift was something that was sustained throughout post glacial time and was continuing to the present, at least close to the present.

So this, as this bullet says, this indicates that retreat of the bay has continued in recent centuries.

The fact that the uplift continues today is indicated by observations such as results from the Churchill tide gauge, where high quality data collected since 1940 indicates that sea level at that site is retreating at a rate of about 0.7 metre per century. So decade by decade, our understanding of what is driving the evolution of Lake Winnipeg came into focus, first with radiocarbon dating of marine shorelines in the '50s, and then through the '60s and '70s, sources of information such as the Churchill tide gauge clarified that not only was uplift happening in recent centuries, it's continuing today.

So that Churchill tide gauge trend was first recognized to be about 0.7 metre per century, allowing for global sea level rise of about 20 centimetres per century in recent decades, that's the inference that has been derived over recent decades from a synthesis of sea level trends around the world. This allows the uplift rate to be rounded off to about a metre per century. So if sea level falls at Churchill at a rate of 0.7 metre per century, while global sea level is rising at 20 centimetres per century, you can see that without that global component, sea level would have fallen about .9 metres per century, and for the sake of this discussion I'll just round that off to about a metre per century.

The pattern of subtle trends and the

strength of gravity across Canada supports these conclusions and indicates, along with information from the Great Lakes, that the general trend in uplift is for rates to diminish inland from Hudson Bay in all directions.

So this is something I stressed in my introduction, and now I'm describing how we gradually assembled that knowledge over the past half century as information such as the radiocarbon dated shorelines became available, the Churchill tide gauge, Great Lakes gauges, and other measurements, we gradually came to realize that uplift is not only ongoing at Hudson Bay, it's also ongoing inland all the way to Southern Manitoba, and it's a pattern that diminishes inland from Hudson Bay.

So differential uplift simply refers to this notion that the rate of uplift, the rate of isostatic rebound diminishes inland from Hudson Bay. So differential just means a lower rate farther inland. So because that rate diminishes inland, this is why we get a tilting action, higher uplift to the north, lower uplift to the south causes the landscape to be tilted.

And again, as I have mentioned, we

know that the Lake Winnipeg region was tilted after the retreat of Lake Agassiz because the shorelines of Lake Agassiz, which would have been horizontal at the times of the formation, now rise in elevation toward the northeast. Hence for at least much of its history, at least much of its history the Lake Winnipeg basin has been rising and the north end has been rising more rapidly than the south end.

So now I would like to very carefully go through how best to infer how the lake is operating, what is the link between isostatic rebound and the way the lake works? And to do so I would now like to focus on hydrological budgets. And my introductory bullet point states, a clear discussion of the influence of tilting on a large lake requires a review of the natural mechanisms that control lake level.

An open container of water, such as a lake, undergoes fluctuations in its level as water is gained and lost. That's exactly the same as the glass of water in front of you, or any other container, all of the principles that apply to your glass of water apply here. If you reach for the pitcher and pour water in your glass, the water level rises. And I think it's important for us to think like this, because if I get into the details of visualizing how Lake Winnipeg works, I think it's a challenging thing for us all to visualize. And so for me, for us all, it's important for us to visualize these things whether we think about a pan of water or a glass of water, or if you picture lifting up one end of your bathtub at home, that's the kind of thing that we need to visualize. So I'll try to use illustrations like that as we go through these bullet points.

So an open container of water, again, such as a lake, undergoes fluctuations in its level as water is gained and lost. The volume of a lake does not determine lake level, volume is a result of lake level. And I'm dwelling on this point because some of us feel that a lake is a fixed volume of water. Some of us hear that Lake Winnipeg is a remnant of Lake Agassiz. And that makes it sound like Lake Winnipeg is a body of water that's there, that's fixed, the volume of water. And something I'll dwell on is I think it's better to visualize Lake Winnipeg as being water in motion. As we all know to a degree, the rivers flow into the lake, Nelson River flows out of the lake, and it's better to think of lake level as being related to that flow.

Sometimes I think of your bank account as a good way to think about this. You could think about your bank account as a fixed amount of money, and your money sits there in the bank account never changing, and it has a bank balance that doesn't change. Well, I think for most of us, it doesn't work that way. And our duty is to ensure that the deposits we make to our bank account are balanced with the cheques that we write. If you write too many cheques relative to your paycheque, you're in trouble, your cheques bounce. On the other hand, if you make way more money than you are spending, then you are denying yourself the benefits of what you could be spending out of your bank account.

And so that is the kind of picture that we all need to help us understand lakes. The lake, such as Lake Winnipeg, is like your bank account. You get deposits from the inflow, you get expenditures from the outflow. And the level of the lake is related to the balance of inflow and outflow, a very dynamic balance. So if you have difficulty visualizing Lake Winnipeg and that dynamic relationship between lake level and the inflows and the outflows, then think about your bank account. Just remember if you keep writing cheques with no income, you are in big trouble. So I think it's a good way to think about these things.

So input of water to a lake occurs in the form of river inflow, direct precipitation and groundwater discharge from underwater springs. Like your bank account, you get your paycheque, you get your gifts, you get your income tax refund and all in the same way the lake has its inputs of water. Losses from your bank account are largely cheques that you write. Losses from the lake include river outflow, evaporation, and a trivial amount of groundwater recharge as seepage into the lake bottom.

So we are thinking of the lake as having a budget. If inflow is greater than losses due to evaporation and groundwater recharge, the lake has a water surplus, and excess water is evacuated from the outflow at the outlets.

If evaporation and groundwater recharge together exceed inflow, the lake has a water deficit and no outflow will occur. Hence, the water budget of a lake is dictated chiefly by climate, with secondary effects related to groundwater. Climate controls the inflows and the outflows.

In the case of a lake with no outflow, a closed basin with a negative water budget, lake level is purely a result of climate. As climate changes, the water level rises or falls directly linked to those climatic effects. Examples of closed lakes are Great Salt Lake in Utah and Devils Lake in North Dakota.

To the east of Manitoba, we don't have closed depressions because the climate is simply too moist to have closed depressions. To the west it's possible to have a negative water budget, and we don't have to go far to where we see closed depressions. Devils Lake we know has been a very challenging issue because there's no natural outlet to balance the fluctuations related to climate. And so that's an example of a closed depression.

In contrast at present, however, Lake Winnipeg has a large water surplus. Water primarily derived from the Winnipeg and

Saskatchewan Rivers is evacuated from by the Nelson River at a rate of about 60 cubic kilometres per year, a large flux compared to the small volumes stored in the lake, about 300 cubic kilometres.

Now, this is something I have said to help counter our tendency to think of the lake as a fixed volume of water. And just as I have stressed, illustrations such as bank accounts, here I'm saying the lake is really water in motion. There's only 300 cubic kilometres in the lake, and every year 60 cubic kilometres enter the lake and, therefore, 60 cubic kilometres exit the lake. So the level of the lake is a dynamic thing related to that flow through the lake. The flow through the lake is almost as important as the volume in the lake. So we want to think about the lake as being a very dynamic system of water flowing through the lake.

Lake Winnipeg, therefore, is governed by processes related to a positive water budget. Secondary short-term effects on lake level are caused by wind setup and to a lesser extent barometric pressure.

Now, I think this afternoon we'll hear

more about climate fluctuations and my thinking is largely about, I'll also largely be thinking about mean lake level and mean river flow, and I'll be thinking about how the water level is fixed at the outlet in relation to mean flow. And I think, Greg, this afternoon you'll emphasize more the way things fluctuate, but I'll work hard to clarify that when I need to, I think.

So we have fluctuations due to wind, fluctuations due to barometric pressure and, of course, the dry years and the wet years that cause the rise and fall of the lake, which is now subsequently influenced by regulation.

So lake level controls, in the case of an outflowing lake with a positive water budget, lake level is controlled by a combination of climate and outlet geometry. In other words, what dictates what the lake level is. Well, that's a function of what the climate is currently doing, whether it's a wet year or dry year, but how that level of flow in a wet year and a lesser level of flow in a dry year, how that translates into actual lake level is a function of the geometry of the outlet. Whether we're talking about Lake Winnipeg in its natural state or in its modified state, outlet geometry is what translates the climate into an actual lake level. Climate over the drainage basin determines how much excess water there is to be evacuated. That's that 60 cubic kilometres per year number that I mentioned there. So that's what we need to evacuate through the outlet.

Lake level has to reach at least the elevation of the lowest point on the topographic barrier around the lake, and that lowest point is the bed of the outlet stream.

Now, lake level has to reach at least that level to begin evacuating the excess. Above this level, an additional depth is required for outflow to be adequate to evacuate the surplus water. So a trickle of water over the bed of the stream isn't enough to get rid of that excess, we need an adequate depth to evacuate the surplus.

Now, how much additional depth depends upon the geometry of the outlet channel. So there's no direct relationship between the amount of flow and the additional depth. A narrow outlet channel requires more depth than a broad outflow to achieve a given flow rate. This is called the stage, or water level, versus discharge, which is the volumetric rate of flow, relationship for the outlet.

Lake Winnipeg has, at least in recent millennia, been an outflowing lake. The mean lake level, therefore, is constant at the outlet relative to mean climate at the time given that a certain depth is required to evacuate excess water. So by this, I mean that thinking of the average climate of the time, thinking of the average flow of the Nelson River where it originates from Lake Winnipeg, lake level is fixed relative to average climate and average lake level.

So if lake level is fixed at the outlet, relative to average climate and average lake level, that means that if the basin is being tilted -- I'll just read the bullet: Tilting of a lake basin causes mean lake level to pivot at the outlet. So our lake level is fixed by that hydrological balance at the outlet on Lake Winnipeg, the outlet is at the north end, so the level at the outlet is governed by climate. If we take that lake basin, which you could visualize as a pan of water, and we lift one end of that pan of water, if lake level is fixed at the outlet, then it has to respond to that tilting by a change in lake level throughout that pan of water. And if lake level is fixed at the outlet, that means it expands everywhere.

So because the outlet of Lake Winnipeg is in the north, uplift of the north end of the lake progressing at a rate more rapidly than the basin to the south has meant lake level rise over the entire basin with the rate increasing southward.

And at this point, I'm yearning for a pizza pan or something like that to demonstrate this. But I hope that if you think of a pan of water in front of you and you visualize, for example, a cake pan, if you tilt that pan you can visualize that the water is going to be driven to the other end of the pan. But if you have water flowing into your pan and that water is flowing out of the pan at this end, in other words you're holding that cake pan under the tap in your kitchen sink, you've got that cake pan and you've got a notch at one end of the cake pan, you hold that cake pan under your tap in the kitchen sink and you watch the water accumulate in the pan until the water flows out of the notch. Then you tilt the pan a little bit, but you still have the kitchen sink tap flowing, so as soon as you tilt it, the water level has to rise until it trickles out that notch again.

So you can do this experiment in your kitchen if you have a cake pan -- well, get a disposable aluminum pan so no one is in trouble for ruining a cake pan. Cut that notch, turn on the kitchen sink faucet, and you can do this experiment. Tilt the pan, you'll see the water level rises, because the water flowing in, the water flows out your notch, but when you tilt the pan, water level rises at the far end. That's what Lake Winnipeg is doing.

So the importance of outlet position relative to the pattern of uplift, thinking of that demonstration we just did in which we are visualizing a cake pan in your kitchen, or whether we think of Lake Winnipeg, a key point is that the lake is expanding because the outlet is in the north and the uplift rate is higher in the north. But not all lakes are rising, not all lakes are expanding, because how the lake behaves depends upon where the outlet is located.

An example is Lake Nipigon, which is

the largest lake within Ontario. It has its outlet in the south, so it's contracting. The lake basin is rising relative to the outlet. And so you can do that experiment in your kitchen. Raise the pan at the end that's far away from your notch, where the water is flowing, and you find that the water level falls. Lake Superior has its outlet in the middle relative to the pattern of uplift, so it's rising in the south, falling in the north.

In Manitoba, Lake Winnipegosis is perhaps a good example of a lake with its outlet in the south. So the basin is rising relative to the outlet. So if you look around Lake Winnipegosis, and you can see this in Google Earth, you see shorelines inland because Lake Winnipegosis is shrinking as the basin rises relative to the outlet. So Lake Winnipeg is expanding because the outlet happens to be in the north.

So now let us consider what we know from Lake Winnipeg, what did we learn in the studies of Lake Winnipeg in the 1990s that clarify and confirm or otherwise these inferences? For example, we can look at Hudson Bay sea level, we can look at Great Lakes lake gauges, we can infer that the lake is being tilted. Can we confirm this in the lake?

Well, we worked very hard to do this through the 1990s. So in this bullet point, I say we have collected cores from the bottom sediments of Lake Winnipeg. This is why we needed the Coast Guard ship, the Mayo, this is why we needed a semi-trailer full of oceanographic equipment from Nova Scotia, in order to collect those cores, as well as the surveys we needed to support that work. We have collected cores from the bottom sediments of Lake Winnipeg that allow us to sample the entire sequence of sediments deposited since Lake Agassiz, including the first layer of Lake Winnipeg sediments that buried the older Lake Agassiz deposits.

So when we take that pipe and drive it into the floor of Lake Winnipeg, when we sample the layers of sediments, we see the entire Lake Winnipeg sediment sequence, and then we see Lake Agassiz sediments below. We have obtained radiocarbon ages from this procedure that indicate that much of the south basin of Lake Winnipeg was dry land 4,000 years ago. In other words, we look at the sediments we recover from the bottom of the lake, and first we see soft muds, and then deeper down we actually see a prairie soil in our sediments recovered from what is now the middle of the south basin.

In Netley Marsh -- and we found that prairie soil under Lake Winnipeg, and we radiocarbon dated that prairie soil offshore from Gimli to about 4,000 years. Similar cores in Netley Marsh indicate that the main portion of Netley Marsh was only inundated 1,500 years ago. So with this sort of analysis we began to actually measure what turns out to be confirmation of the expansion of Lake Winnipeg.

We also have radiocarbon dates from rooted tree stumps just below lake level that suggest gradual rise in lake level over recent centuries. So you can see that the cores offshore of Gimli were indicating the progression of the lake expansion a few thousand years ago. Netley Marsh is giving us data from about a thousand years ago. The roots in the shore face are giving us data from recent centuries. In other words, this is a story that we have assembled from many different perspectives in order to ensure that everything fits together and that there weren't unanticipated phenomena going on.

So these observations indicate that gradual expansion of Lake Winnipeg in response to tilting has been continuous throughout post Lake Agassiz time.

So while we place our emphasis on uplift, based on what we infer to be the dominant control, at least in the south four other processes should be mentioned as secondary factors affecting Lake Winnipeg lake level over the long-term, by the long-term, I mean over thousands of years. In order to look at this research in a broad perspective and to ensure that our interpretation of uplift and shoreline erosion is appropriate, we need to look at other factors going on, that includes climate, river diversions, basin merging and outlet down cutting. So now I want to consider to what extent these phenomena are a factor.

With respect to climate on a long-term perspective, running over thousands of years, our radiocarbon dating of basal Lake Winnipeg sediments in cores indicate that, unlike the gradual inundation of the rest of the lake, the inundation of the central south basin was not gradual. It seems to have occurred rapidly as basal ages across this area cluster around 4,000 years. And this was not entirely unanticipated, because we know from pollen records that span the full 10,000 years or so of post glacial time, we know that the climate in the region was warmer and dryer, and grasslands were more extensive earlier in post glacial time. But around 4,000 years ago, there was a shift to moister and cooler climate, grasslands became less extensive, spruce and pine became more extensive. And so this was well established before we looked at the lake. And therefore, it was interesting, but not entirely surprising that we saw that the expansion of the lake in response to uplift was supplemented by that shift to cooler, moister climate about 4,000 years ago.

So to summarize, this was the time when climate changed rather abruptly -- now, abruptly, that means it took place over a few centuries -- when I say abrupt I am speaking as a geologist -- over a few centuries there was a shift to that cooler and moister climate, probably raising lake level a few metres.

So this is something that the lake would have been adjusting to as well, that shift to moister conditions.

So climate of the Lake Winnipeg region has been relatively stable in the past 4,000 years. Again, I'm speaking as a geologist. You'll hear more from Greg this afternoon about fluctuations such as 1930s drought and recent moist climate, but from a longer-term perspective, the shift to moister, cooler climate 4,000 years ago that caused the retreat of grasslands is something that was followed by relatively stable climate in the late post glacial time.

So the impact of this climate change would have been applied rapidly with control of lake level evolution to their present day returning to uplift dominance.

Now, another significant factor in the evolution of Lake Winnipeg are river diversions. Another factor in Lake Winnipeg lake level history was diversion of the Saskatchewan River, which formally bypassed Lake Winnipeg in a channel now occupied by the Minago River. Between 4,000 and 5,000 years ago, uplift caused diversion of the Saskatchewan River to Lake Winnipeg. And the way this happened was, just as Lake Winnipeg has been expanding in response to uplift, Cedar Lake was responding in response to uplift, And eventually the expansion of the lake caused a new route to be found. And so the Saskatchewan River switched from bypassing Lake Winnipeg to entering Lake Winnipeg. So thinking back to our discussion about hydrological budgets, I emphasized how thinking of your bank account was a good way to think about this. This was like suddenly having your salary increased. If your salary increases, you can spend more. And so thinking of the water budget for Lake Winnipeg that governs the level of the lake at its outflow inheriting the Saskatchewan River significantly increased the inflows to the lake. So this would have raised lake level on a one-time basis by about a half metre.

So on top of that moister climate, we also had the switch of the Saskatchewan River into the lake.

We also had a number of -- Lake Winnipeg functioning as multiple lakes, and through post glacial times, those multiple lakes began to merge. And so I will start this point by saying at present Playgreen Lake and Lake Winnipeg are almost functioning as one lake.

Strong northward currents typically flow through Warren Landing in what could almost be considered a narrows rather than a river, feeding the Nelson River to the north. So by this I'm stressing that the level of Playgreen Lake very much influences the rate of flow out of Lake Winnipeg. And so Playgreen Lake and Lake Winnipeg, in pre regulation time and in post regulation time, very much influence each other. And to illustrate this point more, when strong north winds blow, however, flow at Warren Landing, for example, can be to the south.

Now, this wasn't the case earlier because for a few millennia after Lake Agassiz, what is now Lake Winnipeg was multiple lakes, three or more lakes, a south basin lake draining through a river and a narrows to a north basin lake, which in turn drained to a completely separate Playgreen Lake.

All of these lakes expanded in response to tilting, and eventually the north basin and south basin lakes merged. Relocation of the outlet for the south basin lake to a point farther north where uplift is more rapid would have accelerated lake level rise in the south. And more recently, perhaps about 2000 years ago, Playgreen Lake would have begun to merge with Lake Winnipeg, again increasing the rate of lake level rise and lake expansion in the south basin, once again renewing the otherwise gradually diminishing rate of rise.

So in the past few thousand years, first there was moister climate, then there was the inflow of Saskatchewan River, and then there was the gradual beginning of the merging of Playgreen Lake and Lake Winnipeg that continues at present. And this resulted in the Jenpeg area, Whiskey Jack more specifically, becoming the outlet of Lake Winnipeg rather than the level being dictated at Warren Landing. So a number of factors are causing a supplement to the expansion of the lake.

Now, one final consideration that we can largely dismiss, outlet down-cutting, we're trying to be thorough here thinking of how has climate changed, how have river diversions changed. Outlet down-cutting is a factor that seems not to be a significant control on the history of Lake Winnipeg. In contrast, whereas this was the dominant factor controlling the early history of Lake Superior, the outlet of Lake Winnipeg at Warren Landing is shallow and broad and would have been rapidly eroded to the resistant bedrock.

Therefore, while this could have been a compensating factor offsetting the rise due to uplift, it seems not to have played a role.

So now we have talked about the control, what controls lake level? We have thought carefully about the multiple factors. We have thought about climate, we have thought about basin merging, we have thought about down-cutting. And we're saying that the dominant control on Lake Winnipeg, from a geological point of view, has been uplift. So let's now focus on the more detailed considerations of that pattern of uplift, and thus how isostatic rebound is affecting Lake Winnipeg.

This bullet is derived from the writing I did in 1998. And what I said at the time was that maps showing the pattern of present uplift on the world in continental scales may be seen, and I provided examples of the time, at the time. And my point was to emphasize that the research that was going on through the '80s and '90s made rapid progress. And global syntheses were made based on sea level trends and other observations such as lake gauges in the Great Lakes to begin putting together a more quantitative picture for the pattern of uplift.

So these general models that began to be synthesized in the 1970s and 1980s, general models such as these based to varying degrees on continent wide syntheses of radiocarbon dated marine shorelines, tide gauge trends, lake gauge trends and gravity, gave us a rough estimate for uplift rates of 0.4 metre per century at the north end and 0.2 metre per century at the south end of Lake Winnipeg.

So while we were making our inferences directly from cores in Lake Winnipeg, or tree stumps in the shore face, we tried to come at this topic from multiple directions to use one observation as a check for the other. We came to be able to use global syntheses to infer what the apparent rate of tilting was.

And so what came available in the 1990s was the inference that the tilting of the lake is causing a 20 centimetre per century rise in the south. And so later in my presentation, I'll go through more recent research which is suggesting that the rate might actually be higher, possibly 40 centimetres per century. But I'll go through now, the way I wrote this largely in 1998, in terms of how we reconcile our observations on Lake Winnipeg and confirm for multiple perspectives our understanding of what's happening on Lake Winnipeg in terms of what's driving its natural evolution.

So to summarize at this stage, the difference between these two values implies a 20 centimetre per century rise in lake level at the south level of Lake Winnipeg.

This prediction can be tested by comparison to available data from Lake Winnipeg. Offshore from Gimli, at our site 122, the pre Lake Winnipeg surface lies under 10 metres of water and four metres of sediment. We have dated the initiation of Lake Winnipeg sedimentation at this site, as I mentioned, at about 4,000 years. A rise of the lake to its present level over the past 4,000 years implies a rate averaging 35 centimetres per century. So that's the 10 metres of water and four metres of sediment adding up to 1,400 centimetres of lake level rise over 4,000 years or 40 centuries. You can do the arithmetic yourself, 1,400 centimetres divided by 40 centuries implies a rise of about 35 centimetres per century. This would be an average of higher rates earlier in the period in question, because uplift is gradually diminishing in post glacial time, and lower rates at present, perhaps comparable to the current estimate of 20 centimetres per century. So it's a reasonably good fit, a few tens of centimetres per century inferred by our cores and independently implied by uplift syntheses.

Now, in the 1970s during the preparation for regulation, a very important study was done. We refer to this as the Penner and Swedlo study, which is best known, I think it's fair to say, for a measurement of pre regulation shoreline recession rates. A synthesis of those recession rates appears in the appendix of the Lake Winnipeg shoreline management handbook.

And also in that report, Penner and Swedlo reported a 40 centimetre thick peat bed found three metres below lake level near Elk

Island, which was radiocarbon dated at 1,060 years for the upper part of the bed and 1,660 years for the lower part of the bed. Interpolating between the upper date and present lake level gives an estimate of 28 centimetres per century, in other words, 300 centimetres in 10.6 centuries for lake level rise over the past millennium.

And so it's a comforting confirmation yet again that this general interpretation of how uplift is causing expansion of Lake Winnipeg is fitting together from many perspectives.

Also at the time I wrote work by Dr. Erik Nielsen of the Manitoba Geological Services Branch on the radiocarbon age of drowned stumps in the Lake Winnipeg shore face also indicates a submergence rate of about 20 centimetres per century over the past 300 years.

So available data at the time, and this continues to be the case, are strongly supportive of the lake level rise predicted by uplift models. So no matter what you assume to be your observation versus your inference, whether you begin with our observations in the lake, whether you look at rates of shoreline recession, whether you look at gravity first, things are fitting together for multiple perspectives.

So even without this sort of data, the experienced eye can quickly see that water levels are rising on Lake Winnipeg. So here I'm trying to come at this topic yet again from as many different perspectives as we possibly can. And this is something that geologists can say with more confidence as research continues. For example, geologists now agree that barrier islands are a sign of water level rise. The sandy beach that separates the south end of the lake from Netley Marsh is a barrier island. Other good examples can be seen on Lake Manitoba, the East Coast of the U.S., Duluth, Hamilton, Ontario, northwestern Europe. In other words, we see where water levels are rising on a geological time scale, where sediments and gradients are favourable, we see barrier islands form.

The geological model for how barrier islands work is for there to be erosion on the basin side and accretion on the lagoon side. In other words, the natural behaviour for a barrier island is for it to migrate landward like a conveyor belt.

One can also recognize water level

rise on a geological time scale on Lake Winnipeg in the form of drowned valleys, also known as estuaries such as lower Netley Creek and lower Icelandic River. So things are fitting together from many different perspectives.

So now even if Hudson Bay is still being uplifted, and even if the Great Lakes are still being tilted, and even if there's evidence for Lake Winnipeg having expanded in recent millennia, centuries and even decades, this does not prove that Lake Winnipeg is presently being tilted. So we need to obtain that confirmation from additional observations. It's possible that complexities in the uplift pattern could have formed in recent time.

Lake gauge data, however, have provided that indication. So in order to confirm present day uplift within Lake Winnipeg, the lake gauge data are an example of how we now confirm that the uplift is indeed ongoing.

Now, in the case of this example, this takes the form of a gradual increase in the difference between southern gauges and northern gauges over several decades. So on top of all those other observations, we confirm that the uplift is indeed happening today. And as I'll mention, this has now been confirmed by GPS and gravity. I'll mention that in greater detail.

So this quote from my 1998 writing talked about the initiation of that research that has been published since that time. And what we said at the time is that we also are investigating this topic with new approaches, in cooperation with NASA, the National Aeronautics and Space Administration in the U.S. We have installed two new global positioning system satellite receiving stations, and several more have been installed since that time. But initially we installed stations at Pinawa and at Flin Flon that, at the time, were meant, in combination with existing stations in Iowa and Churchill, to give us measurements of uplift rates. And we now have results from that work.

In cooperation with the U.S. Government, we also are doing very sensitive measurements of gravity along a transect of sites from Iowa Churchill that will give us an independent check on uplift or subsidence rates. So that's a quote from my 1998 writing that I have quoted in my report and we now have results in from that work, as I will mention.

The 1974 Penner and Swedlo report supplemented existing knowledge of shoreline erosion rates with information from surveys done at intervals of one to a few decades from the 1870s to the late 1960s. It was found that the shoreline of the south basin retreated over this period at rates typically a half metre per year to five metres per year. So Penner and Swedlo demonstrated that before the time of lake level regulation, the shoreline in the south basin was retreating typically a half metre per year on the western shore, typically five metres per year on the southern shore. An average rate of, for example, one metre per year could, of course, represent 10 metres in one year and no recession for nine years.

So the question that, of course, arose, and a good question to ask to this day is, can this steady rate of shoreline erosion be explained by a 20 centimetre per century rise in lake level? And that question remains before us, of course. So let's relate that 20 centimetre per century rise to regional topographic gradients.

At Gimli, the land rises about 25

metres within 10 kilometres inland, so that inland gradient from the shore is a gradient of about two and a half metres per kilometre.

In this case, a 20 centimetres per century lake level rise would translate to a lateral shift of about 0.8 metres per year. This is very similar to the actual shoreline erosion rates reported by Penner and Swedlo.

So if we take the inferred water level rise driven by uplift, we impose that on the inland gradients, then we would predict rates of shoreline recession similar to what were observed in pre regulation time and that had been ongoing in post regulation time.

Thinking of the southern shore from the centre of the south basin to Netley Creek, the surface under Lake Winnipeg sediments rises to the present land surface at a rate of about 0.3 metres per kilometre.

A 20 centimetre per century lake level rise in this case translates to a lateral migration of about 6.7 metres per year. Again, this estimate is compatible with our data offshore from Gimli that shows that the south end of the lake has migrated 30 kilometres to its present position in 4,000 years, in this case implying an average rate of shoreline retreat of about seven and a half metres per year.

This agreement is, as I would suggest, surprisingly good. So regardless of what we consider the observation and the inference, it all fits together in a very consistent manner.

Penner and Swedlo reported similar retreat rates over much of the southern shore. So what was observed in pre regulation time, and being observed to be sustained in post regulation time, fits with what would be predicted from uplift.

So now let's dwell on this, let's ensure that we can convince ourselves that this makes sense. And so what I'm saying here is that large increments of basin expansion being driven by a few inches of lake level rise may seem counter-intuitive. So what I'm saying here is that I think it's fair for anyone to say, Harvey, you need to convince me that a few centimetres of uplift can devastate people's homes on Lake Winnipeg, for example. So let us try to illustrate this.

When I talked about glaciers earlier,

I urged you all to think about pancakes. So now I'll do my best to help us all visualize how can that uplift, how can that isostatic rebound be responsible for the devastation we observe related to shoreline erosion?

So in the next bullet I say, a one metre rise in lake level happens frequently due to wind setup, and the water level, water line only moves a few metres. So here I'm trying to visualize a person saying, lake level fluctuates by metres and I see what it does. Harvey, you need to convince me that uplift of a few centimetres can cause the impact we see in shoreline erosion.

But according to the above reasoning, a one metre permanent rise in lake level will drive the shoreline inland 400 metres to the west and over three kilometres to the south. So let's illustrate this. How can this apparent contradiction be reconciled?

The key point is that shoreline processes have cut a notch at the waterline that has a much higher gradient than the surrounding landscape.

Penner and Swedlo indicate that the

gradient between the high water and low water line on Lake Winnipeg typically is about 10 percent, or a hundred metres per kilometre. And of course we can see this on any hydrographic chart. Penner and Swedlo is a nice source, but we can readily see that.

It is this slope that takes up the short-term fluctuations. The steeper near shore gradient can also be seen on the hydrographic chart for the south basin, as I mentioned. Around Gimli, the offshore gradient is about 3.4 metres per kilometre between the shore and 10 feet depth, while farther offshore the gradient is less than one metre per kilometre. Along the south shore, the gradient to 10 feet depth averages 1.2 metres per kilometre, while farther offshore it's about 0.25 metres per kilometre. Hence, short-term fluctuations are taken up by that high gradient slope at the water line. So if we have a dry year or a wet year, if we have a strong sustained north wind, if we have a strong sustained south wind, we see the fluctuations that occur in lake level. And those fluctuations cause a retreat of the waterline, or an advance of the waterline, largely governed by that high gradient slope immediately below water level and at the waterline. But a permanent rise that related to the relentless progress of uplift exposes the south slope, that slope which is a notch formed by erosion along the shoreline, to a sustained increase in wave power.

So, in the case of a one-step lake level rise, the shoreline would retreat and the shore profile would flatten until wave power delivered to the shore diminishes to a level that allows a stable coastal position. In the case of a steady ongoing rise, which is what we have inferred to be the case, a steady retreat of the shore results.

So the rise in lake level driven by uplift delivers wave power to the shoreline that cause a relentless attack of the shoreline, which results in the sustained and pervasive shoreline erosion and the continued retreat in shoreline due to the shoreline recession that results from that erosion.

So even if a steady rise were to stop, or if we wanted to slow or stop shoreline erosion by manipulating lake level, there would be a continued adjustment of the shoreline, because it takes time for the landscape to adjust to that geological time scale adjustment in lake level. And so lake level rise, if stabilized, would result in no stop in shoreline erosion because it would take decades to centuries for the landscape to fully adjust to the uplift that has already occurred.

So it is useful to compare shoreline erosion on Lake Winnipeg with global trends at sea level in order to further illustrate and to firm up our comfort level. And these are well-documented on the U.S. coast in a reference I cited in my 1998 writing by Pilkey and Thieler, the values on the Atlantic and Gulf Coasts of the U.S. are about a half metre to four metres per year. And so these were values that are similar to what we're seeing on Lake Winnipeg. Shoreline erosion is a major issue on Lake Winnipeg. Similarly, shoreline erosion is a major issue on the Atlantic Coast of the U.S., on the Gulf Coast of the U.S. And we now see that shoreline erosion on the Atlantic Coast and the Gulf Coast is driven by global sea level rise. And the inferred rate, 20 centimetres per century, just happens by a fluke to be similar to the rate of lake level rise that we infer for Lake Winnipeg.

So what we observe on Lake Winnipeg, what we deal with on Lake Winnipeg is very similar to what we're observing on the Atlantic Coast. And so by looking at these other regions, that ensures that what we are inferring to be taking place on Lake Winnipeg makes sense, because it's similar to what is being observed and what is being inferred elsewhere.

So my presentation so far is largely a restatement of what I said in my writing in 1998, and so now I'll mention some examples of research that has been published since 1998. And that research has firmed up what we inferred to be taking place in the 1990s, and if anything, it is implied that the actual rate of differential uplift is actually higher.

I've been using the number 20 centimetres per century. The most recent syntheses imply that the actual rate might be closer to 40 centimetres per century. But to give examples of the research that has taken place over the last couple of decades, Lambert and others, including myself, published the first synthesis of gravity and GPS and lake gauge syntheses from the region in 1998, that firmed up what we were inferring from global syntheses. So that was the first regional synthesis. And it was comforting that there were no big surprises.

Erik Nielsen's work was published in 1998, and that was the inference from tree stumps that not only showed a 20 centimetre per century ballpark rise at the south end, he also showed manifestations of more basin wide rise that may relate to the climate and river diversion and basin merging trends that we see elsewhere on the lake.

Gary Tackman, for example, published syntheses from Lake Winnipegosis and Lake Dauphin that provided further confirmation of the broad regional trends.

Our work on Lake Winnipeg was published under the lead authorship of Mike Lewis in 2001. And this is where we published our results on the uplift driven expansion, as well as that more climate related supplement 4,000 years ago.

Tony Lambert and co-authors provided additional updates in research largely supported by Manitoba Hydro and linked in with research elsewhere, beginning with his paper in 2001. An update in 2005 was very comprehensive in scope, and steadily provided updates in terms of what the results we were getting from GPS global positioning stations, from gravity, from lake gauges, and gradually over the past decade this has been firmed up.

I was a co-author of a research project that demonstrated how the Red River is losing gradient to uplift. So in this case, we drew attention to the way the differential uplift is impacting the Red River, just as it's impacting Lake Winnipeg.

This paper, van der Wall and others, in 2009, is an example of a recent synthesis in which people are coming at this topic from multiple directions. And it's comforting, of course, that we're not getting any real surprises. There are no effects that we didn't anticipate. What we're doing is just gradually firming up the notion that uplift is ongoing and that uplift is gradually diminishing inland, and we're just getting better quantitative estimates all the time.

And most recently this synthesis, again under Tony Lambert's lead authorship, is the most recent synthesis for the entire region. And it's this synthesis that not only includes the GPS stations that have been installed in the region, also the absolute gravity stations that we began to install in the 1990s, now we also have satellite, the gravity measurements, the GRACE satellite, Gravity Recover and Climate Experiment. This simply adds to the story. It provides details. We actually see the impact on gravity from changing water levels. But the key point is that we're just gradually firming up our interpretations, and actually inferring from this most recent work that the rise in lake level at the south end of Lake Winnipeg in response to ongoing isostatic rebound, according to this most recent synthesis, is actually 40 centimetres per century, a higher number than what we estimated in the '90s.

So to summarize, again, I have tried to carefully go through what is the ice age, what was the continental ice sheet, why did it grow, what did it look like, how extensive was that ice sheet, where was it thickest, and what impact did that have on all of Canada, all of the northern United States? And I focused on how that ice sheet was thickest over Hudson Bay, and how removal of the ice sheet resulted in isostatic rebound of the land with that thick, most rapid uplift in Hudson Bay. And here I summarize this uplift, which we now have confirmed to be ongoing, is greatest in and around Hudson Bay, that the uplift rate diminishes in all directions from Hudson Bay.

The Lake Winnipeg outlet is thus rising relative to the rest of the basin. Lake Winnipeg, therefore, is expanding due to isostatic rebound. And the final bullet in my summary is that ongoing shoreline erosion on Lake Winnipeg is natural. This was known because of the steady progress of shoreline erosion in pre regulation time. And we have tried to be as careful and thorough as we can to assemble a quantitative measurement of post glacial isostatic rebound in terms of how it has impacted Lake Winnipeg.

Perhaps the most relevant conclusion is that we have gradually and progressively confirmed that isostatic rebound is ongoing, from multiple sources of information, we have quantified it to the best of our ability. We infer how this isostatic rebound would be expected to be impacting Lake Winnipeg. We have measurements in Lake Winnipeg that confirm that the expansion of the lake that would be inferred from measured isostatic rebound is indeed taking place. And we see that the rates inferred from isostatic rebound in terms of shoreline recession, if we look at inland gradients on the western shore of Lake Winnipeg, south basin, if we look at inland gradients on the southern shore of Lake Winnipeg, we see that the shoreline erosion that is so pervasive and persistent is taking place at a rate that fits very well with what would be predicted in relation to isostatic rebound. And so we have, I believe, confirmed the shoreline, the isostatic rebound rates, and we see that this fits with what would be predicted from shoreline erosion.

So that's the end of my powerpoint presentation. And I note that I also have submitted a written report that included some discussion on specific points regarding shoreline erosion. For example, at the time there had been the suggestion that if we see a hundred year old tree falling on the shore of Lake Winnipeg, this proves that Lake Winnipeg is higher than it has ever been in a hundred years. And so in the writing that I did in 1998, that I have quoted in my written report, I attempted to help people understand that this is not an appropriate way to look at Lake Winnipeg, given that the natural state of Lake Winnipeg is to be steadily rising.

Also in my written report, I was asked to comment on whether we can expect isostatic rebound to continue in the future. And I indicated in my written report that, yes, we can expect isostatic rebound to continue at a gradually diminishing rate. And as a rough estimate, we might estimate the rate might diminish something like 10 percent per millennium. And so from a human perspective, that's just a relentless ongoing rate.

I also was asked to assess whether I felt that isostatic rebound is appropriately depicted in the documents submitted by Manitoba Hydro for these deliberations. And I quoted a number of cases of references to isostatic rebound in the reports. And I commented that I felt that isostatic rebound is appropriately depicted in the documents that have been submitted.

I also noted the suggestion from

Manitoba Hydro that it's their understanding that they have not increased shoreline erosion rates by their activities, and I have no discomfort with that statement given my familiarity with the way that shoreline erosion has progressed persistently over the entire period of post glacial time, given the measurements that were made in pre regulation time, given what we infer to be taking place in terms of differential uplift, and in terms of our measurements from GPS, from gravity and from other measurements, we can see that those uplift rates are ongoing.

And so indeed we know that climate causes fluctuations in lake level. There are dry years and wet years, there are dry decades and wet decades, but those fluctuations are imposed on the relentless ongoing expansion of the lake. And so while the lake fluctuates, the overall pattern of shoreline recession is driven by the long-term trend. And that lake level rise has been imposed on landscape, even if we attempted to manipulate lake level, there might be short-term manifestations on the rate of shoreline erosion. But over the longer term, the expansion of the lake driven by that expansion will be relentless, and thus the shoreline erosion that has been observed on Lake Winnipeg for many decades is the natural behaviour that can be fully explained and that can be expected to continue in the future.

I hope that my presentation has been helpful, and I look forward to further discussion.

THE CHAIRMAN: Thank you very much, Dr. Thorleifson. Thank you for a very interesting presentation, and particularly thank you for making it understandable to those of us who are not scientists.

We'll take a 15 minute break, come back at about 25 after, and then we'll open the floor to some questions of Dr. Thorleifson.

(Proceedings recessed at 11:09 a.m. and reconvened at 11:25 a.m.)

THE CHAIRMAN: We'll come back to order. Dr. Thorleifson is now available to answer questions. First up will be Manitoba Hydro.

MR. BEDFORD: And we have no questions, thank you.

THE CHAIRMAN: Thank you. Do any of the participant groups have questions?

Oh, you're getting off easy.

Panel members? Edwin, Mr. Yee?

MR. YEE: Thank you, Mr. Chairman.

Dr. Thorleifson, I asked you this at the break but I'll ask it again. I sort of have a double question here. The first one is do we have a prediction when isostatic rebound will eventually reach some sort of equilibrium, there will be no more isostatic rebound? And I guess the other thing is, and it seems to be obvious from your presentation, but this is affecting all of the lakes in Manitoba as well?

DR. THORLEIFSON: Thank you for that question, sir. And in very round figures, I would say something in the order of another 10,000 years will bring the after-effects of the last glacial cycle to an end. And so that means that Hudson Bay will largely disappear. Hudson Bay is relatively shallow. And if we recognize that, we have uplift taking place at about a metre per century, then Hudson Bay will largely disappear. And although the rate will diminish, there is significant uplift left to be completed so the process that I have described will be ongoing for several millennia into the future. And so that means that Lake Winnipeg will continue to expand and it can be predicted within a few thousand years that it would expand all the way to Winnipeg and beyond if we allow it. But no doubt, human ingenuity will be brought to bear whenever the time comes.

But you also added the point to further clarify whether all lakes are affected by this phenomenon. And the answer is yes, every lake is being tilted. However, the very significant consideration is the extent of the lake perpendicular to the lines of uplift, perpendicular to the effect. So, for example, a small-ish lake is being tilted, but because the effect is projected on an angular basis, it's just not significant in the case of a small lake.

This phenomenon is significant for Lake Winnipeg because it's a large lake. And when the effect is projected at an angle from the outlet, it becomes significant. Now if Lake Winnipeg happened to be elongate parallel to the lines of equal uplift, then it wouldn't be as significant a factor.

So it's all a question of geometry. And I had been working hard to find illustrations today. And if you could think of using a lever, if you want to lift a heavy object with a lever, you need a long board. If you try to lift a rock with a short board, you're not going to have much luck. But if you have a long board, it works as a lever because of the way that the length of the object magnifies the effect.

Similarly, it's the large lakes that are vulnerable to this effect because the effect is projected from the outlet. And the larger the lake, the greater the effect.

MR. YEE: Thank you very much.

THE CHAIRMAN: Bev, Ms. Suek?

MS. SUEK: Yes. I am not a scientist. So I'd like to put these in layperson's terms. We heard a lot when we did the community consultations about erosion in the lake from people around the lake who some of them supposing that Lake Winnipeg Regulation is the cause of erosion. From what I hear you saying, this is a big contributor to erosion around the lake. And I assume there's other things like climate change and it's wetter these last few years. So that is essentially what you're saying, is it? Is my conclusion correct?

DR. THORLEIFSON: Yes. The principal cause of shoreline erosion is isostatic rebound.

MS. SUEK: And I'm wondering at Jenpeg, they had been releasing water pretty constantly over the last few years because of the lake level. In the more recent future, not 10,000 years, but in the next 20 years, is the flow at Jenpeg going to have to be more or will we see impacts from this on the actual operation of Lake Winnipeg Regulation? Is this a long-term thing or will we see anything in the short term with this tilt?

DR. THORLEIFSON: Well the way that pervasive and persistent shoreline erosion is being driven by isostatic rebound is a very long-term process. The uplift that has accumulated causing Lake Winnipeg to expand against that landscape is something that will take significant time to adjust to regardless of how we manipulate lake level.

So even if we tried to lower the lake, that might have some effects. But the bigger picture is that the landscape has to adjust to the accumulated uplift. And even though some shoreline erosion would be taking place here and there, were it not for isostatic rebound, the way that shoreline erosion is pervasive and persistent in the south basin is a result of isostatic rebound over the longer term. And broadly speaking, that will be sustained no matter what we do because it would take decades to centuries to adjust to the uplift that has already taken place. And the shoreline erosion continues under the water level, even if at lower levels.

So although manipulation of lake level would no doubt have some effect on the detailed aspects of erosion from the longer term and a broader perspective, shoreline erosion is inevitable and it's dictated by uplift that has already occurred. And any adjustment to changed water level regime will take decades and centuries anyway.

MS. SUEK: Just one final question. You mentioned Netley, a lot of concern around the Netley Libau Marsh and the fact that it's wetter and continues to be wetter. Is this a factor in terms of the marsh at all in your view?

DR. THORLEIFSON: Well, the isostatic rebound is driving the evolution of Netley Marsh in the sense that the barrier island that separates Lake Winnipeg from Netley Marsh is there because on that low gradient surface, the water gets ahead of the shoreline. That's the simplest way to explain a barrier island. So Netley Marsh represents the expansion of Lake Winnipeg getting ahead of the beach.

And as Lake Winnipeg expands in response to isostatic rebound, the natural behaviour for the barrier island that separates Netley Marsh from Lake Winnipeg is for the shoreline to erode on the lakeward side and for it to accrete on the landward side. So the barrier island very naturally is migrating into Netley Marsh. And meanwhile, Netley Marsh, over the geological time scale, expands to the south. And so the overall evolution of Netley Marsh as well as its very existence is entirely dictated by isostatic rebound.

MS. SUEK: Okay, thank you.

THE CHAIRMAN: Neil?

MR. HARDEN: So you're saying to me I should not be making any long-term investments in the Port of Churchill?

Okay, a couple of questions. Does underlying geology affect the rebound rates? For instance, you were saying that the granite, bedrock on the eastern side of the lake versus the

Limestone. Granite being more rigid, would that have an impact on the rebound rates?

DR. THORLEIFSON: Well, thank you for that question. And first with respect to the material, the short answer is no, there's no effect because those buoyancy effects, the flexural effects relate to rocks deeper down. And although we have changes from, for example, granite to the east and Limestone to the west, at shallower depths, the controls on the uplift manifest themselves deeper down. And so the change from granite to limestone has no effect.

Elsewhere in the world, uplift of this nature can be affected by faults. For example, most of us are familiar with the San Andreas Fault in California and how it's active and how it is the source of major earthquakes. If we had active faults in our region, then those features likely would influence the way the uplift takes place. But we are instead in the older more geologically stable continental interior where we don't have active earthquakes. And so this is why the post glacial uplift, the manifestation of isostatic rebound is a pattern that's simple in its regional pattern. The way we're able to say that uplift rates diminish gradually inland from Hudson Bay, that very gradual trend and simple pattern in part is a reflection of the fact that we're in the old stable continental interior rather than in the continental margins, for example, such as California where there are active major faults that would change the pattern.

So that makes my work simpler because we don't have phenomena such as active faults playing a role.

MR. HARDEN: Okay. And one last question then. You're saying there's a rise in lake level from 20 centimetres to 40 centimetres per century in the south basin. Does that follow then that say the flood control benefits of Lake Winnipeg are diminishing by that, Lake Winnipeg Regulation are diminishing by that rate per Century?

DR. THORLEIFSON: Yes. Yes, in the sense that if we were to keep lake level constant relative to a certain discharge at the outflow, then on a relentless and chronic basis, we would expect lake level to be rising at the south end by what we previously would have inferred to be 20 centimetres per century but the most recent syntheses are actually saying more like 40 metres per century. So indeed, yes, the tendancy for coastal flooding would increase unless we respond in terms of the way that the outflow is managed.

MR. HARDEN: Okay, thank you.

THE CHAIRMAN: Thank you. I have a couple questions, Dr. Thorleifson. One or two of my questions were answered already.

What we have heard two or three times in our community hearings was that with erosion, the sediment that erodes would fall to the bottom of the lake, making the bottom shallower so rising the lake level.

Now we also heard from other people that when it erodes, that just sort of makes the lake wider so the water goes into there and keeps the lake more or less the same. This may not be your field of expertise but can you comment on that?

DR. THORLEIFSON: This is a good example of how challenging it is to visualize how a lake works and this is how I dwelled on my various illustrations like bank accounts and cake pans in your kitchen. And I think we need to be fully understanding that for us all, this is a challenging thing to visualize and that's why I went through all those bullets as carefully as I could.

I think what I hear you saying, Mr. Chairman, is that some of the members of our communities that you have dealt with have observed that if there is material being removed from the shoreline, such as sand and gravel and silt and clay, it's going somewhere. And indeed they are right. That sediment, to a significant degree, would be carried out into the lake and it would be deposited on the lake bottom. And indeed that's why we were able to take cores from Lake Winnipeg as a record of geological history.

And so you mentioned, Mr. Chairman, that some members of our communities that you interacted with expressed the concern that if large amounts of geological material are being carried out into the lake causing the bottom of the lake to rise, then they have a good question; does this cause lake level to rise if the bottom is rising? This is where we need to focus on my discussion that lake level is dictated by outlet geometry and climate and not by the volume of the lake. Because we all have a tendency to think of a lake as a fixed volume of water, a body of water that is there. In fact, we grow up hearing this, that a lake is a body of water. And so we say fine, if it's a body of water then it must be a thing that is there. And if we raise the lake bottom, why wouldn't the lake level rise?

And the reason is yes, indeed we think of a lake as a body of water but it's a body of water in motion, whether that motion is flow or evaporation. And so this is the reason why I went through that discussion.

And so as you know, Mr. Chairman, if the level of the lake bottom rises, and the level at the outlet doesn't change, the response to that person who expressed the concern doesn't just cause a rise in lake level, the response in fact is with respect to constant climate and with respect to sedimentation of the lake bottom, the volume of the lake is getting smaller.

So that's the short answer to that question. That thinking of the scenario as outlined rather than lake level rising due to that sedimentation, volume decreases.

THE CHAIRMAN: Thank you. I have a couple of questions that related to how the rising of the lake, at least at the south end, well I guess at both ends because of isostatic rebound, how that might impact Manitoba Hydro's operations? And first if we take, at the south end, 20 or 40 centimetres over a century, the controls have been in place for about 40 years now. Some of the power dams on the Nelson are over 40 years. But just talking about Lake Winnipeg Regulation specifically, the first question, would the additional four or five, eight inches over the last 40 years, how would that impact Hydro's ability to maintain the lake level at 715 or between 711 or 715, or would that have any direct impact?

DR. THORLEIFSON: Well, it does have impact and it simply means that gradually with time, a commitment to maintaining constant lake level would call upon slightly but significantly more aggressive promotion of outflow to maintain the mean, if that's the commitment.

And so I haven't attempted to calculate, you know, maybe someone has, but I think that -- so it's significant, it's measurable. And as the decades accumulate, it will actually influence policy.

So if that's the point that you're seeking to discuss and clarify, Mr. Chairman, then I agree with you that with the passage of time, it gradually is a factor. And as we think about working together to optimize circumstances on Lake Winnipeg as we work together to optimize benefits for the people of the region and for ecosystems, then we have certain objectives in terms of lake levels and electrical power generation, then gradually with time, I think one of the objectives of these deliberations is to clarify what considerations should guide us all as we go forward. And as we make commitments to how lake level is regulated, as we make commitments with respect to electrical power generation, as we make commitments with respect to impacts on ecosystems, and as we make commitments in terms of how lake level interacts with the people who live on the lake, then these various considerations are balanced.

And I think it would be fair to say that so far, those management considerations could largely disregard isostatic rebound because even though it's the geological factor that's driving the shoreline erosion that is so devastating for people who live on the lake, the impact on operating rules for the lake could reasonably be ignored.

And I agree with you, Mr. Chairman, that with the passage of time, with each decade, it will gradually become more relevant. Given that, for example, if our criterion is maintenance of a long-term mean, then with each passing decade, it will be a slightly more significant factor to deal with.

THE CHAIRMAN: Manitoba Hydro has presented evidence that since the controls at Jenpeg went into operation in 1976, the average height of Lake Winnipeg, the average level of Lake Winnipeg is about one or two inches higher. Could some of that be accounted for by isostatic rebound?

DR. THORLEIFSON: Well, I would be hesitant to word it that way in the sense that I think as will be expanded upon this afternoon and as we all know, recent lake levels have largely been driven by moister climate. And so I think you're asking an interesting question, Mr. Chairman, and I'm glad you asked it because this is the sort of thing that we all need to structure in our minds.

I think it's fair to say that slightly increased mean lake level is a tendency encouraged by isostatic rebound. So in other words, it's a factor, it was a factor. It was one of the contributors, however, I think that it's appropriate to say a greater factor -- well, I want to reword this. It would have been a contributing factor and a greater factor has been the moist climate.

THE CHAIRMAN: But that one or two inches could also have been caused by the controls at Jenpeg. I think that's the impression that most readers of their document would assume, that the controls at Jenpeg had that slight rise of the lake or caused that slight rise of the lake.

DR. THORLEIFSON: Well, perhaps we're starting to venture beyond my expertise; however if you have asked me for an answer --

THE CHAIRMAN: Actually, it was more of an observation.

DR. THORLEIFSON: I think I would largely say that it was the controls at Jenpeg that prevented even more of an increase.

THE CHAIRMAN: Even more?

DR. THORLEIFSON: Even more of an increase in recent years.

THE CHAIRMAN: Yes. I think this is my final question and it's just sort of the bigger Hydro picture. Isostatic rebound, is everything lifting equally at the same time in a broad area? The specific question then, Hydro has these big generating stations on the Nelson River and I mean they are humongous structures. If they have lifted eight or 10 or 12 inches in the last 40 years, could that have any impact on the operation or the efficacy of those structures?

DR. THORLEIFSON: Great question. And the answer is that isostatic rebound is a pervasive phenomenon that affects the entire landscape. So indeed, the Nelson River is losing gradient. After the 1997 Red River flood, everyone, including us all to some degree no doubt, were called upon to do whatever we could do to make sure that Winnipeg and the surrounding region would not be threatened by a flood of that magnitude again. So that's why the floodway was expanded and that's why I was heavily involved in a program of research that followed the 1997 Red

River flood.

And so that's why we did many things, including the research that I mentioned that quantified the way that isostatic rebound has caused the Red River to lose half of its gradient. One reason we did that was part of the research we did after the 1997 Red River flood was to ask the question how large have floods like this occurred in the past so that we could understand whether the 1997 Red River flood, for example, was unnatural. And what we demonstrated from multiple sources of information was that Red River floods of that magnitude have been taking place once or twice per century for many centuries.

And one of the sources of information that we pursued to work out that flood record were archeological sites going back thousands of years. So we needed to quantify how isostatic rebound has changed the flooding behaviour of the Red River. Because if we found evidence for a flood in an archeological site from thousands of years ago, we need to bear in mind how the behaviour of the river has changed. So I slip that in there as an example of how we did do research on how isostatic rebound has changed the behaviour of the Red

River.

Now, Mr. Chairman, you have asked me about the Nelson River and whether the isostatic rebound that we're talking about today is impacting the way that the Nelson River operates? And the answer is absolutely. The Nelson River is losing gradient to isostatic rebound.

And so now to extend that discussion as you have presented, Mr. Chairman, how does isostatic rebound affect human activities such as hydroelectric power generation on the Nelson River? And I am happy to have the question and I intend to answer it and I have to pause because it's not something I think about everyday. Again, thinking of the earlier question, thinking of the Forebay, the water stored, the reservoir behind the dams, those reservoirs are getting larger. But the effect is insignificant given what I referred to earlier, isostatic rebound primarily manifests itself on large lakes because the effect is magnified on an angular basis from the outlet.

And so the actual impact on the reservoirs is not significant. And the head by which electricity is generated isn't changing because that's a local drop in elevation from point A to point B. And in those points, point A and point B are both rising but they are rising by the same amount.

So to summarize, isostatic rebound is occurring everywhere across the region. It affects rivers on the long-term time scale, but it wouldn't affect hydroelectric operations on the Nelson River.

THE CHAIRMAN: Thank you. And I just want to clarify an answer you made to Ms. Suek earlier just about shoreline erosion. I think you said that the majority or the vast majority of it would be due to isostatic rebound?

DR. THORLEIFSON: Yes. When we look at how the lake as a whole is expanding, when we look at the rates of uplift that we have inferred, when we look at inland gradients, for example, on the western shore of the south basin or the southern shore of the south basin, we can see that the rate at which the shoreline is receding matches what we would predict on the basis of isostatic rebound.

So we can therefore conclude, with progressively greater confidence, that isostatic rebound is driving shoreline erosion. And no matter what we do with lake level, we might be able to affect the rate of shoreline erosion to some degree, at least on a temporary basis. But the big picture is that that persistent pervasive shoreline erosion is driven by isostatic rebound.

Now without isostatic rebound, what would the lake be doing? Well, there would still be shoreline erosion here or there just because things evolve, things change. The lake might break through a barrier and there would be shoreline erosion. We see adjustments to the shoreline in the north basin that may be simply because there's wide expansive vulnerable materials that are just being relentlessly chewed at by the shoreline, so there are exceptions. But on the south basin, we see that shoreline erosion is so extensive throughout the basin and the rate of retreat is so steady, we, on that basis, can see that by far the dominant factor is isostatic rebound, and it's an effect that has accumulated. And even if we strive to minimize shoreline erosion through lake level modification, it will take decades and centuries for the landscape to adjust to the uplift that has already occurred.

And so indeed, isostatic rebound is a

natural aspect of Lake Winnipeg that's driving shoreline erosion. We know that that causes great consternation and distress amongst the people who live on the lake. Just because it's not natural, that doesn't mean it's deeply troubling and difficult for the people who live on the lake. But it's a natural aspect of the lake that was well-documented before regulation and that we could maybe slightly modify. But broadly speaking, it's something that I think we're stuck with.

THE CHAIRMAN: Thank you, Dr. Thorleifson. Has that provoked any questions from Manitoba Hydro? Other panel members?

Well, thank you very much, Dr. Thorleifson. You are getting off quite easy today. I think it speaks to how good your presentation was and how well you explained this, that it didn't provoke a lot of questions or any challenges.

So thank you very much for taking your time to prepare the paper in the first place and then to come up here for this hearing this morning. Thank you.

We're finished early now so we'll

adjourn until 1:30. So back here at 1:30.

(Proceedings recessed at 11:57 a.m. and reconvened at 12:02 p.m.)

THE CHAIRMAN: Okay. I'd like to go on the record for two minutes or three minutes. When we broke, I asked Harvey a question about Willow Island just out of personal interest because I grew up near there. Then the response he gave me, and then I recall that we did have a presentation from the Willow Island Cottage Owners Association in Gimli, so I think it is relevant or may be relevant.

So, Dr. Thorleifson, I'd like to ask you whether or not Willow Island would be considered a barrier island as you described them earlier in your presentation.

DR. THORLEIFSON: Yes, I regard Willow Island to be a barrier island. In our discussions, we talked about how Netley Marsh is a prominent feature on Lake Winnipeg. And Netley Marsh is separated from Lake Winnipeg by a barrier island. And we now increasingly recognize that barrier islands form where water levels are rising on a geological time scale. And what happens is that the water gets ahead of the shoreline. So we have the marsh, the lagoon behind the shoreline. And then when the barrier island is exposed to sufficient wave power in deeper water, then what we see the natural behaviour of the barrier island being is for there to be erosion on the lakeward side and accretion on the landward side such that the natural behaviour of a barrier island is for it to migrate landward.

We also see a similar barrier island on Lake Manitoba where the lake is separated from Delta Marsh by a barrier island. We see a similar barrier island at Duluth, Minnesota on Lake Superior. We see a similar barrier island at Hamilton, Ontario. And in all of those cases, these are lakes that are naturally expanding. Lake Manitoba is rising in the south. Lake Superior is rising in the south, Lake Ontario is rising in the south.

And something I have mentioned is that global sea levels are rising. And this supplements the previous rise that related to the transfer of water from continental ice sheets. So the barrier islands we see up the eastern U.S. are a manifestation of that rising water level trend.

So on Netley Marsh, we have a barrier

island and we see that it is behaving in the way it's expected. Barrier islands migrate landward.

Now my interpretation of Willow Point is that it's a fragment of a Lake Agassiz barrier island that may well have connected to Grand Beach. Because at Grand Beach, we see a similar barrier island. We see the alignment of Willow Point and Grand Beach. And so they both have the morphology of a barrier island and we can explain why they are across each other by it being a Lake Agassiz shoreline that was later breached by the expansion of Lake Winnipeg.

So Willow Point, being a barrier island fragment that is now exposed to the processes of Lake Winnipeg, given what we know about the natural behaviour of barrier islands, we can infer the natural behaviour for Willow Point is for it to migrate landward due to erosion on the lakeward side and accretion on the landward side.

THE CHAIRMAN: Thank you very much. Now I think that should conclude finally. Thank you, Dr. Thorleifson.

Okay, we're back off the record and back at 1:30.

(Proceedings recessed at 12:06 p.m.
and reconvened at 1:30 p.m.)

THE CHAIRMAN: Good afternoon, we will continue with the presentations. This is the second presentation from a witness commissioned by the Clean Environment Commission. This afternoon we have Dr. Greg McCullough, geographer, climate change scientist and researcher at the University of Manitoba.

Dr. McCullough, I will ask the Commission secretary to swear you in.

Greg McCullough: Sworn.

THE CHAIRMAN: You may proceed with your presentation.

DR. McCULLOUGH: Hello. As I was introduced, this is a presentation that was requested by the Manitoba Clean Environment Commission. The topic that I will be talking to you about will be the level of Lake Winnipeg, water levels in Lake Winnipeg as they are influenced by climate. And by climate, we are going to be talking about both climate history, how it has changed over the last century in the recorded record, and how it may change in the future as is best predicted by global climate models.

So I will begin by saying that this follows a submitted a written presentation. My CV is in that presentation. I have a Bachelor of Science, a Masters of Science and a Ph.D, all from the University of Manitoba. Beginning with graduation with the Bachelors in 1971, and then a long hiatus, and then I went back to school about 10, 15 years ago and completed my Ph.D just in 2007, so a more recent part of my history.

In that long hiatus I worked for almost 20 years with the Department of Fisheries and Oceans. And relevant to this document, and what I'm able to talk about up here, I spent about 10 years of that studying in particular shoreline erosion, erosion processes, sedimentation processes, and sediment transport on Southern Indian Lake and throughout the Churchill River Diversion region and on the lower Nelson.

Since then, since 2006, I've worked as a research associate with the Faculty of Environment, and I have been specifically employed to look at or to -- I suppose the most specific part of my work is to look at the freshwater interactions with the marine system of Hudson Bay.

So I continue to work on the lower Nelson system.

But in the interim, over the last 15 years, I've been working with a group of people from the Department of Fisheries and Oceans, either on contract research or other independent research on questions related to eutrophication of Lake Winnipeg, both from the point of view of satellite remote sensing of algae, and at the other end from the point of view of nutrient loading to the lake. And I suppose most recently I am involved very directly again with questions of shoreline erosion in Lake Winnipeg, though not with the shoreline erosion most of you think about. I've worked specifically on questions of erosion and how they affect Lake Winnipeg along the north shore.

I think that's sufficient introduction. There is a complete CV attached to my presentation and you can refer to that.

Dr. Thorleifson, who presented this morning, presented the long-term picture. The long-term story on Lake Winnipeg is a geological story. The interim term is probably a climate story and I'm going to present that side of it.

By way of introduction, I think you

could say that Dr. Thorleifson was talking about processes that are geologic in time, understood well enough to be able to predict them with great confidence going off into the future. So that he is talking about processes that are almost inevitable. I'm talking about processes that we have much less power of prediction for. I'm talking about the effects of climate on the level of Lake Winnipeg. And it does have long-term trends, but when we talk long term in terms of climate, we are talking maybe centuries, and in many cases we are really only talking multi-decadal sort of periods, so a very different time scale from what you heard this morning.

I will talk -- and moving into restructured as on that slide in front of you, I will talk about historical climate and runoff into the lake and runoff is driven ultimately by climate, in very large part. I will elaborate on that. I'm going to talk specifically in terms of temperature, precipitation, that's rain or snow, and discharge of the major tributaries into Lake Winnipeg. I will talk about temperature briefly because it is climate, but I will not have much -- there is not much to say about it in terms of regulation on Lake Winnipeg. There are some, I suppose, rather more tenuous connections that one can make with regulation, but I'm really going to be talking mainly about precipitation and river discharge on the lake level. I will go on to historical climate and talk about what we foresee in the 21st century to be the most likely scenario and I will be probably couching that in a lot of qualifications about uncertainty. And I will finally talk about those aspects of climate specifically with regard to how they affect lake level.

So temperature. Very simply then we can look historically at temperature, we have historical records for temperature going back in a few cases to the late 19th century, the late 1800s. You can go a little further if you take things like the City of Winnipeg records and you can take other records. But the picture over the last century is up on the screen in front of you. You will see if you take stations scattered around Lake Winnipeg, there are six different temperature records, those are annual values connected by curves. You will see that they all say pretty much the same thing, that temperature right now, average temperatures are a little more than -- a little more than a degree higher than they were at the turn of the 20th century, 115 years ago.

I would say, though, that you should not interpret that as a long-term trend. If you look at that, you in fact see that the highest temperatures in the recorded history around Lake Winnipeg were in the 1930s. These are not annual temperatures, these are July, August temperatures, and I chose that specifically because those are the temperatures that would affect Lake Winnipeg particularly.

You will see long-term trends described in the literature. For this region they are usually only statistically significant if you describe the minimum daily temperatures, for instance, you have to get very particular before you can be very clear about how temperature is responding to a global condition where mean annual, or mean global temperatures, pardon me, are clearly rising, and have been over a century. In the local case they are going up and down. There are warmer periods and cooler periods in that record, and the rise is not nearly so clear if you just take the daily means in midsummer.

However, that does connect very directly to lake temperature. And the graph on the left, if you look at that, what you see are water temperatures on the Y scale and vertical scale, and air temperatures on the horizontal scale. Those are monthly mean temperatures, and what you see is that in general a degree in rise in air temperature, an average monthly temperature will yield an average monthly temperature increase in surface water in the lake of about a degree.

And more specifically on the right -- pardon me, on the right I have actually used a better equation to estimate temperature, and all that does is take the current monthly temperature and the previous monthly temperature, and if you put the two of them together into a polynomial regression, you get a good estimator from air temperature to water temperature. In other words, if you go back to the graph I presented earlier, you would expect that the lake temperature had moved pretty much as you see the air temperature has moved in terms of the summer monthly mean temperatures at least.

I won't say much about that. Those are very important things from the point of view of the ecology of the lake, the biota of the lake, temperature is probably the single most important factor. If you are thinking about the fisheries, for instance, we have whitefish in that lake that may well disappear if the temperature of the lake rises by a couple of degrees more. They are near the southern limit of their habitat in Lake Winnipeg.

If you look at our current overriding concern, which is cyanobacteria blooms, or blooms of blue green algae, they do respond and produce -- are more likely to produce blooms in warmer years, given the same, more or less the same concentration of nutrients. So temperatures are very important to the lake. However, it doesn't seem that I can make really strong connections between that and regulation, so it is just a fact.

Let's go on to precipitation. Historically, precipitation in the Lake Winnipeg basin has overall increased over the century. What you see are a series of graphs from Alberta through Saskatchewan, Manitoba, down into Minnesota and over to Ontario. In each of those graphs the gray circles are the annual mean precipitation, or the annual total precipitation, pardon me, total precipitation in millimetres per year. And overlaid on those is a smooth running mean, a 10 year running mean to show the general patterns. And overlaid on that is a dashed line which shows the overall century long trend. In every case the century long trend is to increasing precipitation.

It is important to realize, of course, that that trend, which suggests that throughout the basin precipitation has increased by 7 to 14 per cent over the early part of the 20th century, that in any given year, or even through a several year wet period, it can be much higher or much lower than differing from even 13, 15 per cent of the normal. In other words, annual precipitation can still be higher or lower than it was at the turn of the 20th century in any given year.

And so you always need to bear that in mind when you consider these long-term trends. They are trends in the average. They are very important to some kinds of understanding of the lake, but in other concerns you really do need to be concerned about the fact that precipitation in any given year is very low. If you look at the --

I'm looking at some places where you actually see, I believe it is in Minnesota, you can see that the highest and lowest annual precipitation occurred within a year of each other. So bear that in mind.

The other thing that you begin to see here, when you look at the black curvey lines, is that you are beginning to see that there are wet periods and dry periods. There is not only really wet years and really dry years, but there are decades when it tended to be wetter and decades when it tended to be drier. And I will talk about that a little bit more when you see it in the runoff, you see it that much more strongly.

Now I'm going to, in this graph which you are looking at now, you are looking at those patterns displayed on a map instead of in a time series. And what we are looking at here are circles that show, in three cases for precipitation and in the fourth case for the runoff from the watershed, that show the change in precipitation and runoff. And in this case I've taken the period, and I did this several years ago, the period from 1996 to 2005. And I show in these maps the per cent change or difference between that last decade of precipitation and the previous 50 years. So if you look at a circle in the upper -- let's look at the upper left, that biggest circle within Eastern Saskatchewan is actually Cote, Saskatchewan, and it shows the December, March precipitation was about 25 per cent higher in the last decade that I'm showing here compared to the previous 50 years. In other words, it had increased by about 25 per cent over the previous average.

So now you look at all of them, and what you will see is that -- let's look at April to June, first of all, where there are the biggest changes. There has been a lot more rainfall in the northern Red River basin, and actually the northern and eastern, northern and western English, really the whole English River basin and Lake of the Woods area. Tremendous increases in precipitation, those amount to, many of those circles, well over 30 per cent changes. Modest changes throughout the whole of the Lake Winnipeg watershed.

So the Lake Winnipeg watershed from that picture can be said to be generally getting wetter in the spring period. It is not changing nearly as consistently in December to March. So snowfall is not changing a lot, except for a few odd places, and in fact snowfall, because there is some blue circles there, is slightly less than it used to be. We are not getting bigger snow, in average years, by the way, in decadal averages, not in annual values.

And in July to November, that's summer, fall, it is a little wetter in the Red River and again the English River Basin than it used to be. That covers those three precipitation maps.

Now if you look at the lower right you will see the runoff that results from that. I want you to know, first of all, I changed the scale. So those circles for precipitation, the maximum values are only of the order of 30 to 40 per cent changes. But the increases in runoff, in the Red River in particular, in the Red River basin are in the order of 50, 40 to 50, up to well over 100 per cent, or a doubling of precipitation in the southern Red River Valley. Some of the biggest changes, consistent changes are actually right along the main stem of the Red River, which, by the way, goes a long way to explaining why 1996 to 2005 were very wet years. And, in fact, if I repeated this exercise now, you would say probably see a similar thing. Those circles are all the small streams that are monitored in the Red River basin. So that throughout the basin, every stream is producing more water. But that's not happening in summer and -- those are annual values, it is not happening throughout the watershed, it is happening in the southern and southeastern part of the watershed by that map.

I will go to what I have in the written documentation, which is not presented here exactly, but if you go to the literature you will find that for runoff, there are very thorough studies, several of them published now for the Red River basin and the Winnipeg River basin, that show that in both cases the runoff is statistically higher, has increased statistically over the century, and that in the Red River basin that increase is between -- I have to look back at my document, but it is over 50 per cent, very large increases in the Red River basin.

I will leave that for a second, actually I will talk about this a little bit better with another graph that should come up soon, when I talk about river discharge itself.

So I will move on to talk about what we were looking at in the lower right-hand corner in a little more detail in this next section, to make more sense here. But I will preface talking about changes in totals by talking about changes in contributions throughout the watershed of the major tributaries.

Now, there are four major tributaries that we are concerned about; the Winnipeg River, which has always contributed more than 40 per cent of the flow to Lake Winnipeg, and actually now contributes well over 50 per cent. So over the century, the proportion of flow from the Winnipeg River going to Lake Winnipeg has increased say from 40'ish to 50 something per cent. At the same time the contribution of the Saskatchewan River has decreased from about almost equal to the flow of the Winnipeg River to only about a third of the flow of the Winnipeg River. And coincidentally, the flow of the Red River has increased as well. So that we now -- it now requires the Saskatchewan, the Red, and the Dauphin to contribute what Saskatchewan used to contribute alone, I suppose you could say. I think the Red

River, if you look at those numbers, the contribution of the Red River was something like seven or eight per cent at the turn of the 20th century, and it is now at the order of 15 to 18 per cent on any given year. So big changes in the contributions of the different systems, and those have happened because the flows from each of those tributaries has changed over the century. And here they are, the flows from those four rivers, Saskatchewan, Dauphin, Red and Winnipeg River.

Again, I have presented the annual values as circles, the ten-year running mean as a black line, and the long-term trend, the linear trend as a dashed line.

The first thing you should notice is that in this case only three out of the four major contributors have increased over the century. I will begin with the Saskatchewan. The Saskatchewan River total discharge has decreased by almost 20 per cent over the century. Some of that has been shown to have been due to human usage. And the main uses -- the main reasons that water is removed from the Saskatchewan River is for irrigation and domestic consumption purposes, but mainly for irrigation in southern Alberta and to a lesser extent in southwestern Saskatchewan. These probably have removed almost -- or contributed at least a third to the decrease in flow in the Saskatchewan River.

Another major contributor to the losses in flow in the Saskatchewan are the large reservoirs on the Saskatchewan, particularly the Diefenbaker reservoir. Putting a large reservoir in the middle of a system gives you a very large surface area in the hot, dry climate in the summer, to evaporate, and Saskatchewan loses a lot of water as it passes through Lake Diefenbaker in the summertime. And I suppose since only a third of the losses in the Saskatchewan River are attributed to consumptive uses, as they are called, then a large part, maybe two-thirds of the losses in the Saskatchewan River may be due to climate change.

If you remember back, the precipitation data suggests there is certainly less snow falling over the Saskatchewan basin, over a large part of it there is no big changes, no significant changes in rainfall. But there probably have been increases in evaporation over the Saskatchewan basin, as well as transpiration.

Evaporation is directly off the water, transpiration is water lost off plant surfaces and therefore largely by crops in Saskatchewan.

Let's move on to -- I will go down to the Winnipeg River for just a moment then. The Winnipeg River has increased -- the flows have increased by over 50 per cent, and that's a statistically significant increase. There was one, at least, publication describing that very carefully and ascribing it to various reasons. But I want you to look at the Winnipeg River and realize that it too is not a linear trend. In fact, the highest flows, the highest decadal flows, if you take the decadal mean, not the short-term mean, we are way back circa 1969, 1970, very, very wet years. It is only now recovering to the amount of flow that it had in the late '60s, early 70s.

The Dauphin River and the Red River both show large increases, almost 100 per cent for the Dauphin and 160 per cent increase for the Red River. Very large increases in total flow. That 160 per cent increase is from of the order of 5,000 cubic feet per second in the turn of the 20th century to 12 to 13,000 cubic feet per second for decadal averages now. Also, though, not a simple linear trend.

In the case of the Red -- well, in every case if you look at those data you will see that there are, through the 20th century, generally three dry periods and four wet periods, I guess. The dry periods are well known to all of us, certainly to every one of us who has connections with farming roots, the '30s, the '60s, and the '80s. One part, or a very large part of the Winnipeg basin, particularly the southwestern basin and the Red River were affected by drought at some time or other during those three periods, '30s, '60s and '80.

In between that the flows of the Red, and the Dauphin for that matter, have risen back to new and higher levels each time. So the important thing, from the point of view of Lake Winnipeg, I think, is that although there are -- there are two important things. The dry periods are important, but the other important thing about the wet periods is that every succeeding wet period has been wetter during the 20th century. So that's a very solid trend, it is not strictly speaking a linear trend, although the peaks of the wet periods are pretty much linear, and it is rising.

You will notice for the Dauphin River, by the way, in case I didn't say this but I should, perhaps the outlet to Lake Manitoba, the Dauphin River has a remarkably high peak in 2011, and that's due to the diversion of the Assiniboine River through it. You can see in 2011, both the Red River and Dauphin River peaked. Both the Red and -- the Assiniboine was at an all time high flood, I think it recorded as much as a 300-year return period flood. And the Red River was suffering one of its half dozen highest floods of record at the same time.

Now, if you think back to those precipitation graphs, we were talking about 10 to 20 per cent changes in precipitation over a century. And now I'm telling you that the rivers have increased by 50 to 60, I think it was for the Winnipeg, 90 per cent increase in the Dauphin River, and 150, 160 per cent increase in the Red River. Why the big difference? Don't those rivers flow from the rain? Isn't it the rain and the snow that supply the water? Well, yes, it is, but it is not a direct and simple relationship.

To preface this, the way I put it in the report I wrote, if you have increasing rain, even small amounts of increasing rain, they are often associated with increasing frequency of rainstorms, and also often with increasing intensity of rainstorms. If you have a half inch of rain out at Starbuck, after a dry spell, you are not likely going to see the LaSalle River rise. But if you have a half an inch of rain after a wet summer, its probably -- a lot of it is going to run off. And that's going to happen because either the capacity of the soil for more moisture has increased, or has decreased in the way I'm talking about it, or in the case of a dry spell there are probably a lot of little hollows, rills, places that water is going to sit for a few days, in which case it may well evaporate. In other words, it is not only the total amount of rain that falls, it's how it falls, how frequently it falls, whether it is falling on wet soil. With the result that a small increase in rain or precipitation can result in a large increase in runoff.

And I will give you this example here. This is from data for the Red River basin. These are for amalgamated runoff for streams in the western Red River basin, the eastern Red River basin, east of the Red River main stem, the southern Winnipeg River watershed and the northern Winnipeg River watershed, which is actually the English River. You will notice that, of course, as precipitation rises on the X axis, runoff increased on the Y axis. It should be obvious. But how much does it increase?

Well, if you have -- and I drew two red lines on here to illustrate this -- if you have an increase in precipitation from 550 to 660 millimetres, that's about a 20 per cent increase. Look at the runoff in -- that's the eastern Red River watershed that I chose there -- it actually increased from 50 to 110 millimetres of runoff. So now we have more than doubled the runoff. We have increased the rainfall, snowfall, whichever it was, by 20 per cent annually, and we put out twice as much runoff, more than twice as much runoff. So a small change in rainfall over the watersheds, especially in our dry western watersheds can result in very large increases in runoff. That's why when you saw on that map changes of the order of 10 to 30 per cent in precipitation were matched by changes in runoff of the order of 50 to well over 100, getting on towards 200 per cent in the worst cases.

So when people, when I get into talking about future climate, when people model a 10 per cent increase in precipitation, you better watch out for your runoff, it is going to be more than that. It is likely going to be more than that.

Let's put it all together. This is the total inflow to Lake Winnipeg, this is just a composite, add up all of the major tributaries, add in a little bit for the unmonitored area, and you get total flow into Lake Winnipeg. And that black line is the total flow into Lake Winnipeg.

As with the other graphs, the gray dots are annual flow into Lake Winnipeg. What you will see there is that the wet, dry, wet, dry, wet dry pattern -- I think there was one too many dries there -- three dry periods separated by three wet periods is reproduced in the total inflow. This is the sum of all inflows. So whatever else happens, even though droughts may not cover the entire prairies at once, they must be sufficient phases across the Lake Winnipeg watershed that they do affect the total inflow. And that's what you see happening.

But as with each river, you still can have vastly different annual flows from year to year, that are much larger than the average decadal flow from period to period. So even though you are in a wet period now, if you look back to the lower right most gray dot, that's 2003. 2003 is in the early part of a wet phase, and yet the third lowest annual inflow to Lake Winnipeg occurred in that year. So bear in mind that, when I talk about wet periods and dry periods, that's important from some perspectives, but from the point of view of individual years, you can not guarantee that a wet period will not have a dry year, and vice versa. I just don't want to make it too simple for anybody here.

There is one other thing on there that I want to talk about. So we have this wet, dry, wet, dry thing, that's actually -- and this is no surprise to hydrologists, no surprise to farmers, no surprise to anybody who lives on the prairies, we have here what we often refer to as the prairie drought cycle, which is maybe to some people a more or less accurate way of describing it. But we have a multi-decadal oscillation between wet and dry in the Canadian prairies, the whole west, and I think into the midwest of the United States, it is a very broad thing. And it is no -- they are not independent, they are affected by global climate.

And just for example I have put on here the Pacific decadal oscillation, which is really just an index that uses the pressure, the air pressure, or the sea temperature, which comes out to the same kind of pattern in two points in the Pacific Ocean, and if you make an index of the difference between pressure in, I think it is the northeastern Pacific and the western Pacific, you will find that that index correlates very well with a lot of different weather patterns throughout North America. It is not the only global index that will do this, but it does this very well with, for instance, the total inflow to Lake Winnipeg. So you have a system here that is responding exactly as you would expect it to on a hemispheric scale, a scale with the whole of North America for sure and actually more globally than that. So none of this is unusual.

What is a little bit interesting is

that although there is an approximate fit between that black line and that blue line, there is, to my way of thinking, a fairly dramatic divergence at the latter part of it in that although we are following the same pattern, we are getting more runoff out of it than we would expect if it followed the same pattern and kept the same relationship to the Pacific decadal oscillation.

And there are also hemispheric scale or global scale reasons to think that might be actually happening. And that is you have an index that is basically over the oceans which are responding to climate change actually more slowly with much more buffering from the ocean than the continent, so that the relationship between an oceanic index like the Pacific decadal oscillation and the actual weather, as opposed to the pattern of weather on the North American continent, may be changing, we may actually be getting wetter for any given oscillation and what is happening in the Pacific ocean. And there is quite a lot of evidence and investigation in the literature to support that. But we will talk about that a little bit more when I talk about future climate. And that's what I'm going to talk about now apparently.

Quickly, temperature, I won't spend a lot of time on it, but I do have a couple of graphs just to show you that we do expect, first of all, global climatic model expect that air temperature over central North America -- actually I'm thinking of a study of the Prairie Provinces, that global, that temperature over the Prairie Provinces over the next 50 years -- actually over the next 30 years, they begin these studies usually ending in about -- comparing usually about the 1970 to 1990 or something like that. By 2030 it is expected that the Prairie Provinces will be two to three degrees warmer. By 2050 it is expected that they will be four to five degrees warmer. These are results based on global climatic models that run many different scenarios ranging from, do everything you can to reduce our use of our burning of carbon based fuels, to do nothing. So when people give you a range of future temperatures, they are often saying that's because there's a range of things that we might do about it. But we do expect warming in the order of about two to three degrees by 2030s, and maybe four to five degrees by the 2050s.

What you see here is based on a study that I did actually about five or six years ago, and it was actually based on if there were an increase of two degrees in the average summer temperatures in Southern Manitoba, then you would see Lake Winnipeg increase by these amounts. And what you are looking at is the black line with the boxes are the 1970 to 1992 average temperatures estimated for the north basin and south basin of Lake Winnipeg. And the lines above it are a series of temperatures predicted for the lake for different scenarios. And it is suggested that the lake in the south basin or the north basin will warm by at least two degrees by 2090, as I put it there.

Now, if I did that today it would probably be higher, because more recent study suggests more warming than I was working with when I was doing the studies that I was thinking about at the time. Regardless, of whatever warming is predicted for Southern Manitoba is going to show up as a warming for Lake Winnipeg about a degree for a degree. That has a whole bunch of ramifications for algae and for the fishery, which are really not part of our concern here but something to be aware of.

Possibly a little closer to the concern here is how that might affect breakup and freezeup. What you see here are, on the X axis are all of those different scenarios from really reduced carbon consumption, carbon fossil fuel burning, to do nothing, sort of from B1 to A2, increasing effects. And I show what would happen from 2050 to 2090. And again, the box on the left shows the current mean and standard deviation and range of surface water -- sorry, well, first of all, ice melt and breakup in the north basin and the south basin, so the left two graphs. So currently the average breakup in the south basin is about the 8th of May, and in the north basin about the 22nd of May. And you can expect both of those to progress downwards by the order of a week by the 2050s, and possibly in the north basin in the order of two weeks by the 2090s.

So you will have an earlier breakup, a week to two weeks earlier over the next century. And conversely, you will have a week to two weeks later in the following century. That probably has some -- actually, it is something that you would be interested in if you are regulating the lake because ice can affect regulation. Though I doubt very much it is a significant thing, because you have specifically developed outlet channels to avoid and reduce the effect of ice on outflow. However, it is where the future lies in terms of ice on the lake, where it may lie.

Now, looking at the Lake Winnipeg basin and looking at temperature, I've just pulled out one of several predictions. This is data from a Natural Resources Canada study, and it is a pretty thorough, interesting, careful study Canada-wide, but with groups from each of the regions, including the Prairie Provinces, producing data for it.

The basis of this study was to run seven global climate models from the United States, from Europe, and the Canadian models, and to run them with seven different scenarios. So there is be 49 different possibilities here. The trend now when you are looking at climate prediction is, for safety sake I guess, to run as many different models as you can and see what they all do, and talk about the range of results. And the reason for that is there is a lot of uncertainty in this modeling business, and you might as well at least know what the uncertainty is.

What I presented here is not uncertainty, but some of the median results. What you see is predictions for the 2050s, shown there by season, and then annual, I think I will just mention the annual ones right now, suggests that in the grasslands of the Prairie Provinces, it will be, by the 2050s, about three degrees warmer, and there will be something like a five per cent increase in precipitation. And for the 2080s, by the 2080s there might be as much as a five degree increase in temperature and a 10 or 11 per cent increase in precipitation.

If you go to the forest, the numbers are fairly similar for temperature, a little bit lower, and that the forest would actually be the northern part of the Lake Winnipeg basin and the eastern part of the Lake Winnipeg basin. You would be looking at three to five degree increases in temperatures, but overall still only 11, 12 per cent increase in precipitation. However, that appears to have come earlier in the case of the forest and the grasslands.

Regardless, we are looking at this

thing about the precipitation itself. Overall, we are thinking that in the future we are going to have a slightly wetter climate. That's on balance of probabilities. This is a map that shows really the same data for precipitation, which gives you some sense of what they are talking about when they are talking about grasslands and forest, they are really dividing up the Prairie Provinces and the region around them into some pretty big squares. And what that says is that, it gives you some idea of a range that they are talking about. And you will notice the range goes from right from slight decreases in precipitation in southern Saskatchewan and south central -- southern Saskatchewan and central Alberta. I'm looking at the two brown squares in the upper left-hand graph. So you see that the predictions range from slightly drier to considerably wetter, but slightly drier is maybe in the order of 10 to 20 per cent drier, and wetter is of the order of at most in the 20 to 30 per cent range, I think, on that graph.

I think the take-home picture, though, is less change to the south and west and greater -- less change in precipitation to the west and slightly greater changes to the northeast and southeast. I'm going to buttress that by moving on to runoff, which is probably even more tenuous because it is now a derived value. You take those model precipitations and now you model the runoff, which means that you have incorporated into your model things like the -- not only the total precipitation, but when it occurs, whether it occurs with snow, whether the runoff is as a result of snow melt or of rainfall, which makes quite a big difference to the per cent that are runoff. And they take into account -- they would have had to take into account in their models evaporation and transpiration of the crops, all are big estimates. So you get this picture here, this is a picture, again, with many models and many scenarios put together and averaged and, in this case, interestingly they have added another map which shows an agreement in the model. This is a paper by Milly et al a few years ago.

And looking at North America, you can see on the top that northern North America is expected to get wetter, and the southwest is expected to get drier, and Lake Winnipeg, the basin sits right on the edge. To the southwest, either not changing or drier, right over Lake Winnipeg and throughout the Winnipeg River basin, wetter, with a lot of uncertainty in the Red River basin itself.

If you go down to the bottom graph you will see what is really just an evaluation of the number of models and scenarios that agreed or disagreed with the top graph, or the total agreement. And you can see for the white area, which is the whole southwest of the Lake Winnipeg basin, half of the models say wetter and half of the models say drier. That's what white means there. And at best in the northern part of the basin, only up to maybe 10 per cent -- no, 10 of the 20 -- I need to look at that, I think it is 10 of the 20 models, 10 of the 20 models. In other words, only a fraction of the models agree.

What I'm getting to here is there is a prediction for drier in the southwest and wetter over Lake Winnipeg and to the southeast, but there is a lot of uncertainty about it. And I think every planner who is planning for the next few decades had better plan for uncertainty. And again, this is not comforting, I suppose, to managers, but it is certainly very common among researchers to be aware of this. And hydrologically, what we talk about here, the word we use for this is we are moving into an area, a time of lack of stationarity. Stationarity is a comfortable thing whereby you can calculate the duration curve for a hydrological event. So what is -- which is a way of talking about the frequency or likely occurrence of this event. In an unstationary -- in a stationary system all you have to do is take the historic data and calculate the probabilities based on historical data. In an unstationary or non-stationary system, you can't rely on that anymore, because the climate itself is changing that gave you what you thought was a stationary system.

We already knew that, everybody who has dealt with floods in the Red River Valley. We grew up, I grew up, some of you maybe not have grown up quite as long ago, but I grew up knowing that the 1950 flood was a 100-year flood. That was an example of -- that was based on a duration curve of probability derived from that, that we all accepted until about 1979, and we began to get uncomfortable with it when there were a series of floods in the 1970s. And by 1997, we had recalculated it and 1950 became a 25-year flood.

That's probably not good enough for some of us, we also think that you should no longer calculate things quite that way. We don't quite have a better idea perhaps, but the point is that times are changing.

Okay. Let's talk about -- let me talk about how we think about this in terms of lake level. What does this do to the lake, and how should we think about it?

Well, not surprisingly the lake has its low periods, its low stand and high stand decades, and they fit right on with the wet periods and dry periods. So the '30s are low stands, the early '60s is what you might see as a series of low stands, and the late '80s, early 1990s were relatively low stands. Once again, if you look at that graph, and that graph shows you the dark blue is the minimum annual level, the mid blue, the light blue is the top -- that's the mean level, and then the white bar on top shows you the maximum level. So you have the range there. And the black lines are simply 10-year running means of that data.

Once again you can see that the lake

can be very high or very low, in particular it can be very low even during the relatively wet period.

Secondly, there is something wrong with that graph because the total inflow rose, the wet periods rose in each succeeding wet period for the total inflow, but they don't rise in each succeeding period for the lake level. And that is because, of course, since 1976 that lake has been regulated and the maximum level has been dictated, in so much as we can dictate to nature, by the Province's requirement that at 715 you turn on all of the spigots and get it back down as fast as you can.

Now, if you take the average annual level of the lake and try and correlate it with the total inflow, you will find there is actually a very poor correlation. You would think that inflow would be enough. You knew how much came into the lake, you would know how high it is going to be. Well, it is not quite that simple. But something that does work pretty well, and this is the black dots on this graph, if you take the peak lake level during the year -- and by the way, I probably didn't preface this as I should have so I will go back and say what I mean about peak water level. I will take these water levels and average two stations, one in the north basin and one in the south basin for a week, and I have done a running mean. What that has done, it has smoothed it, it has gotten rid of the peakiest peaks, the ones that only last a day or so, in particular it has gotten rid of setup due to the wind. So right now I'm talking about water levels have no setup on them. And these levels, if you take the peak of these setup free levels, you find that if you know the amount of flow that occurred in the previous 12 months, and you know the peak monthly flow in this year, you can estimate pretty well what the water level should be. And that's what those black dots are.

So from 1914 to 1971, I took every year in which there were no gaps in the level records, so that I knew for sure that if I saw a maximum level, it was the maximum level. That's why there aren't quite enough -- as many dots there as you might think over that long period. Those are the ones that have no gaps in the record, for either inflow or for level. And you find that if you use an estimating equation that includes, it is actually -- well, the previous 12 months flow prior to April, and the highest flow in this current year, the highest monthly flow, you can fairly accurately predict what the water level should have been. And it would fall along that dotted line, more or less. And you can see by the black dots how much uncertainty there is in it. So you are going to be right, give or take a foot. So it is not perfect, but not too bad.

Now, let's look at 1978 to 2013, which are the years when lake level didn't follow inflow. If you are below 715 peak lake level, you will likely fall pretty much right on the predicted curve. In other words, if you are at low level, nothing much has changed, inflow still predicts lake level fairly well. So at lowest values, those boxes down in the lower left-hand corner, I can't remember which is which, but one of those would be say 2003, very low inflow, very low previous year's inflow, and very low level. It falls right on the pre-regulation curve line. But as you go up above 715 on the X axis, so following the estimated peak level, the estimated level starts to head off to the right, it starts to be larger than the actual recorded peak level. And that, of course, is because as soon as it gets above 715, we do everything in our power to prevent it from getting higher.

So if you go over to the far right, you are looking at two boxes there, that top red box is 2011. Peak flow on the highest ever flow on the Assiniboine River, and it is all getting into Lake Winnipeg during that year, even though some of it is going through Lake Manitoba, and a very high flood on the Red River, it would have -- I would have to check this, but I think it was pretty high on the Winnipeg River and not bad on the Saskatchewan, a big inflow year all in all. And it gave us a value of 718 and a half or so feet for the peak level, which is a long ways above 716, and it is also -- it is quite a ways above that line, it is a foot higher than the model predicts it. In other words, if we didn't regulate the lake, it would have been a foot higher in 2011.

And the next one down on the far right is 1997. In 1997, even bigger case, the inflow, total inflow was -- well, it was the '97 flood, it was a very big year, very high peak in that year, which is one of the factors in the equation, and also a very high previous year. 1996 was, until

1997, 1996 was a miserably bad flood. So we had two flood years in a row that raised that lake to 718 and a half, again, roughly speaking, just reading off the graph. It should only have been 716 if it weren't regulated -- no, it was only 716 because it was regulated, it would have been 718 and a half, according to that graph and that relationship. And that relationship is pretty good if you don't have regulation from 1947 to '71. I trust very much that 1997 would have been almost two feet higher, and 2011 would have been a foot higher by that analysis.

You have seen perhaps similar analysis in the book and presentation made by Ray Hesslein, that has graphs that tell you the same thing in a different way, certainly presentations by Manitoba Hydro which tell you the same thing in a different way.

I think this is an interesting way to do it because it doesn't actually require any complex modeling of the lake to see that things would have been different. This is a pretty simple empirical relationship that appears to work fairly well and it is unlikely to be that far in error. So I think we can say those two things about 2011 and '97 with some confidence.

Now, you heard a lot about isostatic rebound this morning. Lovely presentation actually by Harvey, and I just wanted to add to it, and I'm going to put a different emphasis on it than Harvey. And we shook hands on this earlier, we will still be friends. But I think that climate is really important right now, even if it isn't important over the next millennia. I don't know what climate is going to be like over the next thousand years, and I do know what isostatic rebound is going to be like. So on the side of prediction and certainty, the effects of isostatic rebound, as Harvey described it this morning, is going to happen. On the side of climate, there are a lot of maybes. But right now, if we look at the last century of data, climate has been important in terms of the total water level of Lake Winnipeg, and the peak levels for that matter.

So if you look at that table at the bottom, from 2002 to 2011, the average regulated level was only 714, but if it had been unregulated -- and this is modeled and I will get to the model in a second, you know what these models look like because you have seen presentations by Manitoba Hydro, and I don't do anything hugely different than they do -- unregulated it would have been 715 plus. In the first decade of record, it was only 713. So that lake is two feet higher than it was a century ago. Isostatic rebound accounts for 20 centimetres, which is about .7 feet over that period. I would say that the extra foot and a bit, and I know Harvey put it before you, so I have to -- he made me rethink. I think I might have to rethink and it is hard to say, but isostatic rebound right now, as we understand it, accounts for about .7 feet. So a lot of that rise is due to the fact that there is more flow into the lake.

And I send you back to the previous graph, I won't go backwards in this, but if you go back to the previous graph, I explained why I think why the level is very closely related to inflow, even though over the long run, isostatic rebound has been an important effect and is a continuing effect.

I will come back to some of these things in a minute, but I'm going to go on to talk about what I haven't talked about, and that is that's not the total level of the lake. The level of the lake, as we are concerned about it, also includes setup, and I was asked to talk about how climate affects the lake level, and it affects not only levels through total precipitation on the watershed, which gives you runoff, but it also effects it through wind, a very direct effect on water level on the lake.

What I have done here is, I want to show you the long term history of setup, but before I do, I will show you what I'm going to talk about. If you look at setup, you can measure the lake level at Gimli, for instance, and that blue line is the hourly lake level at Gimli. But over the century I really, though, I could dig it out -- I didn't ask for enough money to look at the hourly records, it would be more work than I contemplated, so I looked at the daily records over the last 100 years. And the daily records also show you setup.

And here what you are looking at is the water level comparing the daily mean to the hourly mean. If I were working with hourly means, everything that I'm going to say about setup would be a foot or two higher. In other words, the blue line often peaks a foot higher than the daily mean says it would. So the next two graphs are going to be using daily mean setup. And every number that I throw out at you in terms of feet, think of it as a foot or two higher if you happen to live right at the south end of the lake, that's the preface.

So we now can look at the long-term history of setup. Now, climate is wind, and one can look at the long-term history of wind through wind records, but I warn you that that's a very tenuous thing to do, because wind is one of the most difficult things to measure consistently over a hundred years. We have changed our instruments. Many of those instruments have moved from place to place. The tower has moved here, it has moved there. It is moved because somebody built a building, the tower was too close, so they moved it away from it. Well, they got away from it but the record is now changed, because the wind record is very sensitive to obstructions nearby, near the anemometer, it is very sensitive to the height of the anemometer, and the instruments themselves have changed.

So let's forget about the wind and use

the water level itself. The water level acts as a response to wind, and I describe this in more detail in my report, I explain a little bit how you get from wind to water level. Basically, a setup is a response to sustained, usually strong northerly or southerly winds. And a setup, in my terms, is always a setup, if it is positive, it is up and if it is negative it is down. Some people would say setup and set down, but they understand the way I'm talking about it is positive or negative. But I'm really talking here, I'm going to use the water level at Gimli. Now, a setup is a short term thing, it happens when the wind happens. So I can remove it by taking averages of a week, especially if I take averages from the north and south end of the lake it works even better. But if I take the wind from Gimli and compare it with the daily mean, to the median level over the previous week, and just say that's the setup, that's how much it changed from what it was more or less for a week or so previous on average, now it is suddenly higher. It is just a consistent way of measuring it. The actual setup will be higher than this. If you look at that over time, you will see that over time it has gone up and down from year to year. Those are the annual values in the top row. So you can look at either the highest setup event in the year in the blue, or in the brown you can look at the median of the 10 highest setups. However you look at it, there is no really significant trend over time.

Maybe -- well, there is a very slight negative slope in that, but you could never get a statistical significance of it. If you go down to frequency though, similar thing, there is a kind of decrease over time, a little bit of a decrease in frequency of setup events, that is how many setups per year. It is interesting to note there are periods to them, there are windy periods and less windy periods. So the '30s and '70s for sure were not as windy as '40s and later '50s, early '60s, that's just an interesting thing.

The long-term point about this is setup, wind and setup are with us and haven't changed a lot. They may change over time into the future, but I think that the kind of events we see now are the kind of events that we will see in the near future in terms of setup events. They are not unusual now in the century. If anything, they were unusual at the turn of 1914 to 1918, it looks really high there. I would actually wonder a little bit about making the record, but maybe it is real, who knows? But I don't care too much about the first decade. I think over a long period we have a situation where it is not changing very much.

Those were -- this is just one slightly different way of looking at it, I won't dwell on this too long, but really what you care about if you are a cottage owner, I suppose, you have a structure on shore that you are concerned about, is whether the setup occurs at the highest water levels, not whether or not 10 setups occur this year. If they all occurred when the water was low, you are not going to care too much. If you look at it this way, the frequency and relationships haven't changed very much again over time, but what you can see in that top graph is, I take in the brown, that's the annual maximum setup free level, and in blue is the setup that was on top of that maximum level. So you will note that by and large, the largest setups are not frequently occurring at the highest levels.

That's a very -- that's a little bit of an oversimplification. You could do a lot of statistics on this. But just because there are 10 setup events per year, it doesn't mean that there are 10 setups of concern each year, that's what I'm saying.

If you look at the bottom graph, you are actually looking at the maximum setup during the year, and what the water level was at that setup. So I just reversed the situation. And you can see that almost all of those setups are almost twice as high.

So the highest setups did not occur at the highest levels, except on very few occasions. And that's just a probability thing, which I haven't delved into a great range, but it is just a way of thinking about it.

I will say one more thing about this, and this confirms what anybody who lives on the lake will tell you, autumn is windier. If you look at the distribution of setups, I just did two graphs here, anything that exceeded one of foot change in the daily level from the previous median week level is a one-foot setup, and if it exceeded two feet it is the two feet setup. What you see there is that if you look at October, over 25 per cent of all setup events occur in October. And if you add, September, October and November together, that's about 65 per cent, or two-thirds of all setup events occur in September, October and November. And for the very highest setups in recent decades, especially from 1980 to 2009, that tall purple line, almost half of the big setups occurred in October. That's all that graph shows you. So these are fall events.

Now from the point of view of regulation, I will comment on this, and I don't think -- you can ask me about it later, but I don't think it is a major issue -- if most of your setup events are occurring in the fall, then if possible, and the best of all possible worlds, you would want that lake level to be -- if that's all you cared about, you would want the lake to be as low as possible in the fall, hang all of the other things, you are not going to care about April, May and June so much. But that's not the way rivers work in the first place. Rivers do peak in the spring and they cause the lake to peak a little while afterwards. And then depending on whether it is a really dry year or really wet year, regulation will move that peak.

So these are all things that you can

keep in the back of your minds when you are thinking about regulation. The key thing to remember is the data itself says when the setup events are primarily occurring, so it gives you a way to think about it.

I will take you on to my last three graphs, if I'm not mistaken. And this graph, I really put it on there to show you the black dots, but maybe I will discuss them both very briefly. What this is, is a form of stage discharge curve, which is something that Harvey talked about this morning. What it says is that for any given water level which is across the X axis, you will have a given outflow value. So the higher you raise the water, the bigger your outflow cross section is, the more water will flow out, if it is not regulated. So the black dots are the data from 1958 to 1972 unregulated. And we've all used these, Manitoba Hydro used a very similar graph to create a model of regulated versus unregulated flows, which I'm going to do in the next couple of graphs. Ray Hesslein used the same kind of data.

This takes the data not from the outflow directly, because there was no measurement there, but it takes the data from Ladder Rapids actually, which is a little further downstream, up until the 1969 or so, and then they built, put in a hydrometric station at Jenpeg. This takes the pre-regulation data of the black dots and says that there are two curves. There is a curve in the summer and a curve in the winter. I didn't overlay them, but what you will see is that for a given elevation, you can get more water out of that lake in the summer than you can in the winter under natural conditions. And the reason that happens is because the natural outlet at Warren Landing is a broad, shallow outlet. And a broad shallow, outlet that is, I think, on average only about three metres deep, it really depends on the water level on the lake, and it depends on -- it is near a regular wide cross section, but it is three to five metres deep, and much of it is only three metres deep. If you put over a metre of ice on top of that, you have constricted the outlet. So for a given elevation in the winter, you can't get as much water out in unregulated conditions.

Now, if I had overlaid those two graphs, if you look at the dots, the dots for winter and summer in 1978, 2011, actually the winter and the summer curves fall right on top of each other. They have a lot more scatter in them, because sometimes at a low level you can still be slowing down the flow. You can do whatever you want now -- not whatever you want, but you have a lot of control over it. But summer and winter is not much different there, because we don't depend on the outlet at Warren Landing, we depend on the 2-mile channel and the 8-mile channel and Ominawin bypass. Those structures have deepened and increased the efficiency of the total of the outflow. The reason for the deepening, many things maybe, but one thing for sure is if you can get an outflow that's 10 metres deep, which I think is the median depth of the 2-mile channel, you don't care about a metre of ice nearly so much, that's going to constrict the flow by a small fraction, whereas if the depth is only three metres it is a big fraction.

So, in fact, we now have a system that has a lot more efficient outflow. In fact I think it is claimed to be about 50 per cent more efficient outflow. It is in Hydro documents somewhere. That's the whole point of those channels is to get the water more efficiently through Playgreen, Kiskittogisu, and down to the

Whiskey Jack landing to Jenpeg. And you want to do that because you have better control over the lake that way, you have more efficient, precise control over the lake if you have direct control. But it also means that you can get water out more quickly, which of course from the Province's point of view is the important reason for doing that. Hydro may be concerned about winter and summer efficiency and ice, everybody is concerned about high water levels. You increase the depth and the capacity of those outflow channels, you now have much more flow going out.

If you look at those two graphs, if you are at 716-foot elevation in summer, you can get around 120,000 CFS going out the outflow and that's it. But if you are at 716 feet now, we can actually pump 160, and more actually, I think the numbers go up even higher than that, but 716 to 717, it is 160 to 180,000 CFS going off of that system. So we have vastly increased the capacity of the outflow.

And before I go on I will say one more thing, and this is based on conversations with Dr. Thorleifson. When you -- I will do this just for a second here -- when you fill a pan with water -- I will do his pan -- you fill a pan with water, and you have a spigot coming in here, and you have a notch on the end of the pan here and you tip it this way, you are going to raise the water back here. Just hold it like that. Water keeps flowing at the same pace, we have a gallon per minute coming in and a gallon per minute going out. We have a level. Let's cut that notch deeper, the water level will drop. If natural outflow sill was 3 to 5 metres below the current lake level, and the 2-mile channel, sill, bottom of it is 10 metres below the lake level, we have gained 5 metres of control over isostatic rebound.

So although we may regulate it, and we do actually by law regulate it between 711, 715, which means we are not going to change it, as long as we do that, we can make the level stay at 711, 715. But if we wanted to, we have the capacity to change that. We don't have ultimate capacity, we still have a maximum flow you can actually get out. So in a year like 2011, or 1997, it is doubtful that you could change that, because there is huge flows going in and they are quite a bit larger than the capacity of the outflow, so it is going to build up anyway. But again, something to think about.

The natural state of that lake is to rise and flood at the south shore, but the engineering state of that lake might not be. You should be aware of that as a possibility. I wouldn't take that much further than that, but I would think that's something that everyone should think about. We are not operating in a natural world anyway, we are operating in a managed world right now. We are managing our climate for sure and we are managing our lake.

So let me take that -- let me take the stage discharge curve and calculate the discharges for given elevations, use that to model the lake levels in the lake approximately the same way that you have seen in reports by Manitoba Hydro and by Ray Hesslein. I have seen two of them that have used this basic model, which is you take the inflows, you take the fact of the stage discharge curve and the outflow, and you can calculate what the lake level will be for any given outflow, because you can calculate -- for any given inflow you can calculate the outflow and, therefore, calculate the lake level. That's a very simple model. This is based on monthly data, it's not based on daily data, but it does things reasonably well.

I'm going to present two graphics here. This one really is just preparation for the next one, I suppose, to tell you how I'm doing this. I'm going to go back just for a second and say why I have got all of these lines here. Although I can calculate the outflow for a given level on that graph, if you look at those black dots, say around 714, go straight up from 714 in the summer to that line, you will notice that at 714, the outflow could be anywhere from maybe around 80,000 to 110,000 cubic feet per second. It is not a precise stage discharge curve. We can too, when we develop a stage discharge curve, I'm saying we as in a hydrological hat here, we tend to pick a cross section and a river that is ideally smooth and simple so that for any given level there will be a fairly accurate estimate of the flow. And we often think that our discharge records, like the record on the Red River at Selkirk where it is measured, for instance, we expect that to be within 5 or 10 per cent of the exact number. We don't expect it to be within 1 per cent by the way. But we expect any given day that that number will be within 5 per cent we hope for actually.

Here the uncertainty is much larger because we have got a lousy cross section. Warren Landing, irregular, got a lot of weeds in it, it's got ice in the winter, we don't know when the ice went on or the ice went off exactly, we will just say from December to April we will call that ice, the rest of the year we will call that no ice. So we have a rough number here. I did a little bit of work to see how accurately I could do that and then I put bounds on it. I want to show you the effect of these bounds. This is actually a little bit artificial here, the next will be more real. That blue line is the average, actually, the average actual record of flow. And the larger, the wider blue lines on the outside of that, the inner bounds, are that value plus or minus the error from the estimate that you would make if you are using that curve at Warren landing. So that's the estimate of my uncertainty, and then on top of that narrow blue lines I add on setup. In that case I took the peak setup in each year, which I calculated, and I took the recorded flow. And to the recorded flow first I added the standard deviations, which is the error from that graph, and then I added setup, and the outer bounds of that are what should have been the maximum and minimum flow that year under regulated conditions, in fact, here, I'm not using the equation yet, I will in the next one. And then I plotted on that the actual maximum and minimum level on the dotted line. What you will notice is the actual maximum and minimum level is pretty close to what I estimated, and that's all I wanted to get across here is that this system works fairly well.

So now let's estimate what it would have been like under unregulated conditions. So now we have a more real graphic here, where the blue line is now, the big fat blue line is the average unregulated water level, given the total inflow and given the capability for outflow that year. So it is a modeled value. The bounds around it are the error, the uncertainty in that estimate, so the dark lines are the uncertainty in that estimate. And then to that I've added the setup. And those were the actual setups in those years. Those setups would have been the same whether it was regulated or unregulated.

So now when you look at it, look at

the line for 715, and you will see that it is likely, under unregulated conditions, that in every year except 2003, in every year since 1992 except for 2003, the lake would have been higher than 716.

Let's go back up again. These are not -- you have seen this in other ways I think already. If I go back up here, at 715 it would have been -- it was indeed higher, perhaps I should have overlaid these, but it actually has gone higher.

If you look at 2011, this is the year of the Assiniboine/Red flood, peak year, we actually probably would have reached a level with setup of between 719 and 720, and we didn't. The actual record back here where we did reach 718, we would have been a foot to a foot and a half higher, which by the way is exactly what I showed you in that graph before. So we have now come at this in two different ways. Either way, if you live along that lake and your concern is high water, you are better off than you might have been.

Other things that could be said about that is how this works, I think to a certain extent this is covered in my report, but how this works depends very much on whether you are in really wet years or really dry years too. If you look at that pink line, you will see that through the period from 1978 to 1987 or so, the pink line is either equal to or slightly higher. So the regulated values are slightly higher in some years, equal to what they would have been in the low years, and slightly lower in the high years. So they have narrowed the range of the 80 by regulation. But from 1995 on, in almost every year, the water level has been lower than it would have been, the average water level. What I'm adding to this here to some extent is, it is not only the average water levels, of course, the high water levels as well have been reduced.

So I'm going to summarize, and then you can take it from here with questions if you want. What have I said? Well, I didn't say this, but I might have said this at the beginning, or I should have. There is a lot of range in the annual inflow to Lake Winnipeg, so it has varied on an annual basis by four times. So a big range to work with, it has got to have an effect on lake level, I think, so I went about figuring out how much.

Climatically, over the 20th century, there are several studies that show that both rainfall, snowfall, outflow, that's runoff or flow in the rivers, have increased in the Winnipeg and Red Rivers. And they have increased by substantial amounts, over the century the Winnipeg River by I think I said 60 per cent, and the Red River by 160 per cent. Those are very big changes.

In the Saskatchewan River, a decrease in runoff or total flow of about 30 per cent. Hard to say whether the rainfall has increased or decreased, it is up and down at different stations. For the 21st century, more of the same. We expect, if anything, that there will be increases in precipitation over the Red and Assiniboine. Over the Winnipeg River watershed there is the strongest, possibly the Red River watershed, it's a bit iffy. In the Saskatchewan, either no change or drying, it is not very clear. So some show increases, some show decreases, I wouldn't go very far with them. But if the flow increases in the Winnipeg, it will probably take care of any decreases in the Saskatchewan. If it increases in the Winnipeg and Red, it will pretty much for sure because those provide more than half of the total inflow now. So there, on the plus side the wettest regions will probably get wetter and they will continue to provide more than half of the flow that Lake Winnipeg needs.

A real consideration is that there are marked decadal or multi-decadal wet and dry spells or periods. So they cause variability in runoff and a bunch of other things, and that variability is bigger than most of these trends we are talking about, except in the Red River where actually the wetter periods will continue getting wetter.

But in a general way, if you were asking me to predict what was going to happen by 2050 or 2080, I might say it is going to get wetter. But if you were going to ask me what happened in a year, or what it would be like 10 years from now, I would not necessarily say that. We are in a wet period now. Even if average climate is going to get wetter, I think it is likely there will still be dry periods, and there will certainly be dry years. 2003, remember, third driest flow year on record, and definitely I think the third lowest lake level -- that's not quite true, fifth lowest or something lake level on record. So very low year, 2003, but it is in a wet period. So don't count on anything that I say, or at least think of it as complicated.

Daily mean setup free water level on Lake Winnipeg. Get rid of the setup and its range from 709 to almost 718 naturally, and then with setup, certainly at the top of that range it has gone up over 719, and would have been higher, would have been a record high say in 2011 if not for regulation.

Water level records, like the climate records, is marked by succession of high and low water periods to correspond to the wet and dry periods. But overall the lake is one foot higher than early in the 20th century, and without regulation it would have been two feet higher.

And I would say that if indeed the 21st century is wetter, then there will be more runoff. If it is 10 per cent wetter by precipitation, it will be much more than that by runoff. Remember, 10 per cent could easily give you a 50 per cent runoff. If all of those things are borne out, then it is not going to be easy, and I may be going out on a limb and say it might be impossible, it will be very difficult to manage Lake Winnipeg level below 715 in the future, unless we have a good long drought, and then we will think about it again when the next wet period comes along.

I think I have run out my time and I need stimulation from questions or else I will quit. Thank you.

THE CHAIRMAN: Thank you, Dr. McCullough. We will take a short break to allow you to become stimulated again before the questions hit you. So if you could come back within 15 minutes, that will be just about before 20 after.

(Recess taken at 3:05 p.m. and reconvened at 3:20 p.m.)

THE CHAIRMAN: Okay, let's get back at it. Questions for Dr. McCullough? Manitoba Hydro any questions?

MR. BEDFORD: No, thank you.

THE CHAIRMAN: Thank you. Any of the participants? Mr. Williams?

MR. WILLIAMS: I thought Ms. Whelan Enns --

THE CHAIRMAN: If she is outside on

the phone, if she doesn't come in the next minute or so she is out of luck.

Panelists? Mr. Yee?

MR. YEE: Yes, Dr. McCullough, I noticed on slide 31 you have got the regulated observed in the Red, I'm just wondering, Lake Winnipeg Regulation began in 1976, I'm just wondering why the line starts at 1967?

DR. McCULLOUGH: Actually I was just -- my own conservativeness. I was looking at the pre--- when I did this, I had actually extended back further than that, and I was looking at the regulated versus -- let's say the observed versus the modeled in the pre-regulated period just to make myself comfortable that the model was coming out reasonably so. If you saw large differences before 1976 in that graph, you should be concerned about whether or not I had a model that worked. So it is on there because I wasn't particularly concerned about hiding it.

MR. YEE: Thank you.

THE CHAIRMAN: Ms. Suek?

MS. SUEK: Yes, I do have some questions. One of the things that you mentioned is that the effect of the water warming up on whitefish. I don't know if I have heard that before, but that was interesting to note because whitefish is -- the loss of the whitefish seems to be a very important item for people downstream who depend on that as a domestic fish. The fish have been affected by climate change, in fact, is that correct?

DR. McCULLOUGH: Would you say the last part of that again?

MS. SUEK: The whitefish have been affected by climate change, which has warmed up the water in the lake and I assume downstream?

DR. McCULLOUGH: Yeah, well, the reference that I was thinking of there is to, yeah, the sensitivity to temperature in the -- as I understand it, they are not common in the south basin because it is too warm. If the north basin warms by as little as two degrees they may be endangered there, and the reference to that, it is not my own work of course, it is a study by Bill Franzen out of the Department of Fisheries and Oceans in the 1990s, where he looked at -- I worked on this study with him -- where he looked at the effects of climate change on the fisheries in general, and whitefish was one of the fish species that was of concern and that is because it is near the southern extreme of its habitat there anyway. The question would be an important question and qualification as it always is, is that surface water temperatures I am describing, but in general the lake mixes fairly thoroughly, fairly frequently during the summer, not always. If the lake does mix deeply, then it is mixing that warm water all of the way down to the bottom. If it doesn't mix deeply, it may form a -- this is getting a little complicated -- it may form a thermocline in which case it could actually go anoxic below the bottom and they couldn't get there anyway. So either way a warming of the lake is a great concern with regard to whitefish. And as I recall, this could be checked from the references, two degrees was sort of the point which they would become concerned.

MS. SUEK: Okay. It looked from some of the charts that we haven't had a drought period for quite some time. There were comments from people around the lake that the marshes need that drought period to regenerate. And it looked like there was a long period of time, and we know it is wet conditions, and it sounds like what you are saying is we will probably continue to have wet conditions which will continue to affect the marshes around the lake, is that --

DR. McCULLOUGH: Not quite that simple, but the answer is yes, sort of. We expect on average that the climate will get wetter, particularly in the Red and the Winnipeg River basin, which probably means the total inflow to Lake Winnipeg is more likely to increase than to decrease. That's on the basis of quite a lot of studies. Having said that, that's the average, and when you look at those trend lines for total inflow, let's say, just for example, if you look at that dashed line, that's the trend line, but that's what we mean when we say that the runoff is going to increase. But you can see that in a dry year it can go well below that line. So if we are in a wet period now that is going last, it has already lasted as long as any has in the past, this is going to come to an end and we are going to be followed by a dry period, then it may well drop below that trend line again. So even though it is going to get wetter on average, we do expect that we will still have droughts, and for Lake Winnipeg it is really a question of whether droughts are widespread enough throughout the basin and in the critical regions like the Winnipeg River and the Red River in particular, whether those ones are dry enough to lower it.

So I expect, based on the experience of 100 years, I expect it is going to continue to go up and down and up and down, but overall each time it gets wet it will be a little wetter. That would be the basis of my experience based on the past and what I've read of the climate prediction literature.

MS. SUEK: Okay. So -- I think you very clearly said that Lake Winnipeg Regulation did help or has helped the fluctuations, the high fluctuations in Lake Winnipeg since its inception; is that correct?

DR. McCULLOUGH: No, since we have been in a wet period in particular, so since the mid 1990s, in most years the lake has been lower on average than it would have been, and in the last half dozen years in particular it has been quite commonly as much as a foot lower and very particularly I pointed in 1997 and 2011 where it has been in 2011 it was probably a foot lower than it would have been, and in 1997 it may well have been two feet lower than it would have been, if I have got that right.

MS. SUEK: Okay, thanks.

DR. McCULLOUGH: So it has been lower.

THE CHAIRMAN: Mr. Harden.

MR. HARDEN: Okay. I have got a few questions. Your charts on page 11, annual discharge of major tributaries, could the runoff increase, particularly for the Red River, be partially explained by the influence of land use and drainage in the watershed?

DR. McCULLOUGH: Yes. And the answer to that is equivocal again, but there are studies in the Red River basin, actually in the Assiniboine River part of the basin, I am referring to Pomeroy et al from the University of Saskatoon, a widely cited study now, that showed that the 2011 flood produced I think 30 per cent higher flows, or maybe 30 per cent higher total discharge than it would have had wetlands not been removed. So, if you went back to 1958 and had the same rainfall, snowfall conditions and the same rate of melt, et cetera, everything else the same, he is saying that the flood would have been 30 per cent lower. So he says, based on a modeling study, yes, land use has changed runoff in the prairies.

There is a separate study by Ehsanzadeh, who was also out of Saskatoon I believe, who did a modeling studying -- no, he did a historical study, and he looked at 50 years of data from the Assiniboine River, he looked at what is called gridded precipitation data, which means that he took historic precipitation data and calculated the average or total precipitation over the watershed annually and the total flow out of the Assiniboine annually, and he could show no change over 50 years, and therefore concluded that whatever had happened, the response of the Assiniboine River to precipitation had not changed, therefore land use practices had not changed. In other words, there are studies that say exactly the opposite things within the basin. And I guess since I'm supposed to know about these things, I will comment on that a little bit and say that it is very, very difficult to do the kind of study that Ehsanzadeh did, because precipitation records are very scattered.

If you looked at that data that I showed, those map data, you would see that stations side by side could look entirely differently. So we just -- I don't think that we have good enough precipitation data to do it the way he did it. I am hesitant to accept that study. I think Pomeroy's study was probably state of the art modeling, could be wrong, but I would lean a little towards that.

So in brief, it is very possible that in the Red River basin in particular the land use changes have contributed to the increased runoff. Having said that, there is no question that there is more rainfall and that you could probably explain most of that change in runoff in the Red River basin based on precipitation, just using that graph. In other words, there has been at the rainfall stations a 11 per cent, I think it is an average of 11 per cent increase in precipitation over the Red River basin comparing the 1996 to 2005 period, the previous 50 years, and there was 100 some per cent increase in flow. I have forgotten the number right now. In other words, I think precipitation has probably been the bigger driver. But there is no reason not to say that land use may have been a significant driver as well, and there is some reason to say it.

MR. HARDEN: Okay. So taking that to its logical extension then, I'm thinking about a paper that we have from the IISD. Okay, if we can take it to a logical extension, with regard to the paper we have from the Institute for Sustainable Development, would it be, I don't know the correct word, would it be proper to say that simply increasing small basin storage in the watershed would be insufficient to reverse the trend in inflows to Lake Winnipeg then?

DR. McCULLOUGH: I think to reverse them probably, it would certainly -- if you could store more water in the watersheds, which is really what you are doing with wetlands and as with the Pomeroy study, or by other means store water in the watersheds, you would reduce the total flow into Lake Winnipeg. It would take a lot of doing to overcome 1997 or 2011, for instance. You could reduce the peaks probably, according to that study, so yes, I think you can reduce the increase, I don't think that you can turn around the increase is what I'm saying. And I will just throw an aside in there, I think that document mentions there are side benefits to that, and those side benefits with regard to Lake

Winnipeg are nutrient storage.

MR. HARDEN: Yes.

DR. McCULLOUGH: And there are quite a few studies that show also that that's very real.

MR. HARDEN: Yes, for sure, I am just going on that inflow basis. Also I think you have partially answered this, but just to confirm, that there was no correction for say the Red River and Dauphin River watersheds for the Assiniboine River diversion at Portage, you just took the flows as they were recorded?

DR. McCULLOUGH: The flows are as measured, but they are both in there because the flow is measured at Dauphin, and the flow was measured at Selkirk in that graph. So you can actually see the 2011 event in that graph, that very high peak on the Dauphin River, and the subsequent year, those are the water coming out of Lake Manitoba and it took two years to get out. So there is a huge amount of water involved in those 2011, 2012 point. If that had not gone through the Dauphin River, even more of it actually would have gone through quicker through the Red River system and the dot in the Red River graph would be higher. But the same total amount of flow is going into Lake Winnipeg. It is taking a little longer to get there through Lake Manitoba.

MR. HARDEN: Just a note that we have to be careful in interpreting those results because they are affected by man-made works.

DR. McCULLOUGH: Yes.

MR. HARDEN: Now on page 16, your bar charts for the average date of breakup I guess on the north and south basin, would it be reasonable to expect the outlet lakes to act the same?

DR. McCULLOUGH: Yes, the absolute dates would be a little different, but the changes would probably be similar. I think the outlet lakes, Playgreen Lake in particular breaks up a little before the north basin on Lake Winnipeg. But that would move probably the same amount over the two 50 year periods, or the two 40 year periods, so yes, there would be changes in the Playgreen Lakes would be corresponding, but just that the precise dates would not be the same.

MR. HARDEN: And my last question relates to increased temperatures. So you -- the long term trend seems to be increasing water temperatures in Lake Winnipeg, would that be reflected in an increase, corresponding increase in net evaporation from the lake?

DR. McCULLOUGH: Yes, it would be and I haven't calculated evaporation here. And I can't off the top of my head say how significant a two degree difference would be to evaporation, it would need calculation to say that. There would be a couple of things happening, the temperature would increase, it would be a question of whether -- if we look at global climate modeling actually, you calculate evaporation directly you may actually have changes in route of humidity that would affect it, for sure. Winds of course would affect it, but I have already said I don't think that they are changing a lot. There would be many things that affect it, but most simply put, two degrees of warming of the surface water has to increase the total amount ratio, I don't know how significant the number would be.

MR. HARDEN: Thank you, those are my questions.

THE CHAIRMAN: Thank you. I have no specific questions. Ms. Whelan Enns, did you have some questions?

MS. WHELAN ENNS: Gaile Whelan-Enns,

Manitoba Wildlands. And thank you, Dr. McCullough. I can sort of see you. I'm going to try to go quickly through the questions for you.

The Clean Environment Commission in the hearings we were in last winter asked our office for some definitions and explanation of the precautionary principle. Would you consider that the precautionary principle is incorporated in your thinking in terms of the analysis that you have done for the CEC?

DR. McCULLOUGH: Not directly, because I'm not offering advice directly as to the solutions here. I think I'm mostly presenting what I understand to be the relationship between climate and level records in Lake Winnipeg. I -- as I understand, the cautionary principle would take effect if I were to be offering solutions here, which you can ask me about I guess, but I haven't, I have had fairly limited mention of solutions.

MS. WHELAN ENNS: Thank you, that's fine. Could you tell us briefly in terms of your slide 4, how you determined these three locations, The Pas, Dauphin and Brandon weather stations?

DR. McCULLOUGH: Those stations were selected because they have been reviewed by the AHCCD, that's the Adjusted Historical Canadian Climate Data set I think. Historical weather records are subject to error, or to change -- are subject to the effect of changes in instrumentation, the instruments you actually use to measure things, where they are placed, location of stations, a whole bunch of things. If you select weather stations directly, if you are looking at historical temperature, for instance, and you take weather records from the atmospheric environment services website, for instance, directly, they would be uncorrected data. I chose these ones because each of them has a record in excess, or of close to or in excess of 100 years long. They have been corrected for instrument and station changes according to the best estimates of the atmospheric environment service. I couldn't do a better job of correcting historical data for any other stations. There are other stations, of course, that could be used, and I wouldn't actually say -- I even did a very thorough canvass -- but there are many other weather stations in Manitoba, of course, only a select set of them last that long at one station, and only a smaller select set have been selected by atmospheric environment services to go through the long process of correcting them. So that when you look at a 1910 or 20 temperature, you can believe that it was measured, represents about the same temperature as if it were measured ten years ago.

MS. WHELAN ENNS: Thank you very much. I have heard a couple of comments from you today about precipitation data having some challenges in terms of obviously consistent over time precipitation data, but also having to move instruments, having to adjust things, having changes along the way, even if it is was 50 or 100 years worth of data. Do you consider that our precipitation data in Manitoba is of high quality consistently, or again you selected, for instance on page 7, on slide 7, you selected stations again. My question is similar, that is did you select stations where the data is of higher quality and has been through previous testing and assessment?

DR. McCULLOUGH: In terms of how I selected the processes is analogous. The Canadian data is corrected exactly as I described, it is the AHCCD data set again corrected historically and the American data is corrected in approximately the same manner by their agencies. So they are strictly -- those data sets are again limited by the length of record, in that case they are 80 to 100 years or so. No stations with shorter records were selected and not every station was selected for this.

In other words, if I just for comparison go to the next graphic, page 8, you will see there are many more stations on there. Those ones are all of the stations in those corrected data sets that have records that go back at least to 1946. As I go back further and further in time I have fewer and fewer stations that I can really rely on. Also if you look at that graphic, you will see that the data is not very smoothly distributed. If you look in particular at the winter data in the upper left hand you will see stations that are close, they are within several hundred kilometres, that may be increasing or decreasing. In other words, there is a lot of spatial variability in especially precipitation data. There is a paucity of good really long term precipitation data sets in

Western Canada in particular, and that's even compared to just across the border in Minnesota. I envy Harvey.

So, yes, the reason that there are selected data sets and fewer data sets than one would want to do certain kinds of studies, these are designed, and this graphic is designed mainly to give you a general picture that if it didn't coincide and make sense in terms of the pictures of runoff, I would be very hesitant to know how to interpret. It is really the runoff data that I would lean on for this particular study. The runoff data is -- runoff is a measure that generally speaking historically has fewer problems.

MS. WHELAN ENNS: Does the AHCCD process include then water gauges in Manitoba and water gauges on Lake Winnipeg?

DR. McCULLOUGH: Not directly. I don't know that we have a Canadian process. There is an American data set that is corrected historical hydrometric data. I can't say that there is one in Canada, I don't know.

MS. WHELAN ENNS: Thank you. For my next question I apologize not having the exact title of this report that I'm going to ask you about, I have been receiving but having trouble sending email this afternoon. But I want to ask you whether you have had occasion to review or rely on the study that was done in I believe 2010, 2011, through Dr. Blair's department and grad students at the University of Winnipeg where they collated the data from all meteorological stations in the province?

DR. McCULLOUGH: I have a digital copy of it, I read it, and I'm aware of it. I didn't use it in a direct way for anything here, but I certainly use -- make reference to it and have gained knowledge from it in my other studies. When I begin to do more particular studies, as I do in sub watersheds, I do quite a lot of work, for instance, in the LaSalle watershed where I need more intensive, spatially intensive weather data, I have referred to that to find where there is other data. So, yes, I have used it.

MS. WHELAN ENNS: Thank you. Next question is somewhat related, and that is the Manitoba climate atlas that is being developed at the University of Winnipeg, again through Dr. Blair's department and his grad students. My question then is whether or not you would agree with what seems to come forward pretty clearly on their graphs and their maps, that the frost in and frost out dates, the start and end of frost and ice, those dates are shifting significantly in Manitoba?

DR. McCULLOUGH: Well, I can't answer directly about the frost dates. I've probably read some things, but I have not -- I don't have any particular expertise on it. I'm aware of reports about it, that's all. I am -- I can certainly say, for instance, with regard to ice, if you are referring to river ice or lake ice, I have made studies of it myself, and I think I refer, actually would refer anybody to the work of Bill Rannie, also from the University of Winnipeg, on the ice in the Red River which provides us with almost 200 years now of pseudo climate or pseudo weather, pseudo temperature records for the southern province by way interpreting the breakup and freezeup dates on the Red River, which have changed. In that regard over the century and a half, or almost two centuries, that he stated century and a half, but it is a while ago now, he showed from the mid 19th century to the late 20th century about a two degree increase in spring temperatures in Manitoba, based on the ice out record from various sources, including Hudson Bay Company and so on. I can't say too much, no one can say very much about the long term ice record on Lake Winnipeg. There is not a very good, long term record of ice on Lake Winnipeg, to my knowledge. I think there is something like 40 or 45 years of data on the south basin by a weather recorder at Gimli, but for the lake as a whole, for the north basin we don't know much.

MS. WHELAN ENNS: That's our understanding too. Thank you.

You have made a couple of quick comments today regarding the channel, that is the increased discharge overall from the Dauphin River, and there was a reference to the emergency channel, now channel, from 2011 in one of the things you said.

Have you given any consideration to what you are telling us about the Dauphin River inflows and the potential for the inflow from that channel, and what I think of as channel 2, as the one that is intended that does not -- is not in place yet?

DR. McCULLOUGH: I'm not quite sure I got the question part?

MS. WHELAN ENNS: I could try again.

Do you see the inflows from the Dauphin River that are going to go through the 2011 channel, and then potentially a further channel, do you see them as significant in terms of your analysis of the inflows to Lake Winnipeg?

DR. McCULLOUGH: No. In terms of this analysis presented to you, no. The actual flows, all of the flows into Lake Winnipeg are recorded regardless of where they came from or what caused them. They are just -- in those graphs that you see in front of you on the screen right now are data as it was actually measured at those stations, so we know how much came through. And it is a bit of a coarse analysis to take -- a coarser analysis that would take that into account. For instance, as I just commented in answer to a question, when I look at it I can see that the Dauphin River was high not only in 2011, I think it was high in 2012 as well from the look of it. If that's correct, that would suggest to me, and it is not surprising to me that the lake managed to store water, quite a bit of water, and deliver it the following year, that would not have been stored and delivered the following year if it had gone via the Assiniboine into the Red, into Lake Winnipeg. So there are differences to the way water is delivered. There are differences to where water is delivered. And finally, there are great differences as to the chemistry of that water, quality of that water.

If you want me to elaborate on that, the simplest thing is if you put Assiniboine River water through Lake Manitoba, you will lose a very large portion, say of the order of three quarters of the phosphorous, for instance, that is carried in the Assiniboine River that was diverted to Lake Manitoba, never made it to Lake Winnipeg in 2011.

MS. WHELAN ENNS: Thank you. That is pause for thought in the room.

DR. McCULLOUGH: Not if you live on Lake Manitoba.

MS. WHELAN ENNS: Correct. I'm looking at slide 11, and this is just a quick question. Your reference is to the Saskatchewan River, on the South Saskatchewan; is that correct?

DR. McCULLOUGH: My reference is to consumptive use on the Saskatchewan River are to the South Saskatchewan. Those flows are for the whole Saskatchewan River. So what you are looking at on that graph is the river flow as it is measured at Grand Rapids and/or at The Pas. So we are looking at the whole flow from the Saskatchewan River as it enters Lake Winnipeg. When I talked about consumptive use and loss of water, the actual consumptive use and studies that I know of are all on the South Saskatchewan and that's where it is really taking place, most of it.

MS. WHELAN ENNS: Thank you, didn't catch that.

On slide 11 you also referred to the year 2011. So simple question I think; are there many of these slides that you have used in your presentation today where 2011 data is there?

DR. McCULLOUGH: 2011 data is in the slide that's in front of you right now, number 11. Sorry, what was --

MS. WHELAN ENNS: Basically, again, non-scientist asking a question here, your slide goes to 2010, you identified the 2011 information on the slide for the Dauphin River in your presentation, so that's why the question, and that is, do we have many instances where 2011 data is in front of us?

DR. McCULLOUGH: I'm sorry. Actually, I see why you ask that question now, I didn't understand it. Okay, I will clarify. You have dots on that graph -- just a second. I believe that last dot on each of those graphs is 2013, so the data is 1912 to 2013, annually. The black line, which is a 10-year running mean, and the 10-year running mean has to end five years from the end of the record, so the 10-year running mean ends in '28 or '29 on that graph. And yes. So, one, the answer is you are looking at the record that goes, the last three dots are 2011, '12 and '13 I believe. Yes, you have 2011 on that graph.

MS. WHELAN ENNS: That's a real help just in terms of all of us thinking in terms of what happened in 2011, and understanding your charts.

You beat me to a question I was going to ask you in terms of slide 22, because we have already talked about ice and ice breakup, and what isn't in your mandate at this time.

I'm now looking at slide 17. You said that the temperature and precipitation amounts provided here, the increases or decreases are median only. Can we take that to mean that they are the middle or moderate range in these scenarios?

DR. McCULLOUGH: Yes, you can. I didn't present for temperature, but precipitation, slide 18 does show the range. So it shows the minimum, medium and maximum for each of those. I refer you actually to that study, which is online, and if you need help I can give you a link to it. There is a lot more in that study. This is just a little bit out of it that seemed to help interpret what was going on here. But the ranges are discussed, as well as the median in that study, and you see them in this graphic. There is a similar graphic in the study for the temperature data and a lot more besides that.

MS. WHELAN ENNS: The offer of the link is appreciated. And one other question I guess then is, you have used 2009 data, you have used this study that's 2009 information. Did you see this as most relevant to your mandate here? Did you look at sets of data that are more recent and determine that they were not on the scenarios that you were looking for? My immediate thought, this is just an environmentalist comment, is that this is five years ago, when I look at this.

DR. McCULLOUGH: There are two kinds of information in this presentation. This is from published literature, and I took what I could get. This seemed to be the most thorough study that I had seen related to the aspects of climate change that I was interested in, in the Canadian Prairie Provinces. And it is more recent than many and some others that I quoted here that go back all of the way to 2005. So those references to published literature are whatever I saw in the literature that seemed to be useful in this presentation, and there are quite a few more quoted in my document, in the document accompanying this topic. But with regard to my own data -- to those charts of precipitation and water level, I used a standard set of data that ran from 1912 to 2013, I believe it was. You would have to check the book, the document. But the rationale for that really was the most -- the oldest records go back to the middle of the second decade of the 20th century for many of these things. And the newest complete years of data I could get for some things, including for instance the outflow of Lake

Winnipeg, I can -- well, I can get by one of two ways. I can get it from the Environment Canada website, which is what I did, and the most recent data there allowed me to go to 2013, I believe. For more recent data I think I would have to go to Manitoba Hydro which I didn't bother to do because I thought I had enough data to work with. But I expect either way -- I think that looking at 100 years of data told me what the trends were, and that's what I was interested in.

MS. WHELAN ENNS: Did you give any consideration to showing us the trends between the year 2000 and 2050?

DR. McCULLOUGH: The trends between 2000 and 2050?

MS. WHELAN ENNS: Still on 17.

DR. McCULLOUGH: No. Did I give any consideration to that -- this is from, again this is from the literature. No. I guess the short answer is no, I did not prepare any new -- from when I went into talking about what is predicted for the 21st century, I did not produce any new data for this report, I referred always to the literature, except for the studies of Lake Winnipeg water temperature for which I did the calculations myself several years ago.

MS. WHELAN ENNS: Thank you.

DR. McCULLOUGH: So the answer is I guess, no.

MS. WHELAN ENNS: Thank you. You made a comment today about how we used to relate to one in 50-year flood, and then we shifted to one in 100-year flood. And the Province, Manitoba Water Stewardship, and I presume what they are commissioning is moving to a 200-year flood. Would a one in 200-year flood perspective affect anything that you have reported here?

DR. McCULLOUGH: Well, let me think about commenting on it. Yes, a large flood will affect everything that I'm saying, I suppose. This data does include, for the Assiniboine River, what is currently labeled the one in 300-year flood. It doesn't include a one in 200-year flood in any way for the Red River. So it includes what we have had historically and nothing more.

A single flood, a single very wet year will certainly affect the lake and how you regulate it and how you live on it. But I really -- I'm trying to talk here, or have been trying to talk, and I think I was asked to talk about how things have been, how they are changing, and yes, how individual years can vary from that very much. And as you can see, or as I've said several times, a very wet year like a 200-year flood can occur at any time, probably even in a dry spell. It is more likely to occur in a wet spell admittedly and vice versa. So they are all critical to anyone who lives on the lake, but they are also in the future somewhat unpredictable. You can predict that it will happen, but not when it will happen.

MS. WHELAN ENNS: Thank you. A quick question on slide 22, and I just need a reminder here, and that is which station in the north and the south basin did you select?

DR. McCULLOUGH: I used Berens River, and in the south it is Gimli after 1966, and Winnipeg Beach before 1966. Winnipeg Beach was changed to Grand Beach -- sorry, Winnipeg Beach was changed to Gimli in 1966, so I used those two stations, and I used Berens River. Those are two good, long continuous records.

MS. WHELAN ENNS: Thank you. The sort of reason for some of these questions about which stations and so on has to do with the stations that are the basis for the licence for regulation of the lake, and Berens River is essential in those calculations. So thank you.

On slide 25, you are assuming, I believe, that ice is off the lake by the 28th of June?

DR. McCULLOUGH: Yes.

MS. WHELAN ENNS: And you are assuming that the lake is beginning to freeze by the 26th of September? Do I understand your slide?

DR. McCULLOUGH: No.

MS. WHELAN ENNS: Well, there you go.

DR. McCULLOUGH: That is merely an example. I wanted to be able to talk to you about the difference between the way I described setup in this slide, which is meant to be a very consistent way of describing setup through 100-year period. So how have setup events changed? Have they gotten larger or smaller over the century, have they gotten more or less frequent over the century? To do that I needed a consistent record, so I chose the daily mean record.

I used the graphic on figure 25 merely to show you that by using the daily mean, I was describing literally smaller than realistic setups. It is just that they are consistently measured for 100 years.

If you followed what I was saying as an example, you would say that between the low and the high, in any given sudden change in water level, there is often one foot at the top and nearly a foot at the bottom of change. So there is almost two feet more water level change involved in the setup, if you measure the hourly water level the way I measured it for this. So when I say that a frequency of -- when I'm talking about the maximum setup here of three feet, for many of those blue lines in this graph, this is slide 26, for many of these maximum setups, half a dozen of them exceed three feet. Those probably exceeded five feet. I just wanted that to be an example, it has nothing to do with anything, but it had a nice bunch of highs and lows in it.

MS. WHELAN ENNS: Thank you.

Slide 27, in this sequence that you are working through, a question sort of popped up. The setup, to use this term, and the wind-included water levels at the narrows are of concern and difficult to understand and analyze. So I wanted to ask you whether you, in going through this sequence for us, and what you've analyzed for the CEC, whether you at any time zeroed in on setup and water levels at the narrows?

DR. McCULLOUGH: No, I didn't study them, I didn't look at them specifically. There is a good record there. The same kind of analysis could be done fairly easily for any single station on something like seven stations on the lake.

MS. WHELAN ENNS: Yes, and some with a good long time line on them.

DR. McCULLOUGH: Yes, most of them do, in fact.

MS. WHELAN ENNS: Thank you.

On slide 29 on the right-hand side, that is the monthly mean water level in summer, is it accurate to say, looking at this, that we in fact have lower lows and higher highs in terms of mean water level in the summer with regulation?

DR. McCULLOUGH: Well, on that graphic there you have lower flows. Yes, we have a range that includes lower flows out of the lake and higher flows out of the lake in the regulated period. And in the non-regulated period, and the opposite is true of water levels, there is a higher range of monthly mean water levels in the --

MS. WHELAN ENNS: Winter.

DR. McCULLOUGH: -- pre-regulation data.

MS. WHELAN ENNS: Thank you.

You have been very thorough in your comments and references as you went through your presentation in terms of the current wet period or wet cycle that Manitoba is in. Do you think that Saskatchewan and Alberta are also in a wet cycle?

DR. McCULLOUGH: Certainly eastern Saskatchewan has been very wet. Certainly we have had -- and I will go back a slide here so I can be more specific. Let us look at -- sorry, I went the wrong way twice. All right. No, I don't want that one, that's precipitation, sorry, I beg your pardon for that last one.

I am now on slide 11. You can see, in fact, that in every one of those graphics the Dauphin River -- sorry, the Dauphin River, the Saskatchewan River and the Red River are all, and have all been higher than average over the last half dozen years or more. The period is longer in the case of the Red, since the mid 1990s, but in the Saskatchewan River since at least 2005 -- and as many of you will remember, 2005 was a remarkable year in which the Saskatchewan River, the Winnipeg River and the Red River all were at or near record high flows. Since then the Saskatchewan River has continued to see high flows quite frequently. So I would say on average over the Saskatchewan River watershed, it is in what I would call a wet period.

Now, if you happen to live in Saskatoon, it might not be particularly wet there. Most of this water does come from the slopes of the Rocky Mountains. So, in fact, it is more likely that it is the Foothills and the Rockies that are in a wet period. And of course, they have seen the most remarkable floods in their history in the last two years, three years.

So, yes, Saskatchewan River is in a wet period.

MS. WHELAN ENNS: Thank you. Finished, Mr. Chair.

THE CHAIRMAN: Thank you, Ms. Whelan Enns.

Dr. McCullough, I would like to pursue one response you gave to Ms. Whelan Enns. When she asked you about the emergency drain out of Lake St. Martin in the fall of 2011, and you said, and I didn't quite get it, that there are differences in how the water is delivered to the lake and that, I think you said that the water going from the Assiniboine to Lake Manitoba, Lake St. Martin and then Lake Winnipeg, they were able to use it for power production or -- I didn't quite -- but if it had gone its normal route through the Assiniboine and Red to Lake Winnipeg, it would be different?

DR. McCULLOUGH: Well, whatever I may have said, that would be certainly not what I meant, not for power production. They might well have wanted to use it for power production, but nobody has generators along the system. All I meant to say, when it was delivered differently, obviously a very large part of the flow was delivered through the Portage Diversion into Lake Manitoba. It passed through Lake Manitoba, more slowly into Lake Winnipeg than it would have had it followed the Assiniboine River down to the Red River and into the south basin of Lake Winnipeg. And the evidence is pretty much before our eyes. Lake Manitoba stayed above natural levels, above what we think of as normal historical levels well into a year after. And all of that time they were draining Lake Manitoba as fast as they could. So it takes longer for the water to get from the upper Assiniboine into Lake Winnipeg if it goes through Lake Manitoba, and that was demonstrated in 2011, 2012. That's all I meant, it was a longer path.

THE CHAIRMAN: So that was it, there is no other advantages or disadvantages, just that it takes longer to get to the north basin?

DR. McCULLOUGH: Depends on what you mean by an advantage or a disadvantage. I did add that there is a big water quality difference.

THE CHAIRMAN: No, I understood that, and that is a concern for another time.

DR. McCULLOUGH: No, I don't think in terms of the levels of Lake Winnipeg, or regulation of Lake Winnipeg or anything like that, I'm not quite -- I don't see an advantage or disadvantage there. The huge difference is to the people who live along those rivers and on the lakes.

THE CHAIRMAN: But you don't think there would be any, or much difference to lake levels because of this routing?

DR. McCULLOUGH: Lake Winnipeg level would have peaked higher because water would have come into it faster if it had all come via the Assiniboine and Red into the lake. If you put water in there faster, and you have a limited capacity, albeit an enhanced capacity, but still a limited capacity in the outflow, you will peak at higher. Sorry, I guess I should have -- I probably should have thought that out more carefully before I answered it. But under your prodding, I think I came to a conclusion that it would have made a difference, it would have been a higher peak.

THE CHAIRMAN: Okay, thank you. Any other questions?

Okay. I think that brings us to the end of this presentation. So thank you, Dr. McCullough, for first preparing the paper for us, and for taking the time to come here today. It has been an important contribution to this process, so thank you for that.

DR. McCULLOUGH: Thank you.

THE CHAIRMAN: And before we adjourn, we have some documents to register.

MS. JOHNSON: Yes, I'm not sure if I previously put on Mr. Hesslein's report on Lake Winnipeg basin and the effects of nutrients, that would be CEC 10. Number 11 the isostatic rebound report by Dr. Thorleifson. Number 12 will be his presentation that we saw today. And number 13 will be the climate change paper by Dr. McCullough. And number 14 is his presentation.

(EXHIBIT CEC 10: Mr. Hesslein's report on Lake Winnipeg basin and effects of nutrients)

(EXHIBIT CEC 11: Isostatic rebound report by Dr. Thorleifson)

(EXHIBIT CEC 12: Dr. Thorleifson's presentation)

(EXHIBIT CEC 13: Climate change paper by Dr. McCullough)

(EXHIBIT CEC 14: Dr. McCullough's presentation)

THE CHAIRMAN: Thank you. Tomorrow we have two more Commission witnesses. In the morning, we will have Gordon Goldsborough who will be talking about marshes and wetlands, and in the afternoon, George McMahon, who will talk about hydrology and operations. There is no other compelling business? We will adjourn until 9:30 tomorrow morning. Thank you.

(Adjourned at 4:25 p.m.)

OFFICIAL EXAMINER'S CERTIFICATE

Cecelia Reid and Debra Kot, duly appointed Official Examiners in the Province of Manitoba, do hereby certify the foregoing pages are a true and correct transcript of my Stenotype notes as taken by us at the time and place hereinbefore stated to the best of our skill and ability.

Cecelia Reid

Official Examiner, Q.B.

Debra Kot

Official Examiner Q.B.